Journal on Mechanics of Solids, 1:1 (2022) 3-8
ISSN 2975-8262
DOI: 10.24840/2975-8262_001-001_001798

Received: 5 September, 2022
Accepted: 7 October, 2022
Published: 11 November, 2022

Effect of Surface Contamination on the Peel Properties of Adhesive Joints

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Author Keywords

Adhesive Joints, Contamination, Surfactant, Interface, Peel Test

Type: Rapid Communication

Open Access
Peer Reviewed

Abstract

One of the main setbacks to the use of adhesive joints is their sensitivity to surface quality and preparation, with high strength decreases being reported for contaminated surfaces. This contamination effect can arise from surfactants used to clean lubricants used during substrate machining, which can remain on the bonding area. In this paper, the effect of surfactant contamination on joints with aluminium substrates and a silicone adhesive was studied using a peel test. It was concluded that as the level of contamination applied to the substrate increases, the peel strength of the joint decreases and failure is progressively interfacial. Numerical models were developed to reproduce the experimental results.

1. Introduction

Nowadays, adhesives are a preferable alternative to more conventional joining processes, such as welding, riveting and bolting. Adhesives are used in several applications due to their high strength to weight ratio, as well as not needing the introduction of holes or local heating of the components to join two materials (da Silva et al., 2018). However, one of the main setbacks to their use in industrial processes is their unpredictable behaviour when subjected to severe environments, such as high temperature, humidity or contamination, as well as their susceptibility to different surface preparations. Therefore, adhesives' properties and behaviour in severe environments and surface conditions, that compromise or degrade the bond strength, should be extensively analysed and investigated. The knowledge of the joint behaviour and development of more accurate prediction tools makes adhesive joining a safer, more predictable, and better alternative to other joining processes, such as welding, bolting or riveting.

Although surface contamination can degrade the bulk adhesive, the failure of a bonded joint is often ultimately interfacial (Borges, CSP et al., 2021). When an adhesive and substrate are in contact, there is the creation of an interphase between them, due to the adhesive/substrate interactions. This interphase has specific physical and chemical properties, different from those of the adhesive and the substrate (da Silva et al., 2018). When surface contamination is present on the substrate, the contaminant may (i) be absorbed by the adhesive, affecting its properties particularly in the adhesive closer to the interface, or (ii) remain at the adhesive/substrate interface, creating a physical separation between them than inhibits chemical bonds and mechanical interlocking, inhibiting adhesion (Borges, CSP et al., 2021). This is important to understand because, in both scenarios, the contaminant degrades the adhesive joint and can change the path of the failure progression to the interphase area or even the interface.

Brandão et al. (Brandão et al. 2022) analysed the same adhesive and contaminant materials used in this work, through double cantilever beam (DCB) and single lap joints (SLJ), and concluded that the increasing amount of contaminant decreased the failure load and shifted the failure from the adhesive to the adhesive close to the substrate and, ultimately, the interface.

In this short paper, the effect of surface contamination of a surfactant found in detergents used to clean aluminium substrates was analysed. The experimental procedure consisted of conducting peel test for three different quantities of contaminant applied to an aluminium substrate: 0, 10 and 20 sprays. Afterwards, the adhesive was applied to the contaminated substrate and a metal sheet was placed on top, which is the material that suffers a displacement, forcing the adhesive to fail. This experimental procedure and its results were validated through a numerical model of the test using *Abaqus 2017*.

2. Materials and Methods

There are three solid materials that constitute the peel testing procedure that was prepared: a 2 mm thick aluminium substrate (Al 6082-T6), the silicone adhesive, and a 0.03 mm thick metal sheet (Steel 1.1274). The adhesive is a commercially available addition curing silicone, that cures at 125°C for 25 minutes, which was previously characterized by Borges et al. (Borges et al., 2022). The elastic properties of each material can be found in **Table 1**. Although the adhesive has a low tensile strength compared to structural adhesives, which is 3.5 MPa, it has a strain-to-failure of approximately 400%, and does not have plastic deformation (Borges et al., 2022).

