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SURFACE ROUGHNESS INFLUENCE ON INTERMOLECULAR FORCES RATIO

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ABSTRACT
Bonding is permanent joining process of parts, by usually non-metallic material that combines the adhesion and cohesion forces without significant influence on the structure of the joined parts. The strength of the bonded joint depends on many factors. Many studies have shown that beside of type of glue, great influence have environmental conditions, temperature, load duration, type of load, etc. Influence of surface roughness to the joint strength was shown in this paper. In experimental part, non-alloy quality structural steel E 295 *with different state of surface roughness was bonded, using Loctite 3471 - two component epoxy, commonly used for rebuild worn metal parts. Joint quality was analysed through joint strength and appearance of the fracture surfaces.*
Keywords: Epoxy, bonding, adhesion, cohesion, surface roughness, analysis of fracture

1. INTRODUCTION
Modern materials found the most use in cases where materials which are usually used, cannot meet the requirements that are expected of them. Only with good knowledge of the proper selection of "liquid metal", its preparation, and preparation of surfaces to be joined or repaired, the desired results and the required quality can be achieve, and which will meet the requirements of exploiting parts that are joined. Experimental research conducted in this paper aimed to determine the dependence of surface quality to the value of tensile strength "of adhesive joints."

2. BASE MATERIAL
In the experimental part of this research the samples which were used were made of structural steel. These steels are used mostly for making shafts, axles, gears, bearings springs, screws, caps, valves, etc. With regard to mechanical properties, structural steel must have a high-yield, sufficient plastic deformability (to avoid the occurrence of brittle fracture), high limit for creeping, high strength at higher temperatures, and sufficient toughness and fatigue strength. A specially selected structural steel for machine building St 50-2 has been used for the making of the samples. The chemical composition and mechanical properties of the material are given in Table 1 and 2.

Table 1: Chemical composition of the base material

Type according to DIN	C [%]	Si [%]	Mn [%]	P [%]	S [%]	N [%]
St 50-2	0,3	-	-	0,05	0,05	0,009

Table 2: The mechanical properties of the base material

Type according to DIN	R_M [N/mm^2]	$R_{P0,2}$ [N/mm^2]	A_5 [%]
St 50-2	470	285	20

3. FILLER MATERIAL

When choosing filler material for joining samples, a couple of factors must meet. The liquid metal used in this experiment was supposed to meet the specific requirements related to the submission of the load; it should not distort the geometry and process parameters, it should give excellent adhesion to the base material, and the tensile and shear strength should be good.

As additional material, or material for joining samples, liquid metal Loctite 3471 was chosen. This is a multi-purpose two-part epoxy that is commonly used for repairs on damaged mechanical parts, repair of cavitations and others. It is characterized by a slight shrinkage after solidification (0.1%), high compressive strength and good workability with machine tools. Features of the used material are given in Table 3.

Table 3: Properties of two-component liquid metal Loctite 3471

Volume / mass mixing ratio	1:1
Time of action	45 min.
Fixture time	180 min.
Shear strength	20 N/mm^2
Compressive Strength	70 N/mm^2
Operating temperature range	-20 do +120 °C

4. MEASURING ROUGHNESS ON EXPERIMENTAL SAMPLES

In this study the samples were processed on machines with different modes of application processing. To achieve a certain level of quality of treated surface, a knife cutter with carbide was used. Measuring the roughness of processed specimens was performed in the laboratory of the Faculty of Mechanical Engineering in Sarajevo. A device by the manufacturer Mitutoyo, type Suftest – 402 was used. The given parameters of processing the specimens for testing with associated parameters and the degree of surface roughness are given in Table 4.

Table 4: *Parameters of processing the specimens for testing with associated parameters and the degree of surface roughness*

Sample (code)	Processing pattern		Quality parameters of tested surface					Degree of surface roughness
	Speeds	Feeds	R_A [μm]	R_Z [μm]	R_{MAX} [μm]	R_{3Z} [μm]	λ_c	
1.	400 o/min	0,036	6,2	44	67	15	2,5	N9
2.	400 o/min	0,2	15,2	88	106	56	2,5	N10
3.	200 o/min	0,5	40,5	191	217	126	2,5	N11

5. TESTING OF EXPERIMENTAL SAMPLES

The study was conducted at the Faculty of Mechanical Engineering in Mostar. The universal hydraulic machine for testing - HMT.50.EM was used. This testing machine is designed for testing of small diameter samples. The testing was carried out at room temperature.

The testing machine is connected to the computer, and by entering data about the cross section of the samples in the proper software, the values of tensile strength are scanned immediately. From the diagram it could be seen that the depending force strain lines have a rough appearance, primarily due to the very small elongation caused by the way of merger of the test samples. The diagram matches the diagram on breaking hard and brittle materials.

