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Full Length Research Paper

The effects of adhesive thickness, surface roughness and overlap distance on joint strength in prismatic plug-in joints attached with adhesive

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The aim of this study is to determine the effects of surface roughness, adhesive thickness and overlap distance on the joint strength in prismatic plug-in joints combined with adhesive. For this purpose, samples produced in three different types of overlap distance, three different types of adhesive thickness and three different types of surface roughness were attached by three different widely used epoxy-based adhesives, resulting in a total of 81 prismatic plug-in joints. The strength of each joint was determined by subjecting them to axial tensile tests and the results are presented as a comparison.

Key words: Adhesive, surface roughness, prismatic plug-in joint, joint strength.

INTRODUCTION

Adhesives are generally mixtures composed by chemically mixing materials such as epoxy, phenol, polyamide, polyimide and silicone, which produce the desired design features when at least two different materials are combined by bonding (Morrisey and Johnson, 1985).

Adhesives that are most widely-used for metal bonding are epoxies. Epoxy adhesives composed of resin and hardener, and these adhesives provide extremely strong bonding. They are available in three different forms: single component, double component and film. Their deep hardening rate is very good and they can be used for bonding various materials (Solmaz, 2008). Factors such as overlap distance, adhesive thickness and surface roughness affect the strength of the joints combined with adhesives.

Venables (1984) in one of his studies, in which he researched the effects of surface roughness and surface features, emphasizes that pores and oxidations on the surface are extremely effective at increasing the strength of adhesive bonded joints. He states that the oxidized layer decreases joint strength, surface roughness adheres the bonded materials and adhesive by providing adhesive attachment, and therefore, the joint becomes more durable.

Surfaces should not be very polished (smooth) for adhesive bonded joints. The wedge effect is lost on smooth surfaces and this makes the attachment of the adhesive difficult. Optimum surface roughness should be between the value of R_a= 0.8 to 3.2 µm (Loctite, 1998). In a study by Sancaktar and Gomatam (1998), researching the effect of surface roughness in single-lap joints bonded by adhesive states that the damage load is at the maximum level between 1.65 and 2 µm surface roughnesses. In a study by Kwon and Lee (2000), concerning tubular joints, the surface roughness on the cylindrical pieces was examined between the values of R_a being equal to 0.56 and 5 µm, and they discovered that the optimum roughness value is 0.3 µm and the adhesive thickness is 0.17 mm for fatigue strength.

Şekercioğlu et al. (2003) researched on the effects of surface roughness on cylindrical plug-in steel-to-steel adhesive bonded joints. For surface roughness values between R_a equal to 0.45 and 6.3 µm, and stated that the optimum surface roughness in terms of joint strength was R_a equal to 1.5 and 2.5 µm. They obtained low shear stress levels for very polished (R_a < 1 µm) and very rough (R_a > 2.5 µm) surfaces. The effect of adhesive thickness

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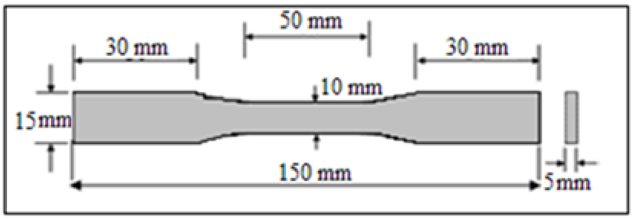

Figure 1. Specimens.

was examined by Bascom et al. (1977) for the first time. Later, many researchers carried out scientific studies based on fracture mechanics and conventional tension analysis. Ojalvo and Eidinoff (1978) stated that adhesive thickness is extremely important for short overlap distances, thick parts to be adhered and hard adhesives. The work of Tamblin et al. (2001) reported shear results in the range of 0.4 to 3 mm adhesive thickness through thick adhered shear test (TAST). They clearly expressed that, as the thickness of the parts to be adhered increases, their shear strength decreases. Grant et al. (2009) accepted that shear strength decreases linearly when the adhesive thickness increases from 0.1 to 0.3 mm. This is due to flexural stress occurring on the thick adhesive layer. Davies et al. (2009) carried out a study related to the effect of adhesive thickness. As a result of their analysis, they stated that tensile strength decreases as the adhesive thickness increases and the optimum thickness should be 0.8 mm and less.

