COMPARATIVE STUDY OF ADHESIVES FOR PULL-OFF ADHESION TESTING IN THE AEROSPACE INDUSTRY

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Abstract - The pull-off test is essential in assessing the adhesion of paints in the aviation industry, where durability and safety are paramount. However, the lack of clear recommendations on suitable adhesives for this test can affect the accuracy and relevance of the results. The objective of this study was to identify an optimal adhesive for the pull-off test that would provide higher adhesion to the paint and primer than the dolly, thus allowing the correct assessment of the adhesion of the coating. The research method consisted in selecting nine common adhesives (cyanoacrylic and epoxy) and testing them on specimens painted with paints specific to the aeronautical industry. After application of the adhesives, the specimens were subjected to pull-off testing and the tear site was analyzed to determine the performance of each adhesive. The results showed that most of the cyanoacrylic adhesives failed, with breakage occurring in the adhesive film. In contrast, the epoxy adhesive Bison Epoxy Universal showed superior performance, with breakage occurring predominantly in the paint or primer coat. We conclude that the choice of the right adhesive is crucial for obtaining relevant pull-off test results. Bison Epoxy Universal was found to be the optimal adhesive for the paints tested, but further studies are needed to evaluate its performance on a wider range of coatings. This research contributes to the improvement of adhesion testing practices in the aviation industry, ensuring a more accurate assessment of the quality and durability of the paints used.

Keywords: Pull-off test, Paint adhesion, Aviation industry, Epoxy adhesive, Bison Epoxy Universal, adhesion evaluation, Coatings durability, Cyanoacrylate, Surface preparation.

1. Introduction

Adhesion is an essential parameter in assessing the performance and durability of surface coatings, particularly in the aeronautical industry, where operating conditions are particularly demanding. Jothi et al [1] performed a comprehensive review of studies on adhesion of aerospace coatings, emphasizing the importance of this parameter in ensuring structural integrity and corrosion protection. The pull-off test, standardized by ISO 4624:2023 [2], is a widely used method to quantify adhesion, but its results can be significantly influenced by the choice of adhesive, as the standard itself emphasizes.

Previous studies have investigated various factors affecting adhesion such as surface preparation, coating thickness and environmental conditions. Purabggola et al [3] demonstrated that surface preparation by sandblasting and application of a chemical conversion coating can significantly improve the adhesion of aerospace coatings. Zhang and Huang [4] analyzed the effect of coating thickness on adhesion, finding that an optimal thickness can maximize peel strength. Croll [5] investigated the effects of humidity and temperature on adhesion, highlighting the importance of environmental conditions in coating performance.

In addition, different types of adhesives, including epoxy, cyanoacrylic and polyurethane, were analyzed to evaluate their performance in the pull-off test. Comyn [6] provides an overview of the science of adhesion, including the different types of adhesives and adhesion mechanisms. Bartlett and Authors paper [7] studied the adhesive bonding of aluminum alloys used in the aerospace industry, emphasizing the importance of selecting the right adhesive for each type of alloy. Marques et al [8] conducted a review of studies on the adhesion of polyurethane coatings to metallic substrates, highlighting the challenges and opportunities in this area.

However, there is no clear consensus on the optimal adhesive for each type of coating and substrate. Bandl et al [9] emphasize that the choice of adhesive depends on several factors, including substrate properties, coating type and operating conditions. In the aerospace industry, performance requirements are particularly high, and the choice of the wrong adhesive can lead to erroneous results and incorrect coating quality decisions, as emphasized by Barshilia [10].

Mayer et al [11] provide a detailed description of the pull-off test, including how to prepare specimens, apply adhesive and interpret results. Adams [12] investigated the adhesion of organic coatings to metals, emphasizing the importance of surface preparation and chemical compatibility between coating and adhesive. Hart-Smith [13] conducted a review of polymer adhesion studies, emphasizing the complexity of the phenomena involved and the need for further research.

Nazari et al [14] have edited a comprehensive handbook on adhesive technology, covering a wide range of aspects, from the chemistry of adhesives to their applications in various industries. Sundryial et al [15] reviewed the use of adhesives and sealants in aerospace engineering, emphasizing their importance in ensuring the safety and performance of aircraft structures.

Given the particular importance of adhesion in the aeronautical industry and the lack of clear recommendations on adhesives for pull-off testing, further research in this area is needed. [16] This study aims to comparatively evaluate the performance of common adhesives in the pull-off test on paints used in the aerospace industry, to identify the optimal adhesive that will ensure reliable and relevant results.

