ANALYSIS OF ALTERNATIVES

and

SOCIO-ECONOMIC ANALYSIS

Legal name of applicant(s):	LUC (UK) Limited
Submitted by:	LUC (UK) Limited
Date:	24.06.2022
Substance:	2,2'-Dichloro-4,4'-methylenedianiline (MOCA, MbOCA) [CAS 101-14-4; EC 202-918-9]
Use title:	Industrial use of 2,2'-Dichloro-4,4'-methylenedianiline (MOCA) in the manufacture of high-performance polyurethanes specifically for custom-made rollers with high reliability requirements for steel and aluminium sectors
Use number:	Use #1

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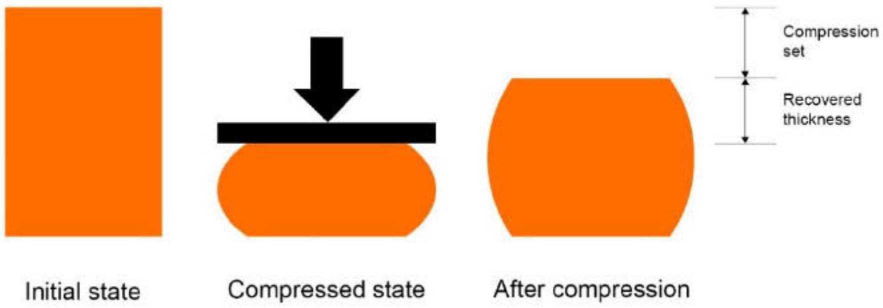
LIST OF ABBREVIATIONS

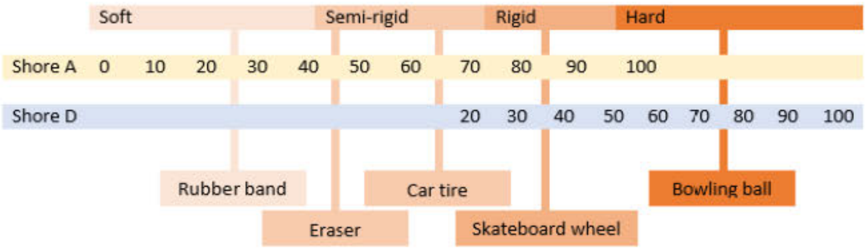
AISI	American Iron and Steel Institute
AoA	Analysis of Alternatives
BAU	Business as Usual
BDO	Butane-1,4-diol
C&L	Classification and Labelling
CAS	Chemical Abstract Service
CLP	Classification, Labelling and Packaging
CoF	Coefficient of Friction
CSR	Chemical Safety Report
DETDA	Diethyl toluenediamine
DMTDA	Dimethylthiotoluenediamine
DUIN	Downstream User Import Notification
EC	European Commission
ECHA	European Chemicals Agency
ELR	Excessive Lifetime Risk
EPA	Environmental Protection Agency
EU	European Union
GC-MS	Gas Chromatography - Mass Spectrometry
HH	Human health
HQEE	2,2'-p-phenylenedioxydiethanol
ID	Identity
IR	Infra-red
ISO	International Organization for Standardization
IUPAC	International Union of Pure and Applied Chemistry
LEV	Local Exhaust Ventilation
LF-MDI	Low-Free MDI
MACM	4,4'-methylenebis(2-methylcyclohexylamine)
MbOCA	MOCA
MBOEA	4,4'-methylenebis(2-ethylbenzenamine)
M-CDEA	4-[(4-amino-2-chloro-3,5-diethylphenyl)methyl]-3-chloro-2,6-diethylaniline
MDBA	4,4'-methylenebis[N-sec-butylaniline]
MDEA	4,4'-methylenebis(2,6-diethylaniline)
MDI	4,4'-diphenylmethane diisocyanate
MOCA	2,2'-Dichloro-4,4'-methylenedianiline
MXDA	m-Xylylenediamine
NDI	1,5-naphthalene diisocyanate
OEL	Occupational Exposure Limits
OELV	Occupational Exposure Limit Value
OSHA	Occupational Safety and Health Administration
PBT	Persistent, Bioaccumulative and Toxic
PDPAB	1,3-propanediol-bis-(4-aminobenozate)
PPDI	1,4-Phenylene diisocyanate
PU	Polyurethane
R&D	Research and Development

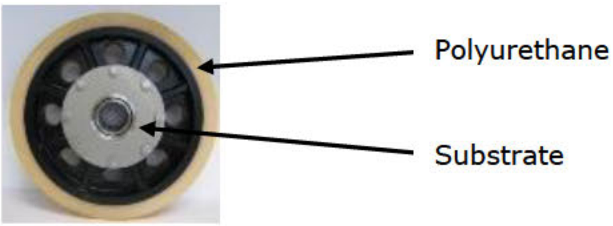
RAC	Risk Assessment Committee
RCRA	Resource Conservation and Recovery Act
REACH	Registration, Evaluation, Authorisation and Restriction of Chemicals
SDS	Safety Data Sheet
SEA	Socio-economic Analysis
SEAC	Committee for Socio-economic Analysis
SME	Small and medium-sized enterprise
STOT-RE	Specific target organ toxicity - repeat exposure
STOT-SE	Specific target organ toxicity - single exposure
SVHC	Substance with Very High Concern
TDI	Toluene diisocyanate
TWA	Time Weighted Average
UK	The United Kingdom
USA	The United States of America
WCS	Worker Contributing Scenario

Glossary

Term	Definition
Abrasion resistance (unit: mm^3) Standard: ISO 4649 method B	Abrasion occurs when one object moves over another, resulting in minute tears in the objects' surface. The minute tears are caused from minute sections of the object's surface breaking off. Abrasion resistance is therefore measured as the volume loss due to abrasion. A polyurethane has a high abrasion resistance when the volume loss is low while it has a low abrasion resistance if the volume loss is high.
Adhesion	The bonding of the polyurethane layer to a **substrate.** A weak adhesion will lead to the separation of the polyurethane layer and the substrate requiring the part to be changed.
Casting	The action of filling moulds by pouring a liquid polyurethane (PU) mixture into them.
Catalyst	A substance which increases the speed of a chemical reaction, which is not consumed in the catalytic reaction.
Coefficient of Friction (unit: dimensionless) Standard: internal	Friction is the resistance to motion that one object encounters when moving over another. Friction enables traction. For instance, cars rely on friction between the wheels and asphalt to move forward and brake. The Coefficient of Friction (CoF) represents the ratio between the force of friction between a pair of objects (i.e. the force that opposes the motion of an object) and the force pressing them together (also known as normal force). The CoF varies based on the two objects/surfaces that are causing friction. It is therefore a system property and does not only depend on the properties of the PU. The CoF typically has a value comprised between 0 and 1 but it can also be greater than 1 in some cases. If the CoF is 0, it means there is no friction between the two objects in question, which is a situation not typically encountered in everyday life. When the CoF is 1, the force of friction is equal to the force pressing the two objects together (normal force). Ice on steel will have a low CoF while it will be high for rubber on rubber. A high CoF is desirable for applications where it is required that no slippage occurs between the two objects (i.e. grip is needed). For instance, friction is needed between the drive roller and the conveyor belt in order for the conveyor belt to move forward. In contrast, a low CoF is desirable for applications where sliding is needed.

Term	Definition
Compression set (unit: %) Standard: ISO 815-1	When a material is compressed, its shape may be permanently altered. The permanent deformation that remains in the material after being compressed is called compression set (see figure below).  A compression set of 0 % means that the material has fully recovered its original thickness. In contrast, a compression set of 100 % means that there was no recovery.
Curing	A chemical process where cross-links between polymer chains are formed which results in the toughening of the material.
Cutting resistance	Cutting is a type of abrasive wear (see **abrasion resistance**) that involves sharp objects or blades penetrating the material surface. A polyurethane with high cutting resistance can withstand the cutting action of such objects. High cutting resistance is a combination of high tear resistance, low abrasion and high toughness.
Damping	A PU with high damping prevents or reduces vibrations induced to it by converting energy to heat. Related to **rebound resilience**.
Deflection (unit: %)	Deflection is the degree to which a polyurethane is displaced when compressed.
Diisocyanate	A substance containing two isocyanate functional groups (R-N=C=O). It is one of the two components, which form the prepolymer.
Dynamic load bearing	Dynamic load bearing represents the PUs ability to withstand a load that is non-static (i.e. in movement) without the presence of structural damage or cracks in the object or flaking of the surface.
Dynamic properties	Refers to the dynamic properties exhibited by the end-product when subjected to repeated cyclic deformations and flexing.
Elongation at break (unit: %) Standard: ISO 37	Elongation at break indicates how much a material can be stretched before it breaks (i.e. ductility). A material with high elongation at break percentage will stretch and deform more before breaking than a material with low elongation at break percentage.

Term	Definition
Fatigue	Fatigue is one of the most common sources of failure of polyurethane parts. It is the deterioration the PU undergoes due to cyclic loading (i.e. repeated application and removal of a load on the PU part, which is typical during PU product end-use). Fatigue damage can occur even when the stress experienced by the part is far below the limit it can withstand. Fatigue develops in three stage process: 1. After multiple load cycles, localised structural damage at the microscopic level may occur. The damage develops until a macroscopic crack is formed. 2. The crack grows with each load cycle until it reaches a critical size. 3. At this point, the crack rapidly propagates in the material leading to the complete fracture of the part.
Hardness (unit: °A or °D) Standard: ISO 48-4	In the polyurethane industry, hardness corresponds to the polyurethanes resistance to localized deformation (i.e. indentation). Cast polyurethanes are typically measured using the Shore A (°A) and Shore D (°D) hardness scales (see figure below). The higher the number, the harder the polyurethane. 
Hysteresis	Rebound resilience gives an indication of the polyurethane's hysteresis. Hysteresis is the energy that is lost as heat during recovery due to internal friction. Hysteresis will therefore cause the polyurethane to build up heat.
Mechanical strength	Mechanical strength corresponds to the materials ability to resist an applied load without plastic deformation (i.e. irreversible deformation) or failure. Important material properties that influence mechanical strength include hardness and tensile strength.
Mould	A metal recipient, which has the shape of the desired end-product. There is an example of a mould for a wheel on the right. 
Moulder	A polyurethane manufacturer who uses raw materials (i.e. a prepolymer and MOCA pellets) to produce different PU-parts for many end-use sectors.
Oven	A hot-air chamber that has precise temperature controls.

Term	**Definition**
Polyol	A substance containing multiple hydroxyl groups (-OH). It is one of the two components, which form the prepolymer.
Post-cure	After a polyurethane part has been cured, it is removed from the mould and placed back in the oven for post-cure. Phase separation of hard and soft segments occurs during post-curing. This step is required to achieve high mechanical and dynamic properties.
Pot-life (unit: minutes)	The timeframe between adding chain extender to prepolymer and polyurethane mixture being too viscous to cast.
Primer	A substance designed to chemically react with the **substrate** and polyurethane such that a strong bond is formed between them.
Rebound resilience (unit: %) Standard: ISO 4662	Energy is required to deform a material. When a material recovers from deformation, part of this energy is returned. Rebound resilience is the ratio of energy returned to the energy applied, expressed as a percentage. A material with 100 % rebound resilience returns all the energy applied. A damping ball is an example of an object with high rebound resilience. A material with low rebound resilience will return less energy during recovery. This type of material is good for applications where bounce-back has to be minimised. A material with inappropriately low rebound resilience may melt during use.
Scrap rate	Percentage of PU products rejected during production due to faults (e.g. cracks, flaky surface) and are therefore, discarded because they cannot be sold.
Strain (unit: %)	The deformation of the PU material due to a force (i.e. tension) applied to it.
Stress (unit: MPa)	The amount of load (force per area) exerted on the PU material.
Substrate	Material on which the polyurethane is casted. Typically made of metal. Not all polyurethanes are casted on a substrate. 

Term	Definition
Tear resistance (unit: kN/m) Standard: ISO 34-1 method B, procedure b	Tear resistance (also called tear strength) corresponds to the polyurethane's ability to resist the formation and propagation of tears and nicks.
Tensile strength (unit: Pa) Standard: ISO 37	Tensile strength (also called ultimate tensile strength) is one of the most important properties in material science. It represents the capacity of a material such as polyurethane to withstand being stretched or pulled apart (i.e. tension) without breaking. A material with high tensile strength will withstand a lot of tension before breaking (e.g. steel) while a material with low tensile strength will break more easily (e.g. rubber). Measuring tensile strength thus helps predicting how the finished product will behave in use.
Toughness	Toughness corresponds to the polyurethane's ability to absorb energy and deform plastically before breaking. It can be seen as the polyurethane's resistance to fracture when under load. The toughness of PU is measured by calculating the area under the stress-strain curve (see Table 5 for additional information).
Viscosity (unit: mPa*s)	Viscosity can be thought as a liquid's "thickness". A substance with low viscosity (e.g. water) will flow more quickly when poured than a substance with high viscosity (e.g. honey).

DECLARATION

The Applicant, LUC (UK) Limited, is aware of the fact that further evidence might be requested by the UK HSE to support the information provided in this document.

Also, we request that the information blanked out in the "public version" of the Analysis of Alternatives and Socio-economic Analysis is not disclosed. We hereby declare that, to the best of our knowledge as of today (24.06.2022), the information is not publicly available, and, in accordance with the due measures of protection that we have implemented, a member of the public should not be able to obtain access to this information without our consent or that of the third party whose commercial interests are at stake.

Signature:

Date, Place: 24th June 2022 Cardiff.

1. SUMMARY

The Analysis of Alternatives (AoA) and the Socio-economic Analysis (SEA) form part of the Application for Authorisation (AfA) for the usage of MOCA in the manufacture of high-performance polyurethanes, specifically custom-made rollers with high reliability requirements in the steel and aluminium industries at LUC Group's UK site in Dowlais.

LUC Group is a downstream user of MOCA in the supply chain of Suzhou Xiangyuan New Materials Co., Ltd. (Suzhou) and their use of MOCA is currently covered by the application submitted by REACHLaw acting as only representative for Suzhou under Brexit transitional arrangements, as the Commission has not yet taken a decision on the application. LUC Group submitted a downstream user application to cover its use at 4 sites in the EEA on 20.05.2020 and the ECHA opinion on this application was issued to the Commission for decision making on 28.07.2021. Details of the application are available on the ECHA website.[1] As this application was submitted before the end of the Brexit transition period, it included also use at the UK site. Since the 01.01.2021, the UK site is now under UK REACH and the application submitted under EU REACH is not relevant. LUC (UK) Limited (LUC UK) is submitting this application to cover use at the UK site.

LUC UK manufactures their custom-made rollers in close collaboration with the customers, based on their specifications and the specific production line where the roller will be used. The rollers consist of a metal core on which LUC UK casts a layer of polyurethane (PU) using a low pressure casting process (see Figure 1).

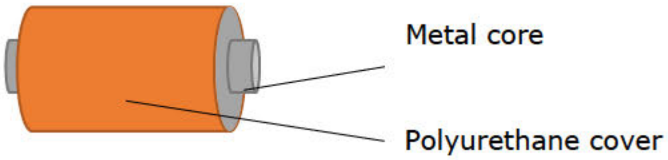


Figure 1. A schematic representation of a polyurethane roller

LUC UK's customers, the end-users, use LUC UK's custom-made rollers in their production lines dedicated to the manufacture of steel, stainless steel and aluminium sheets and strips. These strips are used in high-end applications with demanding requirements such as high strength and high-quality surface finish. Typical end-use for the strips include the automotive, aerospace, food packaging, medical or health care, chemical process industry, renewable energy sectors and other sectors.

The manufacture of high-end metal strips requires the use of top-quality rollers fitted with a highly performant polyurethane cover in terms of mechanical and dynamic properties. Key properties include:

- **Mechanical strength:** A high mechanical strength is necessary to handle the high loads and tensions that are applied on the rollers' PU covering during end-use.
- **Coefficient of friction:** A high coefficient of friction is important to be able to maintain grip during end-use.

[1] LUC Group's application for authorisation for 2 uses of MOCA under EU REACH; use 1 ECHA ID 0225-01 and Use 2 ECHA ID 0225-02 available on the ECHA website at https://echa.europa.eu/applications-for-authorisation-previous-consultations

- **Dynamic load bearing capacity:** The rollers must be able to withstand the high dynamic loads that are common in the steel and aluminium industry sectors.
- **Cutting resistance:** The rollers get in contact with sharp metal parts and cutting blades during end-use. A high cutting resistance is needed to avoid pieces of polyurethane getting cut out and contaminating the end-user's production line.
- **Adhesion:** High bonding strengths are necessary to maintain adhesion between the PU and substrates. If delamination occurs, this could lead to major costs and equipment damage due to the stop in production to replace the roller.

As the metal strip production lines are enormous assemblies that run 24/7 at high output, LUC UK's rollers also need to be highly durable, highly reliable and have good fatigue properties to avoid expensive downtimes. Such high-performance polyurethanes are achieved when using MOCA as a chain extender/curing agent.

MOCA – a core ingredient in the manufacture of high-performance polyurethane

MOCA is an excellent all-round chain extender with toluene diisocyanate (TDI) based prepolymer systems, which made it the chain extender of choice in the European cast polyurethane industry for decades. It is still the most widely used chain extender outside of the EEA and UK as there are no commercially available alternatives to the TDI/MOCA system that are both cost effective and have comparable performance. MOCA key advantages include:

- **Long pot-life:** it allows the casting of large volumes (e.g. the rollers covered by this use). Long pot-life results in less rejected products during manufacture (low scrap rate). See end of Chapter 3.1.1 for additional information on pot-life.
- **Robust and easy processing:** The properties and the quality of the resulting elastomer are not significantly affected by slight variations in raw material ratios. MOCA also has an excellent solubility in a variety of prepolymers. Both contribute to a low scrap rate.
- **Technical performance:** Tough and durable polyurethanes having excellent mechanical and dynamic properties can easily be produced with the TDI/MOCA system
- **Economical:** There are no commercially available alternatives to the TDI/MOCA system that are both cost effective and have comparable performance.
- **High sustainability:** TDI/MOCA polyurethane is currently unequalled in terms of sustainability. It is easy to process and has a long pot-life, which results in low scrap rates. In addition, the processing temperatures to manufacture MOCA PU are relatively low and the curing times are short (i.e. less time required in the curing ovens). This limits the energy consumption of the production process. Furthermore, TDI/MOCA PU products are known to have high durability, reliability and fatigue properties thus, they need to be changed or recovered less often. As cast polyurethane cannot be recycled, it is critical to limit the amount of wastes generated and maximising the lifetime of products.

  Overall, TDI/MOCA PU has a lower load on the environment than alternatives currently available on the market due to being associated with low amounts of waste and lower energy consumptions.

- **Proven track-record:** TDI/MOCA high-performance PU products have decades of industrial use and are proven in industrial end use setting to be highly durable, reliable high quality products.

Potential alternatives to MOCA

LUC Group has looked for and tested potential alternatives to MOCA since June 2009. In this AoA, the most common alternatives to MOCA according to raw material manufacturers or the ones that gave the best results are discussed. However, none of the alternative were found to be suitable to replace MOCA in the manufacture of high-performance polyurethane rollers for the steel and aluminium industry. An overview of the results of the alternative assessment is presented in Table 1.

Table 1. Overview of the alternative assessment results

	TDI/DMTDA	TDI/Addolink® 1604	Diamine blends	(LF-)MDI systems	NDI/BDO	PPDI/BDO	PPDI/HQEE
Technical feasibility	Red	Red	Red	Red	Red	Red	Red
Economic feasibility	Yellow	Red	Red	Yellow	Red	Red	Red
Availability	Yellow	Red	Red/Yellow	Green	Red	Green	Green
Safety considerations	Green	Green	Green	Green	Green	Green	Green

Red = requirement not met, yellow = fulfilment of the criteria not clear, green = requirement met

The alternative cured polyurethanes were found to have significant limitations in terms of technical performance, including insufficient mechanical strength, especially in terms of tensile strength, but also insufficient dynamic load bearing capacity, coefficient of friction, fatigue properties and reliability. In some cases, the pot-life was so short, it was not even possible to cast products at all. These materials are therefore unsuitable for use in the high-performance polyurethane rollers covered by this use.

In addition to technical limitations, the alternative PU materials had higher environmental loads. The alternatives had one or more of the following limitations in terms of sustainability:

- Lower fatigue properties
  - This results in products having shorter durability thus, the PU parts need to be changed or recovered more often. This increases the amount of wastes generated.
- Shorter pot-lives
  - Some PU systems have shorter pot-life, which increases the risk for delamination (i.e. separation of the PU layer from the substrate). This shortens the product's lifetime.
- Longer curing times and higher energy consumption
  - Longer curing times means that more oven space will be needed to equal the output achieved with MOCA PU and for a longer time. This also translates into higher energy consumption and production costs (especially considering the current energy price levels in Europe) as curing is carried out at elevated temperatures.

    - Some chain extenders need higher processing temperatures as they have higher melting points compared to MOCA and/or they crystallise at lower temperatures. This results into higher energy consumption.
- Higher scrap rate
    - Some PU systems have shorter pot-life and/or they are complex to process. Both increases the number of defects in PU, which leads to a higher rejection of products (higher scrap rate).

End users have no motivations to change to non-MOCA based PU products

For LUC UK's customers (the end-users) are accustomed to TDI/MOCA-PU products. Changing to non-MOCA based PU products would require end-users to switch to relatively untested products for installations that have long service life and where any downtime for repair, maintenance or replacement will result in lost production time. Furthermore, the current non-MOCA based products are more expensive to produce while their performance may be lower at best, at worst, the non-MOCA based products do not work at all. As LUC UK's customers have no driver to transfer to non-MOCA based products, there is a very real risk that customers prefer to stick with what they know and stay with TDI/MOCA-PU products. If LUC UK's customers were in the same situation where they would also need to find alternatives, the situation would be easier in that the goal would be a common one. However, the current situation is that LUC UK's customers are only concerned about price and performance.

TDI/MOCA-PU products from outside of the UK distorts the market

LUC UK's customers can easily switch to non-UK moulders. As the finished PU products do not contain any MOCA, they are not affected by authorisation thus, non-UK moulders can continue freely to place their TDI/MOCA PU products on the UK market. LUC UK has to compete with these non-UK moulders, which puts them in a vulnerable position in that at any time, LUC UK's customers may leave them for a non-UK moulder. Therefore, any non-MOCA based products LUC UK manufacture must perform at least as well as their TDI/MOCA-counterparts. This also means that it is essentially impossible for LUC UK to reflect the substitution costs (estimated at 850-962 k GBP) or the higher production costs in the price of the non-MOCA based products.

Note that, in the non-use scenario LUC Group would close LUC UK's production and business. LUC Group would relocate LUC UK's entire production to its facilities in the EU.

Review period

LUC Group has made extensive efforts to find a suitable replacement and substitute for MOCA in the manufacture of their PU products. LUC Group tested several dozens of non-MOCA based curatives and polyurethane systems, including like-for-like diamine alternatives, chain extender blends and non-TDI polyurethane systems.

LUC Group has an extensive knowledge of polyurethane chemistry. They have been using both MOCA-based and non-MOCA based PU systems for several decades (e.g. NDI systems since 1973 and PPDI systems since 1987). Thus, the characteristics, advantages and drawbacks of the PU systems currently available on the market are well-known to LUC Group. LUC Group has substituted MOCA wherever it was possible (e.g. PU products with lower technical requirements or where pot-life of the material was not problematic).

However, for the high-performance PU products, such as the rollers for the steel and aluminium industries, the alternatives were found to lack the required pot-lives, mechanical and dynamic properties. Therefore, the present authorisation application covers the products for which no suitable alternatives were found.

LUC UK took several factors into account when deriving the review period requested in this application. These are the following:

- LUC Group has tested several dozens of alternatives to MOCA since 2009 however, none of the alternatives have been suitable to replace MOCA in the production of high-performance polyurethanes for custom-made rollers covered by Use 1
- It is currently uncertain when a non-MOCA chain extender that can produce a high-performance and high durability polyurethane material that fulfils all technical key requirements would be available on the market.
- LUC UK is fully dependent on alternative providers to develop new chain extenders/PU systems, thus it can easily take several years before a suitable alternative is available.
- Even if an alternative was to become available, the successful substitution of MOCA with another chain extender or polyurethane system will take many years. It is a time-consuming process requiring extensive testing as well as verification trials at end-user facilities.
- The established reputation of TDI/MOCA polyurethanes as high-quality material, alongside the continued availability of TDI/MOCA PU products originating from outside the UK make the task of finding a substitute to MOCA more complicated. In order to remain competitive, LUC UK would either need to provide an alternative PU product performing as well as their MOCA counterparts for the same price or a better performing product for a higher price.
- The most likely non-use scenario is to close the business in the UK and relocate the TDI/MOCA manufacture in LUC Group's facilities in the EU (where their use is authorised).
- The monetised benefits of the continued use of MOCA for Use 1 are 0.19 M GBP per year.
- The monetised risks of the continued use of MOCA for Use 1 are 0.000012 M GBP per year.
- The benefits outweigh the risks over 15,000 times.

Taking into account these factors, LUC UK selected a long review period of 12 years. LUC Group has developed an R&D plan consisting of five phases, which are discussed in further details in Chapter 4.1.3.

MOCA use in the manufacture of cast polyurethanes as intermediate use as per Article 3(15) of the REACH Regulation

LUC Group considers that its use of MOCA in the manufacture of polyurethane as described in this application fulfils the definition of intermediate use as per Article 3(15) as clarified in the ruling of the 2017 European Court of Justice ruling in case C-650/15 P. However, as it is not yet clear to LUC Group how to demonstrate this to the relevant authorities in the UK, it is submitting this application as a contingency measure.

When MOCA was proposed for inclusion on the candidate list, it was stated in the Annex XV dossier[2] that MOCA use in the manufacture of polyurethanes was not an intermediate use based on a definition of intermediates given in the ECHA Guidance from 2010.[3]

Specifically

> *According to the guidance on intermediates (ECHA 2010) document a substance should not be regarded as intermediate as soon as the main aim of the chemical process is not to manufacture another substance, but rather to achieve another function, specific property, or a chemical reaction as an integrated part of producing articles (semi-finished or finished). In accordance with this statement, the end use described above and the use as curing agent described in section 2.2.1 cannot be regarded as use of MOCA as intermediate. Similarly, it appears not possible to consider the use of MOCA as a cross-linking agent as use of the substance as intermediate.*

Based on this understanding, an upstream application was submitted to cover downstream users of MOCA as a chain-extender/curing agent in the manufacture of polyurethanes.[4] LUC Group is a downstream user of MOCA covered by this upstream application under transitional arrangements. However, in October 2017 the European Court of Justice has ruled in Case C-650/15 P that ECHA in its 2010 definition on intermediates has added a condition that is not in the legal text.[5] Specifically

> *Article 3(15) of that regulation contains no additional criterion allowing a differentiation to be made according to whether that purpose was primary or secondary in nature or examination of whether or not the chemical process by which one substance is transformed into another is indistinguishable from the end use for which that substance is intended.*

In this ruling, the Court found that by failing to classify acrylamide, in the context of the process of transformation into polyacrylamide for grouting purposes, as an 'intermediate', the General Court, by adding a condition that is not laid down in Article 3(15) of the REACH regulation, misinterpreted that provision.

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[2] The documents are available on the ECHA website at https://echa.europa.eu/fi/registry-of-svhc-intentions/-/dislist/details/0b0236e180e49371

[3] ECHA Guidance on Intermediates, V.2, 2010, available at https://echa.europa.eu/guidance-documents/guidance-on-reach

[4] Details of the application are available on the ECHA website at https://echa.europa.eu/applications-for-authorisation-previous-consultations/-/substance-rev/15329/term?_viewsubstances_WAR_echarevsubstanceportlet_SEARCH_CRITERIA_EC_NUMBER=202-918-9&_viewsubstances_WAR_echarevsubstanceportlet_DISS=true

[5] Judgment of the Court (First Chamber) of 25 October 2017, Polyelectrolyte Producers Group GEIE (PPG) and SNF SAS v European Chemicals Agency, Case C-650/15, available at http://curia.europa.eu/juris/document/document.jsf?text=&docid=195945&pageIndex=0&doclang=EN&mode=lst&dir=&occ=first&part=1&cid=596449

Considering this ruling in the context of MOCA use in the manufacture of polyurethane, MOCA use also fulfils the definition of intermediate use and the statement to the contrary given in the Annex XV dossier is based on criteria that are not in the legal text. Following the rationale given in the court decision,[5] three conditions need to be fulfilled for the use of a substance to be capable of being regarded as use of an intermediate. The first of those conditions concerns the intended purpose at the time of the manufacture and use of a substance as an intermediate, which consists of transforming that substance into another. The second condition concerns the technical means by which that processing takes place, namely a chemical process known as 'synthesis'. The third condition restricts the scope of the definition of 'intermediate' to uses of a substance which remains confined to a controlled environment, which may be either the equipment within which synthesis takes place, or the site in which the manufacturing and synthesis takes place or to which that substance is transported, 'site' being defined in Article 3(16) of the REACH Regulation as a 'single location' in which infrastructure and facilities are installed.

Applying these criteria to the use of MOCA in the manufacture of PU substances, it can be seen that as the intended use at the time of the manufacture and use of MOCA is to transform it into another substance, the first of these three conditions is satisfied. MOCA is used in the manufacture of another substance during which it is itself transformed into that other substance, namely polyurethane. The use of MOCA to manufacture polyurethane at LUC Group's site also fulfils the other two criteria; namely that the reaction can be described as synthesis and is confined to a controlled environment.

Consequently, LUC Group consider their use of MOCA to be intermediate use and that authorisation is not required for this use. The reasoning is given below.

LUC Group has also considered the draft update of the ECHA guidance on intermediates that was made available in March 2022.[6] The guidance update was initiated in light of the court ruling and gives the three conditions that must be fulfilled for a use to be considered "intermediate use".

Considering the 1st condition, the draft guidance states that this condition is fulfilled when the following conditions are met;

- *it can be demonstrated that the intermediate substance has been manufactured and used with the intention to be transformed into another substance*
- *it can be demonstrated that the intermediate substance has been actually transformed into another substance*
- *Information can be provided on the identify the other substance into which the intermediate has been transformed*

These conditions are fulfilled as MOCA is manufactured is manufactured and supplied to be used as a reactant in the manufacture of polyurethanes. MOCA is consumed in the reaction to yield a polymer substance, polyurethane.

[6] Draft presented at the 44th Meeting of Competent Authorities for REACH and CLP (CARACAL) 23 March 2022 under agenda point 4.3 Open session on "Intermediates – ECHA revised guidance document and REACH revision"

Considering the 2nd condition, the draft guidance states it is fulfilled when the following conditions are met;

- *it can be demonstrated that the transformation of the intermediate substance into another substance (link to condition 1) takes place in the context of a chemical process and a specific equipment is used for this process;*
- *that chemical process is a 'synthesis' process;*
- *it can be demonstrated that, to avoid risks for human health and the environment, the intermediate substance remains contained after its manufacturing throughout the whole chemical process. The containment of the intermediate substance must be ensured by technical means at the site (for an on-site isolated intermediate) or during the transport/storage at the site where it is later used (for a transported isolated intermediate).*

These conditions are fulfilled as MOCA is used at an industrial site in dedicated equipment for the manufacture of polyurethanes. The process is synthesis whereby the reactants including MOCA are transformed to a polymer substance, polyurethane. MOCA is transported from the site of manufacture (in Suzhou, China) to the site of use in sealed drums. The drums are solely opened in a glove box and fed via a closed system to a casting machine.

Considering the 3rd condition, the draft guidance states that this condition is fulfilled when the following conditions are met;

- *it can be demonstrated that the equipment or site where the chemical processing takes place is a controlled environment ensuring the confinement of the intermediate substance through technical means avoiding risks for human health and the environment (link to condition 2) where transformation to another substance takes place (link to condition 1);*
- *it can be demonstrated that in case the intermediate substance is removed from the equipment during the chemical process, the intermediate substance remains confined to a controlled environment through technical means avoiding risks for human health and the environment (link to condition 2).*

These conditions are fulfilled as MOCA is used at an industrial site in dedicated equipment where technical and organisation controls are in place to avoid risks to human health and the environment. For the automated polyurethane production process, MOCA is confined to the casting machine. For the semi-automated process, liquid MOCA is dispensed from the storage unit in the casting machine to a vessel, after which it is transferred to a closed reaction vessel where MOCA reacts with the other reactants under stirring to yield polyurethane.

In conclusion, for the reasons outlined above MOCA use in the manufacture of polyurethanes as described in this application fulfil the criteria to be considered as intermediate use. As it is not yet clear how LUC Group would document its decision, it is submitting this application as a contingency measure.

2. AIMS AND SCOPE

2.1. Aims of the analysis

LUC (UK) Limited (referred to as LUC UK from here on) is producing high-performance hot cast polyurethane elastomers using 2,2’-dichloro-4,4’-methylenediamine (“MOCA”), which is classified as carcinogen (Carc. 1B) under UK REACH. MOCA is not considered to be a threshold carcinogen and, therefore, the adequate control of risks arising from its use cannot be demonstrated in accordance with Annex I, section 6.4 of UK REACH, for the uses applied for. LUC UK is preparing this Application for Authorisation covering two uses to ensure continuity of their business and providing suitable polyurethane products to their current customer base, because LUC UK is vulnerable to their customer base switching to suppliers outside the UK.

LUC UK is a downstream user of MOCA in the supply chain of Suzhou Xiangyuan New Materials Co., Ltd. (Suzhou) and their use of MOCA is currently covered by the application submitted under EU REACH by REACHLaw acting as only representative for Suzhou under Brexit transitional arrangements, as the Commission has not yet taken a decision on the application. LUC Group submitted a downstream user application to cover its use at 4 sites in the EEA on 20.05.2020 and the ECHA opinion on this application was issued to the Commission for decision making on 28.07.2021. Details of the application are available on the ECHA website. As this application was submitted before the end of the Brexit transition period, it included also use at the UK site. Since the 01.01.2021, the UK site is now under UK REACH and the application submitted under EU REACH is not relevant. LUC UK is submitting this application to cover use at the UK site.

The aim of this combined Analysis of Alternatives (AoA) and Socio-economic Analysis (SEA) report is to: 1) demonstrate that no suitable alternative substances or technologies are implementable by LUC UK before the extended sunset date of 30th June 2022; and 2) to demonstrate that the socio-economic benefits of the continued use of MOCA outweigh the related risk to human health.

In particular this document will provide:

1. Details of the specific polyurethanes manufactured using MOCA
2. Details of the technical requirements of these products (custom-made rollers) used in the steel and aluminium sectors
3. The rationale for why there are no suitable alternatives available at this time
4. The benefits from continued use exceed the monetised risks to workers significantly
5. A detailed description of LUC Group’s strategy for substituting MOCA

This Analysis of Alternatives (AoA) and Socio-economic Analysis (SEA) report has been prepared for LUC (UK) Limited as the applicant, addressing its use of MOCA in the UK.

2.2. LUC Group

LUC Group was established in 1971 and is specialised in producing and processing hot cast and cured polyurethane elastomers. LUC Group has one facility in the United Kingdom and 3 facilities in the EU territory (Netherlands, Hungary and Belgium) and one in the USA. In addition, there is a sales office and logistics centre in Germany. The UK facility and the facilities in the EU manufacture MOCA cured high-performance PU products. In total, LUC Group has 104 employees (most of them in the EU).

LUC Group has been in the UK market since 2005, when it acquired the South Wales Roller Company in Newport, Wales, as of 2008 named LUC (UK) Ltd. In 2009, LUC UK moved to a completely new build to purpose 1200 m^2 facility in Dowlais in the borough of Merthyr Tydfil, in Wales. LUC UK currently employs 13 people in its facility in Dowlais.

During the past three years (2018-20), LUC Group's revenue has on average been 13 M GBP. In a typical year, the Group's profit margin is approx. 10 %. In the same timeframe, LUC UK's revenue has on average been [1-2] #B M GBP with a profit margin in line with the Group's margin. Note that during the three-year period, LUC UK's revenue has increased over 20 %. LUC UK operates on domestic markets in the UK, 99 % of their sales is from the UK.

As is typical of moulders using MOCA to manufacture polyurethane, LUC Group is a SME company (small and medium-sized enterprise). LUC Group also offers a large portfolio of PU products driven by customer demands for their high-performance PU products.

LUC Group uses MOCA as a curing agent/chain extender in the manufacture of high-performance polyurethane elastomers by the hot casting process. MOCA is used both in the automated and semi-automated processes. LUC Group's MOCA cured high-performance PU products consist of different types of rollers, pads and spring blocks.

For this use (Use 1), the high-performance custom-made rollers with high reliability requirements are supplied to the steel and aluminium industry. The products and requirements of the sectors of use are given in Chapters 3.1.3.1 and 3.1.2.3, respectively.

High-performance heavy-duty rollers, tension pads and spring blocks with high reliability requirements are used in the offshore and renewable energy sectors (Use 2). These are described in detail in Chapter 3.1.4 of Use 2 AoA-SEA report.

2.3. Supply chain

This chapter addresses both Use 1 and Use 2. LUC Group receives MOCA from a global supplier (Suzhou, see Chapter 2.5.3 for more details) and distributes it to the LUC UK. LUC UK uses MOCA to manufacture high-performance PU products that it supplies to customers in the (industrial end-users) steel and aluminium sectors (Use 1) and in the offshore and renewable energy (Use 2) sectors in the UK market. Approx. [25-40] #B % of LUC UK revenue is generated with MOCA based high-performance PU products. LUC UK is not able to account how much MOCA is used for which sector but an estimation between uses is 68 % for Use 1 and 32% for Use 2 (Figure 2). In terms of revenue, 99 % of LUC UK's customers, the end-users of the high-performance PU products, are located in the UK.

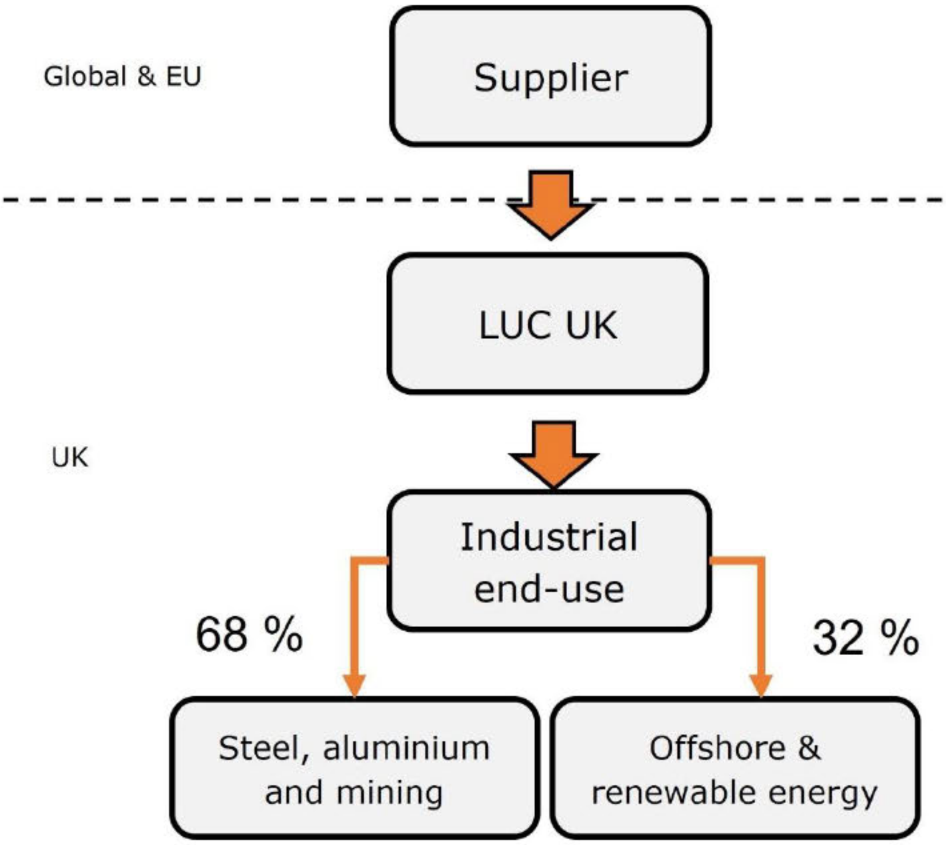


Figure 2. LUC UK Supply Chain

2.4. Scope of the analysis

2.4.1. Geographical scope

LUC UK is located in Dowlais, borough of Merthyr Tydfil, Wales, UK. Area, population and population density of Merthyr Tydfil are outlined in Table 2. A map showing the location of Dowlais in south-east Wales is given in Figure 3. Economic, social and human health impacts of the non-use scenario are mostly felt Merthyr Tydfil, thus the geographical scope of this application is the borough of Merthyr Tydfil.

Table 2. Geographical scope

Geographical Scope	Population	Surface area (km^2)	Population density (population per km^2)
Merthyr Tydfil	60,424	111	544

Figure 3. LUC UK located in Wales

2.4.2. Temporal scope

LUC Group's use of MOCA at the UK site are currently covered by an upstream application under transitional arrangements concerning the entry into force of UK REACH. The upstream application was submitted before the latest application date under EU REACH. The extended latest application date and sunset date for MOCA under UK REACH is 30th of June 2022.

There are currently no suitable alternatives to MOCA for the manufacture of the high-performance PU products covered by this use. Therefore, LUC Group will need to continue their R&D (research and development) efforts to identify a suitable alternative that result in PU products with equivalent proven performance that customers in these sectors trust in their harsh environment activities and installations. The temporal scope of 12 years is based on the review period requested in this application.

The impact calculations assume a 12-year review period starting from 2022 and ending in 2033. The assumption is solely for the calculations prepared in the socio-economic assessment and LUC UK is requesting 12 years starting from the sunset date according to the transitional arrangements (Article 127GA).

More information about the length of the review period can be found in Chapter 4.7.

3. ANALYSIS OF ALTERNATIVES

3.1. SVHC use applied for

3.1.1. Introduction to cast polyurethane and their chemistry

The application is for the use of MOCA as a chain extender/curative in the manufacture of high-performance PU products for use in specific sectors. In this chapter, an overview of the complexity of polyurethane chemistry is given to help the reader understand the role MOCA plays in the PU manufacturing process and the material properties of the resulting PU product.

Polyurethanes (PUs) are organic polymers that are used in products by a wide variety of sectors. Different types of PUs can be manufactured depending on the starting material used and the ratios of each (type of diisocyanate, type of polyol, type of curative/chain extender) – see Figure 4. This means that PUs can have very different material properties. LUC UK is covering the use of MOCA as a chain extender/curative for the manufacture of "hot cast polyurethanes".

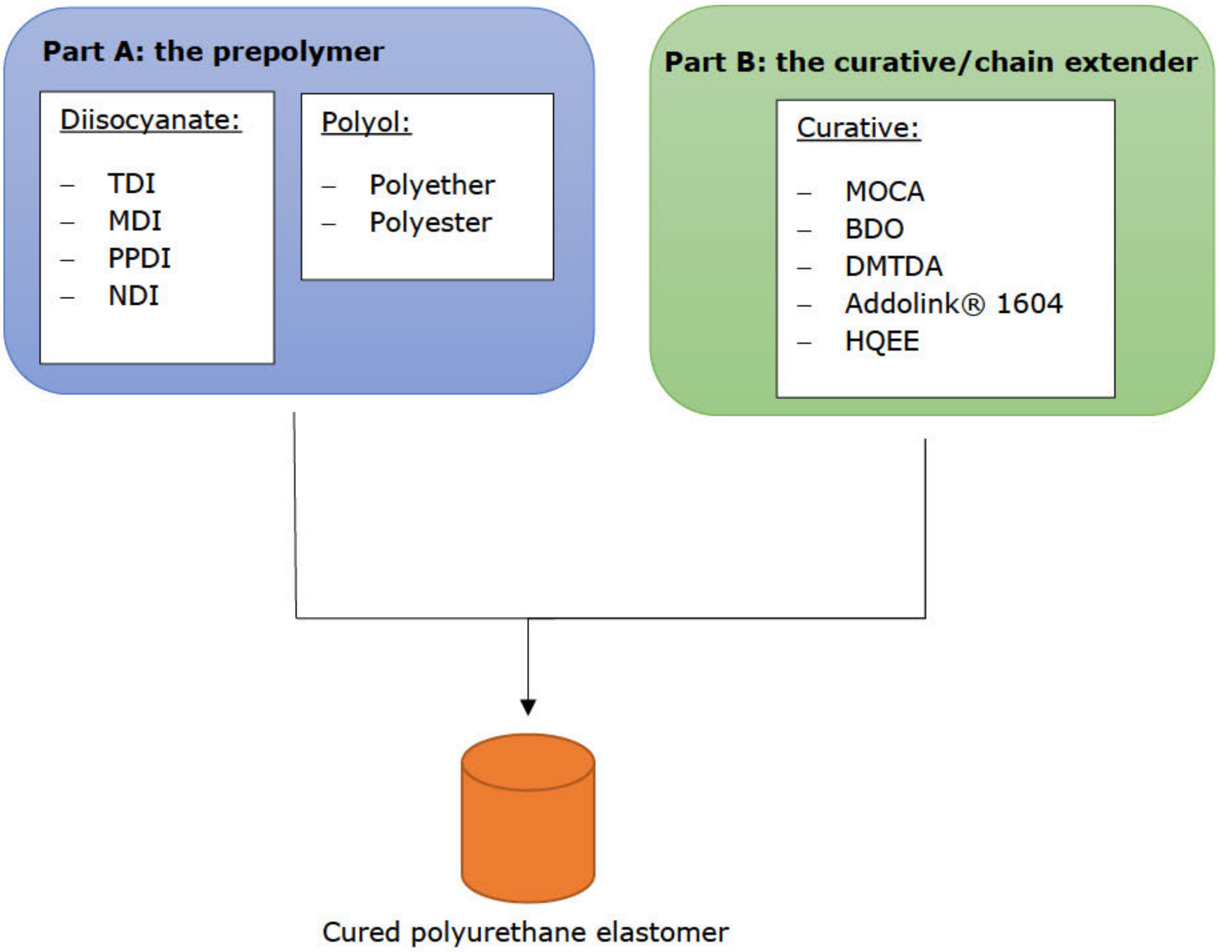


Figure 4. Principles of polyurethane manufacturing

Hot cast polyurethanes represent one type of polyurethanes and they cover PU products manufactured using moulds and low-pressure casting process. The mould gives the shape to the PU product. The mould can be very small (e.g. a few centimetres in size) or very large (e.g. a few meters long). Moulds may be custom-made for custom-products or the same mould may be used for standard products.

Hot cast polyurethanes are typically produced by first mixing all the starting materials together and then pouring the liquid mixture into moulds to set, after which the mixture is cured in an oven. During curing, the strength of the PU material develops allowing for the part to be demoulded (i.e. removed from the mould) without being damaged or distorted. At this point, the full properties of the PU material are not yet developed. To this end, a (post-)cure is still needed. The demoulded PU part will be returned to the oven for (post-)cure, where it will be kept from one day to several weeks for its full physical properties to develop.

The hot cast PU industry has a wide array of options available when it comes to the synthesis of cast polyurethanes. As each combination of starting materials affects the properties of the final PU product, production processes are customised to produce PU products that meet specific material property requirements needed for the sectors where they are used. The starting materials and their ratios used in the reaction can be varied to tailor the mechanical, dynamic, chemical and thermal properties of the resulting polyurethane (soft vs. hard elastic material). Each piece may be custom-made to customer specifications for the performance they need. This results in PU products that have the highly specific material properties required for their use in diverse sectors.

It should be noted that a finished polyurethane product (i.e. fully cured) is chemically inert and is not hazardous to human health or the environment.

What are polyurethanes?

Despite of their name, polyurethanes are not made of "urethane monomers" rather, they are produced by the exothermic reactions between chemicals known as polyols and diisocyanates (see Figure 5). Following this reaction, prepolymers containing urethane linkages (called carbamates in organic chemistry) are formed.

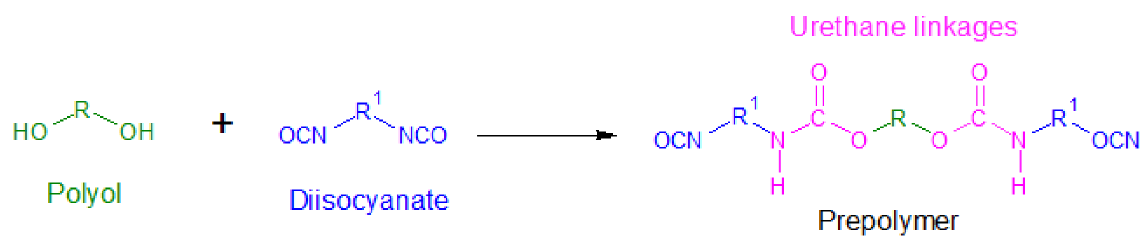


Figure 5. Polyols and diisocyanates react together to form prepolymers containing urethane linkages

The three reactant types: the polyol, the diisocyanate and the chain extender/curing agent are the main reactants used to manufacture polyurethanes. The polyol reacts with an excess of diisocyanate to form the **prepolymer**. These three reactants are described in more detail below. Other chemicals may be used in addition to the reactants mentioned above e.g. catalysts, pigments, flame retardants etc.

A. Prepolymer

Polyols:

The main polyols used in the production of cast PU are either polyethers or polyesters (Figure 6).

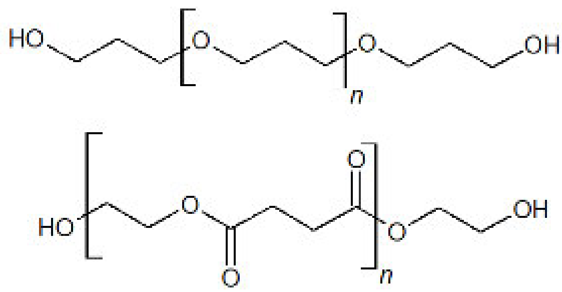


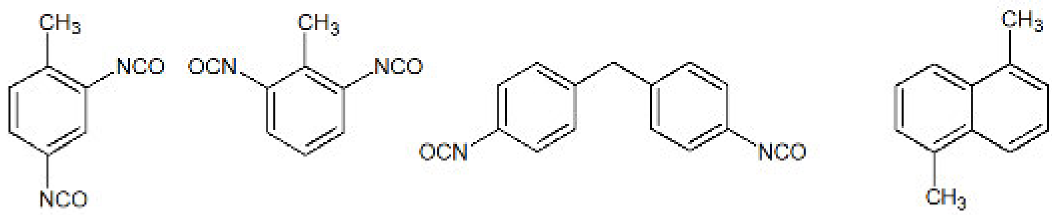
Figure 6. Top: polyether polyol. Bottom: polyester polyol

Polyols form the soft segment of the polyurethane and the choice of polyol impacts the PU material properties. Polyether glycol-based PUs are preferred for their hydrolytic resistance and their flexibility whereas polyester based PUs are preferred for their strength, toughness and higher oil resistance.

Both polyester and polyether polyols can be used in combination with MOCA to produce a diversity of PU products with very different final material properties. LUC UK uses both polyester and polyether based prepolymers in their TDI/MOCA PU products depending on the type of PU product to be produced.

Diisocyanate:

The majority of diisocyanates used in the hot cast PU industry are aromatic. Toluene diisocyanate (TDI), 4,4'-diphenylmethane diisocyanate (MDI) and 1,5-naphthalene diisocyanate (NDI) are the most important commercial aromatic diisocyanates (see Figure 7). They can be ranked by their reactivity as follows: NDI > MDI > TDI. TDI is typically sold as either an 80:20 mixture of the 2,4- and 2,6-isomers or as 100 % 2,4-TDI.



TDI MDI NDI

Figure 7. Structural formula of TDI (left: 2,4-TDI right: 2,6-TDI), MDI and NDI

Less reactive diisocyanates allow for the manufacture of large-sized products as the viscosity of the mixture increases slowly enough to avoid layering and cracking when casting.

MOCA is used almost exclusively with TDI-prepolymers.

