ANALYSIS OF ALTERNATIVES

Legal name of applicant(s):	Rolls-Royce plc
Submitted by:	Rolls-Royce plc
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Substance:	*Bis (2-ethylhexyl) phthalate (DEHP)* *EC: 204-211-0 CAS: 117-81-7*
Use title:	*The processing of a stop-off formulation containing DEHP during the diffusion bonding and manufacture of aero engine fan blades.*
Use number:	1

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LIST OF ABBREVIATIONS

AoA - Analysis of Alternatives

AFRC - Advanced Forming Research Centre

CSR - Chemical Safety Report

DB - Diffusion Bond

DEHP - bis(2-ethylhexyl) phthalate

ECHA - European Chemicals Agency

FPA - Fixed Process Approval

HCF - High Cycle Fatigue

IPT - Integrated Project Team

LCF - Low Cycle Fatigue

JSF - Joint Strike Fighter

MTOC - Mechanical Test Operations Centre

OGV - Outlet Guide Vanes

R&D - Research and Development

RMMs - Risk Management Measures

RR - Rolls-Royce plc

SIMS - Secondary-ion mass spectrometry

Stopyt-62A Bonding stop-off agent containing DEHP

Stopyt-62G Bonding stop-off agent containing Glycerol

Stopyt-62PL Bonding stop-off agent containing Triethylene glycol bis (2-ethylhexanoate)

WCFB - Wide Chord Fan Blade

DECLARATION

The Applicant Rolls-Royce plc is aware of the fact that evidence might be requested by ECHA to support information provided in this document.

Also, we request that the information blanked out in the "public version" of the Analysis of Alternatives is not disclosed. We hereby declare that, to the best of our knowledge as of today (19th August 2020) 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: DPease 21/8/20

Date, Place: 21 August 2020,
Barnoldswick,
Lancashire,
UK

David Pease
Chief of Manufacturing Engineering
Wide Chord Fan Blade

1. SUMMARY

DEHP (bis (2-ethylhexyl) phthalate) is used by Rolls-Royce within a mixture called 'Stopyt-62A' which is purchased from Morgan Advanced Materials, a US company. Stopyt-62A as a mixture provides key functionality in diffusion bonding. A process used in the manufacture of aero-engine fan blades, a vital safety critical component. Fan blade technology is a particular source of competitive advantage for Rolls-Royce and this particular process is common across much of the Rolls-Royce civil and defence engine product range.

Each Rolls-Royce engine undergoes a rigorous development and validation programme in order to obtain approval from the European Aviation Safety Agency (EASA), amongst other aircraft safety regulatory bodies, which provides type-certification of aircraft and components. The process to develop, test and validate alternatives to Stopyt-62A has consisted of an extensive programme of work and has involved significant research and development costs. As such, the work to identify an alternative is still on-going and this report presents the relevant information that is currently available at the time of submission.

Initially there were four identified mixtures/formulations which were considered good candidates as potential alternatives to Stopyt-62A. These were:

1. GG4400 B2
2. Dag MS-401LR
3. Stop-flo No2
4. Stopyt-62G

With regard to each of these formulations/mixtures, analysis was conducted, and all have now been discounted as potential alternatives to Stopyt-62A. At the time that the previous submission was made, the first two formulations had already been assessed and discounted as potential alternatives and the latter two formulations (Stop-flo No2 and Stopyt-62G) had been identified as candidates for continued testing, with Stopyt-62G the most promising as a potential substitute due to its similarity to the existing formulation and encouraging initial testing results.

Since our previous submission, both Stop-flo No2 and Stopyt-62G have failed technical validation testing. Because no other suitable candidates were identified, in order to progress our work on finding a suitable replacement for the Stopyt-62A (DEHP-containing) formulation a commercial and technical relationship has been developed between Rolls-Royce and Morgan Advanced Materials with agreement to further develop the failed Stopyt-62G formulation. The product Stopyt-62PL was developed as a follow-on re-formulation of Stopyt-62A and Stopyt-62G, where DEHP is now replaced with triethylene glycol bis (2-ethylhexanoate) as the plasticiser within the mixture.

To date, the new Stopyt-62PL formulation has surpassed all previous alternatives that have been assessed. It has achieved the required technical and functional analysis to a point where only a programme of High Cycle Fatigue (HCF) testing remains to be carried out to fully validate the product as a suitable alternative to Stopyt-62A. The material qualification and test programme is scheduled to be complete by the end of 2020.

The purpose of this review report is to seek Authorisation to allow Rolls-Royce to continue using the DEHP-containing product Stopyt-62A beyond February 2022 in the event that the candidate alternative Stopyt-62PL fails to demonstrate equivalence to current design tolerances and test specifications. Due to unplanned failures with test hardware and difficulties encountered during qualification of the defence blade test methodology the project has already experienced a number of setbacks. If the final HCF test programme is unsuccessful, Rolls-Royce will be required to initiate a further programme of work to identify and develop another alternative, which will take a further 5-7 years and require further significant investment to complete.

Rolls-Royce is fully committed to the removal of DEHP from Fan Blade manufacture. Over the past 10 years significant time, resource and investment has been made by Rolls-Royce in the research and development of potential alternatives to the DEHP-containing formulation and an extensive programme of validation is being managed to validate the integrity of safety critical fan blades.

Details on the work carried out to date on suitable alternatives are included in this document.

2. CONSULTATIONS

Initial activities undertaken by Rolls-Royce in order to find potential candidates as alternatives to Stopyt-62A involved pro-actively working with suppliers, sector associations and academic bodies. Alternatives were identified either directly through consultation or through data searches that led to consultation activity within the supply chain. In addition, Rolls-Royce approached specialist bodies such as the British Ceramics Institute and other industry organisations such as BAE Systems and Pilkington's European Research Centre. This work resulted in the initial identification of a number of potential alternatives, which were discussed in our previous Authorisation submission. At the point of our previous submission, we had already discounted some of these potential alternatives because they had failed early testing and we were focusing our resource on continued testing of two alternatives that both showing positive initial test results. Unfortunately, both of these alternatives have since failed further testing and have had to be discounted.

Since the failure of the two alternatives that we were testing at the time of the previous submission, our consultation activities have focused on working with Morgan Advanced Materials to develop a new formulation. Morgan Advanced Materials products have shown the most favourable technical properties with regards to equivalence to the existing DEHP-containing formulation; Stopyt-62A.

The Morgan Advanced Materials product, Stopyt-62G was developed through collaboration as a candidate for Stopyt-62A substitution. Stopyt-62G, which was the most promising candidate as an alternative at the point of our previous application, used glycerol instead of DEHP as the plasticiser. Initial laboratory testing and manufacturing trials were successful however the product failed functional testing and did not demonstrate equivalence to the existing formulation (details of this are discussed in section 6). Working with Morgan, reformulation was undertaken to produce another candidate; Stopyt-62PL, which uses triethylene glycol bis (2-ethylhexanoate) as the plasticiser within the mixture. Initial trials of Stopyt-62PL have been successful and final product testing is ongoing at the time of issue of this document.

Consultation is also underway between Rolls-Royce and Morgan Advanced Materials on the development of a suitable alternative should Stopy-62PL fail the final stage of testing. Morgan Advanced Materials have stated that there are a further two potential alternatives to DEHP. The proposed products are not yet available for testing as the final formulation will be agreed once all Rolls-Royce testing and validation results are available and have been shared. The development and formulation of the final product will be subject to contractual agreements between Rolls-Royce and Morgan Advanced Materials.

