FATIGUE BEHAVIOR OF GLASS-FIBRE REINFORCED EPOXY COMPOSITES

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ABSTRACT

The purpose of this research was to characterize the effect of the dynamic load with constant amplitude on glass fibre reinforced epoxy resin. The specimens were manufactured using a hand lay up method and the volume fraction was controlled through their thickness. The test was performed using a cantilever beam method and the dynamic load was generated by a cam, which was coupled to an electric motor. The performance of each specimen was evaluated through the degradation of modulus of elasticity.

From the observation, it was shown that by using a hand lay up process, the distribution of fibres is considerably good. The degradation of composite panels appears after reaching $1{,}5x10^5$ for d/L equal to 0.125 and 0.143. However, the degradation does not appear for d/L = 0.1.

1. INTRODUCTION

Composites have been intensively developed in the last decade. These materials initially were used for secondary components in aircraft structures such as in interior parts. However, for the time being, composites have been used for main components such as vertical and horizontal stabilizers, wing skin, flap and other components in the aircraft. The advantages of composites are generally due to of high specific strength and high specific stiffness compared to metallic materials, and also the user can arrange their strength according to the fibre orientations.

The development of polymer also takes an important aspect of the development of composites. Since some polymer materials were used as matrix, such as epoxy, PEEK, the performance of composites were increased very significantly.

Even composites have been widely used in many structures. However, the percentage of composites in those structures is still very low. This is obviously caused by the weakness of composites, for instance, in compression and shear loads, which may cause delamination in inter layer of laminates and/or debonding between fibre and matrix. This is the reason why these two phenomena become the main topics in the composite researches.

There are several methods to manufacture engineering components based on glass-fibre and resin. The user usually selects a process depending on the complexity of geometry of components to be manufactured, time duration, requirements of strength and also requirements of resin. In this research, it was manufactured by a hand lay up method,

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which is a relatively simple process. This process can be used to manufacture a wide variety of components as far as the geometry of structures is relatively simple (Johnson, 1990). The process is relatively easy by preplacing dry fibres in the mold before the mold is closed, and the resin is introduced by pouring it into the mould.

The unique of composites is that the designer can arrange the strength and stiffness of a engineering component according to their needs. Therefore, by using the same materials with the same fibre content, the strength and stiffness of a engineering component will vary significantly depending upon the fibres orientation. The strength and stiffness of an engineering component will also be influenced by the quality of manufacturing process. Therefore, before applying an engineering component in real situation, it has to be tested appropriately.

There are two types of composites test, namely static and dynamic tests. Static test is aimed to determine basic material properties. These material properties are always carried out before applying in the real engineering structures. When the engineering structures exhibit dynamic loads dominantly, dynamic test has also to be carried out. This test is obviously aimed to see the effects of the dynamic loads to the change of basic material properties. Hence, the designer can justify whether the material can be used or not and also when the material has to be replaced.

Composite test methods have been reported by Whitney et. al. (1982), which consist of tensile test, flexure test, compression test and shear test methods. Some efforts have been performed to develop test methods which are appropriate to asses material properties. Such test methods have been used by Air Force Materials Laboratory (AFML, 1977) to select materials for a particular aircraft structure. Other test methods have also been reported by Munjal (1989). He argued that test data depend on the test method, specimen design, fabrication method and void content. Therefore, he proposed test methods for determining allowable design for fibre reinforced composites.

Fracture and fatigue test methods were basically adopted from metal test methods. Simonds et. al. (1989), for example, has investigated the effect of matrix toughness on fatigue response of graphite fibre composite laminated. The results show that matrix toughness influences the long term behaviour of graphite fibre composites. Similar fatigue tests were also carried out by a number of investigators (Daniel et. al., 1989, Berg et. al., 1989, Poursartip et. al., 1989 and Bakis et. al., 1989).