In this study, we attempted to determine the effects of surface roughness and adhesive properties of the adhered parts on the strength of prismatic plug-in joints.

MATERIALS AND METHODS

In this study, we used St60 tool steel as a joint fitting and three epoxy based adhesives with different properties (Devcon A, Devcon Titanium and Akfix-E300). The mixing ratio of the selected adhesives by volume was 2:1 for Devcon A, 3:1 for Devcon Titanium and 1:1 for Akfix-E300.

Three bulk specimens that comply with ISO 527-2 standards and whose dimensions are given as shown in Figure 1 were prepared for each adhesive via a press suitable for temperature and pressure applications (ISO 527-2, 1993). In this way, not only were the gas voids removed, but we were also able to apply the pressure required for curing the adhesive. Stress-strain behaviors of the adhesives, as shown in Figure 2a, b and c, were determined by applying the tension testing procedure, defined in ASTM D1002 (1983) on these samples. The mechanical specimens of the combined pieces determined as a result of tensile test are given in Table 1. The dimensions of male and female specimens produced by St60 tool steel according to test parameters are given in Table 2.

Roughness values were determined by averaging at least four measurements obtained from each surface using a Mitutoyo SJ-201P surface roughness measuring device. Three different roughness values were selected for male specimens for Ra equal to 1, 3 and 5 µm. These values were obtained by sanding the overlap surfaces.

The bonding process was carried out for each parameter given in Table 2 after the bonding surfaces were cleaned by acetone. The dimensions of test specimens are given in Figure 3. The bonding joints were subjected to tensile tests in a computer-controlled UTEST 15 (1 kN) universal testing device with 1 mm/min tensile speed. Tests were carried out in an environment with 50 + 5% humidity and room temperature. In order to prevent errors, while the free ends of the joints were attached to the device, we made every effort to maintain the same pressure levels and paid strict attention to alignment.

Strength displacement data and maximum load were recorded as the joints were being tested and the average sliding strength of the joint was calculated by placing the value of maximum load that can be carried by the specimens in its place in Equation 1.

$$\tau_{ort} = \frac{P_{max}}{A} \qquad (1)$$

where "P_{max}" indicates damage load and "A" indicates the bonding surface.

RESULTS AND DISCUSSION

In Figure 4, the shear strength of joints having three different overlapping distances as 10, 20 and 30 mm for Ra = 1 µm surface roughness value are given according to adhesive thickness. For the roughness value R_a =1 µm, the shear strength decreases as the overlapping distance increases. The highest obtained value of shear strength was 5.96 MPa for the junction bonded by Akfix E300 at a 10 mm overlap distance and 0.1 mm adhesive thickness.

In Figure 5, the shear strength of joints having three different overlap distances as 10, 20 and 30 mm for Ra = 3 µm surface roughness value are given according to adhesive thickness. For the roughness value R_a = 3 µm, the shear strength decreases as the overlap distance increases. The highest obtained value of shear strength was 7.01 MPa in the junction bonded by Akfix E300 at a 10 mm overlap distance and 0.1 mm adhesive thickness.

In Figure 6, the shear strength of joints having three different overlap distances as 10, 20 and 30 mm for Ra = 5 µm surface roughness value are given according to the adhesive thickness. For the roughness value R_a = 5 µm, the shear strength decreases as the overlap distance increases. The highest obtained value of shear strength was 6.66 MPa in the junction bonded by Akfix E300 at a 10 mm overlap distance and 0.1 mm adhesive thickness.

In Figure 7, some of the surface images obtained from adhesive joints as a result of tensile tests are given according to their overlap distance. When the images are reviewed, it can be seen that there was cohesional and adhesional damage to the adhesive joints.

There was damage on all adhesives in the form of peeling and breaking. On rough surfaces, damage occurs in the form of breaking, and on surfaces with low roughness, damage occurs in the form of peeling.