At the time of submission of this document, no other candidate formulations have been identified for evaluation and Morgan Advanced Materials remain the sole partner in consultation.

3. ANALYSIS OF THE SUBSTANCE FUNCTION(S) AND TECHNICAL REQUIREMENT(S) FOR THE PRODUCT(S)

3.1. Description of the technical function provided by the annex XIV substance

The Rolls-Royce wide-chord fan blade (WCFB) manufacturing process uses Stopyt-62A which contains DEHP. WCFBs are designed to be hollow in order to save weight. This employs a unique manufacturing process developed by the Group and employed at the manufacturing facility.

The blades feature an internal structure that is created during a process that diffusion bonds and super-plastically forms three sheets of titanium. Hollow design allows significant weight savings to be made in the fan blade, especially at larger fan sizes, and a follow-on weight saving in the fan disc, structure and containment features.

The active ingredient in the Stopyt-62A is Yttria (Yttrium (III) Oxide) which prevents diffusion bonding in the printed areas of the blade. DEHP is added to the Stopyt-62A as a plasticiser to ensure a smooth, even and accurately positioned coating of Yttria is printed onto the blade. The DEHP also modifies surface tension and plasticity of the dried Yttria ensuring that it does not crack or flake off the blades. The DEHP content of the Stopyt-62A also ensures that the required bake-out temperature is achieved prior to diffusion bonding.

3.2. Description of the product(s) resulting from the use of the annex XIV substance

The Rolls-Royce wide chord fan blade is perhaps the best example of the application of titanium, coupled with advanced processing techniques, to give a significant service advantage. Modern blades are manufactured from three sheets of titanium representing the two outer skins and the internal corrugated structure. A bonding stop-off agent (Stopyt-62A) is applied, to define the internal structure, and then the three pieces are bonded in a high temperature pressure vessel. The blade is twisted, and the cavity inflated at very high temperature using an inert gas in a shaped die to yield its final aerofoil shape. The total process results in bonds with properties equivalent to the parent material and an internal stiffening structure which bears its share of the centrifugal load. Compared to the original solid clapper design this gives a fan module which is 24 per cent lighter, an overall engine weight benefit of 7 per cent, with a significant increase in foreign object damage (FOD) resistance over competitor designs (Rolls-Royce 1995, 2012b).

According to the fan blade design approved by European Aviation Safety Agency (EASA), a specific pattern of the Stopyt-62A liquid is printed onto the titanium fan blades using a silk screen. This process is proprietary to Rolls-Royce and is covered by a number of internationally registered Patents (Rolls-Royce 1995, 2012b) having been developed and perfected by the company over the last 30 years.

3.3. Description of the technical requirements that must be achieved by the product(s) made with the substance

Process Description

The wide-chord fan blade (WCFB) manufacturing process involves several stages of production. The manufacturing stages that are relevant to the application and function of Stopyt-62A are:

- Screen printing of panels
- Assembly and sealing of panels
- Bake-out
- Diffusion bonding
- Inspection of bonds
- Superplastic forming of the blades

During screen printing of panels, Stopyt-62A is poured on a screen and printed on to the panel. The panels are then stacked and the edges are welded together. The assembly is placed in an autoclave and heated so as to “bake-out” the binder from the material which may prevent diffusion bonding. The location of diffusion bonds is controlled by applying the stop-off material (Stopyt-62A) to preselected areas. The sealed assembly is then placed in a pressure vessel and is heated and pressed to diffusion bond the work pieces together to form an integral structure. Diffusion bonding occurs when matt surfaces are pressed together under temperature and pressure conditions for a period of time that allows atom interchange across the interface.

After inspection, the assembly is then put into an autoclave and heated again with pressurised fluid between appropriately shaped dies. The work pieces then become superplastically formed to produce an article matching the shape of the dies.

Tasks Performed by Substance and Substance Function Data

In analysing the substance function, consideration has been given to the tasks performed by Stopyt-62A (rather than DEHP alone) as it is the mixture that provides the key functionality in the diffusion bonding process. The manufacturing process has been rigorously optimised and validated around the properties of the mixture. The specific contribution of the DEHP is as a plasticiser but it is the properties of the Stopyt-62A mixture as a whole that are relevant. Stopyt-62A has been subject to rigorous investigations and tests and any alternative will also be required to pass these rigorous investigations and tests so that the

design organisation can provide the necessary evidence to EASA that the alternative satisfies the product type design certification basis.

A summary of the substance function information is provided in Table 1 below together with a synopsis of customer and legal requirements relating to the validation and introduction of alternatives.

Table 1: A summary of the substance function of Stopyt-62A (with DEHP in the mixture)

Functional Aspect	**Information**
Task performed	Stopyt-62A is used in diffusion bonding of the titanium blades under high pressure and temperature ensuring only specific areas of the blades are bonded together to give the correct strength and stiffness whilst retaining a light-weight hollow structure. DEHP is a plasticiser within the approved Stopyt-62A mixture. The stages of application of Stopyt-62A to achieve the necessary product quality are as follows: • Manual handling, shaking and opening of Stopyt-62A bottle: • Transfer and sampling of Stopyt-62A: • Pouring Stopyt-62A for printing and use of wipes: Exposure to operators can occur at the stages above the diffusion bonding and superplastic formation stage, by inhalation and / or dermal exposure. Risk management measures are in place that include use of closed systems, extraction booths, restricted operating times, employee training and personal protective equipment (chemically resistant gloves, coverall and eye protection).
Critical properties and quality criteria	<u>Substance ID and Properties (Stopyt-62A)</u> **Chemical Name**: Stopyt-62A **Classification of the mixture**: CLP/GHS Classification (1272/2008): The mixture has been self-classified as: H225 Flammable liquid (cat 2) H332 Acute toxicity – inhalation (cat 4) H319 Eye irritant (cat 2) H336 Specific target organ toxicity (cat 3) H360FD Toxic to reproduction (cat 1B) **Composition and Information on Ingredients:**

Component	Concentration % by weight	CAS Registry No.	EINECS No.
Yttrium Oxide	<50	1344-36-9	215-233-5
Isopropyl alcohol	30-40	67-63-0	200-661-7
Methyl isobutyl ketone	10-50	108-10-1	203-550-1
Di (2-ethylhexyl) phthalate	<10	117-81-7	204-211-0

Critical properties and quality Criteria (cont.d)	Note: Morgan Advanced Materials that supplies Stopyt-62A, stated that DEHP was 100% pure and is present at only 5% w/w (+/- 2%) <u>Substance ID and Properties (DEHP)</u> **Chemical Name**: bis(2-ethylhexyl) phthalate (DEHP) **IUPAC Name**: bis(2-ethylhexyl) phthalate

