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Effect of adhesive thickness and loading speed on bonding strength in single-lap adhesive joints with aluminum 5754-H111

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Abstract

This study provides shear test results of single-lap adhesive joints with aluminum 5754-H111. To investigate the effect of adhesive thickness on joint strength in single-lap adhesive joints, three different thicknesses (0.2, 1, and 2 mm) were applied. Increasing the adhesive thickness from 0.2 mm to 1 mm and from 0.2 mm to 2 mm resulted in a reduction in shear load of roughly 36% and 44%, respectively. It has been observed that the joint strength decreases with increasing adhesive thickness in single-lap adhesive joints with aluminum 5754-H111. In addition, single-lap adhesive joints were tested at various loading rates (1, 10, and 100 mm/min), and the influence of loading speed on adhesive strength was studied. The shear load increased with the loading speed in the test results of single-lap adhesive joints.

Keywords: *Adhesive bonding, adhesive thickness, loading speed, single-lap joint*

Alüminyum 5754-H111 ile oluşturulan tek bindirmeli yapıştırma bağlantılarında yapıştırıcı kalınlığı ve yükleme hızının yapışma dayanımına etkisi

Öz

Bu çalışma, alüminyum 5754-H111 ile oluşturulan tek bindirmeli yapıştırma bağlantılarının kayma testi sonuçlarını sunmaktadır. Tek bindirmeli yapıştırma bağlantılarında yapıştırıcı kalınlığının bağlantı mukavemeti üzerindeki etkisini araştırmak için üç farklı kalınlık (0.2, 1 ve 2 mm) uygulanmıştır. Yapıştırıcı kalınlığının

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0.2 mm'den 1 mm'ye ve 0.2 mm'den 2 mm'ye arttırılması, kayma yükünde sırasıyla yaklaşık %36 ve %44'lük bir azalmaya neden olmuştur. Alüminyum 5754-H111 ile oluşturulan tek bindirmeli yapıştırma bağlantılarında yapıştırıcı kalınlığı arttıkça bağlantı mukavemetinin azaldığı görülmüştür. Ayrıca, tek bindirmeli yapıştırma bağlantıları çeşitli yükleme hızlarında (1, 10 ve 100 mm/dk) test edilmiş ve yükleme hızının yapışma dayanımına etkisi araştırılmıştır. Tek bindirmeli yapıştırma bağlantılarının test sonuçlarında, kayma kuvveti yükleme hızıyla birlikte artmıştır.

Anahtar kelimeler: *Yapıştırma işlemi, yapıştırıcı kalınlığı, yükleme hızı, tek bindirmeli bağlantı*

1. Introduction

Adhesive-based joining is a technique of joining two or more materials using a synthetic-based adhesive in such a way that the joint is unresolvable. Metal, polymer, ceramic, composite materials or combinations of these are used in joining [1, 2]. Joints made by adhesive method are preferred to other connection methods due to their advantages such as high strength, low cost, ease of assembly and lightweight [3]. In addition, adhesive-based joints do not cause changes in the crystal structure or create stress concentrations as a result of melting compared to rivet, welding and similar unresolvable traditional connections.

In recent years, the value of aluminum and its alloys for engineering applications where weight reduction is crucial has increased [4-6]. Particularly, Al 5754 aluminum alloy has a high strength value and superior resistance to corrosion [7, 8]. Besides the important application areas of Al 5754 in various sectors, its corrosion resistance and easy formability provide a great deal of potential of widen its usage not only in the automotive and aerospace industries but also in marine applications. Epoxy-based adhesives are used to join aluminum used in various applications in these industrial areas [9].

There are different joint types in the literature, such as single-lap joints (SLJ), double-lap joints (DLJ), stepped-lap joints, and scarf joints. However, single-lap bonding is the most preferred joint in practice due to its ease of design and manufacture, its effectiveness compared to other joint types. In the literature, there are many parameters that affect the bonding strength of single-lap adhesive joints, such as the material being joined, adhesive type, form of the bonded surface, part geometry, adhesive thickness, overlap area and test speed [10-14].

