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Study of Contact Surface Roughness on Adhesive Performance in Steel and Aluminium Joints

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ABSTRACT

Adhesive bonding is a technique widely used in various industries to join materials together. This process provides several advantages over traditional mechanical fastening methods, such as welding or nailing, including improved appearance, weight reduction, stress distribution, and the ability to join dissimilar materials. The advantages of adhesive bonding are simpler assembly, lightweight and lower production costs. This research is one of the developments of the glue adhesive connection method. The materials used in this research are 1100 series aluminium and low carbon steel where both are metals that we often encounter in everyday life. This study aims to analyse the effect of roughness treatment on the surface of each different test specimen using sandpaper with different roughness levels, namely 80 grit, 150 grit and 400 grit. The test conducted in this study was a tensile test to determine the maximum strength of the adhesive strength of each test specimen with ASTM D1002 test standards. The results showed that test specimen A with surface roughness treatment using 80 grit had a tensile strength of 226.7 MPa, test specimen B with surface roughness treatment using 150 grit had a tensile strength of 168 MPa, and test specimen with 400 grit roughness treatment had a tensile strength of 31.5 MPa.

Keywords: adhesive bonding, tensile test, surface roughness, steel, aluminium

ABSTRAK

Adhesive bonding adalah teknik yang banyak digunakan dalam berbagai industri untuk menggabungkan bahan-bahan secara bersama-sama. Proses ini memberikan beberapa keuntungan dibandingkan dengan metode pengencangan mekanis tradisional, seperti pengelasan atau paku, termasuk penampilan yang lebih baik, pengurangan berat, distribusi tegangan, dan kemampuan untuk menggabungkan bahan-bahan yang berbeda. Kelebihan adhesive bonding ini adalah perakitannya lebih sederhana, ringan dan biaya produksi lebih murah. Penelitian ini adalah salah satu pengembangan pengembangan dari metode sambungan perekat lem. Bahan yang digunakan dalam penelitian ini adalah alumunium seri 1100 dan baja karbon rendah dimana keduanya adalah logam yang sering kita jumpai di kehidupan sehari hari. Penelitian ini bertujuan untuk menganalisa pengaruh perlakuan kekasaran pada permukaan dari setiap spesimen uji yang berbeda menggunakan amplas dengan tingkat kekasaran yang berbeda yaitu grit 80, grit 150 dan grit 400. Pengujian yang dilakukan pada penelitian ini adalah uji tarik untuk mengetahui kekuatan maksimal kekuatan rekat pada masing masing benda uji dengan standar uji ASTM D1002. Hasil penelitian menunjukan bahwa benda uji A dengan perlakuan kekasaran permukaan menggunakan grit 80 memiliki kekuatan tarik 226,7 MPa, benda uji B dengan perlakuan kekasaran permukaan menggunakan grit 150 memiliki kekuatan tarik 168 MPa, dan benda uji dengan perlakuan kekasaran grit 400 memiliki kekuatan tarik 31,5 MPa.

Keywords: ikatan perekat, uji tarik, kekasaran permukaan, baja, aluminium.

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1. Introduction

The development of building material technology is progressing rapidly, and construction implementation is always innovating to achieve the most cost-effective and fastest execution system possible. Wood, which used to be commonly used for roof frames and ceiling frames, has now shifted to the use of lightweight steel. Besides the relatively lower material cost compared to wood, the implementation time is also shorter, which ultimately affects the overall execution cost [1]. Adhesive bonding is very useful for the community for joining materials because the bonding process is simple and the cost of this process is cheaper compared to other methods. This method can make it easier for the community to solve several issues related to material bonding. However, the community needs to be guided on the process and use of this method and to use glue according to the needs that will be carried out.

