TECHNOLOGICAL TESTS REGARDING THE QUALIFICATION OF THE REACH COMPLIANT SURFACE TREATMENT PROCESSES FOR HELICOPTER DYNAMIC SYSTEMS

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Abstract

REACh regulation imposes to European industrial companies to apply viable alternatives for the components which contain hexavalent chromium from 2017. Hexavalent chromium is mainly used in surface treatment operations, which affect the strength relevant properties of the helicopter components, such as the fatigue behaviour as well as the resistance against wear, fretting and corrosion. The components of the helicopter's dynamic system treated by alternative surface treatment processes have to be certified after the qualification of the REACh compliant processes.

This paper presents a technological test program used for determining the performances of the proposed REACh compliant surface treatment processes compared to the current ones. One key issue for the dynamic system components is the contact between two components for which new surface treatments will be applied. In order to determine the contact pairs to be tested, a complete screening of the critical components of the dynamic system has been performed, whose failure is catastrophic (e.g. rotors, gearboxes, etc.), and representative technological samples have been designed. This technological test program includes the fretting wear tests for different plane to plane contacts, fretting fatigue tests in cylinder to cylinder contacts, corrosion tests inside bolted connections and the combined wear-corrosion tests. The principle is to compare each time the current design with the REACh substitutes. Depending on these tests results, some complement can be done in case of differences observed or some additional specific tests can be required based on the service experience coming from the development and/or major incidents. The results of the technological test provide not only a performance check required for the certification of the REACh compliant products, but also an extensive experimental knowledge on the fatigue, wear, corrosion and fretting resistance of the materials used in the aerospace industry.

1. INTRODUCTION

REACh (the Registration, Evaluation, Authorization and Restriction of Chemicals) is a European regulation managed by the European Chemicals Agency (ECHA) based in Helsinki, Finland. The purpose of this regulation is three-fold:

- To ensure a high level of protection of human health and the environment from the risks that can be posed by chemicals,
- To promote alternative test methods,
- To support the free circulation of substances on the internal market.

Manufacturers putting products on the market in the European Economic Area (EEA) have to ensure that they follow all obligations put in place by the REACh regulation. Challenged by the REACh requirements, Airbus Helicopters is fully committed to the progressive retirement of Substances of Very High Concern (SVHC) -in particular Hexavalent Chromium- from all aircrafts, products and manufacturing processes.

Complying with REACh regulation is not only an important requirement for the entire aerospace industry, but it is also an opportunity for the companies -and also for their suppliers- to demonstrate their commitment to safety in products and operations for the benefit of employees, customers and the environment. Therefore, besides contributing to the common goal of a protected environmental future, Airbus Helicopters takes the process of implementation of REACh compliant substances as an opportunity to improve its processes and products.

This paper presents a technological test program used for determining the performances of the proposed REACh compliant surface treatment processes compared to the current ones.

2. AIRBUS HELICOPTERS' REACH SUBSTITUTION PROCESS

Two official REACh lists are of main importance for Airbus Helicopters:

- Annex XIV: List of substances that are banned on a defined date (sunset date).
- Candidate list: List of substances that are candidate to be banned in the next years.

According to this, for any new aircraft, the use of Annex XIV and candidate list substances shall be prohibited. For running programs, Annex XIV and candidate list substances shall be replaced as soon as the appropriate alternatives are qualified, design is modified and the supply chain implementations has started .The subject of converting supply chain processes is organized in collaboration with the suppliers in order to ensure the progressive and appropriate eradication of hazardous substances.

To ensure timely and effective adherence to the REACh process and timeline, Airbus Helicopters has established a transversal organization – the Hazardous Material (HazMat) Program – with a team dedicated solely to coordinate the activities in line with REACh requirements.

Airbus Helicopters' REACh substitution process consists of three phases: Regulatory Survey, Preparations, Impact Analysis and Substitution (see Figure 1).

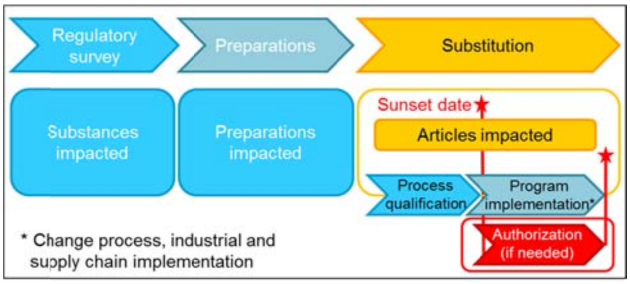


Figure 1: Global Substitution Process.

