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# Effect of surface treatment on the shear strength of aluminium adhesive single-lap joints for automotive applications

Yasmina Boutar [a,*], Sami Naïmi [a], Salah Mezlini [a], Moez Ben Sik Ali [b]

[a] Mechanical Laboratory, National Engineering School of Monastir, Monastir, Tunisia
[b] Automotive Industry, ICAR, Sousse, Tunisia

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ABSTRACT

Adhesive joints exhibit very high toughness and good fatigue resistance. This technique is a serious candidate to replace rivets or welding in primary structural components. Nevertheless, there is hesitation on the part of the industry to replace traditional fasteners in primary structural applications, mainly due to the limited understanding of joint performance over the life of structures. In the present research, we focus on the static strength of adhesive bonded aluminium alloys for the automotive industry. So, the aim of this work is to carry out and quantify the various variables affecting the strength of single lap joints, especially the effect of the surface preparation. Aluminium single lap joints (SLJs) were fabricated and tested to assess the adhesive (structural one-component polyurethane adhesive) performance in a joint. We found that the decrease in surface roughness was found to increase the shear strength of single lap joints. Furthermore, it has been possible, qualitatively, to identify the relative sensitivity of the effects of various surface roughnesses on the behaviour of spreading kinetics. Experimental results show that rougher surfaces have less wettability which is in coherent with shear strength tests.



## 1. Introduction

Structural adhesives are more frequently used in manufacturing processes as they provide numerous advantages when compared with the traditional joint systems, such as corrosion resistance, weight reduction, and elimination of stress concentration due to the fastener mounting hole. Other benefits include improved stiffness, rigidity, impact behaviour and energy absorption, less vibration and sound deadening [1]. However, obtaining these advantages requires a specific adhesive joint design that improves its performance and restricts its limitations [2]. The analysis of the main contributions on design rules of structural adhesive joints [3,4] together with results of studies on the selection of adhesives and joint analysis allows structured planning for adhesive joints design [5]. Furthermore, durable bonds which are capable of taking structural loads can be created due to a careful consideration that must be given the way in which the joint is formed, the appropriate treatment of the adherend surfaces prior to bonding, the thickness of the adhesive layer and the type of environment in which it is to be used [6].

For this purpose, it is necessary to delve further into the knowledge and characterisation of the mechanical properties of this type of joint depending on the technical and geometrical parameters. One of the most relevant geometrical parameters is the surface finish of the substrates, as this has a decisive influence on the mechanical properties of the joint and has a clear economic impact on the mass production manufacturing processes. Furthermore, the relationship between roughness and adhesion is not very simple. Optimum surface profile varies from one adhesive to another and depends upon the type of stress applied [7]. As well, the roughness of adherend surfaces has frequently been used as a design parameter for adhesive joints. A number of researchers have examined its effect on the strength and durability of adhesive joints using various adherends and adhesives [8,9]. In addition, the pre-treatment of aluminium to enhance adhesion has been the subject of a very large amount of research [3].

Few wettability data are available although indirect wettability information is given from the different degrees of pore penetration observed by electron microscopy with different treatment/primer/adhesive combinations. Harris et al. [10] show that surface energy decrease with the increasing of surface roughness as the peaks, ridges and asperities form barriers which restrict the spreading of the droplet. Huh and Mason [11] and Yost et al. [12] have noted that with a cute contact angles the three-phase line is reluctant to flow over ridges and peaks. However, they also reported that the

* Corresponding author.
*E-mail address:* jasmina.boutar@gmail.com (Y. Boutar).

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droplet "seeks out" areas of the surface where it can spread more easily, particularly through troughs and valleys, perhaps as a result of capillary channelling.

This paper aims to contribute to a better understanding of the effect of surface roughness and wettability on the strength of single lap joints with an experimental study that characterises the surface using three statistical parameters ($R_a$, $R_q$ and $R_z$) and contact angle measurements.

## 2. Experimental procedure

### 2.1. Materials

The materials used in this study were Aluminium–copper alloys (Material properties are shown in Table 1) and structural one-component polyurethane adhesive. The mechanical tensile and other properties of the adhesive used are shown in Table 2.

Standard Single Lap Joint specimens were conform to Standard ASTM D1002 [13] with bonded dimensions of 25 mm × 12.5 mm. Configuration of the specimen are shown in Fig. 1.

