SUBSTITUTION PLAN

Legal name of applicant(s):	*Rolls-Royce plc*
Submitted by:	*Rolls-Royce plc*
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

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 Substitution Plan 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: DPlease 21/8/20.

Date, Place: 21 August 2020,

Barnoldswick,

Lancashire,

UK

David Pease

Chief of Manufacturing Engineering

Wide Chord Fan Blade

INTRODUCTION

The Rolls-Royce wide-chord fan blade (WCFB) manufacturing process uses Stopyt-62A which contains DEHP (bis (2-ethylhexyl) phthalate). WCFBs are designed to be hollow in order to save weight. This employs a unique manufacturing process developed by Rolls-Royce and employed at a manufacturing facility in Barnoldswick, UK.

First generation wide-chord fan blades, used on older engine families, use a titanium honeycomb sandwich structure, where the honeycomb is diffusion bonded between two solid sheets. The next generation of fan blades, for the latest range of engines, features 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 total quantity of DEHP imported to the UK by Rolls-Royce and used in the fan blade manufacturing process is significantly less than 1 tonne per annum. The life-cycle for DEHP terminates at the Rolls-Royce UK site where DEHP is ultimately destroyed by the very high temperature fan blade forming process. A number of risk management measures (RMMs) are employed by Rolls-Royce to protect human health and the environment from the potential risks of DEHP use. Based on the monitoring data presented in the Rolls-Royce DEHP CSR, the risks to human health and releases to the environment from the Rolls-Royce processes are considered to be acceptable (based on the RMMs in use and the extremely low risk ratios achieved). Consequently, there are likely to be no human health or environmental benefits from removing DEHP from the process.

Fan blades are safety critical components of aero-engines and any change to their design or manufacture requires extensive research, testing and regulatory approval. Rolls-Royce has worked in conjunction with a number of suppliers to date including the supplier of the currently used Stopyt-62A, Morgan Advanced Ceramics, on the research and development (R&D) of a technically and economically viable alternative to the DEHP-containing formulation.

To date, development work carried out in conjunction with Morgan Advanced Materials has developed a new formulation; Stopyt-62PL, which is the most promising substitution candidate to date for replacing Stopyt-62A. The supporting Analysis of Alternatives document contains the details of the work carried out to date during the identification and selection of trial alternatives.

Rolls-Royce's has substantial experience of engine validation and flight tests. The alternatives test program required to validate the DEHP-free formulation Stopyt-62PL is comprehensive and has not yet been completed. Therefore, a technically and economically viable alternative to DEHP-containing Stopyt-62A is not yet approved and available for use. Final equivalence testing of Stopyt-62PL is in progress with likely completion by the end of 2020. If successful, substitution planning will be required to replace the current Stopyt-62A used in manufacture of WCFBs across the Rolls-Royce engine product range. Detail of the plan and timescale required to undertake the substitution plan is contained in this document.

1. FACTORS AFFECTING SUBSTITUTION

Each Rolls-Royce engine type undergoes a rigorous development and validation programme in order to obtain approval from the European Aviation Safety Agency (amongst other aircraft safety regulatory bodies) which provides type-certification of aircraft and components. Stopyt-62A, which contains DEHP, is used in the precision manufacture of fan blades for Rolls-Royce engines. Taking into account the work to date; the process to develop, test and validate DEHP-free alternatives to Stopyt-62A has involved significant research and development costs. The current programme of development testing is planned for completion by the end of 2020. Once complete, Rolls-Royce will be in a position to agree whether the test programme undertaken for Stopyt-62PL demonstrates equivalence to the current manufacturing method for WCFBs.