The HazMat Program has completed Airbus Helicopters' Regulatory Survey (the identification of substances impacted) and the identification of impacted preparations containing those substances used in Airbus Helicopters' site.
Based on Regulatory Survey, the following substances have been identified as priority for substitution:

- Trichloroethylene
- Chromium (VI) trioxide
- Sodium dichromate
- Potassium dichromate
- Dichromium tri(chromate)
- Strontium chromate
- Potassium hydroxyoctaoxodizincatedichromate
- Pentazinc chromate octahydroxide

In addition to these substances, Cadmium replacement for surface treatments is also considered a priority by Airbus Helicopters. Ten technical working groups were established to deal with the substitution of impacted preparations. Each group will ensure that the concerned substance is eliminated in accordance with the final application date and sunset date listed in the table below.

Table 1: Technical Working Groups for Substitution.

	Topic	Last Application Date	Sunset Date
1	Cadmium Plating + Chromium VI Passivation	21.03.2016	21.09.2017
2	Hard Chromium Plating	21.03.2016	21.09.2017
3	Chromic Acid Anodizing for Corrosion Protection + Dichromate Sealing (CAA)	21.03.2016	21.09.2017
4	Chromic Acid Anodizing for Bonding Application	21.03.2016	21.09.2017
5	Aluminium Chromate Conversion Coating (CCC)	21.03.2016	21.09.2017
6	Chromate Painting Primer P05/P20 & Wash Primer P15	22.07.2017	22.01.2019
7	Magnesium Chromate Conversion Coating	21.03.2016	21.09.2017
8	Manufacturing processes: Trichloroethylene, Sulfochromic Pickling	21.10.2014	21.06.2016
9	Corrosion Protective Sealant Mastinox 6856K	22.07.2017	22.01.2019
10	Chromate Bonding Primers	22.07.2017	22.01.2019

Here, the "Last Application Date" defines the date by which applications for authorization must be submitted to allow continued uses after the sunset date until a decision on the application for authorization is taken, whereas the "Sunset Date" is the date from which placing on the market is prohibited unless authorization is granted.

In the following section, processes in the working groups mentioned above, their application areas as well as their REACh compliant potential substitutions are mentioned briefly.

2.1. Technical Working Group 1

This technical group includes the substitution of cadmium plating with chromium VI passivation including local touch-up by brush plating, which is mainly applied for corrosion protection, especially in dynamic components and fasteners.

Since this process includes substances such as Chromium trioxide and Sodium dichromate substances, it has to be replaced by a REACh compliant substitute.

The selected alternative is similar to cadmium plating in performance (in particular, in corrosion, thickness ranges, local touch-up feasibility, etc.) and needs to be associated with friction control lubricant on fasteners. The deployment in the supply chain is under analysis.

2.2. Technical Working Group 2

In this technical group, the replacement of hard chromium plating is investigated. The process is applied for the purpose of fretting and wear protection. For several applications, alternative solutions are already qualified: hard coatings deposited by thermal spray. The current in-progress approach for these alternatives is to select the best candidates and launch the design changes.

2.3. Technical Working Group 3

Chromic Acid Anodizing (CAA), dichromate sealing including local touch-up by brush anodizing is mainly applied for corrosion protection of light alloy parts (with or without painting). The process contains Chromium trioxide and Potassium dichromate.

For new programs, an alternative solution standard associated with Chromate sealing, is already qualified and used already since several years for some applications. The second step, which is under investigation, is to associate this anodizing with Chromate-free sealing. Associated local touch-up by brush anodizing are under evaluation.

For running programs, with the objective of having less impact on the supply chain, two thin film anodizing methods are under investigation.

2.4. Technical Working Group 4

This technical group includes the substitution of Chromic Acid Anodizing for bonding applications used mainly for light alloy corrosion protection for structural bonding. The process includes Chromium trioxide to be eliminated.

