Effect of Temperature on the Strength Properties of Adhesively Single-Lap Bonded Joint for Composite Laminates

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ABSTRACT

The use of adhesive bonding is valued in structural design in which the single-lap joint has been widely used in the manufacture of aerospace and automotive structures. It has been anticipated that improper or inadequate surface treatment is the most known cause of failure in adhesive bonding. Hence, the objective of this research was to study the effect of surface preparation with different surface roughness by using different number of grit (#220, #400 and #600) of sandpapers on the joint strength of adhesive bonding for glass fiber composites. In addition, effect of various temperatures for different surface roughness on the joint strength has also been investigated through tensile tests under different temperatures. The relationship between joint strength with its surface roughness and temperatures effect was observed. It was found that as the mesh number of grit increased, surface roughness decreased, leading to the increase in joint strength due to better mechanical resistance or interlocking of joints. At temperature below T_g, the adhesive became brittle, leading to a reduction in strength. But, as the testing performed at higher temperature (70°C), the highest strength of bonding was obtained. At 130°C, the adhesive softened and was unable to sustain the load which led to the decrease in joint strength. Finally, the failure mode on the bonded region was analyzed and categorized as adhesive failure, cohesive failure, and mixed failure.

Keywords: *Adhesive bonding, joint strength, single lap joint, failure analysis*

INTRODUCTION

The use of structural adhesives in engineering applications can offer substantial benefits in comparison to more traditional joining such as mechanical fastening and welding. Many authors have made various attempts to investigate the effects of various factors on the stresses in the adhesive layer and the joint strength [1-6]. These factors include spew fillet [7], bondline thickness [8], overlap length [9, 10], environmental conditions [11] and surface preparation [8, 9]. Single lap joint was widely known and used to characterize bond strength [9, 12], as its arrangement is very common in practice and simple design rules should be available for design purposes.

A proper surface pretreatment is essential for achieving good bond strength with any adhesives, which include physically, mechanically and chemically alteration of the surfaces. At minimum, the adherend surfaces that are prepared for bonding should be clean enough to provide a good adhesion. A variety of surface treatments have been used to increase surface tension and surface roughness and to change the surface chemistry, thereby increase bond strength and durability of adhesive joints [13-15]. Grant et al [12] has used acetone to degrease the adherend surfaces and followed by grit blasted to give a surface finish of 2.5 μm of surface roughness. Lucas et al [9] has used #800 SiC sandpaper to treat the surfaces of adherend, together with the acetone to degrease and clean the surface. Kim et al [8] and Katona et al [14] have observed that as mesh number of abrasive paper increased, surface roughness has decreased within the range from 0.5 to 2.1 μm, thus improving the joint strength [8]. Comyn [13] has indicated that surface treatment was very important in removing contamination and weak boundary layers and hence, changing the morphology and surface chemistry of the adherends. In addition, wet channel treatment was also proposed to improve the durability of bond in wet air.

Normally, the adhesives used for the adhesive bonding have its specific properties within the certain range of temperature. The adhesive and the adherend can become brittle due to low temperatures or may melt or decompose under conditions of extreme heat. Grant et al [16] has found that failure load of lap joints under tension at both 90°C and -40°C showed some decrease in strength of the joint as the bondline thickness increased in comparison to those joints tested at 20°C. Likewise, Zhang et al [17] has proposed the effect of low and high temperatures on tensile behavior of adhesively-bonded glass fiber reinforced polymer (GFRP) joints. The failure mechanism has changed with increasing temperature from fiber-tear to adhesive failure. The temperature changes in adhesively bonded joints would cause a wide variety of different stress states [18, 19]. As the adhesive was heated, its viscosity was reduced, thus enabled it to flow and wetted the surface. In contrast, the adhesive will turn brittle at lower temperature, leading to a reduction in strength and greater scatter in the results.

METHODOLOGY

The adherend used was 6-layer of Glass fiber 7544/7000 plain weave with 600g/m2 and the resin was a high temperature epoxy Epolam 2025 with glass transition temperature, Tg of 140oC. The laminate was cured in the oven at 100oC for 90 min and left it under vacuum for 1atm of pressure. The average thickness of the six layers of fiberglass after curing was about 2.7mm. Araldite 2014 was selected as the adhesive for this study where it can sustain high temperature condition with good chemical resistance.

