*Applied Mechanics and Materials Vols. 465-466 (2014) pp 101-105*
*Online available since 2013/Dec/19 at www.scientific.net*

*doi:10.4028/www.scientific.net/AMM.465-466.101*

# Tensile Properties of Angle Cured Laminated Composites Structures under Gravity Effects

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**Keywords:** Tensile; Angle Cured; Laminated Composites; Gravity Effects; Limited Space; SMI/E.

**Abstract.** As the usage of composites materials are significant in the industries of automobiles, shipping and constructions due to their non-corrosive and high strength to weight ratio. Anyway, the production of composites needed to be increased to meet the demand. At this stage, problem faced by Small and Medium Industries / Entrepreneurs (SMI/E) is the confined and limited space available that restricts the optimum productivity. They commonly cure the composites horizontally that requires ample space and unable to afford for high-end equipment such as mechanical oven and autoclave in the production as a result of high capital cost.This research is carried out to study the feasibility of the gravity effects on curing position of the laminated composite structures to enhance the curing space needed. The aim of the research was to investigate the tensile properties of the thermosetting laminated composite by curing the laminate at different angle using vacuum bagging technique. From the testing, SN 5 which denominated to be 60˚ found to have the best tensile properties in term of maximum force exerted and Young's modulus.

## Introduction

Utilization of laminated composite materials has become increasingly common in a wide range of structural components over conventional materials because of their superior specific properties; such as high strength and stiffness-to-weight ratio, improved corrosion and environmental resistance, design flexibility, improved fatigue life, potential reduction of processing, and life cycle cost [1,2]. Laminate composite plates are also extensively used in civil, mechanical and aerospace industries [3]. The most common man-made fibers used in fibrous composites are glass, carbon (graphite) and aramid, while for the matrix the widely used materials are organic polymeric materials. The polymeric materials used for matrix are often, in engineering terminology, referred as plastics. Hence, the fibrous composite is often called as Fiber Reinforced Plastics (FRP) [4]. FRP products are recognized as high tech materials when compared with conventional engineering materials [5,6]. In addition, advanced fiber reinforced polymer composites have been increasingly used in various structural components [7,8]. Since the quality of laminated composites is largely affected by cure cycle, selection of cure cycle for each application is important and must be optimized.

During the manufacture of FRP components, the polymer being liquid with low viscosity has good flowability, whereas the fibers have high stiffness and do not take shape easily over the high curvature of FRP components. Therefore, application of pressure is an important parameter to provide shaping of material before solidification of polymer. Several methods have been developed to manufacture FRP products including filament winding, pultrusion method, vacuum bagging technique, autoclave technique, compression molding and so on [9].

By applying appropriate manufacturing technique for laminated composite, the curing condition of the laminate is one of the factors that will influence the properties of composite. Gravity effect may influence the resin flow during curing process of a laminate composite. Mechanical and physical properties may be different when the laminated composite is cured at different angle position. When an internal resistance develops within the fluid to mobility is called the viscosity. The viscosity is inversely proportional to the fluid flow of the resin in the composites. A frictional force will be created when the surfaces of two mediums come into contact with each other. When the composite is cured at an angle position instead of horizontal position, the viscous uncured resin used will tend to flow downwards slightly due to the gravitational force exists. The higher the curing angle tilted, the higher the gravity effects on the matrix. However, it is important to clarify whether the effect of flow of uncured resin at different curing angle position is significant to the properties of the composite produced [10,11]. Thus, the main objective of the research was to investigate the tensile property of the thermosetting laminated composite by curing the laminate at different angle using vacuum bagging technique.

