INVESTIGATION OF THE EFFECT OF THICKNESS AND SURFACE ROUGHNESS ON ADHESIVE JOINT STRENGTH

Başar ALTINTAŞ[1,2], Tuncay KARAÇAY[1], Bülent ACAR[2]
[1]Gazi University, Maltepe, Ankara 06570, Turkey
[2]Roketsan Inc. Elmadağ, Ankara 06780, Turkey

ABSTRACT

Adhesives are widely used in many different areas such as aerospace, automotive and marine applications. Due to their low costs and mechanical advantages, adhesive joints have become preferable solutions. However, strength of these type of joints may vary with manufacturing process. In this study, adhesive thickness and surface roughness which are major factors that affect joint strengths were investigated. Uniaxial tensile and shear tests were performed for determining failure loads. Both tests were carried out in accordance with ASTM standards. Tensile tests have been performed for three different surface roughness and three different adhesive thickness. For tensile test specimens, a modification was done to curing mold in order to eliminate alignment problem between clamping jaws of test machine. In that way, scatter in test results were reduced. Standard thick adherend shear test (TAST) specimens were used for shear tests and only surface roughness effect was investigated. Test results showed the relation between joint strength and mentioned factors.

Keywords: adhesive, surface roughness, thickness, tensile test, strength
Corresponding author: Başar ALTINTAŞ

1. INTRODUCTION

Development in adhesive materials and bonding techniques made adhesively bonded joints to better solutions for many applications. They have many advantages in mechanical and economical aspects. The main advantages of bonded joints over mechanically fastened joints such as bolted or riveted joints are their uniform stress distribution. Fatigue resistance of bonded joints are better because there is no hole or assembly detail that makes stress concentration effect on the structure. Additionally, lack of these holes, assembly details etc., means less production process and lower costs. On the other hand, joint strength is affected by some parameters that related to adhesive application and adherend manufacturing. Surface roughness and bond line thickness are the major factors.

Roughness values are highly dependent to surface treatment methods which are done during manufacturing. Many researchers have studied to effect of surface roughness and treatment on adhesive bond strength. Hirulkar et al. [1] investigated the influence of mechanical surface treatment methods including sanding, grinding, polishing and lapping with aluminum SLJ specimens. There are also many researches focused on chemical surface treatment methods. Correia et al. [2] worked on effect of surface treatment on adhesive bond strength. They used different acid anodizing methods for surface treatment. Xu et al. [3] also used acid anodizing on their work and surface morphologies with different water contact angles were shown. Zhan et al. [4] made similar study with different grades of silicon carbide abrasive papers and acidic solution. Plasma surface treatment is another way to change roughness and adhesive properties. Leahy et al. [5] employed plasma surface treatment to improve the bond strength of an adhesive joint of a glass-fiber-reinforced and commercially pure titanium. Contact angles for oxygen and argon plasma treated specimens were shown. Effect of surface roughness on fatigue behaviour is also investigated. Studies can be found in [6-7].

Another major factor mentioned before is adhesive bond line thickness. Akhavan-Safar [8] et al. performed series of shear tests and FE analysis with different bond line thicknesses. They used chemical treated aluminum SLJ specimens for tests. Castagnetti et al. [9] performed experimental campaign, which examined two structural adhesives in two different joints. For the TBJ, four different values of adhesive thickness were examined under torsion load. On the other hand, three different thickness were examined for SLJ. Lißner et al. [10] made a comprehensive study on adhesive interfaces. They investigated influence of influence bond line thickness, loading rate, and deformation mode. Void distribution of the investigated bond line thicknesses represented with X-ray tomography. They also determined parameters for CZM and simulate mix-mode deformation. Fractured surface details were showed with SEM. Shokrian et al. [11] investigated effects of both surface treatment and adhesive thickness on shear strength. They used AFM on aluminum substrates and 3D topology results of different surface treatments were shown. They also measured different shapes of microcapsule sizes with SEM. Finally, studies which are dealt with effect of bond line thickness on interfacial strength can be found in [12-13].

In this work, effects of surface roughness and bond line thickness on adhesive joint strength are investigated. Mechanical surface treatments were done and DP490 epoxy based structural adhesive was used for tests. Tensile tests were performed for three different bond line thickness and surface roughness. Test results showed that rupture load is very sensitive to pin hole alignment. Tensile tests were continued after some modifications done on curing mold. For shear tests, standard thick adherend shear test (TAST) specimens were used. Only two different surface roughness were tested since bond line thickness is constant for this type of specimen.