The key technical and economic criteria which affect the suitability of alternatives to Stopyt-62A (i.e. replacement with a DEHP-free diffusion bonding stop-off agent) are as follows:

- Ability to print a precise pattern on the titanium blade
- Yttria pattern is held firmly in place until diffusion bonding takes place
- High diffusion bond strength achieved in non-printed areas

- Quick drying time to meet printing and assembly window
- Minimal product contamination
- Highly reproducible printing results
- Plasticiser that is less toxic than DEHP
- Plasticiser that is compatible with the other process solvents used
- Bake out temperature required
- Plasticiser with correct wettability with our alloy of titanium
- Cost-effective solution to maintain competitiveness
- If a substantial and lengthy airworthiness validation programme is required
- If an extensive non-destructive, destructive and flight testing may be required

Rolls-Royce has been fully committed to the programme of work required in the development of alternatives to DEHP. The programme of development work has identified a number of key milestones in the development of an alternative to the current standard Stopyt-62A;

Key Milestones in the development of an alternative to Stopyt-62A

Analysis of DEHP-free alternatives including:

- Validation strategy definition and requirements
- Production readiness and manufacturing capability assessment
- Chemical Safety Risk Assessment of the proposed alternatives

Analysis and validation of Alternatives including:

- Laboratory assessments including metallurgical cut-up of test specimens and blades
- Material and component testing
- Assessment of trial results and improvements
- Assessment of risks to fan blade performance and production volumes
- Assessment of solution and process modifications required
- Detailed development program with costing and board approval
- Introduction of solution and process modifications
- Production scale testing of fan blades
- Destructive testing of fan blades
- Submission of design approval changes to EASA
- Approval by EASA for safety critical fan blade modification
- Introduction of full-scale production of fan blades using DEHP-free alternative

To date, testing on the Morgan Advanced Materials product, Stopyt-62PL has been shown to demonstrate equivalence to the current standard Stopyt-62A. The decision to pursue Stopyt-62PL as an alternative to Stopyt-62A was based on the results from the technical assessment of the failed alternative previously tested; Stopyt-62G. Stopyt-62G testing initially showed favourable results in initial chemical and metallurgical testing however subsequent testing showed a lower 3-point bend (Low Cycle Fatigue) life compared to samples produced using Stopyt-62A. The specifications governing the safety critical design integrity of WCFBs do not allow for any deviation to drawing or design tolerances and lower fatigue life does not demonstrate equivalence to the current standard material. Lower fatigue life can potentially lead to premature failure of the WCFB in service thus potentially affecting the safety and integrity of the engine.

From discussions with the project and design teams some initial options to re-assess Stopyt-62G were identified. These were;

1. Repeat the 3-point bend (LCF) testing on Stopyt-62G.
2. Seek a new formulation from Morgan Ceramics and complete a full test programme

Initial LCF testing was carried out on 5 flat test pieces and 5 test blades. 1 of the test blades failed prematurely due to a defect known as "bond through" where a small area of bond was found to encroach into the stop-off pattern. All 5 of the test pieces failed prematurely of the baseline set by the current standard Stopyt-62A specimens which were tested concurrently.

The evidence gathered from the LCF test results was presented to the design and engineering authorities and it was agreed that the results were significantly different from the current standard that the test methodology could be discounted for the difference in results and there would be no value from repeating the testing.

The results were shared with Morgan Advanced Materials and agreement was made to develop and test an alternative formulation; Stopyt-62PL.

Stopyt-62PL is a follow-on reformulation of Stopyt-62A and Stopyt-62G. Stopyt-62G used Glycerol as the plasticiser in the mixture instead of DEHP. Glycerol was initially chosen due to having a similar boiling point to DEHP and was therefore expected to exhibit similar performance in the bake out process. After showing unfavourable results, the Glycerol was substituted with Triethylene glycol bis (2-ethylhexanoate). Triethylene glycol bis (2-ethylhexanoate) also chosen due to having similar chemical properties to DEHP. At the time of the submission of the original request for Authorisation, Triethylene glycol bis (2-ethylhexanoate) had not yet been identified by Morgan Advanced Materials as a suitable candidate for substitution of DEHP in Stopyt formulations.

A feasibility testing programme to validate Stopyt-62PL was agreed and funding allocated to carry out technical feasibility assessment consisting of;

- SIMS chemical composition analysis of the bonded surfaces following bake out
- Metallurgical assessment of the internal blade cavity to assess microstructure and check for contamination
- 3-Point bend testing (LCF)
- Full blade HCF testing

The use of Stopyt-62PL will be required across both Civil and defence engine programs. The differing nature and operating conditions of the end products that the fan blades are used in means that there are differences in the required validation strategies. The specific validation strategies were agreed by the different Rolls-Royce Design and Engineering authorities.