Conclusions

A total of 81 prismatic plug-in joints, which were produced

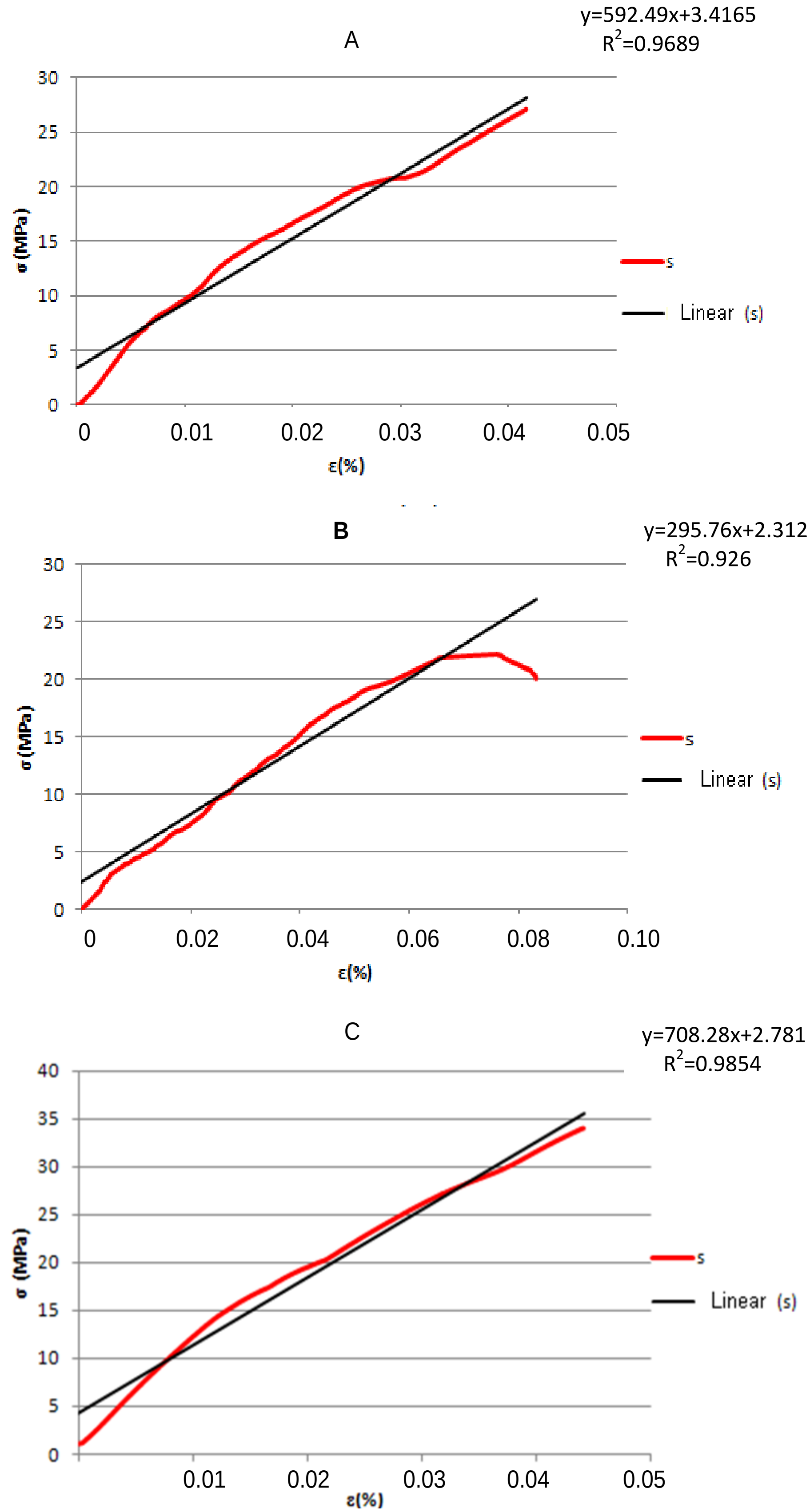

Figure 2. Stress-strain behaviors of adhesives. (A) Devcon A, (B) Devcon Titanium and (C) Akfix E300.