For structural bonding of such parts, an alternative anodizing process which supplies adequate properties to replace Chromic Acid Anodizing (CAA) prior to bonding primer application is under qualification in Airbus Helicopters plants. The deployment in the supply chain is under analysis.

2.5. Technical Working Group 5

In this technical group, the replacement of Chromate Conversion Coating (CCC) is investigated. The process is applied for surface preparation of light alloys before painting and includes Chromium trioxide as well as Dichromium tri(chromate) (for touch-up) to be eliminated.

Here, alternative processes were identified, have been tested for replacement of CCC process.

2.6. Technical Working Group 6

In this technical group, the replacement of chromate painting primer & wash primer is investigated. These primers that contain Strontium chromate, Potassium hydroxyoctaoxodizincatedichromate and Pentazinc chromate octahydroxide are to be eliminated.

Today, chromate painting primers are used for application on metallic parts (aluminium, magnesium, steels, titanium, stainless steels) to not only ensure corrosion protection on single parts, but also to provide electrical isolation in assembly, and mechanical protection during maintenance and assembly. The alternative must guarantee the same level of performance. This is a real challenge that leads common efforts between Airbus Helicopters and paint suppliers. In association with paint suppliers, the first screenings of alternatives have been performed and two different chromate-free high solid products were selected for the qualification process. In parallel, other emerging products are under evaluation.

Chromate wash primer has also a large scope of applications on metallic parts not only for adhesion but also for corrosion protection. Here again, the first screenings of alternatives have been performed with paint suppliers and two different chromate-free products were selected for the qualification process.

2.7. Technical Working Group 7

Magnesium Chromate Conversion Coating including local touch-up applied mainly for corrosion protection and surface preparation before painting. The process contains Potassium dichromate to be eliminated.

For the replacement of Magnesium Chromate Conversion Coating several chromium-free chemical conversion products are under evaluation.

2.8. Technical Working Group 8

In this technical group, the replacement of Trichloroethylene and the replacement of Sulfochromic etching applied for surface preparation are investigated. These treatments contain Trichloroethylene and Chromium Trioxide respectively, which should be eliminated.

For some applications, Sulfochromic etching has been replaced and implementation is in progress. Sulfochromic etching before CCC and CAA is still under qualification phase.

For main Trichloroethylene applications, alternative solutions are qualified and implemented.

2.9. Technical Working Group 9

This technical group includes the substitution of chromic sealant Mastinox applied almost in all of the assemblies as a sealant for galvanic corrosion. Mastinox is a chromate-based sealant and includes strontium chromate. This sealant is now replaced by a chromate-free product from the same manufacturer. Implementation is in progress.

2.10. Technical Working Group 10

This technical group includes the substitution of Chromate Bonding Primers MB 6726 and BR127, which include strontium chromate to be eliminated. MB 6726 is now replaced by EC 3909. Several alternatives to replace BR 127 are under investigation.

3. COMPATIBILITY ANALYSIS OF THE SUBSTITUTES BY TECHNOLOGICAL TESTS

Global equivalence of the current surface treatments and their REACh compatible substitutes is demonstrated by technological tests. The technological test program which is presented in this paper deals only with the components of the dynamic systems. Airframe components are not included in this work.

The qualification process of the substitutes is carried on by the Airbus Helicopters' Laboratory Materials & Processes (LMP). This department is in charge of finding the most convenient process to replace the current one following a specification and to do qualification of the new process. In addition to the qualification of the processes, the qualification of the affected components has to be ensured as well. For that purpose, the performance of the REACh compliant surface treatment processes is tested by the technological test program.

A change in the surface treatment of mechanical components of a helicopter is an important issue regarding the performance of the affected component, in particular in wear, fretting and corrosion occurrence as well as fatigue behaviour.

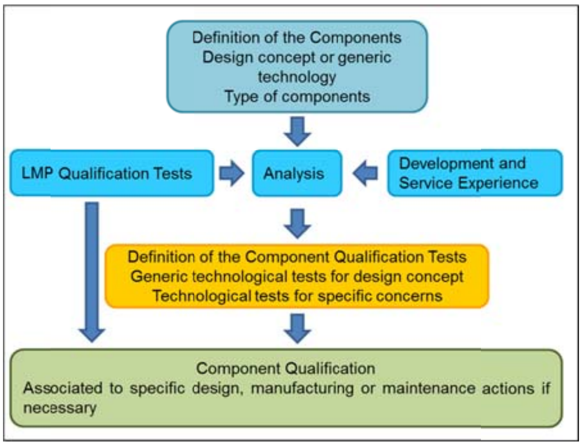


Figure 2: Qualification process for the alternative substitutes.

