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THE INFLUENCE OF SELECTED ADHESIVE PROPERTIES AND THE MANNER OF SURFACE PREPARATION UPON IMPACT STRENGTH OF BLOCK ADHESIVE JOINTS

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Abstract

The research described in this article is part of investigating impact strength in block adhesive joints. The authors checked experimentally the effect, on the test results, of the manner of surface preparation and compressive strength and Young's modulus of an adhesive used to make the connection. The experimental testing was carried out with an impact pendulum tool, designed to examine adhesive joints. During such testing, the energy used to tear off the upper part of the specimen, that is the energy lost by the dropping device, is the measure of the impact strength of an adhesive connection. The elements of the samples were made with an aluminum alloy 2017A. In the investigations, the authors used non-normative samples whose upper element was a cylinder rather than a cuboid, as advised in the norm. The adhesive joints were made using epoxy adhesive Loctite, named EA 3421, or an adhesive composition Epidian 57 with Z1 hardener. The glued elements were prepared by treating the surfaces for bonding by means of the stream-abrasive processing. The abrasive mediums were three types of materials of different gradation. In addition, two series of samples were prepared using roughening by sandpaper. For control samples, the authors made joints, in which the surfaces for bonding became degreased merely by petroleum ether.

The results of the experimental studies indicate that the impact strength of adhesive joints is dependent on the manner of preparation of the bonded elements as well as on the longitudinal modulus of elasticity of the adhesive, which was used to make the connection.

Keywords: *adhesive joint, impact strength, adhesive properties*

1. Introduction

The development of modern technology, particularly aviation and aerospace would be practically impossible without the use of bonding technology. Connecting various construction materials with adhesives gives rise to a great deal of possibilities in terms of both design and manufacturing, successfully competing with conventional methods, i.e. riveting, welding, soldering, or screwing [1]. Adhesive connections may also be used in repairs (particularly of composite items), including repairs conducted in field conditions, which are often significantly different from the normative conditions. In this type of repairs, usually there is no possibility of using methods to prepare the surface for bonding, recommended by manufacturers of adhesive. Instead, roughening

with sandpaper or stream-abrasive processing is carried out, using abrasive mediums, available on-site.

In numerous static investigations of adhesive bonds, it was found that even when connecting the same materials with the same adhesive, where there is the same degree of surface development, although obtained by different ways of surface treatment, various connection strengths are achieved. It depends upon the degree of surface activation, which is related to the surface energy, obtained by the material undergoing treatment. Another adhesion activity can be observed in surfaces subjected to electrical discharges. It is different in surfaces undergoing chemical etching or anodized surfaces, and in surfaces subjected to stream-abrasive treatment (which causes additional surface compression), although they will be characterised by the same degree of roughness [2].

Based on the investigations with regard to the static strength of adhesive joints [3, 4], it was found that the abrasive blasting significantly increases the surface roughness and in most cases it improves the strength of the connection. Appropriate surface preparation is also crucial in other processes, where the appropriate roughness and surface structure are important [5]. However, it is necessary to pay attention to the shape and properties as well as the size of grains of the abrasive medium.

The article presents the dependence between impact strength of block adhesive joints and the manner of preparation of the surface for bonding as well as the properties of the used glue. The authors examined the connections in which the elements intended for bonding had only been washed with petroleum ether; also connections, in which the surfaces to be bonded were prepared with the following methods: abrasive blasting using copper slag or artificial corundum, and also roughening with sandpaper.

2. Research methodology

In order to conduct impact strength investigations, 10 series of adhesively bonded block samples were made. All the samples were performed in accordance with the provisions of norm EN 13887 "Adhesives for structural connections. Guidelines for the preparation of metal surfaces and plastics before bonding".

The material, which was used for making all the samples, was aluminum alloy 2017A. The block samples were built with bottom, rectangular elements, sized 60x30x25 mm, with glued cylinders, 12.6 mm in diameter 5 mm in height (Fig. 1). The surface of the joint was equal to the surface of the cylinder base, equalling 125 mm^2, i.e. it equalled half the surface of a normative sample. Such a relationship between the values of the surface areas will allow comparing the findings obtained in different investigations.