	CAS Number: 117-81-7 **EC Number**: 204-211-0 **Classification of the substance**: CLP Classification (1272/2008): Reproductive toxicity (Category 1B) Acute aquatic toxicity (Category 1) Chronic aquatic toxicity (Category 1)
Function Conditions	Estimated fate of Stopyt-62A: Majority is thermally destroyed during bake-out with the remaining amount disposed of by a licensed contractor as hazardous waste. Negligible amounts are discharged to the site effluent system and to atmosphere (as verified by monitoring and analysis).
Process and performance constraints	The process and performance constraints are summarised as follows: • Overall assembly process duration • Bake-out temperature and vapour pressure • Plasticity of Yttrium Oxide printed pattern • Drying technique and time • Ease and effectiveness of screen cleaning • Avoidance of screen damage • Standard inspection covering c-scan, binocular checks, chisel tests and micro checks • Fine edge definition • Colour for visual inspection • Compatibility with superplastic forming process • Bond efficacy • Contamination prevention
Is the function associated with another process that could be altered so that the use of the substance is limited or eliminated?	This is a key Rolls-Royce patented process that is used in the wide-chord fan blade (WCFB) manufacturing in the UK. There are no other processes that could be altered so that the use of the substance is limited or eliminated other than a direct substitution or a different technological approach to applying the stop-off agent.
What customer requirements affect the use of the substance in this use?	WCFBs are a critical component in the Rolls-Royce manufacturing process and a reliability sensitive part which is subject to extreme stress conditions in normal operational service. They have to withstand operational incidents and failure events and deform/fail within well-defined safety driven parameters. The customer requirements are driven by the industry standards to achieve airworthiness and environmental certification of aircraft and related products as detailed in the regulations below.
Are there particular industry sector requirements or legal requirements for technical acceptability that must be met and that the function must deliver?	**<u>European Regulations</u>** The use of Stopyt-62A is required to comply with Commission Regulation (EU) No 748/2012 of 03 August 2012 laying down implementing rules for the airworthiness and environmental certification of aircraft and related products, parts and appliances, as well as for the certification of design and production organisations. The design process using Stopyt-62A in WCFB manufacturing process is part of the Type Design of a range of products, in accordance with (EU) No 748/2012 paragraph 21A.31 as follows: 21A.31 Type design (a) The type design shall consist of:

	1. The drawings and specifications, and a listing of those drawings and specifications, necessary to define the configuration and the design features of the product shown to comply with the applicable type-certification basis and environmental protection requirements; 2. Information on materials and processes and on methods of manufacture and assembly of the product necessary to ensure the conformity of the product; 3. An approved airworthiness limitations section of the instructions for continued airworthiness as defined by the applicable airworthiness code; and 4. Any other data necessary to allow by comparison, the determination of the airworthiness, the characteristics of noise, fuel venting, and exhaust emissions (where applicable) of later products of the same type. (b) Each type design shall be adequately identified Stopyt-62A has been subject to investigations and tests as defined by paragraph 21A.33. 21A.33 Investigation and tests (a) The applicant shall perform all inspections and tests necessary to show compliance with the applicable type-certification basis and environmental protection requirements. (b) Before each test required by paragraph (a) is undertaken, the applicant shall have determined: 1. For the test specimen: (i) That materials and processes adequately conform to the specifications for the proposed type design;(ii) That parts of the products adequately conform to the drawings in the proposed type design; (iii) That the manufacturing processes, construction and assembly adequately conform to those specified in the proposed type design; and 2. That the test equipment and all measuring equipment used for tests are adequate for the test and are appropriately calibrated. (c) The applicant shall allow the Agency to make any inspection necessary to check compliance with paragraph (b). (d) The applicant shall allow the Agency to review any report and make any inspection and to perform or witness any flight and ground test necessary to check the validity of the declaration of compliance submitted by the applicant under 21A.20(b) and to determine that no feature or characteristic makes the product unsafe for the uses for which certification is requested. (e) For tests performed or witnessed by the Agency under paragraph (d): 1. The applicant shall submit to the Agency a statement of compliance with paragraph (b); and 2. No change relating to the test that would affect the statement of compliance may be made to a product, part or appliance between the time compliance with paragraph (b) is shown and the time it is presented to the Agency for test. (EU) No 748/2012 sub-part D defines the responsibilities of the design organisation with respect to changes of the type design. Changes are classified as minor or major. Both require an application for approval of a change to a type design to be made. The change in manufacturing process using either a different product or method could potentially alter fit, form or function of the fan blade therefore

	would be classified as a major change. There is other EU legislation that is applicable to aviation safety including: • Commission Regulation (EC) No 2018/1139 on common rules in the field of civil aviation and establishing a European Aviation Safety Agency; • Commission Regulation (EC) No 748/2012 on rules for establishing initial airworthiness; • Commission Regulation (EC) No 1321/2014 on the continuing airworthiness of aircraft and aeronautical products, parts and appliances, and on the approval of organisations and personnel involved in these tasks. These legislative requirements are to ensure airworthiness by ensuring that product changes will require substantive evidence of compliance with safety standards and approval by the Agency. Therefore, alternatives may not be substituted where they are not validated. This implies that product changes will not be possible at short notice. **Rolls-Royce Standards** Where switching to an alternative would also mean the introduction of new processes and techniques, there are a number of phases at Rolls-Royce known as Manufacturing Capability Readiness Levels (MCRL) that need to be attained. The MCRLs are a sequence of carefully defined stages of manufacturing and process maturity. This is aimed at managing the complex process of development and introduction of new manufacturing capabilities within Rolls-Royce. MCRL is a key process principle within the Rolls-Royce manufacturing capability acquisition process – a framework of best practice principles for acquisition of manufacturing capability. For the introduction of alternatives substances / techniques the MCRL must be attained unless otherwise agreed by the relevant technical The phases are summarised as: Phase 1: Technology Assessment and Proving: • MCRL 1: Process concept proposed with scientific foundation • MCRL 2: Applicability and validity of concept described and vetted, or demonstrated • MCRL 3: Experimental proof of concept completed • MCRL 4: Process validated in laboratory using representative development equipment Phase 2: Pre-production • MCRL 5: Basic capability demonstrated using production equipment • MCRL 6: Process optimised for capability and rate using production equipment Phase 3: Production Implementation • MCRL 7: Capability and rate confirmed via economic run lengths on production parts • MCRL 8: Fully production capable process qualified on full range of parts over significant run lengths

	• MCRL 9: Fully production capable process qualified on full range of parts over extended period (all Business Case metrics achieved) When a candidate alternative is identified, the scope and format of qualification and validation necessary will be agreed with the relevant Technical Authority and will be based on its compatibility and function in the end product. Differing parts and functions will require different programmes of validation and qualification testing.

4. ANNUAL TONNAGE

The quantity of DEHP used by Rolls-Royce during the manufacture of WCFBs is < 1 Tonne per annum (nominal 5% w/w DEHP in the Stop-Off Formulation).

5. IDENTIFICATION OF POSSIBLE ALTERNATIVES

5.1. Description of efforts made to identify possible alternatives

Since the initial application for Authorisation was submitted, Rolls-Royce has continued to work on the development of a suitable alternative to the DEHP-containing formulation; Stopyt-62A. Work on two promising candidate alternatives that were still undergoing testing at the point of submission of the previous Authorisation application has been concluded and unfortunately both candidates were found to be unsuitable.

Rolls-Royce has built a successful commercial relationship with Morgan Advanced Materials; they have provided the most technically favourable solutions to date. At the point of submission of our previous AoA, the Morgan product;, Stopyt-62G was the most promising of the two alternatives that we were still testing. Although this formulation was eventually shown to be unsuccessful in later technical trials, it did show the most promise of any alternative material investigated. Rolls-Royce has subsequently continued to work with Morgan Advanced Materials to develop a follow-on formulation; the product Stopyt-62PL. Since being developed, Stopyt-62PL has undergone a significant programme of qualification and validation and has passed all testing to date. See the supporting Substitution Plan document for details of the validation and qualification efforts taken with Stopyt-62PL to date.

5.1.1 Research and development

Due to the complex nature of WCFB manufacture, limited material and technology solutions are available. Since the submission of the original AoA Rolls-Royce has worked with Morgan Advanced Materials to develop a new formulation; Stopyt-62PL in the search for a suitable substitution candidate.