2. TEST

2.1 Test Procedure

Both tensile and shear test specimens manufactured of aluminum alloy 2024-T3. 3M Scotch-Welt DP490 was used as adhesive. DP490 is a black, thixotropic, gap filling two-component epoxy adhesive with particularly good application characteristics. It is designed for use where toughness and high strength are required and shows special benefits in the construction of composite assemblies [14]. Mechanical treatment methods were used for roughening the aluminum surface. Different grades of sandpapers were used, and sand blasting process were done in order to determine surface roughness magnitudes. Dummy aluminum plates were grinded in one direction with P120, P220 and P360 grit sized sandpapers also sand blasting process was taken. Surfaces were grinded in only one direction. Then, surface roughness measured with Mitutoyo SJ-201 roughness tester (Figure 1). Roughness values are shown in Table 1.

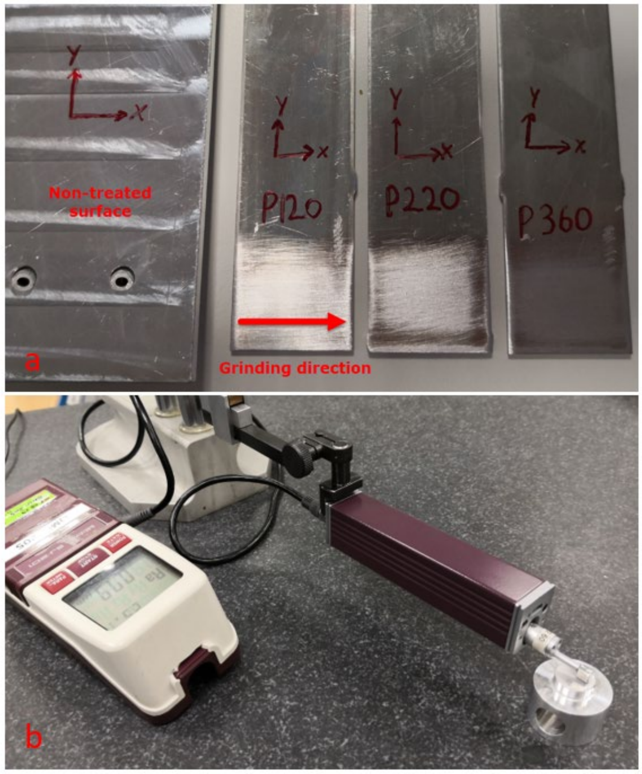

Figure 1. Dummy plates with different surface roughness and grinding direction (a). Roughness measurement of specimen grinded randomly with P220 sandpaper (b).

Table 1. Surface roughness values of measured surfaces.

Surface	**Direction**	**Ra (µm)**	**Rz (µm)**
Non-treated	(Almost Equal)	0.14	1.03
Grinded (P120 Sandpaper)	X	1.08	10.12
	Y	1.32	9.82
Grinded (P220 Sandpaper)	X	0.69	4.43
	Y	0.79	7.47
Grinded (P360 Sandpaper)	X	0.37	4.64
	Y	0.55	3.98
Sand Blasting (with fine sand)	(Almost Equal)	2.27	16.37
Grinded randomly (P220 Sandpaper)	(Almost Equal)	0.56	5.47

After the roughness magnitudes were determined P220 grit sized sandpaper and sand blasting process were selected for tests. Before adhesive application, bond surfaces were grinded randomly and surface roughness were measured again. After adhesive application, mold assemblies were cured at 80°C in temperature-controlled oven for one hour. Finally, all tensile and shear test were conducted at room temperature under 1.3 mm/min speed.

2.2 Tensile Test Specimen

For tensile tests, specimens were designed simply so that no extra parts or fixtures needed for tensile test machine. However, on this type of specimens bending may occur if pin holes are misaligned or contact point of pin is undetermined. It is an unwanted side effect and its level cannot be determined directly. In order to eliminate these problems, specimen rotation in curing mold was constrained with pins. Additionally, a notched pin was used so contact between specimen and pin is always clear. Test specimen dimensions, curing mold assembly and notched pin are shown in Figure 2.

