SURFACE TREATMENT IN AEROSPACE INDUSTRY: A STUDY ON ACID PICKLING AND PAINT ADHESION

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Abstract - This paper provides an overview of the essential elements in the design and production of aviation components, namely surface treatment, acid pickling, paint adhesion, and Failure Modes and Effects Analysis (FMEA). These factors are critical in ensuring the dependability and safety of aircraft components. Surface treatment is necessary to ensure that paint and coatings adhere to the substrate, while acid pickling is used to treat surfaces and remove impurities, increasing surface roughness. The paper discusses the factors that affect paint adhesion and the procedures used to assess it. FMEA is a systematic approach used in the aerospace industry to identify potential failure modes and evaluate their severity, probability, detectability, and countermeasures. The authors highlight the importance of each of these criteria and emphasize that significant attention must be given to ensure the reliability and safety of aviation components. Careful regulation of acid application is necessary to prevent surface deterioration. Proper preparation of the surface, coating technique, and application circumstances significantly influence paint adhesion. In summary, the aircraft industry places significant emphasis on dependability and quality, and these essential elements must be considered in the design and production of aviation components.

Keywords: Surface treatment, Aerospace industry, Acid pickling, Paint adhesion, FMEA.

1. Introduction

The quality, functionality, and longevity of the components are all impacted by surface treatment, which is a critical stage in the aerospace sector. Contaminants must be eliminated, a homogeneous surface must be created, and a protective coating must be applied to stop corrosion and guarantee proper adhesion.

The current study focuses on two crucial surface-treatment factors—acidic pickling and paint adhesion—and how important they are to the aerospace sector. In the aerospace sector, surface treatment is a crucial step in improving the components' robustness, corrosion resistance, and aesthetic appeal. To increase the performance and longevity of their aircraft, which contain a variety of components like airframes, engines, and interior parts, the aerospace industry needs high-quality surface treatments. Anodizing is one of the often-employed surface treatment techniques in the aerospace sector. Anodizing is an electrolytic passivation process that coats aluminum alloys with a protective coating of aluminum oxide to boost their durability, corrosion resistance, and paint and primer adhesion [1].

Physical Vapor Deposition is yet another well-liked surface treatment (PVD). In PVD, thin films of materials, including titanium nitride (TiN), are deposited on aerospace components' surfaces to increase their wear resistance and decrease friction [2].

Chemical Vapor Deposition is a third frequently employed surface treatment (CVD). In the CVD process, gases react to form solid materials that are then deposited onto the surface of the aircraft component. Diamond-like carbon (DLC) coatings, which are renowned for their great hardness and minimal friction, are frequently applied via CVD [3].

This paper focus on paint adhesion and acid pickling as surface treatments in the aerospace sector. It discusses the steps in the process, such as the removal of smut and oxides, degreasing, and tank-rinsing, and places emphasis on the value of proper bath air agitation as well as humidity and temperature control during paint application.

To confirm that the surface treatment complies with the standards, the document also covers the final inspection process, which includes the adhesion tape test. The aerospace industry uses a systematic method known as Failure Mode and Effects Analysis to identify and evaluate potential failure modes in surface treatment operations (FMEA). The goal of FMEA is to identify potential problems before they occur and implement corrective actions to reduce the risk of failure.

The research presented in this paper adds scientific novelty to the field of aviation engineering by providing an in-depth analysis of the crucial elements that contribute to the dependability and safety of aircraft components. The study highlights the importance of surface treatment, acid pickling, paint adhesion, and Failure Modes and Effects Analysis (FMEA) in ensuring the reliability and safety of aviation components.

One of the unique contributions of this study is the detailed analysis of the factors that influence paint adhesion, including the preparation of the surface, coating technique, and application circumstances. The research also provides a comprehensive overview of the procedures used to assess paint adhesion, which can aid in the development of improved coating techniques to enhance aircraft performance and longevity.

Moreover, the paper emphasizes the importance of FMEA in the aerospace industry to determine potential failure modes, their severity, probability, detectability, and countermeasures. This approach can aid in identifying potential risks and developing strategies to eliminate or manage them, which can ultimately improve the dependability and safety of aviation components.

Overall, this study enhances the scientific novelty in the field of aviation engineering by providing a comprehensive overview of the critical elements that contribute to the dependability and safety of aviation components. The research findings can be used as a foundation for future studies and development of improved techniques to enhance the reliability and safety of aircraft components.

2. Study About the Surface Treatments

To clean metal surfaces of contaminants like rust and scale, the aerospace industry frequently uses the surface treatment method of acid pickling (figure 1). The method is submerging the metal parts in an acidic solution, where the impurities react to create a chemical compound that can be easily removed [4].

Smut and oxides produced during alkaline etching as well as the MgF2 layer are removed from the surface of parts using the acid pickling process. To get the best results, the immersion time must stay within the predetermined range.