According to the majority of research on the relationship between adhesive thickness and single-lap joint strength, joint strength declines as adhesive thickness increases [15-17]. In addition, whether the adhesive is tough or ductile creates differences in bonding strength. The effect of increasing thickness on reducing bonding strength is greater in joints using tough adhesives compared to ductile adhesives. The maximum stresses occurred near the edge of the overlap zone in under tensile tests of single-lap joints. They stated that stresses increased with increasing overlap length and material thickness and stresses decreased with increasing adhesive thickness [18]. A parametric study conducted to determine the mechanical behavior of the lap joint they created using with an aluminum and a carbon fiber reinforced plate. In the test results, they stated that the shear load in the single-lap joints was impacted by changes in lap length and adhesive thickness [19].

Parts joined by adhesive bonding method cause changes in the bonding strength as they are exposed to loads at different rates in working environments. This makes it difficult to determine the load capacities that adhesive joints can safely carry. In the literature, different strength values were found by using different speeds in the tests of adhesive joints. The single-lap adhesive joint using carbon fiber reinforced plastic and aluminum at four different loading speeds were tested. The results of the research demonstrated that shear strength rose as loading speed increased [20]. The bonding strength between BFRP and aluminum alloy under various loading rates were investigated. Different bonding strength values were observed in the joints when the loading speed changed [21].

In this study, shear test results of single-lap joints with Al 5754-H111 material are presented. The effect of adhesive thickness on the bonding strength of Al 5754-H111 sheets joined by the single-lap method was examined. Additionally, single-lap adhesive joints were tested at different lo+ading speeds and the effect of loading speed on joint strength was examined by comparing the experimental results.

2. Material and method

In this work, Araldite® AV138 epoxy adhesive was used to produce single-lap joints using Al 5754-H111 material. Aluminum 5754-H111 is a tempered aluminum alloy with excellent impact and wear resistance, as well as high strength and corrosion resistance. The single-lap joints were made in accordance with ASTM D1002-10 standards [22]. The example dimensions of the single-lap adhesive joining produced using Al 5754-H111 are displayed in Figure 1.

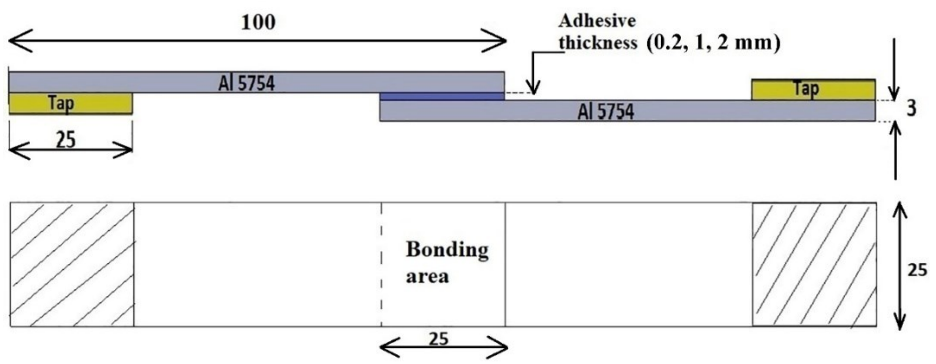

Figure 1. Single-lap joint geometry used in experiments.

Aluminum 5754-H111 plate, supplied with 1000×2000 mm dimensions, was cut to 25x100 mm in the rolling direction (0°) using a cutting bench (Figure 2).

Figure 2. Cutting process of aluminum 5754-H111 adherends

The mechanical properties of Al 5754-H111 are given in Table 1, and its chemical composition is given in Table 2. The properties of Al 5754-H111 given in Table 1 and Table 2 were taken from the datasheet provided by the manufacturer. The properties of Araldite® AV138 epoxy adhesive used in creating single-lap joints are presented in Table 3.