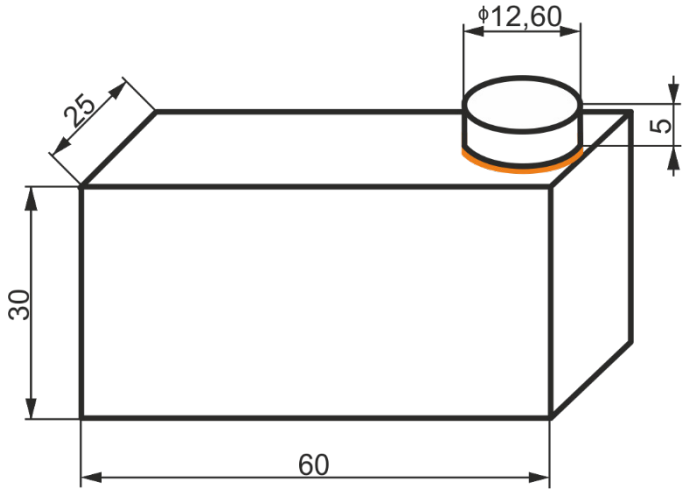

Fig. 1. Measurements of the block sample

The glues were adhesive plastics with a significant difference in Young's modulus and very similar compressive strength, listed in the table (Table 1). In accordance with the recommendations of the PN-ISO 9653 [6], sets of samples, ten pieces each, were prepared.

Tab 1. Mechanical properties of adhesives used in the investigations

No	Name of glue	Compression strength R_c [MPa]	Young's modulus [MPa]
1.	Epidian 57/Z1	70	1,800
2.	Loctite EA 3421	69	963

Before bonding, the metal elements were prepared by different mechanical methods. In addition, the samples in which the glued elements had been prepared only by washing their surface with petroleum ether were bonded. The remaining adherends were cleaned; their surfaces were given an appropriate structure and roughness by the method of abrasive blasting or roughening with sandpaper. The abrasive medium was copper slag with grain size equal to 0.4-0.9 mm and corundum with grain size equal to 220 and 500. The stream-abrasive processing was carried out until a uniform structure of the treated surface was achieved. Roughening of the surface of the bonded elements was performed with sandpaper, 180 grit. The direction of roughening was perpendicular to the direction of applying load to the sample. Next, the authors made a visual assessment of the prepared surfaces by a metallographic microscope (magnification x100) and a measurement of the obtained surface roughness, using the Minutolo Surf test SJ-210 profilometer, because they intended to characterise quantitatively the manner of surface preparation, also using an arithmetic mean deviation of the profile from the mean line (*Ra*).

After mechanical treatment, the glued elements were washed with petroleum ether for degreasing and removing any residual abrasive powders. After the evaporation of petroleum ether, the authors applied glue and put together the bonded pieces by placing them in a bonding device, where they were pressed and left for curing for a period of 7 days at a temperature of 21°C.

The investigation of impact strength was conducted by a pendulum hammer, designed for testing impact strength of block adhesive connections and lap adhesive connections [7, 8] (Fig. 2).

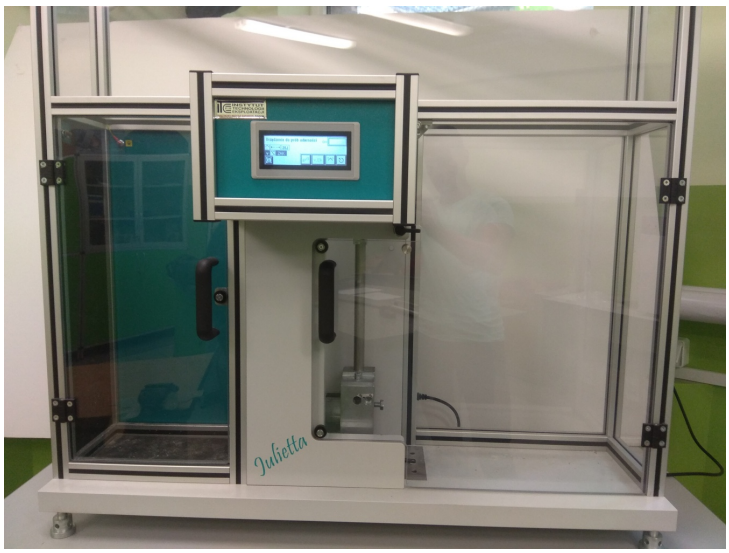

Fig. 2. Device used in impact strength tests of adhesive joints

The investigation was conducted, using the pendulum whose maximum energy equalled 15 J, and whose speed in the lowest position was 2.96 m/s. The investigation was conducted by applying impact load in accordance with the scheme shown in Figure 3 [9]. The impactor struck the sample element at a height of 2.6 mm over the joint. Special attention was drawn to keeping a steady distance from the adhesive joint, since the value of this parameter noticeably affects the recorded test results [10].

