Fractography Study of Fibre Reinforced Epoxy Resin Composites

V. K. SRIVASTAVA

Department of Mechanical Engineering, Institute of Technology,
Banaras Hindu University, Varanasi–221005, India

ABSTRACT

In order to study the fractographs of the unidirectional carbon fibre reinforced epoxy resin, glass fibre reinforced epoxy resin, hybrid glass fibre, carbon fibre reinforced epoxy resin and zirconia filled glass fibre reinforced resin, a number of composite specimens were tested in tension. Once the specimens failed in tension, fractured surfaces were studied using a Scanning Electron Microscope (SEM). Scanning Electron Microscope studies revealed that the cracks generally start from resin rich areas and cracking of epoxy resin, debonding of fibres are arrested by zirconia particles, which increase the fracture energy of composite materials.

KEYWORDS

Glass fibre; carbon fibre; epoxy resin; zirconia oxide; Scanning electron microscopy

INTRODUCTION

Many materials used in practice are composite in that they are made up of two or more distinct substances which are not homogeneously mixed together. An example is fibre reinforced polyester resin, which consists of fibres embedded in a block of polyester resin; the resin is called the matrix of the composite material. A characteristic of many fibre reinforced composite materials, both natural and artificial is that the mechanical properties of the composite material are more favourable than those of homogeneous materials consisting of one or the other of the constituents alone. Guild and Silverman (1978) have studied the microstructure of glass fibre reinforced polyester resin composites. Two methods of analysis are presented. The first method involves the determination of the variance of the values of fractional area covered for different cell sizes. Information regarding the nature of the fibre distribution is sought both from comparing the variance values with those predicted for the null hypothesis, a random distribution and from examining the shape of a surface defined by a variance matrix. The second method of analysis is based on the concept that a structure may be defined by its relationship to a structuring element. Devilbiss et al. (1985) have studied the SEM fractography of fractured adhesively bonded graphite fibre reinforced polyimide composites. Scanning Electron Microscopy demonstrated a progressive shift from cohesive to adhesive failure for composites aged at elevated temperatures. Dean and Turner (1973) have also studied the elastic properties of carbon fibre reinforced plastic (CFRP) laminates. They found that the processing conditions while making CFRP laminates play a very important role in determining the microstructure of CFRP. Microstructure of CFRP in turn has a very significant effect on the mechanical properties of CFRP. Even a small quantity of voids can cause a marked reduction in the mechanical properties, in particular the strength of a composite (Thompson et al. 1973; Prakash, 1981; Nahas, 1985).

Beaumont (1974) also found that the energy required for creating new fracture surface is less than that predicted by the rule of mixture. Model of microscopic fracture behaviour, together with measurements of fibre debonded lengths and pull-out lengths are successful in quantitatively describing the observed fracture behaviour of the hybrid composites. However, the more brittle epoxy and tougher thermoplastic showed very dissimilar fracture surfaces for equal mixed mode ratios (Donaldson, 1985). Recently, sheet moulding compounds (SMC) have been widely used in structural applications. Watanabe and Yasuda, (1982) have reported that the cracking in composites made from SMC may be reduced by using a matrix with high failure strain. The purpose of the present research program is to understand the failure mode of different unidirectional composites under tensile loading.

EXPERIMENTAL WORK

Four different composites were used for the present study. These were glass fibre reinforced epoxy resin, carbon fibre reinforced epoxy resin, hybrid glass fibre-carbon fibre reinforced epoxy resin and zirconia filled glass fibre reinforced epoxy resin. Using a hand lay-up technique, a number of unidirectional composites were moulded. Commercially available, E-glass fibre, High modulus carbon fibre, zirconia powder (63 μ dia) and epoxy resin (Areldite, CY-205 and Hardner, HY-951) were used for making unidirectional composites. The value of fibre volume fraction of glass fibre reinforced epoxy resin, carbon fibre reinforced epoxy resin and hybrid glass fibre-carbon fibre reinforced epoxy resin was (47 ± 1.5) per cent. Hybrid glass fibre/zirconia/epoxy composites were prepared with E-glass fibre, zirconia (ZrO_2) and epoxy resin. The ratio of zirconia and epoxy resin was 0.25 by weight.

Using unidirectional composite sheets, tensile specimens were prepared according to the A.S.T.M. standard. Tensile tests were performed using a Instron Universal Testing Machine. From these testing data, relationships between stress and strain for different fibre reinforced epoxy resins (FRP) were obtained. The fractured specimens were out to 10 mm height from different composites, which failed under tensile loading and fastened to SEM mounting studs with metal clamps. To enhance the conductivity of the FRP composite specimens, a thin film of gold was vacuum-evaporated onto the specimens. After coating of the specimen, fractographs were obtained using PHILIPS PSEM-500 Scanning Electron Microscope.