Following the technical exclusion of Stopyt-62G as a suitable alternative candidate, Rolls-Royce entered discussion with Morgan Advanced Materials on the development of a new formulation. Initial testing was carried out by Morgan Advanced Materials on triethylene glycol bis (2-ethylhexanoate) as a suitable replacement for DEHP in the Stopyt formulations. Triethylene glycol bis (2-ethylhexanoate) was chosen due to having similar chemical properties to DEHP as a plasticiser with a similar boiling point. It is postulated that the similarities in chemical properties would allow for similar performance in the key bake out process which allows the Stop-Off media to perform its required task in the formation of titanium WCFBs.

Additionally, we have looked into the possibility of using a water-based stop-off media, as is used by the Rolls-Royce Hucknall facility to manufacture OGVs (Outlet Guide Vanes). In their experience, water-based Stop-Off media does not offer similar Bake-Out performance to the solvent-based Stop-off media used in the manufacture of WCFBs, and regular technical reviews of each process take place to share such experience. The Rolls-Royce change control process is used to capture and share any proposed technology or material changes to each process. Both teams continually monitor developments in the marketplace and ongoing business and manufacturing improvement activities take place in the company drive for Continuous Improvement.

5.1.2 Data searches

Since the submission of the original AoA, Rolls-Royce has been working with Morgan Advanced Materials on the development of a potential alternative candidate to DEHP-containing Stopyt-62A. Morgan Advanced Materials have been actively working on the identification of suitable candidates to DEHP in their product Stopyt-62A, focusing on the range of physicochemical properties of the formulation in order to ensure similar process performance when it is used in WCFB manufacture at Rolls-Royce. Morgan Advanced Materials have undertaken comparative searches on the chemical properties and performance of various plasticisers and have identified a number of proposed alternatives to DEHP. A number of the solutions have been commercialised for general metal fabrication, but due to the tight parameters required for the manufacture of Safety Critical WCFBs the number of potential candidates is limited. The cost and technical program required to test every potential candidate is unfeasible and so resource is focused on developing the most promising alternatives.

5.2. Identification of known alternatives

To date, the alternate substitution candidates to DEHP in Morgan Advanced Materials Stopyt-62A formulation suitable for the manufacture of WCFBs have been:

- Alternative formulation – GG4400 B2
- Alternative formulation – Dag MS-401LR
- Alternative class of formulations – Water based stop-off formulations
- Alternative formulation – Stop-flo No2
- Stopyt variant reformulation using glycerol - Stopyt-62G
- Stopyt variant reformulation using triethylene glycol bis (2-ethylhexanoate) - Stopyt-62PL

Discussion on the unsuitability of GG400 B2 and Dag MS-401LR is available in our previous AoA submitted with our original application for authorisation. The other alternatives that we have continued to work on assessing since our original submission are discussed in section 6 below.

6. SUITABILITY AND AVAILABILITY OF POSSIBLE ALTERNATIVES

a) ALTERNATIVE 1

6.1. Substance ID and properties (or Description of alternative technique)

Generic assessment of Water-based stop-off formulations.

The investigation into the use of water-based Stop-Off formulations was undertaken in consultation with the Rolls-Royce Hucknall facility. A water based Yttria stop-off media is used in the manufacture of OGV's (Outlet Guide Vanes).

6.2. Technical feasibility

We assessed water-based stop-off formulations, not only as they would be able to replace the DEHP-containing Stopyt-62A but also this technology would enable a reduction in the use of Volatile Organic Compounds (VOCs). The implementation of a water-based stop-off would also eliminate the need to use a non-aqueous solvent when cleaning the screen-printing equipment used in the WCFB manufacture process. Conversion to a water-based stop-off would significantly reduce environmental impacts and provide a significant savings on materials. It was also postulated that the frequency of screen-printing equipment cleaning would be reduced hence allowing greater throughput. Based on trials conducted for the VOC replacement work with different water-based formulations we were able to discount this class of materials as a potential candidate for replacing Stopyt-62A.

In summary, there are a number of challenges in using a water-based stop-off in the manufacture of WCFBs.

- Screen cleaning equipment would require adaptation for use with water
- Pressure tests indicated that the bond on the water-based stop-off printed blade was of a lower strength. The bond strength was thought to be affected in one of several ways:
    - Water in the binder contaminated the bond
    - Increased binder evolution contaminated the bond
    - Higher bake out caused binder / water to diffuse into the bond
    - Binder remaining after the bake out contaminated the bond

Test blades that were made up using a water-based Stop-Off were found to fail earlier than Stopyt-62A printed blades, leading to an unacceptable safety risk for aero-engine performance. On the basis of this, further consideration of water-based stop-off formulations as an alternative to Stopyt-62A is ruled out.

6.3. Economic feasibility and economic impacts

Not evaluated further as the alternative has been discounted on the grounds of technical feasibility.

6.4. Reduction of overall risk due to transition to the alternative

Not evaluated further as the alternative has been discounted on the grounds of technical feasibility.

6.5. Availability

Not evaluated further as the alternative has been discounted on the grounds of technical feasibility.

6.6. Conclusion on suitability and availability for Alternative 1

Water based Stop-Off formulations are not a candidate for substitution due to the shortfalls in technical suitability. Using water-based Stop-Off in place of Stopyt-62A would present unacceptable safety risk for aero-engine performance.

b) ALTERNATIVE 2

6.7. Substance ID and properties (or Description of alternative technique)

Johnson Matthey Stop-Flo No2.

At the time of submission of the original request for Authorisation the testing of Stop-flo No2 as a suitable alternative was still to be completed. The following section provides information on the work carried out on this alternative.

Table 2: Substance ID and Properties of Stop-flo No2

<table>
<tr><th>Functional Aspect</th><th>Information on Stop-flo No2</th></tr>
<tr><td colspan="2">General Information</td></tr>
<tr><td>Description of Stop-flo No2 and associated technology required to achieve the function of the Stopyt-62A</td><td>Stop-flo No2 is a feasible substance alternative only (and not an alternative technique or technology). It is predicted that no process changes will be necessary to implement this alternative but this will be confirmed as further tests are completed.

Stop-flo No2 is a white colour, water based product with the consistency of emulsion paint intended for use as a braze “Stop-off”. It is supplied by Johnson Matthey.

As Stop-flo No2 is not a direct substitution for DEHP in Stopyt-62A, the assessment is based on a comparison of the mixture as a whole.</td></tr>
<tr><td colspan="2">Substance ID and Properties</td></tr>
<tr><td>Chemical Name and Composition</td><td>Stop-flo™No.2 Paint is the trade name. The composition is:
<table>
<tr><th>Substance</th><th>CAS No.</th><th>EINECS No.</th><th>% Concentration</th></tr>
<tr><td>Yttrium oxide</td><td>1314-36-9</td><td>215-233-5</td><td>50 to 80</td></tr>
<tr><td>Denatured ethanol</td><td>64-17-5</td><td>200-578-6</td><td>7 to 8</td></tr>
</table>
The supplier reports that water makes up nearly all of the remainder.</td></tr>
<tr><td>Classification and Labelling Information</td><td>EC Classification: Non hazardous</td></tr>
<tr><td>Physico-Chemical Properties</td><td>Boiling range: 70 to 100°C
Vapour density: Heavier than Air (Air =1)
Solubility in water: Binder and solvent are soluble. Inert material is not soluble.
Specific gravity (H2O =1): 4-6
Melting point Inert material: >1800°C
Evaporation rate: Slower than ether
Appearance and odour: White viscous liquid, alcoholic odour.</td></tr>
<tr><td>Exposure / Work Place Controls</td><td>EH40/2005 Workplace Exposure Limits for substances within the mixture
<table>
<tr><th>Substance</th><th>Long Term (8 hour) TWA</th><th>Short Term (15 minutes) TWA</th></tr>
<tr><td>Ethanol</td><td>1920 mg/m3</td><td>-</td></tr>
<tr><td>Dust (inhalable)</td><td>10 mg/m3</td><td>-</td></tr>
<tr><td>Dust (respirable)</td><td>4 mg/m3</td><td>-</td></tr>
<tr><td>Yttrium</td><td>1 mg/m3</td><td>3 mg/m3</td></tr>
</table>
TWA: Time Weighted Average</td></tr>
</table>

6.8. Technical feasibility

Stop-flo No2 supplied by Johnson Matthey was identified as an Yttria based stop-off alternative to Stopyt-62A. It was identified from a literature search and the supplier was contacted to request a sample for a laboratory trial to assess suitability for further work. The supplier reported that the typical application would be to prevent the flow of filler metal in a brazing application of titanium in a furnace and that the product shelf life would nominally be 6 months.