Although there are numerous studies on adhesion and pull-off testing, few of them focus on applications specific to the aerospace industry. [16,17] In addition, most studies compare only a few types of adhesives without providing a complete picture of the available options. [15]

This study makes a significant contribution by benchmarking a wide range of adhesives against paints commonly used in the aviation industry. The results will provide practical recommendations for choosing the optimal adhesive, thus contributing to improving the quality and reliability of pull-off tests in this field.

Research objectives:

- Comparative evaluation of the performance of common adhesives (cyanoacrylic and epoxy) in the pull-off test on paints used in the aeronautical industry.
- Identification of the optimum adhesive that provides higher adhesion to paint and primer than to dolly, thus allowing the correct assessment of the adhesion of the coating.
- Make practical recommendations on the choice of adhesive for the pull-off test depending on the type of paint and substrate.

2. Materials and Methods

- ***Details of the selected adhesives***

To cover a wide range of properties and applications, nine common adhesives, both cyanoacrylic and epoxy, from different manufacturers have been selected:

Bison Super Glue: single component cyanoacrylic adhesive, known for its fast drying and high initial strength.

Bostik Glue Fix: one-component cyanoacrylic adhesive, like Bison Super Glue, but with a slightly different viscosity.

Loctite Super Bond Power Flex: ethyl cyanoacrylate-based cyanoacrylate adhesive designed for flexibility and impact resistance.

Loctite Super Bond Universal: ethyl cyanoacrylate-based cyanoacrylate adhesive with universal applicability on various materials.

Bison Epoxy Universal: two-component epoxy adhesive with high final strength and good adhesion to a variety of substrates.

Bostik Epoxy Fix: two-component epoxy adhesive, like Bison Epoxy Universal, but with a different curing time.

Loctite 638: one-component urethane methacrylate adhesive with excellent high temperature resistance and good adhesion to metals.

Bison Epoxy Metal: two-component epoxy adhesive, specially designed for bonding metals, with high mechanical and thermal resistance.

Loctite EA 3430: low viscosity, two-component epoxy adhesive, ideal for applications where good penetration in tight spaces is required.

- ***Preparing test specimens and dollies***

The test specimens were prepared by painting with paints commonly used in the aircraft industry according to the manufacturer's specifications. After complete drying of the paint, the painted surfaces were prepared for bonding by fine sanding with sandpaper to ensure a uniform surface and to remove any contaminants. The surfaces were then cleaned with compressed air to remove dust from the sanding and degreased with acetone to remove any traces of grease.

The dollies, metal disks used in the pull-off test, underwent a similar preparation process. They were sanded, cleaned with compressed air and degreased with acetone to ensure optimum adhesion of the adhesive.

- ***Adhesives application and testing procedure***

Adhesive application: A controlled amount of adhesive was applied to the dolly surface, ensuring even distribution.

Bonding the dolly: The dolly was carefully positioned on the painted surface of the test specimen, applying light pressure to ensure good contact between the adhesive and both surfaces.

Curing the adhesive: The bonded assembly was allowed to cure for 24 hours at room temperature according to the adhesive manufacturer's instructions.

Removing excess adhesive: Using a core drill bit, the excess adhesive around the dolly was carefully removed so that only the adhesive remained between the dolly and the painted surface.

Pull-off test: The bonded assembly was mounted in the material testing machine and the dolly was subjected to an increasing tensile force until it detached. The maximum breaking force was recorded for each test.

- ***Criteria for the evaluation of adhesives***

After the dolly was detached, the break surface was visually examined to determine the break site. Adhesives were evaluated as follows:

- *Adequate Adhesive*: The break occurred in the paint or primer coat, indicating a stronger adhesion of the adhesive to the dolly and substrate than the paint to the substrate.

- *Inadequate Adhesive*: Breakage occurred in the adhesive film or at the interface between the adhesive and dolly/paint, indicating insufficient adhesion of the adhesive.

This evaluation identified the optimum adhesive for pull-off testing on paints used in the aerospace industry.