Another crucial phase in the procedure is degreasing, where all surface impurities including oil, grease, and stains are eliminated. The concentrated solution from the earlier baths is eliminated using rinsing tanks

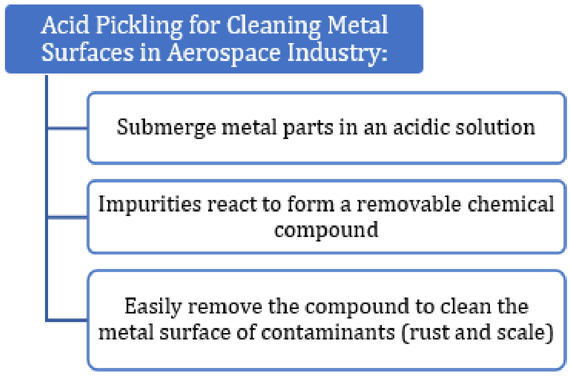

Figure 1: Acid Pickling for Cleaning Metal Surfaces

Preparing metal surfaces for further processing, such painting or plating, is one of the main uses of acid pickling in the aerospace industry. The procedure creates a smooth, clean surface that enhances the adherence and functionality of the ensuing coatings [5].

In the aerospace industry, acid pickling is also utilized to increase the corrosion resistance of metal components. The procedure cleans the surface to prepare it for the application of a corrosion-resistant coating while removing any existing corrosion [6].

In the aerospace sector, the alkaline etching procedure results in the production of smut and oxides. Alkaline etching is a typical method for treating metal surfaces that is used to remove contaminants like surface oxides and get them ready for further processing like painting or plating. To get the desired surface quality and performance, you must remove smut and oxides that the procedure may produce. Chemical cleaning is a technique used to eliminate smut and oxides produced during alkaline etching. In this procedure, the metal parts are submerged in a mixture of cleaning chemicals, such as hydrogen peroxide or nitric acid, which react with the smut and oxides to create a chemical compound that can be readily removed [7].

Electro cleaning is another technique used to remove smut and oxides. An electrical current is applied to the metal parts during the electro cleaning process, attracting, and removing the smut and oxides [8].

Due to its exceptional optical and mechanical qualities, the magnesium fluoride (MgF2) layer is a thin film material that is frequently employed in the aerospace sector. The MgF2 layer can be used in optical coatings and window materials for aerospace applications since it is transparent to visible light [9].

The MgF_2 layer is an excellent material for use in difficult situations, such as high-altitude flying, due to its optical qualities as well as its strong resistance to heat and mechanical stress. The MgF_2 layer is suited for use in shielding aircraft components from weather-related deterioration since it has great weather resistance [10]. The coating of optical windows and mirrors, which protects against atmospheric deterioration and improves light transmission, is one of the MgF_2 layer's main uses in the aircraft [11]. To increase the performance and longevity of delicate components like sensors and instruments, the MgF_2 layer is also utilized as a protective coating (figure 2) [12]. The term "immersion time" describes how long a material or component is exposed to a certain chemical or treatment solution. In the aerospace sector, immersion duration plays a significant role in determining the effectiveness and quality of surface treatments including cleaning, etching, pickling, and passivation. For instance, the duration of an acid pickling operation impacts how well the pickling will remove surface impurities and enhance the component's surface quality [13]. A short immersion period could not completely remove all impurities, while a very extended immersion time could cause over-etching and material degradation [14].

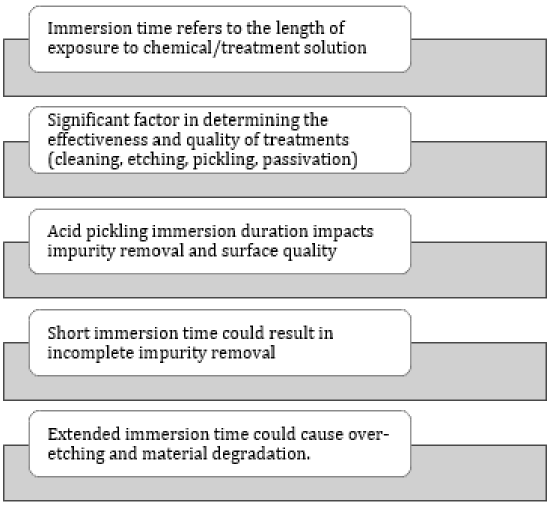

Figure 2: Immersion Time in Aerospace Surface Treatments

Like this, the alkaline etching immersion period has an impact on the consistency and uniformity of the etching process [15].

The number of oxides and smut produced during the etching process, which must be eliminated by subsequent treatments, is also influenced by the immersion period [16].

Another crucial component of surface treatment in the aerospace sector is paint adhesion (figure 3).

With DC current and immersion in an electrolyte, an aluminum oxide layer is created on the components' surfaces. Proper bath air agitation is required to achieve a consistent surface and the creation of a uniform anodic layer. To get the best results, the paint application procedure must be carried out within the required temperature and humidity ranges. The term "paint adhesion" describes a paint coating's capacity to cling to a surface and hold that position over time. In the aerospace sector, paint adhesion plays a crucial role in maintaining the toughness, lifespan, and aesthetic appeal of aircraft parts. Surface preparation, surface energy, and the characteristics of the paint itself are some of the elements that have an impact on how well paint coats adhere [17]. Cleansing, etching, and priming the surface properly can improve the paint's ability to stick to the surface [18]. In the aircraft sector, a variety of test procedures are utilized to gauge paint coating adherence. The most used techniques are peel tests, scrape adhesion tests, and cross-cut tests [19].