The aim of the proposed test program is to compare the performance of the new treatments with the current ones by coupon tests. The proposed test program includes specific tests for the analyses of:

- The wear (fretting wear) for different contacts,
- The corrosion inside bolted connection for different contacts,
- The combination of the wear and corrosion,
- The fretting fatigue.

The principle is to compare each time the current surface treatment process, which includes hazardous substances, with their REACh compliant alternatives. The different tested configurations are issued from a screening of the mechanical components of the dynamic systems of all the products. After listing the affected components, the corresponding material pairs to be analysed were determined. The most representative material pairs of the contact pairs were then tested.

In order to analyse different contact pairs, different working environments and different mechanical properties, which can be affected by surface treatments, four different tests are included in the technological test program:

- Fretting wear: "Pin on disc"
- Fretting fatigue: Clevis Test
- Fretting fatigue and corrosion: Clevis Test
- Specific tests if required

Each test has a specific goal: the wear analysis, the fretting fatigue life limit determination, the cumulated wear and corrosion resistance estimation. Each time, the comparison between the existing surface treatment process and its REACh compliant substitute process is performed.

3.1. Fretting Wear Test

The aim of this test is to identify the wear response of the two materials in contact. In that way, it is possible to compare the actual treatment which is not REACh, to the proposed treatment in accordance with REACh requirements.

These tests are realized using the fretting machine available at the test laboratory. Figure 3 presents the test principle.

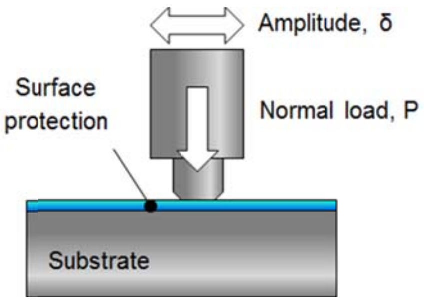


Figure 3: Fretting wear test principle.

Here, a plane pin is put in contact with a plane sample. In this way, a representative plane vs. plane contact is realised.

During test, a normal force P, is applied and a relative displacement δ, is imposed with a given frequency. The normal force has to be representative. For this reason, the loading conditions are precised for each pairs of tests. In this way, it can correspond to the specific contact pressure of the mechanical components under investigation. The test is performed at a certain frequency for predefined number of cycles.

The wear resistance of the investigated contact pair is analysed in two ways:

(1) During the test: The normal and tangential force, the imposed displacement and the friction coefficient are recorded. A coating wear can be identified by the evolution of the friction coefficient during the test as a function of time.

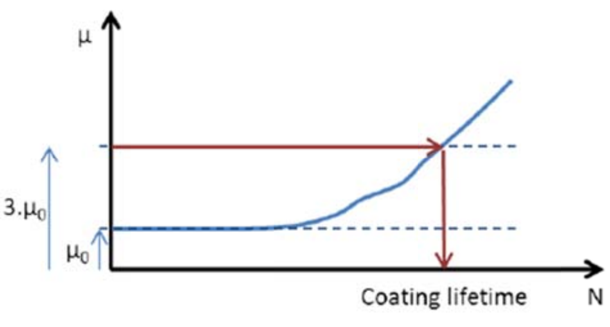


Figure 4: Identification of the coating lifetime.

(2) After the test: the wear resistance is quantified by means of a 3D interferometry. The wear volume of the plane sample is calculated from the surface profile.