US Export control requirements do not allow for read-across validation of Civil and Defence programmes. For example; If the alternative solution is a technically feasible solution for the Civil Testing programme, those applicable product-controlling Rolls-Royce and Customer standards and specifications and do not also allow the alternative to be used on defence parts. An independent test programme for defence is mandated by the controlling authorities.

Two clearly defined sets of validation requirements were identified in order to be able to validate the change to Stopyt-62PL (Table 1).

	Validation Requirements	Civil	Defence	Comments
1	HCF testing on a minimum of 4 x Civil Trent 900 WCFB and compare to baseline validation data.	√	Customer requirements will preclude reading civil validation across to Defence programme	Historical data exists for review and comparison from introduction of Stopyt-62A production method. This data is available for different engine programs.
2	HCF testing on a minimum of 6 x Defence WCFB and compare to baseline.	US export control requirements will preclude reading Defence validation across to civil blades	Back to back testing required - 12 of (6 current standard 62A vs 6 proposed 62PL).	Investigate Defence test methodology. Blade to block assembly proposed however no historical data exists for blades assessed using this method. Method proving will be required.
3	Specimen HCF testing to compare Stopyt-62A to 62PL	√	√	
4	SIMS to compare Titanium 6-4 material at the internal surface coated with 62A and 62PL	√	√	Chemical compositional analysis to check for contamination.
5	Blade standardisations (Laboratory metallurgical assessment) - 1 x Trent 900 1 x Trent XWB-84 and 1 x Trent 700	√	X	To be done in house at Barnoldswick facility.
6	Blade standardisations (Laboratory metallurgical assessment) - 1 x Defence blade	X	√	To be done in house at Barnoldswick facility
7	Report on viscosity and adherence of Stopyt-62PL to blade panels	√	√	Required to assess application & screen-printing methodology.
8	Carry out trials to demonstrate that the bake out cycle is still sufficient to remove the binder	√	√	This test is carried out to ensure all Triethylene glycol bis (2-ethylhexanoate) is removed
9	Provide evidence that the misprint and touch up rate is unaffected by use of alternative	√	√	Screen printing method and application validation
10	Compressors Engineering and design authorities to review and endorse the change	√	√	
11	Peel test	To be included in supporting evidence	√	
12	Impact test / Yttria migration	To be included in supporting evidence	√	
13	Frequency test	X	√	As delivered from Barnoldswick

Table 1: Civil and Defence programme validation requirements for Stopyt-62PL in WCFB manufacture

3. 2. LIST OF ACTIONS AND TIMETABLE WITH MILESTONES

The actions and milestones listed in Table 2 represent the current plan that Rolls-Royce are following in order to validate the use of Stopyt-62PL for use as a replacement to Stopyt-62A in WCFB manufacture.

Ref.	Milestones and Objectives	Key Actions / Comments	Status (at time of submission)
1	Receive Morgan Ceramics development product 62PL	Review SDS sheet and implement appropriate risk control measures to allow use during testing and trials. Initial feasibility and qualification of 62PL was carried out by Morgan Advanced Materials on small scale trial batches of material	Completed August 2018 This date refers to the supply of production batch of material which was used to undertake the test programme.
2	Print A4 test panels using Stopyt-62PL	Clean down and decontaminate print area then repeat to remove the potential for cross contamination	Completed August 2018
3	Diffusion Bond (DB) test pieces	Manufacture test pieces to analyse bonding requirements and function of 62PL	Completed August 2018
4	Manufacture 3-point bend (LCF) test specimens (Production blades and test pieces)	Obtain materials and manufacture required test specimens	Completed September 2018
5	Produce Statement of Requirements for external testing and secure quotes	Engage external test house to produce analysis plan and quotation	Completed September 2018
6	SIMS testing and reporting of results for review.	External laboratory work required to carry out chemical composition analysis of test specimens following DB.	Completed May 2019
7	3-point bend (Low Cycle Fatigue) testing	Plan required for "time on test" of specimens.	Completed June 2019
8	3-point bend (Low Cycle Fatigue) test reporting and review of results.	Analysis and review of results required prior to issue of report. Report presented to design and engineering control authority for review.	Completed August 2019
Test WCFB Manufacture			
9	Print blades for standardisation cut-up. Cross engine projects required. 1 Trent 700 or Trent 800, 1 Trent 1000, 1 Trent 900, XWB & Defence blades.	Allocate material and slot in production schedule to manufacture test blades using Stopyt-62PL. Gap in production required to allow for cleaning to remove cross contamination risk. Test blades will follow full manufacture route and be allocated development part number to ensure there is no engine project risk from development	Completed January 2020