B. Chain extender/curing agent reactant

The molecular weight of the prepolymers is not high enough to produce an elastic polymer thus the prepolymers need to be extended with so called “chain extenders”. The chain extenders increase the molecular weight of prepolymers by joining prepolymer chains to each other to produce high molecular weight polymeric chains.

The chain extenders/curing agents (from here on referred to as chain extenders, curing agents or curatives) used in cast polyurethane elastomer production are either diols or diamines. The hydroxyl group (–OH) of the diols or the amino group ($-NH_2$) of the diamines (e.g. as in MOCA (Figure 8)) reacts rapidly with the isocyanate functional group (–NCO), which terminate the prepolymer on both ends (Figure 5).

The chain extender is typically selected based on the type of part to be produced (e.g. large, small, rollers, pads etc.) and the technical requirements set for the end-product (e.g. mechanical properties, dynamic properties, end-use etc.). Some chain extenders may work with certain prepolymer systems while others do not (e.g. they react too quickly or the mechanical properties are too low).

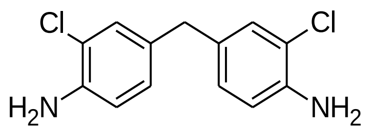


Figure 8. Molecular structure of MOCA, which is an aromatic diamine

The reaction between MOCA and the prepolymer produces polymer chains of high molecular weight that possess high-performance elastomeric properties (Figure 9). As soon as one of MOCA’s two amino group has reacted with the prepolymer, the MOCA molecule is no longer existing but rather, a MOCA-prepolymer unit. The remaining amino group of MOCA will also react with another prepolymer. The reaction stops when all MOCA molecules have been consumed and both amino groups have reacted. MOCA is therefore fully <u>(<0.1% free MOCA in final product)</u> consumed in the reaction (see Table 3 and Appendix 1).

The optimum MOCA to prepolymer ratio is 90-95 % of the theoretical, meaning there is an excess of prepolymer in comparison to MOCA. This ensures that no MOCA remains in the produced PUs. This practice is always in use at LUC UK also because the excess of NCO groups (from the prepolymer) compared to NH_2 groups (from the curative) allows for the formation of cross-links in the PU. This gives rise to tougher PU material.

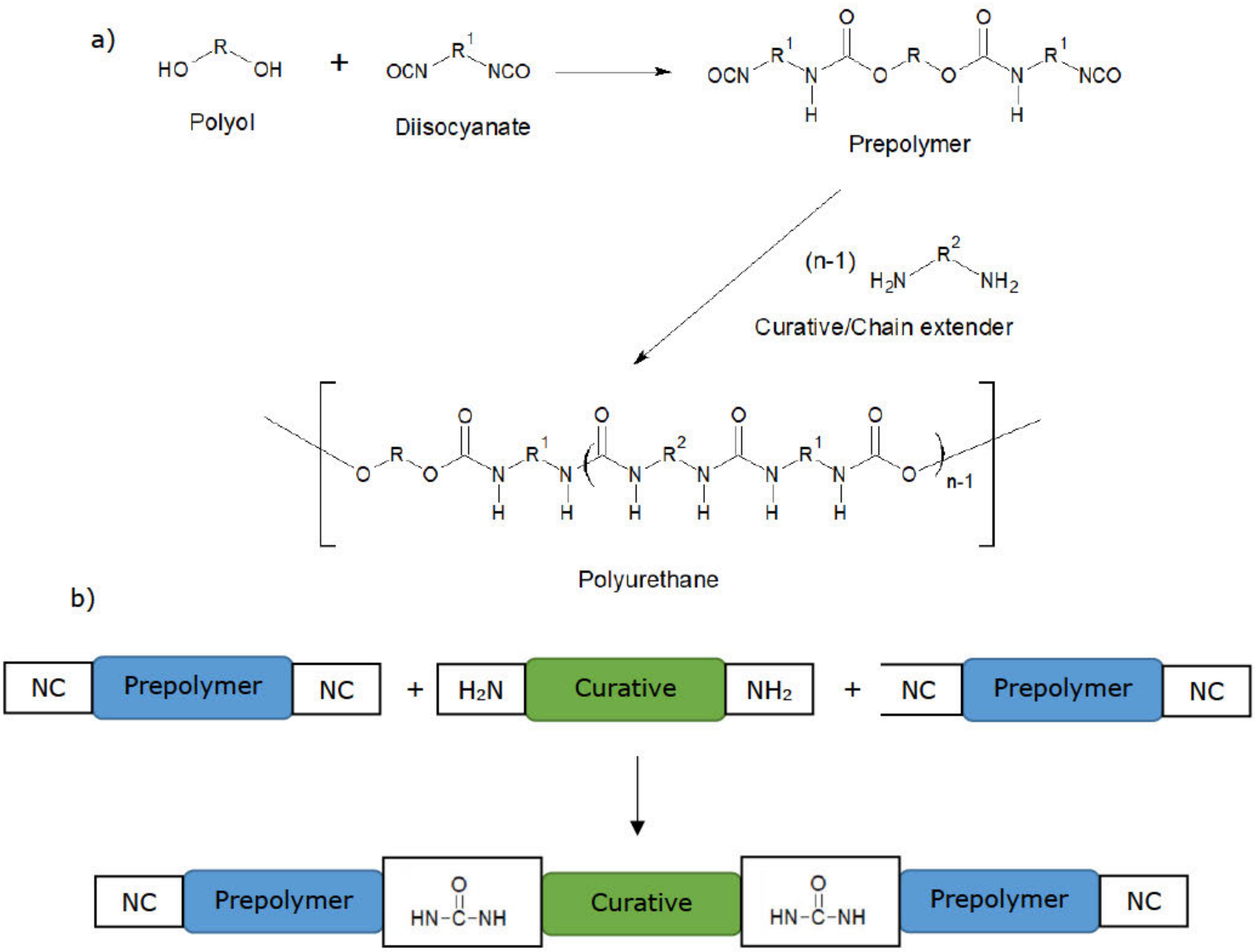


Figure 9. Synthesis of polyurethane using an amine curative/chain extender: a) chemical equation b) simplified representation of the reaction

Due to the stoichiometry of reactants used in the manufacture, the polyurethanes do not contain un-reacted MOCA. LUC Group has demonstrated that their TDI/MOCA polyurethane does not contain free MOCA. Representative samples of polyurethane products of three different hardness's have been analysed with GC-MS by an external laboratory (test methods: EPA 3550C & EPA 8270D). The analytical reports are provided in Appendix 1 of this document and the results are summarised in Table 3.

Table 3. GC-MS results determining MOCA concentration in end products

Sample No.	Sample description	MOCA concentration
#1	Polyether/TDI/MOCA – Hardness 90°A	Not detected
#2	Polyether/TDI/MOCA – Hardness 75°D	Not detected
#3	Polyester/TDI/MOCA – Hardness 80°A	Not detected

LUC UK uses TDI/MOCA as it is recognised to be a general purpose system that can be used to produce high-performance PU products with minimal investments in equipment and low amount of processing errors reducing the number of rejected parts (i.e. lower scrap rate). Furthermore, the energy consumption to produce PU products with TDI/MOCA is low due to the relatively short cure times. Due to this position as an industry standard, the performance and properties of other polyurethane systems are typically judged and compared to TDI/MOCA.

Pot-life:

Pot-life is a critical processing parameter for a PU system. It basically means how long you can work with the mixture before it thickens to the extent that it can no longer be poured. The thickening is due to the viscosity increase as MOCA reacts with the pre-polymer extending the chain length. If the mixture sets, then it is impossible to pour it evenly in the mould.

In polyurethane manufacturing, pot-life starts as soon as the chain extender is added to the prepolymer (

Figure 10). After this, thorough mixing of the two components is required in order to obtain a homogeneous material and avoid mixing errors. Therefore, a portion of the pot-life is "lost" during mixing. The remainder of the pot-life after mixing must be sufficient to cast a product (i.e. fill the mould with an even mixture) and allow any entrapped air bubbles to reach the surface before the viscosity of the mixture increases too much.

If the pot-life of a system is too short, the PU may set in layers which results in cracking and overall weaker part (these are fault-lines in the product). In addition, air bubbles may not have time to reach the surface and become entrapped in the material creating voids and therefore weakening the material. In some cases, pot-life can be so short that it is not possible to cast a product at all.

TDI/MOCA has a long pot-life, which makes it suitable for casting PU in large moulds.

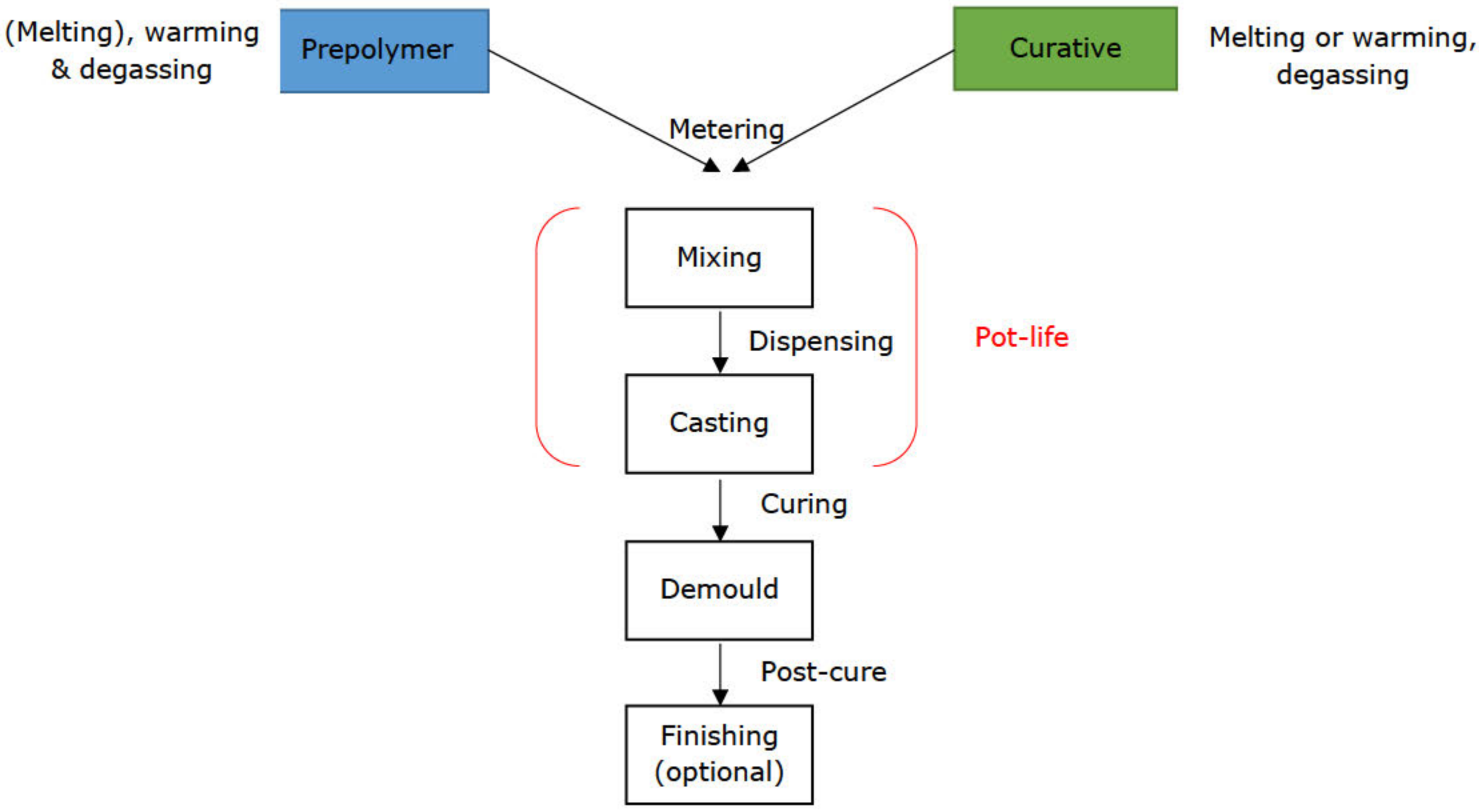


Figure 10. Pot-life starts as soon as the reactants are mixed and should last long enough for the part to be moulded

3.1.1.1. Cast PU production at LUC UK

The polyurethane products at LUC UK are produced via a multistep process. The process differs based on the nature of the PU product: polyurethane on a substrate (**S**) (i.e. rollers, pads), polyurethane without a substrate (**P**) (i.e. spring blocks) and recovering product (**R**) (i.e. recoating of rollers) (Figure 11).

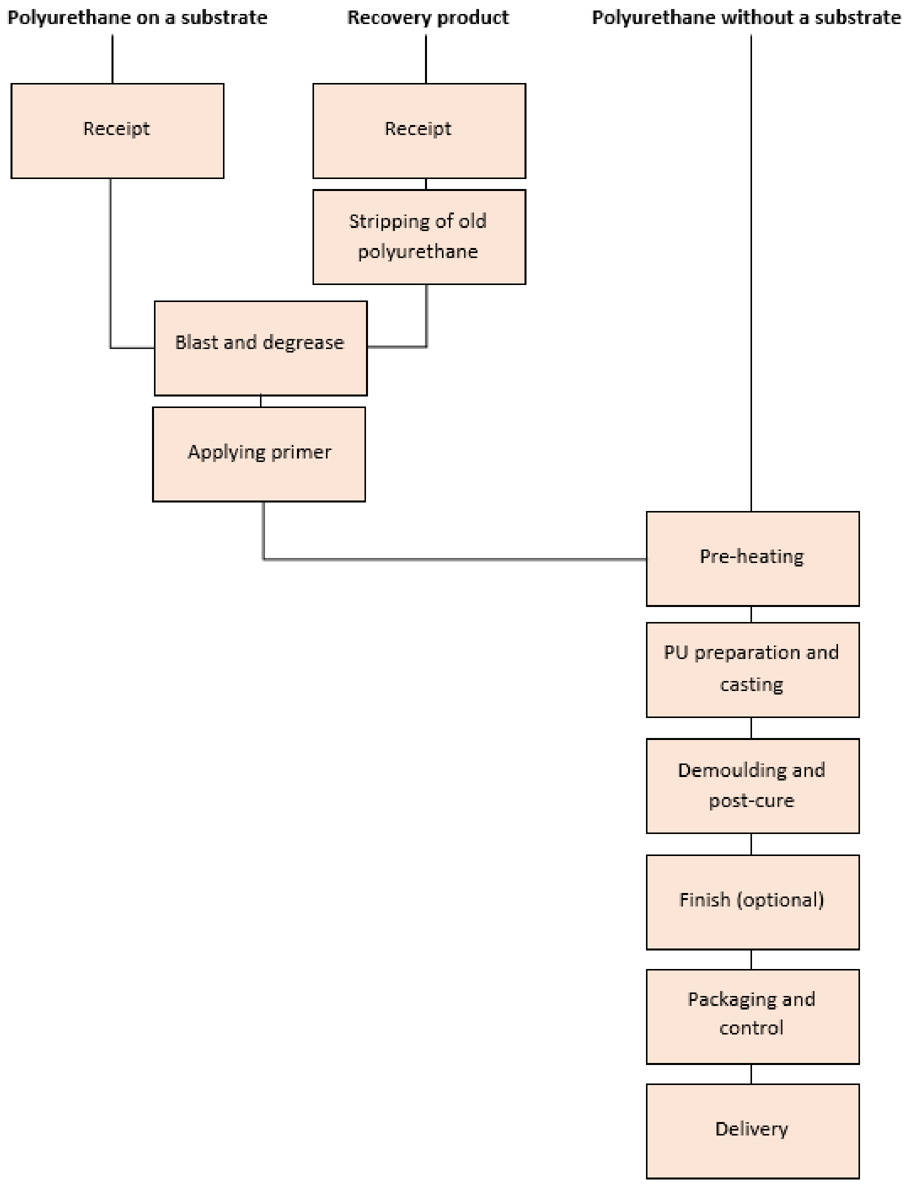


Figure 11. Production flowchart

The different steps are described in more detail below. These steps generally apply to all MOCA cured high-performance products manufactured at LUC UK. However, each step will be adapted to produce a product that fulfils customer requirements.

Receipt (for S and R):

Products, such as rollers and tensioner pads, are manufactured such that the polyurethane is chemically bonded to a metal substrate. The production thus, starts with the delivery of the metal substrates to LUC UK's facility. An operator inspects the received substrates (e.g. plates for pads, cores for rollers) to ensure they are not damaged and disassembles bearings and other parts, if necessary.

LUC UK offers services to cast polyurethane on new metal substrates, but also offers recovery services for damaged polyurethane products. LUC UK's customers send their damaged polyurethane products to LUC UK's facility where an operator inspects them upon reception to ensure they are fit for recovery. If necessary, bearings and other parts are disassembled by an operator.

Stripping of old polyurethane (for R only):

The operator uses a machine (i.e. lathe) to remove the old polyurethane from e.g. the roller core. Excessive dirt, grease and oil will also be removed during the process.

Blast and degrease (for S and R):

For polyurethane to bond successfully, it is important that the surface of the substrate is free from oil and dirt. The surface must also be roughened before the primer is applied. The operator starts by thoroughly cleaning the substrate using a washing cabinet. Then, the operator will shot-blast the substrate with the help of a machine to create minute cavities in the surface of the material. This process increases the surface area, which helps the primer attach to the substrate and makes the bond between the polyurethane and substrate stronger.

Applying primer (for S and R):

After shot-blasting, any dust present on the substrate is removed. The operator will then apply the primer (also called bonding agent) to the substrate. The primer will prevent oxidation of the metal surface and it allows the polyurethane to successfully bond to the substrate.

Pre-heating (all):

The operator pre-heats the mould in an oven to bring it to the same temperature as the PU processing temperature. A cold mould would cause the polyurethane to crystallise and set unevenly during casting, leading to cracks or to an overall weaker part. In case the product is casted on a substrate, the operator will at the same time pre-bake and pre-heat the substrate in an oven. The primer is activated by heat thus, this step is required for the primer to fully bond with the substrate and to become active for reaction with the polyurethane.

Preparation of the polyurethane and casting (all):

LUC UK manufactures TDI/MOCA PU products primarily in the automated casting production process (also known as "machine casting". A small proportion is manufactured via a semi-automated process. The semi-automated process is used for small batch production.

The ratio of semi-automated production and fully automated production is given in Table 4.

Table 4. Percentage of production done by semi-automated and fully automated production processes at LUC UK's site

Site	Semi-automated	Automated
UK	[0-20%] #C	[65-100%] #C

In the automated process, MOCA is loaded to the casting machine via a glovebox. The MOCA drum containing the sealed inlay bag is loaded to the rear of the glovebox and closed after loading the drum of MOCA. Using the gloves, the operator opens the inlay bag and MOCA flows into the funnel of the MOCA feeder. From there it is transferred to the melter. MOCA is heated above its melting temperature in the melting unit and the liquid MOCA is then transferred to the storage tank. From there, an automated system doses liquid MOCA in required quantities to the mixing chamber containing the liquid or melted prepolymer reactants. In the mixing chamber, MOCA reacts with pre-polymer to yield a polymer substance, polyurethane. After the mixing step, liquid polyurethane flows from the mixing chamber to the casting hose. The operator dispense liquid polyurethane using the hose to pre-heated moulds. The operator then slides the filled moulds into the oven for curing using a trolley.

In the semi-automated process, the operator taps the required amount of melted MOCA from machine storage unit into a vessel, which will be sealed airtight directly after tapping. The vessel is then taken to the workbench (containing point extraction) of the production laboratory, where it is added to a reaction vessel with the pre-polymer reactants. The reaction vessel has an automated mixer. When a homogenous solution of polyurethane is obtained, the operator slowly pours the liquid polyurethane into a pre-heated mould. Typically, this operation is done directly in the casting oven (equipped with extraction).

Curing, demoulding and post-cure (all):

The polyurethane is cured for 1-4 hrs in a closed oven. The duration depends on the green strength of the solidifying polyurethane. Once it has built enough strength such that it can be removed from the mould. The mould is removed from the oven, the polyurethane removed from the mould and then transferred back to the oven for curing at elevated temperatures such that the material gains additional strength. The duration can be several hours to several days depending on the polyurethane manufactured.

Finishing (optional) (all):

After this the solid polyurethane is removed from the oven and may undergo additional mechanical treatment. Some products may require machining (grinding, milling, grooving, turning etc.) after being casted to adjust their shape, to create grooves or to achieve a specific surface roughness.

Packaging, control and delivery (all):

The finished parts are then reassembled (if relevant) and undergo a final quality check before shipping. The finished products are delivered to LUC UK's customers either through LUC UK's own transportation services or external service providers.

3.1.1.2. LUC Group – manufacturer of custom-made polyurethane products

At LUC Group, the development of a product is done in close collaboration with their customers, the end-users of the products. With their expertise in polyurethane processing, LUC Group designs the mould and customises the manufacturing process based on customer specifications (size, technical requirements, price, etc.). Test parts are produced and tested at customer's facilities. Based on test results and customer feedback, LUC Group further optimises the process and part. The outcome is custom-made products that have the material properties needed for the customers sectors.

3.1.1.3. LUC Group and MOCA-free PU systems – a long history

LUC Group has long experience in the manufacture of polyurethane. Since the beginning, LUC Group has aimed to find the best possible polyurethane material for a specific product or end-use. For this reason, LUC Group has both MOCA based and non-MOCA based PU products in their product portfolio. Each PU systems have their strengths and drawbacks making them excellent solutions for some products but unsuitable for others. These characteristics are well-known to LUC Group as many non-MOCA PU systems have been in use at LUC Group for several decades (e.g. MDI systems since 1971, NDI systems since 1973 and PPDI systems since 1987).

3.1.2. Description of the functions of MOCA and performance requirements of associated products

3.1.2.1. Description of the technical function provided by MOCA

MOCA is a core ingredient in the manufacture of polyurethane. MOCA is an excellent all-round chain extender with toluene diisocyanate (TDI) based prepolymer systems, which made it the chain extender of choice in the European cast polyurethane industry for decades. It is still the most widely used chain extender outside of the EEA. Due to concerns about its hazard profile, there have been efforts to use alternatives since the 1990's. Since an entry for MOCA was included in Annex XIV, it can only be used where there are no suitable alternatives. As outlined earlier, LUC Group has been phasing out its use of MOCA where alternative curatives and/or PU systems can be used to obtain the PU material properties required by customers. This application is solely for the uses where there is no current suitable alternative that yield high-performance PU for customers with high reliability requirement in specific sectors.

As the prepolymer chains react with MOCA, their length is increased, and they become entangled with each other. This high molecular weight polymer needs to be cured to bring the polymerisation to a completion and obtain a solid polyurethane with fully developed mechanical properties. During curing, an ordering of the chains takes place and zones of hard and soft segments are formed.

The soft segments are composed of the polyol, which contributes to the flexibility of the final product. The diisocyanate and MOCA form together the hard segments of the elastomer. They provide the PU strength and rigidity and account for the "memory" of the material, allowing the part to return to its original shape after being stretched. PU elastomers that have zones with high concentration of hard segments have better all-round mechanical properties.

The bound MOCA molecules contained in the PU elastomer contribute to the alignment of hard segments through intermolecular hydrogen bonding (Figure 12). The alignment reaches a maximum towards the end of the curing process producing a robust and durable material, which has outstanding mechanical, dynamic and chemical properties.

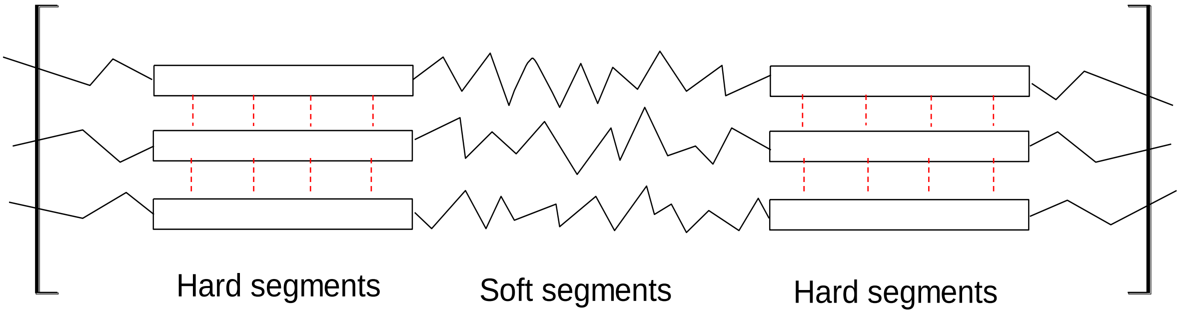


Figure 12. MOCA (hard segments) forms intermolecular H-bonds (in red) that facilitates the alignment of chains during curing

3.1.2.2. Properties of MOCA

The TDI/MOCA system yields polyurethanes with excellent material properties. The material properties can be tailored by the choice of the polyol used in the synthesis of the pre-polymers. MOCA PU elastomers are used in product supplied to a wide diversity of sectors (e.g. wheels, mining parts, oil and gas pipelining, rolls for papermaking and printing, golf balls, abrasives, marine applications, brushings, bearings, seals), which explains its extensive use in the cast polyurethane industry for the past several decades. Due to this proven track-record of successful use, TDI/ MOCA polyurethane products are recognised by customers as high-quality, high reliability and high-performance products.

An overview of the key advantages of TDI/MOCA PU elastomers is given below:

Reactivity:

One of the major advantages of the TDI/MOCA system in processing is its long pot-life. With a pot-life of up to 15 min, TDI/MOCA allows the casting of large volume products like rollers. As the viscosity of the material after the prepolymer and MOCA have been mixed remains low for a longer time, it is possible to thoroughly mix the reactants together and easily fill the moulds, even larger ones.

In addition, the low viscosity allows for any air entrapped in the material to rise to the surface instead of forming air bubbles within the material, which would result in a weakened part.

Robust and easy processing:

Casting with the TDI/MOCA system is known to be a reliable, robust and simple process. The properties and the quality of the resulting elastomer are not significantly affected by slight variations in the chain extender to prepolymer ratios (% theory), which results in less rejected parts (low scrap rate).

In addition, MOCA has an excellent solubility in a variety of prepolymers. This means MOCA will not easily crystallise when mixed with prepolymers ensuring a homogeneous material.

Technical performance:

TDI/MOCA polyurethanes are known to be durable and have a long article service life under harsh end use conditions. This generally means the end users with high durability/reliability requirements select polyurethanes with a proven record of performance. TDI/MOCA polyurethanes have a proven track record and are the norm for durable cost effective polyurethanes.

There are no commercially available alternatives to the TDI/MOCA system that are both cost effective and have comparable performance.

Economical:

There are no commercially available alternatives to the TDI/MOCA system that are both cost effective and have comparable performance. In a report published in December 2016, Chemtura (nowadays Lanxess) reported non-MOCA amine chain extenders to be 2.8-10.9 times more expensive than MOCA based on equivalent stoichiometric amount. For diols, the MOCA:BDO ratio was reported to be 1:0.3.

In LUC UK's opinion, the cost ratios are still representative of the current prices for chain extenders or even higher in certain cases such as Addolink® 1604 (a Lanxess product).

Sustainability:

TDI/MOCA high-performance PU parts typically have a high durability and reliability, which translates to less downtime for LUC UK's customers. In addition, stripping and recovering are less frequently needed when using TDI/MOCA PU-based parts than with other polyurethane systems. Less waste is therefore produced, which results in a lower load on the environment as PU elastomers cannot be recycled.

MOCA-based systems have shorter curing times, which results in lower energy consumption and higher productivity.

Proven track-record:

TDI/MOCA high-performance PU products have decades of industrial use and are proven in industrial end use setting to be highly durable, reliable high quality products. They benefit from a strong customer confidence, which results from decades of successful use of TDI/MOCA PU products. This makes the customers wary of changing to products cured with alternative chain extender in particular when the products are used in harsh environments where high reliability can be a definitive factor in the choice of the material.

In summary, MOCA is an excellent all-round chain extender with TDI based prepolymer systems, which made it the chain extender of choice in the European cast polyurethane industry for decades. It is still the most widely used chain extender outside of the EEA and UK as there are no commercially available alternatives to the TDI/MOCA system that are both cost effective and have comparable performance. It is also economical and benefits from a proven reputation due to being an industry standard. For customers, a TDI/MOCA high-performance PU part corresponds to a high quality and durable product with an established track record coming from decades of use in end-use installations.

3.1.2.3. Description of the technical requirements that must be achieved by the products made with MOCA

The PU products cured with an alternative curing agent must have the same technical properties as the MOCA cured PU products. In some cases, alternative curing agents have been shown to perform as well or even better than MOCA in regards to an individual technical property, but do not have the same performance for all the required properties.

For the custom-made rollers covered by this use, the most important technical requirements are presented below.

- **Mechanical strength:** A high mechanical strength is necessary to handle the loads and the high tensions that are applied on the PU-covering. The loads used in the steel and aluminium industries are typically high. A PU with insufficient mechanical strength will powder or crack rendering the part unusable.

- **Coefficient of friction (CoF):** This parameter depends on whether the roller is driven (powered with a motor) or non-driven.
    - Driven rollers need a high coefficient of friction to be able to maintain grip and thus stretch/place tension on e.g. metal sheets or conveyor belts.
    - For non-driven rollers, CoF is not a key parameter.

- **Dynamic load bearing capacity:** The parts need to have a high dynamic load bearing in these applications. If the PU cannot withstand the dynamic loads, it will build up temperature and melt (degrade) or start cracking.

- **Fatigue:** Fatigue behaviour is an important factor in terms of product life and durability. Parts with low fatigue resistance will need to be changed more often.

- **Cutting resistance:** It is important that the PU parts have high cutting resistance in order to avoid parts breaking or getting cut out and contaminating the customer's production line. Contamination would lead to the damage of the metal sheets and strips in the production line thus, increasing the end-user's scrap rate. Cutting resistance is thus crucial to the high-performance PU rollers used in the steel and aluminium industries as they come in contact with sharp metal parts and cutting blades. A roller with low cutting resistance would not last long during end-use.

- **Adhesion:** High bonding strengths are necessary to maintain adhesion between the PU and substrates. If delamination occurs, this could lead to major costs and equipment damage due to the stop in production to replace the roller.

- **Reliability:** It represents the likelihood of the product to perform its intended function for the defined period of usage and under the defined operating conditions in a manner that customer requirements are either met or exceeded. It is a crucial parameter for LUC UK's high-performance PU products thus, the products cured with an alternative chain-extender must be as reliable as TDI/MOCA PU products. When purchasing LUC UK's products, the customers are expecting a highly reliable product. If LUC UK fails to deliver such a product, their customers will switch to non-UK moulders who can supply MOCA cured PU products. In this case, LUC UK would lose its customer base meaning a negative economic impact on its business.

All these properties in combination contribute to the quality and success of LUC UK's high-performance PU roller coverings in this sector of use. The material properties are based on customer specifications for the products covered by this use. Therefore, non MOCA-based PU coverings on rollers need to fulfil these criteria to be considered "suitable".

The technical requirements listed above are used in this AoA to assess the performance of alternative PU materials compared with their TDI/MOCA counterparts. For quantitative definitions of the technical requirements, please refer to Table 8 in Chapter 3.2.4 including minimum, maximum and typical values for the technical properties described above.

3.1.3. Market analysis of products manufactured with MOCA

3.1.3.1. Description of the products resulting from the use of MOCA

LUC UK's MOCA based product portfolio for the steel and aluminium industry consists of a great variety of large rollers for strip processing mills. Typical roller diameters are in the range of 0.3 m to 2.5 m and roller lengths in the range of 1.5 m to 4 m. The rollers usually consist of a steel roller body with a polyurethane covering of approximately 10 to 30 mm thickness. Figure 13 shows an example of two rollers for a steel mill with a diameter of 2.4 m.

Figure 13. Rollers with a diameter of 2.4 m for a steel mill

Figure 14 shows the typical process for manufacturing strip steel products. The process to manufacture stainless steel and aluminium is similar from the cold rolling mill forward. Figure 15 shows how a typical processing line is set up and a picture of such line is presented in Figure 16.

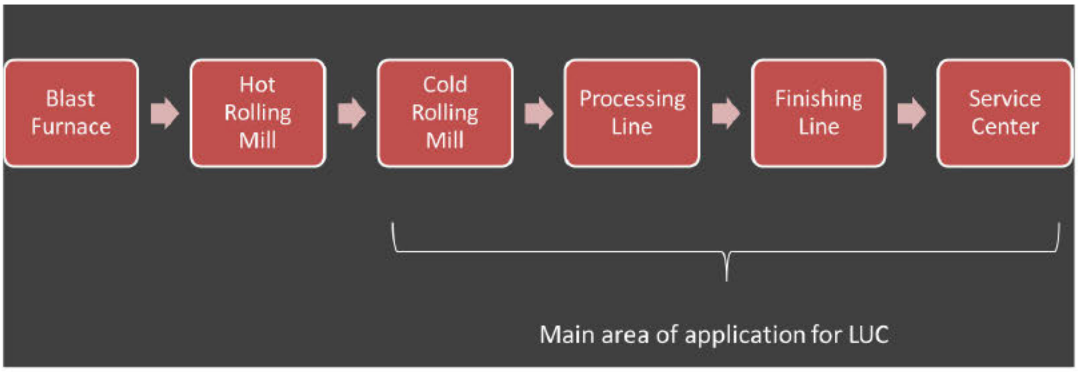


Figure 14. Typical process for manufacturing strip steel products

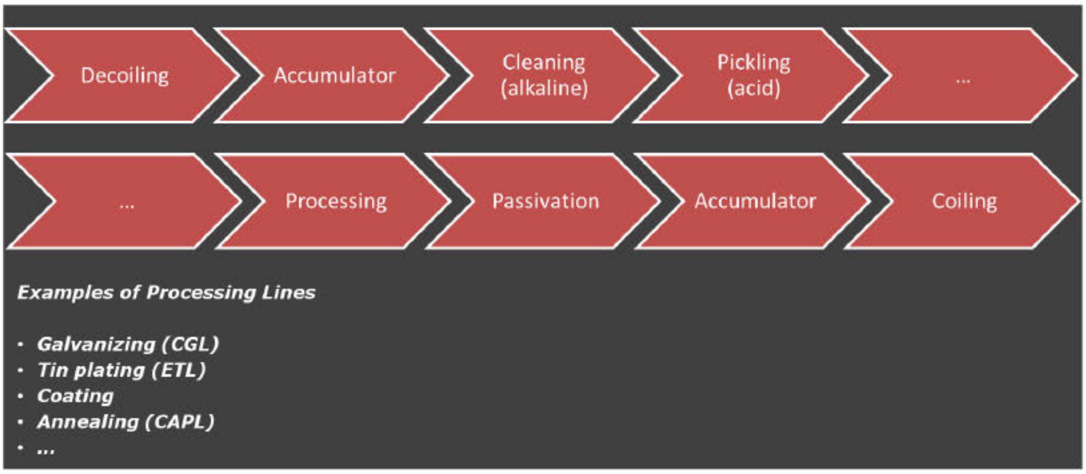


Figure 15. Set up of a typical processing line for the production of steel and aluminium strips

Figure 16. Part of a strip processing line and a welder

Starting from the cold rolling mill, rollers with polyurethane covering are used in each line and in each individual section of a line. Examples of roller types are:

- Applicator rollers
- Braking rollers
- Bridle rollers
- Coating rollers
- Coil Support rollers
- Contact rolls
- Deflector rollers
- Driver rollers
- Laminating rollers
- Looper car rollers
- Pass-line rollers
- Pinch rollers
- Pressure rollers
- Print rolls
- Shape-meter rollers
- Snubber rollers
- Squeeze rollers
- Steering rollers
- Strand gate rollers
- Support rollers
- Table rollers
- Transport rollers
- Wringer rollers

One example of rollers are the bridle rollers, which are used to keep sufficient tension on the strip. They require high coefficient of friction but also high strength because of the very high strip tension. Figure 17 and Figure 18 show examples of bridle rollers.

Figure 17. Set of 4 bridle rollers in a steel processing line

Figure 18. Bridle rollers with a diameter of 1.8 m in a steel processing line

The steel, stainless steel or aluminium strips manufactured in the mills where LUC UK is supplying to are typically used for high end applications. They are typically high-quality steel or aluminium grades, with for example high strength or high-quality surface finish. End-uses of the manufactured strip can for example be in automotive, aerospace, food packaging, chemical process industry and renewable energy.

3.1.3.2. Market analysis

General market information, such as size and trend, regarding MOCA and PU products in the UK market was not found after extensive web search. However, information on global PU market was available. The global PU market was valued at over 39 M GBP in 2021, and the market is projected to register a compound annual growth rate (CAGR) of 5% between 2022 and 2027.[7] Without more specific information, it is assumed that also the UK PU market follows the same type of future projection.

The size of LUC UK's market niche, the high-performance PU products used in the steel and aluminium sectors, is approx. [0.5-1.5] #B M GBP in the UK. LUC UK has ca. 6 main competitors supplying PU products to the steel and aluminium sectors in the UK. LUC UK has a fairly good position in the supply of high-performance PU products in the UK market with a market share of [11-21] #B %. LUC UK's market share of the high-performance PU market is expected to grow because the number of new customers has been increasing as LUC UK is getting a share of the market where customers switch from competitors who offer non-MOCA cured PU products. The switch is due to the customers' dissatisfaction with the performance, quality and reliability of non-MOCA cured PU products offered by competitors since the sunset date for MOCA. Taking the above information into account

[7] https://www.mordorintelligence.com/industry-reports/polyurethane-market

LUC UK expects an annual growth rate of [8–16] #B % for its revenue in the foreseen future.

However, the high-performance PU market is vulnerable to extra-UK competition. If the use of MOCA is not permitted to manufacture the high-performance PU products, this will distort the market in that non-UK suppliers have a competitive advantage. LUC UK's customers can easily switch to non-UK moulders. As the finished PU products do not contain any MOCA, they are not affected by authorisation thus, non-UK moulders can continue freely to place their TDI/MOCA PU products on the UK market. LUC UK has to compete with these non-UK moulders, which puts them in a vulnerable position in that at any time, LUC UK's customers may leave them for a non-UK moulder.

The MOCA cured high-performance PU products covered by this use (Use 1), for example custom-made rollers, are used in the manufacture of steel and aluminium. To assess the demand for the MOCA cured high-performance PU products, overviews of steel and aluminium markets in the UK are presented next.

The UK steel market had total revenues of 2.8 B GBP in 2020, representing a CAGR of 1.9 % between 2016 and 2020. The UK steel market is forecast to grow with a CAGR of 3.2 % from 2020 to 2025 when reaching total revenues of 3.3 B GBP.[8]

In 2020 the UK steel industry contributed 2.0 B GBP to the UK economy in terms of gross value added (GVA). This was equivalent to 0.1% of total UK economic output and 1.2% of manufacturing output. There are 1,100 businesses in the UK steel industry. The industry supported 33,400 jobs in the UK in 2019, 0.1% of all UK jobs. In 2019, the UK produced 7 million tonnes of steel. The EU produced 157 million tonnes of steel in 2019, 8% of the world total. The UK (then still an EU member state) was the eighth largest steel producer in the EU, after Germany, Italy, France, Spain, Poland, Belgium and Austria. The recent fall in international demand for steel, combined with continuing growth in production has created a glut of steel on the international market. This has pushed steel prices down, magnifying the comparative expense of steel produced in the UK, where overheads are higher than in some other countries. Demand for steel fell significantly during the first coronavirus lockdown in early 2020 as construction and manufacturing sectors stalled leaving some companies facing liquidity issues. Additionally, the sector requires considerable further investment to meet decarbonisation targets, which will likely raise costs of production further.[9]

The UK aluminium market had total revenues of 1.1 B GBP in 2021. The market grew 24 % from the previous but that growth is mainly due to recovery from a COVID-19 related dip in 2020. There are 132 business in the UK aluminium industry. The industry supported approx. 4,000 jobs in the UK. In 2019 In the UK, the wider aluminium industry directly contributes around £2.97 billion in GVA. Approximately 37,000 people are directly employed by the wider aluminium industry.[10] [11]

The industry is expected to continue to face mixed conditions over the next five years. On the one hand, an expected recovery in the global economy is anticipated to boost demand

[8] https://www.researchandmarkets.com/reports/5546427/steel-in-united-kingdom-uk-market-summary

[9] https://commonslibrary.parliament.uk/research-briefings/cbp-7317/

[10] https://fraserofallander.org/wp-content/uploads/2021/09/The-Aluminium-industry-in-the-UK.pdf

[11] https://www.ibisworld.com/united-kingdom/market-size/aluminium-production/

for aluminium products, as the metal's relative durability, light weight and recyclability makes it preferable to other metals. The world price of aluminium dictates the price that industry operators receive for their products and therefore has a significant influence on industry revenue. As the global economy recovers from the effects of the coronavirus pandemic, demand for the metal is expected to far outstrip supply, leading to significant price increases. On the other hand, the focus on energy efficiency is likely to remain strong, and limits on carbon emissions may increase compliance costs for operators. As aluminium production is highly energy-intensive, the industry is unlikely to attract new entrants given Britain's high energy costs. Some operators may be unable to cope with foreign competition, and enterprise numbers are projected to decline slightly as a result. In addition, other negative factors affecting this industry are high imports and high competition.[10] [12]

The situation in the UK steel an aluminium market can be described as stable. The market is not rapidly increasing or decreasing. The demand of high-performance PU products from the steel and aluminium market can therefore be assumed to continue similarly than before. The market growth for individual suppliers such as LUC UK is stemming from the competition against other suppliers. In this LUC UK is positioned better than its competitors as described above and therefore can expect a growth above average.

3.1.4. Annual volume of the SVHC used

LUC UK currently uses 2 tons of MOCA annually. The highest forecast annual tonnage over the review period is 3.8 tons. The annual tonnage used in the risk assessment is 3.8 tons The monetised risk values were derived using this value.

The tonnage can be divided between the uses with the same percentage shares as other variables: 68 % for Use 1 and 32 % for Use 2. This accounts 2.58 tons as highest forecast tonnage for Use 1 in the 12-year review period applied for.

3.2. Efforts made to identify alternatives

The efforts made to identify alternatives discussed in this chapter are the efforts of LUC Group.

3.2.1. Research and development

LUC Group has made extensive efforts to find a suitable replacement for MOCA in their PU products. LUC Group’s R&D on alternatives to MOCA started in June 2009 and are still ongoing for the high-performance PU products covered by the two uses of this application. This is due to the fact that no suitable replacements have been found for these products in spite of LUC Group’s extensive R&D efforts. Short pot-life and poorer mechanical and/or dynamic properties have been limiting factors to the use of alternative systems. To date LUC Group has spent more than 0.5 M GBP in R&D to find an alternative to MOCA. Since the submission of the authorisation application under REACH (ID 0225-01 and 0225-02), LUC Group has continued its R&D efforts and tested one further alternative.

In contrast, in some of LUC Group’s PU products, representing approximately 25 % of LUC Group’s MOCA PU product portfolio, the use of MOCA has been successfully phased out and the PU products are now produced using alternative systems. For products supplied

[12] https://www.ibisworld.com/united-kingdom/market-research-reports/aluminium-production-industry/

to specific sectors, MOCA was replaced with a different curative ([redacted]) or by a different PU system ([redacted]). This was possible because the technical requirements of the end products were different and/or the short pot-life of the material was less of an issue (does not apply to [redacted] as its pot-life is similar to MOCA) as the parts are small in size and not very complex. In addition, the MOCA-based system was replaced with [redacted] for some rollers. [redacted]

LUC Group has conducted multiple R&D projects to find potential replacements for MOCA. These projects can be divided into four groups:

1. **<u>Like-for-like diamine alternatives:</u>**

   The list of alternative diamine chain extenders tested by LUC Group is extensive: M-CDEA, MDEA, MBOEA, MXDA, DETDA, DMTDA, Addolink® 1604 and Vibracure® A157 among others. Most of the tested diamines were so reactive that even the casting of a test plate proved to be impossible. The ones that had an acceptable pot-life (i.e. were less reactive) did not meet the required mechanical and/or dynamic properties.

   The two most promising diamine chain extenders, DMTDA and Addolink® 1604, are assessed in more details in Chapter 3.3.1.

2. **<u>Chain extender blends:</u>**

   As reactivity is often an issue with MOCA alternatives, blends of chain extenders were tested in order to remediate with short pot-life issues and the poor mechanical properties of less reactive chain extenders.

   Blending chain extenders did improve the reactivity to a certain extent however, the reactivity of the blend was not uniform throughout the material. LUC Group observed that the more reactive chain extender reacts first, followed by the less reactive one. In practice, this limits the amount of the more reactive chain extender that can be used in the blend as viscosity would increase too fast and unevenly. As a consequence, only limited improvements in mechanical properties were achieved with chain extender blends. Since the submission of the authorisation application under REACH, LUC Group has tested one further alternative [redacted], which is a commercial chain extender blend.

   Please refer to Chapter 3.2.4.2 for additional information on the tested blends. Chapter 3.3.1.1 includes test results of the four most promising chain extender blends (two ether based prepolymers and two ester based).

3. **<u>Newly developed LF-MDI (Low-Free MDI) and conventional MDI systems:</u>**

   LUC Group has also tested the MDI systems of Covestro, DOW and Lanxess (former Chemtura) to be used as alternatives to TDI/MOCA. Although LUC Group has a long experience with MDI-systems (LUC Group has developed their own MDI-systems and have been using them since 1971), LUC Group found that it was more difficult to work with these systems than with the conventional TDI systems (see Chapter 3.3.2 for further details). The mechanical and/or dynamic properties of the resulting PUs were lower. Furthermore, PU products had reduced coefficients of friction.

Two LF-MDI systems and four conventional systems are assessed in more detail in Chapter 3.3.2.

4. **NDI/PPDI systems (already started before 2009):**

LUC Group has also conducted tests on other non-TDI systems – specifically those using NDI (in use since 1973) and PPDI (since 1987). The processability of these systems is different than with TDI-prepolymer systems. Their reaction profiles differ, and curing takes significantly longer. The low hysteresis and dynamic load bearing capacity of the PUs made with these systems outperform the PUs made with TDI systems. The coefficient of friction of these PUs is however significantly lower. In addition to the technical differences (PU grades) there is also a huge difference in costs.

The most promising NDI and PPDI-based alternative candidates are presented in more details in Chapters 3.3.3 and 3.3.4, respectively.

In conclusion, despite the extensive R&D work which LUC Group has carried out for more than a decade, they have not identified a suitable alternative to MOCA in the production of the high-performance PU product groups covered by this application. LUC Group is continuing its efforts to find a non-MOCA based PU system for these products. LUC Group is focusing on finding a like-for-like alternative chain extender as they would preferably continue to use a TDI-based system since the PUs manufactured have better dynamic, fatigue and friction properties in comparison to those manufactured using (LF-)MDI-based systems.

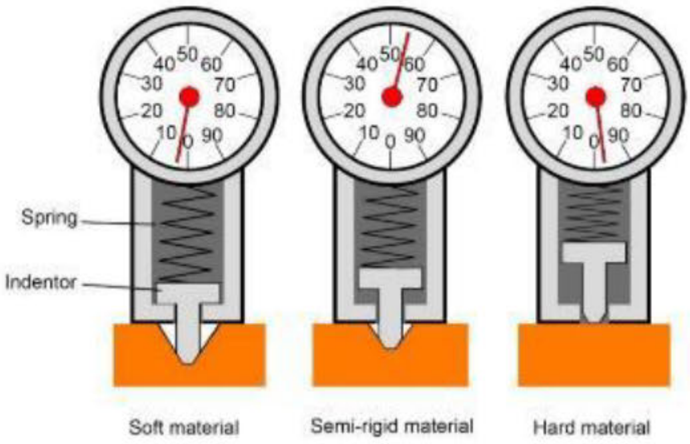
3.2.1.1. Standardised testing

LUC Group uses standard test methods (ISO methods) to test the PU properties. All tests are carried out at LUC Group's facilities. The test data presented in Chapters 3.2.4.1 and 3.3 were generated using the test methods listed in Table 5.

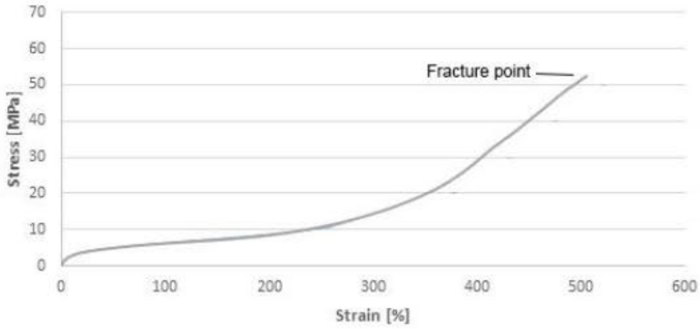
Table 5. Standard testing methods used by LUC Group

<table>
<tr><th>Property</th><th>Unit</th><th>Testing method</th><th>Description of the test method</th></tr>
<tr><td>Hardness (at 23 °C)</td><td>[°A]</td><td>ISO 48-4</td><td>An indenter is pressed into a test piece. The depth of indentation is measured and converted to hardness using a formula.

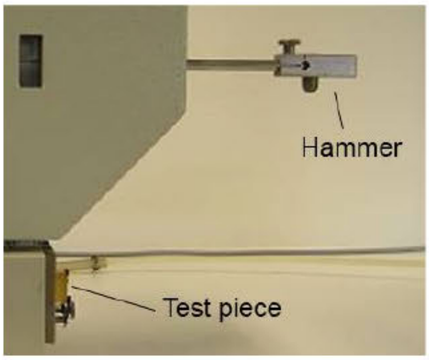
It is measured using a specific instrument called Shore durometer, which consists of an indenter, a spring and a gauge (see figure below). It is a simple instrument that measures the depth of the indentation created in the polyurethane by a given force.


</td></tr>
<tr><td>Tensile strength</td><td>[MPa]</td><td>ISO 37[1]</td><td rowspan="2">A test piece is stretched by a tensile-testing machine until it breaks.

A stress-strain curve can be plotted from the results of tensile strength testing. The curve describes the relationship between stress (force stretching the material) and strain (deformation of the material) for the particular material tested. The curve is unique to each material (see example below).



The fracture point corresponds to the point when the test sample breaks. The elongation at break is the strain value at fracture point while tensile strength is the stress value at fracture point.</td></tr>
<tr><td>Elongation at break</td><td>[%]</td><td>ISO 37[1]</td></tr>
<tr><td>Tear resistance</td><td>[kN/m]</td><td>ISO 34-1 Method B-procedure b</td><td>A test piece having a nick is stretched until it breaks. The force required to propagate the nick is measured.</td></tr>
</table>

Property	Unit	Testing method	Description of the test method
Rebound resilience (at 23 °C)	[%]	ISO 4662	Rebound resilience is measured with a specific apparatus consisting of a hammer at a 90° angle (see picture below). The hammer drops and hits the test piece. The loss in angle is a measure for the energy uptake of the PU. 
Compression set	[%]	ISO 815-1	A test piece of a specific thickness is compressed at a fixed temperature for a specific amount of time. Afterwards, the compression is removed and the test piece is allowed to recover for a specific amount of time at a fixed temperature. The thickness of the test piece is then measured. Compression set is the difference between the original thickness of the material and the thickness after being compressed, expressed as a percentage of the material's original thickness: $Compression\ set = \frac{(Original\ thickness - Thickness\ after\ test)}{Original\ thickness} \times 100$
Abrasion	[mm³]	ISO 4649 Method B	A rotating test piece is made to move over an abrasive surface at a specific contact pressure and over a fixed distance. The test piece is then weighed to determine mass loss, based on which volumes loss is calculated.

[1] LUC Group uses 200 mm/min instead of 500 mm/min as test speed on the tensile tester.

__Coefficient of Friction (CoF) test (internal standard):__

The friction experiments are performed on a friction tester. This apparatus determines the dynamic Coefficient of Friction (CoF) between two different materials under given conditions. In Figure 19, the friction tester and the sample holder are shown in detail.