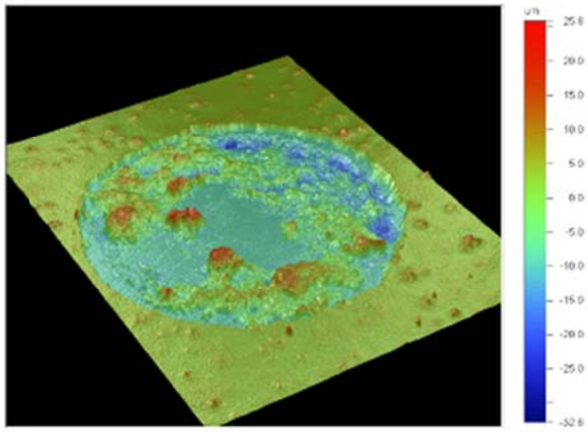
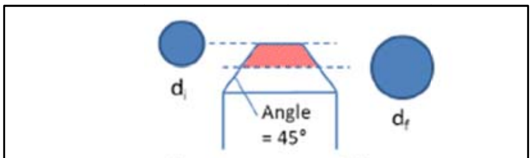


Figure 5: Wear profile measured after the test [1].

Pin wear volume is quantified from pictures of the surfaces before and after the test. A description is given in the following sketch.



$$Volume = \left(\frac{\pi \times (d_f - d_i)^2}{4}\right) \times (d_f - d_i)$$

Figure 6: Wear volume of the pin.

The overall wear volume is then the sum of the two wear volumes.

3.1.1. Friction Coefficient Analysis

Performance of the REACh compliant substitute is considered as equivalent to the current treatment if the friction coefficients are in the same range or if the friction coefficients induced by the substitute is higher than the one induced by the actual treatment as long as it is equivalent in wear.

Figure 7 illustrates the comparison of the friction coefficients of Cadmium plated surfaces and their substitues. It can be seen that the friction coefficients of the substitute plated surfaces are similar to the Cadmium plated ones.

A similar comparison was done for the Chromic Acid Anodizing (CAA) process versus its two alternative substitues. As a first impression, the substitute processes are promising alternatives for CAA process (see Figure 8). However, for some contact pairs additional investigations by means of clevis and assembly tests are needed for a final statement.

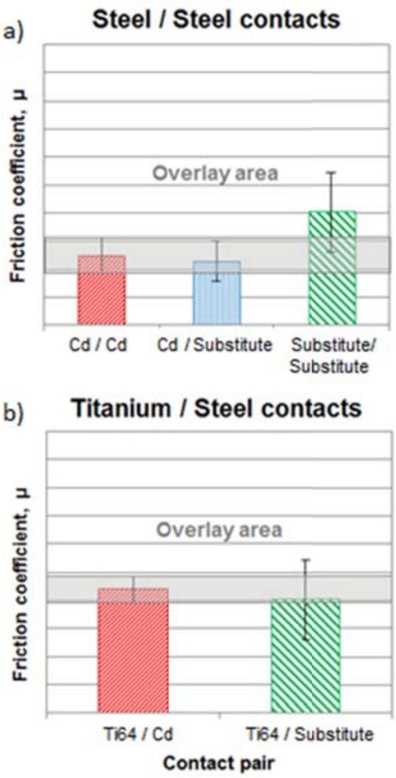


Figure 7: Comparison of friction coefficients of Cadmium versus alternative substitute plated contact pairs: (a) steel/steel contacts, (b) titanium/steel contacts.

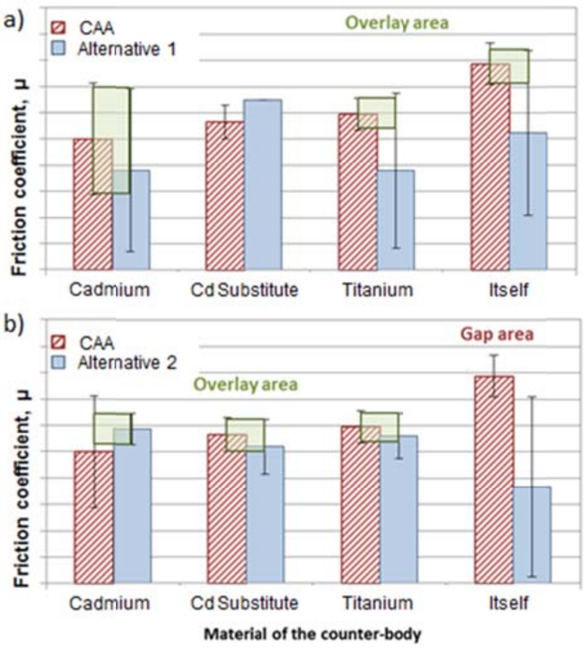


Figure 8: Comparison of friction coefficients of Chromic Acid Anodized surfaces versus two alternative substitutes.