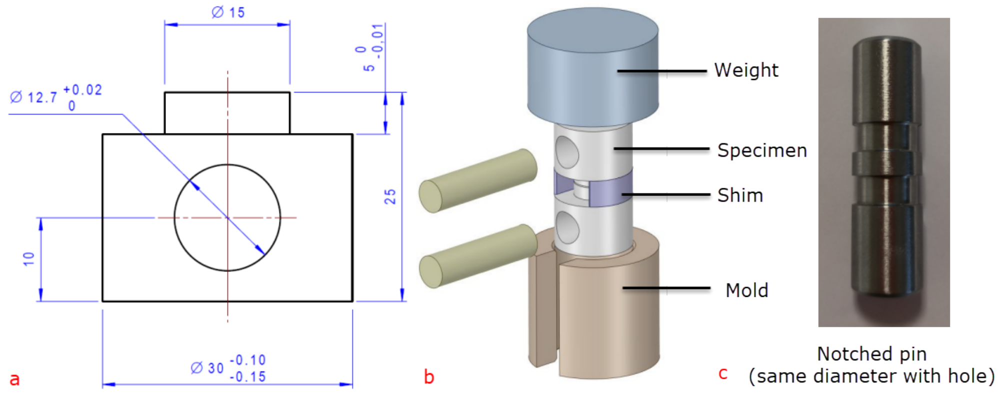

Figure 2. Specimen dimensions (a), curing assembly (b) and notched pin used in tests (c).

Tests were conducted for three different surfaces and three different adhesive thicknesses. These surfaces are non-treated, grinded with P220 sandpaper, and sand blasted surfaces. Thickness was adjusted with precision manufactured shims. Tested adhesive thicknesses are 0.3 mm, 0.5 mm and 1 mm.

2.3 Shear Test Specimen

Thick adherend shear test (TAST) specimens specified in IS0 11003-2 [15] standard was used in shear tests. Specimen dimensions and curing assembly are shown in Figure 3.

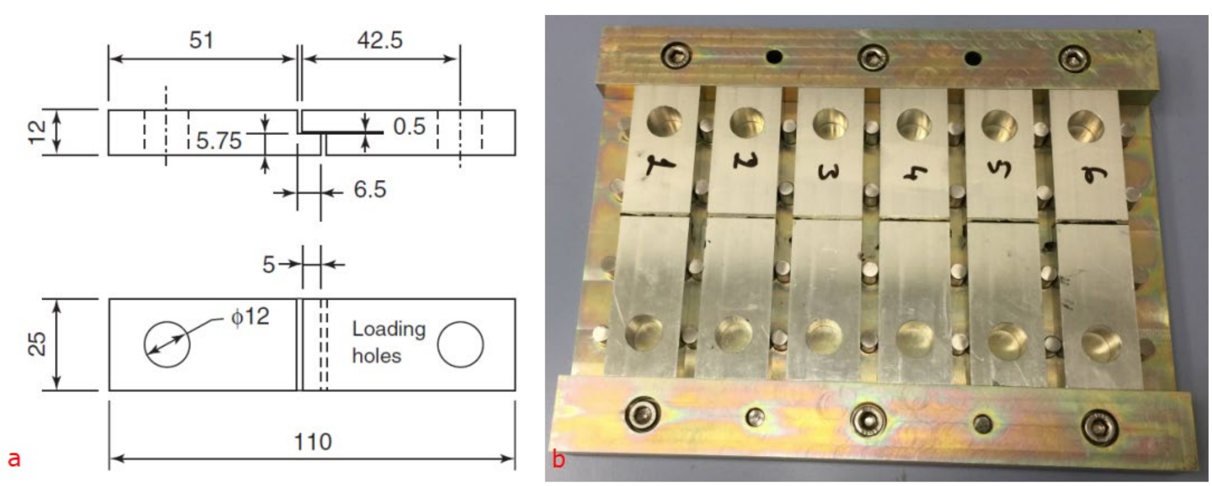

Figure 3. TAST specimen dimensions taken from [17] (a) and curing assembly with 1.5 mm thick shims (b).

There are two 1.5 mm steel shims for each test specimen. To maintain geometric dimensions while curing, shims must be inserted between each gap. Mold release spray was applied to all in contact surfaces with shim before applying adhesive, because shim should not be bonded to specimen. Notched pin was used for test to clarify contact point. All surface treatment and curing processes are same as tensile tests but shear tests were conducted for three different surface roughness and only 0.5 mm adhesive thickness.