[redacted]

Figure 19. LUC Group's friction tester (left) and sample holder (right)

During the experiment a certain load (normal force; F_N) is applied between the PU sample and counter material (e.g. steel or coated steel). After the load is applied, the PU sample will move along the counter material with a certain speed and distance. The required force to move the sample is called the tangential force (F_{tan}) and is measured by a load cell.

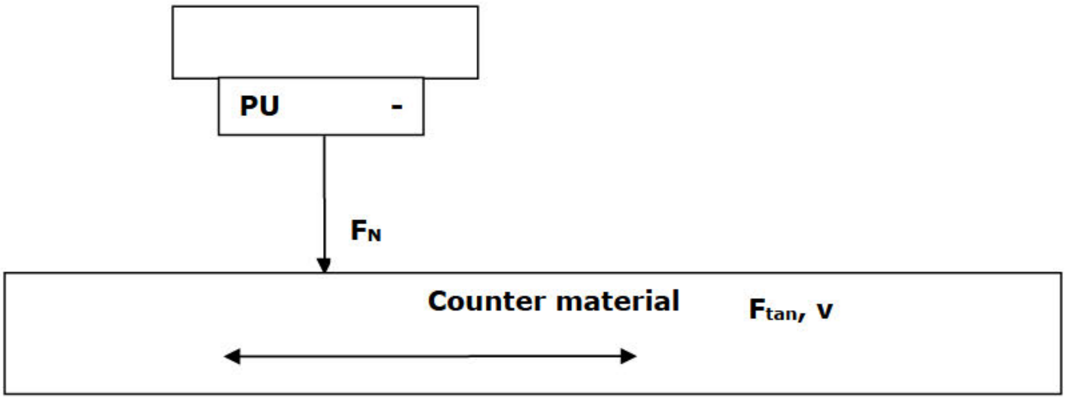


Figure 20. Schematic representation of the friction test

The CoF (μ) is defined as the ratio between F_{tan} and F_N and is not only determined by PU grade but also by counter material, contact pressure and other parameters.

$$\mu = \frac{F_{tan}}{F_N} \neq constant$$

To test the PU samples under equal conditions, all experiments are carried out according to the parameters presented in Table 6.

Table 6. Parameters used when testing the dynamic Coefficient of Friction (CoF)

Parameter	Value
Stroke length	100 mm
Speed	10 mm/s
Number of cycles	10
Test temperature	23 °C
Sample pre-treatment	All PU surfaces cleaned with acetone
Number of samples per PU-grade	5
Number of friction measurements per sample	2
Counter materials	AISI 316L (stainless steel) S355 (steel) Aluminium (Use 1) 3-layer polypropylene (Use 2)
Test conditions	Dry and wet

Wheel test (Ride Simulator; dynamic testing – internal standard):

Wheel tests are conducted on LUC Group's Ride Simulator (Figure 21), which is used to qualify the dynamic properties of the PU material. This test equipment allows test loads up to 70 kN and velocities up to 300 km/h. The temperature development of the wheel covering is monitored during the test using an IR camera.

Figure 21. LUC Group's Ride Simulator. The test PU wheel is shown by an arrow

Typical test conditions are presented in Table 7. Test PU wheels having a diameter of 290 mm (inner) and 320 mm (outer) as well as a width of 90 mm are used in the test. The thickness of the PU covering is of 15 mm. The velocity is typically kept at 2 km/h while the load applied on the PU test wheel is increased by 500 kg every 30 min until the PU covering fails. Failure can be PU cracking, melting or powdering.

Table 7. Typical test program on LUC Group's Ride Simulator

Time [minutes]	Velocity [km/h]	Load [kg]
0	2	450
30	2	450
31	2	950
60	2	950
61	2	1450
90	2	1450
91	2	1950
120	2	1950
121	2	2450
150	2	2450
151	2	2950
180	2	2950
181	...	...
210	...	...
...	...	...
...	...	...
Failure	Failure	Failure

3.2.2. Consultations with suppliers of alternatives and customers

To identify potential suitable alternatives, LUC Group has consulted suppliers of potential alternatives, including Lanxess (previously Chemtura, supplier of LF-MDI and Addolink® 1604), Covestro and DOW. The results from testing are discussed in more details in Chapter 3.3.

PU products manufactured with non-MOCA curatives and different systems have been tested at LUC Group's customers' sites (field trials). The feedback from the customers is considered in the development of new products and is used, along with test data, to assess the technical feasibility of potential alternatives.

3.2.3. Data searches

LUC Group has been extensively searching for potential alternatives to MOCA for more than a decade. In addition to direct consultations with alternative suppliers (e.g. Lanxess, Covestro) LUC Group also monitors developments reported in relevant literature and articles. All the alternatives discussed in the public consultation of the Suzhou upstream MOCA authorisation application (ID 0094-01) previously submitted under EU REACH were tested by LUC Group. LUC Group has also attended targeted industry events (e.g. UTECH, K-Messe, Chemspec).

3.2.4. Identification of alternatives

LUC Group has set minimum requirements for the tested alternative candidates as a pre-selection criterion. These requirements are divided in three categories:

1. **__Primary:__ Reactivity (pot-life) and hardness**

    - The pot-life of the material should be long enough to allow to cast parts without layering or air bubbles staying entrapped in the PU. A pot-life of < [redacted] min is considered too short for the rollers covered by this use due to their large size. The pot-life needed is highly dependent on the size of the roller. [redacted] min is considered the minimum criterion. Some rollers concerned by this use will require longer pot-lives.
    - The alternative candidates were tested in a [redacted]°A ether system and/or [redacted]°A/[redacted]°A ester system. If the measured hardness of the produced PU was lower/higher than the expected hardness, efforts for adjusting hardness were made. If the adjustments did not resolve the deviation in hardness (±2°A is an acceptable deviation), it was rejected.

2. **__Secondary:__ Mechanical properties**

    - Tensile properties (tensile strength/elongation at break), tear resistance, rebound, compression set and abrasion resistance were tested if the alternative candidate passed the primary minimum requirements of the systems tested.
    - Mechanical property ranges were set for the MOCA/TDI systems (see Table 8) for the applications covered by this authorisation application. Three TDI/MOCA systems are used as reference: two TDI-polyester polyol prepolymer cured with MOCA having different hardness's ([redacted]°A and [redacted]°A), and one TDI-polyether polyol prepolymer cured with MOCA at [redacted]°A shore hardness. LUC Group derived the typical, minimum and maximum values from the thousands of tests they have conducted on TDI/MOCA polyurethane. If the mechanical properties of the alternative candidate were out of these defined specifications, it was rejected.

Table 8. Overview of acceptable mechanical property ranges of PU systems (#A for all redactions in the table)

Property	Standard	Unit	MOCA/TDI ester - [redacted]°A			MOCA/TDI ester - [redacted]°A			MOCA/TDI ether - [redacted]°A		
			Min. Value	Typical	Max. value	Min. value	Typical	Max. value	Min. Value	Typical	Max. value
Hardness (23 °C)	ISO 48-4	°A	[redacted]			[redacted]			[redacted]		
Hardness (85 °C)	ISO 48-4	°A									
Tensile strength	ISO 37[1]	MPa									
Elongation at break	ISO 37[1]	%									
Tear resistance	ISO 34-1 method B, procedure b	kN/m									
Rebound (23 °C)	ISO 4662	%									
Rebound (85 °C)	ISO 4662	%									
Abrasion	ISO 4649 method B	mm^3									
Compression set											
70h/ 23 °C	ISO 815-1	%									
22h/ 70 °C	ISO 815-1	%									

[1] LUC Group uses 200 mm/min instead of 500 mm/min as test speed on the tensile tester.

Table 9. Assessment criteria for mechanical properties of PU systems

Property	Assessment criteria
Hardness	±2°A
Tensile strength	The higher the better
Elongation at break	Within range
Tear resistance	The higher the better
Rebound	Within range
Abrasion	The lower the better
Compression set	The lower the better

3. Tertiary: Coefficient of friction and dynamic behaviour

- If the alternative candidate passed the secondary minimum requirements, its coefficient of friction and dynamic behaviour were tested.
- If the dynamic behaviour and/or coefficient of friction of the alternative were too low, it was rejected.

The potential alternatives or the most common replacements to MOCA according to raw material manufacturers are discussed in further details in Chapter 3.3. These alternatives were selected because they gave the most promising results. If an alternative would pass all the minimum requirements, it would be further tested in order to assess their applicability in LUC UK's products.

In Chapters 3.2.4.1 and 3.2.4.2, we present the chain extenders and the chain extender blends that were clearly not suitable to replace MOCA in the manufacture of LUC Group's high-performance PU products.

3.2.4.1. Diamine and diol chain extenders

All the alternatives that clearly did not meet the minimum requirements are listed in Table 10 along with a short description of the test results. Multiple tests were conducted on each alternative candidate.

Table 10. List of rejected alternative candidates (#A for all redactions in the table)

Tradename	IUPAC name	CAS No., EC/List No.	Test results
Ethacure® 100 / DETDA	3,5-diethyltoluene-2,4-diamine (75-81 % (w/w)) 3,5-diethyltoluene-2,6-diamine (18-24 % (w/w))	68479-98-1, 270-877-4	In a [redacted]°A ether system, the pot-life was ca. [redacted] min (with MOCA, pot-lives of ca. [redacted] min are achieved). Such a short pot-life makes it impossible to cast a product. In a [redacted]°A ester system, the pot-life was only ca. [redacted] min, where with MOCA pot-lives are ca. [redacted] min. **Conclusion: failed primary requirement.**

Tradename	IUPAC name	CAS No., EC/List No.	Test results
Vibracure® A157 /Versalink® 740M / PDPAB	1,3-propanediol-bis-(4-aminobenozate)	57609-64-0, 260-847-9	The reactivity of this system was good (ca. [redacted] min in ether system and ca. [redacted] min in ester system) however, hardness was an issue. Only hardnesses of [redacted]°A were achieved for the [redacted]°A ether system. For the [redacted]°A ester system, only hardnesses of [redacted]°A were achieved and the elastomer itself was unstable (the hardness at 85 °C was only [redacted]°A). Efforts were made to compensate for the deviation in hardness but they were inconclusive. **Conclusion: failed primary requirement (hardness too low)**
MBOEA	4,4'-methylenebis(2-ethylbenzenamine)	19900-65-3, 243-420-1	The reactivity of this chain extender is too high and does not allow to cast products. In the tests performed with a [redacted]°A ether/TDI system, the pot-lives were only ca. [redacted]. **Conclusion: failed primary requirement.**
MDEA	4,4'-methylenebis(2,6-diethylaniline)	13680-35-8, 237-185-4	The reactivity of this chain extender is too high and does not allow to cast products. The measured pot-lives in the tests performed with a [redacted]°A ether/TDI system and a [redacted]°A ester/TDI system were only ca. [redacted]. **Conclusion: failed primary requirement.**
MACM	4,4'-methylenebis(2-methylcyclohexylamine)	6864-37-5, 229-962-1	The reactivity of this chain extender is too high and does not allow to cast products. The measured pot-lives in the tests performed with a [redacted]°A ether/TDI system and a [redacted]°A ester/TDI system were only ca. [redacted]. **Conclusion: failed primary requirement.**
Priamine™ 1074	(1E,19E)-10,11-dioctylicosa-1,19-diene-1,20-diamine	68955-56-6, 273-282-8	The reactivity of this chain extender is too high and does not allow to cast products. The measured pot-lives in the tests performed with a [redacted]°A ether/TDI system and a [redacted]°A ester/TDI system were only ca. [redacted]. **Conclusion: failed primary requirement.**
MXDA	m-xylenediamine	1477-55-0, 216-032-5	The reactivity of this chain extender is too high and does not allow to cast products. The pot-lives in the tests performed with a [redacted]°A ether/TDI system was only ca. [redacted]. **Conclusion: failed primary requirement.**

Tradename	IUPAC name	CAS No., EC/List No.	Test results
3,4-diaminotoluene	3,4-diaminotoluene	496-72-0, 207-826-2	The reactivity of this chain extender is too high and does not allow to cast products. The pot-lives in the tests performed with a [redacted]°A ether/TDI system was only ca. [redacted]. **Conclusion: failed primary requirement.**
Lonzacure® P-25	5-chloro-2,4-diethyl-6-methylbenzene-1,3-diamine / 5-chloro-4,6-diethyl-2-methylbenzene-1,3-diamine	1616795-05-1, n/a	The reactivity of this chain extender in [redacted]°A ether/TDI system is a bit too high (pot-life of ca. [redacted] min). In [redacted]°A ester/TDI systems, this chain extender is unusable as pot-lives of only ca. [redacted] were achieved. The hardness of the material achieved using the ether system is correct however, the tensile strength is significantly lower ([redacted] MPa vs. [redacted] MPa with MOCA). For higher hardness systems (up to [redacted]), this chain extender is not suitable due to higher reactivity. This substance is not REACH registered. **Conclusion: failed primary requirement in ester/TDI systems. Passed primary requirement in ether/TDI systems but failed secondary requirement.**
Eracure® 110	Blend containing >60 % (w/w) of 4-methyl-2,6-bis(methylthio)-1,3-benzene diamine / 2-methyl-4,6-bis(methylthio)-1,3-benzene diamine	106264-79-3, 600-731-0	Good/fair processability in both systems. The pot-life with a [redacted]°A ether/TDI system was ca. [redacted] min and ca. [redacted] min with a [redacted]°A ester/TDI system. Overall mechanical properties are similar except for the tensile strength in both systems: – [redacted] MPa for the [redacted]°A ester system vs. [redacted] MPa for MOCA in the same system – [redacted] MPa for the [redacted]°A ether system vs [redacted] MPa for MOCA in the same system **Conclusion: passed primary requirement. Failed secondary requirement.**
[redacted] (Rejected for Use 1, shortlisted for Use 2)	Blend containing [redacted] [redacted] Remainder: classified	[redacted] [redacted] -	Fair processability in [redacted]°A ether/TDI system. Pot-life was ca. [redacted] minutes. Hardness obtained with [redacted] is [redacted]°A compared to MOCA. Poor producibility in [redacted]°A ester/TDI system (pot-life [redacted] minutes). **Conclusion: Failed primary requirement for Use 1.**

Tradename	IUPAC name	CAS No., EC/List No.	Test results
TDI/BDO	1,4-butanediol	110-63-4, 203-786-5	Reactivity with ether/TDI prepolymers is lower than MOCA so longer pot-lives can be achieved. PU produced with TDI/BDO have significantly lower hardness ([redacted]°A vs. [redacted]°A with MOCA), tensile strength ([redacted] MPa vs. [redacted] MPa with MOCA) and tear strength ([redacted] kN/m vs. [redacted] kN/m with MOCA). In addition to the significantly lower mechanical properties, the curing times are an issue with TDI/BDO. Curing times of 7-14 days were required with TDI/BDO instead of 1-3 days with MOCA. **Conclusion: failed primary requirement (hardness too low). Failed secondary requirement.**
M-CDEA / Lonzacure® M-CDEA	4,4'-methylenebis(3-chloro-2,6-diethylaniline)	106246-33-7, 402-130-7	In a [redacted]°A ether system, the pot-life was ca. [redacted] min (with MOCA, pot-lives of ca. [redacted] min are achieved). In a [redacted]°A ester system, the pot-life was only ca. [redacted] min, where with MOCA pot-lives are ca. [redacted] min. **Conclusion: failed primary requirement.**

3.2.4.2. Chain extender blends

In addition to the alternative candidates listed in Table 10, LUC Group also tested a high variety of chain extender blends in an attempt to reduce reactivity of more reactive chain extenders and improve the mechanical properties of less reactive chain extenders. During the tests, many chain extender combinations and ratios were tested. The chain extenders used in the tests are listed in Table 11.

Table 11. List of chain extenders used in blends

Tradename	IUPAC name	CAS No., EC/List No.
Addolink® 1604 DW	2-methylpropyl-3,5-diamino-4-chloro-benzoate	32961-44-7, 251-311-5
Eracure® 110	Blend containing >60 % (w/w) of 4-methyl-2,6-bis(methylthio)-1,3-benzene diamine / 2-methyl-4,6-bis(methylthio)-1,3-benzene diamine	106264-79-3, 600-731-0
DETDA / Ethacure® 100	3,5-diethyltoluene-2,4-diamine (75-81 % (w/w)) 3,5-diethyltoluene-2,6-diamine (18-24 % (w/w))	68479-98-1, 270-877-4
DMTDA / Ethacure® 300	6-methyl-2,4-bis(methylthio)phenylene-1,3-diamine; 2-methyl-4,6-bis(methylthio)phenylene-1,3-diamine	106264-79-3, 403-240-8
MDBA / Polylink 4200 / Ethacure® 420	4,4'-methylenebis[N-sec-butylaniline]	5285-60-9

Tradename	IUPAC name	CAS No., EC/List No.
Unilink® 4230	N,N'-dialkylaminodiphenylmethane (<85 % (w/w)), tetrapropoxylatedethylenediamine (<20 % (w/w))	5285-60-9, 102-60-3 / n/a, n/a
Lonzacure® P-25	5-chloro-2,4-diethyl-6-methylbenzene-1,3-diamine / 5-chloro-4,6-diethyl-2-methylbenzene-1,3-diamine	1616795-05-1, n/a
MBOEA	4,4'-methylenebis(2-ethylbenzenamine)	19900-65-3, 243-420-1
M-CDEA / Lonzacure® M-CDEA	4,4'-methylenebis(3-chloro-2,6-diethylaniline)	106246-33-7, 402-130-7
MDEA	4,4'-methylenebis(2,6-diethylaniline)	13680-35-8, 237-185-4
Vibracure® A157 / Versalink® 740M / PDPAB	1,3-propanediol-bis-(4-aminobenozate)	57609-64-0, 260-847-9
BDO	1,4-butanediol	110-63-4, 203-786-5

The test results for the four most promising blends are given in Chapter 3.3.1.1. Only limited improvements in PU mechanical properties were achieved by blending.

3.3. Assessment of shortlisted alternatives

In this chapter, the most promising alternatives identified by LUC Group are assessed. All test data presented in this chapter result from the research and development efforts by LUC Group.

The following colour codes are used in this chapter to assess the availability, safety considerations, technical feasibility and economic feasibility of the shortlisted alternatives.

Table 12. Colour codes used for the assessment of alternatives

Colour	Definition
(red)	Requirement not met
(yellow)	Fulfilment of the criteria not clear
(green)	Requirement met

3.3.1. Like-for-like diamine alternatives

In this chapter, we assess the like-for-like diamine alternatives: DMTDA, Addolink® 1604 and diamine blends. These alternatives are used with TDI based prepolymers, similarly to MOCA.

3.3.1.1. Diamine blends

3.3.1.1.1. General description of diamine blends

Blend 1 and 2:

Blend 1 and 2 are #A [redacted] blends. #A [redacted] is an aromatic diamine. It is #A [redacted] at room temperature. Additional substance identity information is provided in Table 13.

#A [redacted]

Table 13. Substance identity and classification #A [redacted] (#A for all redactions in the table)

	[redacted]
IUPAC name	[redacted]
Trade name	
Structural formula	
Molecular formula	
Molecular weight	
EC number	
CAS number	
Hazard information	
Physical properties	

Processing:

#A [redacted]

In comparison to MOCA, #A [redacted] more reactive therefore, #A [redacted] have shorter pot-life than MOCA/TDI systems. In addition, #A [redacted] harden more slowly than MOCA counterparts during the early stage of casting. At this point in the curing process, they will be more fragile and stress from shrinkage as well as shocks can easily cause cracks in the moulded parts.

As the reactivity #A [redacted] is too high, it is not a suitable alternative curing agent as such. LUC Group has tested #A [redacted] blends where it was mixed with curing agents having lower reactivity. Blend 1 is a mixture of #A [redacted] while Blend 2 is a mixture of #A [redacted].

#A [redacted] has a harmonised classification and labelling, which is presented in Table 14 as it is defined in Annex VI to GB CLP Regulation.

Table 14. Substance identity and classification of #A [redacted] (#A for all redactions in the table)

	[redacted]
IUPAC name	[redacted]
Tradename	[redacted]
Structural formula	[redacted]
Molecular formula	[redacted]
Molecular weight	[redacted]
EC/List number	[redacted]
CAS number	[redacted]
Hazard information	[redacted]
Physical properties	[redacted]

The substance identity information and classification of #A [redacted] is given in Table 15.

Table 15. Substance identity and classification of [redacted] (#A for all redactions in the table)

	[redacted]
IUPAC name	[redacted]
Trade name	
Structural formula	
Molecular formula	
Molecular weight	
EC/List number	
CAS number	
Hazard information	
Physical properties	

<u>Blend 3 and 4:</u>

Blend 3 is a mixture of [redacted] while Blend 4 is a mixture of [redacted]

3.3.1.1.2. Availability of diamine blends

The availability of [redacted] is uncertain, especially in the volumes that LUC Group would need for the substitution of MOCA. In order to distribute the raw materials to LUC UK, LUC Group should have sufficient stock.

The availability of [redacted] is good while [redacted].

3.3.1.1.3. Safety considerations related to using diamine blends

Based on the information in Chapter 3.3.1.1.1, [redacted] is not classified as hazardous to human health. The other curing agents are also less hazardous to human health than MOCA. Overall, the transfer to Blend 1-4 would lead to an overall risk reduction for both the workers and the environment.

3.3.1.1.4. Technical feasibility of diamine blends

Due to its high reactivity, #A [redacted] is only useable in the polyether/TDI prepolymer system, when blended with curing agents having lower reactivity. In this chapter, the results of Blend 1 and 2 in the ether prepolymer system are discussed in more details.

As it can be seen from Table 16, the PU cured with Blend 1 had worse tensile strength, abrasion resistance and elongation at break. This will produce a part that will not withstand as high loads and would need to be changed more often due to higher abrasion wear. In addition, the deformation behaviour of Blend 1 PU was totally different. The resulting part will have a higher degree of permanent deformation when under compression (compression set) and will be more damping at higher temperatures (lower rebound).

Blend 2 PU also had a different deformation behaviour in terms of rebound and compression set compared to MOCA cured PU. Its tensile strength and abrasion resistance were also lower.

The pot-lives of Blend 1 and 2 were #A [redacted] min and #A [redacted] min, respectively. Thus, Blend 1 did not meet the primary requirement for Use 1 products. Both blends however failed to meet the secondary requirement.

Table 16. The test results of the comparative study between MOCA/TDI ether prepolymer and Blend 1 and 2 with a TDI ether prepolymer[13] (#A for all redactions in the table)

			MOCA/TDI ether - [redacted]°A			TDI ether - [redacted]°A	
Property	Standard	Unit	Min. Value	Typical	Max. value	Blend 1	Blend 2
Hardness (23 °C)	ISO 48-4	°A	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Hardness (85 °C)	ISO 48-4	°A	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Tensile strength	ISO 37[1]	MPa	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Elongation at break	ISO 37[1]	%	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Tear resistance	ISO 34-1 method B, procedure b	kN/m	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Rebound (23 °C)	ISO 4662	%	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Rebound (85 °C)	ISO 4662	%	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Abrasion	ISO 4649 method B	mm^3	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Compression set							
70h/ 23 °C	ISO 815-1	%	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
22h/ 70 °C	ISO 815-1	%	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

[1] LUC Group uses 200 mm/min instead of 500 mm/min as test speed on the tensile tester.

13 Colour code: ☐ = within specification limits, ☐ = out of specification. The same colour coding will be used in the rest of the application.

The tensile strength and abrasion resistance of Blend 3 PU were too low thus, resulting in a weaker and less durable part.

Blend 4 PU had a different deformation profile than MOCA cured PU. At room temperature, it was more bouncy (rebound) and retained more permanent deformation from compression than MOCA cured PU (compression set). In addition, the alternative PU stretched less before breaking (elongation at break).

The pot-lives of Blend 3 and 4 were [redacted] #A min and [redacted] #A min, respectively.

Table 17. The test results of the comparative study between MOCA/TDI ether prepolymer and Blend 3 and 4 with a TDI ester prepolymer (#A for all redactions in the table)

			MOCA/TDI ester - [redacted] °A			TDI ester - [redacted] °A	
Property	Standard	Unit	Min. Value	Typical	Max. value	Blend 3	Blend 4
Hardness (23 °C)	ISO 48-4	°A	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Hardness (85 °C)	ISO 48-4	°A	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Tensile strength	ISO 37[1]	MPa	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Elongation at break	ISO 37[1]	%	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Tear resistance	ISO 34-1 method B, procedure b	kN/m	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Rebound (23 °C)	ISO 4662	%	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Rebound (85 °C)	ISO 4662	%	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Abrasion	ISO 4649 method B	mm^3	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Compression set							
70h/ 23 °C	ISO 815-1	%	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
22h/ 70 °C	ISO 815-1	%	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

[1] LUC Group uses 200 mm/min instead of 500 mm/min as test speed on the tensile tester.

During the tests, information on deflective behaviour and dynamic load properties were also collected on PUs manufactured using the blends. The results are presented below for the sake of completeness as LUC Group has studied these systems for the development of new polyurethane materials for products outside of the scope of this authorisation application. However, Pus made using Blend 1 and 3 have failed the primary requirements while Blend 2 and 4 PU have failed the secondary requirements.

The deflective behaviour of the PU part during end-use can be predicted based on the stress-strain curve of the material (Figure 22 and Figure 23). The stress-strain curve is generated based on the results of the ISO 37 test and is unique to each material. The x-axis (strain [%]) represents the amount of elongation the test part undergoes (the higher the percentage, the higher the elongation). The y-axis (stress [Mpa]) represents the amount of force that is required for stretching the material (the higher the number, the higher the force). This difference in deformation profile translate into end-products behaving differently during end-use. The end of the stress-strain curve is the fracture point. Its x-value corresponds to the elongation at break value and its y-value corresponds to the tensile strength value.

When evaluating the deflective behaviour, the shape of the curve as well as the elongation at break value and the tensile strength value at fracture point are important. A polyurethane that elongates significantly under stress will "bulge" creating a weak spot in the material increasing the risk of cracks and failures. A lower tensile strength at fracture point indicates that the PU material is not as resistant to stretching forces. In practice, this means that the PU part will be less resistant and break more easily under tensile strength. Lastly, the area under the stress-strain curve is also of importance. The larger the area, the higher the toughness of the material, which in turn influences the cutting resistance of the material. Higher toughness's are desired if high cutting resistances are needed.

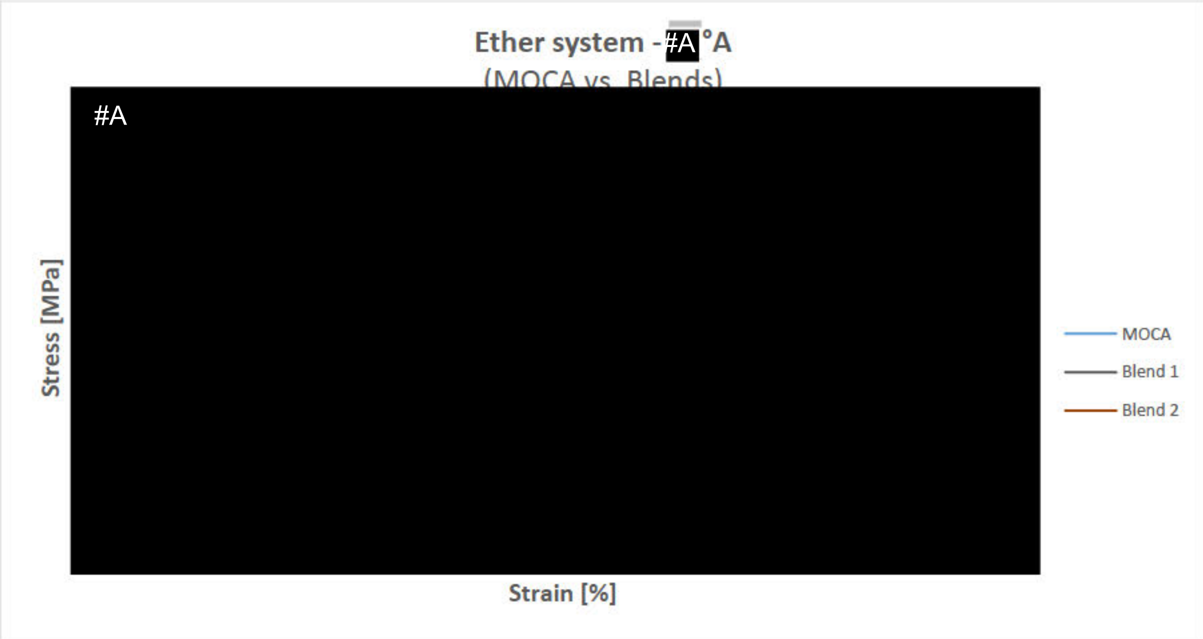


Figure 22. A stress-strain curve plotted from the results of ISO 37 test

As can be seen from the picture above, PU cured with Blend 1 and 2 had a similar deflective behaviour. However, both broke at lower stress and lower elongation than MOCA cured PU. This is a sign of lower tensile properties.

While Blend 3 PU also had a similar deflective behaviour than MOCA cured PU, it was very different for Blend 4 PU (Figure 23). Elongation at break properties and tensile strength were lower for both. PUs made with both alternative curatives, in particular Blend 3, have lower toughness.

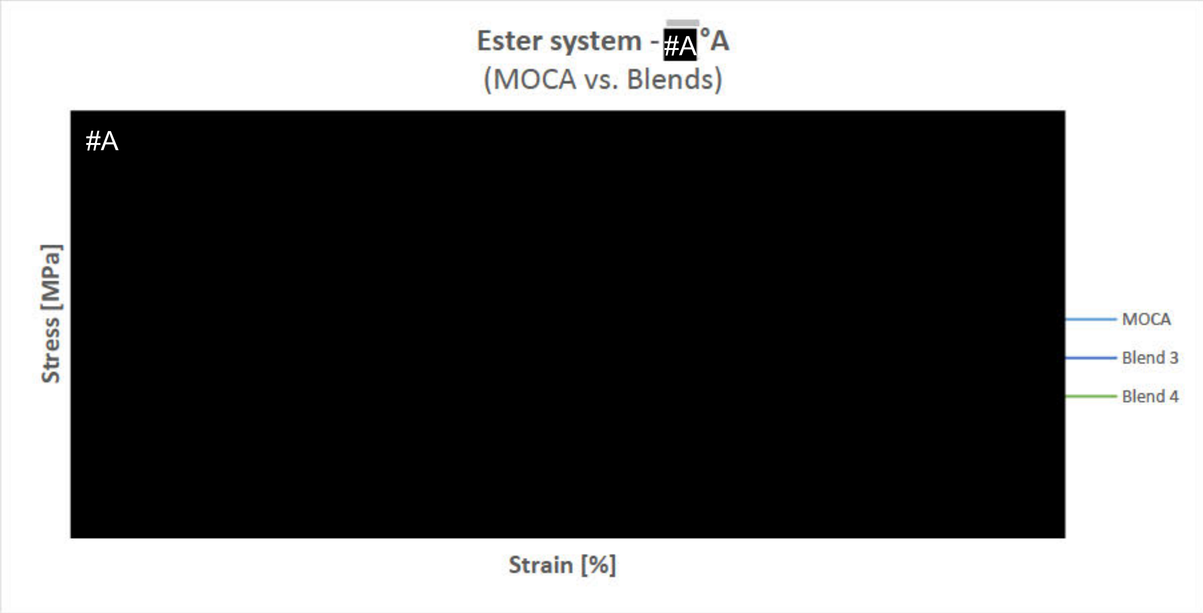


Figure 23. A stress-strain curve plotted from the results of ISO 37 test

Dynamic load bearing properties of PUs made with blends 1, 2, 3 and 4 were tested using LUC Group's ride simulator (Figure 24 and Figure 25). The PU already failed at applied loads ranging between [redacted] kg. In comparison, the limit for MOCA cured PU was [redacted] kg.

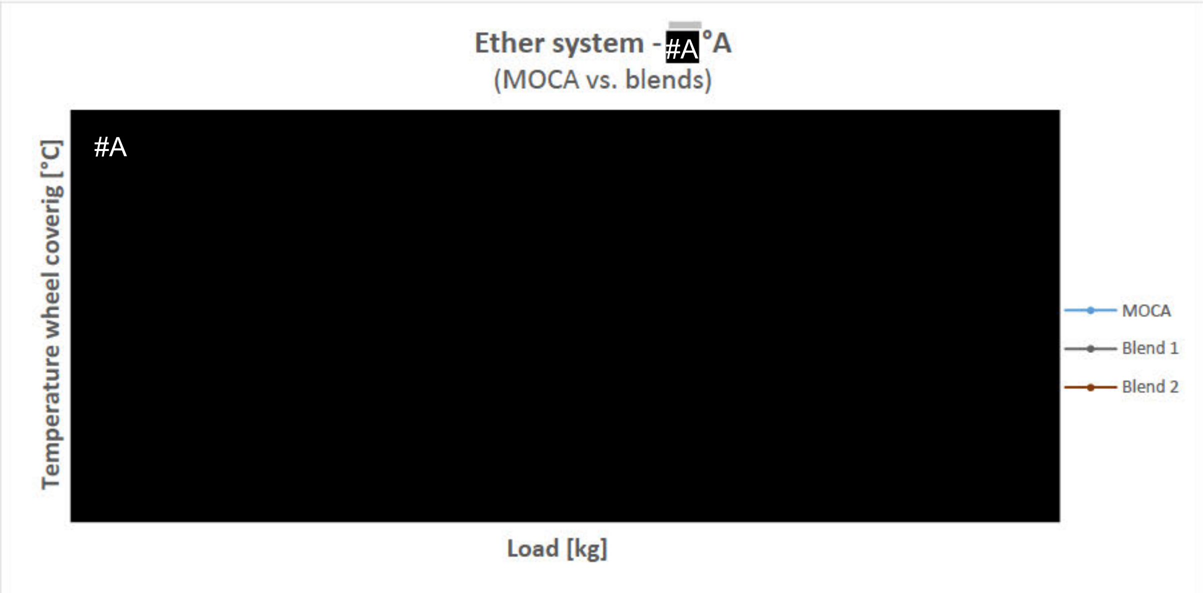


Figure 24. The test results showing the different dynamic behaviour of PU cured with Blend 1, Blend 2 and MOCA

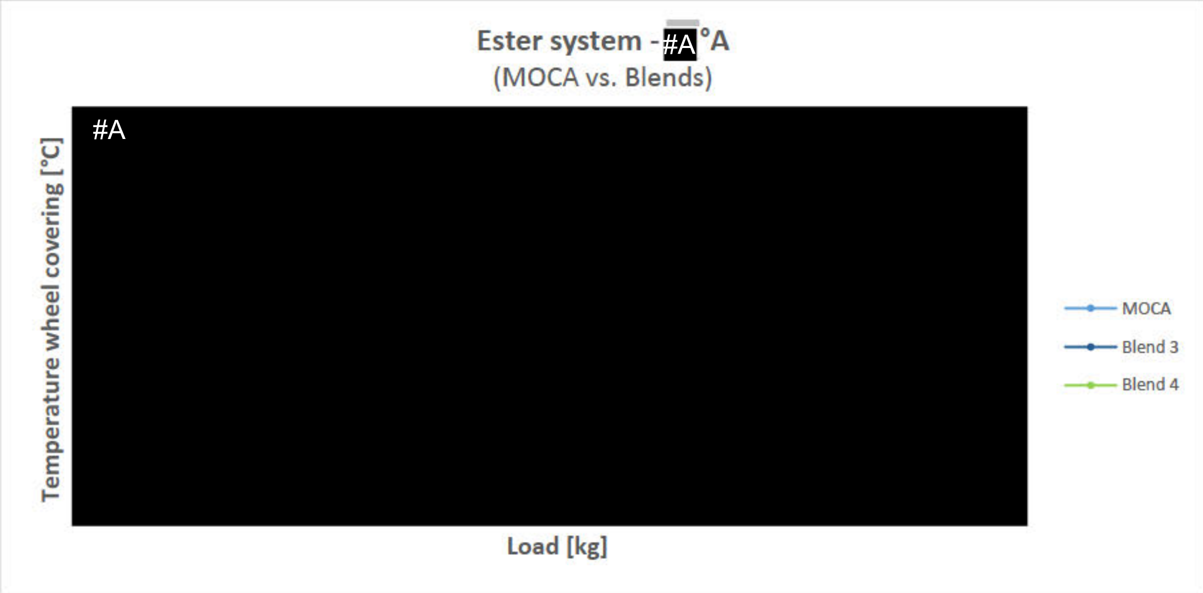


Figure 25. The test results showing the different dynamic behaviour of PU cured with Blend 3, Blend 4 and MOCA

LUC Group also tested the Coefficient of Friction (CoF) using three different counter material. All three counter materials are typical materials that come into contact with the rollers covered by Use 1.

In the figures, the CoF of the materials (y-axis) are represented as a function of contact pressure. The higher the force exerted on the material, the higher the contact pressure (e.g. when you press an object harder against a table, the contact pressure increases).

The high-performance PU rollers covered by this use require high CoF to ensure the proper functioning of the processing line.

The results of the CoF tests conducted on PU cured with Blend 1 and 2 are presented in the next 3 figures. As it can be seen, the CoFs of Blend 1 and 2 PU are similar to MOCA on stainless steel while they are lower on steel and aluminium.

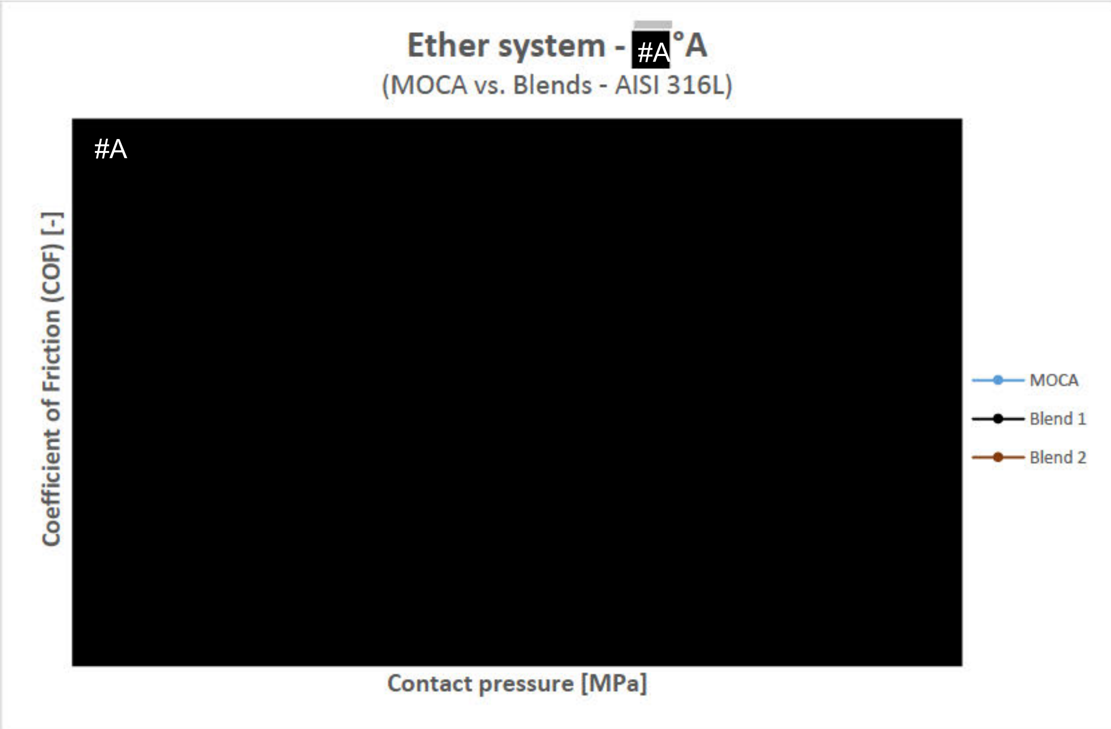


Figure 26. Results of the CoF test using stainless steel

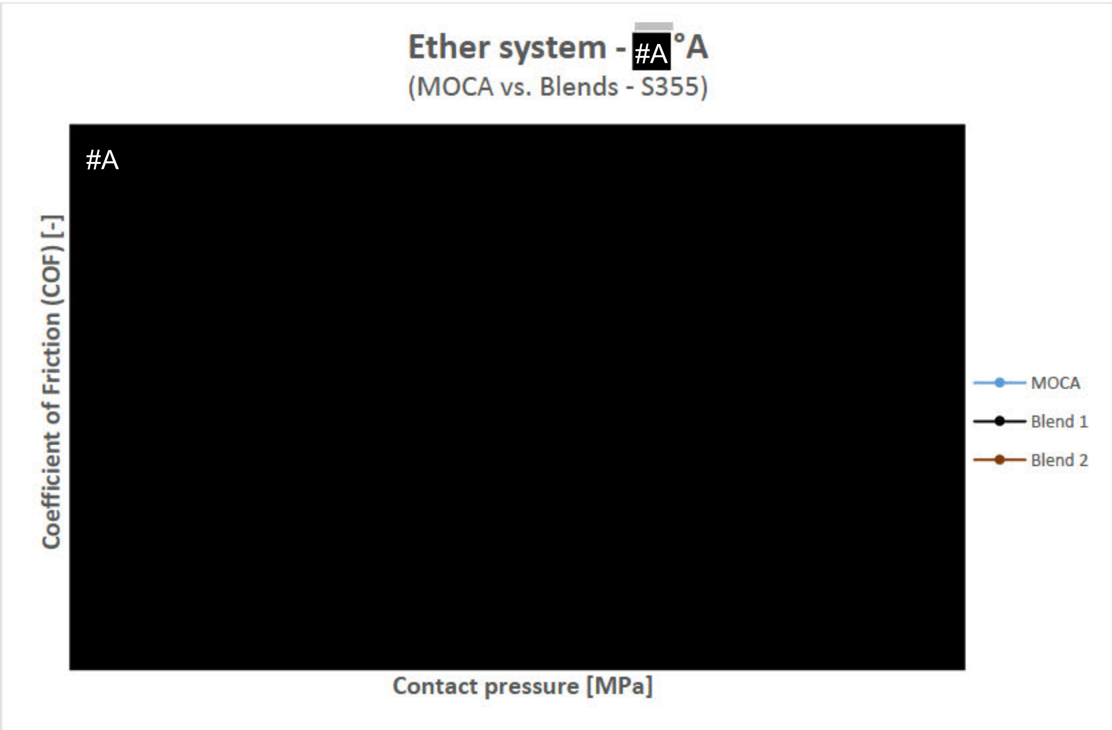


Figure 27. Results of the CoF test using steel

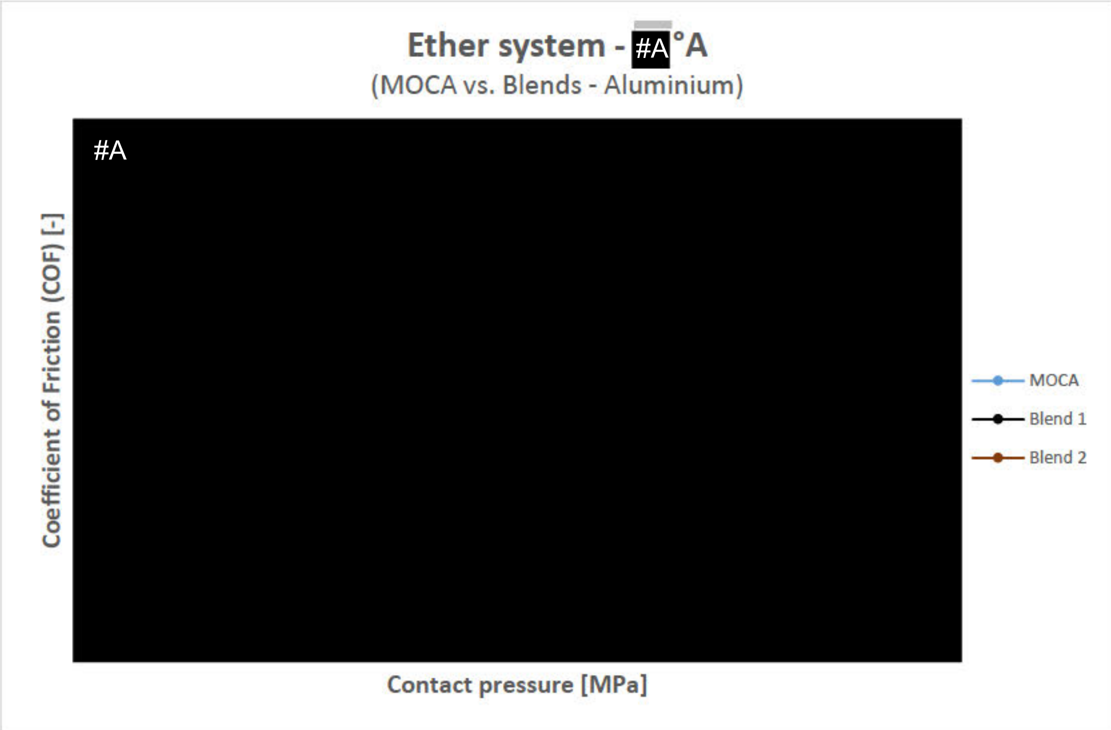


Figure 28. Results of the CoF test using aluminium

The results of CoF tests conducted on Blend 3 and 4 PU are presented in the next 3 figures. A reduction in CoF can be observed on all three counter materials.

Figure 29. Results of the CoF test using stainless steel

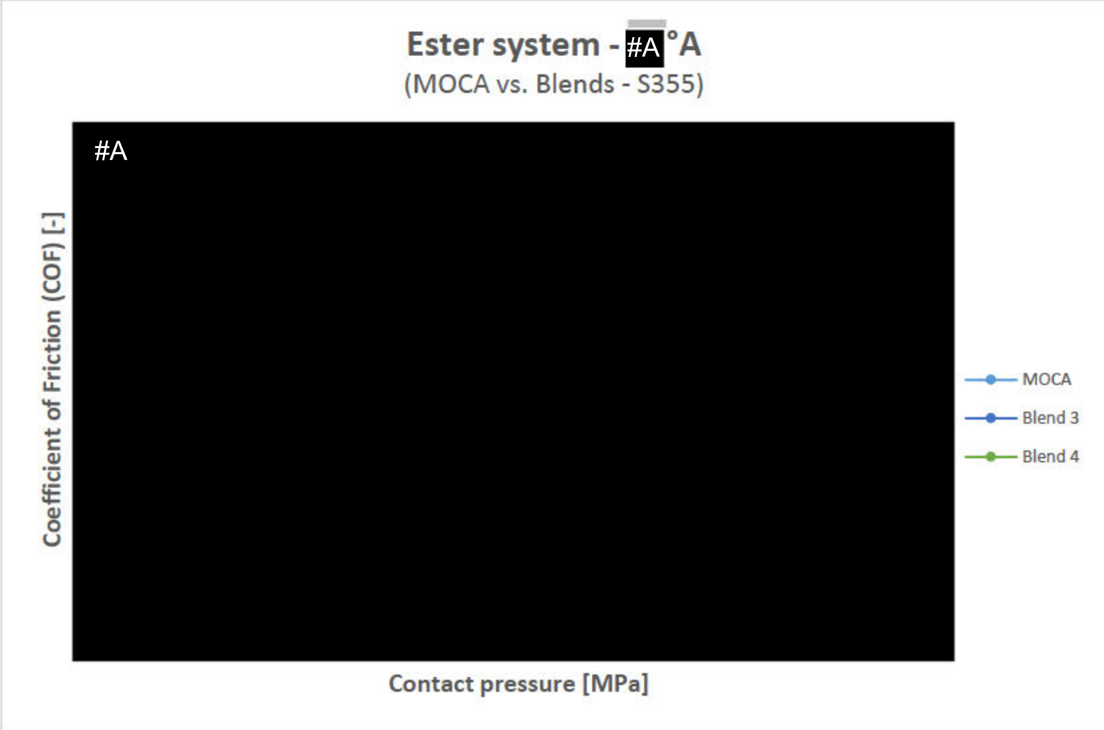


Figure 30. Results of the CoF test using steel

Figure 31. Results of the CoF test using aluminium

In addition to the lower performances achieved with the PU cured with Blends 1-4, reactivity was still an issue. Although LUC Group achieved a reduction in reactivity by blending chain extenders, the reduction was insufficient and not uniform enough (the more reactive chain extender reacted first, then the less reactive one) for the blends to be suitable alternatives to MOCA. All the trials conducted by LUC Group to further reduce reactivity have failed. #A [redacted]

Assessment of product requirements:

Table 18 gives an assessment of the properties of Blend 1 and 2 against the product requirements presented in Chapter 3.1.2.3.

Table 18. Assessment of product requirement (#A for all redactions in the table)

Property	Diamine blends/TDI ether	
	Blend 1	**Blend 2**
Mechanical strength	Tensile strength is too low. The resulting PU products will be less sturdy and break during use. Abrasion resistance is too low. The parts will have lower durability. **Conclusion: requirement not met.**	Same as Blend 1. **Conclusion: requirement not met.**
Coefficient of Friction *Not a key requirement for non-driven rollers.*	On stainless steel, the CoF is similar to MOCA PU. However, on steel and aluminium it is too low. **Conclusion: requirement partly met for driven rollers**	Same as Blend 1. **Conclusion: requirement partly met for driven rollers.**
Dynamic load bearing	The dynamic load bearing capacity of Blend 1 PU is too low. It is [redacted] kg lower than MOCA PU, which corresponds to an approximately 41 % load bearing reduction In practice, this means that the alternative parts will deform permanently and fail (powdering or cracking) during use. **Conclusion: requirement not met.**	The dynamic load bearing capacity of Blend 2 PU is too low. **Conclusion: requirement not met.**
Fatigue	Based on preliminary wheel tests, the PU fatigue properties are lower than TDI/MOCA PU. **Conclusion: requirement not met.**	Same as Blend 1. **Conclusion: requirement not met.**
Cutting resistance	The PU has weaker abrasion properties, acceptable tear resistance and slightly lower toughness as MOCA PU. This will result in a PU with insufficient cutting resistance. **Conclusion: requirement not met.**	Same as Blend 1. **Conclusion: requirement not met.**

Property	Diamine blends/TDI ether	
	Blend 1	**Blend 2**
Reliability	The parts cured with Blend 1 have lower reliability than MOCA PU parts. **Conclusion: requirement not met.**	The parts cured with Blend 2 have lower reliability than MOCA PU parts. **Conclusion: requirement not met.**
Pot-life[14] and adhesion	Pot-life is insufficient for this use. **Conclusion: products covered by this use cannot be casted.**	Pot-life is sufficient for this use. **Conclusion: products covered by this use can be casted. Adhesion is good.**

Table 18 gives an assessment of the properties of Blend 3 and 4 against the product requirements presented in Chapter 3.1.2.3.

Table 19. Assessment of product requirement (#A for all redactions in the table)

Property	Diamine blends/TDI ester	
	Blend 3	**Blend 4**
Mechanical strength	Tensile strength is too low. The resulting PU products will be less sturdy and break during use. Abrasion resistance is too low. The parts will have lower durability. **Conclusion: requirement not met.**	Mechanical strength sufficient. **Conclusion: requirement met.**
Coefficient of Friction *Not a key requirement for non-driven rollers.*	PU CoF is insufficient. **Conclusion: requirement not met for driven rollers.**	Same as Blend 3. **Conclusion: requirement not met for driven rollers.**
Dynamic load bearing	The PU dynamic load bearing capacity of Blend 3 is too low. It is [redacted] kg lower than MOCA PU. **Conclusion: requirement not met.**	The dynamic load bearing capacity of Blend 4 PU is insufficient. It is [redacted] kg lower than MOCA PU, which corresponds to an approximately 41 % load bearing reduction. In practice, this means that the alternative parts will deform permanently and fail (powdering or cracking) during use. **Conclusion: requirement not met.**
Fatigue	Based on preliminary wheel tests, the PU fatigue properties are lower than MOCA PU. **Conclusion: requirement not met.**	Same as Blend 3. **Conclusion: requirement not met.**

[14] Not a product requirement but it is a limiting factor for the casting of products. A short pot-life will not give enough time to cast the product.