Table 1. Mechanical specimens of adhesives and combined pieces.

Material	Testing method		
	ISO 527	ISO 527	ISO 178
	Tensile strength (MPa)	Poisson ratio	Elasticity module (Mpa)
Devcon A	26.5	0.35	663
Devcon Titanium	22.1	0.34	315
Akfix E300	34.1	0.32	758
St60	600	0.35	210000

Table 2. Parameters.

Male specimen overlapping (plug-in) distance (mm)	Female specimen width (mm)	Adhesive thickness (mm)	Roughness of overlapping surfaces (mm)		
a	b	t	R_a		
10	10.2	0.1	1	3	5
20	10.6	0.3	1	3	5
30	11	0.5	1	3	5

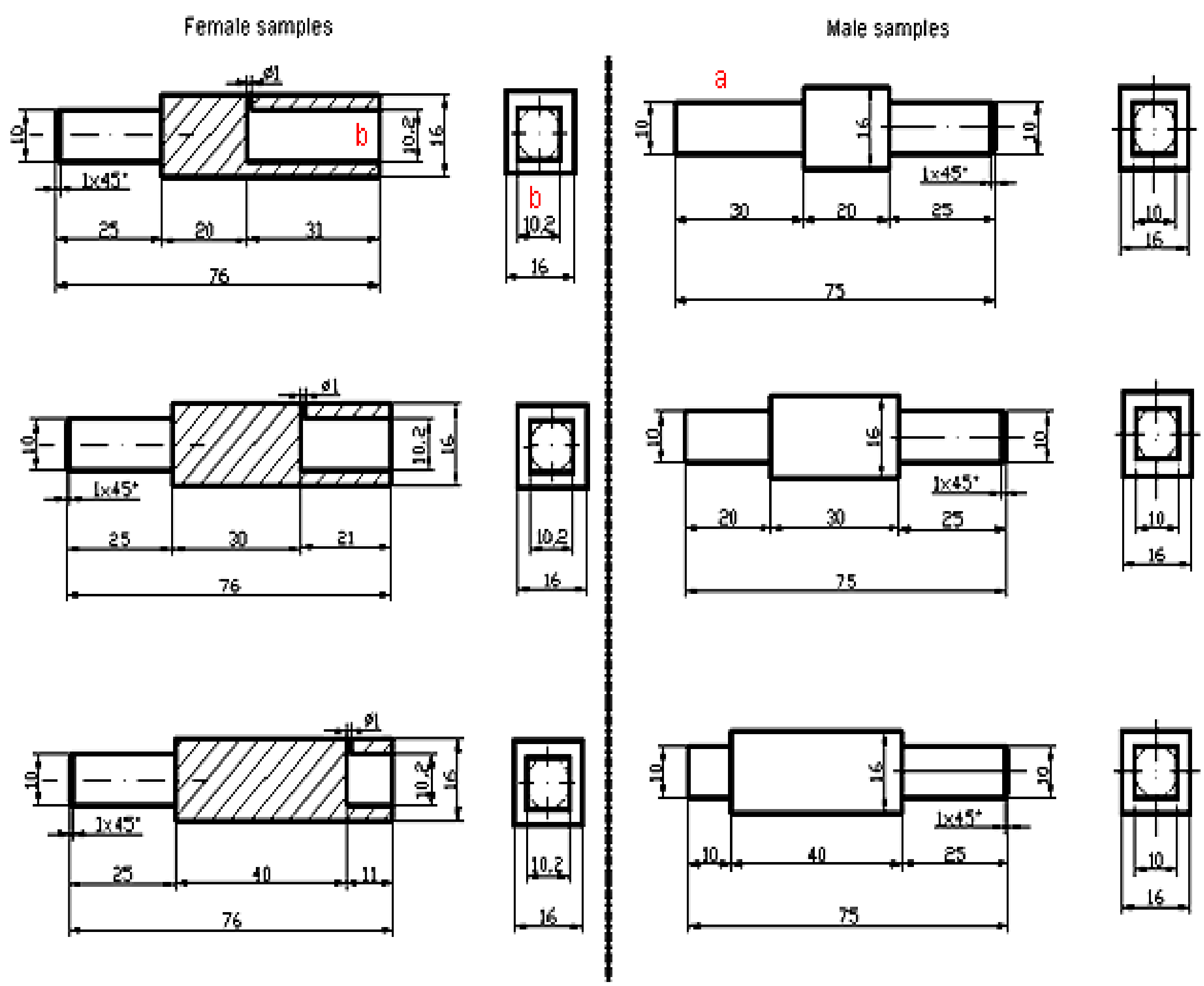

Figure 3. Dimensions of test specimens.

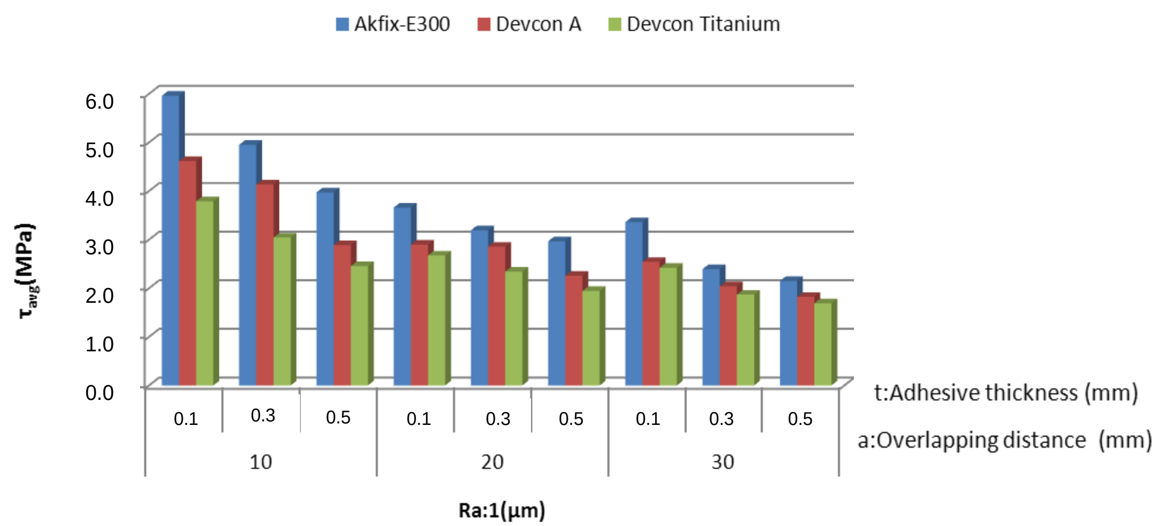

Figure 4. Change in shear strength depending on overlap distance and adhesive thickness for the value R_a=1.