3. RESULTS

As shown in Figure 4, for non-treated surfaces, tensile and shear strengths are lower than treated ones. However, there is not significant change between grinded and sand blasted results. It is seen that tensile properties are increasing with surface roughness until a limit value.

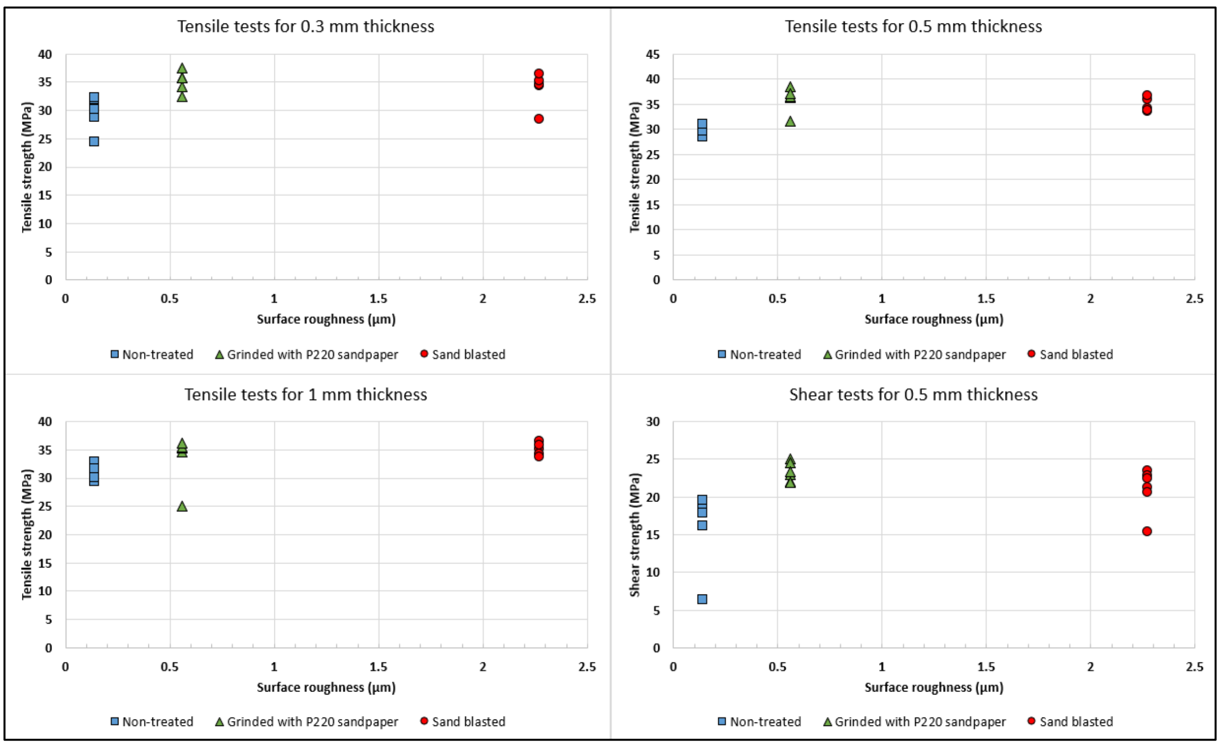

Figure 4. Tensile and shear test results.

Results showed that, for DP490 adhesive, there is no significant effect of bond line thickness on strength. However, it is seen that failure type related to thickness. Adhesive-cohesive failure was seen on 0.3 mm tensile test specimens while fully cohesive failure was observed on 0.5 mm and 1 mm test specimens. During the tests, it was noticed that some of non-treated test specimens have bonding defects. These specimens were ruptured well before expected. The reason of this problem thought to be low roughness values. Failure surfaces is shown in Figure 5.