3.1.2. Wear Rate Analysis

Concerning the wear rates of the tested material pairs with the corresponding surface treatments the following results are reported.

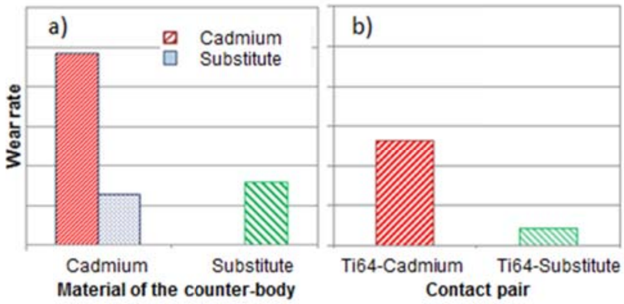


Figure 9: Comparison of the wear rates of Cadmium and substitute platings: (a) steel/steel contacts, (b) titanium/steel contacts.

Figure 9a, presents the calculated wear rates as a function of the contact pair. Here, the wear rate is calculated by the measured wear volume divided by the cummulated dissipation energy. According to this, the highest wear rate is observed for the Cadmium/Cadmium contact. The introduction of the substitute substance in the contact leads to lower wear rates, for the same testing parameters. The same analysis is performed for the contacts with titanium as well. Figure 9b illustrates the wear rates of the when the contact pad is made of Titanium. Measured wear rates is again smaller for the substitute substance than for the Cadmium.

The wear rates of the Chromic Acid Anodized (CAA) surfaces versus their REACh compliant alternatives were also analysed in the same way. Figure 10a illustrates the wear volumes of the CAA and the alternative substitutes as a function of the cumulated dissipated energy for homogeneous contacts, i.e. aluminium versus aluminium contacts. It can be concluded that all are equivalent regarding wear rates.

In Figure 10b, the wear rate of the aluminium which is treated with alternative surface treatments against Cadmium and alternative substance plated steels is shown. Here again, the alternative surface treatments are equivalent to CAA regarding wear rates when there are in contact with Cadmium or alternative plated steels.

Titanium vs. aluminium contact (with CAA and substitute substance) is compared in Figure 10c. Measured wear rates are very small. In that sense, all substances show equivalent behaviour regarding wear rates when they are in contact with titanium.

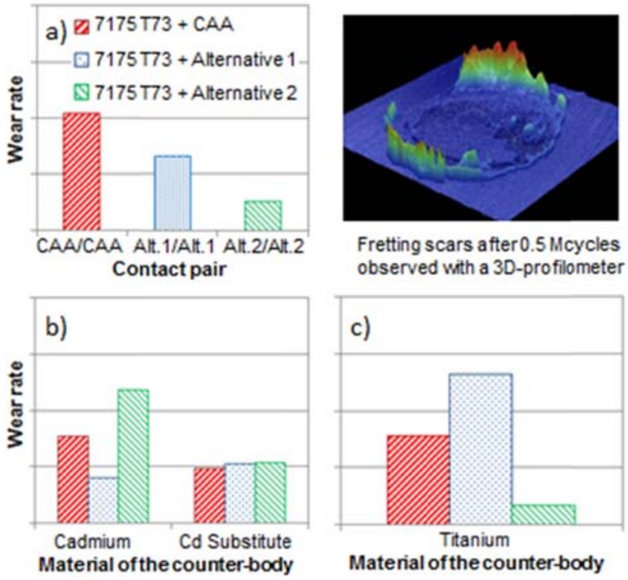


Figure 10: Wear rates of CAA and the proposed substitutes for: (a) aluminium/aluminium, (b) aluminium/steel and (c) aluminium/titanium contact pairs.

3.2. Fretting Fatigue Test

The aim of this test is to identify the behaviour of a contact between a clevis and a bushing regarding fretting fatigue. In that way, it will be possible to compare serial treatments (CAA on aluminium alloys, Cadmium plating on steels etc.) which are concerned by REACh with new surface treatments in accordance with the REACh legislation.

