



EFFECT OF FILLERS CONTENT ON MECHANICAL STRENGTH AND FAILURE MODE OF ALUMINIUM BONDED WITH EPOXY-BASED ADHESIVE

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ABSTRACT

The aim of this study was to investigate the effect of fillers content on mechanical strength and failure mode of aluminium bonded with epoxy-based adhesive. Fillers used are iron ore, aluminium powder and silica with mean diameter of 100 μm . The mechanical strength and failure mode of the adhesive joints was determined by utilizing T-peel and single lap-shear tests and by using macro photo and scanning electron microscope, respectively. The effect of three different fillers on mechanical strength of adhesive was investigated with choosing the highest peel strength and shear strength. The highest value in peel and shear tests were attained with silica and aluminium powder, respectively. The joints fail in mixed failure mode (cohesive and adhesive mode). This is shown that the joint strength depended on the adhesive properties and the bond adhesion between the adhesive and adherent.

Keywords: epoxy-based adhesive, filler content, mechanical strength, failure mode.

INTRODUCTION

Adhesive joint is a method to create a bond material between two or more materials. This method is more effective than the traditional joining methods such as rivet joint, weld joint and bolt joint. This is due to adhesive joint can also be used on non-metallic structures. Recently, the epoxy-based adhesive is widely used for application of vehicle structures. For some structures, thermal and electrical conductivity are needed. The way to modify the physical properties of epoxy-based adhesive is adding a powder material (fillers) which has high thermal and electrical conductivity [1]. In addition, the amount of powder materials has an effect to the structure to obtain a high thermal and electrical conductivity. Theoretically, the amount of powder materials on epoxy-based adhesive will reduce the mechanical strength. However, the effect of adding the powder materials to the mechanical strength of epoxy-based adhesive is still under investigation [1-3].

Wenyu *et al.* [4] have been developed an investigation about the effect of adding silver powder epoxy-based adhesive on the thermal conductivity, electrical conductivity and mechanical strength of the joint. Silver powder mass fraction varies from 70% to 82.5%. In addition, SEM test also examined to determine the distribution of the silver powder on the joint. The results of the study shown that increasing the amount of silver powder, thermal conductivity also increase. However, the greater number of silver powder will reduce the tensile strength and shear strength of the joint with silver powder mass fraction of 70% to 82.5%.

The addition of the powder materials on epoxy-based adhesive has an effect to the behavior of crack propagation on the joint. The addition of this material will allow the powder to inhibit the crack propagation. It is due to when the crack propagates through the powder material

occurs then cracked need a longer time to create a crack initiation. The aim of this study is to investigate the effect of fillers content on mechanical strength and failure mode of aluminium bonded with epoxy-based adhesive. A peeling test is used to determine the tensile strength and tearing test is used to determine the shear strength of the epoxy-based adhesive joint. There are three typical failure modes in adhesive bonds, i.e. cohesive fracture, adhesive fracture, and adherent fracture [5]. Figure-1 illustrates the three typical failure modes in adhesive bonds where P is applied load.

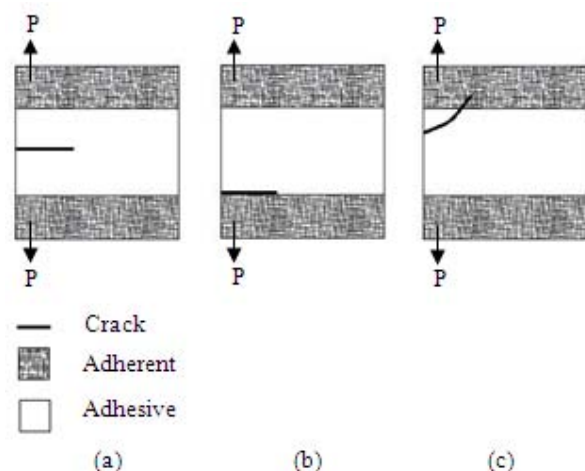


Figure-1. Typical failure modes in adhesive bonds. (a) Cohesive fracture, (b) Adhesive fracture, and (c) Adherent fracture.

Cohesive fracture occurs when crack propagate in the epoxy-based adhesive. Cracks can propagate in the



center of the layer or near the interface. Cohesive fracture occurs due to the attractive forces between the adherent and the adhesive is stronger than the attractive forces between the adhesive itself [6]. Adhesive fracture occurs at the interface due to the attractive forces between the particles of the adhesive is stronger than the forces acting on the interface [6]. Adherent fracture occurs in the joined material. This fracture occurs due to particle of bonded material is not stronger than the adhesive.

