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Original Article

Zero-emission joining methods for low-load automotive structural components

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Abstract: The article contains general information on the bonding of aluminum sheets, considering the most commonly used methods of surface preparation of sheets, a description of the bonding mechanism and a comparison of the different types of adhesives used in the industry, a summary table provides information on the most commonly used adhesives used in the industry. In addition, the static tensile test of aluminum alloys used in the automotive industry is described. In the following part of the article, the research problem of bonding strength of sheet metal by gluing with two types of two-components adhesive Epidian 57 and Epidian 53 is solved. In the practical part of the research, aluminum alloy 2024 - T3, the most used alloy to produce low-load structural components used in the automotive and aerospace industries, was used. The test consisted of gluing together two overlapping (overlap bonding) sheets of metal with different types of adhesives using a specially designed device. The thickness of the sheet used was 1mm, the total thickness was 2mm. After the gluing process, the samples were torn on a testing machine. The results are shown in a summary table and presented in a graph.

Keywords: Energy reduction, aluminium, low-emission, metal joining, adhesive bonding

Introduction

The EU's new restrictive law places a heavy emphasis on low-carbon performance [1]. Hence, cleaner energy and low CO_2 emissions are very important aspects in manufacturing operations [2]. This is why new recycling techniques, new materials or low-waste industrial techniques are being used more and more [3-6]. One of the more innovative and environmentally friendly methods of joining sheet metal is bonding. It is a rather specific method of bonding components that does not require heat or any other type of energy to form a joint [7,8]. Bonding is a versatile sheet metal bonding method and all types of materials used in industry can be joined. It is possible to join metals, e.g. steel, various aluminum alloys, brass, titanium, magnesium or copper, precious metals such as silver, gold can also be joined. It is also possible to bond non-metals to metals [9]. Non-metallic materials such as wood, rubber, all plastics, glass and even porcelain can be bonded [10]. An important advantage of bonding is that materials so thin that other bonding methods cannot be used. Another advantage of bonding is that the process is relatively inexpensive and simple, with even a less-skilled worker able to make a good adhesive joint. In this paper, the results of tensile strength tests on aluminum sheets joined using two types of adhesives were analyzed [11,12],

In order to achieve a bonded joint with adequate strength conditions, it is necessary to apply the adhesive to both components to be joined. One of the most important factors affecting the quality of the joint is the cleanliness of the surfaces before the adhesive is applied [13]. The most harmful tarnishes on bonded surfaces include grease and silicones. The application of a number of mechanical and chemical cleaning operations is necessary to ensure that the joint has the necessary strength, which depends largely on the adhesive's adhesion to the parts to be bonded and the cohesion that occurs in the cured state in the adhesive [14]. There are two types of adhesion: specific and mechanical. Mechanical adhesion plays a very important role in the bonding process. The bonding agent must penetrate the pores, kinks and irregularities of the surface and properly validate itself into the base of the cured adhesive coating. Obtaining the right amount of this type of adhesion involves preparing the surface for optimum surface roughness. Specific adhesion, on the other hand, describes the adhesive's ability to adhere to surfaces with a low degree of roughness. Its magnitude depends on the interaction of chemical and physical forces between the atoms of the surface layer of the component to be bonded and the adhesive molecules. Surface preparation is one of the most important operations in the bonding process, and the quality of the joint largely depends on its correct execution [15].

The table below (Table I) presents the most commonly used methods of surface preparation of aluminum alloy sheets [16].

Table I Most commonly used methods of surface preparation of aluminum alloy sheets [16]

Category	Surface preparation method for aluminum sheets
Mechanical	Griding, blasting, so called removal of aluminum oxides, cleaning, abrading, and brushing adhesion
Adhesion protection	Application of silanes, primers, and zol-gels
Chemical and electrochemical	Degreasing, anodizing with chromic and sulphuric acid, phosphoric acid, chromic acid or phosphor-sulphuric acid, pickling, conversion coating often with the use of chromium, titanium, and zirconium oxides

A well-conducted bonding process consists of many steps. The most important are [17-19]:

- Preparation of the surfaces to be glued
- Preparation of the adhesive mass
- Lubrication of the surfaces with the adhesive mass
- Proper joining of the components
- Curing and drying of the joint
- Finishing the glue

Bonding has many advantages and offers new possibilities for joining components [20,21]:

- Components of unlimited thickness can be joined
- Bodies with different properties and structures can be joined
- The operation is usually carried out at room temperature, no energy is needed to create the bond
- The adhesive layer has anticorrosive properties
- By adding suitable modifiers we can obtain various types of joints, from very strong to flexible
- The low temperature of the process and the lack of stress in the process allows components to be joined after careful processing

Unfortunately, bonding, like other bonding methods, has several limitations:

- The strength properties are at a relatively low level compared to other sheet metal joining methods. Shear strength is around 30 MPa, but can reach 40 MPa depending on the adhesive used
- The joint is not heat resistant. Although adhesives that are resistant to short-term high temperatures have been used for some time
- Adhesives age rapidly, resulting in a reduction in the strength of the joint over time
- The bonded joint has a high susceptibility to creep
- Substances used during the bonding process have harmful properties for the environment and humans and can cause poisoning [22]