The adherend surfaces were treated using three different mesh numbers (#220, #400 and #600) of sandpapers to analyze the effect of grit number to the value of surface roughness of the adherends. Following the treatment, the specimens were placed into the ultrasonic bath with acetone solvent at 50°C for 15 minutes to clean and degrease from any contamination. A clean surface is necessary condition for adhesion [1] and is very important for the efficient bonding. Following the ultrasonic cleaning, the specimens were dried at 80°C for 15 minutes. Prior to the bonding, the surface of the adherends was analyzed using Alicona Optical machine to determine the surface roughness.

The specimens were bonded with 0.5 mm of adhesive thickness for single-lap joint (SLJ) by using the bonding jig to ensure the bonding in the good alignment and dimensions as shown in Figure 1. The SLJ specimens were then cured using vacuum bagging and were placed in the oven at temperature of 80°C for 4 hours. The vacuum bagging process was performed in order to eliminate the void at the adhesive layer, hence enhance the bonding.

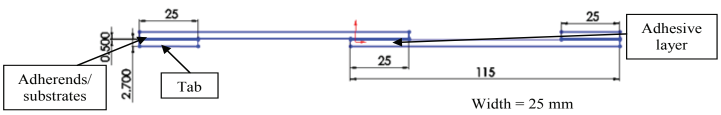

Figure 1: Single-lap joint with dimensions in mm

A total of 12 specimens have been proposed for the project with the specified conditions as shown in Table 1 below. Tensile tests were conducted using Universal Testing Machine (UTM) under three different temperatures of ambient temperature (25°C), 70°C and 130°C to study the effect of temperature on the joint strength. The specimens were subjected to loading under a constant crosshead rate of 1.0mm/min until total failure.

Table 1: Testing sample with conditions

Specimen	Surface preparation	Testing temperature	Specimen	Surface preparation	Testing temperature
A	Without sanding	Ambient	G	*#400	70 °C
B	*#220	Ambient	H	*#600	70 °C
C	*#400	Ambient	I	Without sanding	130 °C
D	*#600	Ambient	J	*#220	130 °C
E	Without sanding	70 °C	K	*#400	130 °C
F	*#220	70 °C	L	*#600	130 °C

*: mesh number of sandpaper used for surface preparation

RESULTS AND DISSCUSSION

Surface Roughness Analysis

Figure 2 shows the 2D and 3D profiles of the adherends for different mechanical treatments. It was noticed that the adherend surface without the sanding provided the roughest surface properties. The surface roughness of the adherend surfaces changed when treated with the sandpapers. It was found that the surface of the adherends showed some noticeable scratches on the macro-scale.

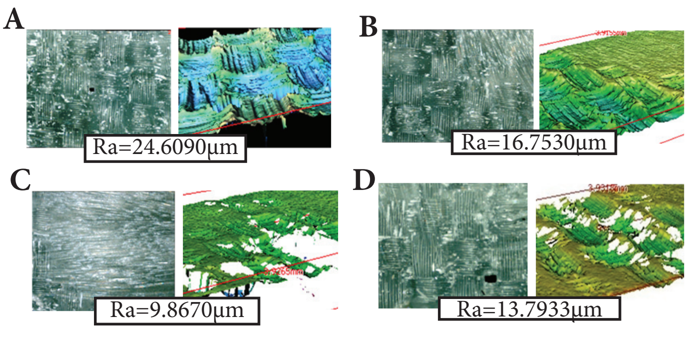

Figure 2: 2D and 3D images for glass fiber adherends: (a) without sanding, (b) sandpaper #220, (c) sandpaper #400 and (d) sandpaper #600

As the mesh number of sandpaper increased to #400, the surface roughness, Ra has found to decrease. Among the considered range of the sandpapers, the mechanical treatment using #400 sandpaper has caused the lowest surface roughness. However, the surface treated with #600 sandpaper has not changed significantly if compared to those of the #400 sandpaper. As the sandpaper with higher mesh number is extremely smooth, it is unable to create a distinct effect on the surface of the adherend. The average surface roughness, Ra for the specimens with respect to mesh number of sandpaper was given in Figure 2.