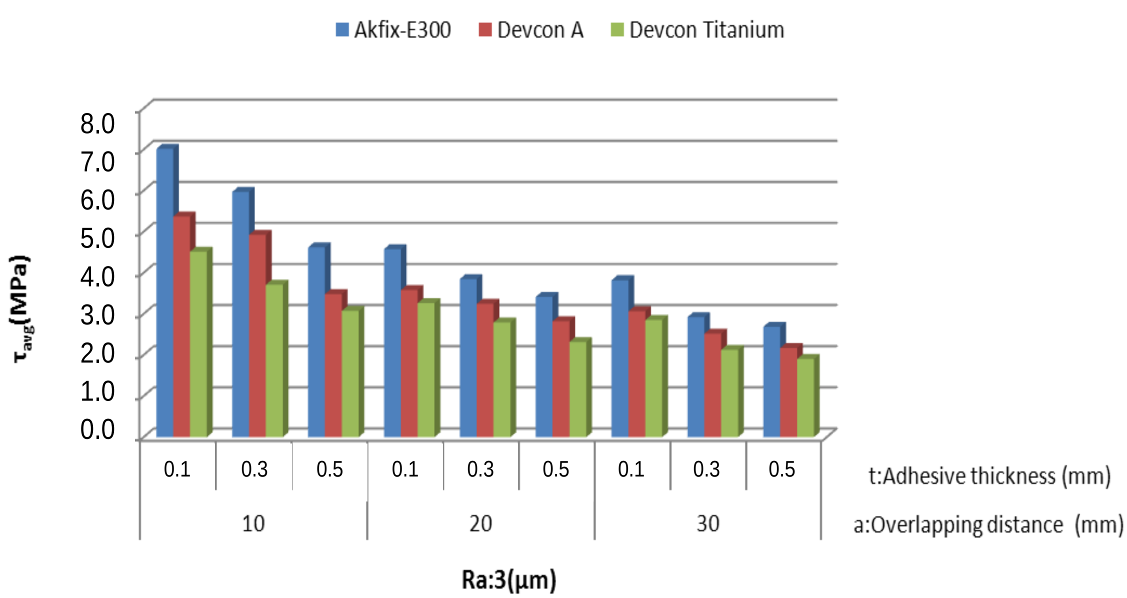

Figure 5. Change in shear strength depending on overlap distance and adhesive thickness for the value R_a=3.

using three different adhesive thickness, three different types of surface roughness and three different adhesives, were subjected to tensile test and the results obtained are summarized as the following.

When the stress-strain graphics of the adhesives were examined, it was seen that Devcon A, Akfix E300 and Devcon Titanium showed a linear material behavior. The shear strength of joints combined with Akfix E300 were discovered to be higher than the shear strengths of joints combined with Devcon A and Devcon Titanium for all the three overlap distances. It was seen that while overlap distance and surface roughness are extremely effective at increasing the strength of adhesive joints, the effect of adhesive thickness is reduced when compared with other factors. The highest obtained value of overlap strength was 7.01 MPa in the junction combined by Akfix E300 at a 10 mm overlap distance, 0.1 mm adhesive thickness and Ra = 3 µm surface roughness.

Peeling was observed in all overlap distances. Figure 7 illustrates that there was cohesional (KH) and adhesional (AH) damage to the adhesive joints. There was damage on the surfaces of all adhesives in the form of peeling

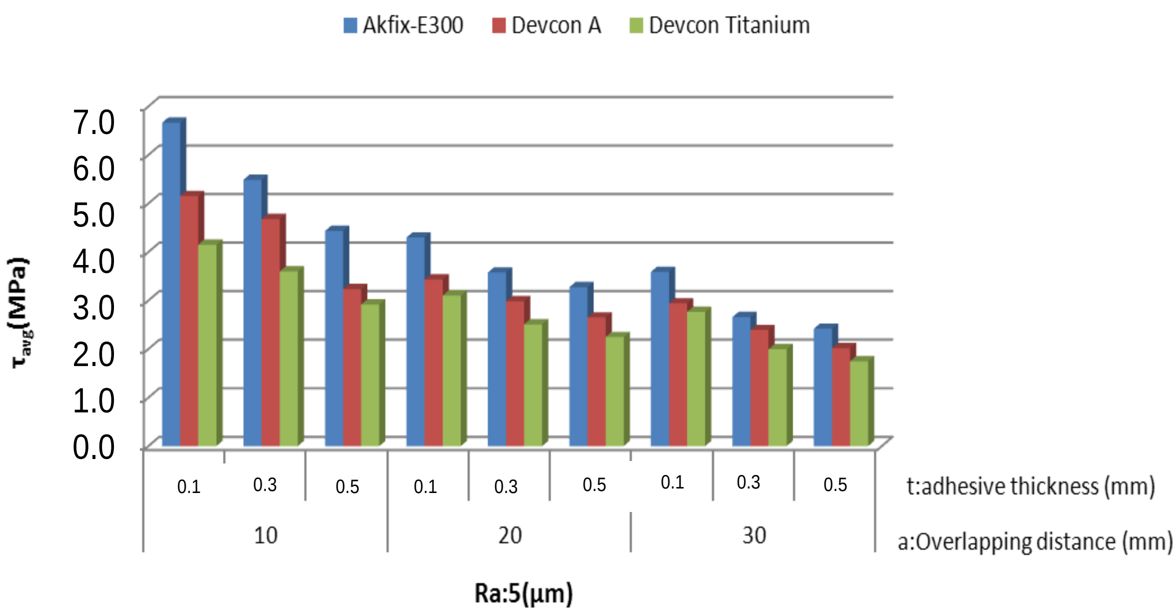

Figure 6. Change in shear strength depending on overlap distance and adhesive thickness for the value of R_a=5.