		blades potentially being built into an engine.	
10	Manufacture 4 x Trent 900 blades for HCF testing	Allocate material and slot in production schedule to manufacture test blades using Stopyt-62PL. Gap in production required to allow for cleaning to remove cross contamination risk. Test blades will follow full manufacture route and be allocated development part number to ensure there is no engine project risk from development blades potentially being built into an engine.	Completed January 2020
11	Manufacture 12 (6 x back to back) Defence blades for HCF testing. 6 off Current 62A and 6 off New standard 62PL blades required.	Allocate material and slot in production schedule to manufacture test blades using Stopyt-62PL. Gap in production required to allow for cleaning to remove cross contamination risk. Test blades will follow full manufacture route and be allocated development part number to ensure there is no engine project risk from development blades potentially being built into an engine.	Completed March 2020
Qualification Testing			
12	Laboratory - Conduct peel test for yttria migration	In house testing	Completed February 2020
13	Laboratory - Conduct impact test for yttria migration	In house testing	Completed February 2020
14	Laboratory - Report approval testing of Stopyt 62PL to internal Rolls-Royce consumable specification	Review results and report results to engineering and design authority.	Completed February 2020
15	HCF testing at MTOC Germany - Civil project	**Delays to testing as a result of failed test hardware at supplier (MTOC). New fixture and tooling required to hold blade and carry out testing.**	1st Blade planned for test Week 3 August 2020
16	HCF testing at Indianapolis - Defence project	**Delays in testing as a result of test method validation. Testing trials of fixture method failed. New fixture method being developed and manufactured.**	1st Blade planned for test Week 3 September 2020
17	HCF test reporting and results - Civil Project	Results and reports will be reviewed by design and engineering authority	Planned for completion by end of Q4 2020. Final date will be dependent on test plan and results.

18	HCF test reporting and results – Defence Project	Results and reports will be reviewed by design and engineering authority	Planned for completion by end of Q1 2021. Final date will be dependent on test plan and results.
19	Frequency test 10 x DEFENCE blades in the finished condition		Completed March 2020
Final Approval by design and engineering authority			
20	Final Stopyt-62PL reports for FPA. Internal and external reports to be collated	Laboratory and HCF test results to be reviewed and reports to be issued and approved by design and engineering authorities.	Planned for completion by end of Q2 2021. Final date will be dependent on test plan and results.
21	FPA Validation and final buy off by design and engineering authority.	Final stage in the change control process to allow the product change to be validated for use during manufacture of fan blades. This final approval will be carried out by the appropriate design and engineering authorities.	Planned Q1 2021
Material Introduction activity and stock control			
22	Introduction of material into plant. (New Work Instructions, Risk Assessments, training COSHH etc)	Approval of change and review of change control documentation and specifications	Planned Q2 2021
23	Manufacture production set of blades with new alternative material.	Production areas will need to be cleaned and all potential sources of contamination from current standard Stopyt-62A must be removed.	Planned Q2 2021
24	Burn down current standard material and introduction of new standard stock.	Any stock of Stopyt-62A must be removed from the production plant to remove the potential for cross contamination of old and new product. In order to minimise environmental risk from disposal of Stopyt-62A, any stock on site, if within shelf life, will be used up. A suitable break in production will be allocated to allow for appropriate change controls to be implemented.	Planned for completion by Q2 2021

Table 2: Alternative Assessment Plan - Technical Qualification

Figure 1 shows the material qualification plan with start and end dates for each scheduled activity that is required.