It is crucial to do a final inspection and adhesion tape testing to confirm that the surface treatment complies with the requirements.

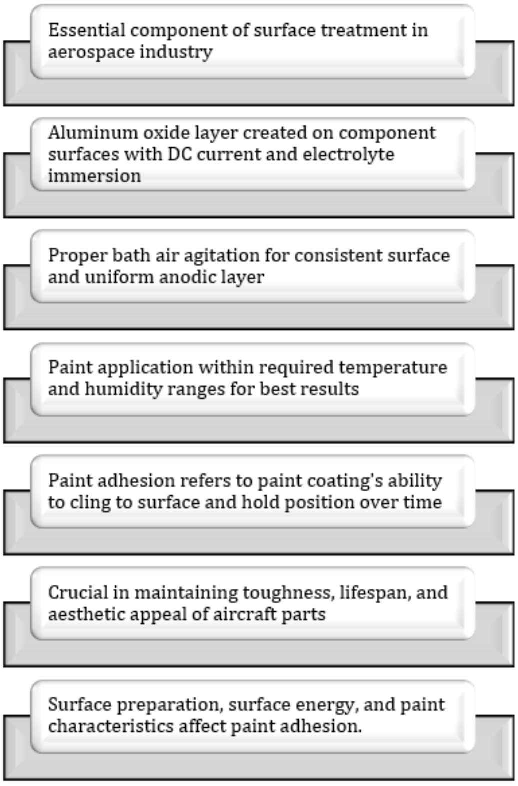

Figure 3: Paint Adhesion in Aerospace Surface Treatment

The strength of the binding between the coating and the surface is measured using the adhesion tape test, and the findings are used to decide if the surface treatment is satisfactory or whether it must be reapplied.

Final inspection ST, also known as final stage inspection, is a vital procedure in the aerospace industry that makes sure that before an aircraft component is placed into service, it satisfies the necessary specifications.

The goal of the final inspection ST is to find and fix any flaws or non-conformities that can compromise the aircraft's performance, dependability, or safety.

A skilled inspector conducts a visual and dimensional examination of the aircraft parts during final inspection ST, checks for the existence of the necessary paperwork and markings, and confirms that the parts fulfill the standards [20].

Additionally, the inspector looks for any damage, corrosion, or other indicators of deterioration that can impair the operation of the components [21] (figure 4).

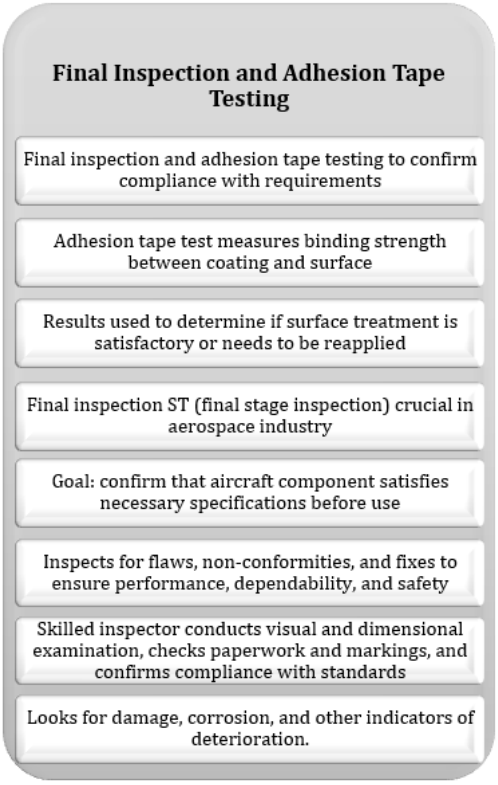

Figure 4: Final Inspection and Adhesion Tape Testing in Aerospace Surface Treatment

The aerospace industry has established standards and guidelines, such as the International Organization for Standardization (ISO) standards, the SAE International Aerospace Standards, and the National Aerospace and Defense Contractors Accreditation Program (Nadcap) guidelines, to ensure that final inspection ST is carried out consistently and effectively [22].

These standards offer a structure for carrying out final inspection ST and give everyone involved a shared knowledge of the inspection standards and procedure. The adhesion tape test is a widely used technique in the aerospace sector to assess the degree of adherence of painted and coated airplane parts. To assess how much coating or paint is still on the pressure-sensitive tape after removing it from the coating or paint surface, the test comprises applying a pressure-sensitive tape to the surface [23]. The quantity of coating or paint that remains on the tape after removal is used to calculate the adhesion strength, which is used to evaluate the caliber and toughness of the coating or paint. The adhesion tape test is frequently used in the aerospace industry because it is easy, rapid, and gives a clear indicator of how well a coating or paint will adhere [24].