Adhesive bonding is used to bind two surfaces together and create a smooth bond; this method involves epoxy glue. Historically, glue produces relatively weak bonds, but adhesive-based materials do not change the shape of the joined materials [2]. Adhesive bondings are generally more efficient than mechanical joints because they distribute the load over a larger area. Additionally, adhesive joints eliminate the need for processes like drilling holes and adding fasteners, resulting in lighter constructions. This method also helps prevent local stress concentrations from occurring [3]. Fuadi [4] also states that bonding is the process of joining two objects using adhesive, making it easier to assemble, lighter in weight, and cheaper in production. The disadvantage is that the joint is weaker compared to other joining methods such as welding and riveting.

Multiple efforts have been made to create an excellent adhesive bond, focusing on factors such as surface wettability, the depth of surface roughness, and proper treatment of plastic joints [5]. Bakar et al. [6] conducted a study on the strength of joints in wood using the Taguchi method. The study focused on several factors, including the area of consumption, open exposure time, environmental temperature, and type of adhesive. The results indicated that the type of adhesive had the greatest influence on joint strength. Notably, the thicker Phosphoserine-modified cement (PMC) adhesive was found to reduce the adhesive strength of the joint [7]. Da Silva et al. [8] also stated that the adhesive shear strength of metal joints increases as the adhesive becomes thinner.

The lap length, adhesive layer thickness, and laminate lay-up method have a significant impact on the tensile-shear strength of joints. In single-lap joints, the shear strength tends to decrease gradually as the overlapping lap length of the plates and the adhesive layer thickness increase [9].

Pretreatment of aluminum surfaces, such as degreasing, etching, alkaline etching, and acidic etching, significantly affects the surface characteristics, surface roughness, elemental composition, and porosity of the oxide layer on the surface. Surface morphology and wettability are essential factors that affect the cracking behavior of adhesive joints on aluminum. A study showed that pretreatment of the surface using a combination of acid etching and mechanical abrasion increased the strength of the adhesive joint compared to the control sample. This increase was due to a better contact area between the adhesive and the substrate, resulting in a mechanical interlock [10]. A study demonstrated that joint surfaces undergoing abrasion treatment exhibited greater shear strength, despite having lower wettability. This suggests that shear strength is not related to wettability [11].

Metals have a relatively high surface energy, which can weaken the strength of adhesive bonds on metal joints. Therefore, the adhesive must penetrate the surface's roughness effectively. Surface roughness affects the strength of the adhesion force. Li et al. [12] demonstrated that greater surface roughness results in increased adhesion force between surfaces. Surface roughness can lead to an increase in the dissipation of adhesion energy. The findings of this study are consistent with those of Khan et al. [13], who noted that surface roughness influences adhesive bond strength. However, the type and material of the adhesive have a more significant impact. Additionally, an oxide layer in joints made from aluminum alloys and steel, such as MgO and Fe_2O_3, reduces the adhesive bond strength.

Surface smoothness significantly impacts the shear strength of adhesive bond; both very smooth and very rough surfaces can reduce the strength of metal joining materials. The bond strength is maximized at a surface roughness of R_a = 1.5-2.5 µm [14]. The adhesive joint strength between steel and aluminum increases with increasing surface roughness and then decreases as a function of the material [11].

This study will examine the effect of surface roughness on the adhesive bond strength using "Dextone Steel-Filled Heavy-Duty Epoxy Adhesives." The surface treatment employed in this study is mechanical abrasion for roughening the surfaces. Mechanical abrasion will be performed using 80-grit, 150-grit, and 400-grit sandpaper to create a rough surface on both steel and aluminum. This research aims to provide guidance to field practitioners in developing effective adhesives for bonding steel and aluminum materials.

2. Method

In this study, the experimental method conducted involves surface treatment of the material, followed by bonding using epoxy glue to adhere the materials to be tested. The variable is the difference in surface roughness on each specimen to be tested, with variations using grit-80, grit-150, and grit-400. The control variables are named as follows:

a. Specimen A with a grit-80 roughness treatment
b. Specimen B with a grit-150 roughness treatment
c. Specimen C with a grit-400 roughness treatment.

The purpose of this variation is to determine the effect of different roughness treatments on the adhesive strength of specimens bonded using adhesive bonding methods.