Table 1. Mechanical properties of aluminum 5754-H111

Tensile strength (MPa)	Yield strength (MPa)	Strain (%)
212.9	135.2	15

Table 2. Chemical composition of aluminum 5754-H111

Si	Fe	Cu	Mn	Mg	Zn	Ti	Cr	Al
0.201	0.235	0.036	0.200	2.807	0.027	0.021	0.025	Bal.

Table 3. Properties of the Araldite® AV138 [23]

Young's modulus E (GPa)	Poisson's ratio ν	Tensile stress σ_y (MPa)	Shear modulus G (GPa)
4.89 ± 0.81	0.35	36.49 ± 2.47	1.81

To increase the microscopic adhesion area on the Al 5754-H111 sample surfaces, roughness was made with P120 silicon carbide sandpaper. This sandpaper was chosen considering the viscosity of the adhesive, and thus the adhesive was fully spread on the surface of the specimen. A surface cleaning solvent was used during the abrasion procedures to eliminate the metal particulates accumulated on the material surfaces. The roughness of the samples was checked following the sanding procedure, and the resulting Ra value of 1.3 ± 0.1 μm was measured (Figure 3).

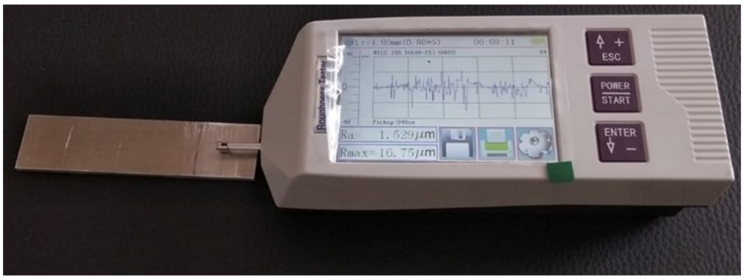

Figure 3. Measurement of surface roughness.

In single-lap adhesive joints, providing uniform adhesive thickness between the plates being connected in all samples is crucial. This standardization is essential for accurate analysis of the test parameters. For this purpose, the adhesive was applied in uniform thickness to the surfaces of the Al 5754-H111 adherends using a bonding fixture. The bonding fixture used in the joining process are given in Figure 4. Like similar studies in the literature, the adjustable wedges in this bonding fixture allow the adhesive thickness to be changed as desired [24-26].

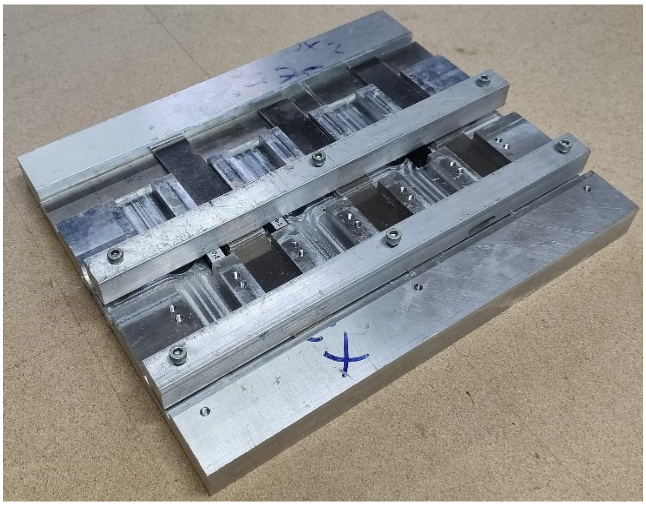

Figure 4. The fixture used in the bonding process.