The best strength properties in the bonding process are achieved with an adhesive layer of optimum thickness. The recommended thickness is between 0.05-0.1 mm. Going beyond this scale results in a huge reduction in the strength properties of the joint [23]. By using the method of bonding the elements, we are able to obtain an even distribution of stresses in the veneer (Fig. 1.), which makes such a connection resistant to changing loads. The adhesive layer can act as a kind of sealing of the joint, making it airtight and preventing the penetration of liquids or gas; moreover, the adhesive provides protection against certain chemical agents, such as water, oil or petrol. The most common type of adhesive joint is the lap joint [24-26].

The types of adhesives most used to join metal structures can be divided according to [27]:

- The nature of the basic chemical component used in each adhesive (e.g. organic synthetic and natural, inorganic
- The consistency (plastic, liquid, solid)
- Method of curing

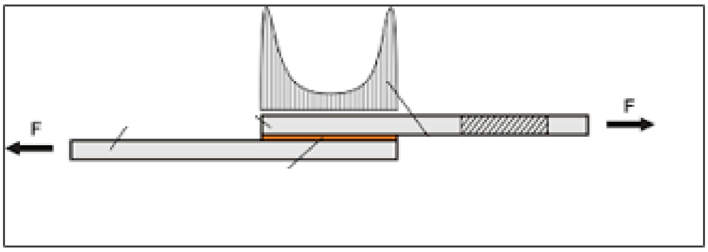

Fig. 1. Lap joint with reduced stress distribution [26]

The most common group of adhesives for joining sheet metal components are two-component adhesives cured by polymerization based on acrylic, polyester or vinyl ester, polyurethane two-component and one-component [28].

There is a wide range of adhesives for joining metal sheets with very good strength properties (Table II) when selecting an adhesive, it is worth paying attention to the strength properties of the obtained joint [29,30].

Table II Selected types of adhesives and their properties [31,33]

No.	Name	Type	Tensile strength [MPA]	Application	Characteristics
1	Korapox 558	2-Component epoxy resin	20	Metal to metal joints, metal glass, metal ceramic	High strength, limited toughness
2	DP 490	2 component expoxy	34	Metal to metal joints, metal to plastic	High strength, resistance to temp. >1200 °C
3	Sika Dur 30	2 component epoxy resin	20	Steel concreto joints	Solvent free mortar
4	Korapur 666	2 component polyurethane	14	Metal to plastic	Moisture resistant
5	Sika Fast 5221	2 component acrylics	3.5	Tool joints	Fast performing, resiliment
6	Korapur 140	1 component polymer	1	Metal to metal joints, metal to wood, metal to plastic	For primed and painted parts
7	Korapop 240	1 component polymer	1.8	Metal to metal	Joints for fixing trapezoidal sheets

One of the most important characteristics of adhesives is the so-called glass transition temperature, i.e. the temperature at which the weld starts to soften, and its mechanical strength properties deteriorate significantly [34,35]. For the various types of construction adhesives used in industry, the glass transition temperatures vary significantly (Table III) [36-38].

Table III Glass transition temperatures of adhesives

No.	Adhesive type	Glass transition temperature [°C]
1	Acrylic	<80
2	Polyurethane	<80
3	Polyamides	280-330
4	part 2 epoxy toughened	60-80
5	Phenolic epoxy	150-200
6	BMI	200 - 300
7	1 component modified epoxy	100 - 150

The following factors must be considered in order to select an appropriate adhesive for sheet metal component joints [39]:

- The type of components to be jointed
- Costs
- The working temperature of the parts to be joined (at a higher or lower temperature)
- Mechanical properties to be satisfied by the joint (tensile strength, shrinkage, creep, etc.)[40]

Materials and Methods

In order to solve the research problem, a research methodology has been adopted that will ultimately allow the determination of the best bonded joint strength for 2024 T3 aluminum alloy sheets bonded by the lap method [41].

In terms of the work undertaken, it is proposed to:

- The selection of the materials, tools and machines necessary to carry out the test
- Selection of process parameters to obtain high peel strength
- Carrying out laboratory tests using a testing machine
- Analyzing the test results obtained

The object of this study was to compare the tensile strength of the lap joint of aluminum sheets of alloy 2024 T3 bonded with two types of adhesives: Epidian 57 and Epidian 53. The joined sheets were 1 mm thick. The material was supersaturated, then cold deformed and subjected to natural ageing to stabilise the alloy. EN 573-1. Bonding was carried out using the apparatus shown in the following photo (Fig. 2).

Fig. 2. Picture of the bonding device with the bonded sample attached

The weight of the load used to press the glued sheets is 1 kg, the pressing time of the samples is 24 hours. The glue application tool is shown in the figure below (Fig. 3). By using it, we have eliminated the need to manually mix the adhesive and hardener, as this is done automatically by using ready-made cartridges.