A sample was received from the supplier and it was used to undertake initial laboratory printing trials. The initial laboratory trials assessed drying times - critical property criteria needed to be achieved should Stop-flo No2 be taken forward for any further work.

Laboratory test piece trials were unsuccessful as the drying times observed were not suitable therefore bake-out and heat treatment would unlikely deliver the required properties for successful fan blade manufacture. In addition, the manufacturing process would need to be modified significantly as Stop-flo No2 is completely different in its composition and therefore properties.

Where there is a design change, there is a need for the change to go through the Rolls-Royce Manufacturing Capability Readiness Levels (MCRL). This gated process defines the steps required to introduce the new product. A decision was taken at the MCRL gated review not to progress the suitability trials of Stop-flo No2 on a technical basis.

6.9. Economic feasibility and economic impacts

The use of Stop-flo No2 would lead to a significant increase in material costs at the current comparable purchase prices of the same quantity for each substance. However, in terms of the overall production costs, this was not a large increase as the quantity consumed per annum is relatively small.

A full in-depth evaluation of economic feasibility was not carried out as the product was discounted on grounds of technical feasibility.

6.10. Reduction of overall risk due to transition to the alternative

Not evaluated further as the alternative has been discounted on the grounds of technical feasibility.

6.11. Availability

Not evaluated further as the alternative has been discounted on the grounds of technical feasibility however no problems were anticipated around availability of this alternative. Stop-flo No2 is supplied by a major chemical manufacturer, Johnson Matthey. The supplier had confirmed the ability to supply in the quantities that would be needed by Rolls-Royce.

6.12. Conclusion on suitability and availability for Alternative 2

Stop-flo No2 was not a suitable candidate for substitution due to the shortfalls in technical suitability and the significant changes and investment required to the production method of manufacture.

c) ALTERNATIVE 3

6.13. Substance ID and properties (or Description of alternative technique)

Morgan Advanced Materials Stopyt-62G

Table 3: Substance ID and Properties of Stopypt-62G

Functional Aspect	Information on Stopyt-62G
General Information	
Description of Stopyt-62G and associated technology required to achieve the function of Stopyt-62A	Stopyt-62G is a feasible formulation alternative only (and not an alternative technique or technology). Because of similarity to the existing formulation, there are not significant process changes envisaged to implement this alternative. Stopyt-62G is used as a barrier to the flow of molten metal alloys during brazing (soldering) processes to protect holes and non-braze areas from coverage and clogging. It is supplied by Morgan Advanced Materials. It is similar to Stopyt-62A, also supplied by Morgan Advanced Materials, the difference being that Stopyt-62G contains Glycerol instead of DEHP. All the other components and compositions are exactly the same. Glycerol has a similar boiling point to DEHP (DEHP 385°C / Glycerol 290 °C) which allows for a similar performance in the critical bake out process.

	As Glycerol is a direct substitution for DEHP in Stopyt-62A, details for both Glycerol and the overall mixture have been provided below.
Substance ID and Properties (Stopyt-62G)	
Chemical Name and Composition	

Component	*Concentration (%)*	*CAS No.*	*EINECS No.*
Yttrium Oxide	<50	1314-36-9	215-233-5
Isopropyl Alcohol	30-40	67-63-0	200-661-7
Glycerol	<10	56-81-5	231-111-4
Methyl Isobutyl Ketone (MIBK, Hexone)	10-20	108-10-1	203-550-1

Classification and Labelling Information

According to the Globally Harmonized System of Classification and Labeling, the US OSHA Hazard Communication Standard and the Regulation (EC) No 1272/2008 [CLP])

Specific target organ toxicity/single exposure, Category 3	H335 H336	due to the presence of methyl isobutyl ketone
Highly flammable liquid, Category 2	H225	due to the presence of methyl isobutyl ketone and isopropyl alcohol
Eye irritant, Category 2A	H319	due to the presence of methyl isobutyl ketone and isopropyl alcohol
Acute toxicity Category 4	H332	due to the presence of methyl isobutyl ketone

Physical and Chemical Properties

Appearance: Off-white to light pink liquid
Odor Threshold: No data available
Melting/Freezing Point: No data available
Flash Point: 52-54°F (11-12°C)
Lower Flammability Limit: No data available
Upper Flammability Limit: No data available
Vapour Density(Air=1): Greater than 1
Solubility: Partially soluble in water

Auto-ignition Temperature: No data available
Viscosity: ISO 2413, 14 (±3) sec with Sheen 417/4 cup
Oxidizing Properties: None
Molecular Formula: Mixture

Odor: Slight solvent
pH: Not applicable
Boiling Point: Greater than 95°F (35°C)
Evaporation Rate: No data available
Vapour Pressure: No data available

Relative Density: No data available
Octanol/Water Partition Coefficient: No data available
Decomposition Temperature: No data available
Explosive Properties: Vapours may be explosive

Specific Gravity (H_2O= 1): No data available
Molecular Weight: Mixture

Exposure / Work Place Controls

Component	OSHA PEL 8-hr TWA	ACGIH TLV 8-hrTWA
Yttrium Oxide	1 mg/m3	1 mg/m3
Isopropyl Alcohol	400 ppm	400 ppm 500 ppm (ceiling)
Glycerol	15 mg/m³ (total dust) 5 mg/m³ (respirable fraction)	10 mg/m³(mist)
Methyl Isobutyl Ketone (MIBK, Hexone)	100 ppm	50 ppm 75 ppm (ceiling)

Substance ID and Properties (Glycerol)

Chemical Name and Composition	Glycerol
IUPAC Name	Propane-1-2-3-triol
EINECS / EC Number	200-289-5
CAS Number	56-81-5
Classification and Labelling Information	Classification of the substance or mixture; Not a Hazardous substance or mixture according to Regulation (EC) No. 1272/2008 This substance/mixture contains no components considered to be persistent, bioaccumulative and toxic (PBT), or very persistent and very bioaccumulative (vPvB) at levels of 0.1% or higher.
Physical and Chemical Properties	a) Appearance — Form: viscous Colour: colourless b) Odour — odourless c) Odour Threshold — No data available d) pH — 5.5 - 8 e) Melting point/freezing point — Melting point/range: 20 °C f) Initial boiling point and boiling range — 182 °C at 27 hPa g) Flash point — 199 °C at ca.1013.0 hPa - Pensky-Martens closed cup h) Evaporation rate — No data available i) Flammability (solid, gas) — No data available j) Upper/lower flammability or explosive limits — Upper explosion limit: 19 %(V) at 1013 hPa Lower explosion limit: 2.7 %(V) at 1013 hPa k) Vapour pressure — 0.004 hPa at 50 °C 0.260 hPa at 100 °C 5.7 hPa at 150 °C l) Vapour density — 3.18 - (Air = 1.0) m) Relative density — 1.25 g/mL n) Water solubility — miscible o) Partition coefficient: n-octanol/water — log Pow: -1.75 at 25 °C p) Auto-ignition temperature — 370 °C q) Decomposition temperature — No data available r) Viscosity — No data available s) Explosive properties — No data available t) Oxidizing properties — No data available