EXPERIMENTAL METHOD

Materials

A commercial aluminum was selected to carry out the test as an adherent. The mechanical properties of the aluminum is 100 MPa, 140 MPa and 15% of yield strength, ultimate tensile strength and elongation, respectively. An ARALDITE Rapid epoxy-based adhesive was used to bond two adherents to create a specimen. And the powder materials used in the specimens include sand (silica powder), iron ore powder, and aluminium powder. The Fe percentage of the iron ore is 80%. Volume fraction and the grain size of the powder materials is constant of 30% and of 100 μm to 200 μm , respectively.

Surface Preparations

The surfaces of adherents were prepared before application of adhesives. Two surface pretreatments were employed in this investigation. Firstly, the adherents were cleaned with water and dried below the sun. Secondly, abrasion was applied to joint surfaces of adherents by 1000 grit silicon carbide grinding paper.

Specimen Preparations

Eight different types of specimens were prepared include four T-peel specimens and four single-lap shear specimens. Preparation of the specimens were completed by using three different fillers (aluminium powder, iron ore powder, and silica powder) and without using filler. The fillers size is ranged between 100 μm and 200 μm . Both T-peel and single-lap shear specimens were then prepared by bonding surface cleaned aluminum sheets together with epoxy-based adhesive and then after addition of fillers at fraction of 30 wt%. Equal volumes of the epoxy resin and the hardener were mixed and then fillers was added into the adhesive mixing again for 5 minutes. A designed fixture was used to assemble the adhesive joints. It had two fixed end plates and a movable one between them. The aluminium sheets were bonded together between the movable plate and the far end plate. The fixture included a micrometer used for controlling the adhesive thickness of 0.5 mm. The specimens used in this study is shown in Figures 2 and 3 of T-peel and single-lap shear specimens, respectively. The thickness and width of aluminium sheets is of 3 mm and 20 mm, respectively. Load were applied at the movable plate by using constant displacement of 0.01 mm/s.

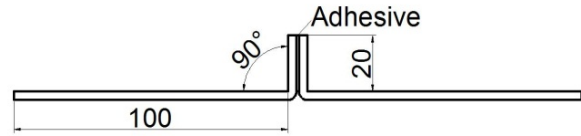


Figure-2. Configuration of T-peel joint test.

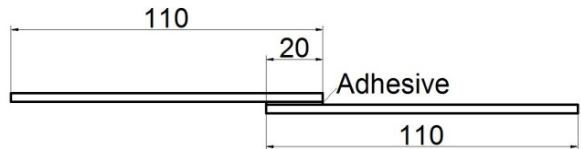


Figure-3. Configuration of single lap-shear joint test.

RESULTS AND DISCUSSIONS

T-peel Joints

Load – displacement curve of T-peel joint test is plotted in Figure-4 for aluminum joints bonded with epoxy-based adhesive with no filler content and with fillers (aluminium powder, iron ore powder, and silica powder). As shown in Figure. 3, the load will increase with increasing displacement until a certain point, which is commonly referred as the maximum load then decrease significantly to zero kN. However, fluctuation of load while increase with increasing displacement occurred for all specimens with filler contents. It indicates that the fillers can resist the crack propagation due specimens loading. Furthermore, the fluctuation might also due to epoxy-based adhesive is an anisotropic material.

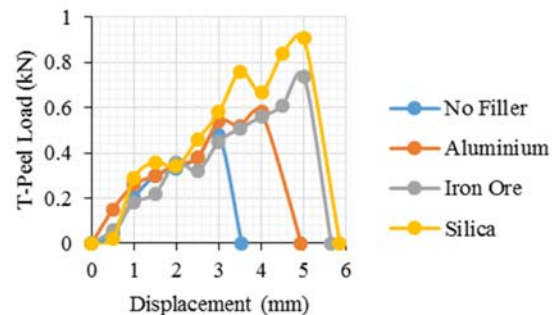


Figure-4. Load - displacement curve of T-peel joint test.

Figure-4 also shows that at some point, the load is not significantly increased indicates that the adhesive fracture were applied. Then when the load is significantly increased, the cohesive fracture was applied. Figure-5 describes how the adhesive fracture and the cohesive fracture occurred at the adhesive joint. Adhesive joint with silica filler choose as an example due to it has high maximum load as shown in Figure-4. Fractography of adhesive joint with no filler and adhesive joint mixed with silica powder shown in Figure-6. It describes that silica



powder resist the crack propagation. Figure-6 also proved that there is air trapped in the adhesive joint. It might be occurred when the adhesive mixed with hardener and the fillers. This void will lead the adhesive to reduce the strength.