## Materials and Method

In the experimental work, four layers of 600 $g/m^2$ E type glass fibers with the dimension of 500 mm x 500 mm are prepared. The quantity of unsaturated polyester needed as the matrix was prepared at the ratio of 60:40 by weight using fiber to resin ratio. The mould used had to be coated with gel wax and dried to ease the composite from removing from the mould. Initially, the glass fiber was stacked layer by layer to form the laminate by applying the unsaturated polyester. One percent of Methyl Ethyl Ketone Peroxide (MEKP) hardener by weight was also added into the unsaturated polyester so that the resin may be hardened. MEKP hardener may also act as the catalyst to speed up the polymerization process in forming bonding.

The laminates would undergo vacuum bagging process in which the glass fiber laminate was laid on the mould followed by release fabric, perforated film, breather and nylon mat in the correct sequence. Next, the silicon spiral pipe was arranged to surround the laminate within the mould. After that, the vacuum bag was laid around the stack laminate and a vacuum port was attached through the bag to provide a fitting for attaching the vacuum hose. The vacuum bag was sealed with sealant to contribute to an airtight seal. The mould was set to cure at horizontal position as a benchmark for the rest of the curing angles. Subsequently, the vacuum pump was switched on to suck out the excessive resin and remove the air out from the laminate. The laminate was left for room temperature curing for 24 hours before detaching from the mould. The fabrication process of the composite laminate was repeated for curing angle position from $10^{\circ}$ to $90^{\circ}$ with the increment of $15^{\circ}$ each sample at specific sample location in one panel as depicted in Fig. 1(a).

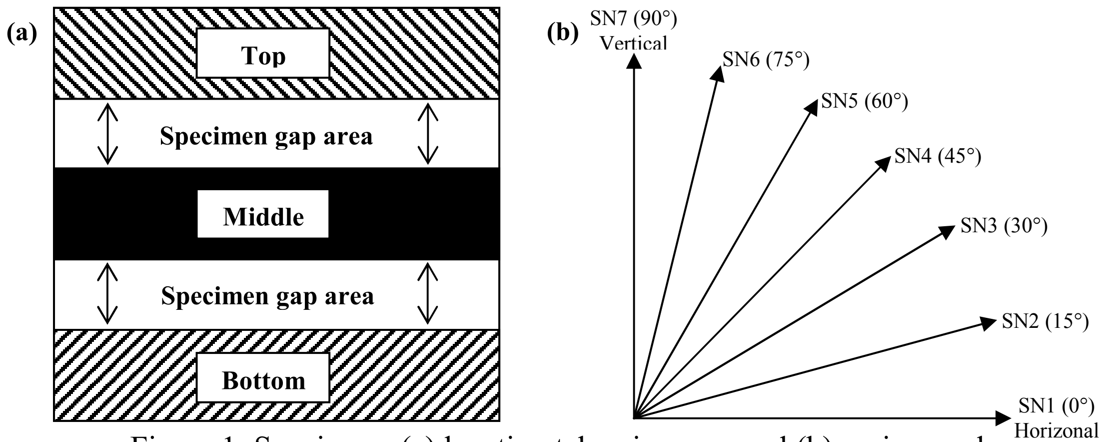


Figure 1: Specimens (a) location taken in one panel (b) curing angles.

The samples of different curing angles were prepared into the dimension according to ASTM D 3039. The samples were tested for maximum force and Young's modulus by using the Universal Testing Machine at the cross-head speed of 2 mm/min. The samples namely SN 1 was denominated for 0˚curing angle and until SN 7 for 90˚as shown in the Fig. 1(b).

**Result and Discussion**

The maximum amount of tensile stress that a material can withstand before breakage is called the tensile strength. The initiation of failure is through breaking of fibers at their weakest point of the composite structure when under the longitudinal tensile load. When partial of the fibers are broken, the load carried by the broken fibers will be passed on to the remaining fibers. As the tensile load is increased gradually, the number of fiber broken will also be getting increased. As a result, some location in the composite structure will be too weak to continuously supporting the applied load. Therefore, it contributes to the catastrophic failure of the composite structures by triggering the pre-existing broken fibers. The behavior of the load bearing composite under the tensile load is mainly dependent on the factors of stiffness and strength of the fibers [12].