Exposure / Workplace Controls	**Components with workplace control parameters**

Component	CAS-No.	Value	Control parameters	Basis
Glycerol	56-81-5	TWA	10 mg/m3	UK. EH40 WEL - Workplace Exposure Limits
	Remarks	Where no specific short-term exposure limit is listed, a figure three times the long-term exposure should be used		
		TWA	10 mg/m3	UK. EH40 WEL - Workplace Exposure Limits
		Where no specific short-term exposure limit is listed, a figure three times the long-term exposure should be used		

6.14. Technical feasibility

Stopyt-62G was identified from consultation with the existing supplier of Stopyt-62A, Morgan Advanced Materials. The Stopyt product range was originally developed as a braze inhibitor for use in metal welding and brazing operations. It was originally registered as a brand in 1992 and various formulations have been marketed since. The key difference between Stopyt-62A and Stopyt-62G is that in Stopyt-62G, DEHP is replaced with Glycerol as the plasticiser within the mixture. Glycerol was chosen because it has a similar boiling point to DEHP and would therefore exhibit similar performance in the bake out process. The suppliers undertook tests with Glycerol which met their requirements for general metal fabrication customers (but not specifically aero-engine customers) which led to Stopyt-62G being commercialised. Stopyt-62G has a product shelf life of 12 months.

In 2013, a production trial with Stopyt-62G was performed with fabrication of a Trent 700 wide-chord fan blade (WCFB). The blade passed initial evaluation testing and metallographic examination thus demonstrating feasibility of the formulation. As a result of successfully producing this blade, and after discussions on various approval route scenarios, it was agreed that a further five off Trent 700 WCFB and 5 off material fatigue test specimens would be manufactured using Stopyt-62G and subjected to LCF (3-point bend) test. Four of the five test blades ran without incident to 14 000 cycles each, however one blade was removed from test at 4000 cycles due to indications identified during phased array inspection.

The blade which was removed due to indications identified during phased array inspection was cut up to be metallurgically examined and it was determined that the indication was due to bond through; there was a small area of bond encroaching into the stop-off pattern, not attributable to the alternation in the stop-off material formulation. Re-examination of the original x-ray identified this as a subtle feature just discernible but within specification requirements. This effect of bond through is seen on a very occasional basis within blade manufacture. There was no evidence that it was associated with the reformulation of the stop off therefore agreement was made to complete the LCF testing to 20 000 cycles on the remaining 4 test blades. The 4 remaining test blades passed the validation requirements.

The 5 material fatigue test specimens were run back-to-back with 5 test specimens made using current standard Stopyt-62A. The test specimens made using Stopyt-62G all failed prematurely of the baseline set by the Stopyt-62A specimens. The Stopyt-62G specimens did not demonstrate equivalence to current standard Stopyt-62A and therefore failed the LCF (3-point bend) testing requirement.

The specifications governing the safety critical design integrity of WCFBs do not allow for any deviation to drawing or design tolerances and the indication observed with the test blade along with the failure of the test specimens did not demonstrate full equivalence to the current standard material.

Although the test blades did demonstrate partial equivalence, the Materials, Engineering and Design Authorities agreed that full equivalence could not be demonstrated, and no further testing was carried out.

In the main it was considered that the production process method and parameters would remain the same with only minor changes in time to the initial mixing and preparation of Stopyt-62G. Overall method evaluation was not finalised due to the unfavourable results observed during LCF testing.

6.15. Economic feasibility and economic impacts

Trials using Stopyt-62G to date showed that minimal changes to the current production process would be necessary and no capital plant or additional operational costs would be incurred. In addition, the supplier, Morgan Advanced Materials confirmed that the cost per quart of the alternative would be the same as the existing Stopyt-62A mixture.

A detailed evaluation was not conducted due to the product being discounted due to shortfalls in technical feasibility.

6.16. Reduction of overall risk due to transition to the alternative

The overall risk due to the transition to alternatives was not fully evaluated due to the shortfalls in technical feasibility.

6.17. Availability

Stopyt-62G was developed by Morgan Advanced Materials, the supplier of the currently used Stopyt-62A specifically to meet demands for a braze inhibitor without DEHP. Glycerol is a readily available non-hazardous raw material with a similar boiling point to DEHP and as such similar bake-out performance.

The availability of Stopyt-62G was confirmed by the supplier to be the same as that for Stopyt-62A and could be supplied in the quantities required by Rolls-Royce to meet load and demand for WCFB manufacture. The product would be imported into the EU by Rolls-Royce.

Further commercial discussions on the supply of Stopyt-62G were not carried out as the product was discounted on the grounds of technical feasibility.

6.18. Conclusion on suitability and availability for Alternative 3

At the time of the original Authorisation submission, Stopyt-62G appeared to be a credible alternative to the current standard Stopyt-62A and initial chemical and metallurgical analysis demonstrated equivalence, however unfavourable LCF (3-point bend) test results discounted the product on the grounds of safety and product integrity. Fan Blades are a safety critical engine component and strict design criteria must be met. Stopyt-62G did not meet the strict design criteria set out in Rolls-Royce design standards and specifications.

d) ALTERNATIVE 4

6.19. Substance ID and properties (or Description of alternative technique)

Morgan Advanced Materials Stopyt-62PL

Table 4: Substance ID and Properties of Stopypt-62PL

Functional Aspect	Information on Stopyt-62PL
General Information	
Description of Stopyt-62PL and associated technology required to achieve the function of Stopyt-62A	Stopyt-62PL is a feasible formulation alternative only (and not an alternative technique or technology). The product is a further iteration based on reformulation of the Stopyt-62A and G products and has been developed to meet the stringent test requirements of Rolls-Royce following the shortfall in technical suitability of Stopyt-62G. There are currently no significant process changes envisaged to implement this alternative. Stopyt-62PL is used as a barrier to the flow of molten metal alloys during brazing

(soldering) processes to protect holes and non-braze areas from coverage and clogging. It is supplied by Morgan Advanced Materials.

It is similar to Stopyt-62A and also supplied by Morgan Advanced Materials, the difference being that Stopyt-62PL contains Triethylene glycol bis (2-ethylhexanoate) instead of DEHP. All the other components and compositions are exactly the same.

Triethylene glycol bis (2-ethylhexanoate) has a similar boiling point to DEHP (DEHP 385ºC / Triethylene glycol bis (2-ethylhexanoate) 344ºC) which allows for a similar performance in the bake out process.

As Triethylene glycol bis (2-ethylhexanoate) is a direct substitution for DEHP in Stopyt-62A, details for both Triethylene glycol bis (2-ethylhexanoate) and the overall mixture have been provided below.