### 2.2. Surface preparation

Two kinds of surface were used for the specimen: the not abraded surface and abraded surface. The surface quality of each overlap, the not abraded and those obtained by polishing with three grades, 1000, 180 and 50 was defined by three statistical parameters provided by a roughness detector with a differential inductance feeler (Mitutoyo SJ-210; Mitutoyo Corporation, Tokyo, Japan). Measured values of $R_a$, $R_q$ and $R_z$ are given in Table 3. Where $R_a$ is the arithmetic average height (μm), $R_q$ is the root mean square roughness (μm) and $R_z$ is the ten-point height (μm).

**Table 1**
Substrate mechanical properties (manufacturer data).

| **Aluminium–copper alloys** | |
|---|---|
| **Yield strength (MPa)** | ≥ 190 |
| **Elongation at yield stress (%)** | 17 |
| **Poisson's ration** | 0.33 |
| **Stiffness modulus (MPa)** | 26,500 |
| **Modulus of elasticity (MPa)** | 70,500 |

Fig. 2 illustrates the specimens surfaces images obtained using a digital microscope for the four types of surface preparation used. Fig. 3 shows a typical roughness profile ($R$ profile) for the two types of surface preparation used.

Surfaces substrates was cleaned and degreased with acetone. In order to ensure maximum shear strength, a treatment by addition of a primer layer adhesion is applied on the surfaces and smoothed dried for about 15 min before the application of the adhesive (Processes used in industrial applications).

### 2.3. Test methods

A specially tool was designed and manufactured (Fig. 4), to ensure that the specimens overlapping was 12.5 mm. The tool was adjustable with shims that allow obtaining the desired thickness of the adhesive with great precision. In our case, an adhesive thickness of 0.5 mm was applied to all specimens.

Once assembled, the excess adhesive was removed (to avoid possible origins of fractures) and a 0.250 kg weight was placed on the joint for 12 h. Tabs were bonded at the ends of single-lap joints to improve alignment, as shown in Fig. 1. The specimens were cured in a drying oven for a duration of $t$=48 h at a temperature $T$=30 °C and a moisture $H$=48%. Following the cure, the specimens were allowed to cool slowly. A dimensional verification was carried out with a calliper.

The specimens were tested destructively on an LLOYD 20 kN tensile testing machine using standard testing fixtures. All tests were carried out under monotonic loading at room temperature with a cross-head speed of 1.3 mm/min. A minimum of three specimens for each surface condition was tested to achieve an average result. After each test, the failure load was recorded and fractured surfaces were examined visually to determine whether the failure was adhesion or cohesion.

The wetting characteristics of all the specimens, after the addition of a primer layer adhesion applied on the surfaces, were determined using a contact angle goniometer (Digidrop gbx) via static de-ionised water contact angle measurements on water drops of size ~35 μl using the Laplace–Young method. A minimum of three tests (longitudinal and transversal) was recorded to achieve an average result. Fig. 5 illustrates the contact angle goniometer "Digidrop gbx".

**Table 2**
Adhesive properties (manufacturer data).

| **Polyurethane adhesive** | |
|---|---|
| **Chemical type** | Polyurethane prepolymers |
| **components** | One-component |
| **Viscosity** | 40–50 g/min |
| **Elongation at yield stress (%)** | 600 |
| **Tensile strength (MPa)** | 10 according to DIN (53504) |
| **Skin formation time (min)** | 25–35 min at 23 °C/50%HR |

**Table 3**
Surface roughnesses.

| **Profilometry parameter** | **Treatment** | | | |
|---|---|---|---|---|
| | ***Not abraded*** | ***p1000*** | ***p180*** | ***p50*** |
| $R_a$ (μm) | 0.3 ± 0.1 | 0.6 ± 0.19 | 1.5 ± 0.14 | 3 ± 0.16 |
| $R_q$ (μm) | 0.4 ± 0.14 | 0.7 ± 0.15 | 1.8 ± 0.12 | 2 ± 0.14 |
| $R_z$ (μm) | 2.8 ± 0.3 | 4.5 ± 0.41 | 9.8 ± 0.22 | 9.8 ± 0.7 |

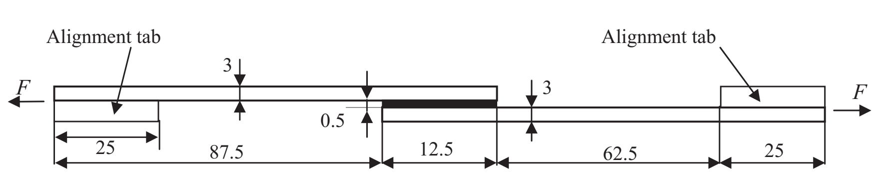


**Fig. 1.** Geometrical parameters of the single lap joint (dimensions in mm).