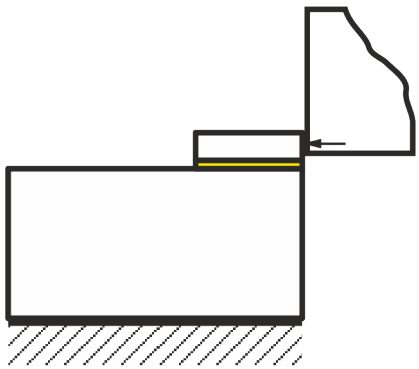

Fig. 3. Scheme of applying load to the sample

The thickness of the joints in all the connections equalled approximately 0.1 mm. The examinations of the samples were conducted for both of the exploited adhesives, 7 days after making the joints.

3. Discussion on research findings

Due to the methodology of the sample preparation, investigating them was performed non-simultaneously. However, the focus was made on maintaining a steady time interval between bonding and examining the samples, as well as maintaining the same temperature during all the tests.

Figure 4 shows the impact of surface preparation of the bonded elements upon the impact strength of the examined joints.

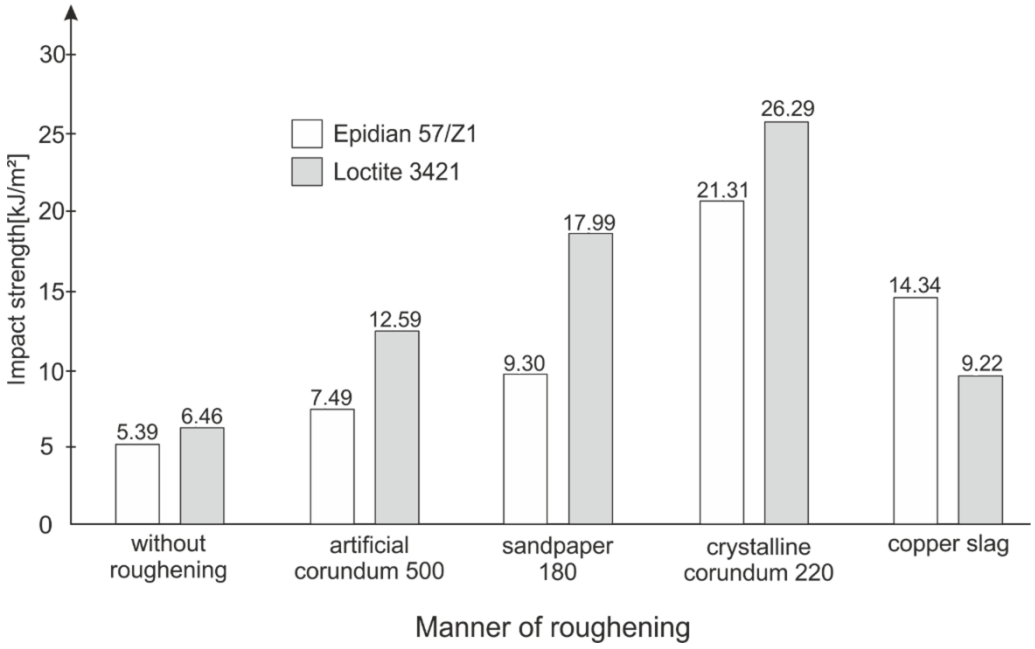

Fig. 4. The influence of the manner of surface preparation upon impact strength of examined joints

An analysis of the condition of the breakthroughs of the examined connections points to cohesive-adhesive destruction of all connections, whose surfaces had been prepared mechanically for bonding. The share of adhesive damage in the majority of breakthroughs was estimated at 10.... 20%. The connections, in which the components for bonding were prepared by washing with petroleum ether, also underwent cohesive-adhesive damage; the share of adhesive destruction equalled approximately 10...30%. It was therefore concluded that the adhesion for all connections was good and that due to a similar nature of the damage, it was possible to compare all the results obtained in the tests.

Figure 4 shows the relationship between impact strength and the manner of surface roughening. One may observe that the manner of surface preparation exerts an influence upon impact strength of block adhesive connections. For both adhesives, the best way of roughening was stream-abrasive treatment made by fine crystalline corundum, with abrasive grit equal to F = 220. Lack of surface preparation for both adhesives adversely affected the strength of the joints. Based on the results for these adhesives, one may draw a conclusion that the roughening of the surface prior to bonding is a good way to increase the impact strength of the connection.

The results of investigating the influence of surface preparation of the bonded elements (roughness) upon the impact strength recorded in the research are shown in figures 5 and 6. The charts presented in the figures include the findings of the research into joints in which the surfaces for joining were roughened with sandpaper. Next, they were washed only with petroleum ether. They then underwent stream-abrasive treatment with fine crystalline corundum, grit F = 220 (due to the fact that this abrasive medium made it possible to achieve higher impact strength in this method of surface preparation).