Figure 1: Material Qualification Plan

		2018					2019												2020												2021					
Ref	Stopyt-62PL	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J
1	Receive 62PL																																			
2	Print A4 panels																																			
3	DB test pieces																																			
4	Produce 3 point bend specimens																																			
5	Produce SoR and secure quotes																																			
6	New SIMS & XPS testing																																			
7	Reissue and review SIMS & XPS report																																			
8	3 point bend testing																																			
9	3 point bend test reporting																																			
	Test blade manufacture																																			
10	Print blades for "standardisation" cut-up. Cross engine projects required. 1 Trent 700 OR Trent 800, 1 Trent 900, XWB & Defence blades.																																			
11	Manufacture 4 x Trent 900 blades for HCF testing (Singapore)																																			
12	Manufacture 12 (6 back to back) Defence blades for HCF testing (Barnoldswick). Current and new standard material.																																			
	Testing																																			
13	LAB - Conduct peel test for yttria migration																																			
14	LAB – conduct impact test for yttria migration																																			
15	LAB - Report approval testing of Stopyt 62PL to CSS236 (RR specification)																																			
16	HCF testing at MTOC Germany – Civil project																																			
17	HCF testing at Indianapolis –Defence project																																			
18	HCF test reporting and results – Civil project																																			
19	HCF test reporting and results – Defence project																																			

20	**Frequency test 10 x Defence blades in the Barnoldswick finished condition**																																								
	Approval																																								
21	**Final Stopyt-62PL reports for FPA (Civil and Defence)**																																								
22	**FPA validation and buy-off (Civil and Defence)**																																								
23	**Introduction of material into plant (work instructions, risk assessments etc.)**																																								
24	**Manufacture production set of blades with new material (Civil and Defence)**																																								
25	**Stock control – plan required for burn-down of current standard material and introduction of new standard stock**																																								

Planned
In progress
Complete

3. MONITORING OF THE IMPLEMENTATION OF THE SUBSTITUTION PLAN

In order to ensure appropriate governance, weekly cross-functional Integrated Project Team (IPT) sessions are in place. Progress against the testing and validation plan is reviewed at each of these sessions and minutes and actions are generated, prioritised and driven to completion in appropriate timescales. The team is a cross-functional group consisting of representatives from the relevant design and Rolls-Royce technical authorities.

Progress is also monitored at an executive level as part of the Diffusion Bond governance and Compressors Risk Review boards. The WCFB technology is a business-critical requirement for a significant number of products. Failure to substitute without Authorisation in place would result in major disruption to global aircraft manufacturing output and the possibility of all European manufacturing being relocated to outside the UK and Europe in the medium-term.

It is noted that our key aero-engine competitors are affected by REACH to a lesser extent due to location outside of Europe.

4. CONCLUSIONS

Fan blade technology is a particular source of competitive advantage and the loss of manufacture will result in Rolls-Royce being unable to meet customer demand and provide new and in-service product for aerospace gas turbine engines.

Qualification testing of a suitable alternative to DEHP containing Stopyt-62A is currently scheduled to be complete by the end of Q1 2021 for both Civil and Defence test programmes. Testing carried out to date on Stopyt-62PL has identified it as a potentially viable alternative.
Once this testing is complete a decision will be taken by design, stress and engineering authorities on whether substitution of Stopyt-62A with Stopyt-62PL can continue. 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 in a position to agree on whether to substantiate the alternative for use in the manufacture of WCFBs.

At the time of submission of the original Authorisation application there was no direct replacement alternative available in the marketplace. Rolls-Royce has been fully committed to the validation of an alternative and has made significant investment financially, in time and resource and has undertaken an extensive research and development program of work on the qualification and validation of a suitable alternative.

The objective of submitting this review report is to allow the continued manufacture of Rolls-Royce WCFBs in the United Kingdom beyond 21st February 2022 in the event that Stopyt-62PL does not demonstrate equivalence to Stopyt-62A.
If equivalence of Stopyt-62PL cannot be demonstrated, then substitution will not be possible, and the development of an alternative formulation will be required. This will consist of a further 5+-year programme of work. Rolls-Royce has been in consultation with Morgan Advanced Materials who will work to identify other potential formulations for testing, based on the knowledge gained from the current and previous programmes of work on Stopyt DEHP-free alternatives for our WCFB application.

1. REFERENCES

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ANNEX – JUSTIFICATIONS FOR CONFIDENTIALITY CLAIMS

N/A – no confidential information is claimed