Table 1: Materials used and its properties.

Material	Young's modulus (MPa)	Poisson's coefficient	Tensile strength (MPa)
Al 6082-T6	70000	0.33	-
Adhesive	1.34	-	3.5
Steel 1.1274	210000	0.28	-

Three levels of surface contamination of the aluminium substrate were analysed: uncontaminated, 10 sprays and 20 sprays of an aqueous solution with a surfactant concentration of 20 g/L. The surfactant is cocosalkylaminethoxylate present in detergents used to clean oil from aluminium surfaces prior to the adhesive application. For the manufacturing of the joint first, the substrate was contaminated, afterwards, a mask was placed in top of the substrate to ensure the adhesive overlap and thickness. The adhesive was applied, the metal thin sheet was placed on top, and the joint was placed in a hot plate press with the appropriate temperature and pressure to cure the adhesive and avoid defects.

Various joints were produced in groups of 3 for each level of contamination. The peel tests were performed in an INSTRON® 3367 universal test machine (Norwood, MA, USA) with a load cell capacity of 30 kN, at room temperature with a constant displacement rate of 10 mm/min.

The aluminium substrate was pinned using a fixing mechanism that allowed the metal sheet to always be perpendicular to the substrate as it was being tensioned (**Figure 1a)**. The load and displacement were directly recorded by the testing machine.

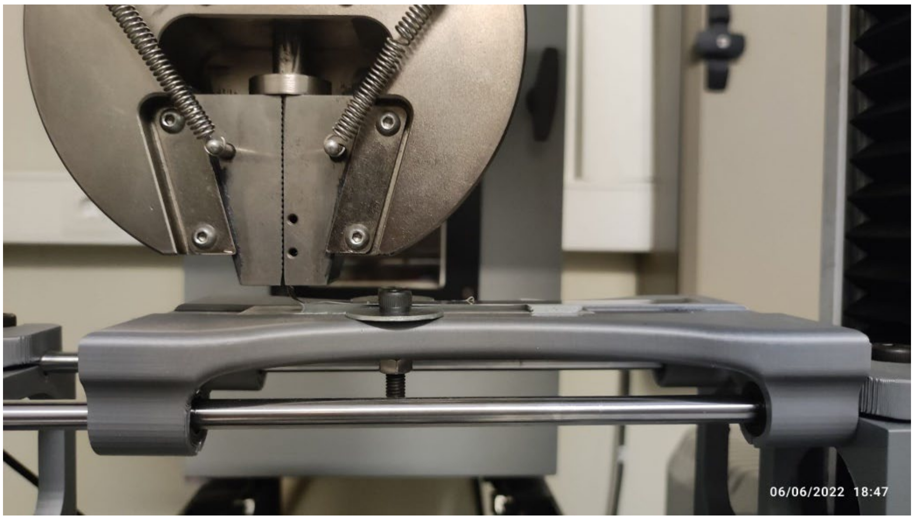

Figure 1a): Experimental procedure of the peel test.

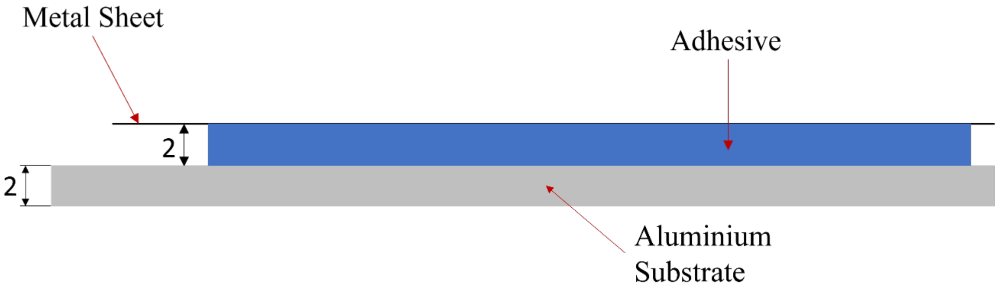

Figure 1b): Dimensions of the peel test and material identification.