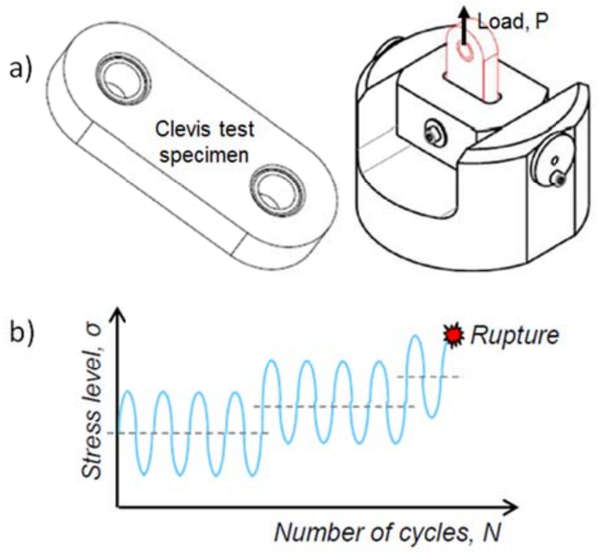


Figure 11: a) Schematic illustration of the specimen and experimental device, b) applied fatigue loading.

Figure 11a illustrates the test sample utilized for testing. Bushings inside the lugs are made of passivated stainless steel, which are placed inside the lugs with certain interference. A fatigue load is applied to the clevis sample until it brakes at the interface between the bore and the bush. Applied fatigue load is increased on many levels, e.g. after each 1 Mcycles (Figure 11b). In this way, the fatigue limits of different material combinations with fretting are evaluated in a cylinder/cylinder contact.

The results are illustrated in Figure 12. Here, a Gaussian repartition of the fatigue results is presented for the statistical comparison, which is a function of the mean fatigue limit of the tested specimens and the scatter factor of the results. It can be seen that the selected substitute is equivalent to Cadmium plating in terms of fretting fatigue loading on clevis (see Figure 12a).

A similar result is obtained for the alternative substances of CAA in Figure 12b. The analysis shows that the fatigue limits with fretting of the alternative substitutes are higher than that of the current CAA treatment. They are both better under fretting fatigue loading.

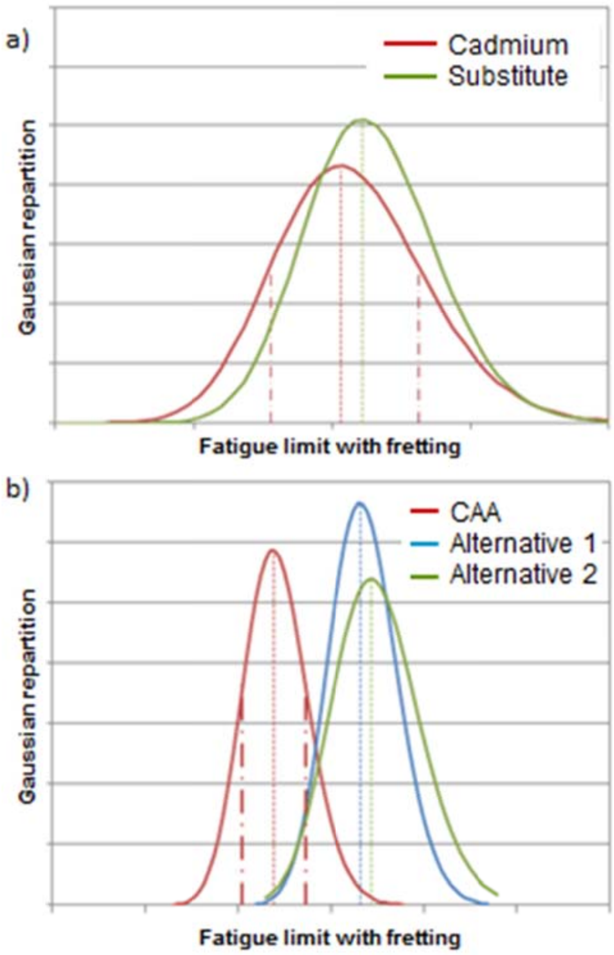


Figure 12: Gaussian repartition against fatigue limit with fretting of: a) Steel plated with Cadmium and its substitute, b) CAA and the two other substitutes.