Property	Diamine blends/TDI ester	
	Blend 3	**Blend 4**
Cutting resistance	Although the PU tear resistance is good, abrasion properties and toughness are worse than MOCA cured PU. This leads to an insufficient cutting resistance. **Conclusion: requirement not met.**	The PU cutting resistance of Blend 4 PU is good (good abrasion and tear resistance, acceptable toughness). **Conclusion: requirement met.**
Reliability	The parts cured with Blend 3 have lower reliability than MOCA PU parts. **Conclusion: requirement not met.**	The parts cured with Blend 4 have lower reliability than MOCA PU parts. **Conclusion: requirement not met.**
Pot-life[15] and adhesion	Pot-life is insufficient for this use. **Conclusion: the rollers covered by this use cannot be casted.**	Pot-life is sufficient for this use. **Conclusion: the products covered by this use can be casted. Adhesion is good.**

3.3.1.1.5. Economic feasibility of diamine blends

[redacted] also more expensive ([redacted]).

The transition to diamine blends would require investments to be made in production. New mixing heads will be needed for quicker mixing of the prepolymer and chain extender in the mixing chamber to have more time available for casting. In addition, other components will need to be changed such as pumps, heating system, valves and sealing.

Table 20 gives an overview of the change in costs due to the substitution of MOCA with diamine blends.

Table 20. Qualitative assessment of the change in costs due to transition to diamine blends

Aspect	Diamine blends vs MOCA
Raw material costs	Significantly higher, especially Blend 2 and 4
Energy costs	Same as MOCA.
Personnel costs	If implemented, training of personnel would be required as this type of blends are not in use at LUC UK. Personnel costs would therefore be momentarily higher after implementation and returning back to normal afterwards.
Scrap rate	Not applicable as the pot-life of Blends 1 and 3 does not allow the casting of the rollers covered by Use 1.

LUC UK has estimated the costs to implement an alternative for Use 1 products to amount

[15] Not a product requirement but it is a limiting factor for the casting of products. A short pot-life will not give enough time to cast the product.

to 360-416 k GBP, should a suitable alternative be found. For additional information, please see the substitution costs section and Table 59 in Chapter 4.1.3.1.

It would be impossible for LUC UK to absorb such a high material cost. The Applicant cannot increase the price of its products as they have to compete with the non-UK MOCA moulders who can still continue to place MOCA based PU products on the UK market. LUC UK's customers will simply not buy the alternative products at a higher price if they can continue to buy the cheaper MOCA based PU products.

3.3.1.1.6. Suitability of diamine blends for the applicant in general

Blends 1-4 cannot be considered suitable alternatives to MOCA in Use 1 products as summarised in Table 21.

Table 21. Limitations of the alternative

<table>
<tr><td colspan="4">
- Pot-life of Blends 1 and 3 is too low. The products covered by this use cannot be casted
- Tensile strength of Blends 1-3 is too low (parts will break during use)
- Dynamic load bearing capacity of Blend 1-4 is too low (rollers will break during end-use)
- Cutting resistance of Blends 1-3 is too low (rollers will wear out quicker)
- CoF of Blends 1-4 is too low for driven rollers (driven rollers will lack the necessary grip to function properly)
- Fatigue and reliability properties of Blends 1-4 are lower (customers will need to change/recover PU parts more often)
- Significantly higher raw material costs
- #A [redacted]
</td></tr>
<tr><td>Technical feasibility</td><td>Economic feasibility</td><td>Availability</td><td>Safety considerations</td></tr>
<tr><td></td><td></td><td></td><td></td></tr>
</table>

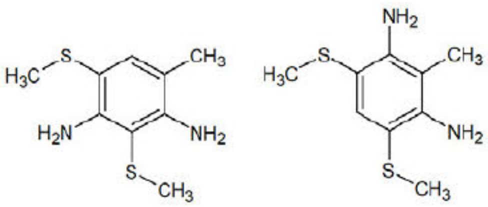
3.3.1.2. DMTDA

3.3.1.2.1. General description of DMTDA

DMTDA (Dimethylthiotoluenediamine) is an aromatic diamine, which is liquid at room temperature. Under UK REACH, DMTDA is considered a multi-constituent substance composed of two major isomers 3,5-dimethylthio-2,4-toluenediamine and 3,5-dimethylthio-2,6-toluenediamine. DMTDA is almost solely used with TDI-based prepolymers.

DMTDA has a harmonised classification and labelling, which is presented in Table 22 as it is defined in Annex VI to GBP CLP Regulation. Based on its classification, DMTDA is very toxic to aquatic life and is hazardous to human health. Based on the registration data published on the ECHA dissemination tool, DMTDA is not PBT nor vPvB.

Table 22. Substance identity and classification of DMTDA

	DMTDA
IUPAC name	Reaction mass of 3,5-dimethylthio-2,4-toluenediamine and 3,5-dimethylthio-2,6-toluenediamine
Tradename	Ethacure® 300
Structural formula	
Molecular formula	$C_9H_{14}N_2S_2$ (one isomer)
Molecular weight	214.4 (one isomer)
EC/List number	403-240-8
CAS number	106264-79-3
Hazard information	Classification according to Annex VI GB CLP Regulation: Acute Tox. 4*, H302 Skin Sens. 1, H317 Aquatic Acute 1, H400 Aquatic Chronic 1, H410 Labelling according to Annex VI of GB CLP Regulation: **Signal word:** warning H302: Harmful if swallowed H317: May cause an allergic skin reaction H410: Very toxic to aquatic life with long lasting effects PBT assessment: The substance is not PBT/vPvB
Physical properties	**Physical state at 20 °C and 1013 hPa:** Liquid

Processing:

Due to being a liquid, DMTDA can be processed at lower temperatures than MOCA, which makes the processing overall easier. It does not need to be melted before it is mixed with the prepolymer and can be easily transferred to the mixing vessel.

3.3.1.2.2. Availability of DMTDA

DMTDA's availability is good however, it is uncertain whether LUC Group would be able to procure it in sufficient quantities, should this alternative be technically feasible in the Applicant's products. In order to distribute the raw materials to LUC UK, LUC Group should have sufficient stock.

3.3.1.2.3. Safety considerations related to using DMTDA

The risk associated with exposure during the use of DMTDA can easily be limited through the use of appropriate measures and LUC UK is confident that their RMMs and PPEs in place are adequate. Every worker working at LUC UK receives appropriate training and they are required to handle every chemical in accordance with good industrial hygiene.

In regards to H302, it should be noted that ingestion is a very unlikely route of exposure in industrial settings as chemicals are only handled by trained personnel.

Regarding the environmental hazards associated with the use of DMTDA, the RMMs in place at LUC UK would be sufficient to minimise the risks of emissions to the environment.

3.3.1.2.4. Technical feasibility of DMTDA

The reactivity profile of DMTDA does not quite meet MOCA's reactivity profile with a pot-life of [redacted] min (hardness [redacted] °A) in comparison to [redacted] min for MOCA. The pot-life for the products in this use should be at least [redacted] min. Moreover, the risk of entrapping air bubbles in the PU, causing weak spots, is higher with these short pot-lives. There is also an increased risk that the material sets in layers, which creates weaker parts that are prone to breaking.

Ether prepolymer system:

During their R&D work, LUC Group conducted comparative studies on MOCA and DMTDA as curing agents in a polyether TDI-prepolymer system. The results are presented in Table 23.

Table 23. The test results of the comparative study between MOCA/TDI ether prepolymer and DMTDA/TDI ether prepolymer (#A for all redactions in the table)

			MOCA/TDI ether - [redacted] °A			TDI ether - [redacted] °A
Property	Standard	Unit	Min. Value	Typical	Max. value	DMTDA
Hardness (23 °C)	ISO 48-4	°A	[redacted]			[redacted]
Hardness (85 °C)	ISO 48-4	°A				
Tensile strength	ISO 37[1]	MPa				
Elongation at break	ISO 37[1]	%				
Tear resistance	ISO 34-1 method B, procedure b	kN/m				
Rebound (23 °C)	ISO 4662	%				
Rebound (85 °C)	ISO 4662	%				
Abrasion	ISO 4649 method B	mm³				
Compression set						
70h/ 23 °C	ISO 815-1	%				
22h/ 70 °C	ISO 815-1	%				

[1] LUC Group uses 200 mm/min instead of 500 mm/min as test speed on the tensile tester.

DMTDA is often mentioned by alternative providers as a potential substitute for MOCA however, as it can be seen from the table above, DMTDA/TDI ether PU does not have the same performance as TDI/MOCA PU in many material properties. The tensile strength of this alternative PU material is significantly lower than MOCA cured PU. Lower tensile strength means that the PU product will be weaker and will have higher risks of breaking during end-use. This is not acceptable for LUC UK's customers.

The PU material has sufficient cutting resistance (optimum cutting resistance results from a combination of low abrasion resistance, high toughness and high tear resistance), which is one of the key technical requirements for this use.

In terms of deflective behaviour, DMTDA/TDI ether PU has a completely different deformation profile than MOCA PU (Figure 32). It stretches significantly more than MOCA PU when exposed to tensile stress. In terms of toughness, MOCA PU outperforms DMTDA PU.

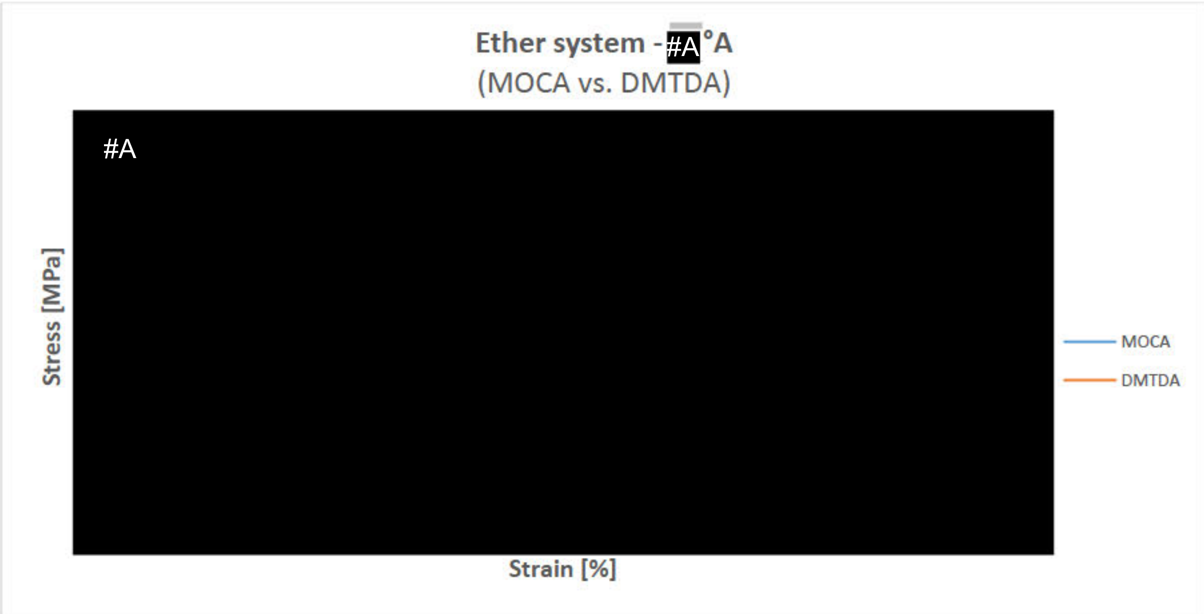


Figure 32. A stress-strain curve plotted from the results of the ISO 37 test

The load bearing properties of the alternative PU are also worse than MOCA PU (Figure 33). As shown in the figure, DMTDA/TDI ether PU fails at lower loads than MOCA PU before failing ([redacted] kg less).

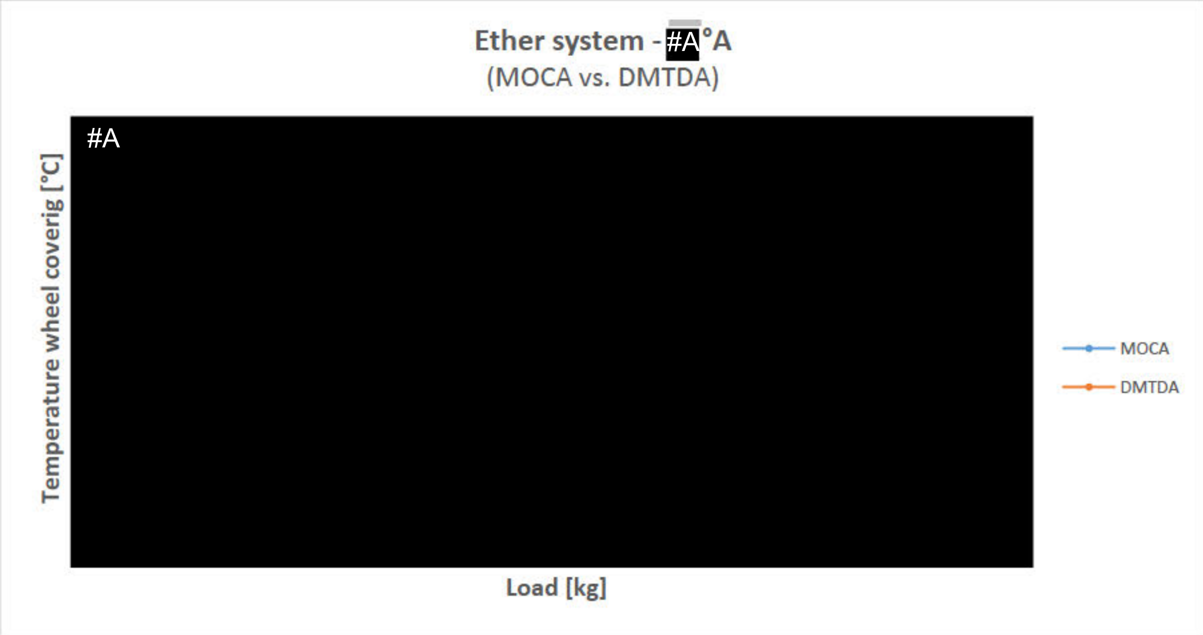


Figure 33. The test results showing the different dynamic behaviour of PU cured with MOCA and DMTDA

The results of CoF tests conducted on DMTDA and MOCA cured PU are presented in the next 3 figures. On steel, the CoF of DMTDA PU is comparable to MOCA PU while there were slight differences in CoF between the two materials on stainless steel. A reduction in CoF on aluminium was however observed.

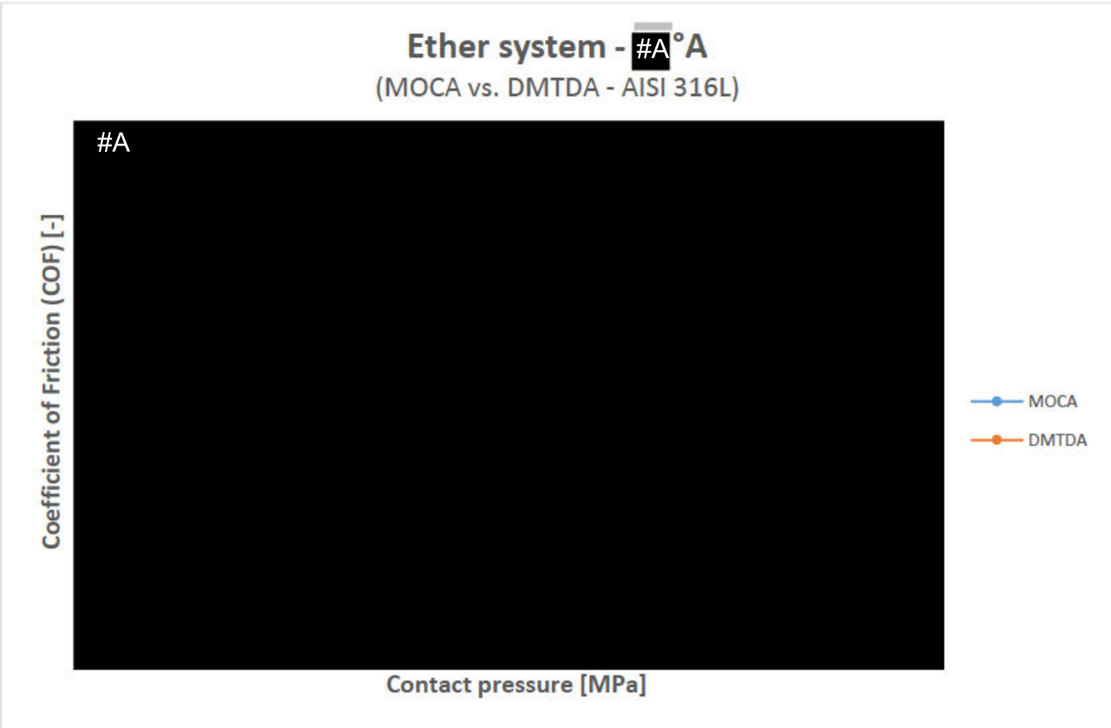


Figure 34. Results of the CoF test using stainless steel

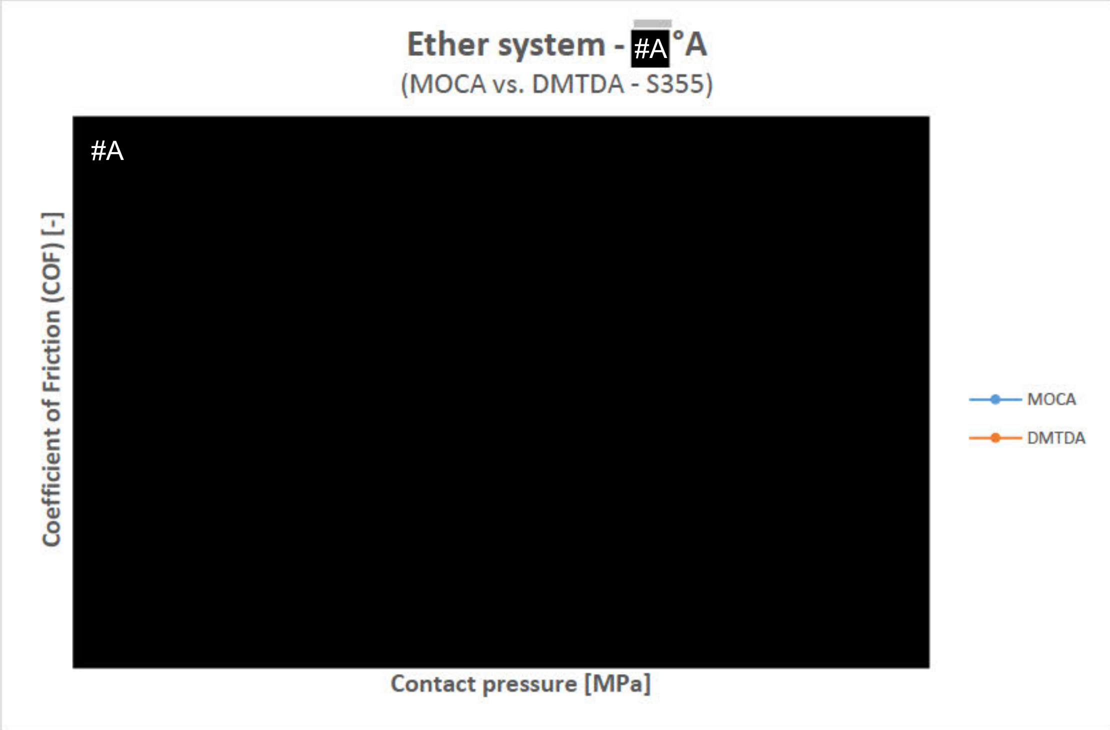


Figure 35. Results of the CoF test using steel

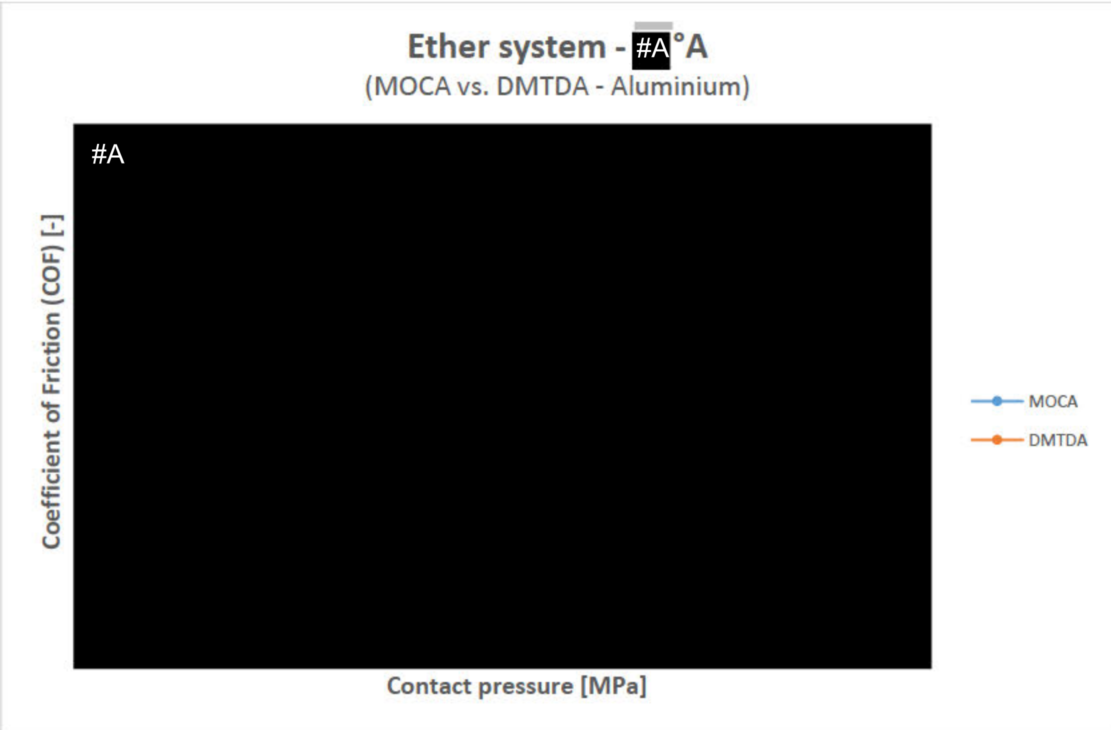


Figure 36. Results of the CoF test using aluminium

Ester prepolymer system:

In the ester prepolymer system, DMTDA gives better results (Table 24). However, the PU tensile properties are still insufficient.

Table 24. The test results of the comparative study between MOCA/TDI ester prepolymer and DMTDA/TDI ester prepolymer (mechanical properties) (#A for all redactions in the table)

			MOCA/TDI ester - [redacted]°A			TDI ester – [redacted]°A
Property	Standard	Unit	Min. Value	Typical	Max. value	DMTDA
Hardness (23 °C)	ISO 48-4	°A	[redacted]			[redacted]
Hardness (85 °C)	ISO 48-4	°A				
Tensile strength	ISO 37[1]	MPa				
Elongation at break	ISO 37[1]	%				
Tear resistance	ISO 34-1 method B, procedure b	kN/m				
Rebound (23 °C)	ISO 4662	%				
Rebound (85 °C)	ISO 4662	%				
Abrasion	ISO 4649 method B	mm^3				
Compression set						
70h/ 23 °C	ISO 815-1	%				
22h/ 70 °C	ISO 815-1	%				

[1] LUC Group uses 200 mm/min instead of 500 mm/min as test speed on the tensile tester.

Figure 37 shows the different deflective behaviour of DMTDA PU in comparison to MOCA PU. DMTDA/TDI ester PU will stretch more before breaking than MOCA PU. However, the force at which break occurs is significantly lower. In addition, the toughness of DMTDA PU is worse compared to MOCA PU.

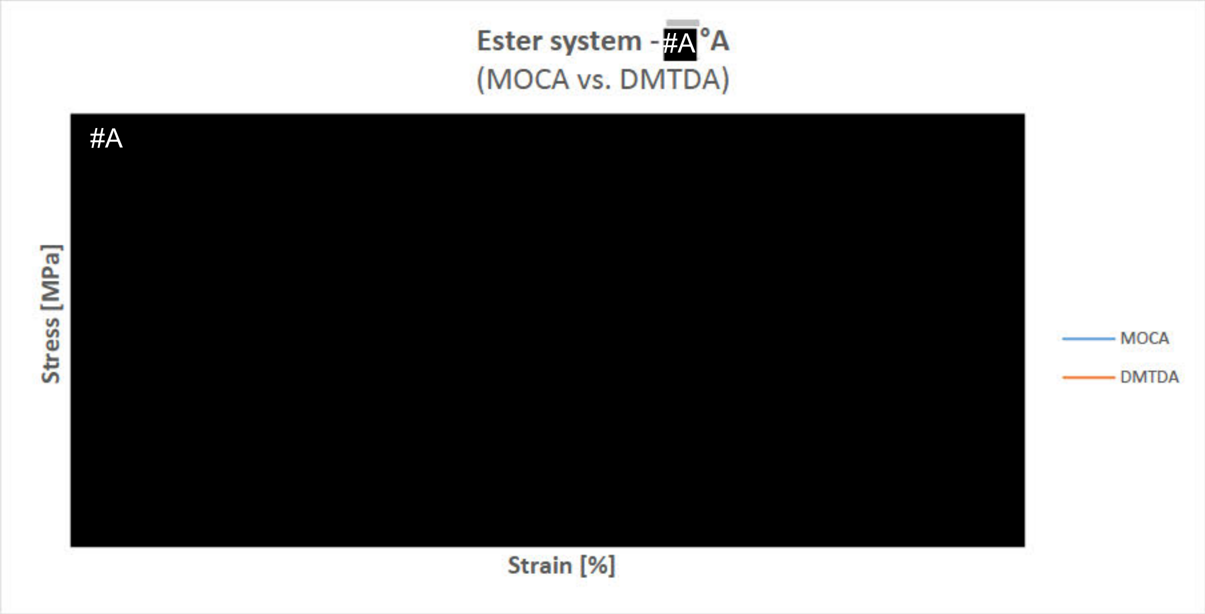


Figure 37. A stress-strain curve plotted from the results of the ISO 37 test

Figure 38 shows the dynamic behaviour of both materials. DMTDA has a lower load bearing capacity ([redacted] kg lower than MOCA).

Figure 38. The test results showing the different dynamic behaviour of PU cured with MOCA and DMTDA

The CoF of DMTDA/TDI ester PU is significantly lower than the one of MOCA/TDI ester with a reduction of more than [redacted] in CoF with stainless steel and aluminium. There is also a reduction in CoF with DMTDA/TDI ester PU on steel, although smaller in scale.

Figure 39. Results of the CoF test using stainless steel

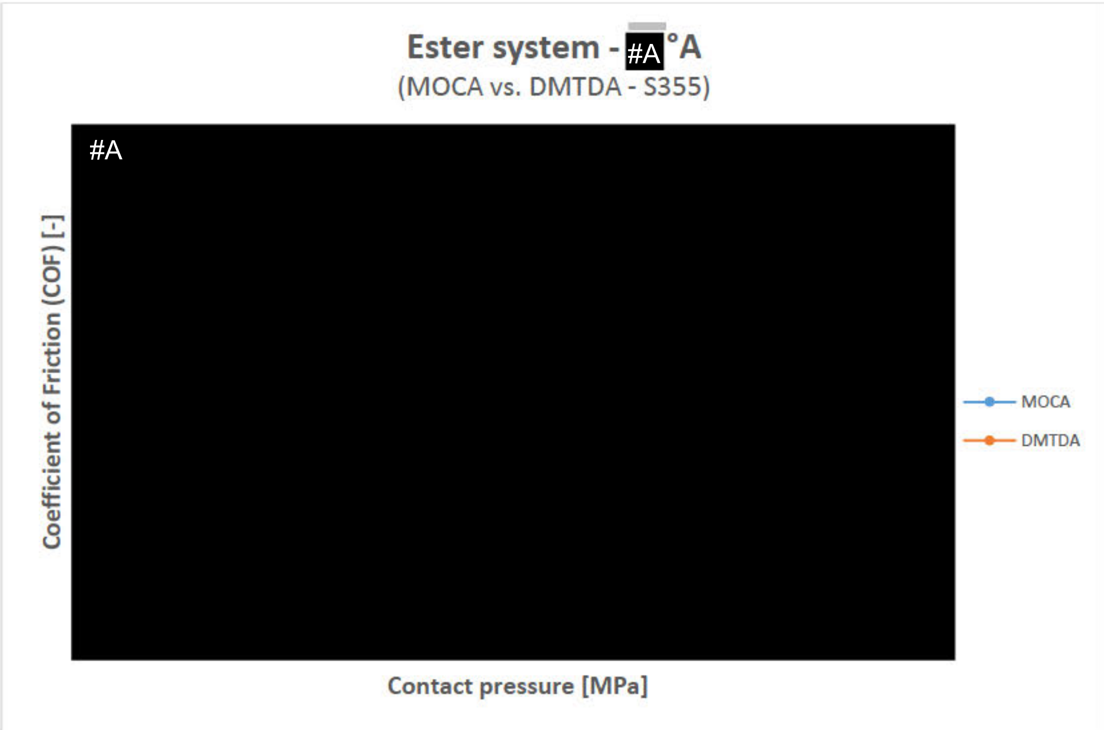


Figure 40. Results of the CoF test using steel

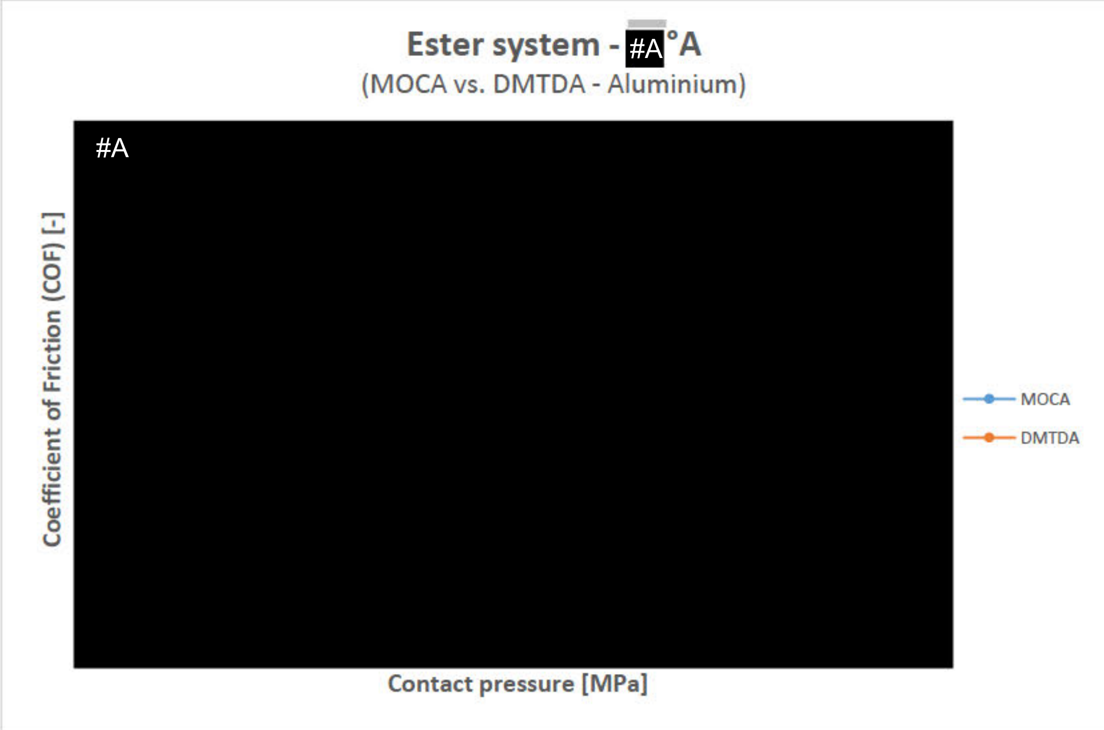


Figure 41. Results of the CoF test using aluminium

<u>Customer trials:</u>

Based on trials conducted at customer's site, the DMTDA-cured parts are less durable and less reliable than their MOCA counterpart. For the end user, a less reliable part is unacceptable as it results in higher maintenance costs and downtimes in the production lines. It requires more frequent maintenance (stripping of old PU covering and product recovery) and the product life is reduced. This means that customers will also have to buy new products more often increasing the costs for LUC UK's customers. Also, this increases the amount of waste PU produced (lower sustainability).

<u>Conclusions on technical feasibility:</u>

The technical properties of DMTDA-cured product are insufficient for the applications covered by Use 1. There is a reduction in mechanical properties, dynamic properties and coefficient of friction (in the ester prepolymer system) when using this alternative instead of MOCA. Pot-life is also significantly shorter with this alternative (half of MOCA's pot-life). The pot-life for this use should be at least [redacted] min. The risk of creating weak spots in the PU material is increase with such short pot-life.

A summary comparing the technical properties of MOCA/TDI and DMTDA/TDI both in the ester and ether prepolymer system is presented in Table 25. Many properties were out of specifications with DMTDA/TDI ether while tensile properties were too low in the ester system.

Table 25. Comparison of mechanical properties (MOCA vs. DMTDA)(#A for all redactions in the table)

Property	MOCA/TDI ether - [redacted]°A Acceptable range	DMTDA/TDI ether –[redacted]°A Test results	MOCA/TDI ester - [redacted]°A Acceptable range	DMTDA/TDI ester –[redacted]°A Test results
Hardness (23 °C)	[redacted]	[redacted]	[redacted]	[redacted]
Hardness (85 °C)	[redacted]	[redacted]	[redacted]	[redacted]
Tensile strength	[redacted]	[redacted]	[redacted]	[redacted]
Elongation at break	[redacted]	[redacted]	[redacted]	[redacted]
Tear resistance	[redacted]	[redacted]	[redacted]	[redacted]
Rebound (23 °C)	[redacted]	[redacted]	[redacted]	[redacted]
Rebound (85 °C)	[redacted]	[redacted]	[redacted]	[redacted]
Abrasion	[redacted]	[redacted]	[redacted]	[redacted]
Compression set 70h/ 23 °C	[redacted]	[redacted]	[redacted]	[redacted]
22h/ 70 °C	[redacted]	[redacted]	[redacted]	[redacted]

Assessment of product requirements:

Table 26 gives an assessment of DMTDA PU properties against the product requirements presented in Chapter 3.1.2.3.

Table 26. Assessment of product requirements (#A for all redactions in the table)

Property	**DMTDA/TDI ether**	**DMTDA/TDI ester**
Mechanical strength	Tensile strength, abrasion and tear resistance are insufficient. Rollers will be weaker and break during use. PU covering will wear out quicker due to lower resistance to abrasion and tear. Pieces of PU may fall into customer's production lines, which can cause equipment malfunction and damage. **Conclusion: requirement not met.**	Tensile strength is too low. The rollers covered by this use require high tensile strength to withstand the high tension forces exerted on them during end-use. A PU roller with low tensile strength will fail during end-use. **Conclusion: requirement not met.**
Coefficient of Friction *Not a key requirement for non-driven rollers*	The coefficient of friction is not as good as with MOCA PU but it is acceptable. **Conclusion: requirement met for driven rollers.**	The coefficient of friction is too low. Rollers will lack the necessary grip provided by friction. They will slip and fail to fulfil their function. **Conclusion: requirement not met for driven rollers.**

Property	DMTDA/TDI ether	DMTDA/TDI ester
Dynamic load bearing	The dynamic load bearing of this material is insufficient. **Conclusion: requirement not met.**	Same as with the ether prepolymer. **Conclusion: requirement not met.**
Fatigue	Fatigue properties are insufficient. **Conclusion: requirement not met.**	Fatigue properties are insufficient. **Conclusion: requirement not met.**
Cutting resistance	The cutting resistance is too low. (lower tear resistance, slightly lower toughness and lower abrasion properties) **Conclusion: requirement not met.**	The cutting resistance sufficient. **Conclusion: requirement met.**
Reliability	The parts produced with DMTDA are not as reliable as their MOCA counterparts. This has been reported by LUC Group's customers when customer trials were conducted. Low reliability parts forces end users to change parts more often which results in more frequent downtimes at user facilities. Downtime results in delays, financial loss and wasted labour. **Conclusion: requirement not met.**	Same as with the ether prepolymer system. **Conclusion: requirement not met.**
Pot-life[16] and adhesion	Pot-life is lower than MOCA ([redacted] min vs. [redacted] min). Due to the lower pot-life, the adhesion of the PU covering to the roller steel core will be weaker. This affects significantly the quality and durability of the product. **Conclusion: pot-life for this use should be at least [redacted] min. There is a higher risk for defects in PU covering and delamination.**	

3.3.1.2.5. Economic feasibility of DMTDA

In terms of raw material costs, DMTDA is more expensive than MOCA. Based on LUC Group's knowledge of the current market, MOCA costs #B [1-10] £/kg whereas DMTDA costs #B [5-20] £/kg. In addition, TDI/DMTDA requires a higher amount of chain extender than the TDI/MOCA system to obtain a material of similar hardness, which further increase the material costs.

Table 27 gives an overview of the change in costs due to the substitution of MOCA with DMTDA.

[16] Not a product requirement but it is a limiting factor for the casting of products. A short pot-life will not give enough time to cast the product.

Table 27. Qualitative assessment of the change in costs due to transition to DMTDA

Aspect	DMTDA vs MOCA
Raw material costs	±3 times higher.
Energy costs	Approximately 1.5-2 times higher. Longer curing times are necessary with this alternative.
Personnel costs	No change expected. LUC Group's personnel will not require additional training to use DMTDA.
Scrap rate	2-10 times higher. The shorter pot-life of DMTDA increases the risk of introducing air bubbles into the material and increases layering. This results in more rejected parts.

LUC UK has estimated the costs to implement an alternative for Use 1 products to amount to 360-416 k GBP, should a suitable alternative be found. For additional information, please see the substitution costs section and Table 59 in Chapter 4.1.3.1.

In conclusion, DMTDA is a more expensive chain extender than MOCA as it is associated with higher raw material and energy costs as well as higher scrap rate. However, the cost difference with MOCA is not significant enough to make it economically unfeasible. Due to the fact that LUC UK cannot reflect the increase in production costs in their PU products due to the competing non-UK MOCA PU products, it cannot be considered economically feasible either.

3.3.1.2.6. Suitability of DMTDA for the applicant in general

DMTDA cannot be considered a suitable alternative to MOCA in Use 1 products as summarised in Table 28.

Table 28. Limitations of the alternative

- The tensile strength is too low (rollers will break during end-use)
- Dynamic load bearing capacity is too low (rollers will break during end-use)
- Cutting resistance is too low in the ether prepolymer system (rollers will wear out quicker)
- CoF is too low in the ester prepolymer system (driven rollers will lack the necessary grip to function properly)
- Fatigue and reliability properties are lower (customers will need to change/recover PU parts more often)
- Pot-life for this use should be at least [redacted] min. DMTDA's pot-life is [redacted] min. The shorter pot-life of DMTDA increases the scrap rate and risk of delamination
- The production costs are higher with DMTDA than with MOCA

Technical feasibility	Economic feasibility	Availability	Safety considerations

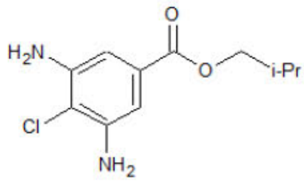
3.3.1.3. Addolink® 1604

3.3.1.3.1. General description of Addolink® 1604

The substance 2-methylpropyl 3,5-diamino-4-chlorobenzoate with trade name Addolink® 1604 (Lanxess) is also an aromatic diamine. It is solid at room temperature. Additional substance identity information is provided in Table 29.

Addolink® 1604 does not have a harmonised classification however, based on the ECHA dissemination tool, the lead registrant of the substance has reported Addolink® 1604 to be hazardous for the environment with a H412 hazard statement.

Table 29. Substance identity and classification of Addolink® 1604

	Addolink® 1604
IUPAC name	2-methylpropyl 3,5-diamino-4-chlorobenzoate
Trade name	Addolink® 1604 DW
Structural formula	
Molecular formula	$C_{11}H_{15}ClN_2O_2$
Molecular weight	242.7
EC/List number	251-311-5
CAS number	32961-44-7
Hazard information	Classification according to GB CLP Regulation: Aquatic Chronic 3, H412 Labelling according to GB CLP Regulation: **No signal word** H412: Harmful to aquatic life with long lasting effects
Physical properties	**Physical state at 20 °C and 1013 hPa:** Solid **Melting point:** 90.4 °C

Processing:

As Addolink® 1604 is a solid at room temperature, it needs to be completely melted prior use. The recommended processing temperature is approximately 100 °C while temperature exceeding 120 °C are to be avoided as the produced polyurethane will be of inferior quality. At temperatures of 170 °C and above, Addolink® 1604 decomposes generating gases, which can be dangerous in closed systems due to high pressure build-up.

In order to use Addolink® 1604, the production equipment needs to be adapted. To prevent decomposition, process controllers need to be installed to ensure that temperatures do not exceed 150 °C. In addition, as non-melted particles may be present in Addolink® 1604, the melted material must be filtered before injection into the weighing/metering system to prevent damage to the equipment and to ensure that the resulting elastomer is of acceptable quality.

3.3.1.3.2. Availability of Addolink® 1604

The availability of Addolink® 1604 is currently poor and has been unavailable in the past. An email from the supplier supporting this is provided in Appendix 2 of this document.

Currently, Addolink® 1604 is only EU REACH registered for 1-10 tonnes/year. This volume is insufficient to overtake the MOCA consumption of LUC Group. In order to distribute the raw materials to LUC UK, LUC Group should have sufficient stock. LUC Group is the supplier for LUC UK and the registration has been grandfathered by LUC UK under UK REACH.

3.3.1.3.3. Safety considerations related to using Addolink® 1604

Based on the information in Table 29, Addolink® 1604 is not classified as hazardous to human health. Regarding environmental hazards, it is classified as Aquatic Chronic 3.

Overall, there is a reduction in risks when transferring to Addolink® 1604 from MOCA.

3.3.1.3.4. Technical feasibility of Addolink® 1604

The reactivity and processability of Addolink® 1604 are good.

<u>Ether prepolymer system:</u>

LUC Group conducted tests on Addolink® 1604 cured PU in the ether prepolymer system. The results are presented in Table 30. Several properties are out of specifications.

Table 30. Test results of the comparative study between MOCA/TDI ether prepolymer and Addolink® 1604/TDI ether prepolymer (#A for all redactions in the table)

			MOCA/TDI ether - [redacted] °A			TDI ether - [redacted] °A
Property	Standard	Unit	Min. value	Typical	Max. value	Addolink® 1604
Hardness (23 °C)	ISO 48-4	°A	[redacted]	[redacted]	[redacted]	[redacted]
Hardness (85 °C)	ISO 48-4	°A	[redacted]	[redacted]	[redacted]	[redacted]
Tensile strength	ISO 37[1]	MPa	[redacted]	[redacted]	[redacted]	[redacted]
Elongation at break	ISO 37[1]	%	[redacted]	[redacted]	[redacted]	[redacted]
Tear resistance	ISO 34-1 method B, procedure b	kN/m	[redacted]	[redacted]	[redacted]	[redacted]
Rebound (23 °C)	ISO 4662	%	[redacted]	[redacted]	[redacted]	[redacted]
Rebound (85 °C)	ISO 4662	%	[redacted]	[redacted]	[redacted]	[redacted]
Abrasion	ISO 4649 method B	mm^3	[redacted]	[redacted]	[redacted]	[redacted]
Compression set			[redacted]	[redacted]	[redacted]	[redacted]
70h/ 23 °C	ISO 815-1	%	[redacted]	[redacted]	[redacted]	[redacted]
22h/ 70 °C	ISO 815-1	%	[redacted]	[redacted]	[redacted]	[redacted]

[1] LUC Group uses 200 mm/min instead of 500 mm/min as test speed on the tensile tester.

Addolink® 1604/TDI ether cannot be used as a replacement to MOCA due to its significantly lower tensile strength. The PU rollers used in Use 1 need high tensile strength in order to withstand the high tension force exerted on the rollers during end-use. A PU roller with insufficient tensile strength will break during end-use.

Figure 42 shows the different deflective behaviour of the materials, where the lower tensile strength of Addolink® 1604/TDI ether can be seen (y-axis). The figure also shows that the PU has a lower toughness than MOCA cured PU.

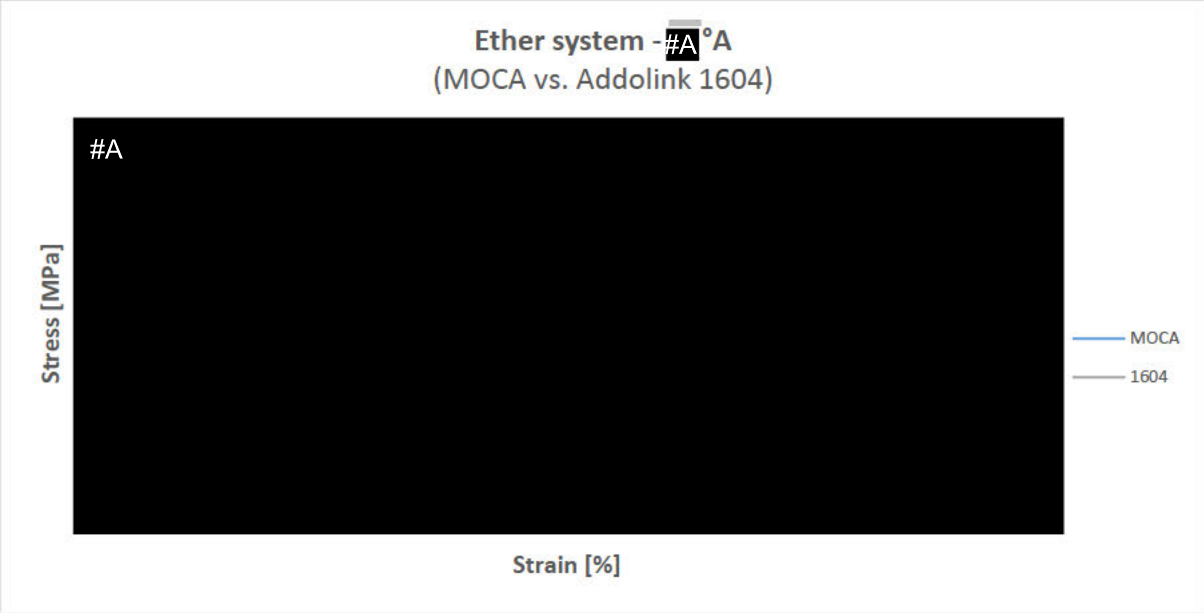


Figure 42. Stress-strain curves plotted from the results of the ISO 37 test

As can be seen from Figure 43, Addolink® 1604/TDI ether PU has a significantly lower load bearing capacity than MOCA cured PU. The alternative PU covering failed at a load of [redacted] kg while it was [redacted] kg higher for MOCA cured PU.

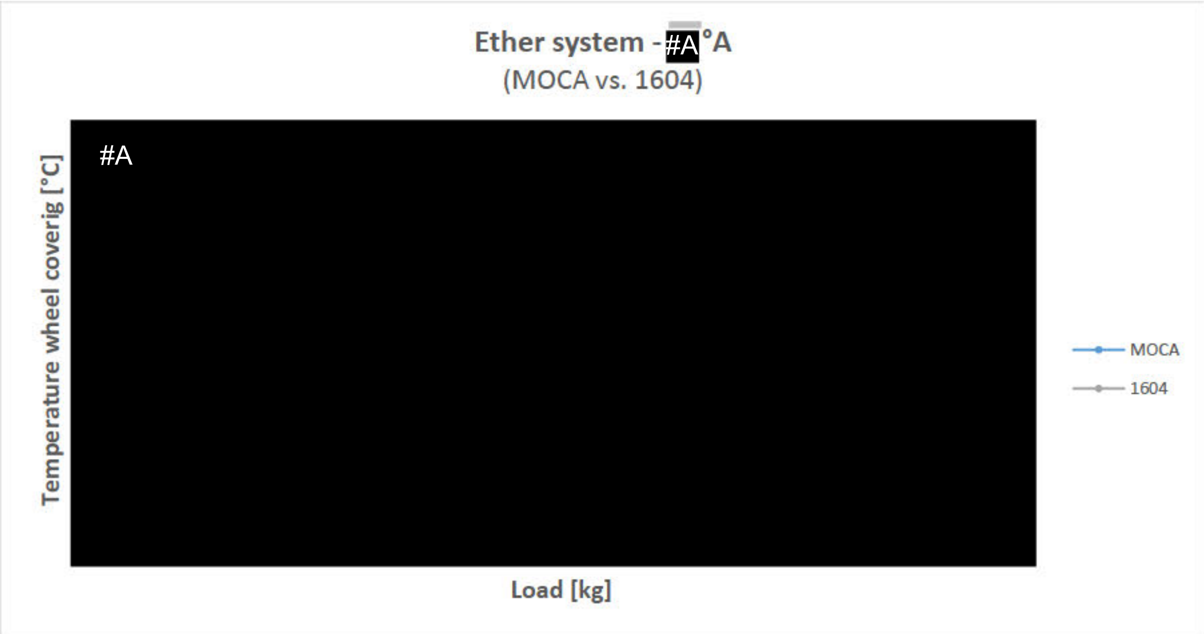


Figure 43. Test results showing the different dynamic behaviour of PU cured with MOCA and Addolink® 1604

The results of the CoF test are presented in the next three figures. Addolink® 1604 cured PU has a lower CoF than MOCA PU on stainless steel and aluminium. In contrast, the alternative PU has a higher CoF on steel.