In single-lap joints, aluminum adherends are joined using Araldite® AV138 epoxy adhesive. The Araldite® AV138 was preferred because it has high strength, low volatility, and excellent corrosion resistance. This structural adhesive consists of two components and cures at room temperature. The Araldite® AV138 adhesive was mixed with a hardener in a ratio of 4:10 (hardener/adhesive) using a precision scale in order to achieve a homogeneous composition. A thin layer of the produced mixture was applied to the aluminum surfaces. After applying the adhesive to the surfaces, the plates were placed in the bonding fixture and left to cure for 36 hours at room temperature under constant pressure. The production of uniform adhesive thickness on all surfaces was facilitated by the use of fixture throughout the bonding process. In this study, adhesive joints with thicknesses of 0.2, 1 and 2 mm were applied. Adhesives overflowing from the edges of the samples removed from the fixture were cleaned. The tabs were cut to the proper size and bonded to the samples in order to connect the samples to the device jaws on the same axis in the shear test. The prepared samples of single-lap joints were placed on to the jaw of the tensile device, and experiments were conducted utilizing the interface program of the device. Image of the experimental setup is illustrated in Figure 5.

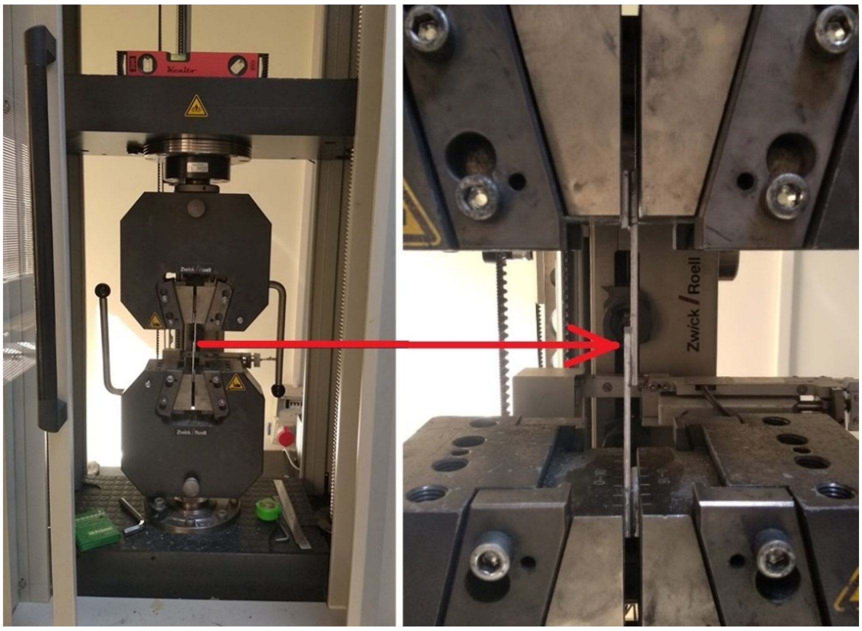

Figure 5. Shear test of single-lap joints.

Shear experiments were carried out at room temperature and at loading speeds of 1, 10, and 100 mm/min using a Zwick Roell Z020 tensile instrument. 5 (Five) samples were tested for each of the parameters that were used in the experiments.

3. Results and discussion

Shear tests were carried out to examine the effect of adhesive thickness and loading speed on bonding strength in single-lap adhesive joints with aluminum 5754-H111 and the outcomes were compared on graphs. The effect of adhesive thickness on joint strength in single-lap joints created from aluminum 5754-H111 is illustrated in the graph in Figure 6.