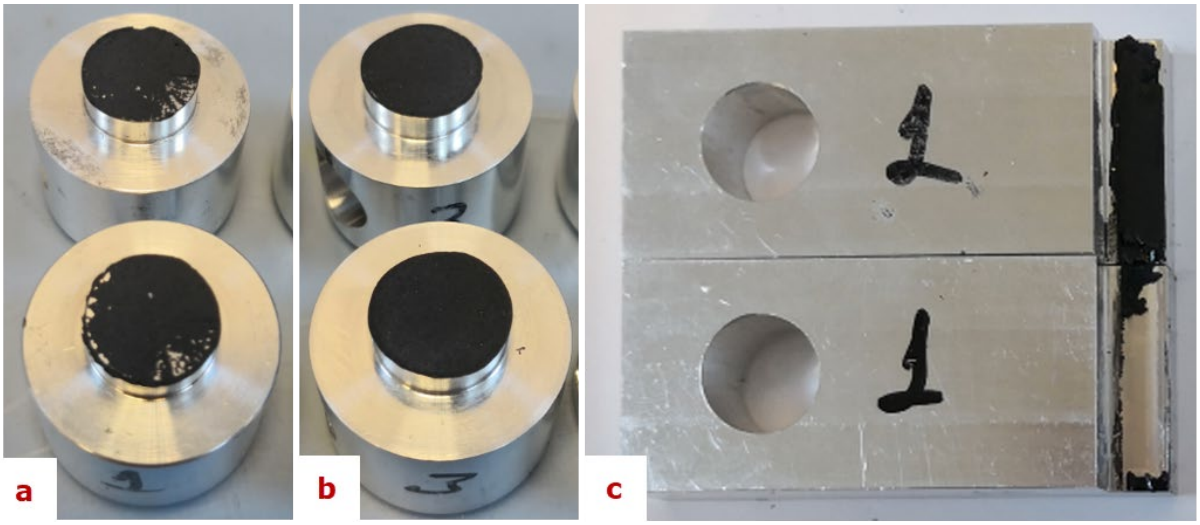

Figure 5. Adhesive-cohesive failure (a), Cohesive faiulure(b) and bonding defect (c).

As shown in graphics, some test results are lower than its mean value. Fracture surfaces of these specimens were examined with optical microscope and big cavities were seen (Figure 6). These cavities, which are larger than others, cause a decrease in strength.

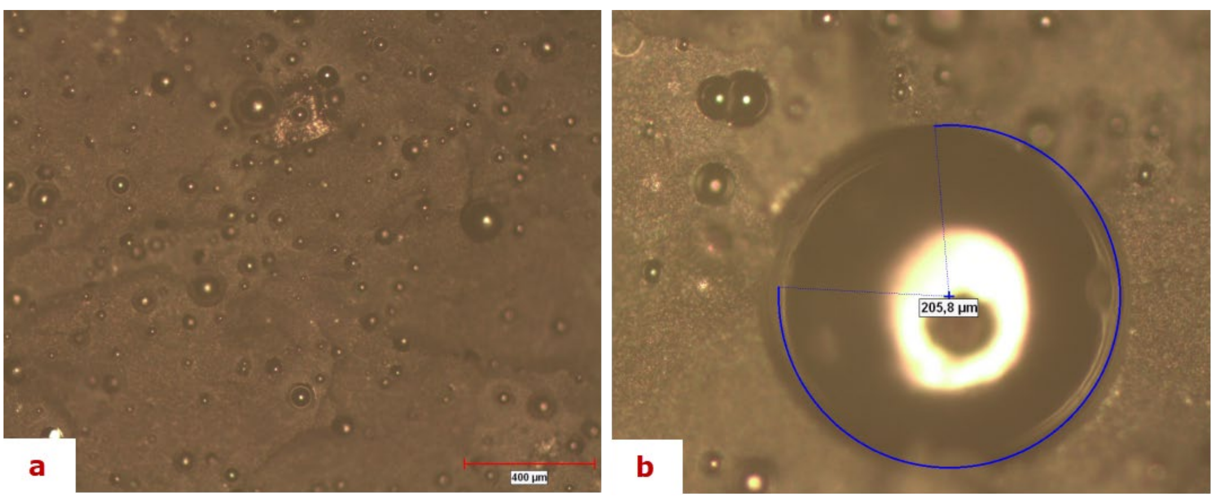

Figure 6. Normal size cavities (a) and large cavities. (b).

4. CONCLUSIONS

Effect of thickness and surface roughness on adhesively bonded joints is investigated. For this purpose, appropriate test specimens were manufactured. Tensile tests were conducted for different roughness and bond line thicknesses. On the other hand, shear tests were only dealt with surface roughness. Test results showed that surface roughness affect tensile and shear strength until a limit value. After that, there is not any significant change on strength. It was seen that there Some bonding defects were seen on non-treated surfaces. For tested adhesive, there is no significant effect of bond line thickness on strength, but failure type is changing. Finally, fractured surfaces were examined, and it was seen that specimens with larger cavities ruptured under lower loads.

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