Often, the test is carried out at several phases of the coating or painting process, such as after surface preparation, after the application of primer layers, and after the application of the final topcoat [25].

The aerospace industry has produced standards and criteria for the adhesion tape test, including the National Aerospace and Defense Contractors Accreditation Program (Nadcap) guidelines and SAE International Aerospace Standards [26].

These guidelines offer a framework for carrying out the adhesive tape test as well as a shared knowledge of the test requirements and procedure.

3. Surface Treatment Processes Analysed by FMEA

FMEA is used in the aerospace sector to assess surface treatment procedures including cleaning, degreasing, sandblasting, and coating [27] (figure 5).

The procedure begins with a detailed comprehension of the materials and tools utilized in the surface treatment process [28].

Using this data, possible failure mechanisms that might lead to subpar performance or even the failure of the surface treatment process are identified. The likelihood, effects, and severity of the potential failure modes are then assessed, and a strategy is created to reduce or eliminate them [29].

The capability of FMEA to proactively detect and handle possible issues in surface treatment operations is one of the primary advantages in the aerospace sector. This contributes to enhancing the surface treatment process' dependability and effectiveness, which is essential for guaranteeing the product's safety and quality (aircraft).

FMEA also increases the overall effectiveness of the surface treatment process by reducing the chance of expensive failures [30-34].

Regarding the way of notating the severity of the error:

1. Catastrophic - The error consists in the delivery of the non-compliant product to the customer. The error is not detectable. The error could have compromised the safety of the aircraft.

2. Risky - The error consists in the delivery of the non-compliant product to the customer. The error has been detected by the client. The error could have compromised the safety of the aircraft.

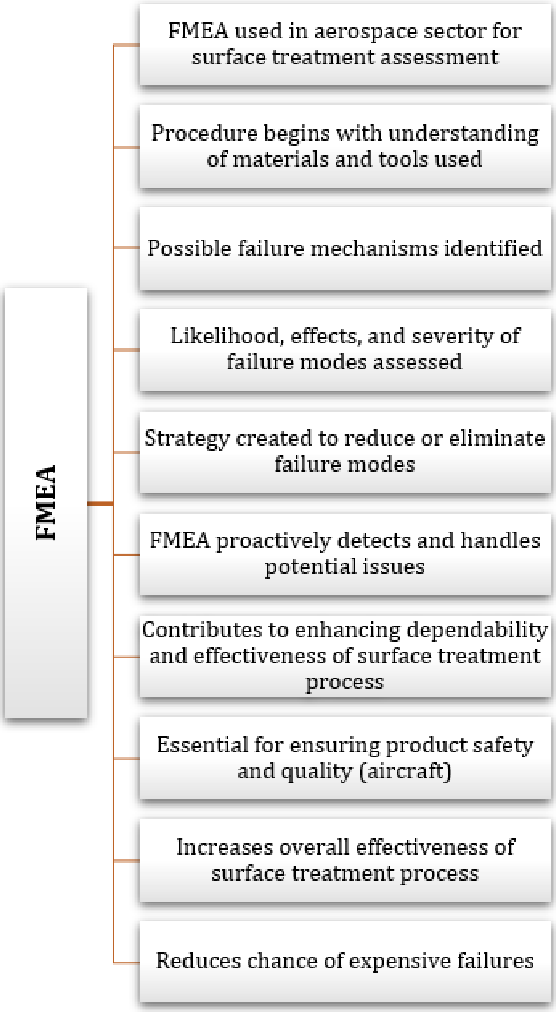

Figure 5: FMEA summary

3. Very Big - The error is delaying delivery to the customer by more than 4 weeks. Customer or final assembly line shuts down due to possible late delivery.
4. Major - The error consists in the major delay in delivery to the customer (1+4 weeks). The customer is very unhappy. The client's production may be affected, but recoverable.
5. Moderate - The error consists of a small delay to the customer (less than a week). The customer is unhappy. The client's production may be affected, but recoverable.
6. Low - The error clearly lies in the delay in internal production. The customer does not feel the direct effect, but the residual effect of the error will have an impact on the internal production schedule requiring the use of spare capacity and/or the payment of overtime.
7. Very Low - The possible error is delayed production. The customer does not feel the direct effect, but the residual effect of the error could have an impact on the internal production schedule requiring the use of spare capacity and/or overtime pay.
8. Minor - The error consists of low efficiency during the production process. Optimization of the affected effect is prevented. No impact on the customer, but internal production is affected.
9. Very low risk - The error consists in very low efficiency during the process. The optimization of the steps of the affected process can be prevented. It does not have a direct impact on the customer, but it affects internal production.
10. None - no effect.