RESULTS AND DISCUSSION

Stress-strain

The load-elongation curve obtained during mechanical testing of FRP composites yielded stress-strain curves for these FRP composites (Fig.1). It can be observed from these curves that for the same increase in stress, the resulting increase in strain (%) for zirconia filled glass fibre reinforced epoxy resin is greater than that for GRP, CFRP and hybrid glass fibre-carbon fibre reinforced epoxy resin. Presence of zirconia particles in the hybrid composite provides areas which may be considered as zirconia reinforced epoxy resin and this zirconia reinforced epoxy resin is weaker than GRP. Hence, at first zirconia reinforced epoxy resin fails and load values fall off. However, at this stage the glass fibres in the hybrid composite become strained and take-up the full load and the hybrid specimen starts to support increasing load once again till the fibres themselves fail giving rise to total failure of the hybrid composite. This explains the "yield-like" appearance in the stress-strain curve pertaining to zirconia filled glass fibre reinforced epoxy resin. In the case of hybrid glass fibre-carbon fibre reinforced epoxy resin also carbon fibres continue to take-up the load even after the failure of glass fibre and that is why a fall is indicated in the stress-strain curves for hybrid glass fibre-carbon fibre reinforced epoxy resin composites.

Fractographs

In case of fibre reinforced epoxy resin composites, internal material failure generally initiates much before any change in its macroscopic appearance. The internal material failure may be observed in many forms separately or jointly, such as breaking of the fibres, microcracking of the matrix, separation of fibres from the matrix (called debonding) and separation of laminae from each other in a laminated composite (called delamination). The model (Fig.2) shows several possible local failure events occuring during the fracture of a fibrous composite (Agarwal and Broutman, 1980).

The failure process described above is well in line with observation made using the SEM on the fractured surfaces of composite specimens. First, series of fractographs were taken on the unidirectional GRP composite; Figure 3(a) is a low magnification (X60) fractograph showing fibre pull-out. The fibre pull-out are usually accompanied by extensive matrix deformation, which is absent in fibre debonding (Agarwal and Broutman, 1980). The brittle type failure (or say cleavage failure) of the epoxy resin can be seen in Figure 3(b) at the magnification (X900). It was also found that the failure crack starts from a resin rich area and travels along the fibre direction till it meets a weak resin plane where it gets diverted into a crack path, which runs across the general fibre directions.

The second series of fractographs were taken on unidirectional CFRP composites. At higher magnification (X960) [Fig.4(a)], typical fibre pull-out and indentation marks due to departing fibres on fractured surfaces were observed. The fibres are separated from the epoxy resin when fracture takes place. When propagating cracks encounter strong fibres, the cracks branch away to run in different planes as can be seen in Figure 4(b) at the magnification (X950).

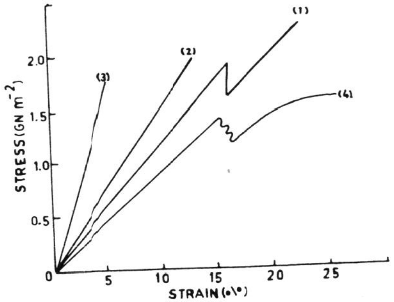

FIG.1. SCHEMATIC STRESS-STRAIN CURVES SHOWING- 1-HYBRID GLASS/CARBON FIBRE REINFORCED EPOXY RESIN, 2-GRP, 3-CFRP, 4-ZIRCONIA FILLED GRP COMPOSITE.

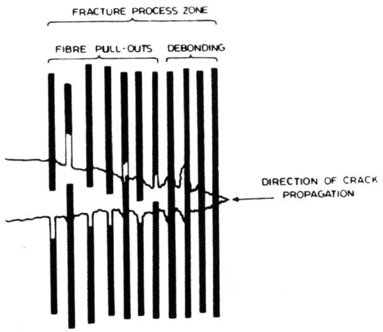

FIG. 2. MODEL OF CRACK TIP IN FIBRE COMPOSITE SHOWING LOCAL FAILURE EVENTS (AGARWAL, BROUTMAN, 1980)