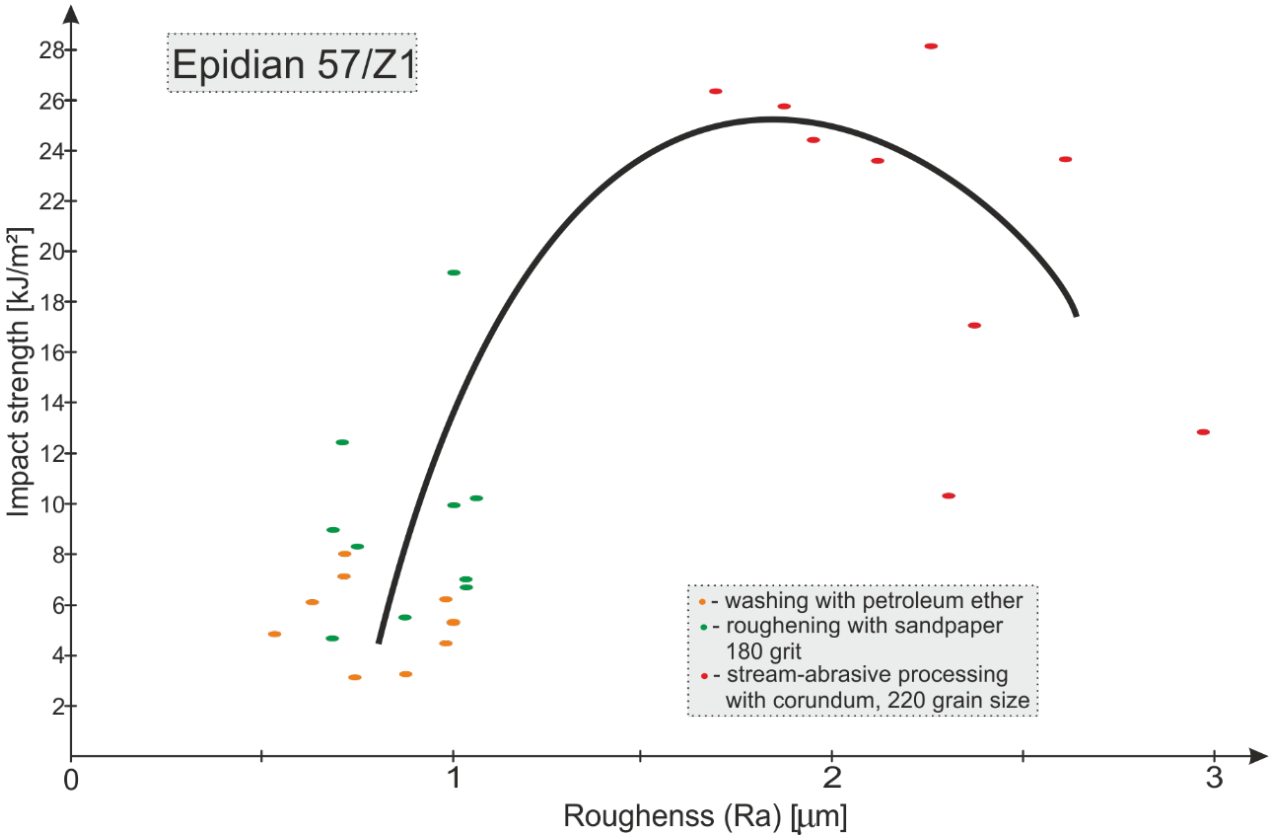

Fig. 5. Dependence between the impact strength of adhesive connections made with Epidian 57/Z1 and surface roughness of glued elements.

As a result of the conducted process of surface preparation, the authors obtained various values of roughness. The arithmetic means of the profile deviation from the mean line (*Ra*) of the surfaces prepared for bonding ranged from 0.76±0.19 µm to 2.25±0.20 µm. An analysis of the investigation findings (Figures 5 and 6) indicates a dependence between block adhesive connections and the manner of surface preparation of the bonded elements. Regardless of the applied adhesive, the glue connections in which the bonded elements had only been washed with petrol were characterised by the lowest impact strength. Along with an increase in roughness values, the impact strength of connections grew, and with Ra equal to approximately 2 µm, it was the highest. Having reached the maximum value, while still increasing the surface roughness, the impact strength diminished; the decrease was characterised by a similar gradient for both adhesives.