Fig. 2 shows the SN5 and SN7 could withstand maximum force higher than SN1 which acted as control sample. According to Miron [13],maximum values of the force when crack propagation initiates and the corresponding relative displacement of the fixtures of the specimen are influenced by the geometry of the specimen and the quality of the interface bonding. Good interface bonding between glass fiberand polyester resin in SN5 and SN7 in three different divisions gave high maximum force value.

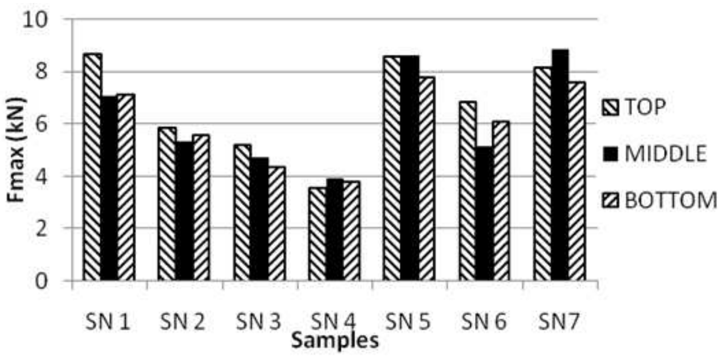


Figure 2: Maximum tensile force at break for all specimens.

Generally, the maximum tensile force that was able to sustain for top part is always higher compared to the middle and bottom parts which seen from SN 1 to SN 3. The resin sucked by the vacuum pump from top part helped to maintain the position of the resin, preventing it from flowing downwards. Besides, the curing angle tilted is not very high from 0˚ to 30˚ only. From the graph shown in Fig. 2, maximum force from SN4 top to SN4 middle increased due to the unsaturated polyester resin tend to move downward to the middle and bottom part when cured at 45˚ angle position even vacuum was applied from top. The lack of distribution of resin on top part of SN4 caused the tensile strength decrease. There was only slight decrease of maximum force less than 3.5 % between SN4 (middle) and SN4 (bottom) as the gravity force act between the two sample parts were very small in difference.

From this average analysis, average tensile strength values for top, middle and bottom part of samples were between 6.01 to 6.66 kN. The average percentage maximum force difference between the three parts of overall samples was below 7.5 % which not even exceeded 10%. From this percentage value, it can be concluded that there was slight difference of maximum force value in between top, middle and bottom samples. From the data, SN4 (45˚) did not gave a good mechanical properties for the laminated composite to be cured at this angle as the behaviour of the composite will be changed sharply than control sample. The decremented value was more than half value of control sample. Thus, SN5 and SN7 gave the optimum maximum force properties among the seven laminated composites.

Young's modulus is a measure of stiffness of a material and it is also related to the stress and strain in the linear elastic region. It is because the stress is proportional to the strain initially when the material is stressed.Therefore, Young's modulus is the ratio of shear stress to the shear strain. Fig. 3 shows the SN5 had better elastic properties than others as it had extraordinary Young's modulus value that was far compare to control sample. SN5 bottom decreased in tensile properties may due to the high gripping force between the composite and gripper resulted internal stress thus lowered down the elastic properties of SN5 bottom. SN6 and SN7 also gave good elastic properties as the Young's modulus for top and middle parts were quite high compared to SN1 and other samples. Hence, SN5 was the best serial number with highest Young's modulus properties among the others.