The numerical model was simulated using the Finite Elements Method (FEM) in Abaqus (Dassault Systemes Simulia Corp. Providence, USA). As for geometry, this model is similar to the ones used in the experimental specimens, **Figure 2a)**. For the uncontaminated joint, the substrate was modelled as elastic and the adhesive as cohesive. The elastic mesh is composed of a 4-node bilinear plane strain quadrilateral, reduced integration, hourglass control, and the cohesive mesh is a 4-node two-dimensional cohesive element. The mesh of the specimen can be seen in **Figure 2b**). For the contaminated joints, a similar geometry was used, with a change that occurred to the adhesive layer, which was divided into a 0.1 mm layer of interphase, close to the substrate, with 1 cohesive layer through the thickness and the remaining of the adhesive, which was simulated using elastic elements, **Figure 2c)**.

The fracture toughness in mode I determined from the experimental tests, both when cohesive and adhesive failure was found was introduced to the numerical model to validate it.

Figure 2a): Peel test boundary conditions.

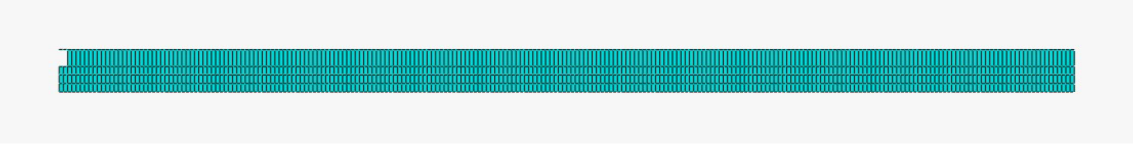

Figure 2b): Uncontaminated peel test mesh.

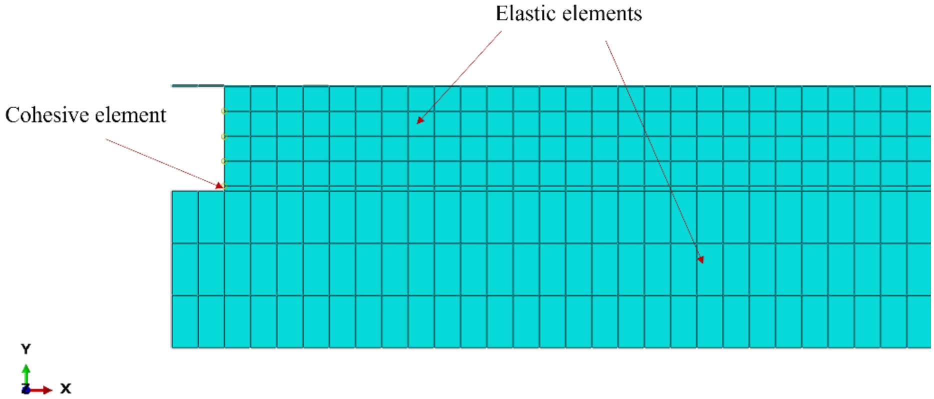

Figure 2c): Contaminated peel test mesh.

3. Results and Discussion

From the experimental tests, the results can be narrowed to a graphic that shows the variation of the fracture toughness as the number of sprays increases. For this graphic to be made, the load vs displacement curves from the testing machine had to be analysed and then, after obtaining an average value of the fracture load, the formula below is used to calculate the fracture toughness,

$$G = \frac{F}{b}$$

b being the overlap width (6 mm), and *F* the fracture load. This relation is possible because there is no plastic deformation to the steel strip during testing. The experimental results for each tested condition as well as the numerical results are presented in **Figure 3**.