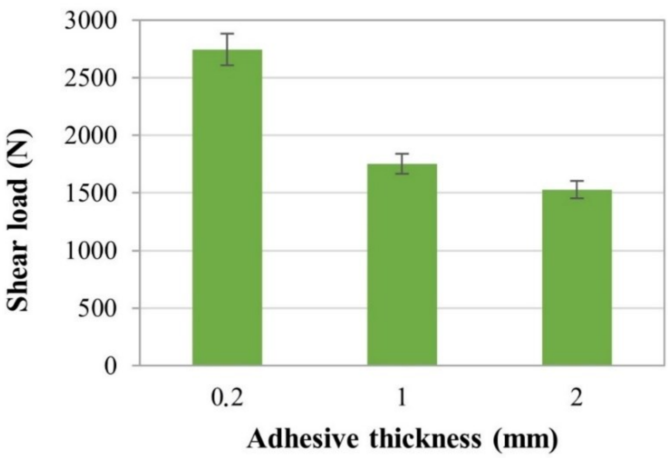

Figure 6. The effect of adhesive thickness on joint strength

The shear load was reduced by roughly 36% when the adhesive thickness was increased from 0.2 mm to 1 mm. As the adhesive thickness increased to 2 mm, the shear load decreased by roughly 44%. This can be explained as the defects caused by cavities and microcracks in the adhesive decrease the joint strength. This decrease varies depending on the fragility of the adhesive used in the joints [27]. This finding confirmed the literature by giving data parallel to the shear test results of joints made with different adhesives [28].

Figure 7 shows the force-displacement graph that resulted from the shear test of single-lap joints produced with various adhesive thicknesses.

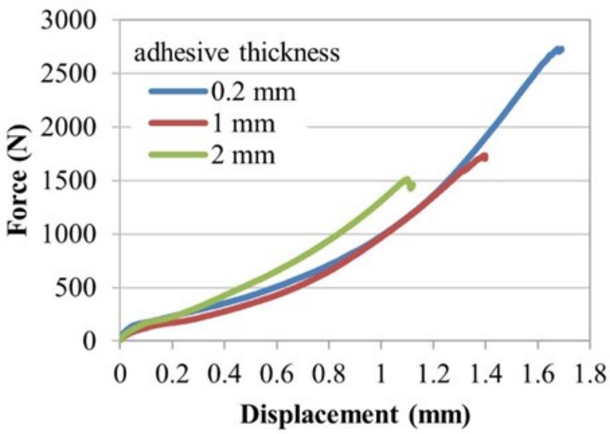

Figure 7. Force-displacement graph of joints produced with various adhesive thicknesses.

As seen in Figure 7, increasing the adhesive thickness reduces both the load-carrying and the displacement capacities in adhesive joints. In the graph, the area at the bottom of the force-displacement curve represents the absorption energy of adhesive joint. Accordingly, it can be concluded that the joints with 0.2 mm adhesive have higher absorbed energy than the joints with 1 mm and 2 mm adhesive.

Figure 8 shows the test results for single-lap joints produced with 3 mm aluminum adherend and 0.2 mm thick adhesive. The joints were tested at three different loading speeds: 1, 10, and 100 mm/min.

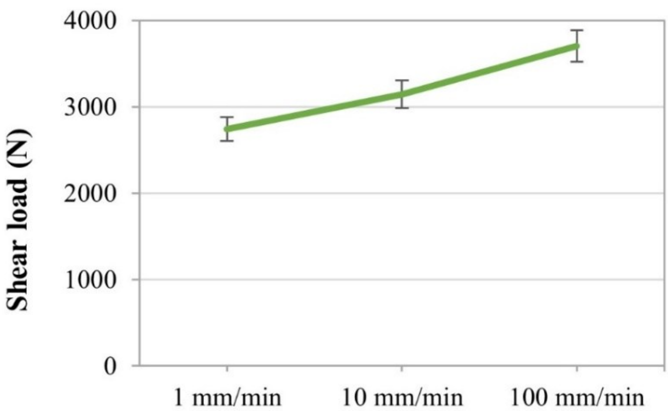

Figure 8. Effect of loading speed on joint strength.

By increasing the loading speed from 1 mm/min to 10 mm/min in the shear testing of single-lap adhesive joints, the joint was able to carry an additional load of approximately 14.6% (Figure 8). The shear load increased from 14.6% to 35.1% when loading speed increased from 10 to 100 mm/min. As a result, in the shear tests of single-lap joints with aluminum plate and 0.2 mm adhesive, an increase in the shear load was observed as the loading speed increased. As the loading speed increases, the breakage time is significantly shortened [20]. This causes the shear load to increase rapidly and reach the fracture energy in a shorter time. Therefore, the shear load of the joint was higher in high-speed tests. This finding confirmed the literature, which reported that the shear load increases as the loading speed increases in shear tests of single-lap adhesive joints with different materials [20]. In Figure 9, the fracture surfaces of adhesive joints after the shear tests are shown.