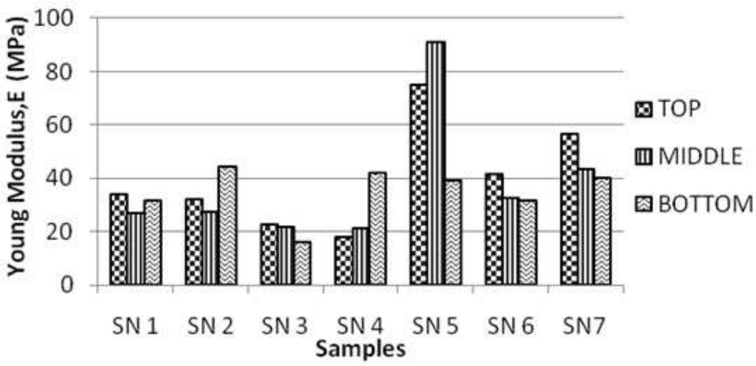


Figure 3: Maximum tensile force at break for all specimens.

In addition, SN4 obtained the lowest Young's modulus at top and middle divisions while SN3 obtained the lowest at bottom divisions. Young's modulus decreased due to incompatibility bonding between both materials fibers and matrix as occurred in SN3 and SN4 had obtained the lowest Young's modulus [14]. Therefore, these two serial number were less likely to withstand force when the samples were been pulled. However, the difference of average Young's modulus between its maximum and minimum only gave a slight difference between the three divisions which not more that 8.5 % and is considered acceptable. Thus, gravity force in between the same laminated composite not vary much until altered tensile properties of laminated composite that gave negative effect.

Wang [15] reported that delamination occurred between the fiber and matrix as well as fiber pulls out cause reduction in structural stiffness and strength, leading to growth of damage and final fracture as occurred in SN4 top when viewed under microscope as shown in Fig. 4(a). The trend for ultimate tensile strength bar chart would be the same as the trend of the maximum tensile force bar chart. This is because the ultimate tensile strength for respective samples could be obtained by maximum force over the cross-sectional area of the samples. Ultimate tensile strength is directly proportional to maximum force of each sample. As the maximum force is decreased, the ultimate tensile strength will be decreased. Since the maximum tensile force bar chart can be used to represent the trend of the tensile strength. Therefore, it can be concluded that the tensile strength for SN 3 and SN 4 were the lowest. It could be due to the matrix crack and fiber pull-out co-existed in the sample as shown in Fig. 4(b). Samples that showed good tensile properties experienced maximum stress transfer efficiency from the perfectly bonded fiber as exhibited by SN 5.

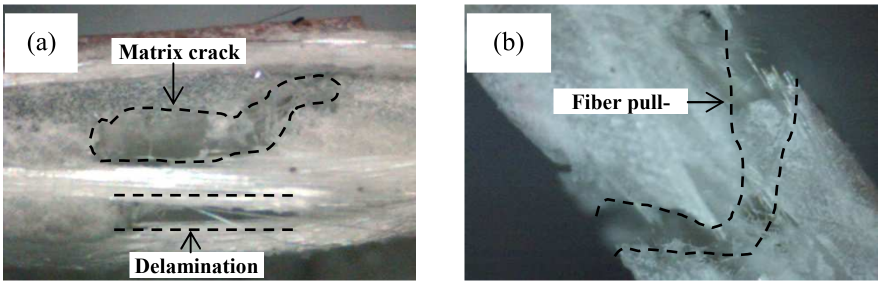


Figure 5: Optical microscope observation at fracture specimen after tensile testing (a) delamination and matrix crack (b) fiber pull-out.

## Conclusion

Research finding shows that the SN 5 which is cured at 60˚ shows the optimum tensile properties compared to composite that cured at 0˚ which is horizontal position that serves as a control sample. Curing composites at the angle of 60˚ will be able to help to maximize the usage of space available in the production floor in SMI/E besides exhibiting improved tensile properties than the composites cured horizontally. The gravity effect does have impact on the samples which clearly seen via the top, middle and bottom parts, however, the properties are not largely varied through the graphs shown.

## Acknowledgement

This research is sponsored by FRGS grant through UTeM, FRGS/2012/FKP/TK01/03/1/F00133.

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10.4028/www.scientific.net/AMM.465-466

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