Table 1. FMEA analysis for the Surface Treatments process

Function	Requirements: Product/ Project /Process	Potential Failure Mode	Potential Effects of Failure	Severity	Potential Causes	Prevention Controls	Occurrence	Detection Controls	Detection	RPN	Recommended Actions	Actions			
												Severity	Occurrence	Detection	RPN
Process / Project Step: Station - Acid pickling															
Removal of smut and oxides created during alkaline etching. Removal of MgF_2 layer.	Nitric acid concentration between specification requirements	The concentration of nitric acid exceeds the maximum specified requirement	Fatigue properties can be decreased	8	Incorrect bath adjustment	The calculation for bath adjustment to be made as per procedure	2	Periodic chemical analysis	6	96					
Removal of smut and oxides created during alkaline etching. Removal of MgF_2 layer.	Tank temperature between specification requirements	Temperature exceeds the maximum specified requirement	Fatigue properties can be decreased (need further investigation)	8	Steam valve malfunction	Preventive maintenance Plan	3	100 % check of the anodizing parameters as per Forms	4	96					
Removal of smut and oxides created during alkaline etching. Removal of MgF_2 layer.	Complete removal of smut Uniform metallic appearance	Incomplete removal of smut	Paint adhesion failure	8	Incorrect racking	Racking system	3	Visual inspection after anodizing (anodic layer will not be uniform)	8	192	Implement angle check with gauge by team leader before process start. Update fly bar checklist with the new requirement.	8	2	5	80

Function	Requirements: Product/ Project /Process	Potential Failure Mode	Potential Effects of Failure	Severity	Potential Causes	Prevention Controls	Occurrence	Detection Controls	Detection	RPN	Recommended Actions	Actions			
												Severity	Occurrence	Detection	RPN
Removal of smut and oxides created during alkaline etching. Removal of MgF_2 layer.	Complete removal of smut Uniform metallic appearance	Incomplete removal of smut	Paint adhesion failure	8	Incorrect racking	Racking system	3	100% Tape test	6	144	Implement angle check with gauge by team leader before process start. Update fly bar checklist with the new requirement.	8	2	5	80
Removal of smut and oxides created during alkaline etching. Removal of MgF_2 layer.	Copper concentration should be less than 1g/L	Copper concentration exceeds 1g/L	TBD (see recommended actions)	8	Alloying elements from parts	Bath replenishes	2	Periodic chemical analysis (1 per week as per procedure)	5	80	Assess the impact on the product/process of exceeding Cu concentration				
Removal of smut and oxides created during alkaline etching. Removal of MgF_2 layer.	Zinc concentration should be less than 1g/L	Zinc concentration exceeds 1g/L	TBD (see recommended actions)	8	Alloying elements from parts	Bath replenishes	2	Periodic chemical analysis (1 per week as per procedure)	5	80	Assess the impact on the product/process of exceeding Zn concentration				
Process / Project Step: Station - Alkaline etching															
Removal of an aluminium layer from part surface, to obtain a smooth surface	Immersion time between specification requirements	Immersion time is below the minimum specified requirement	1. MgF_2 layer is not completely removed which can cause a paint adhesion failure. 2. A smooth surface is not obtained 3. The customer requirement to etch between 3-5 microns is not respected	8	Hoist malfunction	Preventive maintenance Plan	5	100 % check of the anodizing parameters as per Forms Error alarm on PLC	2	80					
Removal of an aluminum layer from part surface, to obtain a smooth surface	Immersion time between specification requirements	Immersion time exceeds the maximum specified requirement	1. Parts dimensions out of tolerance 2. The customer requirement to etch between 3-5 microns is not respected	8	Hoist malfunction	Preventive maintenance Plan	5	100 % check of the anodizing parameters as per Forms Error alarm on PLC	2	80					
Removal of an aluminum layer from part surface, to obtain a smooth surface	Immersion time between specification requirements	Immersion time exceeds the maximum specified requirement	1. Parts dimensions out of tolerance 2. The customer requirement to etch between 3-5 microns is not respected	8	Power supply failure	-	5	100 % check of the anodizing parameters as per Forms	4	160	Backup power supply source				
Removal of a aluminium layer from part surface, to obtain a smooth surface	Uniform smut created on the part without any visible metallic areas	Non uniform smut created on the part with visible metallic areas	Paint adhesion failure	8	See preview items	Bath controls acc to procedure	3	Visual inspection after anodizing (anodic layer will not be uniform)	5	120	Implement a new pre-treatment recipe that can remove the MgF_2 layer	8	2	5	80
Process / Project Step: Station - Degreasing															
Removal from the surface parts all contamination: oil, grease, marking inks, stains or residue and other surface contaminations	Bonderite 4215NC concentration between specification requirements	The concentration of 4215NC exceeds the maximum specified requirement	TBD (see recommended actions)	8	Incorrect bath adjustment	The calculation for bath adjustment to be made as per procedure	2	Periodic chemical analysis (1 per week as per procedure)	5	80	Assess the impact on the product/process of exceeding Bonderite 4215NC concentration				