Jamasri (1992, 1993) has intensively studied fracture mechanics of carbon fibre reinforced plastic (CFRP) composites. In his research, he introduced an artificial crack in the centre of a composite plate. The composite plate was then tested under static loads in order to observe the behaviour of the composite plate, which has a centre crack. The behaviour of composite plate was then showed in term of stress intensity factors and energy release rates. The results were used to validate a finite element model written in a package program (Jamasri, 1993). The finite element model was then developed to characterize other composite plates with different fibre orientations.

Composite tests in real structures have also been carried out, Poe et. al. (1989) for instance has tested Rocket Motor Case dynamically. The study was made to determine from a low velocity impact. Kochendorfer (1988) has investigated CFRP components for reciprocating engines. The piston pins and connecting rods subjected to fired engine tests. After 500 hours testing in a single-cylinder diesel engine, predominantly under maximum loading conditions, the CFRP components were found to be undamaged.

1.1. Theoretical background

In general, composites are a combination at least two materials that have different properties to obtain the third material. Since the base materials have different properties, the behaviour of composites depends on the percentage of each material and fiber orientation. Longitudinal modulus of elasticity can be determined using a mechanics of materials approach with the assumption that the material is homogen in certain orientation (see figure 1).

$$E_1 = E_f v_f + E_m v_m \qquad (1)$$

It can be seen that E_l changes linearly depending on the volume fraction of fibre (v_f) and matrix (v_m).

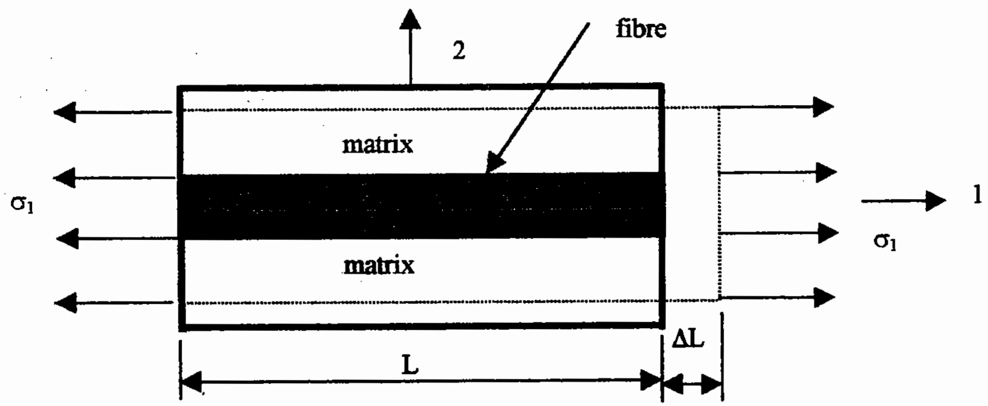

Figure 1. Composite panel loaded parallel to fibre direction (direction 1)

Alternatively, the modulus of elasticity can also be determined from a cantilever beam, such as shown in figure 2.

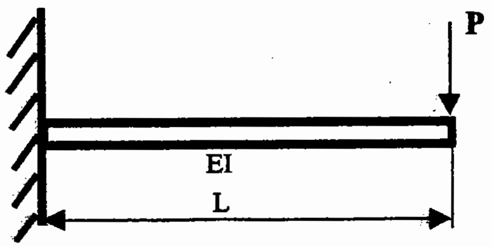

Figure 2. Cantilever beam

The deflection and modulus of elasticity can be determined as follows:

$$\delta = \frac{PL^3}{3E_1 I} \quad \text{or} \quad E_1 = \frac{PL^3}{3\delta I} \qquad (2)$$

If P is assumed as dynamic load for certain cycles, the degradation of E_1 can also be evaluated using the same equation.

2. EXPERIMENTAL PROCEDURE

The dynamic tests were carried out under sinusoidal loads for all specimens, where the magnitude of stress was arranged between 30% and 45% from the strength of each specimen in order to investigate the effect of cycles on the degradation of stiffness. All dynamic test data were then plotted to see the effect of certain fibre content.