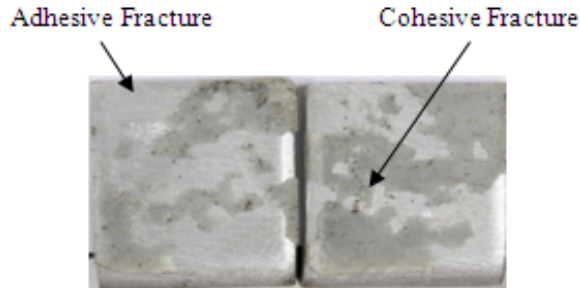


Figure-5. Failure mode of adhesive joint mixed with silica powder.

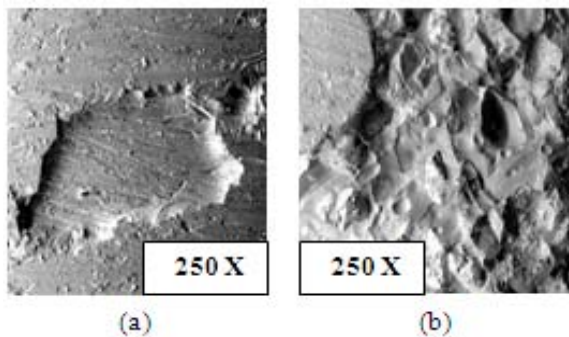


Figure-6. T-peel specimen fractography of (a) adhesive joint with no filler and (b) adhesive joint mixed with silica powder.

As shown in Figure-6, there are three possibilities of failure mode in adhesive joint mixed with fillers by using T-peel joint test. It illustrates in Figure-7.

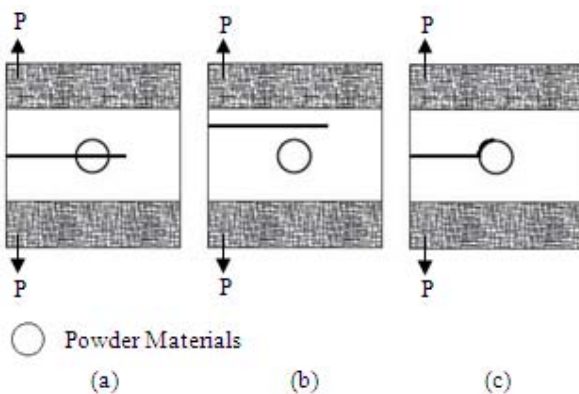


Figure-7. Failure mode in adhesive joint mixed with fillers of T-peel joint test. (a) Powder fracture, (b) Normal fracture, and (c) Adhesive fracture.

Powder fracture occurs when crack propagate through the powder materials. Powder fracture has similar concept with the adherent fracture. This is due to the material properties of powder is weaker than the material properties of the adhesive. Normal fracture shows that the powder material has no effect to the adhesive strength. Cracks can propagate in the center of the layer or near the interface. Adhesive fracture occurs at the interface due to the attractive forces between the particles of the adhesive is stronger than the forces acting on the interface [6].

Single-lap Shear Joints

Load – displacement curve of Single-lap shear joint test is plotted in Figure-8 for aluminum joints bonded with epoxy-based adhesive with no filler content and with fillers (aluminium powder, iron ore powder, and silica powder). As shown in Figure-8, the load will increase with increasing displacement until a certain point, which is commonly referred as the maximum load and decrease significantly until a level of load and decrease slightly to zero kN. The change from significantly decrease of load to slightly decrease occurred due to the fracture in the adhesive joint is not directly occurred after the maximum load. It would delay the crack propagation due to shear load for several time.

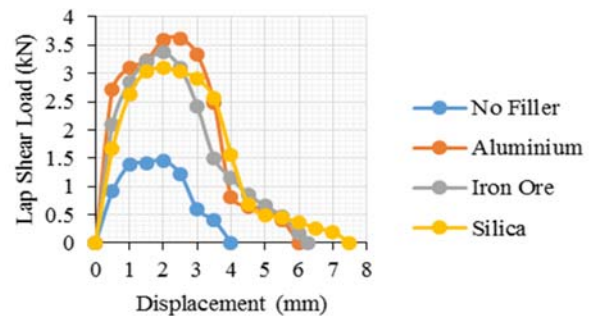


Figure-8. Load – displacement curve of single-lap shear joint test.