5.1. Analysis of surface fracture on experimental samples

After overloading and breaking the experimental samples, which enabled us to perform a visual inspection of the contact surfaces. All samples were photographed vertical the contact surface so the entire fractured surface is clearly visible.

The aim of this review is to try to determine the type of fracture, to define the relationship of adhesion and cohesion forces, as well as the quality of wetting, achieved by the joining between the liquid metal and the surfaces of metal samples, and to try to detect any residual "air pockets". The fracture, depending on adhesion and cohesion forces, can be:

• adhesive fracture
• cohesive fracture and
• adhesive - cohesive fracture

On the Figure 1 is shown the appearance of an experimental sample after the surface fractured. The relationship forces of adhesion and cohesion, fracture type, and quality of wetting are clearly visible.

Figure 1. *Dominant forces on the fractured surface of the experimental samples*

The results of the analysis of the fractured surfaces of samples are given in Table 5. Values Fa and Fc in Table 5 represent the average values of forces on a series of three tested samples.

Table 5 *Results of the analysis of the fractured surfaces of samples*

Number of sample	The variable parameters of the tube		The ratio of intermolecular forces	
	The degree of surface roughness	The thickness of the layer of liquid metal	Fa [~ %]	Fk [~ %]
1.	N9	0,2	65,02 %	34,98 %
2.	N9	0,4	85,08 %	14,92 %
3.	N9	0,6	61,42 %	38,58 %
4.	N10	0,2	88,32 %	11,68 %
5.	N10	0,4	93,59 %	6, 41 %
6.	N10	0,6	84,64 %	15, 36 %
7.	N11	0,2	99,53 %	0,47 %
8.	N11	0,4	98,62 %	1,38 %
9.	N11	0,6	99,48 %	0,52 %

5.2. Analysis of the impact of parameters on the value of intermolecular forces

In the part in which the testing of experimental samples is conducted, an analysis of the fracture and the relationship between intermolecular forces Fa and Fk is described. By analysing this relationship, it is observed that with the increase in the degree of surface roughness, an increase in the percentage of adhesive strength is occurring, relative to the force of cohesion. Figure 2 shows a diagram of dependence of adhesion force Fa of the degree of surface roughness.

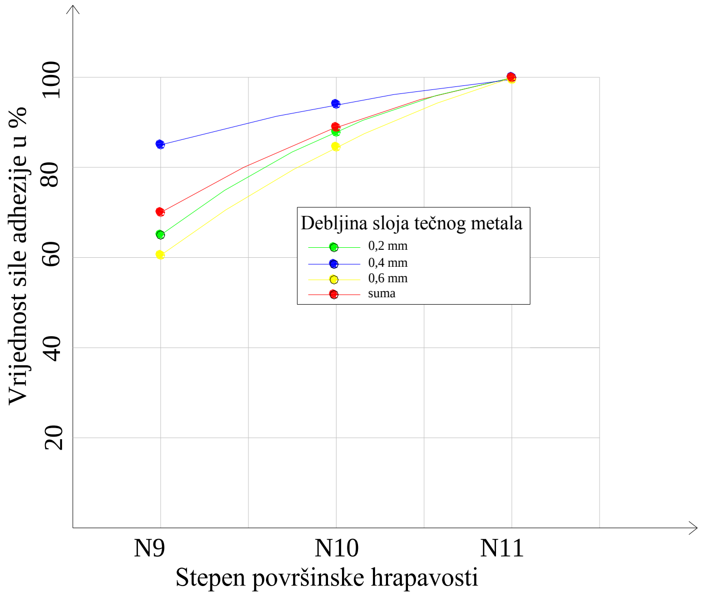

Figure 4. *Dependence of the value of adhesion force F_a of the degree of surface roughness*

Picture 4 shows that with the increasing degree of surface roughness, an increase of adhesion strength, regardless of the thickness of the layer of liquid metal happens. The growth is expressed the most in the value of thickness of the layer of liquid metal 0.6 [mm]. The average adhesion force for a certain degree of surface roughness, regardless of the thickness of the layer of liquid metal, is represented by the red curve in the diagram.

6. CONCLUSION

An analysis of the influence of the degree of surface roughness to the intermolecular forces of the fracture is conducted. It can be concluded that with an increase in the degree surface roughness the relationship between intermolecular forces Fa and Fc are changed, so that the percentage of the fractured surface at which the dominant force is Fa, is increasing in comparison to Fc.

Analyzing the fractured surface, it can be concluded that in experimental samples with degree of surface roughness N9 and N10 started an adhesive - cohesive fracture. Analysing the fractured surface of experimental samples and the degree of surface roughness N11, it can be concluded that a cohesive fracture occurred due to the overload.

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