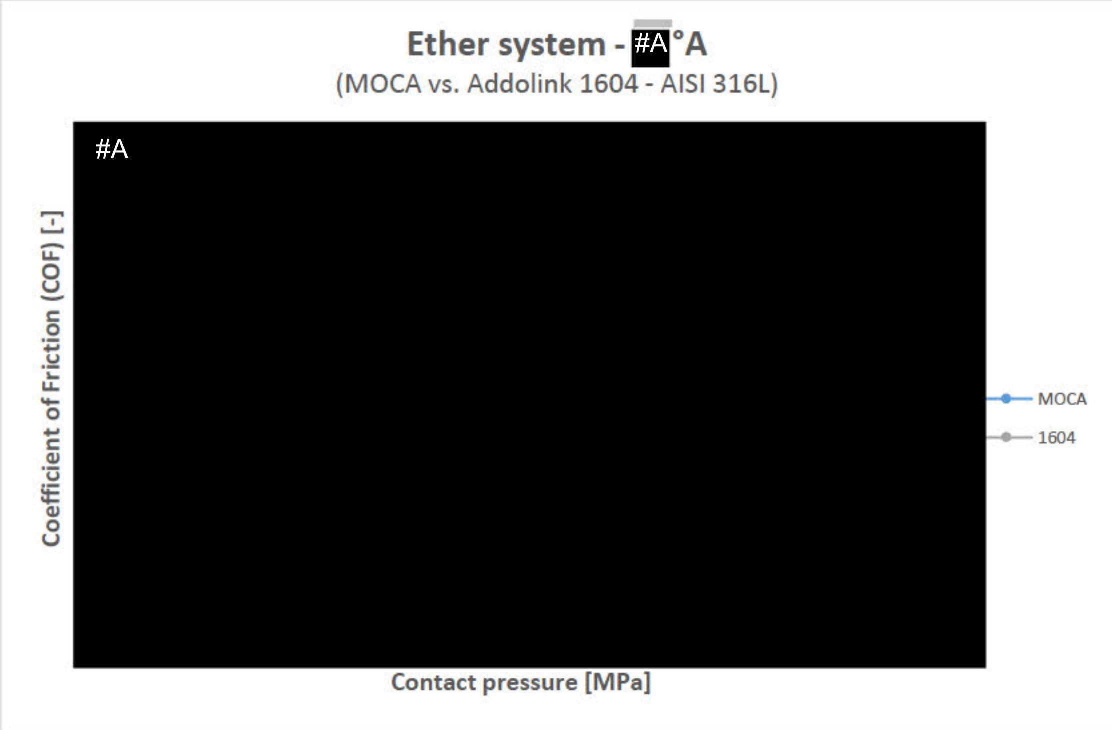


Figure 44. Results of the CoF test using stainless steel

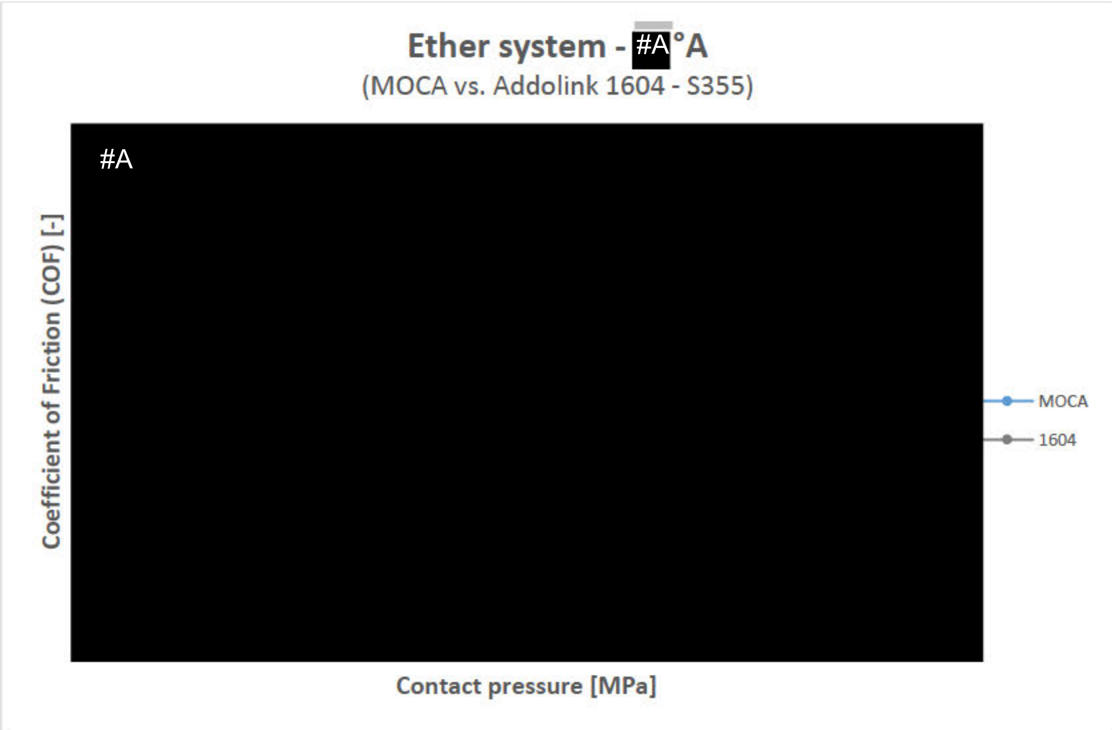


Figure 45. Results of the CoF test using steel

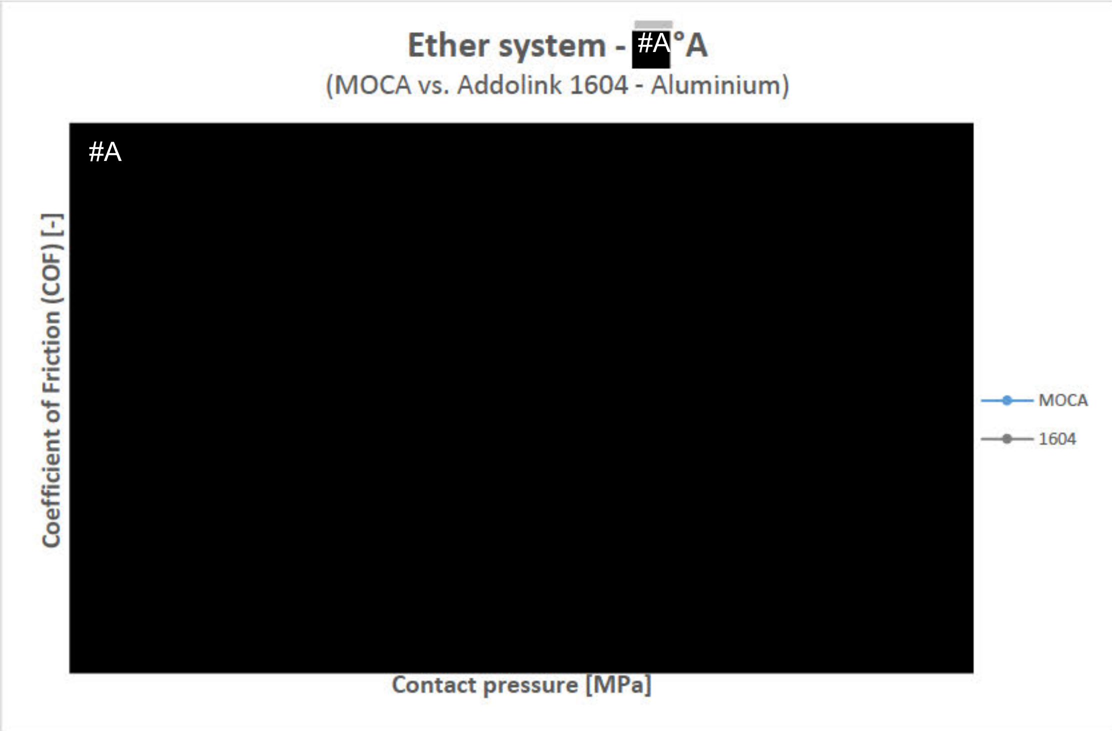


Figure 46. Results of the CoF test using aluminium

Ester prepolymer system:

LUC Group also conducted tests in the ester prepolymer system, the results are presented in Table 31. In this system as well, the tensile strength of Addolink® 1604 PU is lower than MOCA but to a lower extent.

Table 31. Test results of the comparative study between MOCA/TDI ether prepolymer and Addolink® 1604/TDI ester prepolymer (#A for all redactions in the table)

Property	Standard	Unit	MOCA/TDI ester - [redacted] °A Min. value	Typical	Max. value	TDI ester – [redacted] °A Addolink® 1604
Hardness (23 °C)	ISO 48-4	°A	[redacted]	[redacted]	[redacted]	[redacted]
Hardness (85 °C)	ISO 48-4	°A	[redacted]	[redacted]	[redacted]	[redacted]
Tensile strength	ISO 37[1]	MPa	[redacted]	[redacted]	[redacted]	[redacted]
Elongation at break	ISO 37[1]	%	[redacted]	[redacted]	[redacted]	[redacted]
Tear resistance	ISO 34-1 method B, procedure b	kN/m	[redacted]	[redacted]	[redacted]	[redacted]
Rebound (23 °C)	ISO 4662	%	[redacted]	[redacted]	[redacted]	[redacted]
Rebound (85 °C)	ISO 4662	%	[redacted]	[redacted]	[redacted]	[redacted]
Abrasion	ISO 4649 method B	mm^3	[redacted]	[redacted]	[redacted]	[redacted]
Compression set						
70h/ 23 °C	ISO 815-1	%	[redacted]	[redacted]	[redacted]	[redacted]
22h/ 70 °C	ISO 815-1	%	[redacted]	[redacted]	[redacted]	[redacted]

[1] LUC Group uses 200 mm/min instead of 500 mm/min as test speed on the tensile tester.

Both MOCA cured PU and the alternative PU material have a comparable deflective behaviour when exposed to tensile stress as shown in Figure 47. The PU has a lower toughness as represented by the area under the curve.

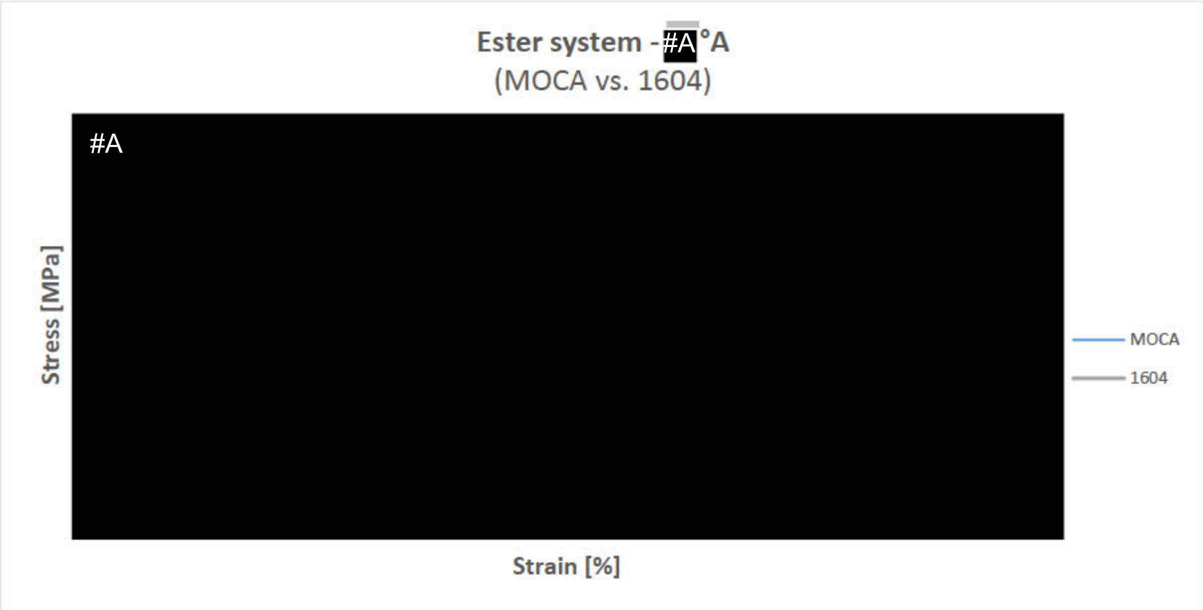


Figure 47. Stress-strain curves plotted from the results of the ISO 37 test

Figure 48 shows the differences in dynamic behaviour between the two materials. Addolink® 1604 PU has a significantly lower load bearing capacity in comparison to MOCA PU ([redacted] kg lower).

Figure 48. Test results showing the different dynamic behaviour of PU cured with MOCA and Addolink® 1604

The results of the CoF tests are presented in the next three figures. The CoF of Addolink® 1604 PU is comparable on steel and stainless steel while it was better on aluminium.

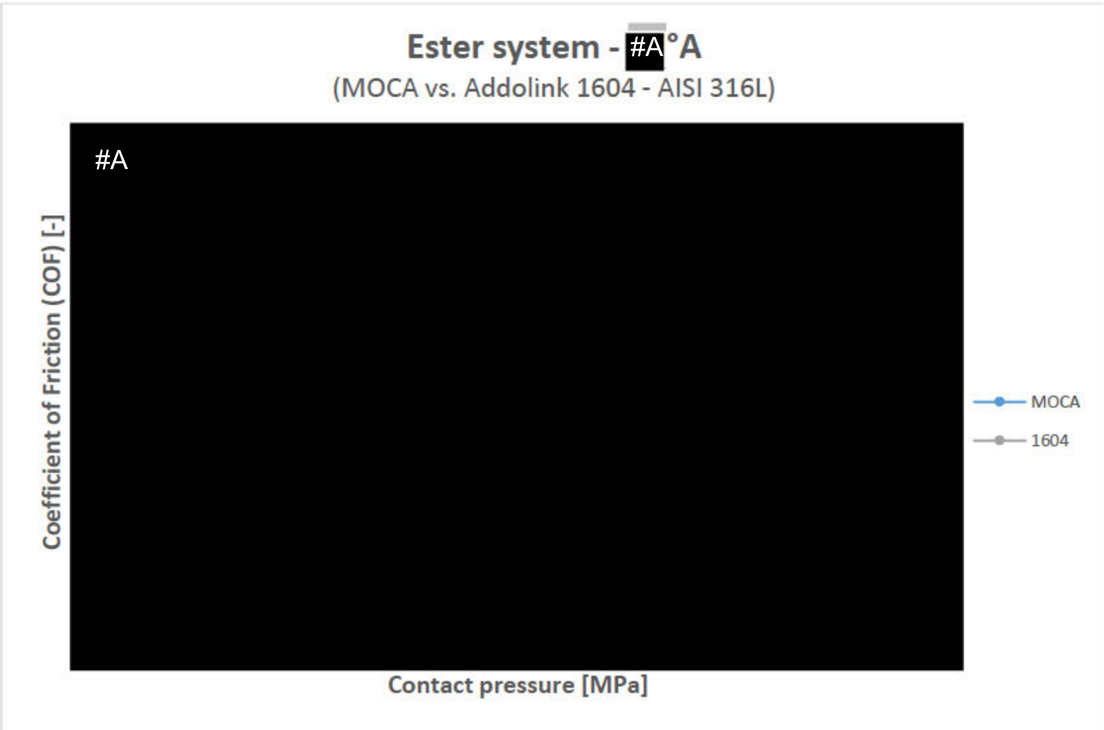


Figure 49. Results of the CoF test using stainless steel

Figure 50. Results of the CoF test using steel

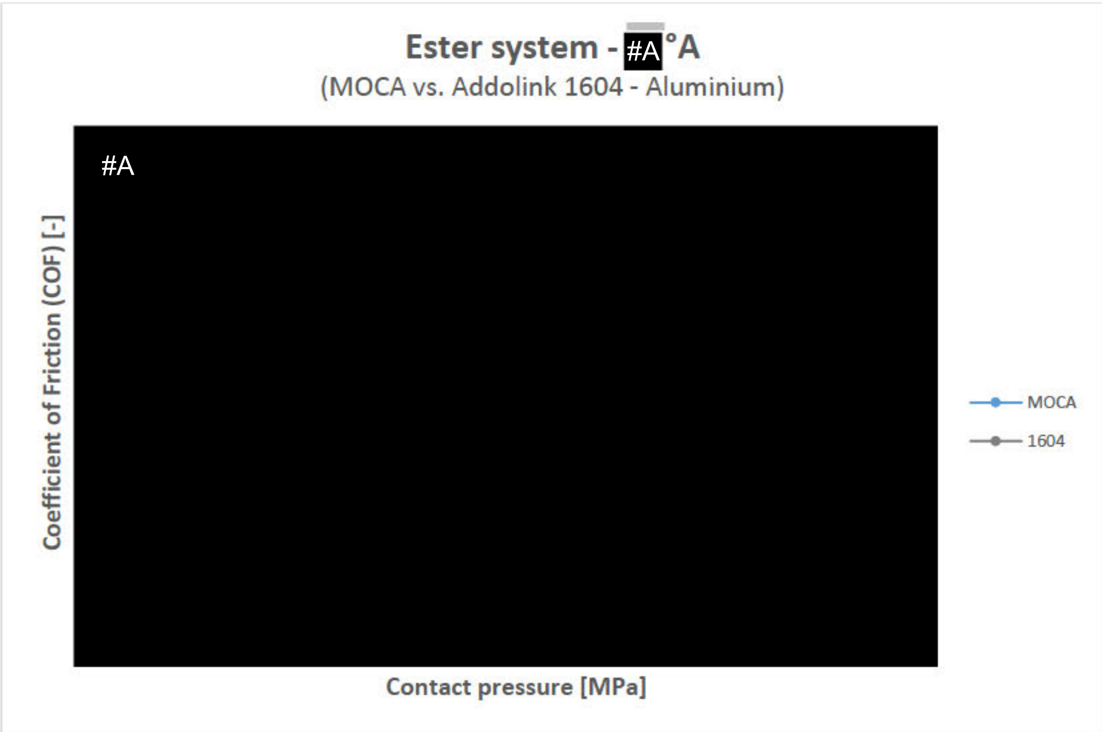


Figure 51. Results of the CoF test using aluminium

<u>Customer trials:</u>

In the trials conducted by LUC Group at customers' sites, the reliability and fatigue of Addolink® 1604-cured products was an issue. The parts needed to be changed more often, which resulted in longer downtimes in the customers' production lines and in an increase of wastes due to the more frequent stripping of old PU covering and more frequent recovering of products (i.e. removing the old PU cover of a roller and casting a new one in its place).

Conclusions on technical feasibility:

In terms of reactivity, Addolink® 1604 is the closest match to MOCA. The pot-lives of PU cured with Addolink® 1604 are similar or even higher than MOCA, which enables the production of large volume products. Thus, all the products covered by Use 1 can be casted when using this alternative.

The technical properties of the alternative vs MOCA are summarised in Table 32.

Table 32. Comparison of mechanical properties (MOCA vs Addolink® 1604) (#A for all redactions in the table)

Property	MOCA/TDI ether – [redacted]°A Acceptable range	1604/TDI ether – [redacted]°A Test results	MOCA/TDI ester – [redacted]°A Acceptable range	1604/TDI ester – [redacted]°A Test results
Hardness (23 °C)	[redacted]	[redacted]	[redacted]	[redacted]
Hardness (85 °C)	[redacted]	[redacted]	[redacted]	[redacted]
Tensile strength	[redacted]	[redacted]	[redacted]	[redacted]
Elongation at break	[redacted]	[redacted]	[redacted]	[redacted]
Tear resistance	[redacted]	[redacted]	[redacted]	[redacted]
Rebound (23 °C)	[redacted]	[redacted]	[redacted]	[redacted]
Rebound (85 °C)	[redacted]	[redacted]	[redacted]	[redacted]
Abrasion	[redacted]	[redacted]	[redacted]	[redacted]
Compression set 70h/ 23 °C	[redacted]	[redacted]	[redacted]	[redacted]
22h/ 70 °C	[redacted]	[redacted]	[redacted]	[redacted]

Assessment of product requirements:

Table 33 gives an assessment of Addolink® 1604 PU properties against the product requirements presented in Chapter 3.1.2.3.

Table 33. Assessment of product requirements (#A for all redactions in the table)

Property	Addolink® 1604/TDI ether	Addolink® 1604/TDI ester
Mechanical strength	Tensile strength is too low. The rollers covered by this use require high tensile strength to withstand the high tension forces exerted on them during end-use. A PU roller with low tensile strength will fail during end-use. **Conclusion: requirement not met.**	Although tensile strength is better than in the ester system, it is still too low. **Conclusion: requirement not met.**
Coefficient of Friction *Not a key requirement for non-driven rollers*	The PU coefficient of friction is insufficient on steel and aluminium. It is sufficient on stainless steel. **Conclusion: requirement partly met for driven rollers.**	The PU coefficient of friction is sufficient on steel and stainless steel. Insufficient on aluminium. **Conclusion: requirement partly met for driven rollers.**
Dynamic load bearing	The PU dynamic load bearing capacity is a significant issue with this alternative. It is insufficient for this use ([redacted] kg lower compared to MOCA). This translates into an approximately 41 % load bearing. **Conclusion: requirement not met.**	PU dynamic load bearing capacity is also insufficient in the ester system. There is an approximately 34 % load bearing reduction ([redacted] kg less). **Conclusion: requirement not met.**
Fatigue	PU fatigue properties of Addolink® 1604 cured PU are not suitable for the products covered by this use. Eventually, this will result in permanent deformation and/or failure of the covering. **Conclusion: requirement not met.**	Same as Addolink® 1604/TDI ether. **Conclusion: requirement not met.**
Cutting resistance	The cutting resistance achieved with this material is insufficient, due to its lower toughness. **Conclusion: requirement not met.**	The cutting resistance achieved with Addolink® 1604 is sufficient. Slightly lower toughness and abrasion resistance, but significantly better tear resistance. **Conclusion: requirement met.**
Reliability	The parts produced with Addolink® 1604 are not as durable as their MOCA counterparts. Users will have to changes parts more often which results in more frequent downtimes at user facilities. **Conclusion: requirement not met.**	Same as Addolink® 1604/TDI ether. **Conclusion: requirement not met.**
Pot-life[17] and adhesion	Pot-life is sufficient. Good adhesion can be achieved. **Conclusion: all products covered by Use 1 can be casted. Adhesion is good.**	

[17] Not a product requirement but it is a limiting factor for the casting of products. A short pot-life will not give enough time to cast the product.

3.3.1.3.5. Economic feasibility of Addolink® 1604

Addolink® 1604 is significantly more expensive than MOCA. The price of Addolink® 1604 used to be [redacted] [20-50] £/kg (approx. 7 times the price of MOCA) however, due to poor availability/unavailability the price has increased to [redacted] [30-80] £/kg. The current price of MOCA is [redacted] [1-10] £/kg, thus Addolink® 1604 is currently approximately 13 times more expensive than MOCA.

The reason behind the high cost of Addolink® 1604 is not only due to its poor availability, it is also expensive to manufacture due to the multistep synthesis required for its production as well as the safety and environmental issues associated with the manufacturing process.

Switching to this alternative would have a large impact on the production process, leading to an increase in production costs. The reaction profile and curing cycle is totally different with Addolink® 1604 i.e. the parts need to be kept in the oven longer thus, the energy consumption will increase with this alternative.

In addition, new equipment (ovens to maintain production capacity, temperature controllers, filtration) will most likely be required in case of substitution with this alternative.

Table 34 gives an overview of the change in costs due to the substitution of MOCA with Addolink® 1604.

Table 34. Qualitative assessment of the change in costs due to transition to Addolink® 1604

Aspect	Addolink® 1604 vs MOCA
Raw material costs	Significantly higher (approx. 13 times higher than MOCA)
Energy costs	Higher (longer time required in the oven)
Personnel costs	No change expected, since Addolink 1604's reaction profile and processing behaviour is the closest to that of MOCA. [redacted]
Scrap rate	Same as MOCA.

LUC UK has estimated the costs to implement an alternative for Use 1 products to amount to 360-416k GBP, should a suitable alternative be found. For additional information, please see the substitution costs section and Table 59 in Chapter 4.1.3.1.

It would be impossible for LUC UK to absorb such a high material cost. The Applicant cannot increase the price of its products as they have to compete with the non-UK MOCA moulders who can still continue to place MOCA based PU products on the UK market. LUC UK's customers will simply not buy the alternative products at a higher price if they can continue to buy the cheaper MOCA based PU products.

In addition to having higher production costs, the PU products cured with this alternative do not have the high-performance and high reliability needed for this sector. Supply of products with inferior performance and reliability will result in damage to the LUC Group brand and customers will switch to other MOCA moulders.

3.3.1.3.6. Suitability of Addolink® 1604 for the applicant in general

Addolink® 1604 cannot be considered a suitable alternative to MOCA in Use 1 products as summarised in Table 35.

Table 35. Limitations of the alternative

<table>
<tr><td colspan="4">- The tensile strength is too low (rollers will break during end-use)
- The load bearing capacity is insufficient (rollers will break during end-use)
- Fatigue and reliability properties are lower (customers will need to change/recover PU parts more often)
- Addolink® 1604 is currently poorly available. Even if its availability improves, it is unclear whether LUC Group would be able to buy enough of the material to overtake their MOCA consumption. Lastly, LUC Group would need the alternative in a tonnage higher than the currently REACH registered (LUC Group is the supplier for LUC UK)
- The significantly higher raw material costs and higher energy costs increases the total production costs significantly</td></tr>
<tr><td>Technical feasibility</td><td>Economic feasibility</td><td>Availability</td><td>Safety considerations</td></tr>
<tr><td></td><td></td><td></td><td></td></tr>
</table>

3.3.2. (LF-)MDI systems

In this chapter, tests with a different prepolymer system ((LF-)MDI) are described. Diols are typically used as curing agents with (LF-)MDI based prepolymers. LUC Group has tested several (LF-)MDI systems (different combinations of (LF-)MDI prepolymers with different polyether or polyester polyols as well as different curing agents). Six of these (LF-)MDI PU systems are presented in more details in the next sections.

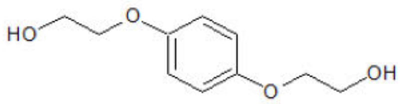
3.3.2.1. General description of (LF-)MDI systems

1. <u>LF-MDI/Vibracure® 2101:</u>

Vibracure® 2101 is a chain extender from Lanxess which, based on the manufacturer SDS, contains >89 % of HQEE. HQEE is an aromatic diol, which is a solid at room temperature. Additional substance identity information is provided in Table 36.

Vibracure® 2101 does not have a harmonised classification however, based on the manufacturer SDS, it is classified as H315 and H319 taking into account the impurity profile of the substance. Based on the same SDS, it is not considered PBT.

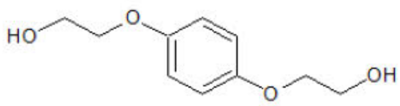
Table 36. Substance identity and classification of Vibracure® 2101

	Vibracure® 2101 (>89 % HQEE)
IUPAC name	2,2'-p-phenylenedioxydiethanol
Trade name	Vibracure® 2101
Structural formula	
Molecular formula	$C_{10}H_{14}O_4$
Molecular weight	198.2
EC/List number	203-197-3
CAS number	104-38-1
Hazard information	Classification according to GB CLP Regulation: Skin Irrit. 2, H315 Eye Irrit. 2, H319 Labelling according to GB CLP Regulation: **Signal word:** Warning H315: Causes skin irritation H319: Causes serious eye irritation PBT assessment: The substance is not PBT
Physical properties	**Physical state at 20 °C and 1013 hPa:** Solid **Melting point:** 107-110 °C

2. (LF-)MDI/HQEE:

LUC Group also tested higher purity HQEE with (LF-)MDI systems. HQEE does not have a harmonised classification however, based on the ECHA dissemination tool, the lead registrant of the substance has reported HQEE to not fulfil the criteria for classification. See Table 37 for additional information.

Table 37. Substance identity and classification of HQEE

	HQEE
IUPAC name	2,2'-p-phenylenedioxydiethanol
Structural formula	
Molecular formula	$C_{10}H_{14}O_4$
Molecular weight	198.2 g/mol
EC/List number	203-197-3
CAS number	104-38-1
Hazard information	Classification according to GB CLP Regulation: Not classified Labelling according to GB CLP Regulation: **No signal word** Not classified PBT assessment: The substance is not PBT/vPvB
Physical properties	**Physical state at 20 °C and 1013 hPa:** Solid **Melting point:** 99 °C

3. Hyperlast 153/55A + Hyperlast LE 5046 + Diprane E + CATD01812-3:

This is a multi-component PU system from DOW, which include a polyol component (Hyperlast 153/55A), diisocyanate component (Hyperlast LE 5046), curing agent (Diprane E) and a catalyst (CATD01812-3).

Based on the manufacturer SDS, Diprane E contains 100 % of propane-1,3-diol. Based on ECHA dissemination tool, propane-1,3-diol is not classified as hazardous by the lead registrant of the substance. See Table 38 for additional information.

Table 38. Substance identity and classification of Diprane E

	Diprane E
IUPAC name	Propane-1,3-diol
Structural formula	
Molecular formula	$C_3H_8O_2$
Molecular weight	76.1 g/mol
EC/List number	207-997-3
CAS number	504-63-2
Hazard information	Classification according to GB CLP Regulation: Not classified Labelling according to GB CLP Regulation: **No signal word** Not classified PBT assessment: The substance is not PBT/vPvB
Physical properties	**Physical state at 20 °C and 1013 hPa:** Liquid **Melting point:** -24.6 °C

4. Diprane C590/45 + Diprane 530 + Diprane CA

This is another multi-component PU system by DOW, which consists of a polyol component (Diprane C590/45), prepolymer component (Diprane 530) and of a curing agent (Diprane CA).

Based on the manufacturer SDS, Diprane CA contains >95 % of butane-1,4-diol (BDO) and has the same classification as BDO. See Table 39 for substance identity and classification information.

Table 39. Substance identity and classification of BDO

	BDO
IUPAC name	Butane-1,4-diol
Structural formula	
Molecular formula	$C_4H_{10}O_2$
Molecular weight	90.1 g/mol
EC/List number	203-786-5
CAS number	110-63-4
Hazard information	Classification according to GB CLP Regulation: Acute Tox. 4, H302 STOT SE 3, H336 Labelling according to GB CLP Regulation: **Signal word:** Warning H302: Harmful if swallowed H336: May cause drowsiness or dizziness PBT assessment: The substance is not PBT/vPvB
Physical properties	**Physical state at 20 °C and 1013 hPa:** Liquid **Melting point:** 20.4 °C **Boiling point:** 230 °C

5. Desmodur MAX D30 + Baytec XL 1705:

This is polyurethane system from Covestro, which consists of a prepolymer (Desmodur MAX D30) and of a curing agent (Baytec XL 1705).

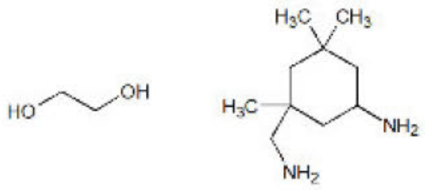
Based on the manufacturer SDS, Baytec XL 1705 contains 75-100 % of DMTDA and it has the same classification as DMTDA. Please refer to Table 22 for additional information.

6. Desmodur MDQ 75164 + Baytec D75 + Baytec XL AL32 + Catalyst SD 25.1:

This is a multi-component PU system from Covestro, which consists of a diisocyanate component (Desmodur MDQ 75164), polyol component (Baytec D75), curing agent (Baytec XL AL32) and of a catalyst (Catalyst SD 25.1).

Based on manufacturer SDS, Baytec XL AL32 is a mixture consisting of ethane-1,2-diol (75-100 %) and of 3-aminomethyl-3,5,5-trimethylcyclohexylamine ($\geq$3-<5 %). Additional information is provided in Table 40.

Table 40. Substance identity and classification of Baytec XL AL32

	Baytec XL AL32
IUPAC name	Ethane-1,2-diol and 3-aminomethyl-3,5,5-trimethylcyclohexylamine
Structural formula	
Molecular formula	$C_2H_6O_2$ and $C_{10}H_{22}N_2$
Molecular weight	62.1 g/mol and 170.3 g/mol
EC/List number	203-473-3 and 220-666-8
CAS number	107-21-1 and 2855-13-2
Hazard information	Classification according to GB CLP Regulation: Acute Tox. 4, H302 Skin Irrit. 2, H315 Eye Dam. 1, H318 Skin Sens. 1, H317 STOT RE 2, H373 Labelling according to GB CLP Regulation: **Signal word:** Danger H302: Harmful if swallowed H315: Causes skin irritation H317: May cause an allergic skin reaction H318: Causes serious eye damage H373: May cause damage to organs through prolonged or repeated exposure PBT assessment: The substance is not PBT/vPvB
Physical properties	**Physical state at 20 °C and 1013 hPa:** Liquid **Pour point:** -19 °C

3.3.2.2. Availability of (LF-)MDI systems

Currently (LF-)MDI systems are available for purchase in sufficient quantities. This situation could change in the future as there has been multiple supply issues of MDI during the past decade. Moreover, MDI has had poor to non-existent availability during two occasions, the latest one being in 2016/2017.[18]

3.3.2.3. Safety considerations related to using (LF-)MDI systems

HQEE and Diprane E are not classified as hazardous. A transition to LFM E370/HQEE and Hyperlast 153/55A would lead to a reduction in risks.

Vibracure® 2101, Diprane CA, Baytec XL 1705 and Baytec XL AL32 are not classified as carcinogenic thus, a transition to these curing agents and corresponding PU systems could lead to a reduction in risks for the workers. Only Baytec XL 1705 is classified as hazardous to the environment however, releases to the environment are unlikely.

3.3.2.4. Technical feasibility of (LF-)MDI systems

The production of polyurethane using MDI-prepolymers is more complex than with TDI-systems. Low Free-MDI systems (LF-MDI), such as Adiprene® LFM E370, have less disadvantages than the conventional MDI-system but they are still more sensitive and less reliable than the TDI-system. The LF-MDI systems require precise raw material ratios. Even small shifts in ratios can have dramatic effects on the mechanical and dynamic properties of the PU. In addition, LF-MDI systems are more moisture sensitive than TDI-systems. Lastly, LF-MDI raw materials have shorter shelf-life than TDI/MOCA raw materials. Overall, this results in more rejected parts and by extension, more waste is produced.

Similar issues are faced with conventional MDI-systems (e.g. Desmodur MDQ 75164, Desmodur MAX-D30). In addition to these issues, the green strength (strength of the material at the beginning of curing) of the PU is lower, which increases the chance of PU cracking or bonding problems to substrates. The reaction of conventional MDI-prepolymers with the curing agent is more exothermic (releases heat) than LF-MDI or TDI. This leads to shrinkage of the polyurethane that would require LUC UK to purchase new moulds to offset the shrinkage. The more exothermic reaction combined with the higher reactivity of conventional MDI-systems makes the production of large parts more difficult. Lastly, the surface of MDI-based polyurethane has typically more cosmetic defects.

<u>Ether prepolymer system:</u>

The results of the tests conducted in the ether prepolymer system are presented in Table 41. The tensile strength of PUS made with these systems is significantly lower than TDI/MOCA PUs making them unsuitable for the applications covered by this use. In addition, the abrasion resistance for LFM E370/HQEE PU is significantly lower. This will result in a PU having unsatisfactory cutting resistance, which is one the key requirement for the products covered by this use due to the sharp materials they come into contact with.

[18] https://www.icis.com/explore/resources/news/2017/05/26/10110409/corrected-contagious-trends-emanate-from-short-europe-crude-mdi-market/

Table 41. Test results of the comparative study between MOCA/TDI ether prepolymer, LFM E370/V2101, LFM E370/HQEE and Hyperlast 153/55A (#A for all redactions in the table)

			MOCA/TDI ether - [redacted] °A			LFM E370/V2101 (Lanxess)	LFM E370/HQEE	Hyperlast 153/55A (DOW)[1]
Property	Standard	Unit	Min. Value	Typical	Max. value			
Hardness (23 °C)	ISO 48-4	°A	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Hardness (85 °C)	ISO 48-4	°A	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Tensile strength	ISO 37[2]	MPa	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Elongation at break	ISO 37[2]	%	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Tear resistance	ISO 34-1 method B, procedure b	kN/m	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Rebound (23 °C)	ISO 4662	%	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Rebound (85 °C)	ISO 4662	%	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Abrasion	ISO 4649 method B	mm^3	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Compression set								
70h/ 23 °C	ISO 815-1	%	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
22h/ 70 °C	ISO 815-1	%	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

[1] System used consisted of Hyperlast 153/55A – Hyperlast LE 5046 – Diprane E - CATD01812-3.

[2] LUC Group uses 200 mm/min instead of 500 mm/min as test speed on the tensile tester.

From Figure 52, it can be seen that the different PUs have very different deflective behaviour. In addition, all alternative PUs have lower toughness compared to TDI/MOCA PU.

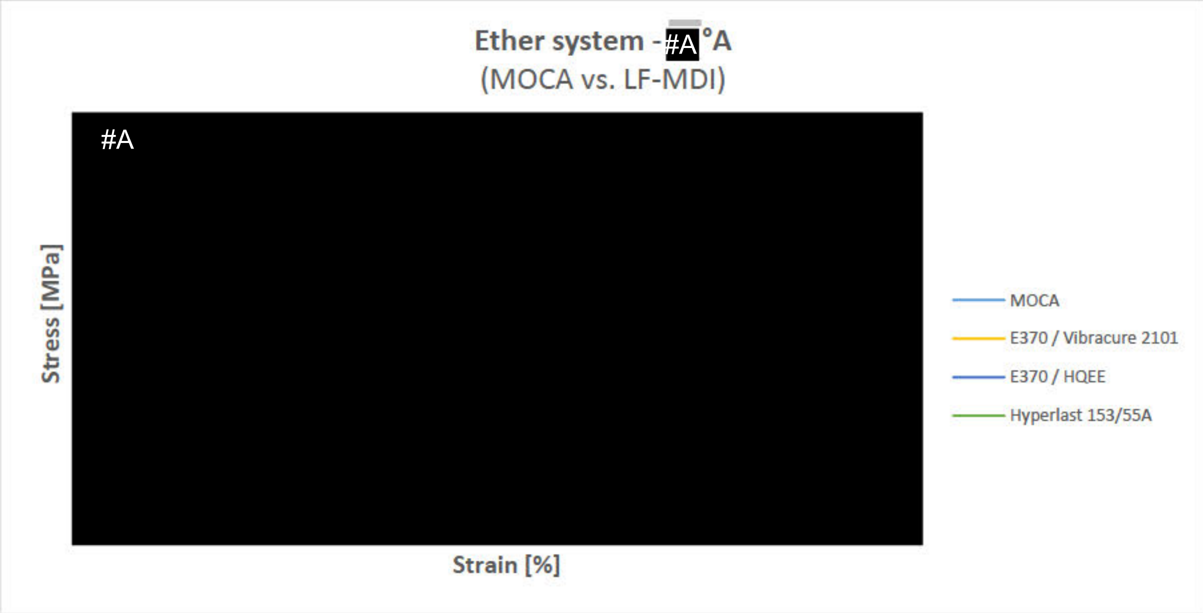


Figure 52. Stress-strain curves plotted from the results of the ISO 37 test

The dynamic behaviours of the alternative PUs were also tested except for LFM E370/HQEE PU as its extremely poor tensile strength makes it unusable. The results are presented in Figure 53. The alternative PU materials failed at significantly lower loads than TDI/ MOCA PUs ([redacted] kg and [redacted] kg lower).

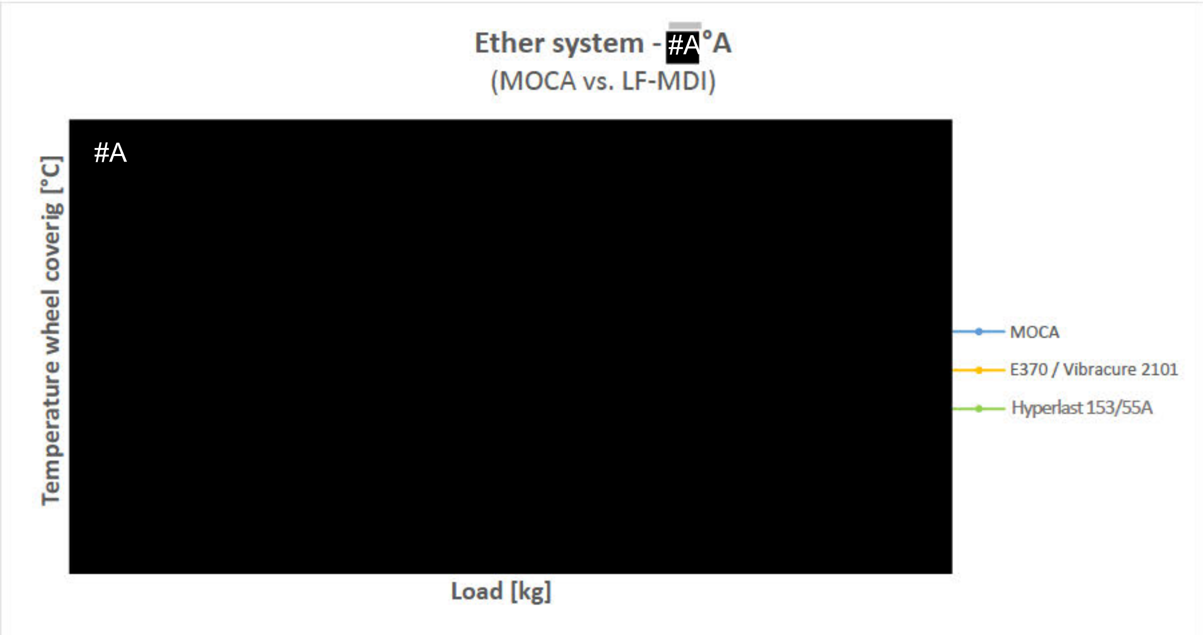


Figure 53. The test results showing the different dynamic behaviour of PU cured with MOCA, LFM E370/V2101 and Hyperlast 153/55A

LUC Group conducted CoF tests on LFM E370/V2101 and Hyperlast 153/55A PU. The results are presented in the next three figures. There was a significant reduction in CoF with the alternative PU materials on aluminium and steel. The reduction in CoF was smaller on stainless steel.

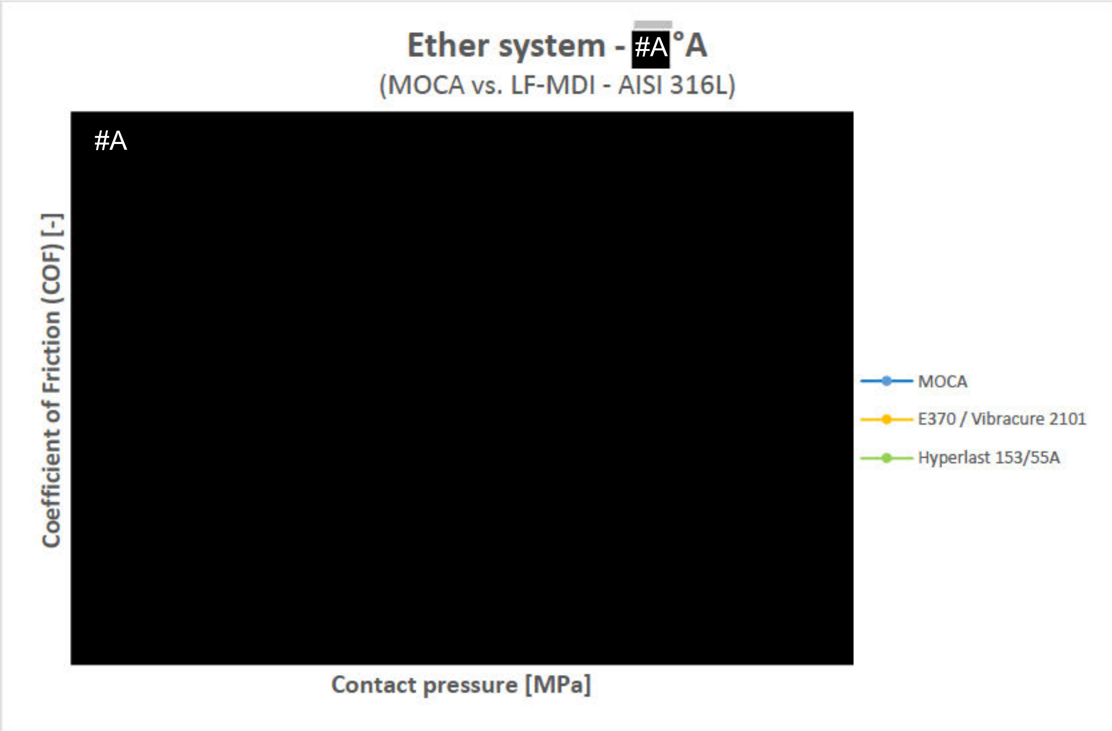


Figure 54. Results of the CoF test using stainless steel

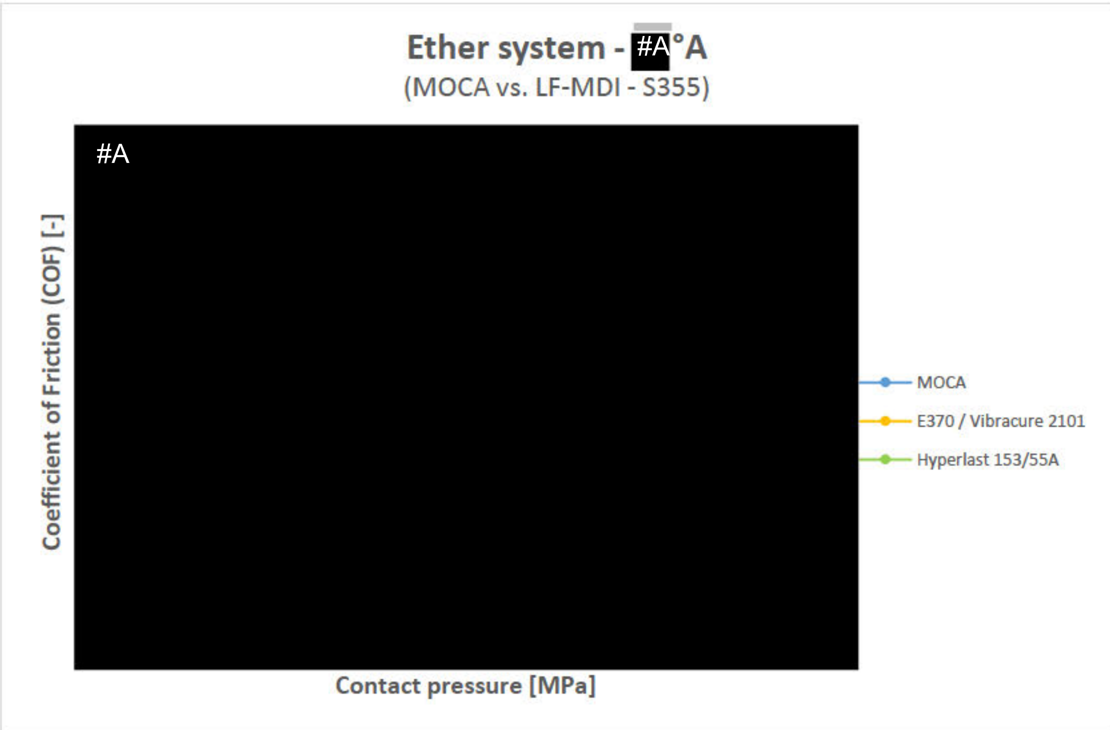


Figure 55. Results of the CoF test using steel

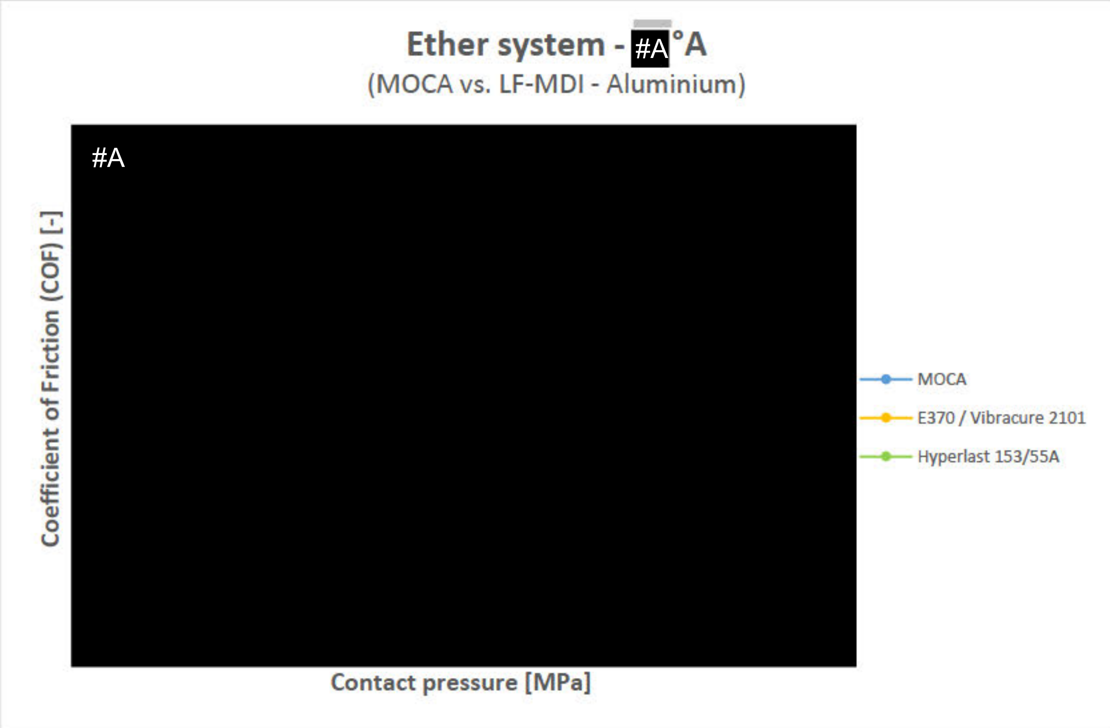


Figure 56. Results of the CoF test using aluminium

<u>Ester prepolymer system:</u>

LUC Group also tested 3 alternatives in the ester prepolymer system. The results are presented in Table 42. The hardnesses of Desmodur MAX D30 and Desmodur MDQ 75164 PUs were out of specifications and the efforts to adjust them were unsuccessful.

Table 42. Test results of the comparative study between MOCA/TDI ester prepolymer, Diprane C590/45, Desmodur MAX D30 and Desmodur MDQ 75164 (#A for all redactions in the table)

			MOCA/TDI ester -[redacted]°A			Diprane C590/45[1]	Desmodur MAX D30[2]	Desmodur MDQ 75164[3]
Property	Standard	Unit	Min. value	Typical	Max. value	(DOW)	(Covestro)	(Covestro)
Hardness (23 °C)	ISO 48-4	°A	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Hardness (85 °C)	ISO 48-4	°A	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Tensile strength	ISO 37[4]	MPa	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Elongation at break	ISO 37[4]	%	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Tear resistance	ISO 34-1 method B, procedure b	kN/m	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Rebound (23 °C)	ISO 4662	%	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Rebound (85 °C)	ISO 4662	%	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Abrasion	ISO 4649 method B	mm³	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Compression set								
70h/ 23 °C	ISO 815-1	%	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
22h/ 70 °C	ISO 815-1	%	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

[1] System components; Diprane C590/45, Diprane 530, Diprane CA.

[2] System components: Desmodur MAX D30, Baytec XL 1705.

[3] System components: Desmodur MDQ 75164, Baytec D75, Baytec XL AL32, Catalyst SD 25.1.

[4] LUC Group uses 200 mm/min instead of 500 mm/min as test speed on the tensile tester.

The deflective behaviours of Diprane C590/45 and Desmodur MDQ 75164 PUs are comparable to their TDI/MOCA PU counterpart while Desmodur MAX D30 PU has a very different deflective behaviour as shown in Figure 57. The toughness's of Diprane C590/45 and Desmodur MDQ 75164 PUs are comparable to TDI/MOCA PU while the toughness of Desmodur MAX D30 PU surpasses that of TDI/MOCA PU.

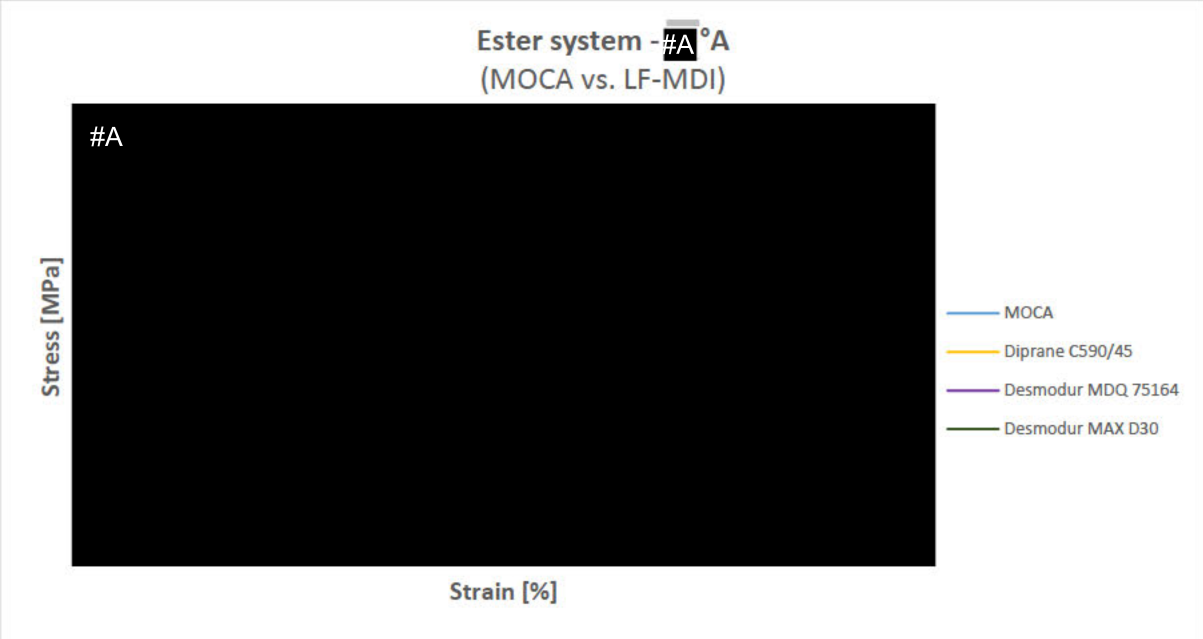


Figure 57. Stress-strain curves plotted from the results of the ISO 37 test

The load bearing resistance of these three alternative PUs is significantly lower ([redacted] kg and [redacted] kg lower) than TDI/MOCA PU (Figure 58).