Joint strength analysis

Figure 3 indicates the joint strength of the adhesive bonding with respect to mesh number of sandpaper at three different temperatures. It was clearly shown that the SLJ strength of the adhesive bonding has increased when treated. At ambient temperature, the untreated specimen has attained the lowest SLJ strength of 26.63 MPa. The joint strength was found to increase after the treatment with #220 sandpaper. It has obtained the increase in strength of approximately 10.5% compared to the untreated counterpart. The surface sanding enables loose and unstable polymers to be removed from the surface, thus increasing the contact surface area [20]. The adhesion is resulted from the molecular contact between the adhesive and adherends, in which the surface forces are developed; as a result of spontaneous wetting.

The SLJ strength was at the highest when adherend was treated with #400 sandpaper, which was at 29.958 MPa. It was shown that the wetting ability of the specimen was better compared to those treated with #220 sandpaper. However, the SLJ strength has decreased slightly as the #600 sandpaper was used. This was attributed to the extremely smooth abrasive materials, unable it to create a distinct effect on the adherend surface as those of using #400 sandpaper. Similar results were observed for those specimens treated in different environmental conditions with temperatures of 70°C and 130°C. The untreated specimens have achieved the lowest single lap joint strength whilst the highest single lap joint strength was obtained for the specimens treated with #400 sandpaper.

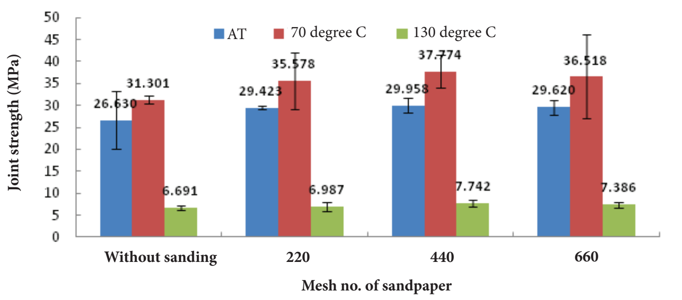

Figure 3: Joint strength of adhesive bonding with respect to mesh no. of sandpaper at AT, 70°C and 130°C

It has been noticed that the joint strengths were increased for all types of specimens when the environmental temperature changed to 70°C from the ambient temperature and were decreased when environmental temperature reached 130°C. As adhesive used is a temperature-dependent, the structural behavior of adhesively-bonded joints is expected to change significantly with temperatures. At 25°C (ambient), the adhesive behavior is relatively hard, inflexible and brittle, at very low viscosity. When the temperature (70°C) was approaching T_g, more uniform stress distribution occurred at the joint, as adhesive behavior became more soft and flexible. The adhesive viscosity was at optimum and a complete wetting of adhesives was observed uniformly over the surface of adherends. However, at temperature above T_g (i.e. 130°C), the joint strength of adhesive bonding strength and stiffness has decreased. The ductility of the adhesive was higher than those in other temperatures as strain capability was increased but the load capability was low due to extremely high viscosity.

Failure mode

The failure mode of the specimens is summarized in Table 2. Significant differences in failure mechanisms were observed at different temperatures and different surface roughness. Although in all cases cracks nucleated and propagated at both ends of the bonded region, the failure processes could be classified into three distinct categories: cohesive failure, interfacial failure and mixed failure. At ambient temperature, an interfacial failure was observed because of the brittle property of the adhesive. At 130^{0}C, the dominant failure mode was a cohesive failure as the adhesive became ductile with lower tensile strength. But, the failure mechanism changed at the glass transition temperature, from mixed failure to cohesive failure for specimen treated with #400 sandpaper. This was attributed to the effective and good adhesion of mechanical interlocking between interface of adhesive and adherend.