2.1. Specimen Preparation

a. Aluminium plate series 1100

The aluminum plate was cut and shaped according to ASTM D1002 standards. The dimensions of the aluminum specimen were 177.4 x 25 x 6 mm, as illustrated in Figure 2.1.

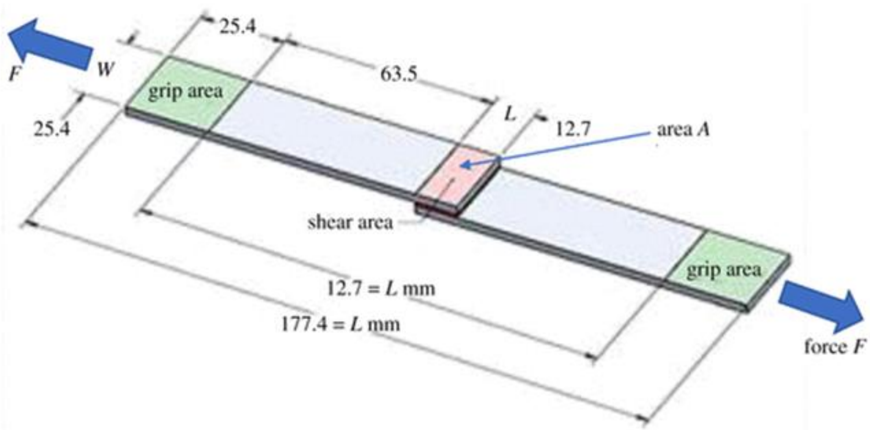

Figure 2.1 Dimension of Alumunium

b. Low carbon steel plate SS400

The steel used in this study is low-carbon steel with a carbon content < 0.3%. The carbon steel plate was cut and shaped in accordance with the ASTM D1002 standard. Its dimensions are 177.4 x 25 x 6 mm, as illustrated in Figure 2.2.

Figure 2.2 Dimensions of steel plate

2.2 Providing Surface Roughness Treatment

Each pair of specimens was subjected to roughness treatment with different levels of roughness using sandpaper. The sandpaper grades used for the roughness treatment were grit 80, grit 150, and grit 400. The results of the roughness treatment were then tested using a surface roughness testing device.

2.3 Choosing Adhesive

In this experiment, the strength being tested is aluminium-steel, therefore the bonding uses Dextone epoxy adhesive, as shown in Figure 2.3. The bonding is done on aluminium-steel that has been treated for roughness. After the bonding is done on the test specimen, it will be left for 3x24 hours to ensure the adhesive is fully set.

(a) (b)

Figure 2.3 (a) Epoxy (b) Bonding process

2.4 Material Testing

The type of test conducted is a tensile test. The tensile test is performed to determine the tensile strength of each specimen that has been subjected to different surface roughness treatments so that the effect of surface roughness on adhesive strength can be determined.

3. Result and Discussion

3.1 Surface Roughness Measurement

Surface roughness measurement assesses the level of unevenness on a surface. This roughness can impact the performance of various equipment and components such as bearings, gears, cutting tools, and joints with polymer adhesives. Table 3.1 presents the results of the measurements taken on metal surface roughness.

Table 3.1 Surface Roughness Measurement Results

Specimen	Experiment	Ra (µm)	Rq(µm)	Rz (µm)
Specimen A	1	2.58	3.22	15.47
	2	2.39	2.88	12.44
	3	2.43	3.00	14.47

	Average	2.47	3.03	14.13
Specimen B	1	1.49	1.86	9.86
	2	1.72	2.15	9.96
	3	1.72	2.12	9.79
	Average	1.64	2.04	9.87
Specimen C	1	1.03	1.29	6.6
	2	1.08	1.17	6.06
	3	1.06	1.35	6.89
	Average	1.05	1.27	6.52

The roughness value is expressed in Roughness Average or Ra, which is defined as the arithmetic average and the presence of deviations in the roughness profile. Rz is the average distance from the base profile to the measured profile at the 5 highest peaks minus the average distance from the base profile to the measured profile at the 5 lowest valleys, while Rq (μm) is the square root of the average squared distance between the measured profile and the mean profile.