Function	Requirements: Product/ Project /Process	Potential Failure Mode	Potential Effects of Failure	Severity	Potential Causes	Prevention Controls	Occurrence	Detection Controls	Detection	RPN	Recommended Actions	Actions			
												Severity	Occurrence	Detection	RPN
Removal from the surface parts all contamination: oil, grease, marking inks, stains or residue and other surface contaminations	Tank temperature between specification requirements	Temperature exceeds the maximum specified requirement	At temperature above 60 deg. solution in the tank can develop an etching character	8	Steam valve malfunction	Preventive maintenance Plan	2	100 % check of the anodizing parameters as per Forms _ Error alarm on PLC	2	32					
Removal from the surface parts all contamination: oil, grease, marking inks, stains or residue and other surface contaminations	Immersion time between specification requirements	Immersion time exceeds the maximum specified requirement	If time is above 30 min. solution in the tank can develop an etching character	8	Power supply failure	-	5	100 % check of the anodizing parameters as per Forms	4	160	Backup power supply source				
Process / Project Step: Rinsing Tanks															
Removal of the concentrated solution from previous baths	pH between specification requirements	pH is below the minimum specified requirement	Paint adhesion failure	8	Incorrect bath adjustment	The calculation for bath adjustment to be made as per procedure	2	Periodic analysis (1 per day as per procedure)	5	80					
Removal of the concentrated solution from previous baths	Conductivity between specification requirements	Conductivity is below the minimum specified requirement	Paint adhesion failure	8	Incorrect bath adjustment	The calculation for bath adjustment to be made as per procedure	2	Periodic analysis (1 per day as per procedure)	5	80					
Removal of the concentrated solution from previous baths	Immersion time between specification requirements	Immersion time is below the minimum specified requirement	Paint adhesion failure	8	Hoist malfunction	Preventive maintenance Plan	5	100 % check of the anodizing parameters as per Forms Error alarm on PLC	2	80					
Removal of the concentrated solution from previous baths	Immersion time between specification requirements	Immersion time exceeds the maximum specified requirement	Paint adhesion failure	8	Power supply failure	-	5	100 % check of the anodizing parameters as per Forms _	4	160	Backup power supply source				
Process / Project Step: Station - SAA															
Creation of an aluminum oxide layer by immersion of the parts into an electrolyte with the application of DC current	Voltage between specification requirements	Voltage is below the minimum specified requirement 12V	The customer requirement related to voltage is not respected	8	Rectifier malfunction	Preventive maintenance Plan	2	100 % check of the anodizing parameters as per Forms Error alarm on PLC	2	32					
Creation of an aluminum oxide layer by immersion of the parts into an electrolyte with the application of DC current	Uniform anodic layer on the parts	Non uniform anodic layer created on the part	Paint adhesion failure	8	An anodic layer is created under MgF2 layer if it is not completely removed in pretreatment baths, which can cause a paint adhesion failure.	Bath controls acc to procedure Preventive maintenance	4	100 % check of the anodizing parameters as per Forms	4	128	Implement a new pre-treatment recipe that can remove the MgF2 layer	8	2	4	64
Creation of an aluminum oxide layer by immersion of the parts into an electrolyte with the application of DC current	Aluminium concentration should be max 14g/l	Aluminium concentration exceeds 14g/L	TBD (see recommended actions)	6	Alloying elements from parts	Bath replenishes procedure	2	Periodic chemical analysis (1 per week as per procedure)	5	60	Assess the impact on the product/process of exceeding Al concentration				

Function	Requirements: Product/ Project /Process	Potential Failure Mode	Potential Effects of Failure	Severity	Potential Causes	Prevention Controls	Occurrence	Detection Controls	Detection	RPN	Recommended Actions	Actions			
												Severity	Occurrence	Detection	RPN
Creation of an aluminum oxide layer by immersion of the parts into an electrolyte with the application of DC current	Sulfuric Acid concentration should be between 180-220 g/l	Sulfuric Acid concentration out of specification between 180-220 g/l	TBD (see recommended actions)	6	Incorrect bath adjustment	The calculation for bath adjustment to be made as per procedure	2	Periodic analysis (1 per day as per procedure)	5	60	Assess the impact on the product/process of exceeding Sulfuric Acid concentration				
Creation of an aluminum oxide layer by immersion of the parts into an electrolyte with the application of DC current	Ramp-up time should be 5 +/- 0.5min	Ramp-up time exceeds 5 +/- 0.5min	The customer requirement related to Ramp-up is not respected	6	Rectifier malfunction	Preventive maintenance Plan	3	100 % check of the anodizing parameters as per Forms	3	54					
Creation of an aluminum oxide layer by immersion of the parts into an electrolyte with the application of DC current	Propper Bath air agitation	Insufficient Bath air agitation	Scorch marks on contact points may appear	6	Air agitation system failure	Preventive maintenance Plan	2	100 % check of the anodizing parameters as per Forms	3	36					
Creation of an aluminum oxide layer by immersion of the parts into an electrolyte with the application of DC current	Propper Bath filtration system	Anodic pores contamination	Paint adhesion failure	8	Filter occlusion	Preventive maintenance Plan	2	100 % check of the anodizing parameters as per Forms	3	48					
Process / Project Step: Station - TSA															
Creation of an aluminum oxide layer by immersion of the parts into an electrolyte with the application of DC current	Voltage between specification requirements	Voltage is below the minimum specified requirement 13V	The customer requirement related to voltage is not respected	8	Rectifier malfunction	Preventive maintenance Plan	2	100 % check of the anodizing parameters as per Forms Error alarm on PLC	2	32					
Creation of an aluminum oxide layer by immersion of the parts into an electrolyte with the application of DC current	Immersion time between specification requirements	Immersion time is below the minimum specified requirement	Paint adhesion failure	8	Hoist malfunction	Preventive maintenance Plan	2	100 % check of the anodizing parameters as per Forms Error alarm on PLC	2	32					
Creation of an aluminum oxide layer by immersion of the parts into an electrolyte with the application of DC current	Tank temperature between specification requirements	Temperature exceeds the maximum specified requirement	Paint adhesion failure	8	Steam valve malfunction	Preventive maintenance Plan	2	100 % check of the anodizing parameters as per Forms Error alarm on PLC	2	32					
Creation of an aluminum oxide layer by immersion of the parts into an electrolyte with the application of DC current	Aluminium concentration should be max 5g/l	Aluminium concentration exceeds 5g/L	TBD (see recommended actions)	8	Alloying elements from parts	Bath replenishes procedure	2	Periodic chemical analysis (1 per week as per procedure)	5	80	Assess the impact on the product/process of exceeding Al concentration				
Creation of an aluminum oxide layer by immersion of the parts into an electrolyte with the application of DC current	Sulfuric Acid concentration should be between 36-44 g/l	Sulfuric Acid concentration out of specification between 36-44 g/l	TBD (see recommended actions)	8	Incorrect bath adjustment	The calculation for bath adjustment to be made as per procedure	2	Periodic analysis (1 per day as per procedure)	5	80	Assess the impact on the product/process of exceeding Sulfuric Acid concentration				
Creation of an aluminum oxide layer by immersion of the parts into an electrolyte with the application of DC current	Tartaric Acid concentration should be between 72-88 g/l	Tartaric Acid concentration out of specification between 72-88 g/l	TBD (see recommended actions)	8	Incorrect bath adjustment	The calculation for bath adjustment to be made as per procedure	2	Periodic analysis (1 per day as per procedure)	5	80	Assess the impact on the product/process of exceeding Tartaric Acid concentration				

