OPTIMAL DESIGN FOR HYBRID COMPOSITES UNDER FLEXURAL LOADING

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Summary A study on the flexural behaviour of hybrid composites reinforced by S-2 glass and T700S carbon fibres is presented in this paper. The effects of fibre volume fractions, hybrid ratio and span-to-depth ratio were studied with the aid of FEA. It is shown that utilisation of hybridisation can improve the flexural strength. A general rule is in order to improve flexural strength, the fibre volume fraction of glass/epoxy plies needs to be higher than that of carbon/epoxy plies. The overall maximum hybrid effect, 37.34%, is achieved when the hybrid ratio is 0.318 ($[0_{2G}/0_{6C}]$) when V_{fc} = 50% and V_{fg} = 70%. The strength increases are 44.55% and 24.07% when compared with those of the full carbon and glass configurations respectively.

INTRODUCTION

Hybrid composites consisting two or more types of fibres in a common matrix have attracted increasing interests [1]. Designing hybrid composites for tailored properties is not a trivial task. In this study, the effects of fibre volume fractions on the flexural performance of S-2 glass and T700S carbon fibre reinforced epoxy hybrid composites were studied using FEA. For both glass and carbon fibre, three fibre volume fractions 30%, 50% and 70% were chosen, and the flexural behaviours of various stacking configurations at four span-to-depth ratios 16, 32, 48 and 64 were simulated. Flexural moduli and strengths were calculated from the FEA results. The results provide a useful guideline to the optimal design of glass and carbon fibre reinforced polymer hybrid composites.

MODEL DEVELOPMENT

In this study, the flexural behaviour of S-2 glass and T700S carbon/epoxy hybrid composites was studied using commercial FEA software package ANSYS v13. Because the loading nose is wider than the test specimens, the centre load is uniformly distributed along the width of the specimens, and the load is in one direction only. Thus, the cross-section of each specimen was modelled by assuming plane strain condition. Eight-node PLANE183 elements are used. Based on the constituent properties, the lamina properties, including the longitudinal modulus E_{11}, the transverse moduli E_{22} and E_{33}, and the shear moduli G_{12}, G_{13} and G_{23}, are derived by Hashin's model [2].
The diameter of the loading nose is 10 mm. In FEA, the load is defined by applying 1 MPa along 1 mm at the mid-span (0.5 mm when symmetric boundary conditions are applied). With this load definition, singularity is eliminated. Using the deflection dy and L/h ratio, the flexural modulus can be calculated.
From the analysis of failure modes, it is seen that failure mostly occurs at the compression side. Thus, the compressive strength needs to be derived. In this study, Lo-Chim model [3] was used to predict the compressive strength of a unidirectional laminate.
The load P is increased until the maximum compressive stress reaches the compressive strength. For hybrid composites, the maximum stress may not always occur at the outermost layer. Thus, the maximum compressive stress and the compressive strength of both the glass/epoxy and the carbon/epoxy sections are examined and the lower $P_{\max}$ is chosen, and the flexural strength σ_{F0} is calculated.
It has been shown that the strength in bending is higher than in tension, which can be explained in terms of Weibull statistical theory [4]. Since the specimens in this study failed in compression, it is also expected that the strength in bending is higher than in compression. In this study, the flexural strength is empirically determined to be $\sigma_F = 1.3\sigma_{F0}$.
The developed FEA approach was validated against the experimental results. Test specimens were manufactured in house utilizing the hand lay-up process. The stacking configuration of the hybrid composite was chosen to be $[0_{2G}/0_{3C}]$. In addition, full carbon and full glass configurations were also chosen as the controls. The details of the experiments are given in [1].

PARAMETRIC STUDY

In this study, the effect of two variables, the fibre volume fractions of carbon/epoxy and glass/epoxy plies, V_{fc} and V_{fg}, was studied using Response Surface Methodology (RSM). For each variable, three levels were chosen, i.e. 30%, 50% and 70%, and a 3^2 factorial design was constructed. A three-level factorial design was used to model possible curvature in the response function and to handle the case of nominal factors at 3 levels.