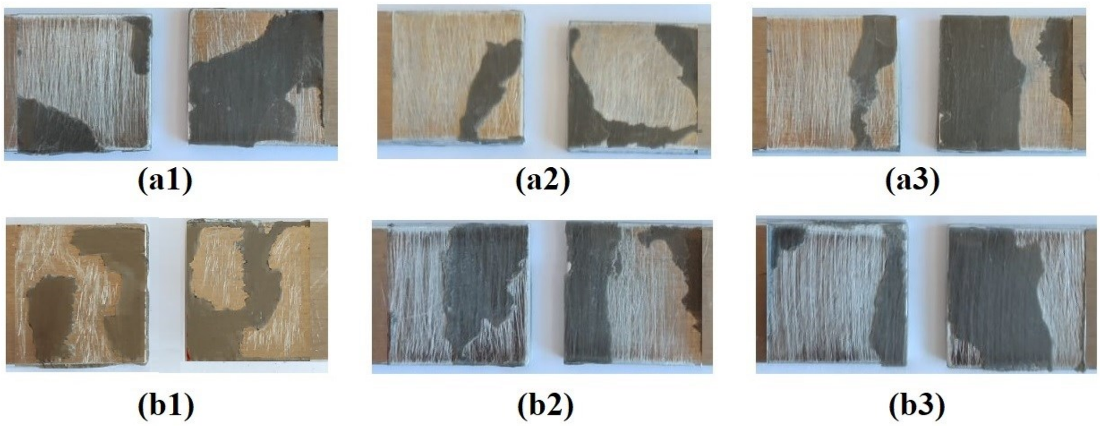

Figure 9. Surface damages of the samples; adhesive thicknesses (a1:0.2 mm, a2:1mm, a3:2 mm) and loading speeds (b1:1 mm/min, b2:10 mm/min, b3:100 mm/min)

Following a set of shear tests at different adhesive thicknesses and loading rates, the damaged surfaces of the adhesively bonded joints were evaluated. By examination of the damaged surfaces of the adhesive joints, it was seen that in all samples, some of the adhesives remained on the upper part and some on the lower part. As a result, it is seen that there is an adhesive failure on the damaged surfaces of all samples bonded with Araldite® AV138, which is damage between the adhesive layer and the interface of the adherend. Furthermore, it was noted that variations in adhesive thickness and loading rate did not influence the type of damage observed in the joint at the shear test.

4. Conclusion

This study aimed to investigate the impact of adhesive thickness and loading speed on adhesive strength in single-lap adhesive joints made of aluminum 5754-H111. For aluminum 5754-H111 single-lap joints, changing the adhesive thickness and loading speed has significant effects on the joint strength. Increasing the adhesive thickness from 0.2 mm to 1 mm and from 0.2 mm to 2 mm resulted in a reduction in shear load of roughly 36% and 44%, respectively. According to this result, the joint strength decreased as the adhesive thickened in single-lap adhesive joints with aluminum 5754-H111. As the adhesive thickness increased, the load-carrying and displacement capacities of the adhesive joints decreased. By increasing the loading speed from 1 mm/min to 10 mm/min in the shear testing of single-lap adhesive joints, the joint was able to carry an additional load of approximately 14.6%. The shear load increased from 14.6% to 35.1% when the loading speed increased from 10 to 100 mm/min. As a result, it was observed that the shear load increased with the loading speed in the shear tests of single-lap joints. Additionally, it was observed that changes in adhesive thickness and loading rate did not affect the type of damage that occurred in the joint after the shear test.

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