Function	Requirements: Product/ Project /Process	Potential Failure Mode	Potential Effects of Failure	Severity	Potential Causes	Prevention Controls	Occurrence	Detection Controls	Detection	RPN	Recommended Actions	Actions			
												Severity	Occurrence	Detection	RPN
Creation of an aluminum oxide layer by immersion of the parts into an electrolyte with the application of DC current	Chlorine concentration should be max 0.1 g/l	Chlorine concentration exceeds 0.1 g/L	TBD (see recommended actions)	8	Incorrect bath adjustment	The calculation for bath adjustment to be made as per procedure	2	Periodic analysis (1 per day as per procedure)	5	80	Assess the impact on the product/process of exceeding Cl concentration				
Creation of an aluminum oxide layer by immersion of the parts into an electrolyte with the application of DC current	Propper Bath air agitation	Insufficient Bath air agitation	Scorch marks on contact points may appear	6	Air agitation system failure	Preventive maintenance Plan	2	100 % check of the anodizing parameters as per Forms	3	36					
Process / Project Step: Paint application															
Protection against corrosion, resistance to aggressive chemicals, cleaning easiness, achieving specific functions or decorative purpose.	Paint application	Contact points, surface defects due to handling	Paint adhesion	6	Due to contact points and surface defects rework paint adhesion may occur	Handling instructions in wet conditions	3	Visual inspection after paint application, 100 % tape test	6	108	Rack loading optimization	8	2	5	80
Protection against corrosion, resistance to aggressive chemicals, cleaning easiness, achieving specific functions or decorative purpose.	Paint application parameters between the specification (angle, distance, speed, gun setup)	Paint application parameters outside the specification (angle, distance, speed, gun setup)	Paint has not closed film (visible anodic layer/primer)	6	Manual application (angle, distance, speed, gun setup)	Visual aid	6	Visual inspection after paint application, 100 % tape test	8	288	Waiting for customer decision regarding the necessity of coverage under crown				
Protection against corrosion, resistance to aggressive chemicals, cleaning easiness, achieving specific functions or decorative purpose.	Temperature and humidity between the specification limits	Temperature and humidity outside the specification limits	Paint has surface defects (sagging, pin holes)	6	Paint booth malfunction	Preventive maintenance Plan	2	100 % check of the paint parameters Visual and sound alarm detection	3	36					
Protection against corrosion, resistance to aggressive chemicals, cleaning easiness, achieving specific functions or decorative purpose.	Paint mix between specification requirements	Paint ratio of hardener exceeds the specification limit +/- 5%	Prepared mix is outside the specification limits	6	Wrong quantity of hardener added due to the manual operations	Visual aid	3	Viscosity measurement Error message in paint management when mix is created	3	54					
Process / Project Step: Paint curing															
Protection against corrosion, resistance to aggressive chemicals, cleaning easiness, achieving specific functions or decorative purpose.	Paint curing time/temperature between specification requirements	Paint curing time/temperature outside specification requirements	Paint film is not completely dried / overcured	6	Paint booth malfunction	Keep pretreatment parameters under control	3	100 % check of the paint parameters	5	90					
Process / Project Step: Final inspection ST															
The role of inspection is to verify and validate the product characteristics in ST	Adhesion tape test	Insufficient sampling plan	Paint adhesion failure	8	Test was performed according to customer specification	-	5	Adhesion test	6	240	100% Tape test to be implemented at Final Inspection	8	2	4	64