3.3. Fretting Fatigue and Corrosion Test

The aim of this test is to compare fatigue and corrosion resistances of different surface treatments in a single test. The test allows for analysing the fretting through contact between screws and bushings. Moreover, wear through contact between clevis and washers can be observed. Since the test is done partially under salt spray environment, the corrosion of the whole system as a function of time can be determined.

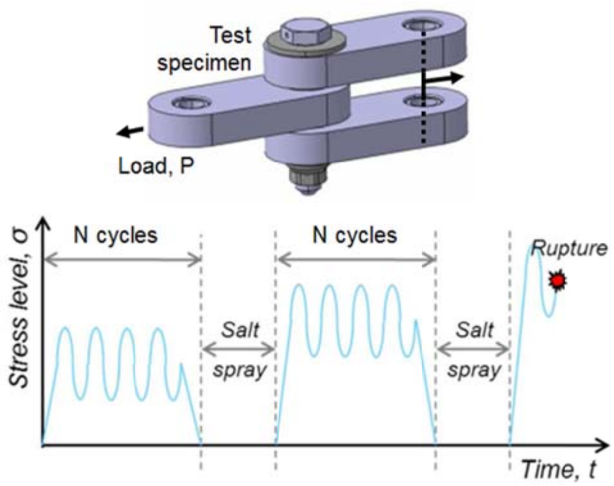


Figure 13: Schematic illustration of the specimen and applied fatigue loading with salt spray exposure.

In performing this test, fatigue loading is applied with loads representating the flight loads during N cycles. After completing this block, the specimen is disassembled from the bench and exposured to salt spray for some predefined hours (see Figure 13). Then, the system is assembled again on the bench with same tightening parameters. The fatigue loads are increased. This block is repeated until the complete failure of any part of the assembly.

The tests and their evaluation are still in progress. The results will reveal the performance of the surface treatments of the assemblies with complex contacts working under dynamic loading and in aggressive environmental conditions.

3.4. Specific Corrosion Tests

Especially for the parts working under corrosive environments, some additional tests are included in the test program. In order to analyse the effect of containment on corrosion, a special test setup was designed, in which the surface of a part is covered partially with a containment sheet with certain gap to the surface. The part is exposed to a corrosive environment. The nucleation and the growth of the corrosion pits underneath the contained surface are observed at certain time intervals. Furthermore, some further specific tests for the determination of the effect of different surface treatments on the galvanic corrosion of the parts, which are in contact with dissimilar materials, are also included in the technological test program.The specific corrosion tests mentioned above are still in progress. The results will reveal the performance of the substitutes for the corrosion resistance of the components under investigation.

4. SUMMARY AND CONCLUSIONS

A technological test program was presented for determining the performances of the proposed REACh compliant surface treatment processes compared to the current ones. This technological test program includes the fretting wear tests for different plane to plane contacts, fretting fatigue tests in cylinder to cylinder contacts, corrosion tests inside bolted connections and the combined wear-corrosion tests. The principle is to compare each time the current design with the REACh substitutes.

The following conclusions can be done based on the test results performed so far:

Tribological behavior:

- The selected substitute for Cadmium plating performs better than Cadmium plating itself regarding the friction and wear properties,
- Concerning the surface treatments of the aluminium, alternative substitutes are equivalent to CAA for wear properties. However, some further investigations by means of assembly tests are required due to differences in friction coefficients of some contacts.

Fretting fatigue resistance:

- The selected substitute for Cadmium plating is at least equivalent to Cadmium plating regarding the fretting fatigue resistance,
- The two alternative substitutes are both better than CAA for fretting fatigue resistance.

In addition to these results, numerous further tests are in progress, the results of which will allow for determining fretting, wear and corrosion resistances of the assemblies. All the technological tests presented in this paper will be performed for the comparison of different surface treatment alternatives of the different technical working groups.

The presented technological test program and the methodology for substituting the existing surface treatements with the environmentlly friendly ones are very benefical to compare the performances of the alternative processes. Moreover, these technological tests provide deeper information on the fatigue properties of different materials with different surface treatments as well as on their resistance to fretting, wear and corrosion, which make it possible to improve the design activities of the current products and the new developments.

5. REFERENCES

[1] S. Fouvry, C.Paulin, S. Deyber, Impact of contact size and complex gross-partial slip conditions on Ti-6Al-4V/Ti-6Al-4V fretting wear. Tribology International, 2008.