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RESEARCH OF ADHESIVE AL– SHEET JOINTS IN THE DEVELOPMENT OF LIGHTWEIGHT STRUCTURES

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Abstract: Adhesion is a major element of the bonding technologies used today. This way of joining meets the requirements of mechanical load, with high reliability of the product, and in connection with the production and climatic conditions. Bonding is the process of making inseparable bonds in mechanical engineering with non–metallic material, through adhesion and cohesion forces, without significant impact on the structure of the parts to be joined. Gluing (adhesive joint), as a way of making joints in mechanical engineering, is gaining importance in the development of spacecraft and aircraft, as well as the automotive industry. This requires high load–bearing capacity and stiffness, with minimal weight, so alloys such as aluminum and titanium are used. Adhesive joining is increasingly displacing the dominant rivets when joining light metals, and is used to join thin sheets made of different types of materials. In this paper, the possibilities of adhesive joining and the characteristics of glued joints made of aluminum alloy AW– 5754 were researched, using static tests, and their fractography was analyzed.
Keywords: adhesive joints, light constructions, static testing, Al alloys

INTRODUCTION

In order to increase energy efficiency, the concept of sustainable lightweight (LW) design has been used for the last few years. This concept of lightweight design, which is currently used, refers to the reduction of the weight of the structure by using lighter materials, which include aluminum. The choice of materials for light constructions also means the choice of joining technology, which is of essential importance [1].

In order to think in the right direction when designing and constructing light structures, the prerequisites are the properties of the material such as: stiffness, strength, ability to absorb energy. Usage the maximum potentials of high– performance materials allows choosing the right way to connect them [2].

Adhesion is a major element of the bonding technologies used today [3–5]. This way of joining meets the requirements of mechanical load, with high reliability of the product, and in connection with the production and climatic conditions.

Adhesives used to achieve adhesion must be resistant to crash at high loads, allow uniform application of adequate force, stress distribution, weight reduction and allow better rigidity of components, durability, as well as properties shown in the crash test. In addition, these types of adhesives have advantages that are reflected in low thermal impact on materials, the ability to damping vibrations and to improve sealing [1].

Bonding is the process of making inseparable bonds in mechanical engineering with non–metallic material, through adhesion and cohesion forces, without significant impact on the structure of the parts to be joined (Figure 1). Adhesion is a state in which two different surfaces made of different (or the same) materials are held together by the interaction of attractive forces due to the interaction of molecules, atoms or ions.

Cohesion or internal strength is the action between two surfaces of a material, ie attractive forces of identical atoms or molecules. Cohesion strength depends on the material and temperature. Metals have the highest cohesive strength, and liquids and gases have the lowest. The molecular weight of the polymer is an important factor in determining the cohesion strength of the adhesive.

Double action of optimal adhesion and cohesion is required to connect the forces and to achieve the optimal strength of the bonded joint. When optimal adhesion forces are achieved in the preparation of the bonding material, then the cohesive strength of the bonded joint is the decisive criterion for its strength [6].

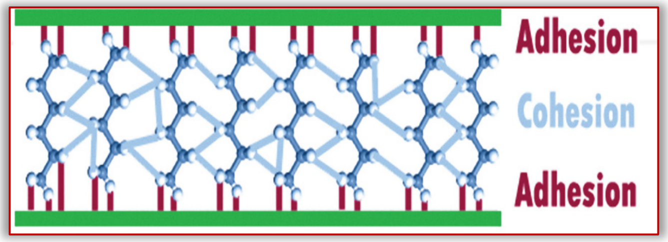

Figure 1. Adhesion and cohesion bonds in adhesive joint [7]

The mechanisms of adhesion have been intensively researched in recent years; so many theories have been put forward that explain the principles of adhesion. However, none of them fully explain adhesion. It can be concluded that the adhesion of the adhesive to the surface of the part to be bonded is the result of mechanical, physical and chemical forces that overlap and affect each other.

After Fe (iron), aluminum is the second metal used in modern mechanical engineering. It is used as a pure metal in electrical engineering, metal processing, food and chemical industries, but its application is much more important in the form of various multicomponent alloys that are widely used in the mechanical industry [8– 10]. Joining of aluminum sheets can be achieved by applying the following technologies [3– 5, 11, 12]:

- Welding;
- Connection with mechanical elements (screws, rivets);
- Gluing (adhesive bonding);
- Hybrid merger.