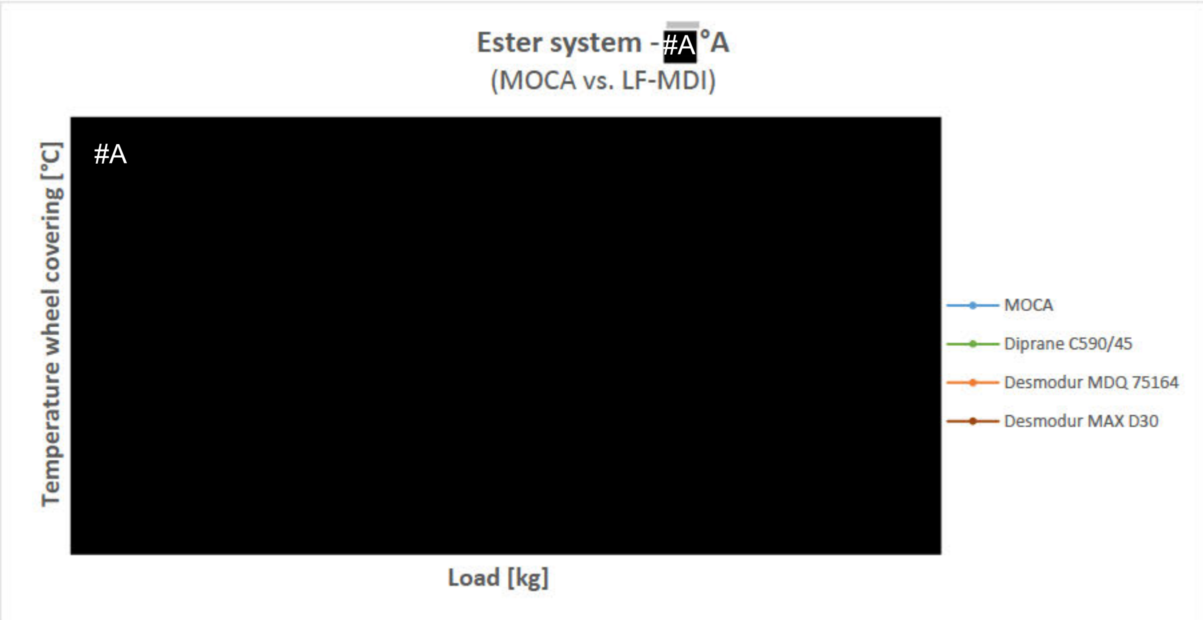


Figure 58. Test results showing the different dynamic behaviour of PU cured with MOCA, Diprane C590/45, Desmodur MDQ 75164 and Desmodur MAX D30

The CoF test results are presented in the next three figures. The PUs have significantly lower CoFs on aluminium ([redacted] lower CoF). On stainless steel, the reduction in CoF is smaller in scale ([redacted]). On steel, Diprane C590/45 and Desmodur MAX D30 PUs have comparable CoFs as TDI/MOCA PU while Desmodur MDQ 75164 PU has a lower CoF.

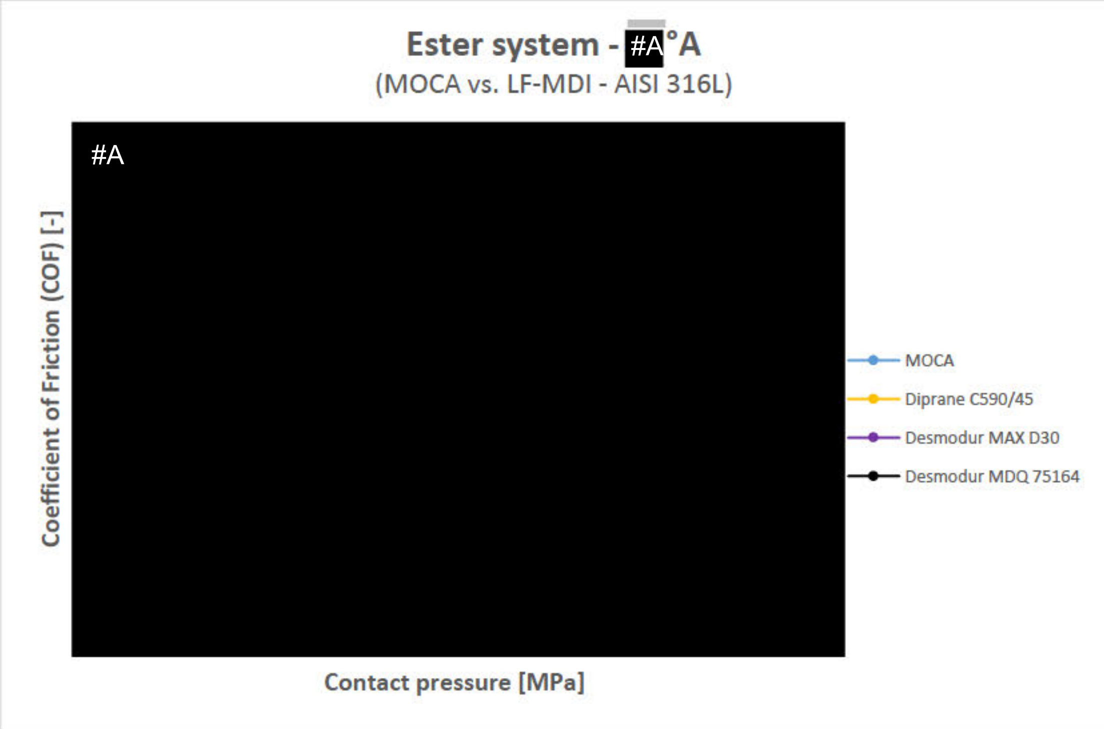


Figure 59. Results of the CoF test using stainless steel

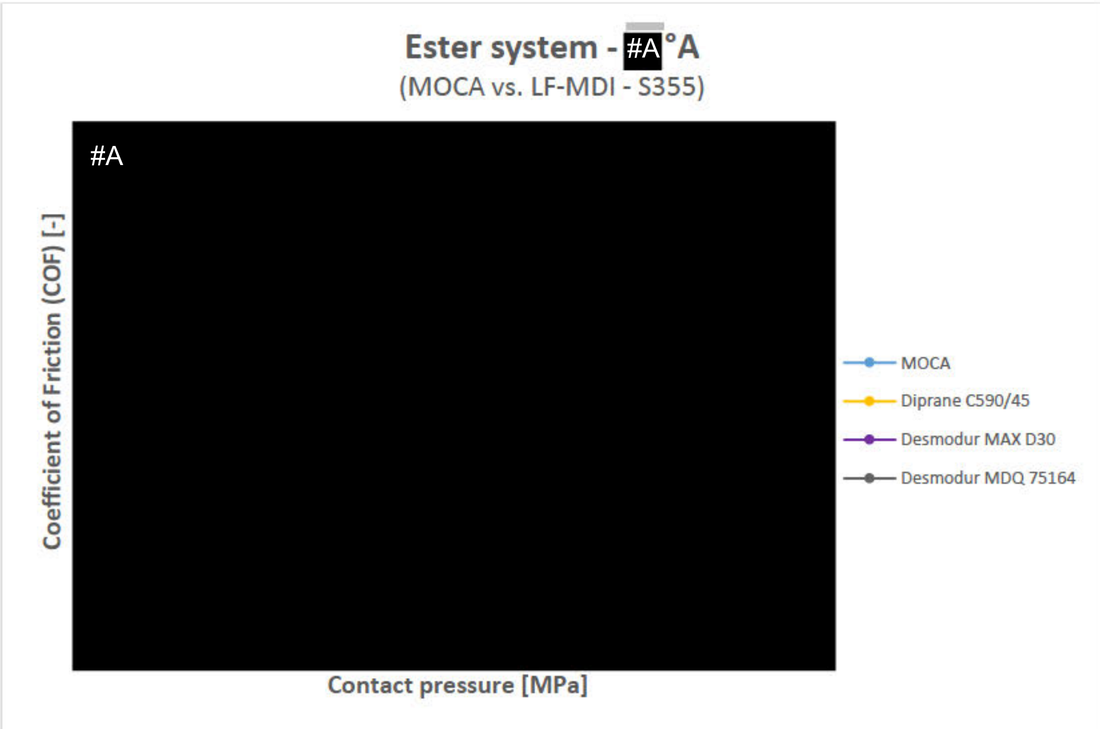


Figure 60. Results of the CoF test using steel

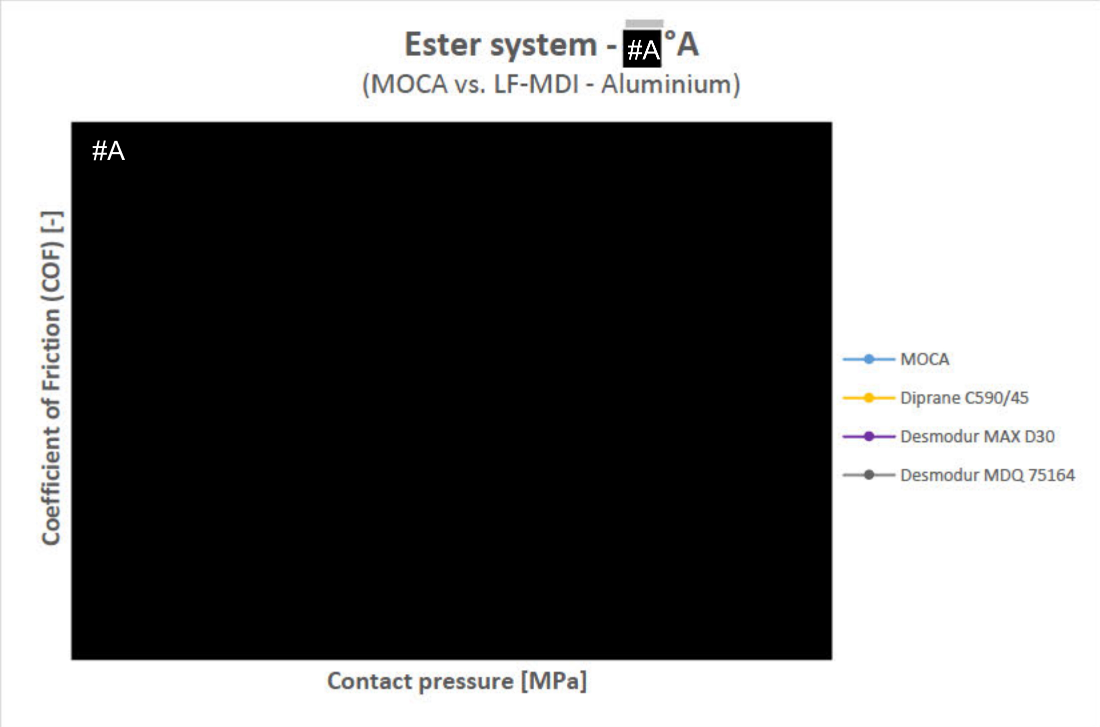


Figure 61. Results of the CoF test using aluminium

<u>Customer trials:</u>

In customer trials, LUC Group's client have reported the (LF-)MDI based PU parts to be less reliable and durable during end-use. The parts needed to be recovered more often.

<u>Assessment of product requirements:</u>

Table 43 gives an assessment of the properties of MDI-systems against the product requirements presented in Chapter 3.1.2.3.

Table 43. Assessment of product requirement (#A for all redactions in the table)

Property	LFM E370/V2101	LFM E370/HQEE	Hyperlast 153/55A
<u>Mechanical strength</u>	Tensile strength is too low. The rollers covered by this use require high tensile strength to withstand the high tension forces exerted on them during end-use. A PU roller with low tensile strength will fail during end-use. **Conclusion: requirement not met.**	Same as LFM E370/V2101. The abrasion resistance is also too low. **Conclusion: requirement not met.**	Same as with LFM E370/V2101. **Conclusion: requirement not met.**

Property	LFM E370/V2101	LFM E370/HQEE	Hyperlast 153/55A
Coefficient of Friction *Not a key requirement for non-driven rollers*	The coefficient of friction is too low. **Conclusion: requirement not met for driven rollers.**	Not tested as the tensile strength of the material was clearly too low rendering it unusable.	The coefficient of friction is too low. **Conclusion: requirement not met for driven rollers.**
Dynamic load bearing	The dynamic load bearing capacity of this material is too low. Its capacity is [redacted] kg lower than TDI/MOCA PU. **Conclusion: requirement not met.**	Not tested as the tensile strength of the material was clearly too low rendering it unusable.	The dynamic load bearing capacity of this alternative is insufficient. It is [redacted] kg lower than TDI/MOCA PU, which translates into an approximately 41 % load bearing reduction. **Conclusion: requirement not met.**
Fatigue	This PU has lower fatigue properties. **Conclusion: requirement not met.**	Not tested as the tensile strength of the material was clearly too low rendering it unusable.	This alternative has lower fatigue properties. **Conclusion: requirement not met.**
Cutting resistance	The PU cutting resistance achieved is sufficient (comparable tear resistance and toughness. Abrasion resistance slightly out of specifications) **Conclusion: requirement met.**	The cutting resistance of this alternative is too low (significantly lower abrasion resistance and toughness while tear resistance is at the lower end of the acceptable range). **Conclusion: requirement not met.**	Cutting resistance achieved with this alternative is insufficient. (comparable tear resistance, better abrasion resistance, but significantly lower toughness) **Conclusion: requirement not met.**
Reliability	LUC Group's customers have reported that the PU parts are less reliable than MOCA PU parts. **Conclusion: requirement not met.**	Same as LFM E370/V2101. **Conclusion: requirement not met.**	Same as LFM E370/V2101. **Conclusion: requirement not met.**
Pot-life[19] and adhesion	Pot-life is sufficient. Good adhesion can be achieved. **Conclusion: all products covered by Use 1 can be casted. Adhesion is good.**		

[19] Not a product requirement but it is a limiting factor for the casting of products. A short pot-life will not give enough time to cast the product.

Property	Diprane C590/45	Desmodur MAX D30	Desmodur MDQ 75164
Mechanical strength	Mechanical strength sufficient. **Conclusion: requirement met.**	Mechanical strength sufficient. **Conclusion: requirement met.**	The mechanical strength of this alternative was sufficient. **Conclusion: requirement met.**
Coefficient of Friction *Not a key requirement for non-driven rollers*	The coefficient of friction is too low. **Conclusion: requirement not met for driven rollers.**	The coefficient of friction is too low. **Conclusion: requirement not met for driven rollers.**	The coefficient of friction is too low. **Conclusion: requirement not met for driven rollers.**
Dynamic load bearing	The PU dynamic load bearing capacity is too low. It is [redacted] kg lower than TDI/MOCA PU, which translates into an approximately 41 % load bearing reduction. **Conclusion: requirement not met.**	The PU dynamic properties are very poor. Its dynamic load bearing capacity is [redacted] kg lower than TDI/MOCA PU, which corresponds to an approximately 61 % load bearing reduction. **Conclusion: requirement not met.**	The PU dynamic load bearing capacity is too low. It is [redacted] kg lower than TDI/MOCA PU. This translates into an approximately 41 % load bearing reduction. **Conclusion: requirement not met.**
Fatigue	The PU has lower fatigue properties. **Conclusion: requirement not met.**	This PU has lower fatigue properties. **Conclusion: requirement not met.**	The PU has lower fatigue properties. **Conclusion: requirement not met.**
Cutting resistance	PU cutting resistance is good. (good tear resistance, abrasion properties and toughness) **Conclusion: requirement met.**	PU Cutting resistance is good. (good tear resistance, abrasion properties and toughness) **Conclusion: requirement met.**	PU cutting resistance is good. (good tear resistance, abrasion properties and toughness) **Conclusion: requirement met.**
Reliability	LUC Group's customers have reported that the PU parts are less reliable than TDI/MOCA PU parts. **Conclusion: requirement not met.**	Same as Diprane C590/45. **Conclusion: requirement not met.**	Same as Diprane C590/45. **Conclusion: requirement not met.**
Pot-life[20] and adhesion	Pot-life is sufficient. Good adhesion can be achieved. **Conclusion: all products covered by Use 1 can be casted. Adhesion is good.**	Pot-life is insufficient with these systems. **Conclusion: the products covered by Use 1 cannot be casted.**	

[20] Not a product requirement but it is a limiting factor for the casting of products. A short pot-life will not give enough time to cast the product.

3.3.2.5. Economic feasibility of (LF-)MDI systems

In order to implement MDI systems, LUC UK would have to make significant investments in fixed installation. As MDI systems require multiple components, new casting machines would be required. Different type of metering pumps, mixing head, stirring systems and different degassing equipment is also required with these systems to avoid cold spots in the material.

Table 44 gives an overview of the change in costs due to the substitution of the TDI/MOCA system with an MDI system.

Table 44. Qualitative assessment of the change in costs due to transition to MDI systems

Aspect	MDI systems vs TDI/MOCA
Raw material costs	No significant change expected. The price of the MDI systems presented are similar than MOCA.
Energy costs	Energy costs will vary depending on the specific MDI system selected. Energy costs can be similar to the TDI/MOCA system in some cases while 2-8 times higher in others.
Personnel costs	Higher at first and will decrease over time. As new machines will need to be purchased to process these systems, LUC UK's personnel will require additional training at first.
Scrap rate	5-20 times higher. The probability of rejected parts is higher with these systems as their processability is more complex. A higher scrap rate leads to more wastes generated.

LUC UK has estimated the costs to implement an alternative for Use 1 products to amount to 360-416 k GBP, should a suitable alternative be found. For additional information, please see the substitution costs section and Table 59 in Chapter 4.1.3.1.

In conclusion, the MDI systems have similar raw material costs as the TDI/MOCA system. However, the scrap rate associated with these systems is very high. Due to the fact that LUC UK cannot reflect the increase in production costs in their PU products due to the competing non-UK TDI/MOCA PU products, MDI systems cannot be considered economically feasible.

3.3.2.6. Suitability of (LF-)MDI systems for the applicant in general

The (LF-)MDI systems tested cannot be considered as suitable alternatives to the TDI/MOCA system in Use 1 products as summarised in Table 45.

Table 45. Limitations of MDI systems

- Dynamic load bearing capacity is too low (rollers will break during end-use) - The pot-life of Desmodur MAX D30 and Desmodur MDQ 75164 is so short that the products cannot to be casted - In ether systems, the PU tensile strength is too low (rollers will break during end-use) - Fatigue and reliability properties are lower than with TDI/MOCA PUs (customers will need to change/recover PU parts more often) - All tested PUs made with alternative systems have too low CoF for driven rollers (driven rollers will lack the necessary grip to function properly) - The cutting resistance of LFM E370/HQEE and Hyperlast 153/55A is too low - MDI-systems have higher scrap rate due to more complex processability. This increases the amount of waste			
Technical feasibility	Economic feasibility	Availability	Safety considerations

3.3.3. NDI systems: NDI/BDO

3.3.3.1. General description of NDI/BDO

The substance butane-1,4-diol, commonly known as BDO, is an aliphatic diol that is a liquid at room temperature. Additional substance identity information is provided in Table 39.

BDO does not have a harmonised classification however, based on the ECHA dissemination tool, the lead registrant of the substance has reported BDO to be classified as H302 and H336.

Processing:

Although a liquid at room temperature, BDO needs to be, at least, slightly heated during processing in order to prevent moisture in the mix.

BDO is very hygroscopic thus, special care must be taken during handling and storage to prevent the absorption of moisture. Moisture will form fine bubbles throughout the PU elastomer (makes the part weaker) and will change the reaction ratios.

3.3.3.2. Availability of NDI/BDO

The availability of NDI is currently poor at the moment LUC Group would not be able to procure it in sufficient quantities. In order to distribute the raw materials to LUC UK, LUC Group should have sufficient stock. The manufacturer isn't able to deliver complete orders due to shortages. An email from the supplier supporting the poor availability of this alternative is provided in Appendix 2 (the situation hasn't improved much and the information is still valid).

BDO is available in sufficient quantities.

3.3.3.3. Safety considerations related to using NDI/BDO

Based on the information in Table 39, BDO is less hazardous for the environment and human health than MOCA. Thus, the transition to this alternative would lead to a reduction in risks for workers and the environment.

3.3.3.4. Technical feasibility of NDI/BDO

The processing of NDI prepolymer systems differ significantly from the TDI-based systems currently in use at LUC UK. NDI systems have a much higher reactivity (shorter pot-life) making it impossible to cast the products covered by this use. The curing process takes significantly longer with NDI prepolymers/systems (3 weeks instead of 1 day for MOCA-based systems), which will result in higher energy consumption and will require additional oven space.

The results of the tests conducted by LUC Group on BDO/NDI ester are presented in Table 46. Overall, the mechanical properties of this material are good except for elongation at break and rebound resilience. The main issues with this alternative are associated with the processing: i) higher reactivity, ii) curing too costly and iii) cracks in PU.

Table 46. The test results of the comparative study between MOCA/TDI and NDI/BDO
(#A for all redactions in the table)

			MOCA/TDI ester - [redacted]°A			NDI/BDO
Property	Standard	Unit	Min. value	Typical	Max. value	Ester - [redacted]°A
Hardness (23 °C)	ISO 48-4	°A	[redacted]	[redacted]	[redacted]	[redacted]
Hardness (85 °C)	ISO 48-4	°A	[redacted]	[redacted]	[redacted]	[redacted]
Tensile strength	ISO 37[1]	MPa	[redacted]	[redacted]	[redacted]	[redacted]
Elongation at break	ISO 37[1]	%	[redacted]	[redacted]	[redacted]	[redacted]
Tear resistance	ISO 34-1 method B, procedure b	kN/m	[redacted]	[redacted]	[redacted]	[redacted]
Rebound (23 °C)	ISO 4662	%	[redacted]	[redacted]	[redacted]	[redacted]
Rebound (85 °C)	ISO 4662	%	[redacted]	[redacted]	[redacted]	[redacted]
Abrasion	ISO 4649 method B	mm^3	[redacted]	[redacted]	[redacted]	[redacted]
Compression set						
70h/ 23 °C	ISO 815-1	%	[redacted]	[redacted]	[redacted]	[redacted]
22h/ 70 °C	ISO 815-1	%	[redacted]	[redacted]	[redacted]	[redacted]

[1] LUC Group uses 200 mm/min instead of 500 mm/min as test speed on the tensile tester.

In Figure 62, the stress-strain curves of the materials are presented. As it can be seen, BDO/NDI-ester PU has a higher toughness and a different deflective behaviour than MOCA PU.

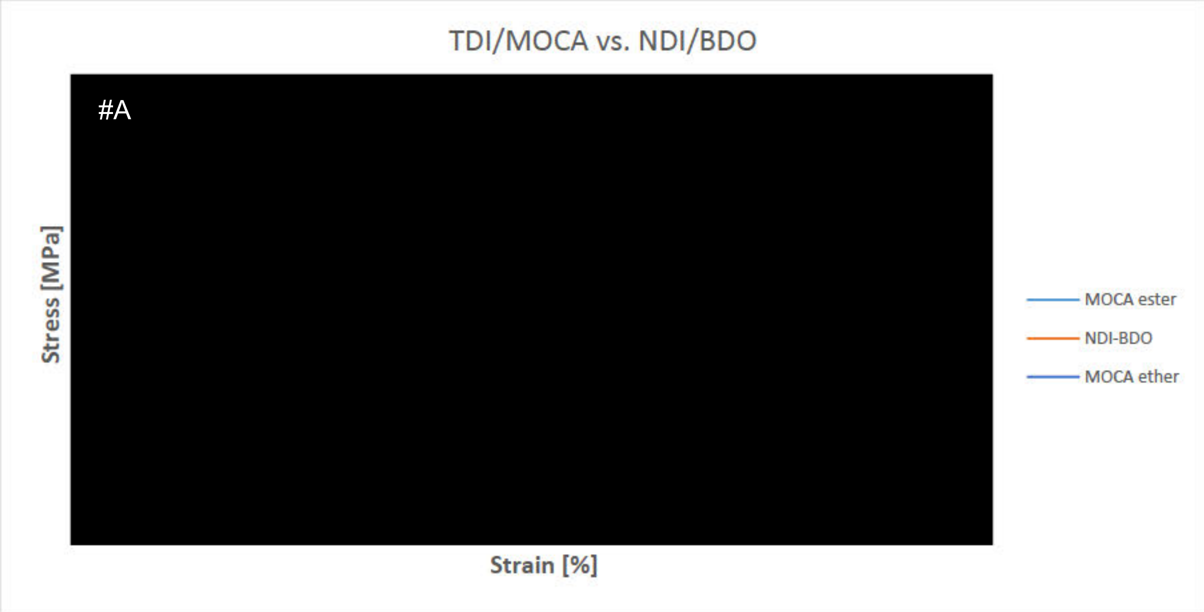


Figure 62. Stress-strain curves plotted from the results of the ISO 37 test

The results of the dynamic load bearing capacity test are presented in Figure 63. Based on the results, NDI/BDO PU can withstand higher loads than TDI/MOCA PU.

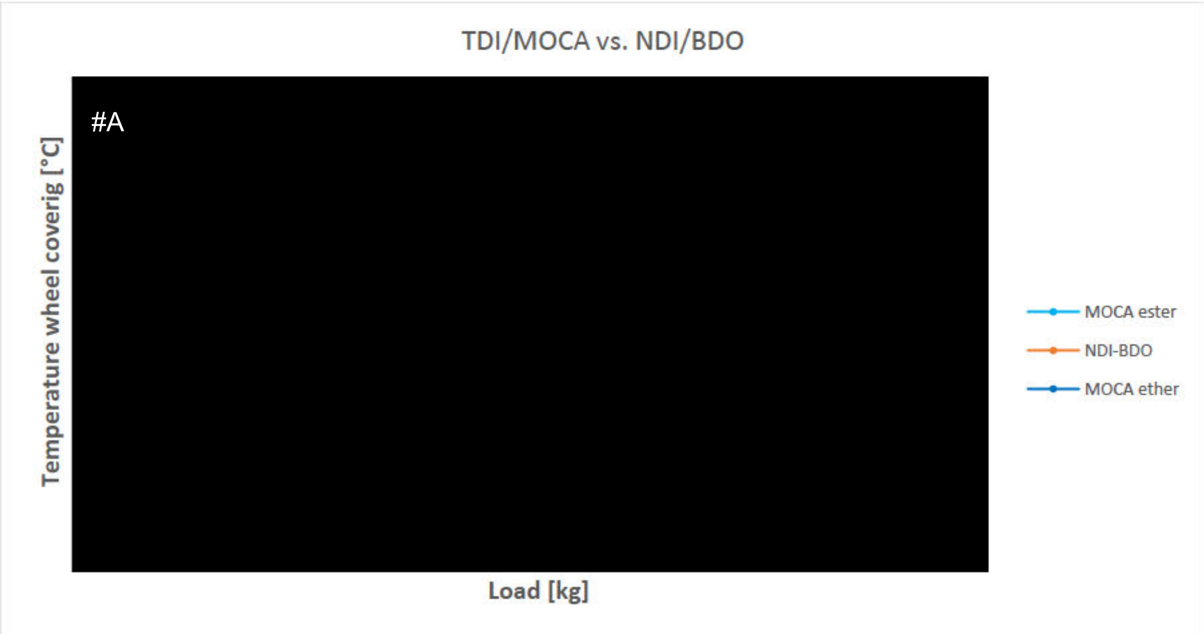


Figure 63. Test results showing the different dynamic behaviour of TDI/MOCA PU and NDI/BDO PU

The results of the CoF tests are presented in the next three figures. NDI/BDO PU has a significantly lower CoF than TDI/MOCA PU (the difference is as high as [redacted] in CoF) on all three counter materials.

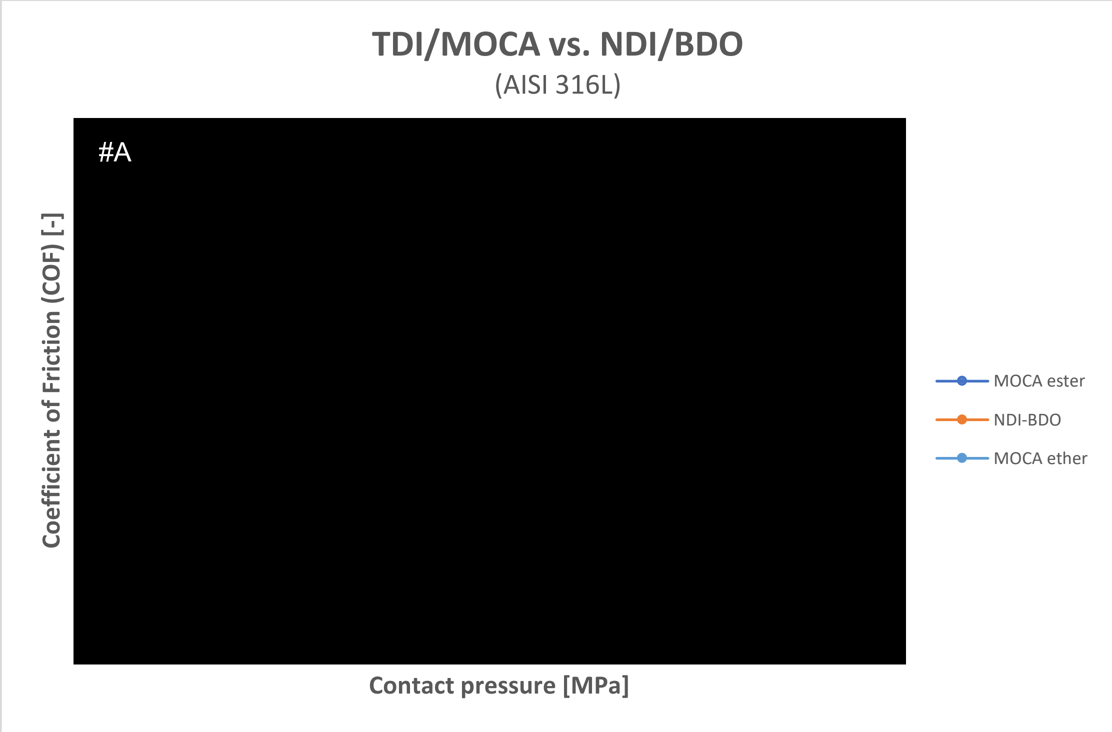


Figure 64. Results of the CoF test using stainless steel

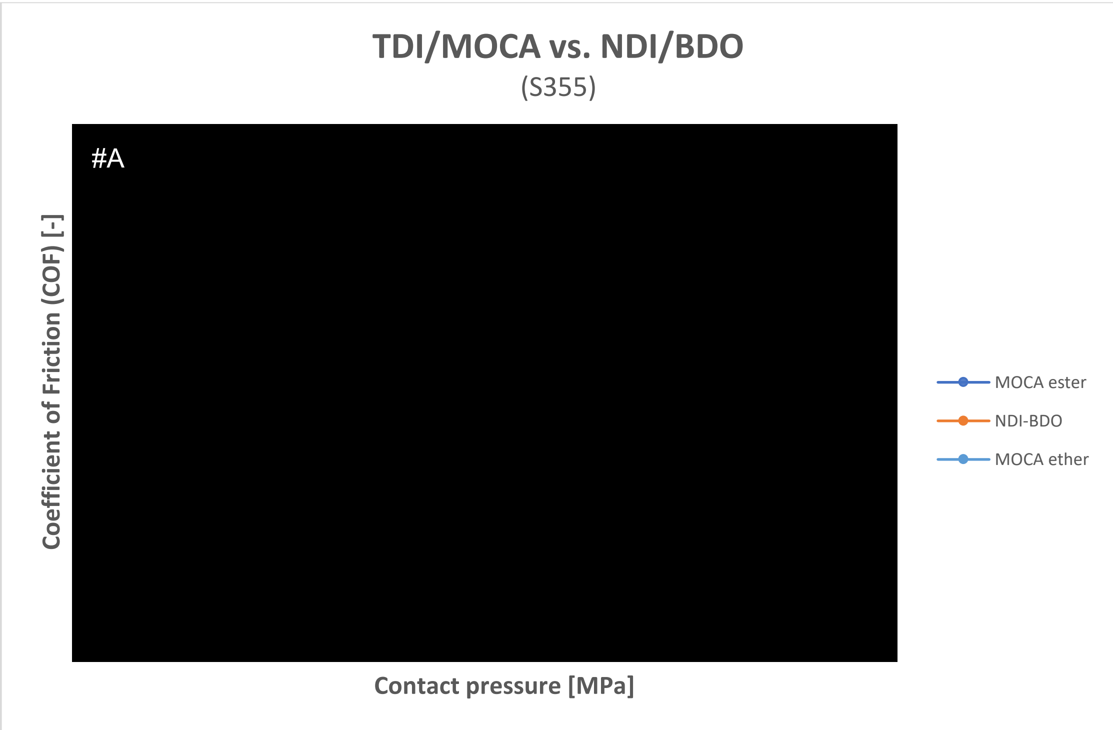


Figure 65. Results of the CoF test using steel

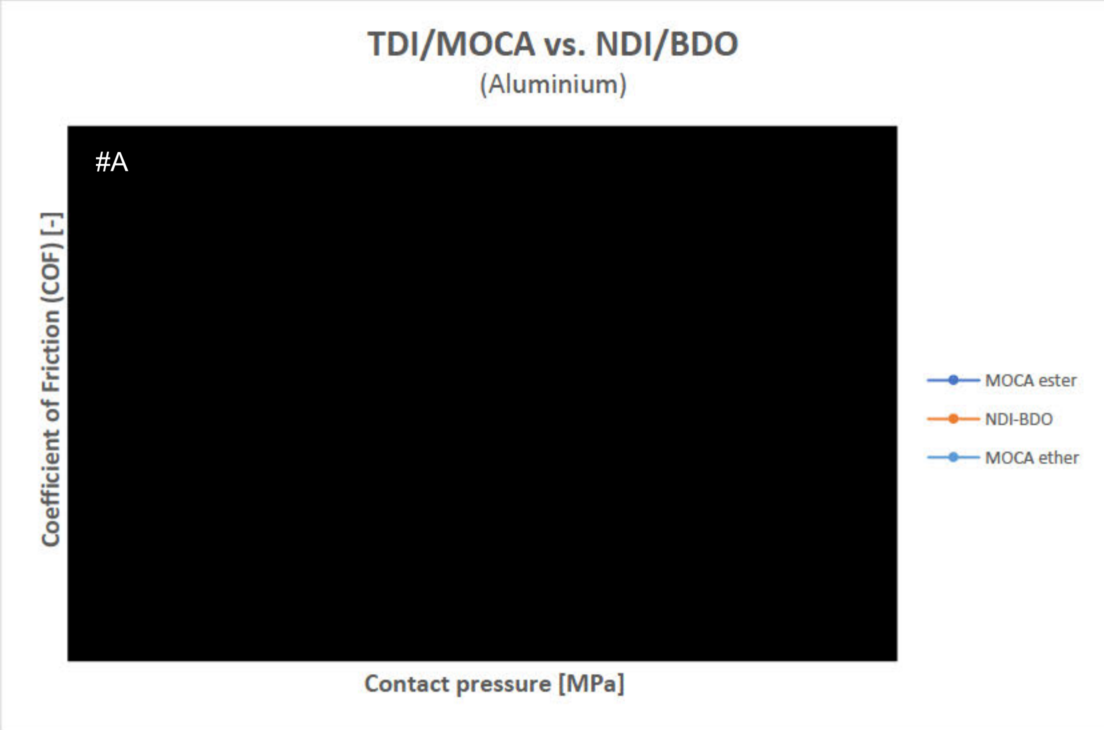


Figure 66. Results of the CoF test using aluminium

Assessment of product requirements:

Table 47 gives an assessment of the properties of NDI/BDO systems against the product requirements presented in Chapter 3.1.2.3.

Table 47. Assessment of product requirements

Property	**BDO/NDI ester**
Mechanical strength	Mechanical strength is good. **Conclusion: requirement met.**
Coefficient of Friction *Not a key requirement for non-driven rollers*	The CoF is too low. The driven rollers covered by Use 1 require high grip in order to function properly. **Conclusion: requirement not met for driven roller.**
Dynamic load bearing	Dynamic load bearing of NDI/BDO PU is higher than TDI/MOCA PU. **Conclusion: requirement met.**
Fatigue	Fatigue properties are excellent. **Conclusion: requirement met.**
Cutting resistance	NDI/BDO PU has an excellent cutting resistance (excellent abrasion, toughness and tear resistance) **Conclusion: requirement met.**

Property	BDO/NDI ester
Reliability	The parts produced with NDI/BDO PU have higher reliability than their TDI/MOCA PU counterparts. **Conclusion: requirement met.**
Pot-life[21] and adhesion	Pot-life is insufficient. **Conclusion: the products covered by Use 1 cannot be casted.**

3.3.3.5. Economic feasibility of NDI/BDO

As the polyurethane is manufactured with an excess of prepolymer in comparison to the chain extender, the price of the prepolymer will have a much larger influence on the raw material costs than the chain extender because it is used in higher quantities. NDI prepolymers are more expensive (increase of a factor of 3) than the TDI prepolymers in use at LUC UK. Although BDO is less expensive than MOCA, the higher price of the prepolymer still leads to an overall higher price of raw materials.

The longer curing times of NDI/BDO will result in significantly higher energy costs (as high as an increase of a factor of 10). In addition, additional oven space will be needed, which is an issue as not all LUC Group facilities, including LUC UK's site, have the space to accommodate additional ovens. This would require building an extension to the facilities. Based on LUC Group's estimates, an extension would cost approximately 1.8 M GBP per facility.

Table 48 gives an overview of the change in costs due to the transition to NDI/BDO.

Table 48. Qualitative assessment of the change in costs due to the substitution of TDI/MOCA with NDI/BDO

Aspect	NDI/BDO vs TDI/MOCA
Raw material costs	Significantly higher
Energy costs	Significantly higher (10 times higher than with TDI/MOCA)
Personnel costs	No change expected. LUC UK's personnel will not require additional training to use NDI/BDO. The substance is in use at LUC UK.
Scrap rate	Not applicable as the products covered by this use cannot be casted with this alternative.

LUC UK has estimated the costs to implement an alternative for Use 1 products to amount to 360-416 k GBP, should a suitable alternative be found. For additional information, please see the substitution costs section and Table 59 in Chapter 4.1.3.1.

It would be impossible for LUC UK to absorb such a high material cost. The Applicant cannot increase the price of its products as they have to compete with the non-UK MOCA moulders who can still continue to place TDI/MOCA PU products on the UK market. LUC

[21] Not a product requirement but it is a limiting factor for the casting of products. A short pot-life will not give enough time to cast the product.

UK's customers will simply not buy the PU products made with alternatives at a higher price if they can continue to buy the cheaper TDI/MOCA PU products.

3.3.3.6. Suitability of NDI/BDO for the applicant in general

NDI/BDO cannot be considered a suitable alternative to TDI/MOCA in Use 1 products as summarised in Table 49.

Table 49. Limitations of the alternative

- PU CoF is too low for driven rollers (driven rollers will lack the necessary grip to function properly)
- The pot-life with this alternative is so short that the products covered by this use cannot be casted
- Significantly longer curing time with this alternative (3 weeks vs 1 day for TDI/MOCA)
- The higher raw material costs (NDI) and the significantly higher energy costs increases significantly the total production costs
- NDI availability is currently poor

Technical feasibility	Economic feasibility	Availability	Safety considerations

3.3.4. PPDI systems

In this chapter, we present the test results for PPDI/BDO and PPDI/HQEE.

3.3.4.1. PPDI/BDO

3.3.4.1.1. General description of PPDI/BDO

The substance identity and hazard information of BDO is presented in Table 39.

3.3.4.1.2. Availability of PPDI/BDO

BDO is available in sufficient quantity.

LUC Group is the lead registrant of PPDI under EU REACH and the registration has been grandfathered under UK REACH (full registration not completed yet). LUC Group imports it from outside of the EEA and the availability is good in terms of quantity. However, in the past there have been issues with the #C [redacted]

3.3.4.1.3. Safety considerations related to using PPDI/BDO

Based on the information in Table 39, BDO is less hazardous for the environment and the human health than MOCA. Therefore, the transition to the PPDI/BDO system would lead to a reduction in risks for the environment and workers.

3.3.4.1.4. Technical feasibility of PPDI/BDO

The results of the tests conducted by LUC Group are presented in Table 50. The tensile strength of PPDI/BDO PU is too low while the rebound resilience is significantly higher, which means that the PU material will be more bouncy.

Table 50. The test results of the comparative study between MOCA/TDI and PPDI/BDO

(#A for all redactions in the table)

			MOCA/TDI ester – [redacted] °A			PPDI-BDO
Property	Standard	Unit	Min. Value	Typical	Max. value	Ester – [redacted] °A
Hardness (23 °C)	ISO 48-4	°A	[redacted]	[redacted]	[redacted]	[redacted]
Hardness (85 °C)	ISO 48-4	°A	[redacted]	[redacted]	[redacted]	[redacted]
Tensile strength	ISO 37[1]	Mpa	[redacted]	[redacted]	[redacted]	[redacted]
Elongation at break	ISO 37[1]	%	[redacted]	[redacted]	[redacted]	[redacted]
Tear resistance	ISO 34-1 method B, procedure b	kN/m	[redacted]	[redacted]	[redacted]	[redacted]
Rebound (23 °C)	ISO 4662	%	[redacted]	[redacted]	[redacted]	[redacted]
Rebound (85 °C)	ISO 4662	%	[redacted]	[redacted]	[redacted]	[redacted]
Abrasion	ISO 4649 method B	mm^3	[redacted]	[redacted]	[redacted]	[redacted]
Compression set						
70h/ 23 °C	ISO 815-1	%	[redacted]	[redacted]	[redacted]	[redacted]
22h/ 70 °C	ISO 815-1	%	[redacted]	[redacted]	[redacted]	[redacted]

[1] LUC Group uses 200 mm/min instead of 500 mm/min as test speed on the tensile tester.

The stress-strain curves of the tested materials are presented in Figure 67. PPDI/BDO PU has a completely different deflective behaviour compared to TDI/MOCA PU. As it can be seen from the figure, PPDI/BDO PU stretches significantly more than TDI/MOCA PU under higher tension loads. The toughness of PPDI/BDO PU is higher.

Figure 67. Stress-strain curves plotted from the results of the ISO 37 test

Figure 68 shows the different dynamic behaviour of the tested material. PPDI/BDO PU has a higher load bearing capacity than TDI/MOCA PU.

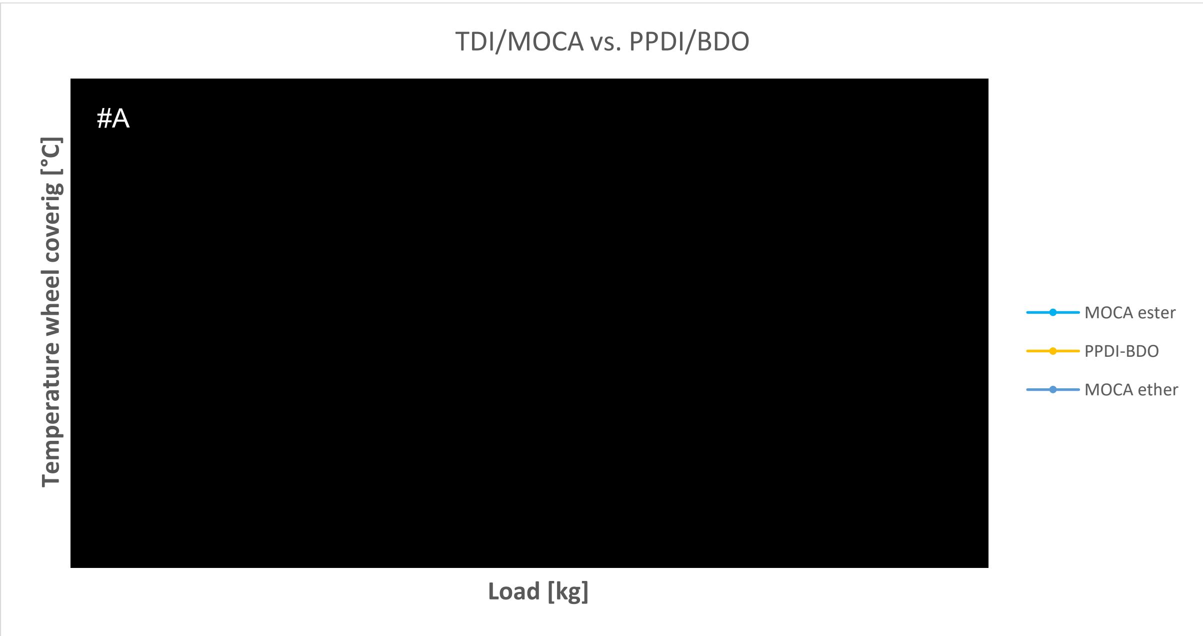


Figure 68. Test results showing the different dynamic behaviour of TDI/MOCA PU and PPDI/BDO PU

The results of the CoF tests are presented in the next three figures. PPDI/BDO PU has a significantly lower CoF than TDI/MOCA PU on all three counter materials.

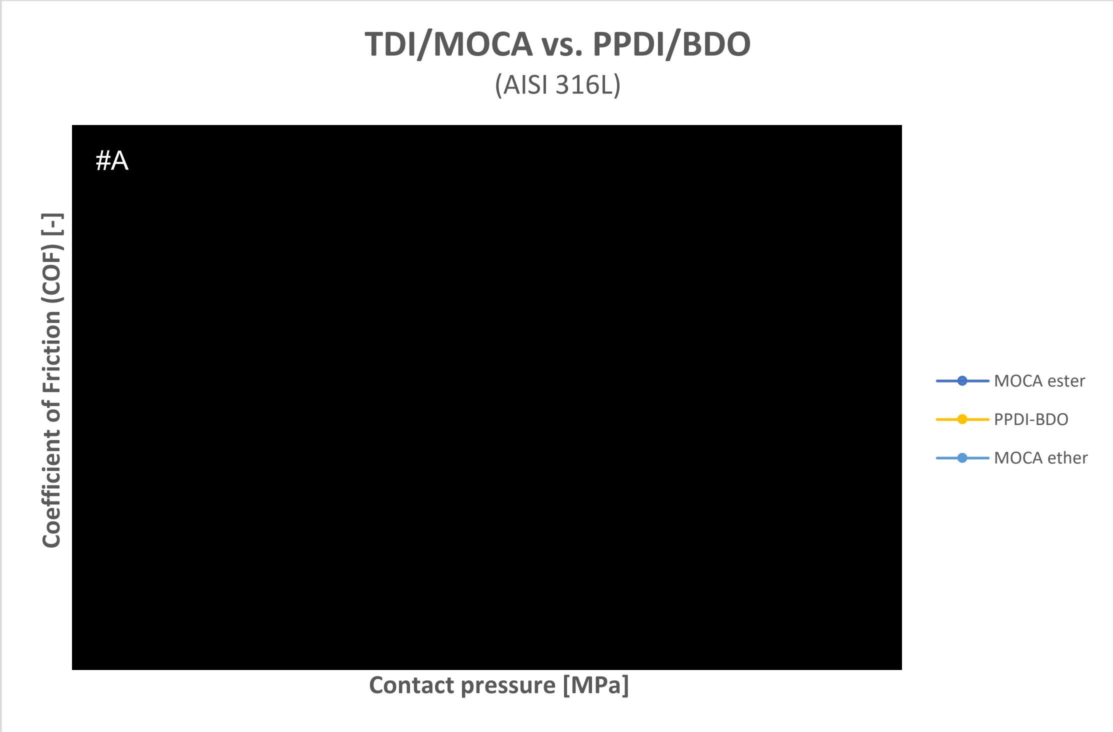


Figure 69. Results of the CoF test using stainless steel

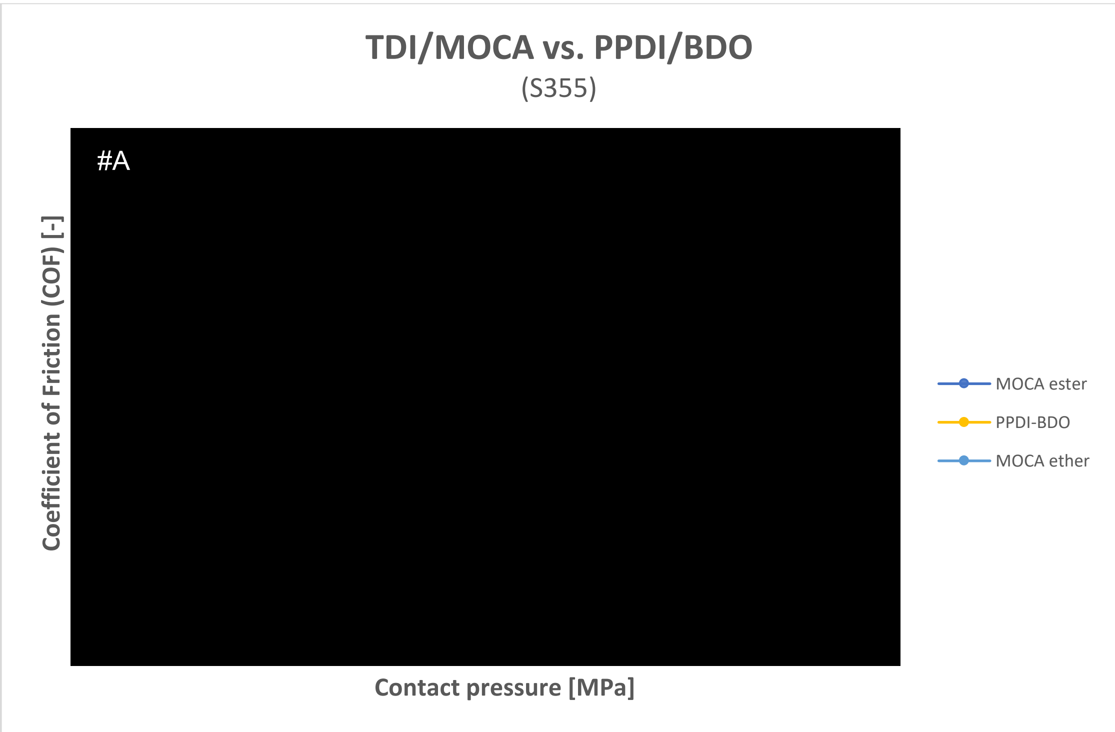


Figure 70. Results of the CoF test using steel

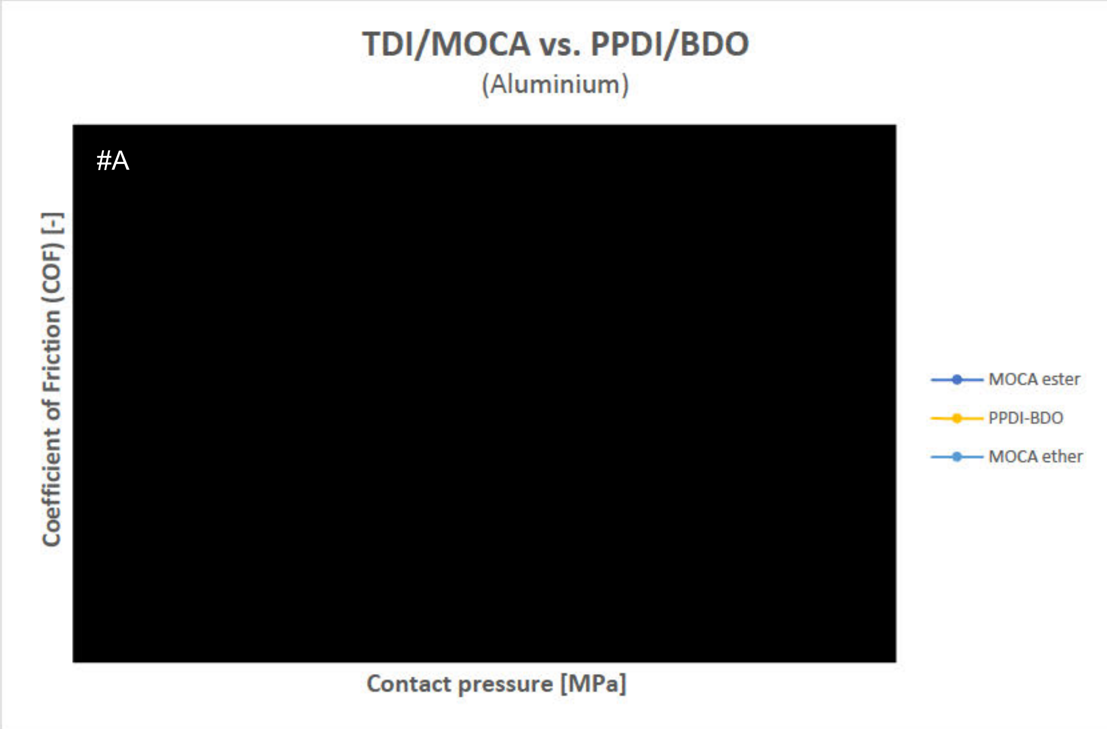


Figure 71. Results of the CoF test using aluminium

<u>Assessment of product requirements:</u>

Table 51 gives an assessment of the properties of PPDI/BDO systems against the product requirement presented in Chapter 3.1.2.3.