3.2 Tensile Strength

Tensile strength testing on adhesive joints was conducted according to the ASTM D1002-01 standard. The test results indicated that greater surface roughness of the metal led to increased tensile strength of the joint, as shown Figure 4. Sample A, with an average surface roughness of 2.45 μm, exhibited a tensile strength of 226.7 kPa. Sample B, with an average surface roughness of 1.64 μm, produced a tensile strength of 168 kPa. In contrast, Sample C, with an average surface roughness of 1.05 μm, had the lowest tensile strength at 31 kPa. This finding of the study are in line with those of Li et al. [12] [15].

It can be concluded from the obtained data that the higher the roughness value, the higher the tensile strength value [16]. Surface roughness can affect the tensile strength of a material due to the interaction between the material and its environment. Surface roughness has a significant impact on several aspects that influence tensile strength. Surface roughness affects two materials to interact adhesively; good adhesion can increase the tensile strength between two contacting materials. The correlation coefficient between surface roughness and adhesive tensile strength of the joint is 0.9493, indicating the significant role of surface roughness in enhancing the adhesive tensile strength in metal joints [17].

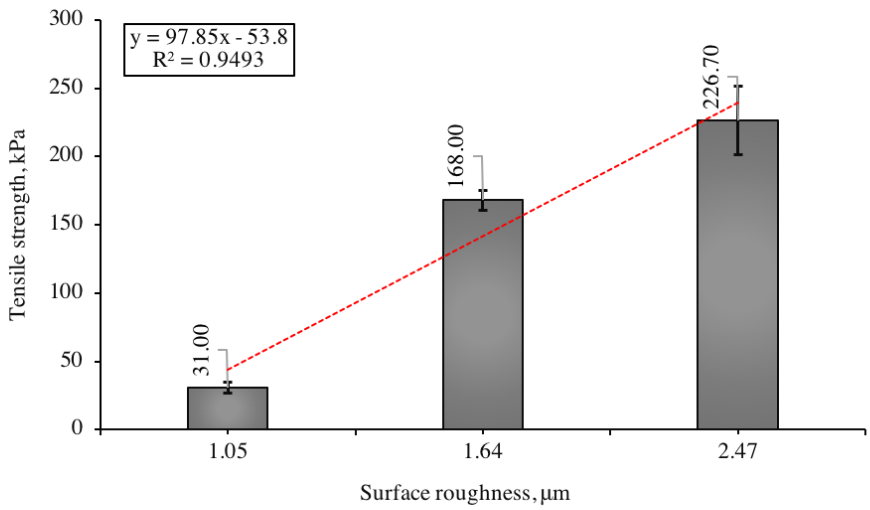

Figure 3.1 The relationship between the surface roughness of metal and the tensile strength of adhesive joints

3.3 Modulus Elasticity

The modulus of elasticity, also known as Young's modulus, is a parameter that measures the extent to which a material can stretch or deform under an applied force. The modulus of elasticity is defined as the ratio of stress to strain; the greater the stress applied, the higher the value of the modulus of elasticity obtained. Figure 3.2 illustrates that the elastic modulus increases as the surface roughness of the metals joined with the adhesive rises.