Adhesion, due to its low specific weight, as well as due to the thin layer of adhesive in the joints, has an advantage over welded and mechanical joints [13]. Aluminum and its alloys are characterized by extraordinary mechanical properties, which have opened many technological sectors. Although they are much lighter than other metals, they have a very high mechanical strength, which is why they are widely used in the aerospace industry (50%, 68%, depending on the manufacturer and model of the aircraft). It is considered that aluminum constructions can be competitive in applications where low specific weight, corrosion resistance, functionality of construction forms and profiles are important.

In this paper, the analysis of the mechanical properties of the adhesive joint of aluminum alloy AW 5754 with a thickness of 1 mm will be presented. Commercial adhesive, Loctite EA 3430, Henkel, (two– component epoxy adhesive) was used for adhesion.

DESIGN OF ADHESIVE JOINTS

The rules for forming adhesive joints are similar to those for solder joints. However, adhesive technology is more complicated and error– prone. The choice of adhesive largely depends on the type of material to be joined, the required joint strength, external influences (humidity, temperature, corrosion) [14].

The possibility of fast and reliable adhesion of all types of materials is the reason why today adhesives are considered a standard part of many production processes. Almost all types of materials such as steel, aluminum, synthetic and composite materials, glass and ceramics can be combined with the help of adhesives. In this way, manufacturers can choose materials without restrictions related to joining different materials [15].

The decisive role, however, is played by the position of the sheets to be joined, with the appropriate parameters of the manufacturer, which relate to the choice of adhesive. E.g [13]:

- Butt joints are undesirable, pipe butt joints are particularly unfavorable, folding joints with beveled edges are more favorable;
- Angle joints cause stress concentration, so they need to be strengthened at the ends;
- In order to avoid stress concentration, the shear load is the most favorable;

The strength of the adhesive joint depends not only on the correct choice of adhesive, but also on a number of other factors. Thus, numerous tests have shown that in addition to the type of adhesive (including correctly implemented adhesive technology), environmental conditions, temperature, duration of load, type of load, surface treatment, etc. are also influential.

Adhesive joints are subject to changes in mechanical properties, depending on the time elapsed in operation regardless of the load (the so– called aging effect of the adhesive). This effect occurs even without load, after long– term storage of the joined elements. The aging of metal adhesives depends primarily on the type of adhesive, the condition of the surfaces before bonding, but mostly on the environment in which the bond is glued (dry air or sea water). Resistance against aging is generally higher with hot–setting adhesives than with cold–setting adhesives [16, 17]. The thickness of the adhesive layer in the bonded joint also affects the strength of the joint. It is always more advantageous that the thickness of the adhesive layer is smaller. An adhesive layer thickness of 0.05 to 0.15 mm is considered optimal for most adhesives [18]. This is all true for folding and butt joints of sheets and similar shapes, where it is relatively difficult to control the thickness of the adhesive layer. Otherwise, the exact thickness of the adhesive layer can be achieved only by connecting pipes and similar elements with a closed contour.

Surface treatment significantly affects the strength of the adhesive joints of aluminum alloys. Yasmin Boutar et al [19] founded that the decrease in surface roughness was found to increase the shear strength of single lap joints. Experimental results show that rougher surfaces have less wettability which is in coherent with shear strength tests. The author's C. Borsellino et al [20] also conclude that roughness significantly affects the the strength of the adhesive joints of aluminum alloys.

The strength of the adhesive joints is highly temperature dependent [21], with cold binder adhesives being more sensitive to temperature rise than hot binders. Hot– melt adhesives are used for temperatures up to about 250 C (there are also special high– temperature adhesives up to 350 C), so that the maximum allowable permanent temperature of the loaded adhesive joint (excluding other influences) is determined by these values.

TESTING OF ADHESIVE JOINTS

The failure mode of the adhesive joint depends on a number of factors: adhesive properties (cohesion and adhesion strength), bonding material properties (free surface energy, surface roughness, surface cleanliness, mechanical properties), adhesion process and flow, pressure, temperature, time, humidity etc.), the design of the adhesive joint (adhesive layer thickness, substrate thickness, joint types and dimensions) and load conditions (load type– static or dynamic: mode, time, temperatures, loads, etc.).

Adhesive joints should be shaped so that they are primarily shear stress (folding joint) and to a lesser extent tension / pressure (butt joint), therefore, in these joints the working force should act in the plane where the joint is made. Bending and twisting stresses should be avoided [14].

Testing of adhesive joints involves static and dynamic testing. Adhesive joints are tested in the following three ways [22]:

- a tensile– shear test known as the TS test (Figure 2a);
- L tensile test (Figure 2b);
- H tensile test (Figure 2c).