3. Results

The table below shows the results of the pull-off tests for each adhesive, indicating the percentage of breakage in different areas and the final grade:

Table 1. Pull-off test results for each adhesive

Adhesive	Cracking in the adhesive film	Cracks in the paint coating	Cracking in the primer	Rating
Bison Super Glue	88%	10%	2%	Fail
Bostik Glue Fix	96%	2%	2%	Fail
Loctite Super Bond Power Flex	100%	-	-	Fail
Loctite Super Bond Universal	98%	1%	1%	Fail
Bison Epoxy Universal	-	25%	75%	Past/OK
Bostik Epoxy Fix	85%	-	15%	Fail
Loctite 638	100%	-	-	Fail
Bison Epoxy Metal	100%	-	-	Fail
Loctite EA 3430	65%	-	35%	Fail

The test results show significant differences in the performance of the adhesives. All the cyanoacrylic adhesives tested exhibited a predominant break in the adhesive film, indicating insufficient adhesion to the paint and/or primer. This suggests that the cyanoacrylic adhesives are not suitable for pull-off testing on paints used in the aircraft industry.

In contrast, Bison Epoxy Universal epoxy adhesive demonstrated superior performance, with predominant tear-off in the paint or primer coat. This indicates a stronger adhesion of adhesive to dolly and substrate than paint to substrate, which is essential for relevant pull-off test results.

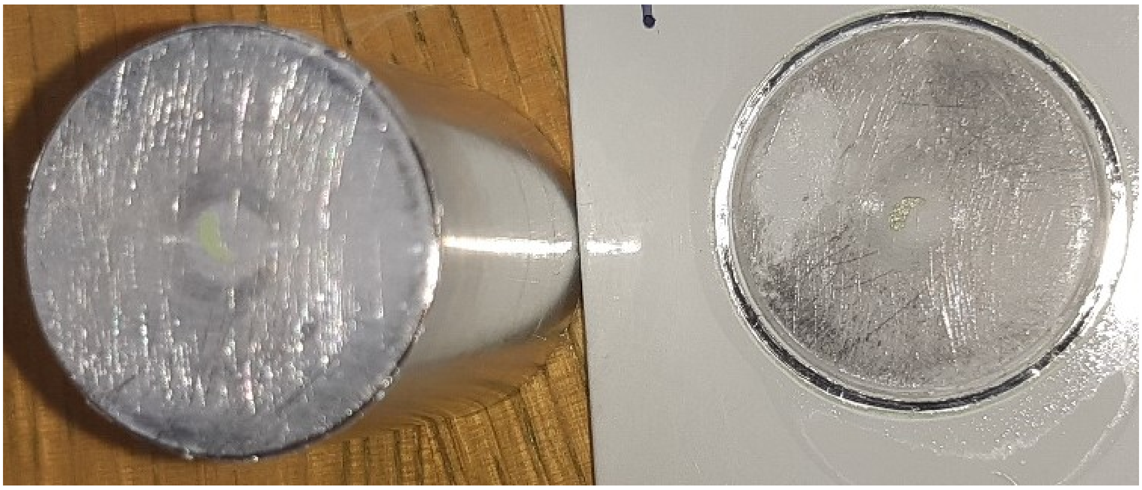

Figure 1: How the sample breaks when using Bison Super Glue adhesive

Figure 2: How the sample breaks when using Bostik Glue Fix adhesive

Figure 3: How the sample breaks when using Loctite Super bond Power Flex adhesive