The test specimens prepared here were unidirectional composites reinforced by S-glass fibres. Epoxy resin was used to bond the fibres with three volume fractions of fibres. The specimens were manufactured through an open moulding and to avoid bubbles and excess resins in the composites the mold was squeezed by an addition cover on the top of the mould. The mold consists of two parts, namely bottom part (female) and upper part (male). To obtain the expected volume fraction and to ensure that the resin has filled among the fibres, the female mold was then squeezed by a male mold such as shown in figure 3.

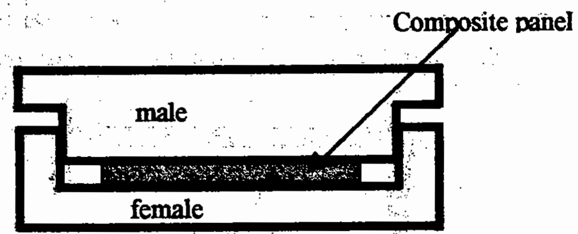

Figure 3. Composite panel between male and female mold

Before performing mechanical tests of the composite panel, it was evaluated its fibre distribution, such as shown in figure 4. It can be seen that the fibres are distributed quite well and no significant voids and other defects found in that surface. The dimension of the specimen used is shown in Figure 5, whereas the testing machine is shown in figure 6.

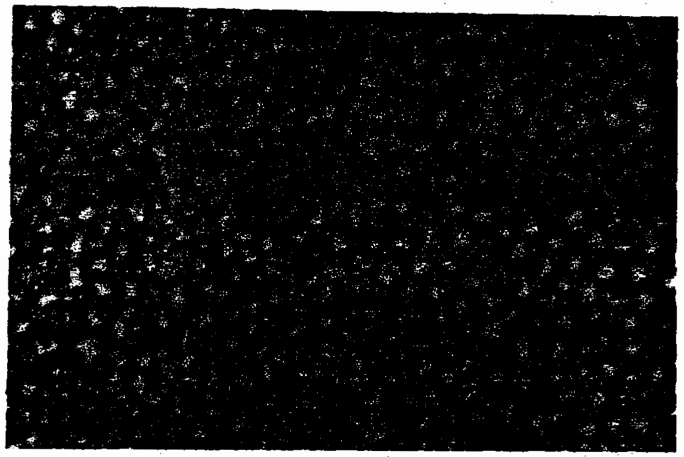

Figure 4. The distribution of fibre in cross section area

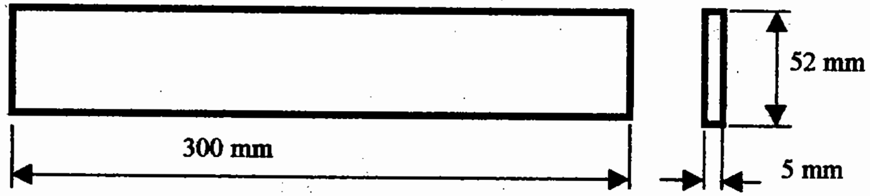

Figure 5. Dimension of specimen used in the research

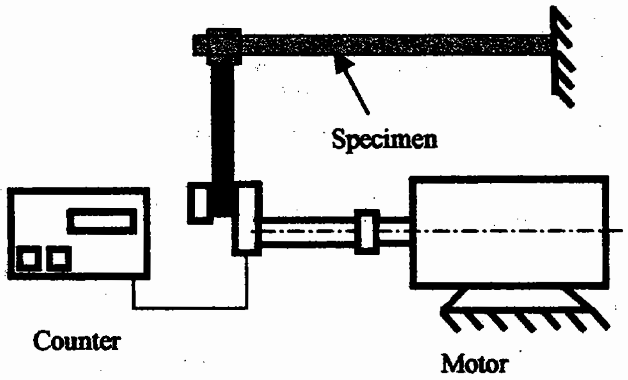

Figure 6. Fatigue bend machine

3. EXPERIMENTAL RESULTS AND DISCUSSION

Before performing the dynamic tests, all specimens were tested statically to see a relation between load and deflection. From this relation, the modulus of elasticity can

specimen was tested in a certain cycle. The performance of composites can be seen from the degradation of the modulus of elasticity.