Figure-9 describes how the adhesive fracture and the cohesive fracture occurred at the adhesive joint mixed with aluminium powder. Even though the adhesive fracture is dominant, the maximum load of adhesive joint mixed with aluminium powder is the highest. Fractography of adhesive joint with no filler and adhesive joint mixed with aluminium powder shown in Figure-10. It describes that aluminium powder resist the crack propagation due to lap shear load.

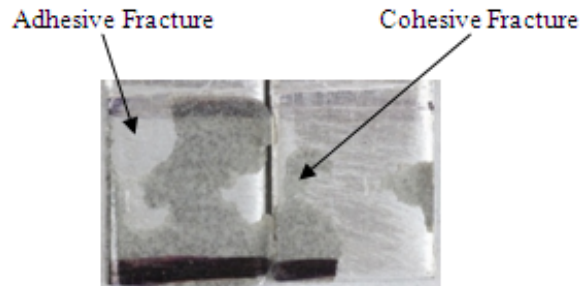


Figure-9. Single-lap shear specimen fractography of (a) adhesive joint with no filler and (b) adhesive joint mixed with silica powder.

Similar with T-peel joint test, there are three possibilities of failure mode in adhesive joint mixed with fillers for single-lap shear joint test. It illustrates in Figure-10.

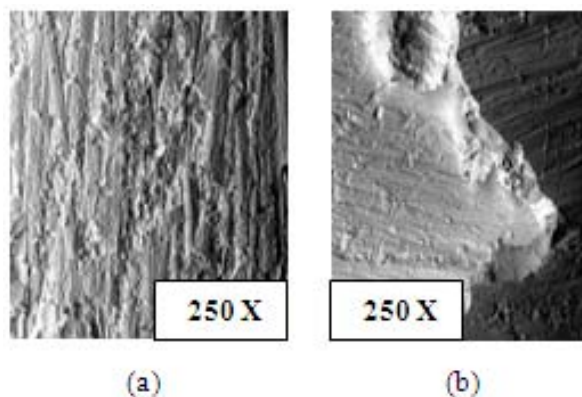


Figure-10. Failure mode in adhesive joint mixed with fillers of single-lap shear joint test. (a) Powder fracture, (b) Normal fracture, and (c) Adhesive fracture.

Peel and Shear Strength of Adhesive Joint

The variation of peel and shear strength in adhesive joint with different fillers shown in Figure-11. It shows that the highest peel strength is the adhesive joint mixed with silica powder of 2.28 MPa and the lowest is the adhesive joint with no filler of 1.2 MPa. In the other hand, the highest shear strength is the adhesive joint mixed with aluminium powder of 9.05 MPa and the lowest is the adhesive joint with no filler of 3.65 MPa. From the results summarized that the shear strength of adhesive joint is higher than peel strength. It proved that the epoxy-based adhesive is good to use for bonding materials which received high shear load.

Figure-11 also shown that adding powder materials to the adhesive joint will increase the peel and shear strength. This is due to the powder material can resist the crack propagation. Therefore, the crack need several time to pass the section or destroy the powder materials.

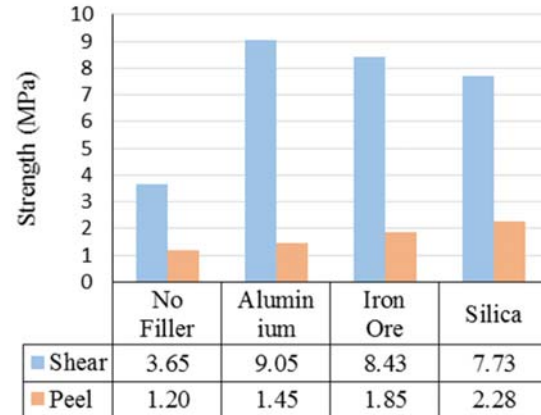


Figure-11. Variation of peel and shear strength in adhesive with different fillers.

CONCLUSIONS

The highest value in peel and shear tests were attained with silica and aluminium powder, respectively. The joints fail in mixed failure mode (cohesive and adhesive mode). The joint strength depended on the adhesive properties and the bond adhesion between the adhesive and adherent. The void due to the air trapped will lead the adhesive to reduce the strength.

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