Figure 4: How the sample breaks when using Loctite Super Bond Universal adhesive

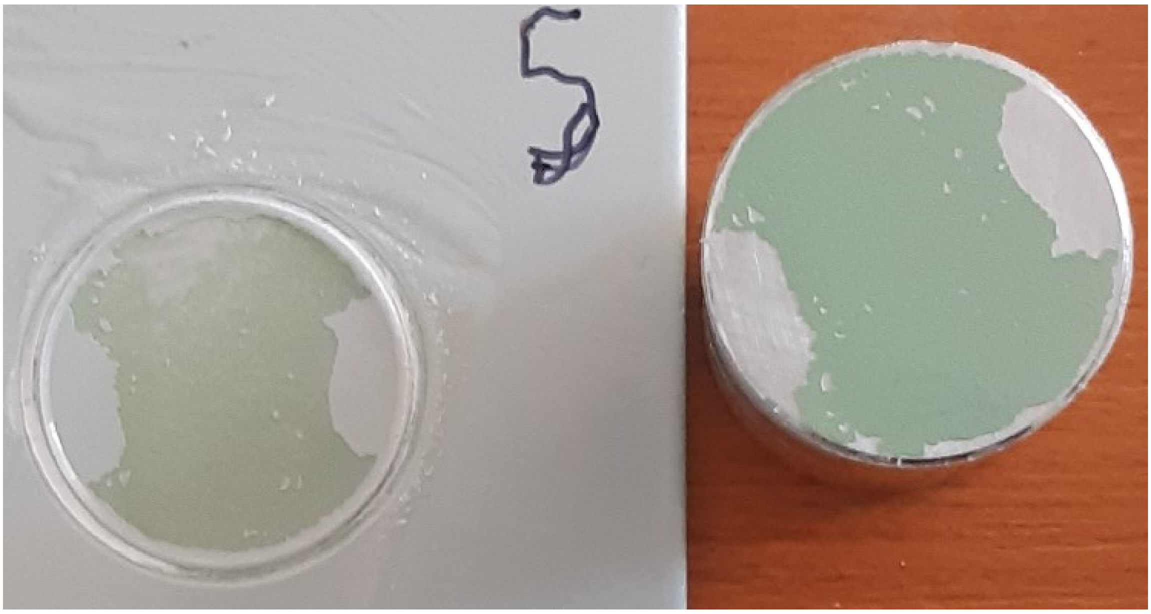

Figure 5: How the sample breaks when using Bison Epoxy Universal adhesive

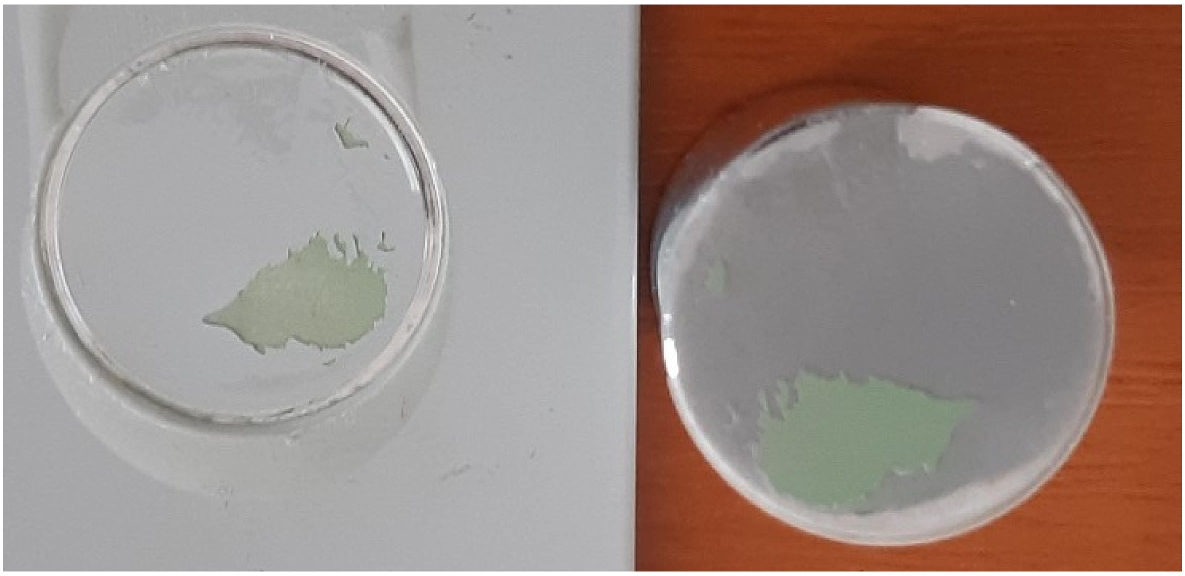

Figure 6: How the sample breaks when using Bostik Epoxy Fix adhesive

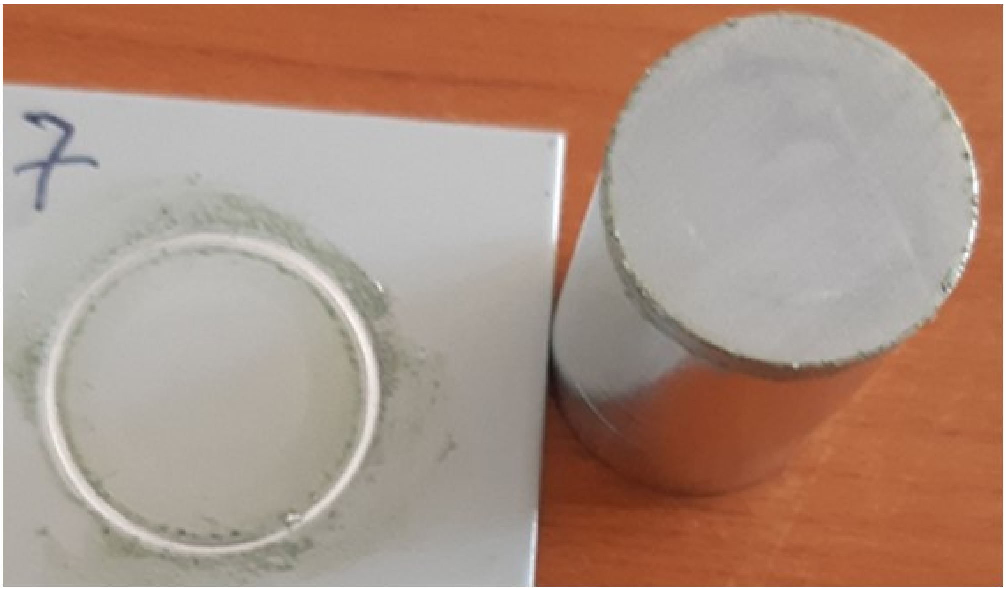

Figure 7: How the sample breaks when using Loctite 638 adhesive

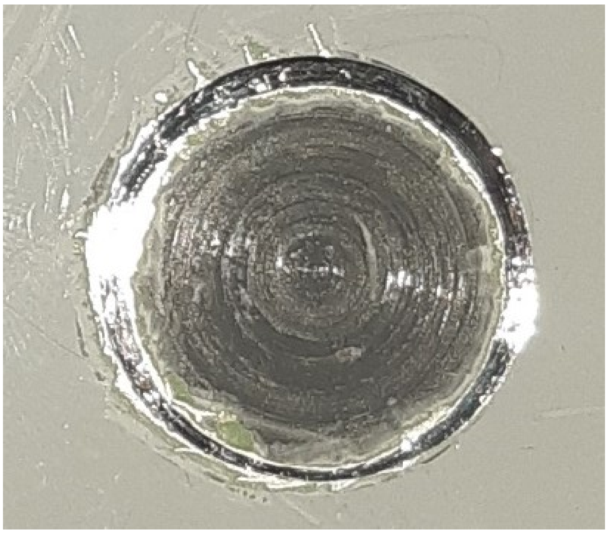

Figure 8: How the sample breaks when using Bison Epoxy Metal adhesive

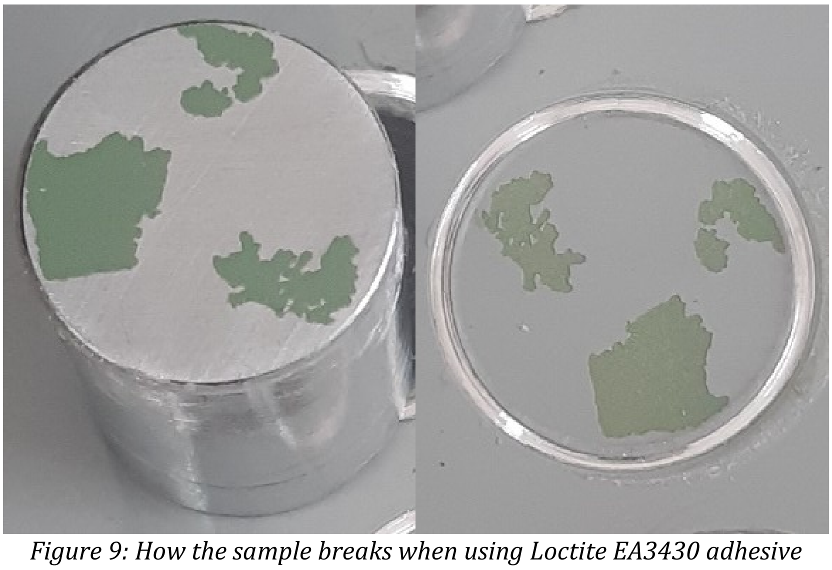

Figure 9: How the sample breaks when using Loctite EA3430 adhesive

However, it is surprising that the other epoxy adhesives tested (Bostik Epoxy Fix, Bison Epoxy Metal and Loctite EA 3430) did not pass the test, with breakage occurring in most cases in the adhesive film or at the adhesive/primer interface. This can be explained by several factors such as:

- *Chemical compatibility*: these adhesives may not be completely compatible with the chemical composition of the paints or primer, which can lead to poor adhesion.

- *Surface Preparation*: Even if standard surface preparation procedures have been followed, they may not have been sufficient to ensure optimum adhesion of the adhesive.

- *Viscosity of the adhesive*: The viscosity of the adhesive can influence the way the adhesive spreads and penetrates the painted surface, affecting adhesion.