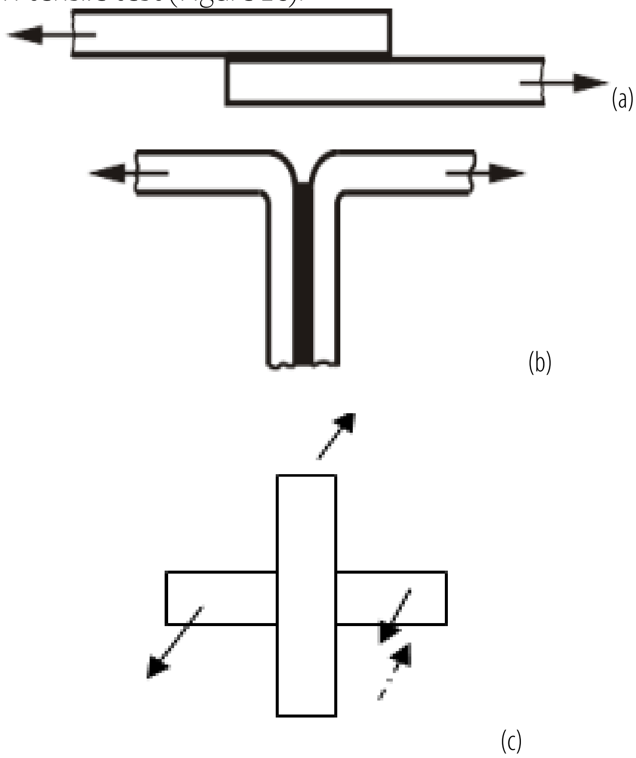

Figure 2. Methods for testing the adhesive joint: a) TS test; b) L test; c) CT test

The values of the degree of safety of the adhesive joint is in the range S = 2– 5. The most important influencing factors on the load– bearing capacity of adhesive joints are the type of material to be joined, the thickness of the adhesive in the joint, the roughness of the adhesive joints surfaces, the environment during operation and similar.

Different types of fractures can occur during tensile testing. Four types of fractures are characteristic for an adhesive joint [23]:

- Adhesive fracture (Figure 3 a);
- Adhesive– cohesive fracture (Fig 3 b);
- Cohesive fracture (Fig 3 c);
- Subtractive fracture (Fig 3 d).

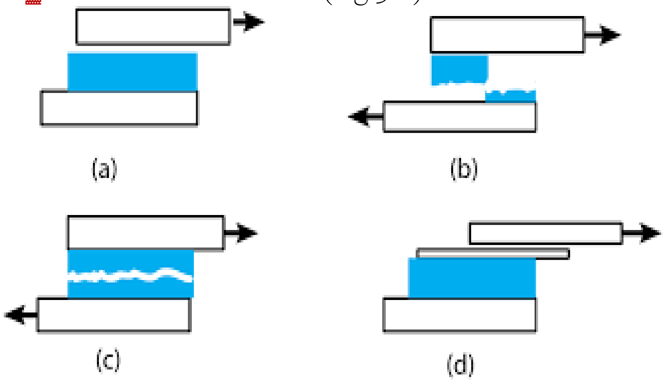

Figure 3. Types of fracture in adhesive joints [23]

EXPERIMENTAL RESEARCH

The test was adjusted to the equipment of the Faculty of Mechanical Engineering of the University of East Sarajevo (SHIMADZU AGS– X test machine). Tension– shear test was performed, i.e. TS test. The speed of the traverse during the test was 2 [mm/min]. The aim of the test is to determine the maximum force that the adhesive joint can withstand. The test was done for three samples.

Preparation of test specimens was performed in accordance with available research, experientially sheet thickness 1mm (Figure 4). Cutting and bending of the samples was done by hand with the use of auxiliary tools. The first sanding was performed with P120 sandpaper, and the final sanding with P240 granulation paper. At the end of grinding, the samples were cleaned with alcohol, Ethanol 96%. This is a common process of preparing samples for adhesion and the goal of sanding and cleaning is to remove impurities from the metal surface that can affect the quality of the joint.