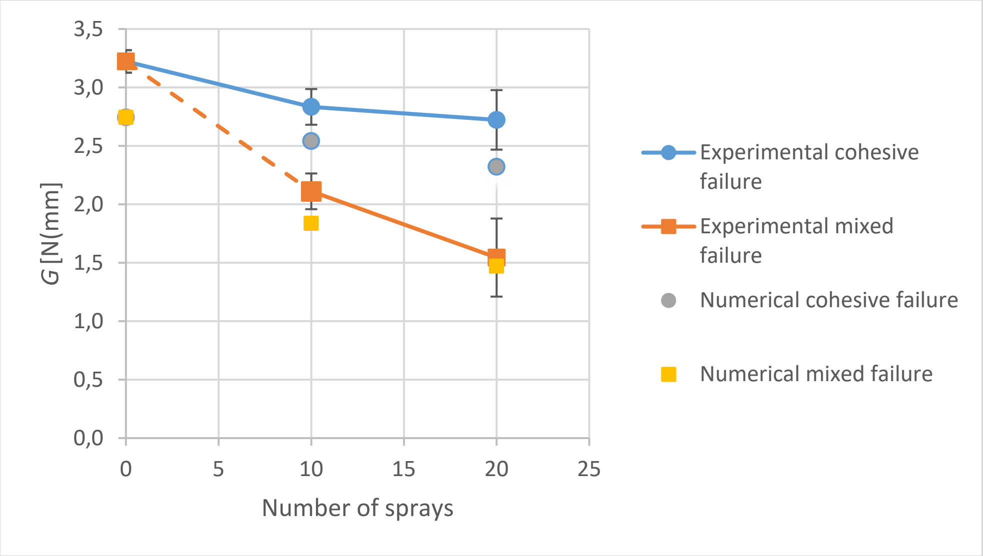

Figure 3: Variation of the fracture toughness in function of the number of sprays.

As the graphic shows, for the uncontaminated joint the failure was cohesive, **Figure 4a)**. The tests with 10 and 20 sprays had mixed failure, as seen in **Figures 4b)** and **4c)**. This means that there are certain regions with adhesive failure and others with cohesive failure. At 20 sprays, the fracture toughness was reduced to half of the initial value for cohesive failure when adhesive failure was found. In addition, the numerical results for each simulation are also represented in the graphic. As it is seen, the numerical results are very similar to the experimental ones.

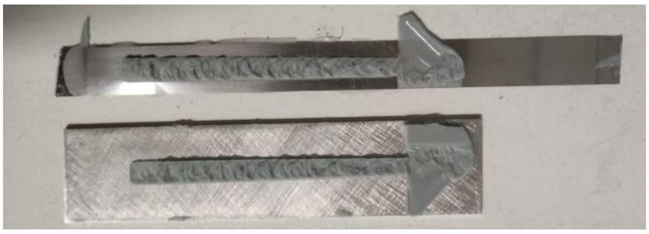

Figure 4a): Uncontaminated peel test.

Figure 4b): Peel test with 10 sprays.

Figure 4c): Peel test with 20 sprays.

Some conclusions can easily be deducted regarding the contamination process. This process, with the minimum lack of precision, can result in the substrate having areas where there is more contaminant, and areas less rich in contaminant. Therefore, in highly contaminated areas, adhesive failure is imminent and expected. However, in less contaminated areas, the failure should be cohesive. It can also be affirmed that, although the joint had mixed failure, all the adhesive was damaged by the contamination, because the value of the fracture toughness, even when cohesive failure is observed, is lower than that of the uncontaminated condition. This phenomenon was also reported by Brandão et al. (Brandão et al. 2022).

4. Conclusions

This paper focused on the effect of surface contamination. It can be concluded that, with the increase of the number of sprays on the aluminium substrate, the fracture toughness of the adhesive was lowered, originating zones where the failure was adhesive. In addition, it can be concluded that even though most tests had mixed failure, the contaminants damaged the adhesive as a whole, lowering the fracture toughness when failure was cohesive in the adhesive, as well as the fracture toughness when failure was mixed or adhesive, mainly due to the increase in area of adhesive failure.

In future works, it would be interesting to develop a test that constantly forces an adhesive joint to fail on the interface, so its interfacial properties could be better comprehended and more accurately compared to the uncontaminated failure, for which failure is always cohesive.

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