Table 51. Assessment of product requirements

Property	**BDO/PPDI ester**
Mechanical strength	Mechanical strength is sufficient. **Conclusion: requirement met.**
Coefficient of Friction *Not a key requirement for non-driven rollers*	CoF is too low. The driven rollers covered by Use 1 require high grip in order to function properly. **Conclusion: requirement not met for driven rollers**
Dynamic load bearing	The dynamic load bearing of PPDI/BDO PU is higher than TDI/MOCA PU. **Conclusion: requirement met.**
Fatigue	Fatigue properties are excellent. **Conclusion: requirement met.**
Cutting resistance	PPDI/BDO PU has an excellent cutting resistance (abrasion properties, toughness and tear resistance are excellent). **Conclusion: requirement met.**

Property	BDO/PPDI ester
Reliability	The parts produced with PPDI/BDO PU have higher reliability than their TDI/MOCA PU counterparts. **Conclusion: requirement met.**
Pot-life[22] and adhesion	Pot-life is insufficient. **Conclusion: the products covered by Use 1 cannot be casted.**

3.3.4.1.5. Economic feasibility of PPDI/BDO

PPDI PU systems have significantly higher raw material costs than TDI/MOCA systems. Although BDO is less expensive than MOCA, the higher price of the prepolymer still leads to an overall higher price of raw materials.

The longer curing time associated with PPDI/BDO result in higher energy costs (as high as an increase of a factor of 10). In addition, additional oven space will be needed, which is an issue as not all LUC Group facilities, including LUC UK's site, have the space to accommodate additional ovens. This would require building an extension to the existing facilities. Based on LUC Group's estimates, an extension would cost approximately 1.8 M GBP per facility.

Table 52 gives an overview of the change in costs due to the transition to PPDI/BDO.

Table 52. Qualitative assessment of the change in costs due to transition to PPDI/BDO

Aspect	PPDI/BDO vs TDI/MOCA
Raw material costs	Higher
Energy costs	Significantly higher (10 times higher than with TDI/MOCA)
Personnel costs	No change expected. LUC UK's personnel will not require additional training to use PPDI/BDO systems. The substance is in use at LUC UK.
Scrap rate	Not applicable as the rollers covered by this use cannot be casted

LUC UK has estimated the costs to implement an alternative for Use 1 products to amount to 360-416 k GBP, should a suitable alternative be found. For additional information, please see the substitution costs section and Table 59 in Chapter 4.1.3.1.

It would be impossible for LUC UK to absorb such a high material cost. The Applicant cannot increase the price of its products as they have to compete with the non-UK MOCA moulders who can still continue to place TDI/MOCA PU products on the UK market. LUC UK's customers will simply not buy the products made with alternative systems at a higher price if they can continue to buy the cheaper TDI/MOCA PU products.

[22] Not a product requirement but it is a limiting factor for the casting of products. A short pot-life will not give enough time to cast the product.

3.3.4.1.6. Suitability of PPDI/BDO for the applicant in general

PPDI/BDO cannot be considered a suitable alternative to TDI/MOCA in Use 1 products as summarised in Table 53.

Table 53. Limitations of the alternative

- PU CoF is too low for driven rollers (driven rollers will lack the necessary grip to function properly) - Pot-life is so short that the products covered by Use 1 cannot be casted - Extremely long curing times are needed with this alternative (too costly) - The higher raw material costs (PPDI) and the significantly higher energy costs increases significantly the total production costs			
Technical feasibility	Economic feasibility	Availability	Safety considerations

3.3.4.2. PPDI/HQEE

3.3.4.2.1. General description of PPDI/HQEE

HQEE is an aromatic diol that is used as a curative in the production of polyurethane. It is a solid at room temperature. Additional substance identity information is provided in Table 37.

HQEE does not have a harmonised classification however, based on the ECHA dissemination tool, the lead registrant of the substance has reported HQEE to not fulfil the criteria for classification.

Processing:

HQEE melts at approximately 99 °C but quickly crystallises if the temperature drops below its melting point. It needs to be heated to 110-120 °C and gently agitated during melting in order to ensure HQEE is homogenous before the addition of the preheated prepolymer. All transfer lines used in automatic processes should be heated to 110 °C such that HQEE does not crystallises in them, otherwise the mix ratio will be affected. Moulds should be preheated to at least 110 °C before the polyurethane mix is poured in them to avoid defects in the end products.

3.3.4.2.2. Availability of PPDI/HQEE

HQEE and PPDI are available in sufficient quantity. LUC Group has experienced issues with the quality of PPDI, although these are currently occurring less frequently. #C [redacted]

3.3.4.2.3. Safety considerations related to using PPDI/HQEE

Based on Table 37, HQEE is not classified as hazardous. Overall, using a PPDI/HQEE system instead of TDI/MOCA would lead to a reduction in risks.

3.3.4.2.4. Technical feasibility of PPDI/HQEE

The results of the tests conducted by LUC Group on PPDI/HQEE PU are presented in Table 54. PPDI/HQEE PU has lower tensile strength and tear resistance. Rebound resilience is significantly higher meaning the PU material is more bouncy.

Table 54. The test results of the comparative study between MOCA/TDI and PPDI/HQEE Pus
(#A for all redactions in the table)

			MOCA/TDI ester – [redacted] °A			PPDI-HQEE
Property	Standard	Unit	Min. Value	Typical	Max. value	Ester – [redacted] °A
Hardness (23 °C)	ISO 48-4	°A	[redacted]	[redacted]	[redacted]	[redacted]
Hardness (85 °C)	ISO 48-4	°A	[redacted]	[redacted]	[redacted]	[redacted]
Tensile strength	ISO 37[1]	Mpa	[redacted]	[redacted]	[redacted]	[redacted]
Elongation at break	ISO 37[1]	%	[redacted]	[redacted]	[redacted]	[redacted]
Tear resistance	ISO 34-1 method B, procedure b	kN/m	[redacted]	[redacted]	[redacted]	[redacted]
Rebound (23 °C)	ISO 4662	%	[redacted]	[redacted]	[redacted]	[redacted]
Rebound (85 °C)	ISO 4662	%	[redacted]	[redacted]	[redacted]	[redacted]
Abrasion	ISO 4649 method B	mm^3	[redacted]	[redacted]	[redacted]	[redacted]
Compression set						
70h/ 23 °C	ISO 815-1	%	[redacted]	[redacted]	[redacted]	[redacted]
22h/ 70 °C	ISO 815-1	%	[redacted]	[redacted]	[redacted]	[redacted]

[1] LUC Group uses 200 mm/min instead of 500 mm/min as test speed on the tensile tester.

The stress-stain curves of the tested materials are presented in Figure 72. The deflective behaviour of PPDI-HQEE PU is completely different than TDI/MOCA PU. It stretches significantly more under higher tensile stress. The toughness of Pus made with this alternative is higher than MOCA PU.

Figure 72. Stress-strain curves plotted from the results of the ISO 37 test

The load bearing capacity of PPDI/HQEE PU is comparable to MOCA/TDI ester PU as shown in Figure 73.

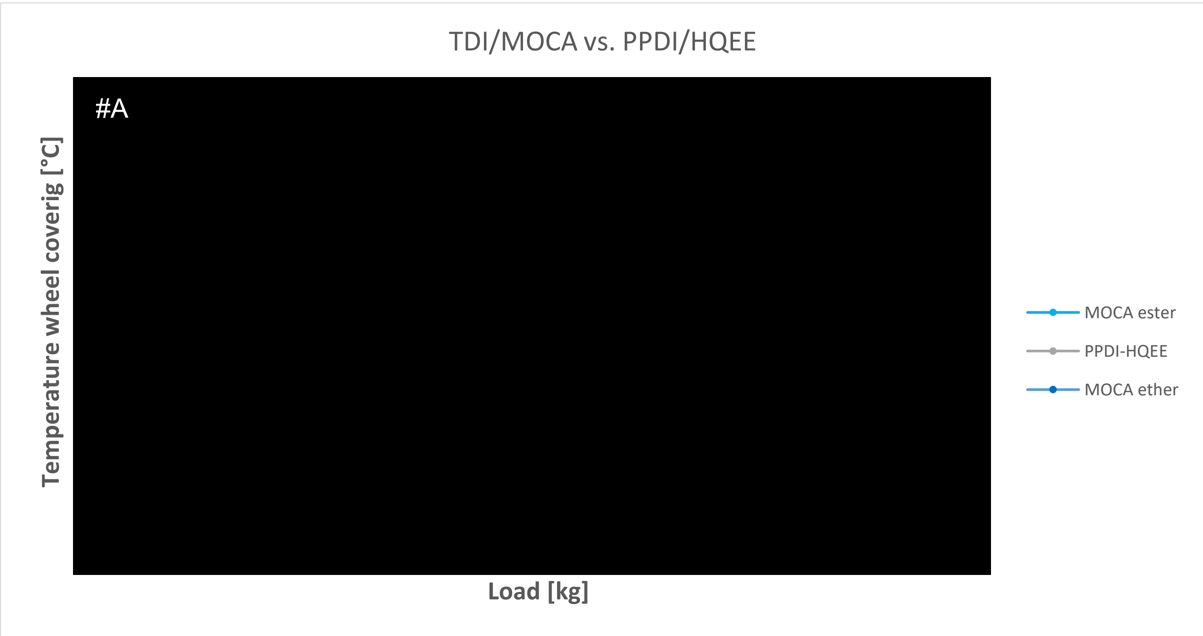


Figure 73. Test results showing the different dynamic behaviour of TDI/MOCA PU and PPDI/HQEE PU

The results of the CoF tests are presented in the next three figures. The CoF of PPDI/HQEE PU is significantly lower than TDI/MOCA PU with all three counter materials.

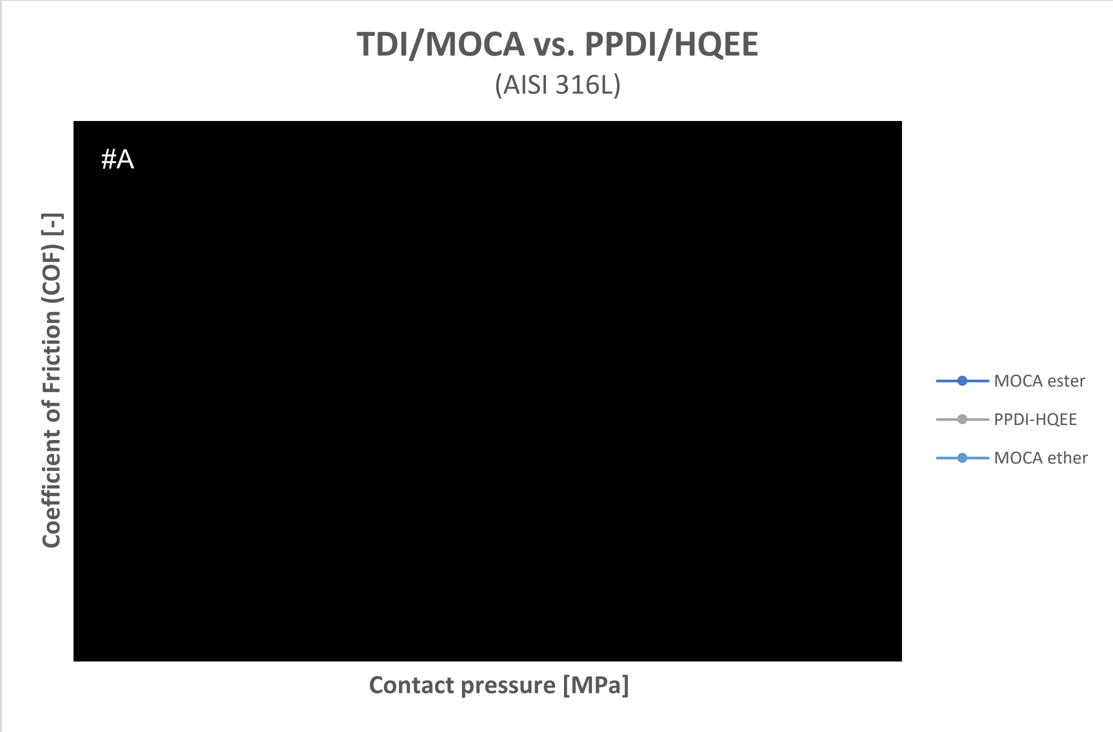


Figure 74. Results of the CoF test using stainless steel

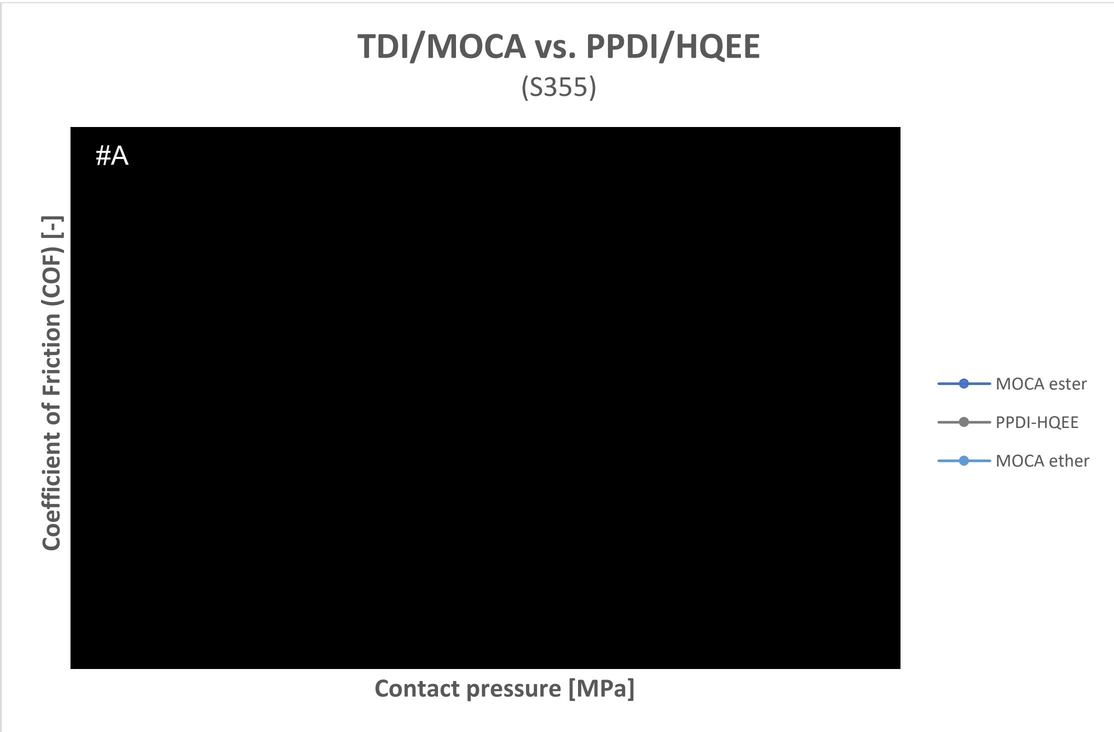


Figure 75. Results of the CoF test using steel

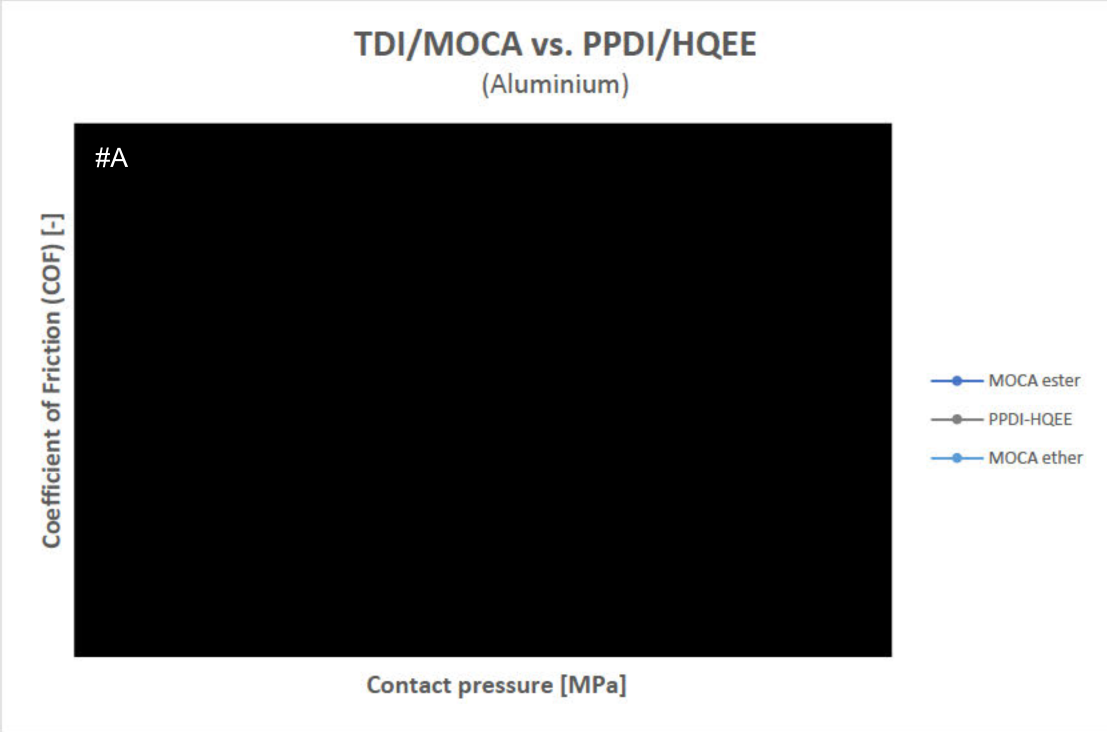


Figure 76. Results of the CoF test using aluminium

Assessment of product requirements:

PPDI/HQEE cannot be considered a suitable alternative to TDI/MOCA in Use 1 products as summarised in Table 55.

Table 55. Assessment of product requirements

Property	HQEE/PPDI ester
Mechanical strength	Tensile strength is too low. **Conclusion: requirement not met.**
Coefficient of Friction *Not a key requirement for non-driven rollers*	CoF is too low. The driven rollers covered by Use 1 require high grip in order to function properly. **Conclusion: requirement not met for driven rollers.**
Dynamic load bearing	Dynamic load bearing of PPDI/HQEE PU is comparable to TDI/MOCA PU. **Conclusion: requirement met.**
Fatigue	Fatigue properties are excellent. **Conclusion: requirement met.**
Cutting resistance	PPDI/HQEE PU has a good abrasion resistance and toughness however, it has a much lower tear resistance than TDI/MOCA PU, leading to an insufficient cutting resistance. **Conclusion: requirement not met.**

Property	HQEE/PPDI ester
Reliability	The parts produced with PPDI/HQEE PU have higher reliability than their MOCA counterparts. **Conclusion: requirement met.**
Pot-life[23] and adhesion	Pot-life is insufficient. **Conclusion: the products covered by Use 1 cannot be casted.**

3.3.4.2.5. Economic feasibility of PPDI/HQEE

PPDI/HQEE PU requires much longer curing times than TDI/MOCA. The longer curing times increases significantly the energy costs of the process (as high as an increase of a factor of 10). LUC Group would need to buy new equipment such as new ovens to implement this alternative. An extension to the current production facilities would need to be built to accommodate the new equipment. LUC Group estimates it would cost approximately 1.8 M GBP per facility.

Table 56 gives an overview of the change in costs due to the transition to PPDI/HQEE.

Table 56. Qualitative assessment of the change in costs due to transition to PPDI/HQEE

Aspect	PPDI/HQEE vs TDI/MOCA
Raw material costs	Significantly higher (both PPDI and HQEE are more expensive than TDI and MOCA, respectively)
Energy costs	Significantly higher (10 times higher than with TDI/MOCA)
Personnel costs	No change expected. LUC UK's personnel will not require additional training to use PPDI/HQEE.
Scrap rate	Not applicable as the products covered by this use cannot be casted

LUC UK has estimated the costs to implement an alternative for Use 1 products to amount to 360-416 k GBP, should a suitable alternative be found. For additional information, please see the substitution costs section and Table 59 in Chapter 4.1.3.1.

It would be impossible for LUC UK to absorb such a high material cost. The Applicant cannot increase the price of its products as they have to compete with the non-UK MOCA moulders who can still continue to place TDI/MOCA PU products on the UK market. LUC UK's customers will simply not buy the alternative products at a higher price if they can continue to buy the cheaper TDI/MOCA PU products.

[23] Not a product requirement but it is a limiting factor for the casting of products. A short pot-life will not give enough time to cast the product.

3.3.4.2.6. Suitability of PPDI/HQEE for the applicant in general

PPDI/HQEE cannot be considered a suitable alternative to TDI/MOCA in Use 1 products as summarised in Table 57.

Table 57. Limitations of the alternative

<table>
<tr><td colspan="4">- PU CoF is too low for driven rollers (driven rollers will lack the necessary grip to function properly)
- Pot-life is so short that the products covered by Use 1 cannot be casted
- Cutting resistance is too low (rollers will wear out quicker)
- Longer curing times are required with this alternative
- The higher raw material costs (PPDI and HQEE) and the significantly higher energy costs increases significantly the total production costs</td></tr>
<tr><td>Technical feasibility</td><td>Economic feasibility</td><td>Availability</td><td>Safety considerations</td></tr>
<tr><td></td><td></td><td></td><td></td></tr>
</table>

3.4. Conclusion on shortlisted alternatives

Table 58 provides a summary of the assessment of shortlisted alternatives.

Table 58. Alternative assessment summary (D = driven rollers, ND = non-driven rollers)

Requirement not met | **Fulfilment of the criteria not clear** | **Requirement met** | **Not a key requirement**

	DMTDA/ TDI ether	DMTDA/ TDI ester	Addolink® 1604/TDI ether	Addolink® 1604/TDI ester	Diamine blends	MDI systems ether	MDI systems ester	BDO/NDI ester	BDO/ PPDI ester	HQEE/ PPDI ester
Mechanical strength										
Coefficient of Friction	D / ND	D / ND	D / ND	D / ND	D / ND	D [1] / ND	D / ND	D / ND	D / ND	D / ND
Dynamic load bearing						[1]				
Fatigue						[1]				
Cutting resistance										
Reliability										
Pot-life										
Technical feasibility										
Economic feasibility										
Availability										
Safety considerations										

[1] Data not available for LFM E370/HQEE

As it can be seen from the table, the alternatives have many limitations, which make them non-suitable alternatives to the TDI/MOCA system. In some cases, it is even impossible to manufacture the rollers with the alternative PU systems due to their short pot-lives.

In terms of technical feasibility, while some PU made with alternative systems may perform as well or even better than MOCA in regards to an individual technical property but do not have the same performance for all key technical requirements for Use 1 products.

Dynamic load bearing capacity is a major issue in the alternative TDI and MDI PU systems. There are also issues with PU mechanical strength, CoF (some systems), fatigue and reliability in these systems. End-users are particularly sensitive to reductions in durability as this increase their costs (parts need to be changed or recovered more often resulting in more frequent downtimes). In addition to these, the pot-life of the TDI/DMTDA system is too low for some products covered meaning that MOCA cannot be replaced in the manufacture of these products. Furthermore, DMTDA/TDI ether PU has insufficient cutting resistance, which increases the end-users' costs due to the need of changing PU parts more frequently and the higher scrap rate due to pieces of PU falling in the productions lines and damaging the metal sheets and strips.

In contrast, PUs made with NDI and PPDI based systems have excellent load bearing capabilities but their CoFs are too low. In addition, system pot-lives are shorter thus, the rollers covered by Use 1 cannot be casted.

Availability is an issue for many of the alternatives, especially in the volumes needed by LUC Group to replace MOCA, keeping in mind that substitution related decisions are taken on a Group level. Only the PPDI- and (LF-)MDI-based systems are readily available in sufficient quantities.

In terms of economic feasibility, the implementation of alternatives would require significant investments from LUC Group (an estimated 360-416 k GBP in total). The estimate covers the purchase of new equipment and machinery (casting machines, feeders, curing ovens etc.), labour costs (R&D personnel, production workers etc.), administrative and regulatory costs. For additional information, please refer to the substitution costs section in Chapter 4.1.3.1.

The production costs of all alternatives are higher than the ones of the TDI/MOCA system. All alternatives have higher raw material costs, as high as 13 times the price of MOCA. In addition, many of the alternatives have higher energy costs and scrap rates. Economically, this is a major issue for LUC UK due to i) distortion of the market by TDI/MOCA PU products from outside the UK and ii) the lack of motivations of the end-users. Next to this the durability is very low (not sustainable).

i. As the finished PU products do not contain any MOCA, they cannot be regulated based on MOCA. Thus, non-UK moulders can continue freely to place their TDI/MOCA PU products on the UK market. LUC UK has to compete with these products both in terms of price and performance. This puts LUC UK in the vulnerable position where their customers (the end-users) may leave them for a non-UK moulder at any time. Thus, any non-MOCA PU based products LUC UK manufactures <u>must</u> perform at least as well as their TDI/MOCA PU counterparts. This means that it is essentially impossible for LUC UK to reflect the substitution costs and the higher production costs in the price of the PU made with alternative systems.

ii. LUC UK's customers are accustomed to use TDI/MOCA PU products and they have no driver to change. As demonstrated in Chapter 3.3, the PU products made with alternative systems are more expensive to produce while their performances are lower. LUC UK's customers have little motivation to pay more for a relatively non-proven PU product that potentially performs worse during end-use (over the lifetime of the article). As LUC UK's customers have no driver to transfer to non-MOCA based PU products, there is a very real risk that they prefer to stick with what they know and stay with TDI/MOCA PU products. If LUC UK's customers were in the same situation where they would also need to find alternatives, the situation would be easier in that the goal would be a common one. However, the current situation is that end-users are only concerned about price and performance.

In conclusion, in order to remain competitive, LUC UK would either need to provide an PU product made with an alternative system that perform as well as their TDI/MOCA PU counterparts for the same price or a better performing product for a higher cost. The alternatives discussed fulfil neither.

4. SOCIO-ECONOMIC ANALYSIS

4.1. Continued use scenario

4.1.1. Summary of substitution activities

As part of LUC Group, LUC UK's efforts to find a suitable replacement for MOCA in the manufacture of their PU products have been extensive. LUC Group's investigations on alternatives to MOCA started already in June 2009 and they have tested dozens of non-MOCA based curatives and polyurethane systems. LUC Group has tested like-for-like diamine alternatives, chain extender blends and non-TDI polyurethane systems.

The rejected alternative candidates along with an explanation why they were rejected are listed in Chapter 3.2.4.1. Chapter 3.2.4.2 contains the chain extenders that were used in different combination and ratios to make chain extender blends. Chain extender blends were rejected as well on the basis that the mechanical properties of the end products were lower and the reactivity of the blend was not uniform. In Chapter 3.3, the chain extenders and polyurethane systems that most closely match MOCA based PUs or the most common replacements to MOCA according to raw material manufacturers are discussed in terms of availability, safety considerations, technical feasibility and economic feasibility.

As highlighted in the alternative assessment, there is currently no suitable alternative to replace MOCA in the manufacture of LUC UK's products covered by this application. None of the chain extenders or polyurethane systems tested provide products with the same mechanical and dynamic properties, nor do the products have the same reliability. This is not acceptable for LUC UK as the products covered by this application have high reliability and technical requirements. Lower mechanical and dynamic properties may lead to failures during end-use, which can cause dramatic accidents involving personal injury and equipment damage. In addition, MOCA based PU systems have relatively short curing times compared to MOCA-free PU systems. This saves oven space and allows for higher production output and saves lots of energy (one day cure vs. 3 weeks).

It is currently uncertain when a non-MOCA chain extender that can produce a high performance and high durability polyurethane material that fulfils every key technical requirement would be available on the market. Based on the current market, it can easily take several years before a suitable alternative is available. LUC Group has therefore developed an R&D plan taking this into account.

4.1.2. Conclusion on suitability of available alternatives in general

There are currently **no suitable alternatives to MOCA** for the manufacture of the high-performance PU products covered by this use. Therefore, LUC Group will need to continue their R&D efforts to find a suitable replacement. As all the potential alternatives currently available on the market have already been tested by LUC Group, it is uncertain when a new potential alternative to MOCA for the products covered by this application can be found. LUC Group has defined an R&D plan in case a suitable alternative is found.

4.1.3. R&D plan

This chapter presents the R&D plan defined by LUC Group in case a suitable alternative to MOCA is found. As part of LUC Group, LUC UK follows this R&D plan and the substitution will be completed on a Group level. The R&D efforts are performed by LUC Group. The R&D plan is valid for both Use 1 and Use 2.

LUC Group's substitution plan consists of five phases and describe the steps LUC Group would take to replace MOCA in their processes should a viable alternative be found. A short overview of the different phases for each use is presented below.

Use 1:

- Phase 0: R&D
  - **Deliverables:** Preliminary test data and potential alternative candidate(s)
  - **Estimated duration:** Unknown
  - **Milestone:** Go/no go

- Phase 1: Upscaling from R&D scale to production scale
  - **Deliverables:** Test data and process parameters
  - **Estimated duration:** 3 years
  - **Milestone:** Go/no go

- Phase 2: Casting prototypes
  - **Deliverables:** List of potentially replaceable products
  - **Estimated duration:** 4 years
  - **Milestone:** Go/no go

- Phase 3: Verification trials with the customers
  - **Deliverables:** Customer feedback and data on the prototype's behaviour in end-applications
  - **Estimated duration:** 6.5 years
  - **Milestone:** Go/no go

- Phase 4: Debriefing
  - **Deliverables:** Final report and list of products where substitution is possible
  - **Estimated duration:** 1.5 years
  - **Milestone:** Go/no go

Use 2:

- Phase 0: R&D
  - **Deliverables:** Preliminary test data and potential alternative candidate(s)
  - **Estimated duration:** Unknown
  - **Milestone:** Go/no go

- Phase 1: Upscaling from R&D scale to production scale
  - **Deliverables:** Test data and process parameters
  - **Estimated duration:** 3 years
  - **Milestone:** Go/no go

- Phase 2: Casting prototypes
  - **Deliverables:** List of potentially replaceable products
  - **Estimated duration:** 4 years
  - **Milestone:** Go/no go

- Phase 3: Verification trials at end-users
  - **Deliverables:** Customer feedback and data on the prototype's behaviour in end-applications
  - **Estimated duration:** 8 years
  - **Milestone:** Go/no go

- Phase 4: Debriefing
  - **Deliverables:** Final report and list of products where substitution is possible
  - **Estimated duration:** 3.5 years
  - **Milestone:** Go/no go

4.1.3.1. Factors affecting substitution

Many factors affect the substitution of MOCA. They arise from the different motivations of the different actors (LUC Group, end-users and alternative providers), the diversity of sectors where PU products can be used in, the top-notch qualities of TDI/MOCA PU and the versatility of parts that can be produced with MOCA (e.g. soft and flexible seal vs. hard and tough roller).

TDI/MOCA has an established reputation: TDI/MOCA PU products are well known to LUC UK's customers as they have been using them for decades with satisfying results. TDI/MOCA PU products have an established reputation as reliable, high performance products with an excellent price/quality-ratio.

End users have no motivations to change to non-MOCA based PU products: LUC UK's customers (the end-users) are accustomed to TDI/MOCA PU products. Changing to non-MOCA based PU products would require end-users to switch to relatively untested products for installations that have long service life and where any downtime for repair, maintenance or replacement will result in lost production time. Furthermore, the current non-MOCA based PU products are more expensive to produce while their performance may be lower. As LUC UK's customers have no driver to transfer to non-MOCA based PU products, there is a very real risk that customers prefer to stick with what they know and stay with TDI/MOCA PU products. If LUC UK's customers were in the same situation where they would also need to find alternatives, the situation would be easier in that the goal would be a common one. However, the current situation is that LUC UK's customers are only concerned about price and performance.

TDI/MOCA-PU products from outside of the UK distorts the market: LUC UK's customers can easily switch to non-UK moulders. As the finished PU products do not contain any MOCA, they are not affected by the ban on MOCA thus, non-UK moulders can continue freely to place their TDI/MOCA PU products on the UK market. LUC UK has to compete with these non-UK moulders, which puts them in a vulnerable position in that at any time, LUC UK's customers may leave them for a non-UK moulder. Therefore, any non-MOCA based PU products LUC UK manufacture must perform at least as well as their TDI/MOCA PU counterparts. This also means that it is essentially impossible for LUC UK to reflect the substitution costs (estimated at 850-962 k GBP) or the higher production costs in the price of the non-MOCA based products. Even when a suitable alternative is ultimately found, LUC UK still runs the risk that their customers will not buy non-MOCA based PU products, in which case LUC UK would not get a return on their R&D investments.

TDI/MOCA is versatile: The TDI/MOCA system can be used to produce a wide variety of PU products for a high number of sectors. TDI/MOCA-polyurethanes have good all-round properties and it is unlikely that a single alternative can replace the TDI/MOCA system in all products. An alternative that works for some products may not be suitable for others. For instance, LUC Group was able to replace MOCA with an alternative ([redacted]) in 25 % of their PU product portfolio because the technical requirements for these products were less demanding. As outlined in the AoA, these alternatives were not suitable for the products covered by this application as their performances, among others, were insufficient. With some alternatives, it is even impossible to produce the products covered by this authorisation application or the alternative products do not work as intended. This brings a certain complexity to the substitution in that LUC UK will have to transfer from one TDI/MOCA polyurethane system for all the products concerned to multiple polyurethane systems, many of which require their own fixed installations.

<u>Substitution costs:</u>

LUC Group has already spent over 0.5 M GBP in R&D work to find and test potential alternative candidates in the past 12 years. They have estimated that replacing MOCA with an alternative substance, which currently is not available as none of the chain extenders present on the market are suitable to replace MOCA in the products covered by this application, would cost LUC Group another 3.4-3.8 M GBP. This is an enormous investment for a company of the size of LUC Group. To put it in context, [redacted] and represent [redacted] of their current annual turnover. LUC Group has no choice but to spread such an investment over several years, hence the long review period requested.

LUC Group's estimate is based on their long experience of manufacturing polyurethane products and their extensive R&D work on potential alternatives. The breakdowns of the estimated costs to replace MOCA in Use 1 and Use 2 products are presented in Table 59 and Table 60, respectively. The administrative & regulatory costs for Phase 2 depend on the alternatives, as explained in further details below, which is why they are in parentheses. The substitution costs are defined on Group level as the goal of the R&D plan to find a suitable replacement for MOCA is common for the entire LUC Group (4 sites).

Table 59. Estimated costs to implement an alternative for Use 1 products

	Material cost	Labour cost	Administrative & regulatory costs	Total costs
Phase 1	760 000 £	220 000 £	900 £	981 000 £
Phase 2	67 000 £	18 000 £	(220 000 £)	305 000 £
Phase 3	270 000 £	89 000 £	900 £	360 000 £
Phase 4	0 £	22 000 £	0 £	22 000 £
Total	*1 097 000 £*	*349 000 £*	*222 000 £*	*1 668 000 £*

Table 60. Estimated costs to implement an alternative for Use 2 products

	Material cost	Labour cost	Administrative & regulatory costs	Total costs
Phase 1	840 000 £	180 000 £	3 000 £	1 023 000 £
Phase 2	13 000 £	71 000 £	(220 000 £)	304 000 £
Phase 3	360 000 £	440 000 £	0 £	800 000 £
Phase 4	0 £	40 000 £	0 £	40 000 £
Total	*1 213 000 £*	*731 000 £*	*223 000 £*	*2 167 000 £*

Phase 1 costs:

Material costs: This covers the costs for new machinery and equipment such as casting machines, feeders, lifting equipment, extra casting and curing ovens, mixing chambers, pumps, heating systems, valves and sealings. Depending on the design, a casting machine by itself can cost 180 000-270 000 GBP. New equipment will need to be purchased and installed in all of LUC Group's production facilities, including the UK site.

There is a large difference in machine output between both uses (due to their large size, Use 1 products require larger amounts of PU compared to Use 2 products). This would require different machines to be purchased for Use 1 and Use 2 even if the same alternative polyurethane system would be adopted for both uses.

The costs for building an extension to the production facility or other infrastructural changes are not included here although they may be required.

Labour costs: This covers the costs for the design of the casting machine(s) and other required equipment (see previous section). It also includes the labour costs of production workers/engineers involved in the upscaling tests (for automated and semi-automated production processes) as described in Chapter 4.1.3.2.2 of this document.

It also includes the labour costs of R&D personnel that are in charge of setting-up and updating the test programs. It also covers the costs for their involvement in the testing itself and for processing test data, writing interim reports and setting-up the product overviews described in Chapter 4.1.3.2.2.

Administrative & regulatory costs: This covers administrative costs arising from, for instance, setting-up purchase orders and paying invoices.

Phase 2 costs:

Material costs:

Use 1: New steel cores (rollers are casted around steel cores) and, in some cases, new moulds must be purchased to cast prototypes. Multiple moulds are needed as multiple design of rollers (e.g. different size and shape) are used by different clients.

Use 2: Base plates (tensioner pads are casted on base plates) and new steel cores for heavy duty rollers must be purchased. In case old moulds cannot be used, new moulds will need to be designed/redesigned and purchased. Multiple moulds are needed as multiple design of the same product types are used by different clients.

For both uses: New finishing tools and grinding equipment to get similar surface finishes as with MOCA based products.

Labour costs: This includes the labour costs of all production workers involved in casting prototypes. This includes the cleaning and blasting of metal parts (substrates), the application of bonding agent to the metal parts, preparing PU, preparing and preheating the moulds, casting, demoulding and finishing of final products. This also includes the labour costs of workers involved in the preparations, which includes requesting quotes, ordering metal parts (e.g. steel cores and base plates) and designing and ordering new moulds.

An R&D team is assigned to follow the casting of prototypes in production. After prototypes are casted, they are tested by R&D personnel to determine their technical properties. For instance, tests are carried out on LUC Group's Friction Test Rig to determine friction pad behaviour. During and after testing, R&D personnel are tasked to process the test data and to write interim and final reports.

Administrative & regulatory costs: This includes UK REACH registration costs, which may be required for some alternatives. LUK UK has submitted Downstream User Import Notifications (DUIN) for some of the alternative substances.

<u>Phase 3 costs:</u>

Material costs:

<u>Use 1:</u> Steel cores for different designs of rollers need to be purchased as multiple customers will be contacted for verification trials.

<u>Use 2:</u> Steel cores and steel base plates for different designs of heavy-duty rollers and tensioner pads need to be purchased as well. For tensioner pads, multiple sets of each pad design must be casted as they are used on multiple tensioners in series. Therefore, a high number of steel base plates are needed, which is why the material costs for Phase 3 are higher for Use 2 than Use 1.

<u>For both use:</u> Besides the costs for the steel parts, also new moulds (to cover a wider variety of designs than the ones covered in Phase 2) and raw material costs are included.

Labour costs: This covers the labour costs of LUC Group's personnel making site visits at customers' facilities. It includes the time spent at customers' sites for safety/approval procedures that must be conducted before any on-site testing can start and any additional testing at LUC Group's facilities that may be required. This is particularly important for Use 2 products, which makes it a more time-consuming task. The customers have stricter safety/approval procedures for Use 2 products explaining the difference in costs between Use 1 and 2.

After approval is received from customers, LUC Group casts the required prototypes for verification trials. The labour costs thus include the costs for all production worker involved in the manufacture of the prototypes from the beginning to the end. It also includes the cleaning and blasting of metal parts, the application of bonding agent to the metal parts, preparing PU, preparing and preheating the moulds, casting, demoulding, finishing and packaging of final products.

It also covers the labour costs of workers involved in the preparations, which includes requesting quotes, ordering metal parts (e.g. steel cores and base plates) and designing and ordering new moulds. The cost of personnel involved in final inspection/quality control of casted parts is also included.

Lastly, it covers the time spent to monitor the performance of non-MOCA based products at end-users facilities by LUC Group's personnel.

Administrative & regulatory costs: None.

Phase 4 costs:

Material costs: None.

Labour costs: This includes labour costs to write final reports, set-up new PU formulations and update product information in SAP. Labour costs to inform LUC UK's production site of the new PU formulations and to give on-site trainings to production workers are also covered.

As the non-MOCA based products do not benefit from MOCA's established reputation, they need to be heavily advertised to other end-users, which is time-consuming for LUC Group. These costs have also been included in the estimate.

Administrative & regulatory costs: None.

4.1.3.2. List of actions and timetable with milestones

A detailed description of the steps LUC UK will take in case an authorisation is granted is given below. The **total time** required for substitution of MOCA is the duration of Phase 0 (unknown) and the duration of Phase 1-4 (10 years for Use 1 and 12 years for Use 2) since Phase 1 can only start once a suitable alternative is found. The phases partially overlap. The potential substitution timelines are given in Appendix 3 of this document.

LUC UK is applying for a long review period of 12 years due to the current unavailability of suitable alternatives to MOCA in the manufacture of the high-performance PU products covered by this application and the time needed to develop a working formulation for each product.

4.1.3.2.1. Phase 0: R&D

As outlined in the AoA, none of the non-MOCA chain extenders/polyurethane systems currently available on the market provide the end-products with the same mechanical and dynamic properties as MOCA and the parts are often less reliable and more expensive to produce. Therefore, none of the alternative candidates tested can be used to replace MOCA in the manufacture of the products covered by this application as the performance of alternative PU products must at least equal the performance of TDI/MOCA PU products for a similar price to be accepted by LUC UK's customers.

Consequently, LUC Group will continue their R&D efforts until a suitable alternative to MOCA is found. LUC Group will continue to consult suppliers and search literature/internet for new potential alternative candidates.

LUC Group will test any new potential alternative candidates in their facilities to determine their technical feasibility. The tests will be conducted in the same sequential manner as presented in the AoA. First, the pot-life (reactivity) and hardness of the material will be tested. In case the results are promising, preliminary tests on the mechanical properties of the material will be conducted. If successful, the coefficient of friction and dynamic behaviour of the material will then be determined in a series of tests.

Go/no-go decision: In case preliminary results are promising, the project will enter Phase 1 otherwise, the project will stay in Phase 0 and LUC Group will continue to look for and test new potential alternatives.

This phase contains the biggest unknown component of the R&D plan in terms of duration. There is currently no suitable alternative to replace MOCA in the manufacture of the products covered by this application due to the products' high reliability and performance requirements. It may take years before a new potential alternative candidate is available on the market and there is no certainty that it will be suitable to replace MOCA in the manufacture of LUC UK's products. LUC UK is dependent on alternative providers to develop new MOCA-free polyurethane systems that have the same high-end properties as the MOCA systems and have similar production costs.

4.1.3.2.2. Phase 1: Upscaling from R&D to production scale

Once a suitable replacement for MOCA is found, upscaling tests must be performed. Several hurdles are expected during upscaling tests including issues with reactivity, which may limit the product's volume that can be casted or narrow the hardness range that can be achieved. Other difficulties can for instance include issues with shrinkage or cracks.

Upscaling is needed for both automated and semi-automated casting processes although the steps to be taken differ depending on the production method.

<u>Semi-automated process:</u>

The steps needed to upscale a potential alternative in semi-automated casting are listed below including the type of personnel needed for each step:

1. Impact assessment of reactivity on higher volume products (R&D/production)
2. Adaptation/optimization of process parameters (R&D/production)
3. Determination of maximum batch volume (R&D/production)
4. Determination of hardness range that can be achieved (R&D)
5. Determination of end-products that may be reformulated (R&D/sales)

First, LUC Group will assess the impact of higher batch volumes on the reaction profile of the alternative PU system including its viscosity, reactivity and exothermicity (i.e. how much heat is released during the reaction and how does it impact the end-product for instance in terms of shrinkage and bonding). Based on the results of the tests, LUC Group may set a maximum limit to the batch volume and product size. LUC Group will also test multiple hardness systems to get an overview of the limits of semi-automated casting and set the hardness range that can be achieved with the MOCA-free system.

After the initial upscaling tests, adaptation or optimization of the process parameters is necessary. The duration of this step is strongly dependent on the outcome of the initial upscaling tests. In worst cases, this can take an additional 9-12 months. The most time-consuming task is the optimisation of the different PU systems at different hardnesses due to the large number of formulations. This step gives a first overview of the number of MOCA formulations that may be replaced with the MOCA-free system.

When upscaling, the highest possible batch volumes are desired. This is to optimise the volume output of PU in production. One large batch is preferred over multiple smaller batches. Once an overview of the maximum allowable batch volumes is available, this information is recorded for each formulation.

Lastly, lab tests are conducted on prototypes to ensure that the products' technical properties have not changed since the lab scale tests.

Go: In case of positive results, continue to the milestone and then to Phase 2.

No go: Return to Phase 0 to search for new alternatives.

<u>Automated casting process:</u>

For automated casting, the steps needed for upscaling are:

1. Designing/buying new casting machines (depends on the alternative). (R&D/process engineer)
2. Performing tests on casting machine. (production/process engineer/R&D)
3. Determination of hardness range that can be achieved (R&D)
4. Determination of end-products that may be reformulated (R&D/sales)

The first step is to determine whether new casting machines or adaptations of current casting machines are necessary. For instance, if some MOCA formulations could be replaced by an LF-MDI/HQEE system, new casting machines would need to be bought with special metering pump, mixing heads, stirrers, degassers etc. to avoid cold spots for working with HQEE. Casting machine design and adaptations need to be discussed with the casting machine supplier. Based on experience, this step typically takes at least half a year before a final decision can be made. After the order has been placed, the supplier still requires approximately 6 months to assemble the machines.

Once the casting machine is delivered to LUC UK, LUC UK needs to run tests on the casting machine. During these tests, optimum machine parameters are determined. The tests need to be repeated for each new formulation. An overview of the machine parameters to be used for each formulation is then made.

Lastly, the hardness range that can be achieved with the alternative PU system is determined and laboratory tests are conducted on the prototypes.

Go: In case of positive results, continue to the milestone and then to Phase 2.

No go: Redesign machine (start-over step 1) or continue the search for new alternatives to MOCA (Phase 0)

Milestone: After the number of MOCA formulations that may be replaced is known, an overview is made by LUC Group's R&D team in cooperation with sales to determine the number of products that may possibly be replaced with a MOCA-free polyurethane system. #A [redacted] Overall, this step is time-consuming due to the large number of end-products/applications involved.

4.1.3.2.3. Phase 2: Casting prototypes

The actions to be carried out in Phase 2 are the same for automated and semi-automated casting processes. These steps are:

1. Casting prototypes for products in both uses. (production, R&D)
2. Determining if mould redesigns are necessary. (process engineer, work preparation)
3. Testing for differences in finishing on lathes. (production, process engineer, R&D)

Based on the overview created in Phase 1, a selection of prototypes is casted. For this purpose, steel parts (substrates) are purchased and existing moulds are used. Depending on the results, LUC Group decides whether the moulds must be redesigned or not. Redesigning is necessary if, for instance, the amount of shrinkage in the PU is higher than when using the MOCA system. The redesign of moulds is done by LUC Group's work preparation and process engineers. They make the new drawings for the moulds and order the moulds as custom-made pieces from an external provider.

Finally, the finishing behaviour of the PU on lathes is checked. LUC Group checks for the difficulty of grinding, melting of PU caused by grinding, grooving, etc. If finishing is more difficult, LUC Group will design and buy new finishing tools in an aim to achieve the same quality of finishing as with TDI/MOCA polyurethane.

Besides the differences in finishing, it is also of importance to know whether it is possible to meet certain finishing criteria, like surface roughness and surface quality (air bubbles or other defects in PU). If there are issues with the finish of the PU, the alternative is abandoned and the list of products where MOCA formulations can be replaced is updated.

Milestone: An overview is made on the finishing surface criteria obtainable with the tested alternatives as well as on the differences in shrinkage per system and their impact on mould design.

Go: Continue to Phase 3.

No go: Improve finishing tooling or continue the search for new alternatives to MOCA in certain applications (Phase 0).

4.1.3.2.4. Phase 3: Verification trials at end-users

The actions in Phase 3 include:

1. Contacting/visiting customers to present substitute for MOCA. (sales)
2. Additional testing at LUC Group's/customers' laboratory for customers' specific production lines. (R&D)
3. Seeking approval from customer to perform trials in process line. (QSHE, sales)
4. Casting prototypes for customer verification trials. (work preparation, production, process engineer, R&D)
5. Reviewing product performance in customers' production line. (sales, R&D)

Based on the more refined list of products obtained in Phase 2, LUC Group's sales department contact a selection of customers. If invited by the customer, LUC Group's sales team will give a presentation to convince the customer to perform a verification trial at their site using the newly developed MOCA-free formulation.

Typically, customers also request to carry out additional tests on the new product to gather information on properties relevant for their production line or require LUC Group to conduct them. The time needed for additional testing depends on the tests however, it typically takes at least 6 months.

Verification trials in a customer’s production line cannot start before LUC Group has received the customer’s approval. To this end, LUC Group’s sales team contact the customer to inform and convince them to carry out verification trials. It is not an easy task as verification trials cause downtimes in the customers’ production lines and there are risks of malfunction. The new material must have promising technical properties, have a lower price or have other benefits in comparison to the old one for customers to agree to conduct verification trials. The customers have no interest in losing time and money in testing a new product that perform worse than the established TDI/MOCA product they are typically using.

If the customer declines the request, LUC Group will conduct additional testing in an aim to convince him/her (back to step 2 of this phase). If no agreement can be achieved, the project will be abandoned with this customer and LUC Group will contact other customers who may be interested in carrying out verification trials (back to step 1 of this phase).

If LUC Group receives the approval of the customer, LUC Group will cast prototypes to be used in the verification trials. To this end, a special order has to be made in SAP and LUC Group will request quotes for the steel parts (substrates). The parts will be ordered once the quotes are approved. Typically, the delivery of steel parts takes 3-5 months after which, it takes LUC Group 1-2 months to make the prototypes (including cast, cure and finishing of PU layer).

LUC Group closely collaborates with the client during verification trials. LUC Group’s engineers regularly visit the customer’s site to monitor the condition of the polyurethane such that defects are discovered quickly. Verification trials typically last multiple years such that the durability of the new polyurethane can be assessed as well as the material’s behaviour throughout its lifetime can be monitored.

Milestone: Get approval from/convince customer to start a verification trial at their site.

Go: Product did not fail the verification trials at end-user sites. Continue to Phase 4.

No go: If the product performed significantly less or even worse than the MOCA PU product or if it shown failure during verification trials: LUC Group will continue the search for a new alternative to MOCA (Phase 0).

4.1.3.2.5. Phase 4: Debriefing

1. Reviewing results with customer. (sales)
2. Writing final report. (R&D)
3. Seeking final approval from customer. (customer)
4. Customer to update documentation internally. (customer)

After completion of the verification trials, LUC Group’s Sales team will discuss the results with the customer. During this discussion, the new PU system will be compared to the MOCA PU system. LUC Group questions the customer about the differences in behaviour between the TDI/MOCA PU and the MOCA-free PU and whether the customer had to adapt their process parameters to implement the MOCA-free PU part. If the customer is not satisfied with the results, LUC Group will need to start the entire process again, starting from Phase 0.