The pictures shown in Figures 1-9 illustrate the differences in the breakage mode for each adhesive, confirming the results presented in the table.

4. Discussion

- ***Comparing the performance of adhesives***

The study revealed a significant difference in performance between cyanoacrylic and epoxy adhesives in the context of the pull-off test on paints used in the aircraft industry. All the cyanoacrylic adhesives tested exhibited a predominant tear in the adhesive film, indicating insufficient adhesion to the paint and/or primer. This finding suggests that cyanoacrylic adhesives, although valued for their fast drying and initial strength, are not suitable for aeronautical applications where a strong and durable long-term adhesion is required.

In contrast, Bison Epoxy Universal epoxy adhesive has been noted for superior performance, with breakage occurring predominantly in the paint or primer coat.

This observation indicates that the adhesive formed a stronger bond with the substrate and paint than their internal cohesion. This characteristic is essential to obtain relevant results in the pull-off test, as it allows the correct assessment of the adhesion of the coating.

- ***Interpretation of results in the context of aeronautics industry requirements***

In the aviation industry, paint adhesion is crucial to ensure corrosion protection, wear resistance and aesthetics of aircraft. The results of this study emphasize the importance of selecting the right adhesive for the pull-off test, as an unsuitable adhesive can lead to underestimation of the actual paint adhesion and incorrect coating quality decisions.

Bison Epoxy Universal, with its superior performance, is proving to be a promising candidate for use in the pull-off test on aircraft paints. However, it is important to note that this study was conducted on a limited number of paints and adhesives. Further studies on a wider range of coatings and adhesives are needed to generalize the results.

- ***Possible explanations for the failure of some adhesives***

The failure of Bostik Epoxy Fix, Bison Epoxy Metal and Loctite EA 3430 epoxy adhesives can be attributed to several factors. One of these is the chemical compatibility between the adhesive and the paint. It is possible that these adhesives did not react optimally with the specific chemical composition of the paints tested, resulting in poor adhesion.

Another important factor is surface preparation. Although standard sanding, cleaning and degreasing procedures were applied, they may not have been sufficient to completely remove contaminants or to create an optimal surface for the adhesive to adhere. The viscosity of the adhesive may also play a role in adhesive failure. An adhesive that is too viscous may not sufficiently penetrate pores and surface irregularities, while an adhesive that is too fluid may not provide sufficient mechanical strength.

- ***Study limitations***

This study was limited to a relatively small number of adhesives and paint types.

In addition, other factors that may influence adhesion, such as paint layer thickness, environmental conditions during adhesive application and curing, or artificial ageing of the samples, were not investigated.

To get a more complete picture of the performance of adhesives in pull-off testing on aeronautical paints, further studies are needed that consider a wider range of adhesives, paints and test conditions.

It would also be useful to investigate alternative surface preparation methods and adhesive application techniques to optimize adhesion.

5. Conclusions

Based on the experimental results obtained in this study, it is recommended to use Bison Epoxy Universal two-component epoxy adhesive for pull-off testing on paints used in the aircraft industry. This adhesive demonstrated superior adhesion to the paint and primer compared to the other adhesives tested, providing a predominant break in the coating, as required for proper adhesion evaluation.

Adhesive selection for the pull-off test is an important step in the coating adhesion evaluation process. An unsuitable adhesive can lead to erroneous results, underestimating the actual adhesion of the paint and thus compromising the quality and safety of the finished product. As this study has shown, cyanoacrylic adhesives are not suitable for pull-off testing on aeronautical paints, as they tend to break in the adhesive film rather than in the coating.

Although this study has provided valuable information on the performance of adhesives in the pull-off test, there are still many issues that require further investigation. First, a wider range of paints and adhesives needs to be tested to evaluate the performance of Bison Epoxy Universal on other types of coatings and to identify potential alternative adhesives.

Second, it would be useful to investigate alternative surface preparation methods and adhesive application techniques to optimize adhesion and reduce the risk of premature adhesive failure. It would also be of interest to study the effect of paint layer thickness and environmental conditions on adhesive performance in the pull-off test.

Finally, it is important to note that this study focused on the evaluation of the initial adhesion of paints. To assess the long-term durability of adhesion, accelerated aging tests that simulate actual operating conditions of aircraft coatings would be necessary.

By addressing these issues in future research, a deeper understanding of the factors influencing adhesion can be gained and more accurate and comprehensive recommendations can be developed on the choice of the optimal adhesive for pull-off testing in the aviation industry.

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