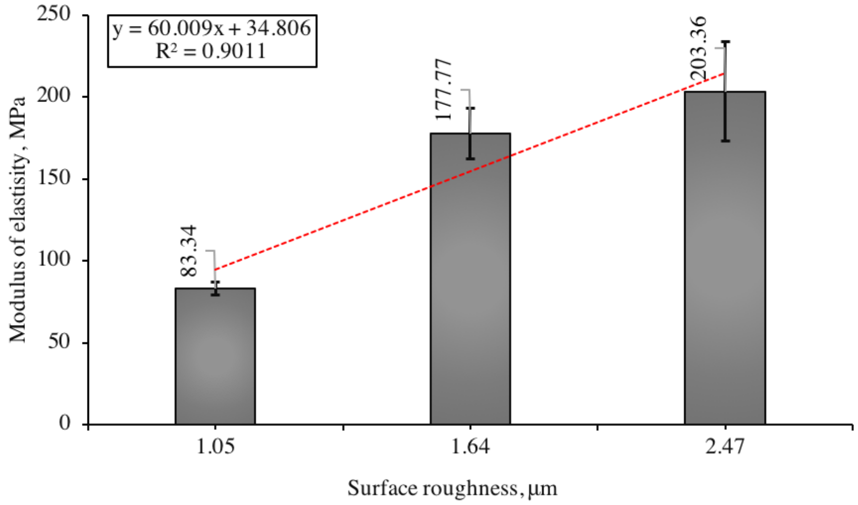

Figure 3.2 The relationship between the surface roughness of metal and the elasticity modulus of adhesive joints

In this test result, each test specimen with different roughness levels has different elasticity modulus values, with specimen A having the highest elasticity modulus value of 203.36 MPa, specimen B having an elasticity modulus of 177.77 MPa, and specimen C having the lowest elasticity modulus value of 83.34 MPa. The roughness of the metal surface is strongly related to the elastic modulus of the adhesive joint. This is indicated by the correlation coefficient of 0.9011 [17]. The elastic modulus increases due to enhanced contact area between the adhesive and the metal [10]. This condition results in a perfect mechanical interlock.

3.4 Strain

It is essential to first highlight the strain conditions in adhesively bonded joints, such as lap joints. As shown in Figure 3.3, the strain distribution along the joint is uniform. This phenomenon explains why the adhesive's elastic modulus and tensile strength also exhibit a uniform distribution. The correlation coefficient between surface roughness and adhesive strain is very high at 0.9993, indicating a uniform distribution of stress and strain.

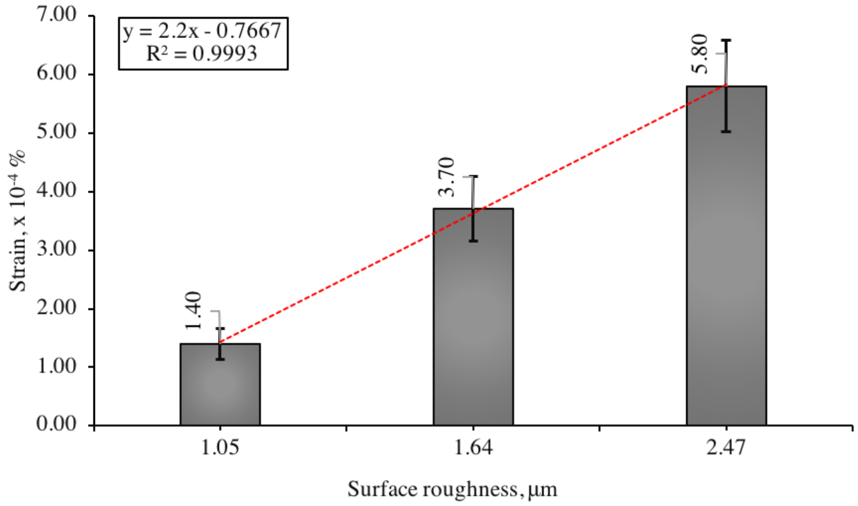

Figure 3.3 The relationship between the surface roughness of metal and the strain of adhesive joints.

4. Conclusion

Based on the study's results, surface roughness treatment can significantly influence the adhesive strength, elastic modulus, and strain of adhesive joints. Specifically, greater surface roughness corresponds to increased tensile strength and elastic modulus of the adhesive joint. In this study, an average surface roughness of metal is R_a = 2.74 μm produced tensile strength, elastic modulus, and strain values of 226.7 kPa, 203.36 MPa, and

5.80 x 10^{-4} %, respectively. The adhesive joint strengths for samples B (R_a = 1.64 μm) and C (R_a = 1.05 μm) were 168 kPa and 31.5 kPa, respectively.

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