Table 2: Failure mode for specimens tested

Failure mode		
Cohesive failure	**Interfacial failure**	**Mixed failure**
Without sanding (130 °C) #220* (130 °C) #400* (130 °C) #600* (130 °C) #400* (70 °C)	Without sanding (AT) #220* (AT) #600* (AT)	Without sanding (70 °C) #220* (70 °C) #600* (70 °C) #400* (AT)

*: mesh number of sandpaper used for surface abrasion; Cohesive failure: separation is within the adhesive; Interfacial failure: separation appears to be at the adhesive-adherend interface; Mixed failure: a mixture of different classes

CONCLUSION

Joint strengths were found to increase for all types of specimens at 70°C; a complete wetting of adhesives was observed uniformly over the surface of adherends. At temperature above Tg, the joint strength of adhesive bonding strength and stiffness has decreased. The failure modes observed could be classified into three distinct categories: cohesive failure, interfacial failure and mixed failure

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Oil Palm Trunk Biocomposite: Mechanical and Morphological Properties

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ABSTRACT

In this research oil palm trunk biocomposites were produced by impregnating dried oil palm trunk with phenol formaldehyde resin. Peripheral region of oil palm trunk bottom parts were kiln dried until it attain 13%–15% moisture content, after that dried oil palm trunk impregnated with phenol formaldehyde resin by using high pressure vessel. In this study impact and compression properties of oil palm trunk biocomposites were studied. It observed that impregnation of oil palm trunk with phenol formaldeyde resin improves the impact and compression properties of oil palm trunk biocomposites.The oil palm trunk biocomposite with 60% resin loading showed better mechanical performance than other oil palm trunk biocomposites but still lower than rubberwood. Scanning electron microscope was used to study the surface morphology of oil palm trunk, and location of resin in the oil palm trunk biocomposites at different resin loading. The phenol formaldehyde resin showed better interaction in oil palm trunk impregnated with 60% resin loading and resin penetration still retain the original dried oil palm trunk structure.

Keywords: *oil palm trunk biocomposite; dried oil palm trunk; rubberwood; phenol formaldehyde*

INTRODUCTION

Oil palm plantations in Malaysia is close to 4.05 million hectares and during replanting process, it generates approximately 8.2 million tons of oil palm trunk (OPT). Constraint for the use of oil palm trunk as value added product making it a serious pollution problem in the field. Te OPT are normally left to rot or burnt in the field and this method is now unacceptable because it could affects the process of planting new crops [1,2]. The high density variation within the oil palm trunk has a significant effect on its strength properties. Based on study by Lim and Gan [3], the modulus of rupture (MOR) and modulus of elasticity (MOE) are found to be linearly correlated to the OPT density. Therefore, the selection of OPT to be value-added product need to consider the variability over the trunk, both radially and vertically.

Phenol Formaldehyde (PF) resins are the most important and common class of resin adhesives. The PF resin is the most frequently used and environmentally more acceptable because of negligible formaldehyde emission. PF resins tend to be the most widely used adhesives for bonding wood products due to the excellent adhesion to lignocellulosic, durable, provide high quality wood bonding and suitable for use under all climatic conditions [4]. However, conventional PF adhesives are slow curing, require higher curing temperature, and are less tolerant to variations in anatomical features and wood substrate. The role of the PF resin in the oil palm trunk is to transfer the load to the stiff fibers through shear stress at the interface. In addition, with the help of PF resin properties, the fiber will acts as obstacles to impede the crack propagation [5].

Studies on the enhancement of OPT characteristic to become high performance product in dimensional stability, durability, and strength has been done by Edi Suhaimi [6], Erwinsyah [2] and Bakar [7]. The thermal properties of OPT modification has been studied by Bhat et al. [1] and showed a great thermal and degradation stability. In the other hand, the biodeterioriation exposure of modified OPT with termite have been done by Edi Suhaimi [6] that exhibited better resistance properties compared to unmodified OPT. Oil palm trunk is largely composed of parenchymatous tissues with numerous fibrous strands and vascular bundles. The tough vascular bundles are scattered in soft parenchyma tissue. Toughening the oil palm trunk with PF resin is novel approach to produce a new type of palm lumber and as an alternative source for wood based industries.

EXPERIMENTAL

Materials

The oil palm trunks at 25 years old were taken from KL-Kepong Berhad Plantation in Kulim, Kedah. Only bottom parts and outer region