Table 2. Noting the occurrence of the error

Description	Chances of Failure Occurrence	Scores
Very High: Failure is almost inevitable and will occur in large proportions.	occurrence > 50%	10
	33.3% < occurrence <= 50%	9
High: Failure is likely to occur in large proportions.	12.5% < occurrence <=33.3%	8
	5% < occurrence <= 12.5%	7
Moderate: Failure is likely to occur, but not to a large extent.	1.25% < occurrence <= 5%	6
	0.25% < occurrence <= 1.25%	5
Low: Failure is possible but not likely.	0.05% < occurrence <= 0.25%	4
	0.0066% < occurrence <= 0.05%	3
Removed: Failure is unlikely.	0.00066% < occurrence <= 0.0066%	2
	0% < occurrence <= 0.00066%	1

Table 3. Error Detection Scoring

Description	Probability of Error Detection	Scores
Absolute uncertainty - The error will not be detected	0% < Detection <= 0.001%	10
Very Remote - Very low chance that the problem will be detected	0.01% < Detection <= 0.001%	9
Remote - Remote chance that Project Control will detect the potential causes and/or subsequent error	0.1% < Detection <= 1%	8
Very Low - Very low chance that Project Control will detect the potential causes and/or subsequent error	1% < Detection <= 20%	7
Low - Low chance that Project Control will detect the potential cause and/or subsequent error	20% < Detection <= 40%	6
Moderate - Moderate chance that Project Control will detect the potential cause and/or subsequent error	40% < Detection <= 60%	5
Moderately High - Moderately high chance that Project Control will detect the potential cause and/or subsequent error	60% < Detection <= 80%	4
High - High chance that Project Control will detect the potential cause and/or subsequent error	80% < Detection <= 95%	3
Very High - Very high chance that Project Control will detect the potential cause and/or subsequent error	95% < Detection <= 99.9%	2
Almost Certain - Project Control will almost certainly detect the potential cause and/or subsequent error	99.9% < Detection	1

In table 2 it is presented the guide to note the occurrence of the error.

In table 3 it is presented the Error Detection Scoring.

4. Conclusions

Surface treatment is an essential stage in the aerospace industry as it significantly impacts the functionality and longevity of components. Our research identified acid pickling as a crucial method of surface preparation in the aerospace sector that enhances the corrosion resistance of metal components and provides a clean surface for further processing. Further research is required to develop more efficient and ecologically friendly acid pickling procedures. We also found that the removal of smut and oxides produced during alkaline etching is critical to obtain the appropriate surface quality and performance of metal components. Our study suggests that chemical cleaning or electro cleaning can effectively remove smut and oxides, and further research is required to identify the most effective and eco-friendly procedures.

Our research also demonstrated the usefulness of MgF2 layers in the aerospace sector due to their distinctive optical and mechanical characteristics. To increase their use in the aerospace sector, further research is necessary to develop more effective and affordable production techniques.

In our study, we found that immersion duration is a critical consideration in surface treatments in the aerospace sector. Proper regulation and optimization of immersion time are crucial to ensure successful surface treatments without causing harm to the material. Further research is required to understand the association between immersion duration and the effectiveness of surface treatments in the aerospace sector.

Paint adherence is a crucial aspect in the aircraft sector that affects the lifespan and durability of aviation components. Our research recommends that surfaces should be properly prepared, and the paint's qualities should be carefully regulated to ensure proper paint adherence. To enhance paint adhesion, new and improved techniques for assessment and optimization are required, and further research is necessary to better understand the factors that influence paint adhesion in the aerospace sector.

Our study demonstrated the importance of final inspection ST procedures in the aerospace industry to guarantee the performance, dependability, and safety of aircraft parts. Standards and guidelines are used to execute final inspection ST in a consistent and efficient manner, ensuring that aircraft components meet the necessary requirements before being put into service.

FMEA is a useful method in the aerospace sector for assessing surface treatment procedures and locating potential failure modes. Our study recommends the use of FMEA to enhance the dependability, effectiveness, and efficiency of surface treatment methods, which is critical for ensuring the safety and quality of aircraft.

The adhesion tape test is a common technique for assessing the adhesive power of coatings and paints used on aircraft components. Our research suggests that standards and guidelines should be used to execute the adhesion tape test consistently and efficiently, ensuring the quality and longevity of the coating or paint.

In conclusion, proper management of variables such as immersion duration, temperature, and humidity is crucial to guarantee effective surface treatment in the aerospace industry. Our research provides specific results and practical recommendations for acid pickling, paint adhesion, final inspection ST, FMEA, and the adhesion tape test, which can help enhance the safety, reliability, and quality of aerospace components.

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