Fig. 3. Device for applying adhesive to the surfaces of araldite 2000 sheets

The dimensions of the joint are 25mm x 10mm, hence its surface area is 250mm2. The samples were bonded with two types of adhesive:

- Epidian 57 glue
- Epidian 53 glue

Results

Epidian 57 glue is a clear, viscous epoxy composition modified with a yellow to light brown polyester resin. After curing, it is characterized by increased peel resistance. This adhesive can be used for bonding many materials, suitable for cold bonding of metals, glass, ceramics, leather. The Z-1 hardener was used in the ratio 100 parts adhesive, 10 parts hardener. The strength parameters of the adhesive with the hardener used are presented below (Table IV).

Table IV Strength properties of Epidian 57 adhesive with hardener Z-1

Parameter tested	**Ep-57+Utw.Z-1**
Breaking load, MPa	45-55
Flexural strength, MPa	70-80
Compressive strength, MPa	65-75
Ball compression hardness, MPa	90-100
Deflection temperature by martens, °C	60-65
Adhesive bond shear strength, MPa	15-20
Adhesive bond strength by bending with shear, MPa	Min. 2.5

The Epidian 53 adhesive is a modified epoxy resin containing the inactive diluent styrene as a modifier. It is characterized by medium viscosity. It has very good electrical insulating properties. It is used for the manufacture of epoxy-glass laminates, bonding metals, glass ceramics, joining rigid structures, flooding capacitors, resistors, connectors, cable terminations and for model casting. The resin cannot be used for bonding polystyrene foam. To cure the adhesive, Z-1 hardener was used in a ratio of 100 parts adhesive, 10 parts hardener. The resin is in the form of a viscous liquid with a light yellow colour and is characterized by:

- The ability to cure at room temperature
- Excellent adhesion to most materials
- Good mechanical properties and resistance to many chemical agents such as oils, greases, diluted lyes and acids
- Excellent dielectric properties

The strength parameters of the adhesive with the curing agent used are shown below (Table V).

Table V Strength properties of Epidian 53 adhesive with hardener Z-1

Parameter tested	**Ep-53+Utw. Z-1**
Breaking load, MPa	40-60
Flexural strength, MPa	80-100
Compressive strength, MPa	70-90
Ball compression hardness, MPa	100-120
Deflection temperaturę by martens, °C	50-55
Adhesive bond shear strength, MPa	Min.10
Adhesive bond strength by bending with shear, MPa	Min. 2,5

Surface preparation consisted of hand-sanding the surfaces with two types of sandpaper, pre-sanding with 400 grit sandpaper and finish sanding with 800 grit sandpaper. They were then degreased with Loctite 7063 chemical degreaser.

Strength tests included a static tensile test, the tests were carried out on a Zwick/Roell Z250 kN ripper. Parameters at which the strength testing of the specimens was carried out:

- Initial tension force 5N
- Testing speed 0.2 mm/s

Discussion and Conclusions

The specimens for the strength tests were cut from bonded strips of sheet metal in a direction perpendicular to the joint line. The width of the specimens was 12.5 mm. The results of the joint strength tests are shown in (Table VI). The best tensile strength values for bonding were obtained with Epidian 57 adhesive and amounted to 4.3 kN. A summary of the average results for bonding is presented in the table below (Table VII).

Table VI Results of measurements

Type of adhesive	Rupture force value F, kN
Epidian adhesive 57	4.15
	4.3
	4.25
Epidian adhesive 53	3.52
	3.54
	3.6

Table VII Average tensile strength values for different adhesives

Type of adhesive	Average tensile strength value, kN
Epidian adhesive 57	4.23
Epidian adhesive 53	3.55

A summary of the average results for the adhesive joints is presented in the graph below (Fig. IV).

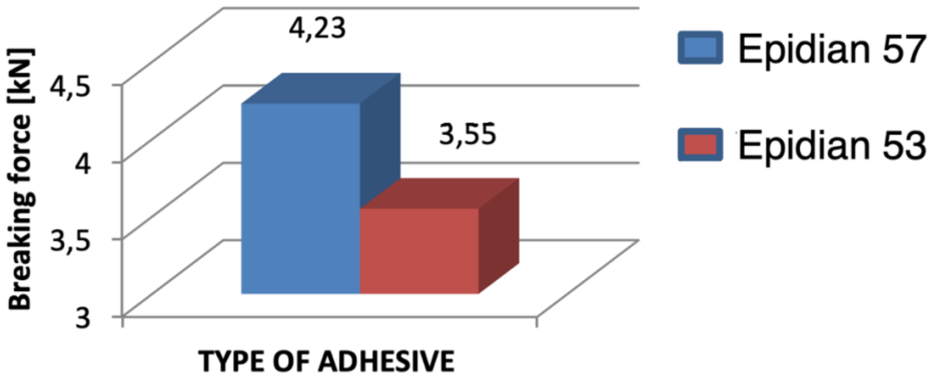

Fig. 4. Summary of average tensile strength results for different types of adhesives

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