Substance ID and Properties (Stopyt-62PL)

Chemical Name and Composition

Component	Concentration % by weight	CAS Registry No.	EINECs No.
Yttrium Oxide	<50	1314-36-9	215-233-5
Isopropyl alcohol	30-40	67-63-0	200-661-7
Methyl isobutyl ketone	10-50	108-10-1	203-550-1
Triethylene glycol bis (2-ethylhexanoate)	<10	94-28-0	202-319-2

Classification and Labelling Information

According to the Globally Harmonized System of Classification and Labeling, the US OSHA Hazard Communication Standard and the Regulation (EC) No 1272/2008 [CLP])

Specific target organ toxicity/single exposure, Category 3	H335 H336	due to the presence of methyl isobutyl ketone
Highly flammable liquid, Category 2	H225	due to the presence of methyl isobutyl ketone and isopropyl alcohol
Eye irritant, Category 2A	H319	due to the presence of methyl isobutyl ketone and isopropyl alcohol
Acute toxicity Category 4	H332	due to the presence of methyl isobutyl ketone

Physical and - Chemical Properties

Appearance: Off-white to light pink liquid
Odor: Slight solvent
Odor Threshold: No data available
pH: Not applicable
Melting/Freezing Point: No data available
Boiling Point: Greater than 95°F (35°C)
Flash Point: 52-54°F (11-12°C)
Evaporation Rate: No data available
Lower Flammability Limit: No data available
Vapour Pressure: No data available
Upper Flammability Limit: No data available
Vapour Density(Air=1): Greater than 1
Relative Density: No data available
Solubility: Partially soluble in water
Octanol/Water Partition Coefficient: No data available
Auto-ignition Temperature: No data available
Decomposition Temperature: No data available
Viscosity: ISO 2413, 14 (±3) sec with Sheen 417/4 cup
Explosive Properties: Vapours may be explosive
Oxidizing Properties: None
Specific Gravity (H_2O= 1): No data available
Molecular Formula: Mixture
Molecular Weight: Mixture

Exposure / Work Place Controls

Component	OSHA PEL 8-Hr TWA	ACGIH TLV 8-Hr TWA
Yttrium Oxide	None established	None established
Isopropyl alcohol	400 ppm	400 ppm; 500 ppm (C)[Note 1]
Methyl isobutyl ketone	100 ppm	50 ppm 75 ppm (C)[Note 1]
Triethylene glycol bis (2-ethylhexanoate	Non established	None established

Substance ID and Properties (Triethylene glycol bis (2-ethylhexanoate))

General Information

Identified uses; Laboratory Chemicals, Manufacture of Substances.

REACH; A registration number is not available for this substance as the annual tonnage does not require a registration

Chemical Name and Composition

Triethylene glycol bis (2-ethylhexanoate)

	Synonyms : TEG(EH) Formula : $C_{22}H_{42}O_6$ Molecular Weight : 402.57 g/mol CAS-No. : 94-28-0 EC-No. : 202-319-2
Classification and Labelling Information	Not a hazardous substance or mixture according to Regulation (EC) No. 1272/2008.
Physico-Chemical Properties	Appearance: Form: liquid; Colour: colourless, clear Odour: mild Odour Threshold: no data available pH: no data available Melting point/freezing point: Melting point/range: -50 °C Initial boiling point and boiling range: 344 °C Flash point: 196 °C - closed cup Evapouration rate: no data available Flammability (solid, gas): no data available Upper/lower flammability or explosive limits: no data available Vapour pressure: no data available Vapour density: no data available Relative density: 0.97 g/mL at 25 °C Water solubility: 1.53 g/l at 20 °C - soluble Partition coefficient: n-octanol/water: log Pow: 6.1 at 25 °C Auto-ignition temperature: 365 °C at 1,027 hPa Decomposition temperature: no data available Viscosity: no data available Explosive properties: no data available Oxidizing properties: no data available
Exposure / Work Place Controls	Contains no substances with occupational exposure limit values

6.20. Technical feasibility

Stopyt-62PL has been developed in conjunction with the existing supplier of Stopyt-62A, Morgan Advanced Materials and is another product from their Stopyt range of braze inhibitors used in metal welding and brazing operations.

The Stopyt-62PL product is a follow-on reformulation of Stopyt-62A and Stopyt-62G. Stopyt-62G was initially the favoured alternative to Stopyt-62A however was unsuccessful in technical trials. The key difference between Stopyt-62A and Stopyt-62PL is that in Stopyt-62PL, DEHP is replaced with triethylene glycol bis (2-ethylhexanoate) as the plasticiser in the mixture. Triethylene glycol bis (2-ethylhexanoate) was chosen as it has similar chemical properties to DEHP, specifically boiling point which will allow similar performance in the bake out process.

Manufacturing Production trials have been carried out on Stopyt-62PL and to date all test results have been favourable. The final validation requirement of High Cycle Fatigue (HCF) testing of finished fan blades has still to be completed. Initial planning had indicated a test completion date of mid-2020 however due to problems with test methodology and test hardware the testing plan has been extended with likely completion by the end of 2020. If testing is successful, Rolls-Royce will work to introduce the alternative formulation through early 2021 with full substitution and manufacturing changes by the end of Q1 2021. See supporting Substitution Plan document for plan and timescales.

To date, Stopyt-62PL has passed chemical composition analysis, structural bonding and metallurgical assessment. Fabrication of test and production fan blades has been carried out and each internally agreed validation step has been completed, with the exception of HCF testing. Unique development part numbers have been allocated to the test blades and if the fan blades pass HCF testing then Stopyt-62PL will be fully approved as an alternative to Stopyt-62A for use in the manufacture of Aero Engine Fan

blades across the Rolls-Royce engine product range. The agreed testing stages and timescales for completion are included in the supporting Substitution Plan Document.

It is expected that the similarity in properties of Stopyt62A and Stopyt-62PL will mean minimal changes to the WCFB manufacturing process are required.

In the event of Stopyt-62PL showing unfavourable results during HCF testing, a new formulation will require development, testing and validation with a further 5+ year programme of work expected. Morgan Advanced Materials have identified a further two potential substitution alternatives to DEHP. The proposed formulations are not yet available for testing as the final formulation will be agreed once all of the Rolls-Royce testing and validation results are available and have been shared. The development and formulation of the final product will be subject to contractual agreements between Rolls-Royce and Morgan Advanced Materials.

6.21. Economic feasibility and economic impacts

Similar to the trials using Stopyt-62G to date, trials using Stopyt-62PL have shown that minimal changes to the current production process are necessary. No capital plant or additional operational costs will be incurred. In addition, the supplier, Morgan Advanced Materials have confirmed that the cost of the alternative is within 10% of the cost of the existing Stopyt-62A mixture.

Nonetheless, a detailed evaluation will be conducted establishing the capital and operating costs (both direct and indirect) for substitution.

6.22. Reduction of overall risk due to transition to the alternative

The overall risk due to the transition to alternatives is not yet fully evaluated however the transition from the use of the Annex XIV substance DEHP to triethylene glycol bis (2-ethylhexanoate), which is not classified as hazardous, will reduce the risk to human health during the handling and production stages of stop-off use. The associated Chemical Safety Report details the overall reduction in risk from the transition to an alternative material.

6.23. Availability

The availability of Stopyt-62PL has been confirmed by the supplier, Morgan Advanced Materials, to be the same as that for the currently used Stopyt-62A and can be supplied in the quantities required by Rolls-Royce to continue full production of fan blades. The product will be imported into the UK by Rolls-Royce directly from the supplier.

6.24. Conclusion on suitability and availability for Alternative 4

Based on known testing information to date, Stopyt-62PL is a credible alternative to the currently used Stopyt-62A. This will be confirmed once the programme of testing is complete however, success in any such programme of work is not guaranteed.