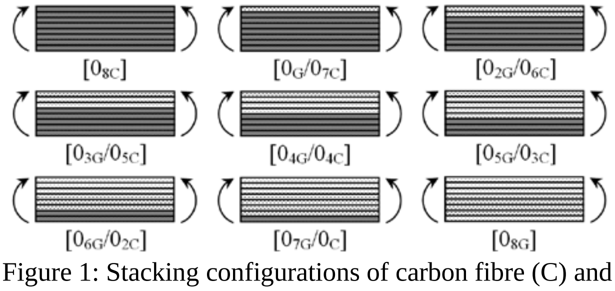

Figure 1: Stacking configurations of carbon fibre (C) and glass fibre (G) plies

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For each variable combination, nine stacking configurations were studied. All the laminates were 2 mm thick and consist of 8 laminas of equal thickness. The stacking configurations are shown in Figure 1.
The hybrid ratio is defined as:

$$r_h = \frac{1}{1+\left(h_{fc}V_{fc}\right)/\left(h_{fg}V_{fg}\right)} \tag{1}$$

where h_{fc} and h_{fg} are the thicknesses of the carbon/epoxy and glass/epoxy sections, respectively, and V_{fc} and V_{fg} are the fibre volume fractions of the carbon/epoxy and glass/epoxy sections, respectively.

RESULTS

The flexural modulus vs. hybrid ratio displays an S curve for all the fibre volume fraction combinations. When the span-to-depth ratio is 64, the flexural modulus vs. hybrid ratio relationships for all the fibre volume fraction combinations are shown in Figure 2. It is noteworthy to point out that when V_{fc} = 30% and V_{fg} = 70%, since the stiffness of the all carbon laminate is very similar to that of the all glass, the curve is relatively flat.
The flexural strength when S/h = 64 for V_{fc} = 50% is shown in Figure 3. When V_{fg} = 30%, flexural strength decreases with increasing hybrid ratio. Most stacking configurations show negative hybrid effects except $[0_{2G}/0_{6C}]$. When V_{fg} = 50%, and V_{fg} = 70%, flexural strength peaks at $[0_{2G}/0_{6C}]$ and then decreases with increasing hybrid ratio. At these two glass fibre volume fractions, all the stacking configurations show a positive hybrid effect.

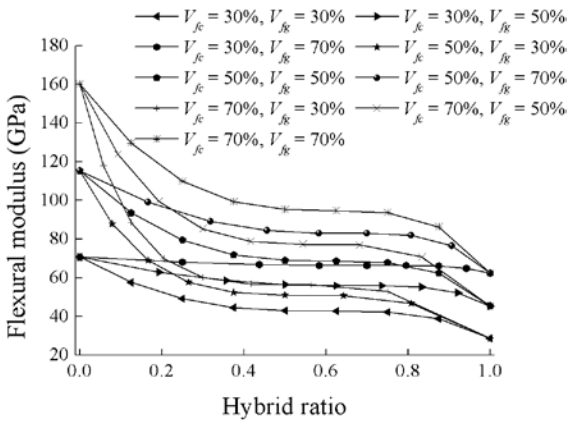

Figure 2: Flexural modulus vs. hybrid ratio for all the fibre volume fraction combinations

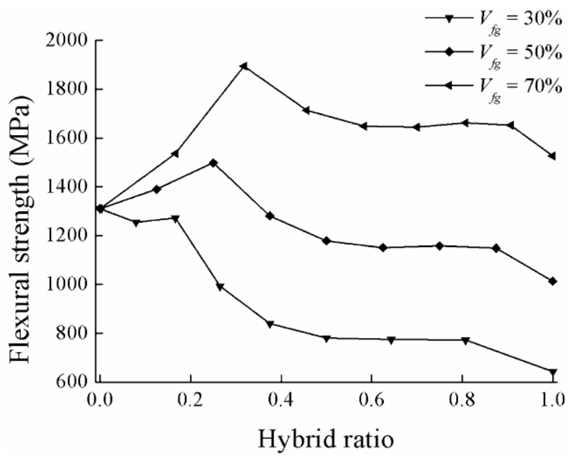

Figure 3: Flexural strength at S/h = 64 for V_{fc} = 50%

CONCLUSIONS

A simulation study on the flexural properties of hybrid composites reinforced by S-2 glass and T700S carbon fibres is presented in this paper. The effects of fibre volume fractions, hybrid ratio and span-to-depth ratio were studied using FEA. It is found that the flexural modulus vs. hybrid ratio displays an S curve for all the fibre volume fraction combinations. Flexural modulus increases when the span-to-depth ratio increases from 16 to 32 but changes little as the span-to-depth ratio further increases. The main conclusions from this study are:

1. For hybrid composites, the maximum flexural strength usually occurs at the $[0_{2G}/0_{6C}]$ stacking configuration.
2. A general rule is in order to improve flexural strength, the fibre volume fraction of glass/epoxy plies needs to be higher than that of carbon/epoxy plies.
3. The overall maximum hybrid effect, 37.34%, is achieved when the hybrid ratio is 0.318 ($[0_{2G}/0_{6C}]$) when V_{fc} = 50% and V_{fg} = 70%. The strength increases are 44.55% and 24.07% when compared with those of the full carbon and glass configurations respectively.

References

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