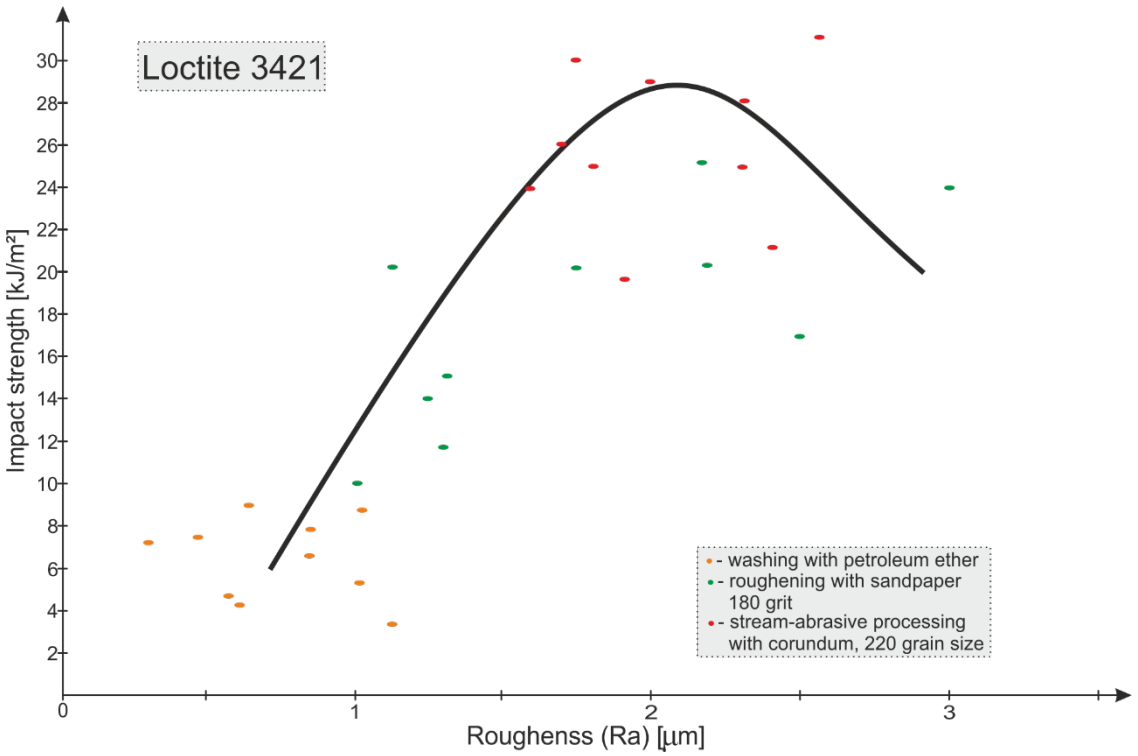

Fig. 6. Dependence between the impact strength of adhesive connections made with Loctite 3421 and surface roughness of glued elements.

In the case of connections made with Loctite 3421 (Fig. 6), whose surfaces were characterized by roughness of Ra = 0.75 µm, the average impact strength was recorded as 4.5 kJ/m^2. Due to an increase in surface roughness up to the value of Ra = 2.0 µm, the impact strength of the examined connections exceeded 26 kJ/m^2. A further increase in roughness caused a drop in the recorded impact strength of the connections. In the case of connections roughened by sandpaper and undergoing stream-abrasive treatment with fine crystalline corundum, grit F = 220, the authors obtained similar roughness values (Ra ≈ 2.2 µm) and the values of impact strength of the connections.

In the value range of Ra = 0.90…2.10 µm, higher roughness values correspond to higher values of impact strength of the connections despite different technologies of surface preparation. Besides, for this range of values Ra, there is greater impact strength in connections made with an adhesive, which has a lower value of Young's modulus (Loctite 3421). It is worth noting that both adhesives, used in the investigations, are characterized by very similar compressive strength and a two-fold difference in the values of Young's modulus, which does not result in the same difference in impact strength (with the exception of connections with roughened elements).

4. Conclusions

1. Impact strength of adhesive block connections significantly depends upon the manner of preparation of the elements of the glued surfaces. It seems that the value of surface roughness is more relevant than the shape of the irregularity, as long as they are the same in their character (e.g. sharp edges).
2. With the same compressive strength of adhesive plastics, a significant impact upon the impact strength of adhesive connections is exerted by the longitudinal modulus of elasticity of the adhesive, which makes the joint.
3. The results of the impact strength investigations have a large discrepancy in their nature, which is likely to be reduced by examining connections, where (in the whole series) the surfaces of bonded elements will be characterized by similar roughness.

4. In order to receive a more complete picture of the impact of surface preparation upon the impact strength of adhesive connections, the authors intend to conduct further research, in which other methods will also be used for surface preparation. Moreover, the extent of surface roughness of the elements intended for gluing will be wider.

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