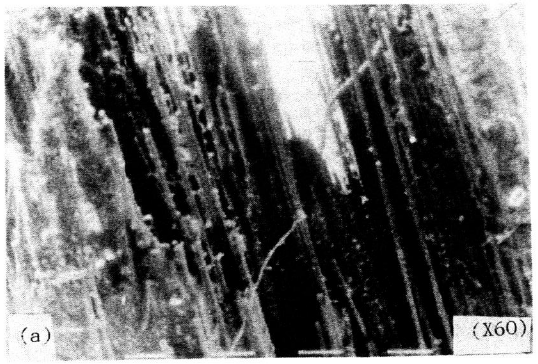

Fig.3. FRACTOGRAPHS OF THE UNIDIRECTIONAL GRP COMPOSITES

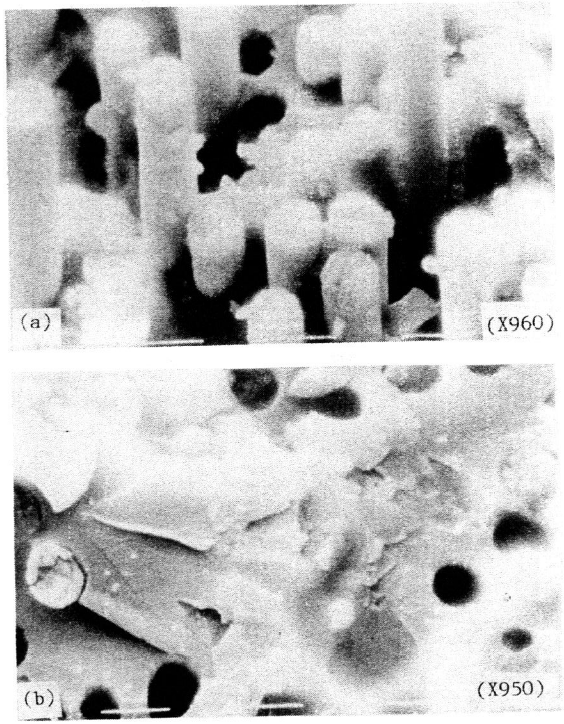

Fig.4. FRACTOGRAPHS OF THE UNIDIRECTIONAL CFRP COMPOSITES

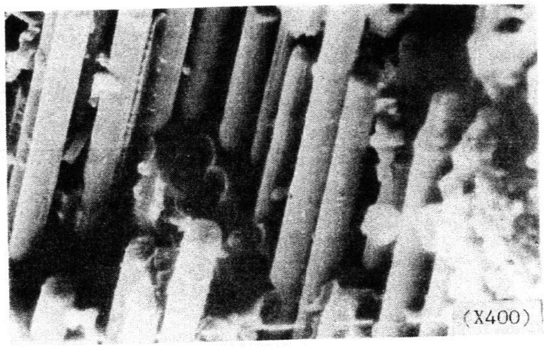

Fig.5. FRACTOGRAPHS OF THE HYBRID GLASS/ CARBON FIBRE COMPOSITES

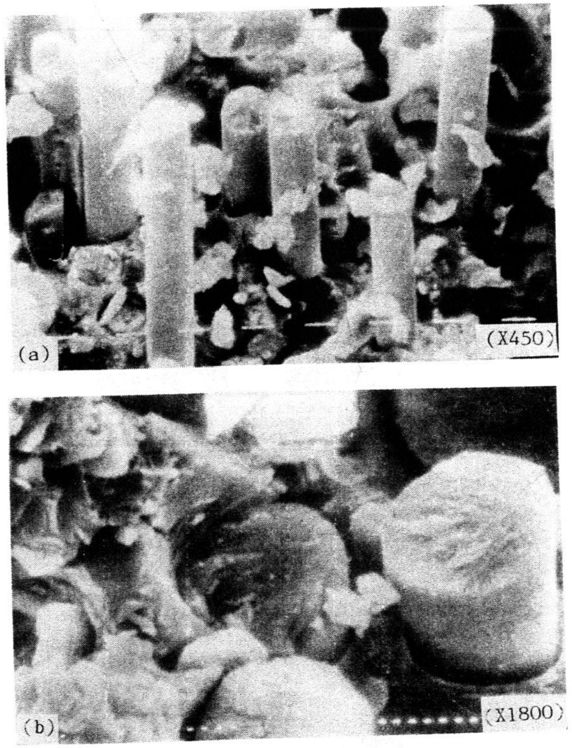

Fig.6. FRACTOGRAPHS OF THE ZIRCONIA FILLED GRP COMPOSITES

The third series of fractographs were taken on hybrid glass fibre-carbon fibre reinforced epoxy resin. Typical fibre pull-outs are observed even in this case as can be seen in Figure 5 at magnification (X400). It can also be seen that it is possible to distinguish between the two types of fibres because of their differential colour and interesting surface features associated with carbon fibres. Finally, Figure 6(a) at magnification (X450) shows that the zirconia particles can easily be distinguished from glass fibre and epoxy resin because of their very different feature. The typical fibre pull-out is observed even in such composites. The hole like appearance on fractured surface suggests that the coefficient of friction between zirconia particle and glass fibre is more than that between epoxy resin and glass fibre because the later situation has resulted in fibre pull-out. This fractograph also shows that zirconia particles help in arresting the path of debonding. Also, the cracking of epoxy resin is arrested by zirconia particles, thereby increasing the toughness of such composites. The crack arresting phenomenon can be observed in Figure 6(b) at the magnification (X1800).

CONCLUSION

Fractography studied show that the cracking of epoxy resin and debonding of fibre are arrested by zirconia particles, which increase the fracture properties (or say energy) of glass fibre reinforced epoxy resin. However, the tensile properties are not increased due to decrease in fibre volume fraction of GRP composites.

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