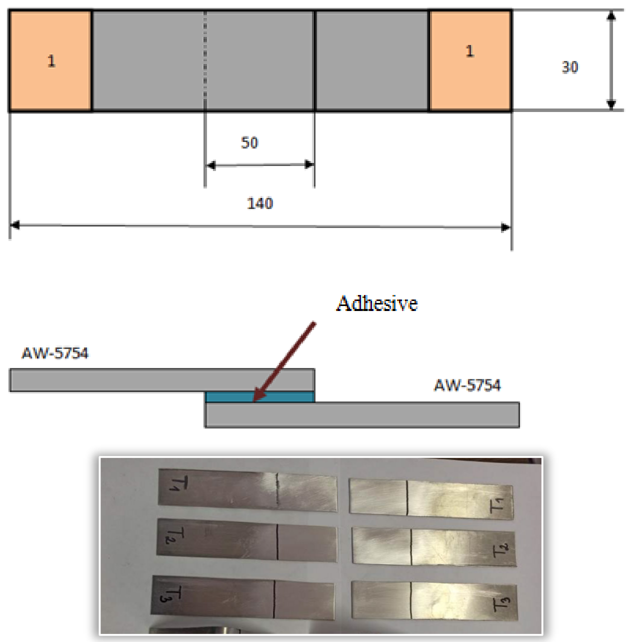

Figure 4. Prepared samples for adhesion

The samples were adhesived with Loctite EA 3430 (Henkel). It is a two– component epoxy adhesive that has great application in industry. Adhesion time 10 minutes, taking into account the viscosity of the adhesive.

After the adhesion process, the samples were clamped with plastic clamps to prevent movement during the drying process. The drying process lasted 24 hours at room temperature (approximately 20 °).

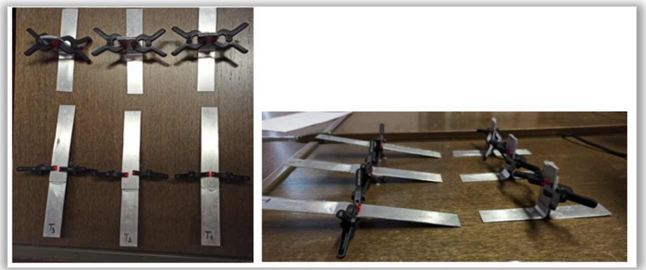

Figure 5. Samples during drying

The results of the tensile test (TS test) are shown in Figures 6, 7, 8.

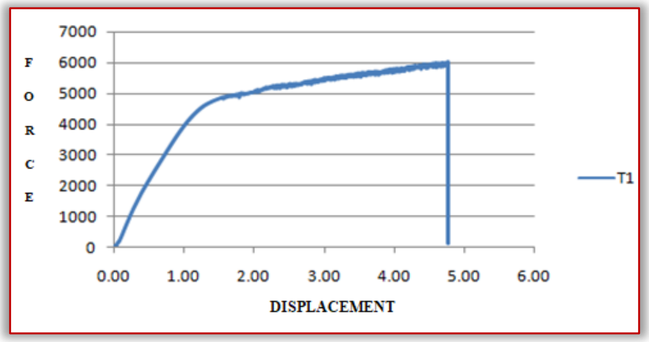

Figure 6. Force–displacement diagram for sample T1

The figures show that the adhesive joint withstood a force in the range of 6000– 6500 [N]. Taking into account the thickness of aluminum alloy sheets AW– 5754, which is 1 [mm], and width 30 [mm], and tensile strength Rm = 245 [N / mm2] it is concluded that sheet metal of these dimensions and this material can withstand a force of approximately 7350 [N]. Comparing this value with the value obtained in the tensile test, it can be concluded that the given joint gives satisfactory mechanical characteristics because the load– bearing capacity of the base material (sample) is only 11% higher than the load– bearing capacity of the adhesive joint.

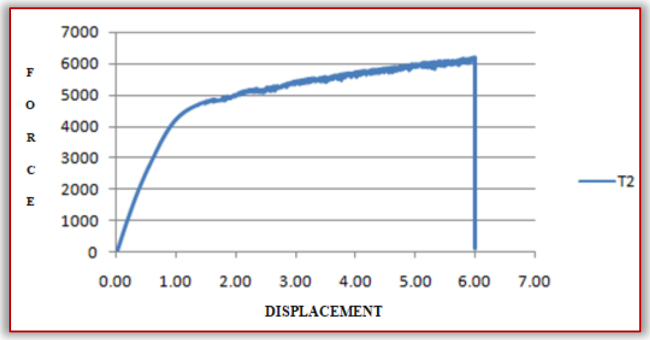

Figure 7. Force–displacement diagram for sample T2

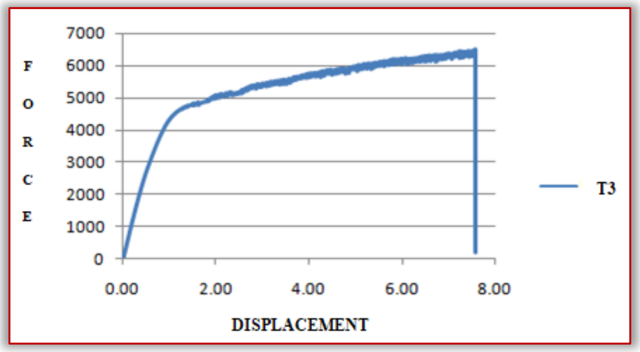

Figure 8. Force–displacement diagram for sample T3

In all three diagrams, it can be noticed that when the moment the force reaches approximately 4000 [N], a zigzag line appears, which manifests itself from the occasional tearing (cracking) of the adhesive.