Figure 7 represents the relation between load and deflection for three differences of fibre contents. It can be seen that for the same load, the specimen gives a smaller deflection for higher fibre content. This indicates that its modulus of elasticity will also be higher. In addition, it also can be seen that all graphs show a relationship between load and deflection linearly. This means that the specimens were loaded under linear elastic ranges.

Figure 8 shows the degradation of modulus of elasticity after being tested under dynamic load. It can be seen that for δ/L=0.100, the value of modulus of elasticity does not decrease even under 10^7 cycles of dynamic loads. By increasing the value of δ/L=0.125, the modulus of elasticity start to decrease at 10^6 cycles and continue to decrease significantly when the cycles of dynamic load is increased. This may be caused by the effect of debonding between matrix and fibre. When the value of δ/L is increased to be 0.143 the degradation of the modulus of elasticity even faster.

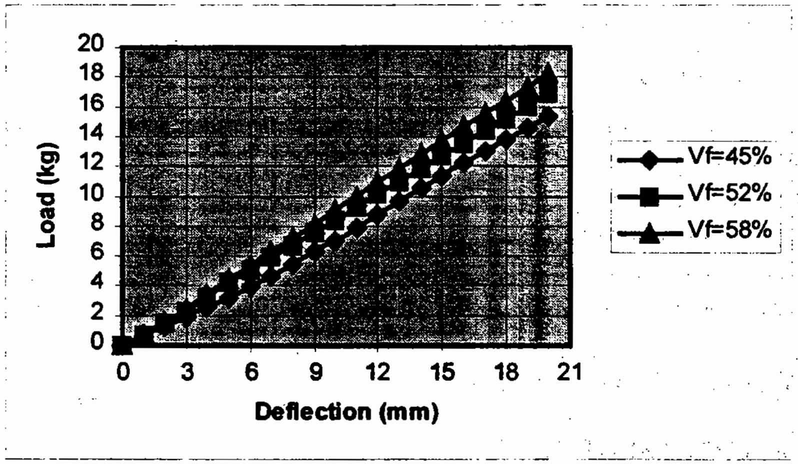

Figure 7. The relation between load and deflection in cantilever beam test

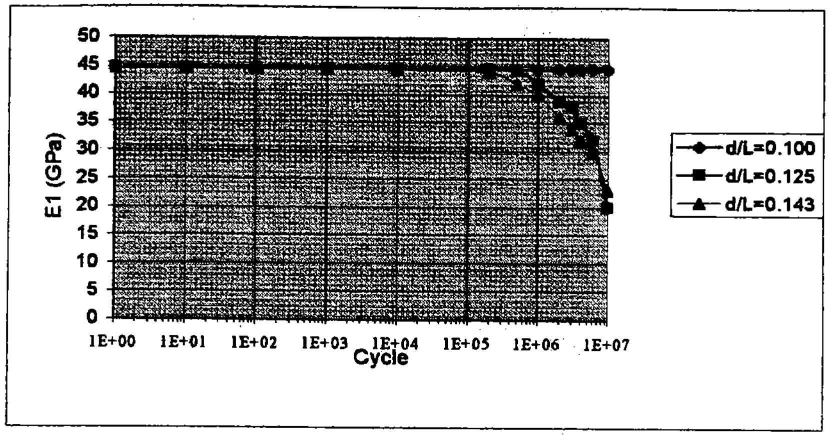

Figure 8. The degradation of modulus of elasticity as a function of cycle

4. CONCLUSION

From the experimental results and discussion, it can be drawn the following conclusions:

1. By using hand lay up process, the distribution of fibres is considerably good and no significant voids are shown.
2. The degradation of composite panels appear after reaching $1{,}5\times10^5$ for d/L equal to 0.125 and 0.143. However, the degradation does not appear for d/L = 0.1.
3. In general, the composites used have a reasonably good performance. However, their stiffness is relatively low compared with a commercial material.

5. ACKNOWLEDGEMENT

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