LUC Group's R&D team will record data gathered from the verification trials and customer feedback in a final report. This data will be used in the development of new PU material.

Before the new product can be officially implemented at a customer's site, the customer must give their approval. Depending on the customer's approval process, this can take several months. For Use 2 products, this step typically takes longer as the end-users have much stricter safety processes and more complex approval processes in place.

After approval of the product, LUC UK's customers need to update their internal documentation (i.e. technical drawings, work instruction). The product is then implemented.

Milestone: A MOCA based product is replaced with a MOCA-free alternative.

Go: The new MOCA-free product is adopted by LUC UK's customer

No go: The customer does not give their approval to take the new product into use at their site. LUC Group must continue their search for a new alternative (Phase 0)

It should be noted that the reformulation of a product may fail at any phase of the substitution work. A material that provides good results at R&D scale may not work in industrial scale production. The verification trials may be unsuccessful, or the customer may decide to keep using the TDI/MOCA PU product regardless of how the alternative product performs.

Overall, the substitution of MOCA is a time-consuming task, hence the long review period requested by LUC UK. Firstly, there are no suitable alternatives to LUC UK's high performance PU product currently available on the market. It may take several years before one is available. Secondly, the substitution work itself is time-consuming due to the number of steps and the need for engagement and buy-in from customers. Time is required to find the correct formulation and operating parameters with the alternative system. This necessarily involves a lot of trial and error. Prototypes go through a long series of tests in laboratory settings and then on-site at end-users facilities. Years of testing are required for verification trials as the durability of products must be demonstrated in end-use. The products covered with this application are high durability products, which must last for several years during end-use.

4.1.3.3. Monitoring of the implementation of the R&D plan

All LUC Group facilities have an ISO 9001 Quality Management System (QMS) in place. This means that the execution of the R&D plan as well as the related monitoring and documentation will all be done according to LUC Group's QMS. LUC Group's project flowchart for R&D projects such as the substitution of MOCA is presented in Appendix 4 of this document.

LUC Group has assigned a project manager (the R&D manager) and an interdisciplinary core project team to work on the substitution. The team consist of R&D personnel, various engineers (work preparation, production and process engineers), sales and production personnel.

As described in the previous section, at the end of each phase of the substitution project, there is a decision gate. At this point, LUC Group's project manager assess whether the phase's deliverables have been successfully completed. A go/no-go decision is then taken and the project either advances to the next phase or an earlier step is repeated.

The progress and results obtained during each phase are recorded in a report, which is then presented to the project manager. The project manager also monitors the status of milestones on a regular basis through meetings organised with the core project team. In case of issues blocking the project, ad-hoc meetings are organised to solve the issue.

4.1.3.4. Conclusions

LUC UK faces many hurdles with the substitution of MOCA. First, the established track record of TDI/MOCA for the manufacture of high performance and high reliability PU material and having an excellent price/quality ratio makes the end-users unwilling to try other PU material. In addition to the "why change something that works"-mindset displayed by end users, replacing a MOCA cured PU product with an alternative would require end-users to take into use relatively untested products for installations that have long service life and where any downtime for repair, maintenance or replacement will result in lost production time, which is extremely unattractive for end-users.

Second, the TDI/MOCA PU products manufactured outside of the UK are a serious threat for LUC UK and their substitution efforts. As the finished polyurethane products do not contain any MOCA (it is fully consumed during the reaction), TDI/MOCA PU products cannot be regulated based on MOCA content and thus, can be freely imported to the UK. This effectively distorts the UK PU market. UK moulders, such as LUC UK, cannot produce TDI/MOCA PU products without an authorisation however, TDI/MOCA PU products are still readily available to end-users for purchase through non-UK moulders placing them on the UK market. Thus, LUC UK has to compete with non-UK moulders for market. This puts LUC UK in an extremely vulnerable position where LUC UK's customers may leave them for a non-UK moulder. As LUC UK's customers have no driver to transfer to non-MOCA based PU products, there is a very real risk that end-users prefer to stick with what they know and stay with MOCA-TDI PU products. Please also see Chapter 4.3 for a description of the non-use scenario in case of a refused authorisation for LUC UK.

This situation set prerequisites to the substitution of MOCA as LUC UK's end-users need to have an incentive to change to non-MOCA cured PU products. In order to remain competitive, LUC UK would either need to provide an alternative PU product performing as well as their MOCA counterparts for the same price or a better performing PU product for a higher price. As outlined in the AoA-SEA reports, none of the alternatives currently available on the market fulfil either of these requirements for the high-performance PU products covered by this application. Thus, LUC Group is continuing their search for alternatives to MOCA, which they started already more than 12 years ago. In this endeavour, LUC UK is fully dependent on alternative providers to develop new polyurethane systems.

4.2. Risks associated with continued use

4.2.1. Impacts on humans

An entry for MOCA was included on Annex XIV of the REACH Regulation due to its intrinsic properties as a carcinogen (Carc.1B). As per Art 62(4)(d), an application for authorisation solely needs to consider those potential risks coming from the intrinsic properties given in the entry. Lung cancer due to the dermal route of exposure is the dominant health impact coming from its classification as a carcinogen. Accordingly, this application only considers potential human health impacts and does not consider potential environmental impacts. However, as humans may be exposed via the environment, this is considered in the assessment.

Worker exposure

The WCSs related to worker exposure are outlined in Table 61.

Table 61. Worker contribution scenarios related tasks

Worker Contributing Scenario (WCS)	Task
1	Delivery and storage of MOCA
2	Transfer of MOCA to MOCA Feeding Unit (glovebox & melter)
3	Automated process
4	Semi-automated process
5	Transferring liquid polyurethane to moulds
6	Maintenance & cleaning
7	Waste management

As outlined in Chapter 9.0 in the CSR, biomonitoring measures overall exposure by all routes of exposure (inhalation, dermal, oral). The ECHA Risk Assessment Committee estimated cancer risks for different urinary MOCA levels measured as total urinary MOCA in samples collected at the end of work-shift at end of a working week. Values < 0.5 µmol MOCA/mol creatinine are considered to be the reference values for a non-exposed population and comes from the LoD of modern analytical methods. 5 µmol MOCA/mol creatinine is the limit value for compliance with the bOELV. The current guidance value in the UK is 15 µmol MOCA/mol creatinine. The cancer risks for these limits are given in RAC/32/2015/10 rev 1

- 5 µmol MOCA/mol creatinine in a Friday afternoon sample (corresponding to a daily dose of 17 µg) corresponds to a risk of 1.64E-05
- 0.5 µmol MOCA/mol creatinine (detection limit of current analytical techniques) corresponds to cancer risk of 1.64E-06

All urine samples at the LUC UK site gave values below the LoD and therefore this value is used for quantifying the excess risk value.

Table 62. Combined exposure and risk characterisation for workers

WCS	Cancer risk type	Route of exposure	Directly exposed workers	Urinary value for MOCA	Excess risk	Estimated statistical cancer cases (time adjusted for 12 years)
1-7	Lung	All	4	< 0.5 µmol MOCA/mol creatinine	< 1.64E-06	< 1.97E-06

Man via environment exposure

For the general population, exposure is possible through the "man via environment" route. This includes inhalation exposure to MOCA and oral exposure to MOCA via the food consumption which are taken into account in the risk estimation. Exposure was estimated with EUSES based on emission monitoring data to air. Chapter 9.3 and Chapter 10.2 in the CSR summarise the predicted exposure concentrations by the two routes of exposure to humans via the environment for the local and regional populations respectively. Table 63 presents the exposure, risk values and estimated statistical cancer cases for the general population via the environment. The general population is divided between local and regional populations to cover all possibly exposed people.

Table 63. Exposure and excess risk to general population

Parameter	Exposure	Group exposed	Excess cancer risk*	Estimated statistical cancer cases (time adjusted for 12 years)
Local				
Human via environment – inhalation	Local PEC: 1.46E-04 µgCr(VI)/m³	Local population (10,000 persons):	7.87E-09	3.04E-07
Human via environment – oral	Local daily dose = 1.63E-04 µg/kg bw/day	Local population (10,000 persons):	1.54E-08	5.90E-07
Regional				
Human via environment – inhalation	PECair, regional = 8.96E-09 µgCr(VI)/m³	Regional population (20,000,000):	4.89E-13	1.67E-06
Human via environment – oral	Regional daily dose = 2.71E-08 µgCr(VI)/m³	Regional population (20,000,000):	2.57E-12	8.76E-06

* Applying the population excess lifetime lung cancer mortality risk for the general population exposed to 70 years (24h/day, 7 days/week)

4.2.1.1. Number of people exposed

Worker

Worker exposure is considered for direct exposure. LUC UK has 4 workers which are directly exposed. The rest of the LUC UK staff (9 people) are indirectly exposed workers and are included in the local people exposure assessment.

Local people exposure

The general people exposure is the most relevant to the local inhabitants nearby LUC UK's site and the indirectly exposed workers who are included in this group. The local people exposure is considered for 10,000 people as a default number in the ECHA Guidance R.16 (ECHA) recommended as the basis of the local exposure assessment. The wide range of population is a conservative approach.

Regional people exposure

Regional people exposure is considered for 20,000,000 people as a default number recommended in the ECHA Guidance R.16 (ECHA) as the basis of the regional exposure assessment. The wide range of population is a conservative approach.

4.2.2. Impacts on environmental compartments

Environmental impacts are not relevant for the proposed identification of the substance as an SVHC in accordance with article 57 (a & b).

4.2.3. Compilation of human health and environmental impacts

Monetised human health impacts are assessed for regional population, local population and workers for the 12-year period from 2022 to 2033 and also average per year.

As outlined above, exposure to the general population is estimated based on modelled data and worker risk level is based on measured occupational exposure data and modelled data. The risk to human health is low due to both the low exposure concentration and the low number of directly exposed workers.

The monetisation of cancer cases is assessed for fatal and non-fatal cases. It is assumed that 80 % of the cases are fatal. Fatal cancer assessment takes into account value of statistical life (VSL) and value of cancer morbidity as explained in guidance document[24]. Non-fatal assessment takes only value of cancer morbidity into account.[25]

Fatal cancer cases

The monetisation of fatal human health impacts for workers, local and general population in the continued for use scenario, and value per statistical cancer case for lower and upper bound[26], is outlined in Table 63. To avoid underestimation due to inflation, lower and upper

[24] https://echa.europa.eu/documents/10162/13630/echa_review_wtp_en.pdf/dfc3f035-7aa8-4c7b-90ad-4f7d01b6e0bc

[25] Value of cancer case = Discount factor x (fatality probability x VSL + value of cancer morbidity)

[26] ECHA, 2016a

values of cancer cases (lung cancer: 2.0 and 3.2 M GBP)[27] have been adjusted to 2021 price level with price adjuster of 1.093 (HICP index)[28].

Table 64. Summary of monetised fatal health impacts

FATAL	2021 price level Lower bound	2021 price level Higher bound	Higher bound per year
Worker			
Direct exposure	4 £	7 £	1 £
Indirect exposure	-	-	-
Total workers	4 £	7 £	1 £
General population[29]			
Local exposure, inhalation + oral	85 £	140 £	12 £
Regional exposure, inhalation + oral	22 £	36 £	3 £
Total general population	108 £	176 £	15 £
Total exposure (worker + local + regional)	112 £	183 £	16 £
Latency		Estimated statistical cancer cases are formed from excess cancer risks which are derived based on the assumption of the continued exposure of 40 year working life (8 h/day, 5 days/week) for workers, and an exposure for 70 years (24 h/day, every day) for the general population. The temporal scope of the current use for the non-use scenario is 12 years, so an exposure time-based correction shall be applied (12/40 for workers and 12/70 for the general population). In the value of cancer case calculations for lung cancer latency of 10 years was used.	

The fatal cancer risk value coming from LUC UK's use (worker + local + regional) in 2021 price level is 159pprox.. 0.0001 M GBP based on the lower value and 0.0002 M GBP based on the higher value with the maximum forecasted tonnage. The average per year for the higher bound is 0.000016 M GBP (16 GBP).

Non-fatal cancer cases

The monetisation of non-fatal human health impacts for workers, local and general population in the continued for use scenario, and value per statistical cancer case for lower

[27] EUR Values provided by ECHA have been converted to GBP with a rate of 0.8889 (2021; https://www.ons.gov.uk/economy/nationalaccounts/balanceofpayments/timeseries/thap/diop)

[28] https://ec.europa.eu/eurostat/web/hicp/data/database?p_p_id=NavTreeportletprod_WAR_Nav 2015: 100, 2020: 109.28. Price adjuster: 109.28 / 100 = 1.093

[29] Inhalation and oral cases have been costed with different multiplier (See Table 63). Here the costs are summed for simplicity to present total exposure to local and regional population.

and upper bound[30], is outlined in Table 65. To avoid underestimation due to inflation, lower and upper values of cancer cases (lung cancer: 0.25 and 0.30 M GBP)[27] have been adjusted to 2021 price level with price adjuster of 1.093 (HICP index)[31].

Table 65. Summary of monetised non-fatal health impacts

NON-FATAL	2021 price level Lower bound	2021 price level Higher bound	Higher bound per year
Worker			
Direct exposure	0.5 £	0.7 £	0.1 £
Indirect exposure	-	-	-
Total workers	0.5 £	0.7 £	0.1 £
General population[32]			
Local exposure, inhalation + oral	10.9 £	13.2 £	1.1 £
Regional exposure, inhalation + oral	2.8 £	3.4 £	0.3 £
Total general population	13.7 £	16.6 £	1.4 £
Total exposure (worker + local + regional)	14.2 £	17.3 £	1.4 £
Latency		Estimated statistical cancer cases are formed from excess cancer risks which are derived based on the assumption of the continued exposure of 40 year working life (8 h/day, 5 days/week) for workers, and an exposure for 70 years (24 h/day, every day) for the general population. The temporal scope of the current use for the non-use scenario is 12 years, so an exposure time-based correction shall be applied (12/40 for workers and 12/70 for the general population). In the value of cancer case calculations for lung cancer latency of 10 years was used.	

Non-fatal cancer risk value of LUC UK's use (worker + local + regional) in 2021 price level is approx. 0.000014 M GBP (14 GBP) based on the lower value and 0.000017 M GBP (17 GBP) based on the higher value with the maximum forecasted tonnage. The average per year for the higher bound is 0.000001 M GBP (1 GBP).

Sum of fatal and non-fatal cancer cases

The above monetised fatal and non-fatal cancer values are summed in Table 66. This represents the entire value of the cancer risk from LUC UK's use.

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[30] ECHA, 2016a

[31] https://ec.europa.eu/eurostat/web/hicp/data/database?p_p_id=NavTreeportletprod_WAR_Nav
2015: 100, 2020: 109.28. Price adjuster: 109.28 / 100 = 1.093

[32] Inhalation and oral cases have been costed with different multiplier (See Table 63). Here the costs are summed for simplicity to present total exposure to local and regional population.

Table 66. Summary of monetised health impacts

FATAL & NON-FATAL	2021 price level Lower bound	2021 price level Higher bound	Higher bound per year
Worker			
Direct exposure	5 £	8 £	1 £
Indirect exposure	-	-	-
Total workers	5 £	8 £	1 £
General population[33]			
Local exposure, inhalation + oral	96 £	153 £	13 £
Regional exposure, inhalation + oral	25 £	40 £	3 £
Total general population	121 £	193 £	16 £
Total exposure (worker + local + regional)	126 £	200 £	17 £
Latency		Estimated statistical cancer cases are formed from excess cancer risks which are derived based on the assumption of the continued exposure of 40 year working life (8 h/day, 5 days/week) for workers, and an exposure for 70 years (24 h/day, every day) for the general population. The temporal scope of the current use for the non-use scenario is 12 years, so an exposure time-based correction shall be applied (12/40 for workers and 12/70 for the general population). In the value of cancer case calculations for lung cancer latency of 10 years was used.	

The sum of fatal and non-fatal cancer risk value of LUC UK's use (worker + local + regional) in 2021 price level is approx. 0.00013 M GBP based on the lower value and 0.00020 M GBP based on the higher value with the maximum forecasted tonnage. The average per year for the higher bound is 0.000017 M GBP (17 GBP).

Monetised cancer risk related to Use 1:

68 % * 0.000017 M GBP per year = 0.000012 M GBP (12 GBP) per year

This figure is taken forward to the comparison of benefits and risks.

4.3. Non-use scenario

By the time the extended sunset date for MOCA under UK REACH expires on 30th of June 2022, a suitable alternative will not be available for the manufacture of the high-performance PU products covered by this use. As a consequence, LUC UK is not able to continue manufacturing of these high-performance PU products and will lose the related revenue (#B [redacted]). In this situation, LUC UK is not profitable anymore. When LUC UK loses

[33] Inhalation and oral cases have been costed with different multiplier (See Table 63). Here the costs are summed for simplicity to present total exposure to local and regional population.

its profitability, it is not valuable to LUC Group anymore. LUC Group would relocate the entire UK production to its other facilities and close the LUC UK facility. As LUC Group's EU REACH authorisation application for MOCA is in a process of being approved, LUC Group would produce the high-performance PU products for the UK market in its facilities in the EU and import the products to the UK market. As the finished PU products do not contain any MOCA, they are not affected by authorisation thus, non-UK moulders can continue freely to place their TDI/MOCA PU products on the UK market.

It can be concluded that in case of a refused authorisation, LUC UK's use would be taken up by market actors using the same substance operating outside the UK.

4.3.1. Summary of consequences of non-use

Supplier of MOCA

Impacts of the non-use scenario on the MOCA supplier are negligible since they will continue supplying LUC Group, only to different location.

LUC UK

As mentioned, the most likely non-use scenario for LUC UK is ceasing of activities and business closure. This will result in producer surplus losses in the UK and costs related to the decommissioning of the UK facility. These negative economic impacts of the non-use scenario are monetised in Chapter 4.4.1.

In addition, the non-use scenario results in societal cost to the UK as LUC UK's 13 employees would lose their jobs. This cost is monetised in Chapter 4.4.4.

End-users

Similarly to the MOCA supplier, the end-users of high-performance PU products in the UK will not be significantly impacted. They will continue purchasing the products from LUC Group, produced in and imported from the EU. However, the price of the products will increase due to an additional cost related to shipping. Global PU market is very competitive, therefore it is possible that some of the end-users could change to another TDI/MOCA producer due to the price increase.

4.3.2. Identification of plausible non-use scenarios

In addition to the business closure, LUC UK has identified 2 other non-use scenarios. These are

- Using alternative curing agent
- Continue other PU production

The plausibility of the non-use scenarios for LUC UK is analysed in Table 67 below. The table outlines the analysed non-use scenarios with plausibility factor.

Table 67. Plausibility of non-use scenarios for LUC UK

Non-use scenario
Non-use scenario 1. Business closure Losing the MOCA related high-performance PU product business ([redacted] #B) makes LUC UK unprofitable and strategically unimportant for LUC Group As a consequence LUC Group will close its UK operations. **Plausible**
Non-use scenario 2. Using alternative curing agent There are currently no suitable alternatives to MOCA for the manufacture of the high-performance PU products covered by this use. Therefore, LUC Group will need to continue their R&D (research and development) efforts to identify a suitable alternative that can give PU products with equivalent proven performance that customers in these sectors trust in their harsh environment activities and installations. For example, sustainability and durability are key characteristics that alternatives must deliver to be considered suitable for the PU products covered by this application. The possible substitution away from MOCA will require at least 12 years. **Not plausible**
Non-use scenario 3. Continue other PU production in the UK For LUC Group it is not economical and sustainable to maintain a facility in the UK when the facility can no longer produce the products which are strategically predominant for the market penetration. LUC Group can relatively ease relocate the entire production of the UK facility to its facilities in the EU. **Not plausible**

The most likely non-use scenario for LUC UK is business closure. This scenario is analysed and quantified in the next chapters where the impacts of the scenario are outlined.

4.3.3. Conclusion on the most likely non-use scenario

The most likely non-use scenario can be concluded as follows:

- LUC UK will be closed, and its production relocated to LUC Group's facilities in the EU
- Chemical supplier will continue supplying LUC Group
- The UK end-users continue supplying from LUC Group

The use would be taken up by market actors operating outside the UK.

4.4. Societal costs associated with non-use

4.4.1. Economic impacts on LUC UK

The main economic impacts of the non-use scenario on LUC UK are

- producer surplus – profit foregone in the UK
- decommissioning cost of the site

Producer surplus - Profit foregone

Producer surplus represents the gain to trade a producer receives from the supply of goods or services less the cost of producing the output (i.e. the margin on additional sales). In the event of a refusal of authorisation to use an Annex XIV substance, there are expected to be negative impacts on producer surplus at those firms facing regulatory action (which may be partially offset by positive impacts on other firms). The loss of producer surplus at an affected firm can be estimated by an evaluation of foregone profits at the firm. The loss of profits arises from the premature retirement of productive tangible or intangible assets, the value of which should be equivalent to the discounted stream of future profits over the remaining life of the assets, minus any value recouped from the sale, scrappage or redeployment of existing capital assets (tangible or intangible). The cost of those capital assets is considered sunk at the point of retirement, such that only future returns (rather than costs) are foregone when the asset is retired. For no-SAGA cases, SEAC recommends using 4 years of profit losses.

In the non-use scenario, LUC UK must stop its operations and close the business. Consequently, the related profit is lost. The profit lost due to business closure is the profit foregone used in the calculation for producer surplus loss in the UK. The gross profit margin reported here is from LUC UK's internal financial reporting and comes from subtracting the production cost from the revenue.

In 2020, LUC UK recorded a revenue of [1-2] #B M GBP with 7 % profit margin. As mentioned in Chapter 3.1.3.2, LUC UK expects an annual growth rate of [8–16] #B % for its revenue in the foreseen future. 2020 figures and the growth rate, together with a discount rate of 4 % are used as a basis for the calculation of the no-SAGA producer surplus loss for 4 years, 2022-2025. 2021 is the base year for discounting. The results of the calculation are outlined in Table 68.

Table 68. Profit foregone in 2022-2025

Profit foregone (4 year period)		**Base year: 2021**	**Sum of 4 year period 2022-2025**	**Average of 2022-2025**
Annual growth rate	[8-16] #B %			
Discount factor	4 %			
Discounted annual gross profit (with 7 % margin)* *Rounded to one decimal		0.1 M GBP	0.7 M GBP	0.2 M GBP

The total discounted (net present value) profit foregone in the UK due to LUC UK's business closure is 0.7 M GBP. This value represents the negative producer surplus in the UK if authorisation was not granted.

Decommissioning cost

In the non-use scenario, LUC UK must decommission its facility in Dowlais. LUC UK estimates that the facility has no residual value since it would be difficult to sell a plant optimised for MOCA and other PU manufacture for other activities. It is also reasonable to assume that the benefit from the possible selling is not substantial in any case.

LUC UK estimates that the total decommissioning costs reach 0.7 M GBP. The cost is comprised of disposal of the equipment such as blasting cabinet, spray cabinet bonding agent, ovens, casting machine, lathes, vulcaniser, LEV + Filterbox, MOCA Feeder, grinding machine, moulds, heating and cooling systems, tooling; and cleaning of work surfaces and of the land area. It may be possible to use some of the equipment and machinery as spare parts in other LUC Group facilities.

Present value, with 4 % discount rate and 12-year period, of this cost is 0.44 M GBP[34]. Annualised it is 0.44 M GBP / 12 = 0.04 M GBP.

Summary of monetised impacts on LUC UK

The total negative economic impact on LUC UK is summarised in Table 69.

Table 69. Economic impact on LUC UK

Cost item	Over period	Annualised / Average
Producer surplus lost in the UK	0.7 M GBP over 4 years	0.2 M GBP per annum
Decommissioning cost	0.44 M GBP over 12 years	0.04 M GBP per annum

As mentioned, 68 % of the revenue is allocated for Use 1. As a consequence, 68 % of the impacts is allocated for Use 1. The total negative economic impact on LUC UK for Use 1 is summarised in Table 70.

Table 70. Economic impact on LUC UK for Use 1

Cost item	Over period	Annualised / Average
Producer surplus lost in the UK	0.44 M GBP over 4 years	0.11 M GBP per annum
Decommissioning cost	0.30 M GBP over 12 years	0.02 M GBP per annum

4.4.2. Economic impacts on the supply chain

Economic impacts of the non-use scenario on the MOCA supplier are negligible since they will continue supplying LUC Group, only to different location. Also, LUC Group's customers in the UK are not impacted since they will continue purchasing the products from LUC Group.

4.4.3. Economic impacts on competitors

High-performance PU products cured with MOCA are still required by the end-use industries, and as concluded in Chapter 4.1.2 there are no suitable alternatives generally available (no-SAGA) for the use applied for. In the non-use scenario LUC UK cannot use MOCA in the UK. This gives an advantage for those manufacturers who can use MOCA.

The impact is already accounted for in the producer surplus loss in Chapter 4.4.1.

[34] PV = C / (1+r)^n

PV = Present Value
C = Cash Flow at a period
n = number of periods
r = rate of return

4.4.4. Wider socio-economic impacts

Quantified social impacts

LUC UK employs 13 people in the Dowlais facility. In the non-use scenario, these jobs will be lost. Annual gross salary including taxes and social security payments of these jobs is outlined in Table 71.

In the following calculation, the scope is the UK. A guidance provided by ECHA[35] notes that tax rate of the country, average salary and default value for job lost should be taken into account when calculating the social impacts.

The total costs of social impacts are calculated with formula provided by ECHA:

$$Social\ impact = jobs\ lost * average\ annual\ salary * (1 - employer\ tax\ rate) * \\ * default\ value\ for\ one\ job\ lost$$

As mentioned, 68 % of the revenue is allocated for Use 1. As a consequence, 68 % of the social impacts is allocated for Use 1.

The societal impacts for LUC UK are summarised in Table 71.

Table 71. Monetised societal cost

LUC UK	Value				
Region	Merthyr Tydfil, UK				
Default value for one job lost	2.09				
Employer tax rate	11 %				
Job related variables	Type	Average annual gross salary	Lost jobs	Total societal cost[36]	Annualised societal cost[36]
	All workers (including production and office)	27,000 GBP	13	0.7 M GBP	0.05 GBP
Use 1: Total societal cost	0.44 M GBP				
Use 1: Annualised societal cost	0.04 M GBP				

The negative social impacts of a refused authorisation for Use 1 are approx. 0.44 M GBP for the society in the UK. Annualised to the review period applied for (12 years), this equals to approx. 0.04 M GBP.

[35] ECHA, 2016b

[36] Calculated: annual salary * (1- tax rate of the UK) * number of lost jobs * 2.09 = total societal cost
Annualised societal cost = total societal cost / review period applied for

Corporate tax loss

LUC UK is subject to UK corporation tax on its income and capital profits. This assessment is focused on income profits and the same timeframe than the producer's surplus assessment, 4 years. The rate of corporation tax is currently 19 %. Total discounted profit for the period is 0.7 M GBP (Table 68). Tax, 19 %, on the profit is 0.133 M GBP. Tax per year is 0.03 M GBP. This represents annual tax loss to the UK society.

68 % of the four-year tax loss is allocated to Use 1: 68 % * 0.133 M GBP = 0.09 M GBP. 68 % of the annual tax loss is allocated to Use 1: 68 % * 0.03 M GBP = 0.02 M GBP.

Wider economic impacts

Wider economic impacts include macro-economic features related to the international trade and competition. In this scale, impacts of business discontinuation of one SME company, like LUC UK, are negligible and doesn't affect the wider economy on the UK level in a stand-alone assessment. However, in case of non-authorisation yet another UK business is moving to the mainland Europe. Money flows and trade balance will consequently be swift in favour of the EU.

4.4.5. Compilation of socio-economic impacts

Societal costs associated with the non-use for Use 1 are outlined in Table 72.

Table 72. Societal costs associated with non-use for Use 1

Description of major impacts	**Monetised impacts**	
1. Monetised impacts	**Over period**	**Annualised / Average**
Producer surplus loss due to ceasing the use applied for in the UK	0.44 M GBP over 4 years	0.11 M GBP per year
Decommissioning cost	0.30 M GBP over 12 years	0.02 M GBP per year
Social cost of unemployment	0.44 M GBP over 12 years	0.04 M GBP per year
Corporate tax loss	0.09 M GBP over 4 years	0.02 M GBP
Sum of monetised impacts	**1.27 M GBP**	**0.19 M GBP per year**

4.5. Combined impact assessment

To make the impacts comparable, the following comparison uses annual figures instead of figures over period since the periods are different (e.g. 4 years for producer surplus and 12 years for decommissioning cost and human health impacts). Societal costs of non-use and risk of continued use are outlined in Table 73.

Table 73. Societal costs of non-use and risks of continued use

Societal costs of non-use		**Risks of continued use**	
Monetised impacts	0.19 M GBP per year	Monetised excess risks to directly exposed workers	< 0.000001 M GBP (1 GBP) per year
Additional quantitatively assessed impacts	n.a.	Monetised excess risks to the general population	0.0000011 M GBP (1.1 GBP) per year
Qualitatively assessed impacts	n.a.	Qualitatively assessed risks	n.a.
Summary of societal costs of non-use	0.19 M GBP per year	**Summary of risks of continued use**	0.000012 M GBP (12 GBP) per year

In conclusion, for Use 1 the societal cost of non-use outweighs the risk on continued use significantly (0.19 M GBP versus ca. 0.000012 M GBP). The benefit-cost ratio compares how many times the benefits outweigh the costs, and the result is over 15,000 times.

4.6. Sensitivity analysis

Several assumptions were made when preparing this application. Table 74 summarises the evaluation of those assumptions. The assumptions are evaluated based on the level of uncertainty (low-medium-high). The last column summarises how the assumptions impact the risk-benefit calculation of the continued use.

Table 74. Uncertainties on assumptions

Assumption	Evaluation	Uncertainty	Impact
Working days (240)	Not taking into account holidays, bank holidays, illness.	Medium	Overestimate risks
Local and regional population based on EUSES model	Local population of 10,000 and regional population of 20,000,000 are a conservative approach	Low	Overestimate risks
Profit calculation assumes constant profits and linearity between profits and revenue.	Revenue and profit are expected to increase in the future. Future estimations are based on current market information, good experience of forecast available and understanding of the market. Changes in the market might negatively or positively affect the profit calculation.	Medium	Affects benefits
Growth rate	Growth rate is an estimation of the future trend. There are many factors on the market which affects this. Growth rate affects the profit estimation over the period used for producer surplus calculation. Total profit might be lower/higher which changes the magnitude of overall impact lower/higher. However, the time period used (4 years) is short and thus even a high growth rate doesn't distort the profit trend, and the risk of overestimation is low. This might affect benefit-risk ratio.	Low	Affects benefits
Combined impact assessment	Impact assessment performed in Chapter 4.5 uses annualised/average figures. Other option is to use totals over period (Total impacts: Use 1 + Use 2): • Sum of monetised impacts: 1.97 M GBP • Higher bound human health impacts: 0.0002 M GBP • Ratio: 9,850 Also, in this method the benefits continued use outweigh the risks significantly.	Low	Affects benefit and risks
Worker exposure and cancer monetisation utilising the LoD value. Considering the limit values set by EU and UK legislation	All urine samples at the LUC UK site gave values below the LoD of the analysis method used (< 0.5 µmol MOCA/mol creatinine) and therefore a corresponding risk value of 1.64E-06 was used for quantifying the excess risk value. With this risk value, the monetised excess worker risk is: • Lower limit: 5 £ • Higher limit: 8 £ • Higher limit per year: 0.6 £ The upper limit value for urinary MOCA is 5 umol MOCA/mol creatinine can be derived from	Low	Affects risks

Assumption	Evaluation	Uncertainty	Impact
	the EU binding OELV (8 h TWA 5 µg/m³)i.[37] This urinary limit value corresponds to a risk of 1.64E-05. With this risk value, the monetised excess worker risk is: • Lower limit: 47 £ • Higher limit: 75 £ • Higher limit per year: 6 £ The UK Biological Monitoring Guidance Value (BMGVs) is 15 umol MOCA/mol creatinine.[38] This urinary limit value corresponds to a risk of 4.95E-05. With this value the monetised excess worker risk is: • Lower limit: 143 £ • Higher limit: 228 £ • Higher limit per year: 19 £ This shows that the risk values are also very low for the limit values for urinary MOCA. Even with the limit values, the benefits would outweigh the risk by a wide margin.		

4.7. Information to support for the review period

Despite the extensive R&D work conducted by LUC Group, there is currently no suitable alternative available to replace MOCA as a curing agent/chain extender in the production of the high-performance PU products covered by this application. There are several issues with the alternatives currently on the market, which include poor mechanical and dynamic properties of the PU, low PU CoF, system pot-life issues, high production costs and availability issues.

LUC UK is requesting for a review period of 12 years. As currently there are no suitable alternatives to replace MOCA in the manufacture of their high-performance PU products, LUC Group will need to look for and test new alternatives that could provide products with the same technical properties as MOCA. This is a lengthy process and there are uncertainties when a new potential alternative will be available. In addition, the substitution work itself takes years to complete due to the rigorous testing and customer trials required. Please see Chapter 4.1.3 for a detailed description of the R&D plan of LUC Group.

In Table 75, the criteria set by the Committees for Socio-economic Analysis (SEAC) and Risk Assessment (RAC) for requesting a long review period are presented along with how LUC UK's situation reflects these criteria. As it can be seen, LUC UK's situation fulfils the criteria for a long review period of 12 years. LUC Group has demonstrated that there is no suitable alternative for MOCA in the manufacture of the high-performance PU products

[37] The Advisory Committee on Safety and Health at Work Opinion on an EU Occupational Exposure Limit value for 4,4'-Methylene-bis(2-chloroaniline) (MOCA) under Directive 2004/37/EC (CMD) available at https://circabc.europa.eu/sd/a/2214b88e-5a69-4c2e-a98a-331aa13dc264/Doc.1336_EN-WPC_Opinion%20MOCA_Adopted%2019102017.pdf

[38] https://www.hsl.gov.uk/online-ordering/analytical-services-and-assays/biological-monitoring/bm-guidance-values

concerned by this Use. LUC Group has conducted extensive research and testing on potential alternatives since 2009. These R&D efforts have already cost LUC Group over 0.5 M GBP.

Table 75. The criteria for a long review period[39]

Criterion	Situation for the applicant
The costs of using the alternatives are very high and very unlikely to change in the next decade as technical progress (as demonstrated in the application) is unlikely to bring any change. For example, this could be the case where a substance is used in very low tonnages for an essential use and the costs for developing an alternative are not justified by the commercial value.	TDI/MOCA is known to be an inexpensive and reliable system for manufacturing high-performance PUs. In comparison, alternative curing agents/polyurethane systems are more expensive, both in terms of material, process and energy costs. Alternative systems are also typically less reliable in production, which increases the number of rejected parts (i.e. scrap rate) and increases the amount of waste generated. As LUC UK cannot reflect the increased production costs in their products due to competing MOCA PU products produced outside of the UK, the products manufactured with an alternative system are not economically viable for LUC UK.
The applicant can demonstrate that research and development efforts already made, or just started, did not lead to the development of an alternative that could be available within the normal review period.	LUC Group has researched and tested potential alternatives to MOCA for more than a decade for a cost of over 0.5 M GBP. During that time, LUC Group has been able to successfully replace MOCA in the manufacture of some of their products (25 % of their MOCA PU product portfolio) because the technical requirements in these PU products were lower. For the high-performance products covered by this use, the technical requirements are higher as they are used in highly demanding applications. There is currently no suitable alternative to MOCA for the manufacture of these products.
The possible alternatives would require specific legislative measures under the relevant legislative area in order to ensure safety of use (including acquiring the necessary certificates for using the alternative).	Every product made with an alternative system needs to be tested in end-user facilities. During trials, the parts are tested to assess whether it fulfils customer requirements. As the durability and reliability of the product needs to be assessed as well, the trials take several years.
The remaining risks are low and the socio-economic benefits are high, and there is clear evidence that this situation is not likely to change in the next decade.	There are no emissions to water and measures to ensure worker health and safety are in place in the facilities and LUC UK is continuously improving its risk management measures. Benefits outweigh the costs significantly. For both uses, the costs for LUC UK are over 15,000 times higher than the human health costs for society.

[39] https://echa.europa.eu/documents/10162/13580/seac_rac_review_period_authorisation_en.pdf/c9010a99-0baf-4975-ba41-48c85ae64861

5. CONCLUSION

The aim of this combined Analysis of Alternatives (AoA) and Socio-economic Analysis (SEA) report was to: 1) demonstrate that no suitable alternative substances or technologies are implementable by LUC UK by the expiry of the extended sunset date MOCA under UK REACH passes on 30th of June 2022 and 2) to demonstrate that the socio-economic benefits of the continued use of MOCA outweigh the risks to human health and environment.

Since June 2009, LUC Group has tested dozens of non-MOCA based chain extenders and polyurethane systems including like-for-like diamine alternatives, chain extender blends and non-TDI PU systems. As it can be seen from the AoA, all the alternatives tested have many limitations making them unsuitable to replace TDI/MOCA in LUC UK's production of high-performance PU products in this use.

In terms of technical feasibility, the mechanical and dynamic properties of some alternatives is too low especially in terms of load bearing capacity and mechanical strength. For other PU systems, CoF is also an issue. In addition, many alternative PU systems have issues with fatigue, reliability and pot-life. End-users are particularly sensitive to reductions in reliability and fatigue as this increase their costs (parts need to be changed or recovered more often resulting in more frequent downtimes).

Some alternatives are also currently unavailable or have limited availability, which further complicates the substitution of MOCA.

In terms of sustainability, the PU materials made with the alternative systems had higher environmental loads compared to MOCA PU. The main reasons behind the lower sustainability of PUs made with alternative systems include lower fatigue properties, longer curing times, higher energy needs and/or higher scrap rate. This results into higher amounts of waste generated and higher energy consumption to produce the same amount of PU parts.

In addition to giving PUs with lower technical performance, alternatives are also more expensive. All alternatives have higher raw material costs, as high as 13 times the price of MOCA and many also have higher energy costs and scrap rates. This is a major issue for LUC UK due to the distortion of the market by TDI/MOCA-PU products from outside of the UK and the lack of motivation of the end-users (LUC UK's customers).

LUC UK's customers are accustomed to use TDI/MOCA-PU products and they have no motivation to pay more for a relatively non-proven PU product that potentially performs worse during end-use. As LUC UK's customers have no driver to transfer to non-MOCA based products, there is a very real risk that they prefer to stick with what they know and stay with MOCA-TDI products. If LUC UK's customers were in the same situation where they would also need to find alternatives, the situation would be easier in that the goal would be a common one. However, the current situation is that end-users are only concerned about price and performance.

In conclusion, LUC UK has to compete with competitor products coming from outside the UK both in terms of price and performance. Thus, in order to remain competitive, LUC UK would either need to provide an alternative PU product performing as well as their MOCA counterparts for the same price or a better performing product for a higher cost. The alternatives currently available on the market fulfil neither.

The most likely non-use scenario for LUC UK would be business closure and the MOCA cured high-performance PU production would be relocated to LUC Group's facilities in the EU. The UK society would benefit from the business closure only in terms of reduced cancer risk for the workers and general population. The human health value, the risk of continued use of MOCA for society for Use 1, is 0.000012 M GBP per year. The benefit of continued use of MOCA for society are the avoided cost of the non-use scenario (the producer's surplus cost, decommissioning cost, corporate tax loss and societal cost from job losses). For Use 1, the benefit is 0.19 M GBP per year. The benefit-risk ratio of the continued use of MOCA for Use 1 is over 15,000 (0.19 M GBP / 0.000012 M GBP). The benefits outweigh the risks significantly.

As outlined in Chapter 1, MOCA use at the LUC UK site fulfils the three conditions for "intermediate use" as given in the European Court of Justice (C -650/15/P[5]) decision and further clarified in the revised ECHA guidance of March 2022[6.] Intermediate use is exempt from the authorisation requirement. LUC UK is submitting this application as a contingency measure as it is not yet clear how to document this decision for the relevant authorities in the UK.

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APPENDICES

Appendix 1. GC-MS results

eurofins | Product Testing

Limburgse Urethaan Chemie BV
Boschstraat 31
6442 PB Brunssum
NETHERLANDS

Eurofins Product Testing A/S
Smedeskovvej 38
8464 Galten
Denmark

CustomerSupport@eurofins.dk
www.eurofins.dk/dk/product-testing

TEST REPORT

06 September 2019

Sample Information

Sample name	Sample 1
Sample reception	28/08/2019
Sample no.	392-2019-00325801
Analysis period	29/08/2019 - 06/09/2019
Client reference	DMKRPT190190-02

Results

392-2019-00325801 (Sample 1)

Please see report attached

Gitte T. Løwenstein
Analytical Service Manager

Performed by Eurofins Testing Technology , Shenzhen
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392-2019-00325801_XN_EN Page 1 of 1

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REPORT NO.: EFSN19090037C-C1
DATE: SEP. 06, 2019
PAGE: 1 of 3

TEST REPORT

APPLICANT	:	EUROFINS PRODUCT TESTING DENMARK A/S
ADDRESS	:	SMEDESKOVVEJ 38 DK-8464 GALTEN
SAMPLE DESCRIPTION	:	POLYUREATHANE CAST ELASTOMER
STYLE / ITEM NO.	:	392-2019-00325801
PO NO.	:	EUDKGA-19003258
AGE REQUESTED ON APPLICATION FORM	:	NOT PRESENT
SAMPLE RECEIVED DATE	:	SEP. 02, 2019
TEST PERIOD	:	SEP. 03, 2019 TO SEP. 05, 2019
RESULT SUMMARY	:	

TEST(S) REQUESTED BY APPLICANT:	RESULT
- 2,2'-dichloro-4,4'-methylenedianiline	Please refer to next page(s).

********************FOR FURTHER DETAILS, PLEASE REFER TO THE FOLLOWING PAGE(S)*****************

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EUROFINS TESTING TECHNOLOGY (SHENZHEN) CO. LTD.

Harry Chen
Lab & Technical Support Manager

Coco Luo
Lab & Reporting Manager

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REPORT NO.: EFSN19090037C-C1
DATE: SEP. 06, 2019
PAGE: 2 of 3

Material list

Testing material No.	Component	Material	Colour
1	Polyureathane cast elastomer	Soft plastic	Coffee

2,2'-dichloro-4,4'-methylenedianiline

Test method : Extraction with organic solvent, analysis with GC-MS

Detection limit : 0.010 %

Test No.			MBOCA-1
Material No.			1
Parameter	CAS No.	Unit	Test result
2,2'-dichloro-4,4'-methylenedianiline	101-14-4	%	N.D.

Note: - 1 mg/kg = 1 ppm = 0.0001%
- N.D. = Not Detected

Other Information / Remark:

N/A

TO BE CONTINUED

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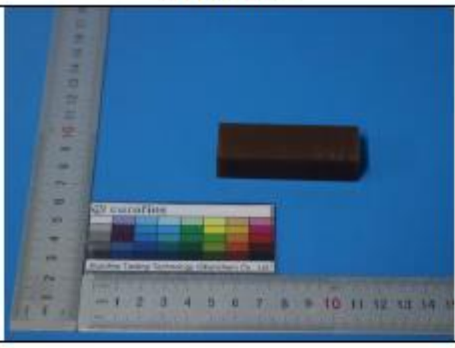
DATE: SEP. 06, 2019
PAGE: 3 of 3

Photo Attachment
Material No. 1


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TEST REPORT

06 September 2019

Sample Information

Sample name	Sample 2
Sample reception	28/08/2019
Sample no.	392-2019-00325802
Analysis period	29/08/2019 - 06/09/2019
Client reference	DMKRPT190190-02

Results

392-2019-00325802 (Sample 2)

Please see report attached

Gitte T. Løwenstein
Analytical Service Manager

Performed by Eurofins Testing Technology , Shenzhen

392-2019-00325802_XN_EN Page 1 of 1

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REPORT NO.: EFSN19090037C-C2
DATE: SEP. 06, 2019
PAGE: 1 of 3

TEST REPORT

APPLICANT	:	**EUROFINS PRODUCT TESTING DENMARK A/S**
ADDRESS	:	SMEDESKOVVEJ 38 DK-8464 GALTEN
SAMPLE DESCRIPTION	:	POLYUREATHANE CAST ELASTOMER
STYLE / ITEM NO.	:	392-2019-00325802
PO NO.	:	EUDKGA-19003258
AGE REQUESTED ON APPLICATION FORM	:	NOT PRESENT
SAMPLE RECEIVED DATE	:	SEP. 02, 2019
TEST PERIOD	:	SEP. 03, 2019 TO SEP. 05, 2019
RESULT SUMMARY	:	

TEST(S) REQUESTED BY APPLICANT:	RESULT
- 2,2'-dichloro-4,4'-methylenedianiline	Please refer to next page(s).

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REPORT NO.: EFSN19090037C-C2
DATE: SEP. 06, 2019
PAGE: 2 of 3

Material list

Testing material No.	Component	Material	Colour
1	Polyureathane cast elastomer	Soft plastic	Beige

2,2'-dichloro-4,4'-methylenedianiline

Test method : Extraction with organic solvent, analysis with GC-MS

Detection limit : 0.010 %

Test No.			MBOCA-1
Material No.			1
Parameter	CAS No.	Unit	Test result
2,2'-dichloro-4,4'-methylenedianiline	101-14-4	%	N.D.

Note: - 1 mg/kg = 1 ppm = 0.0001%
- N.D. = Not Detected

Other Information / Remark:

N/A

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Photo Attachment
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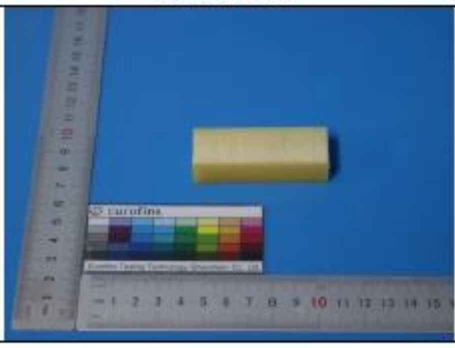

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TEST REPORT

06 September 2019

Sample Information

Sample name	Sample 3
Sample reception	28/08/2019
Sample no.	392-2019-00325803
Analysis period	29/08/2019 - 06/09/2019
Client reference	DMKRPT190190-02

Results

392-2019-00325803 (Sample 3)

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DATE: SEP. 06, 2019
PAGE: 1 of 3

TEST REPORT

APPLICANT	:	**EUROFINS PRODUCT TESTING DENMARK A/S**
ADDRESS	:	SMEDESKOVVEJ 38 DK-8464 GALTEN
SAMPLE DESCRIPTION	:	POLYUREATHANE CAST ELASTOMER
STYLE / ITEM NO.	:	392-2019-00325803
PO NO.	:	EUDKGA-19003258
AGE REQUESTED ON APPLICATION FORM	:	NOT PRESENT
SAMPLE RECEIVED DATE	:	SEP. 02, 2019
TEST PERIOD	:	SEP. 03, 2019 TO SEP. 05, 2019
RESULT SUMMARY	:	

TEST(S) REQUESTED BY APPLICANT:	RESULT
- 2,2'-dichloro-4,4'-methylenedianiline	Please refer to next page(s).

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REPORT NO.: EFSN19090037C-C3
DATE: SEP. 06, 2019
PAGE: 2 of 3

Material list

Testing material No.	Component	Material	Colour
1	Polyureathane cast elastomer	Soft plastic	Dark brown

2,2'-dichloro-4,4'-methylenedianiline

Test method : Extraction with organic solvent, analysis with GC-MS

Detection limit : 0.010 %

Test No.			MBOCA-1
Material No.			1
Parameter	CAS No.	Unit	Test result
2,2'-dichloro-4,4'-methylenedianiline	101-14-4	%	N.D.

Note: - 1 mg/kg = 1 ppm = 0.0001%
- N.D. = Not Detected

Other Information / Remark:

N/A

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DATE: SEP. 06, 2019
PAGE: 3 of 3

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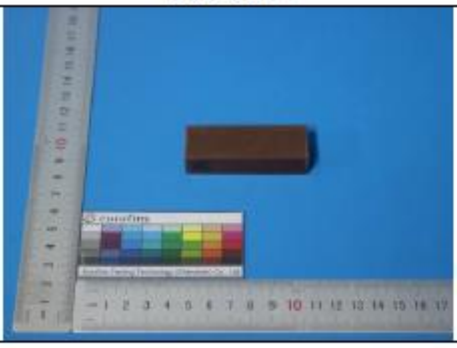

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Appendix 2. Supplier communications

Addolink® 1604:

#C

[redacted]

NDI (trade name Desmodur 15):

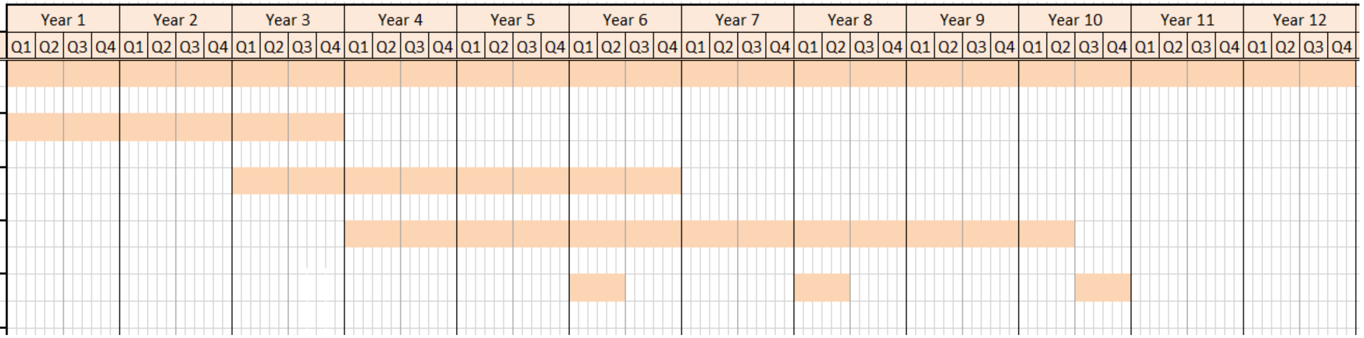
#C

[redacted]

Appendix 3. Potential substitution timelines

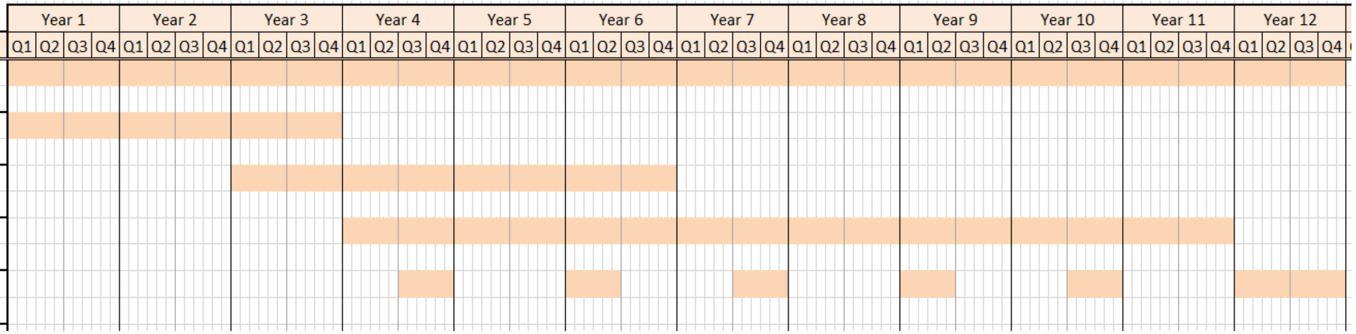
Use 1:

Phase	Task name	Duration
0	R&D	?
1	Upscaling	3 years
2	Cast prototypes	4 years
3	Verification trials	6.5 years
4	Final report + implementation	1.5 years



Use 2:

Phase	Task name	Duration
0	R&D	?
1	Upscaling	3 years
2	Cast prototypes	4 years
3	Verification trials	8 years
4	Final report + implementation	3.5 years



Appendix 4. LUC Group's project flowchart for R&D projects

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#A

[redacted]

#A

[redacted]

#A

[redacted]

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#A

[redacted]