Figure 9 shows the T (T1, T2, T3) samples after fracture, while Figures 10, 11, 12 show the fractography of the compound.

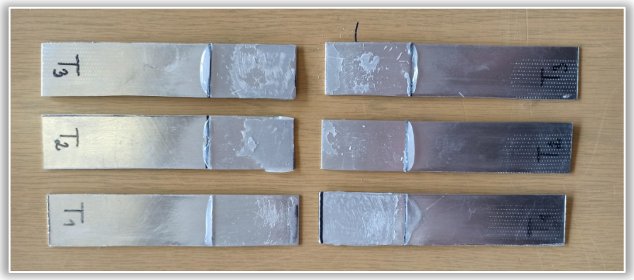

Figure 9. Display of T samples after fracture

Fractography of the compound was performed on a Leica EZ4 microscope, and from the analysis of the result it can be concluded that in these cases there is an adhesive– cohesive fracture.

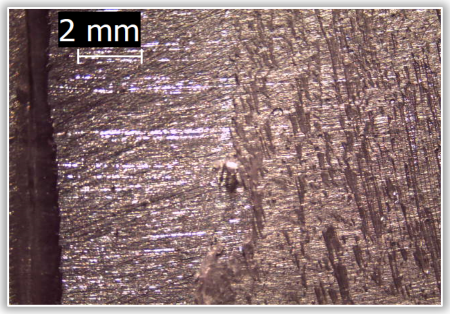

Figure 10. Fractography of the T1 sample compound

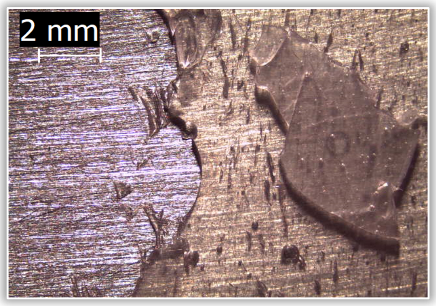

Figure 11. Fractography of the T2 sample compound

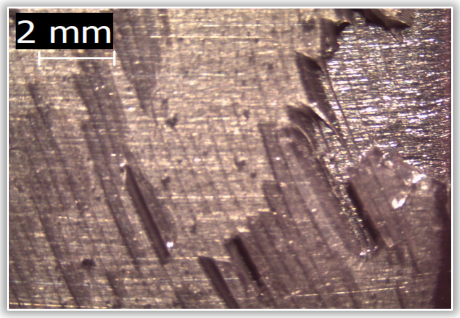

Figure 12. Fractography of the T3 sample compound

CONCLUSIONS

Considering the trend of design development for lightweight structures and the requirements for high productivity in industrial production, the increased use of structural adhesives is expected. Mentioned adhesives will be more and more represented, because the design focused on lightweight constructions means saving resources, and this is impossible to achieve, among other things, without the use of adhesives. There is a clear trend of increasing use of composite materials and aluminum alloys, primarily in the automotive and aerospace industries because weight reduction is very important in these industries. In the future, the success of metalworking companies will largely depend on their ability to exploit the innovative potential of using composite materials. In this sense, structural adhesion is an important factor and key technology (industrial production) in choosing the way of joining in the machine industry, both homogeneous and heterogeneous materials, 21st century. Adhesion is most often used for joining dissimilar materials, but in this paper, bonding of homogeneous materials is presented.

Cohesion and adhesion forces are responsible for the strength of the adhesive joint. Although many mechanisms are known to work in the adhesive material and between the adhesive and the surface of the parts to be joined by adhesion, it is still not possible to determine exactly which mechanism is most responsible for creating the adhesive joint, i.e. which mechanism achieves the highest joint strength.

The procedure for adhesion of aluminum alloy sheets AW– 5754 is presented and analyzed. Loctite EA 3430 epoxy two– component adhesive from Henkel was used for adhesion. Testing of previously prepared samples was performed using test, namely, the tensile– shear test TS. The test results show that specimens prepared and tested for tensile– shear or TS test can withstand a force in the range of 6000– 6500 [N]. Analyzing the fractography of the joint samples tested by TS test, it can be concluded that adhesive– cohesive fracture has occurred.

The results of the performed experiment are satisfactory from the aspect of durability of the adhesive joint.

Acknowledgment

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