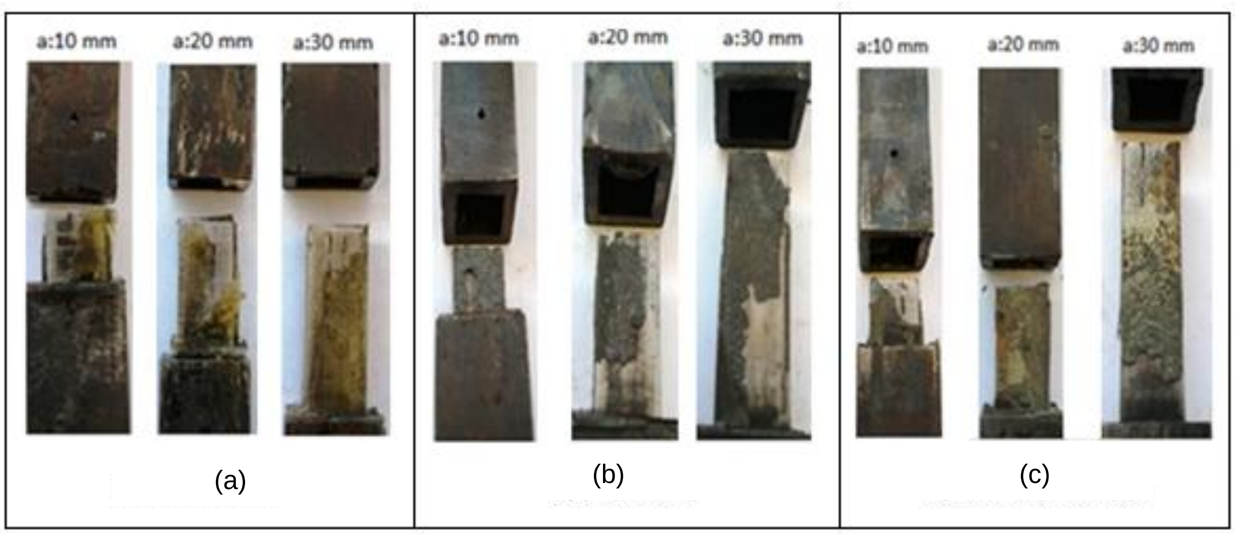

Figure 7. Surface views of test specimens as a result of tensile test. a) Akfix E300. b) Devcon A. c) Devcon Titanium.

(AH) and breaking (KH). It was seen that the adhesive separates in the form of breaking on surfaces with high roughness (Ra = 5 µm) and low adhesive thickness, and in the form of peeling on surfaces with low roughness (Ra = 1 µm) and high adhesive thickness. Adhesive are separated by breaking on surfaces with medium roughness (Ra = 3 µm) and low adhesive thickness.

The lowest obtained values of adhesive-bonded joint strength were for Ra = 1 µm surface roughness with all adhesives (Figure 4). As the surface roughness increases, adhesive strength also increases. When the surface roughness values used in the study were compared, it was seen that the joints reached the maximum strength level on Ra = 3 µm surface roughness (Figure 5), and after this point the strength level decreased as the roughness increased. Average shear stress values of the joints decreased with increasing roughness value (Figure 6).

As the overlap distance increased, the strengths of joints also increased with all adhesives. An increased overlap distance decreased the average shear stress on the adhered surface, and therefore, made a positive contribution to the shear strength of the joint. For each of the three overlap distances, the shear strength of joints combined with Akfix E300 was higher than the shear strength of joints combined with Devcon A and Devcon Titanium.

It was determined that the strength of the joint decreases as the adhesive thickness increases. Correspondingly, the average shear stress values on adherence surface also decreases.

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