7. OVERALL CONCLUSIONS ON SUITABILITY AND AVAILABILITY OF POSSIBLE ALTERNATIVES FOR USE 1

The potential alternatives that have been discounted for technical reasons as alternatives to Stopyt-62A are:

1. Water based stop-off media
2. Stop-flo No2
3. Stopyt-62G

The product Stopyt-62PL, has undergone a significant programme of testing and to date has demonstrated equivalence to Stopyt-62A. This product is the subject of ongoing qualification testing, details of which are included in the supporting Substitution Plan document.

To summarise the findings based on the information available, the alternatives to Stopyt-62A have been ranked based on a simple scoring system for each category (if determined to meet the criteria a score of 1 is given, if not determined to meet the criteria, a score of 0 is given). The ranking is based on data evaluated to date and where there is no information or where assessment has not been undertaken due to the substance being discounted at an early stage, a score of 0 is provided. As such the information provided in the table below is only indicative and may change with the on-going alternatives assessment work that is being carried out.

Where alternatives have scored 0 for technical feasibility, despite overall ranking position, these are not viable for further consideration.

Table 5: Ranking of alternatives assessed

Alternative	Technical Feasibility	Economic Feasibility	Reduction of Overall Risk due to Transition to the Alternative	Availability	Total Score	Ranking (1=Highest)
1. Water based Stop-offs	0	0	1	1	2	4
3. Stop-flo No2	0	1	0	1	2	3
4. Stopyt-62G	0	1	0	1	2	2
5. Stopyt-62PL	1	1	1	1	4	1

Based on the current understanding of the analysis of alternatives, Stopyt-62PL is the only substitution candidate to date that is still showing technical feasibility as an alternative formulation to be used for the removal of DEHP from fan blade manufacture. An advantage of this formulation due to similarity with the current DEHP-containing Stopyt-62A is that if final testing is successful, new manufacturing and processing techniques can be implemented with minimal change to the existing process.

If final HCF testing of production fan blades is unsuccessful, Rolls-Royce and Morgan Advanced Materials have agreed to continue development work on the substitution of DEHP in stop-off formulations. At the time of submission of this document Morgan Advanced Materials have identified two further substitution candidates to DEHP. Further information on the substitution candidates is not yet available. The proposed formulation will be agreed once all Rolls-Royce testing and validation results are available and have been shared. The development and formulation of the final product will be subject to contractual agreements between Rolls-Royce and Morgan Advanced Materials.

The purpose of submitting this review report is to allow continued use of DEHP in the event that Stopyt-62PL should fail final functional testing and a new formulation needs to be developed, assessed, validated and implemented.

All relevant information that is currently available to date has been provided and a substitution plan for Stopyt-62PL has been created and is included in the supporting Substitution Plan document.

The Substitution Plan has been developed and provides an overview of the alternative assessment factors that will affect the substitution actions, timetable, milestones and a monitoring of substitution plan implementation.

8. SUBSTITUTION EFFORTS TAKEN BY THE APPLICANT IF AN AUTHORISATION IS GRANTED

If Authorisation is granted, Rolls-Royce will continue to consult and undertake a suitable programme of development work with Morgan Advanced Materials to qualify a suitable alternative to DEHP. Morgan

Advance Materials have identified a further two substitution candidates and a test programme will be agreed and implemented to qualify one or both candidates. A decision on which candidate to pursue will be dependent on the outcome of the test results and data gathered on all of the alternative materials tested to date. Research and development on the qualification and validation of a suitable alternative will continue to be sufficiently funded as the consequence of being unable to deliver a successful substitution to Stopyt-62A will result in Rolls-Royce being unable to meet customer demand in the production of WCFBs.

A successful programme of development work will take 5+ years based on the evidence on suitable alternatives gathered to date. Rolls-Royce has acquired a significant amount of data from the work carried out to date, to inform further substantiation projects.

9. CONCLUSION

For over 10 years, Rolls-Royce has carried out a significant programme of Research and Development with a number of key suppliers on the identification of a suitable substitution candidate to DEHP. The work has investigated a broad range of alternative material solutions and technologies.

To date, the analysis of alternatives has discounted the use of water-based Stop-Off formulations as a feasible technical solution to the Diffusion Bonding of Titanium in the production of WCFBs. A number of water-based materials were investigated since use of these would also reduce the impact of environmental release of VOC's. The Rolls-Royce Hucknall facility successfully uses a water-based Stop-Off product however the unique, technologically advanced process used to manufacture safety critical fan blades is not suited to the use of these products.

In the marketplace, the availability of suitable alternatives is limited due to the manufacturing processes involved in the manufacture of WCFBs. The process used by Rolls-Royce is unique to the manufacture of WCFBs and has been developed to give Rolls-Royce a competitive advantage over its customers. The manufacturing process is cutting edge technology and at the limits of what is possible with the use of Titanium. The process and products used are subject to Intellectual Property rights and are governed by patents and contractual arrangements between Rolls-Royce and key suppliers.

All of the potential candidates identified in the Analysis of Alternatives submitted in our original application for authorisation were unsuccessful and failed either laboratory or manufacturing trials. The favoured formulation identified at that time, Stopyt-62G, had initially been successful to the point of manufacturing trials but failed LCF testing. Thus it did not demonstrate equivalence to the current Stopyt-62A. Equivalence to the current Stopyt-62A is required to ensure the safety critical properties of WCFBs.

No further alternatives were available at the time of submission of the original AoA and the Morgan Advanced Materials' follow on formulation Stopyt-62PL was only developed following learning from the unsuccessful results observed with Stopyt-62G. Rolls-Royce has worked and consulted with the supplier, Morgan Advanced Materials, and has built a successful contractual relationship over the years that development work has been carried out. Rolls-Royce will continue to work with Morgan Advanced Materials on the development of further substitution candidates should the product, which is currently being tested; Stopyt-62PL, be unsuccessful and not demonstrate equivalence to the current standard.

Substitution of DEHP was expected to have been complete prior to submission of this review report and is expected to be complete before the current Authorisation expiry of 21st February 2022 *if* Stopyt-62PL successfully completes the remaining validation and HCF qualification testing. The purpose of this request for Authorisation is therefore to allow sufficient time to develop and qualify another suitable candidate should Stopyt-62PL fail to demonstrate equivalence.

If testing is unsuccessful, a further 5+-year programme of work will be required to validate a new Stop-Off formulation. A projected 5+-year timeline is based on the substantiation work carried out to date. A new test programme will be a read across from the current Stopyt-62PL plan which is included in the supporting Substitution Plan document.

In the current test plan for Stopyt-62PL the final stage of testing is planned for completion by the end of 2020. At this point a decision will be taken on whether to substitute Stopyt-62A with Stopyt-62PL. This will review the outcome of HCF testing of Stopyt-62PL which to date has shown the closest equivalence to the current standard Stopyt-62A. If Stopyt-62PL successfully passes HCF testing Rolls-Royce will be likely be able to substantiate the alternative for use in the manufacture of WCFBs.

Rolls-Royce has been in discussion with Morgan Advanced Materials and another two potential alternatives to DEHP will be available for test in the event of Stopyt-62PL failing final testing. The final formulations are yet to be agreed and will be dependent on the outcome of testing.

Rolls-Royce requests Authorisation for continued use of DEHP beyond the expiry date of the current Authorisation 21st February 2022. This is a business-critical requirement for Rolls-Royce. Failure to obtain Authorisation would result in major disruption to our global aircraft engine manufacturing output, with the possibility of all European manufacturing being relocated outside the UK and Europe in the medium-term. It is noted that our key aero-engine competitors are both based in the United States and are affected by REACH to a lesser extent.

10. REFERENCES

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Annex – Justifications for Confidentiality Claims

N/A – no confidential information is claimed