NOTES

Temperature Dependence of Tensile Properties of Composites Consisting of Carbon Fiber Tow in Thermosetting Polymers

INTRODUCTION

One of the prominent characteristics of fiber reinforced plastics (FRP) is higher resistance to crack propagation. However, stress is liable to concentrate at a fiber/matrix interface because of the difference in their elasticy and/or a contraction of a resin in curing. Therefore, when FRP is tensioned, debonding at the interface or a fiber failure occurs and this causes a gross failure of the composite. Many fracture mechanisms of FRP have been reported from different points of view. The fracture behavior of FRP at higher temperature is remarkably different from that at room temperature.[1–3]

We have investigated the fracture behavior of composites consisting of a single carbon fiber (CF) tow in thermosetting resins by means of tensile, bending, and fatigue tests. As the CF composites were tensioned in the fiber direction, fiber failure caused a gross failure of the composites.[4] In this note, the tensile properties of CF–epoxy and CF–polyester composites are reported as a function of temperature. The tensile fracture mechanism of these composites will be discussed.

EXPERIMENTAL

In the epoxy system, Epikote 828 (Shell's liquid diglycidylether of bisphenol A) was used with 11 parts per hundred resin (phr) of triethylenetetramine. The resin and cure reagent were mixed thoroughly and poured into a silicone-rubber mold holding a single carbon fiber tow (Torayca T-300A, 3000 filaments, Toray Ind., Inc.). After having cured for 24 hr at room temperature, the specimens were postcured for 30 min at 115°C. During the cure, the CF tow was kept in tension with a 100g load. In the polyester system, Epolac G-180 (Japan Catalytic Chem. Ind. Co. Ltd.) was used with 1.5 phr of 55% methyl ethyl ketone peroxide solution as an initiator and with 1.5 phr of 6% cobalt naphthenate solution as an accelerator. After having cured for 24 hr at room temperature, the specimens were postcured for 3 hr at 100°C.

Dimensions of the tensile specimens (CF composite) are shown in Figure 1. A single carbon fiber tow is located at the center of the cross section of the specimen. Tensile tests were carried out in an Instron testing machine at the crosshead rate of 0.5 cm/min, with 115-mm distance between the grips. At elevated temperature, the specimens were allowed to stand for 30 min before testing.

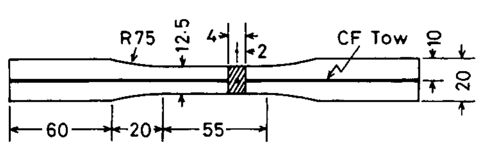

Fig. 1. Schematic diagram of tensile specimen, mm.

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RESULTS AND DISCUSSION

CF–Epoxy Composites

In Figure 2, the Young's moduli, ultimate elongations, and tensile strengths are plotted, respectively, as a function of the temperature for CF–epoxy composites and epoxy resin. The Young's moduli decreased with increasing temperature and the moduli of CF–epoxy composites were only slightly higher than those of the epoxy resin, over the temperature range of 23–130°C. The presence of a small amount of CF in the composites was responsible for higher values of the Young's moduli.

The ultimate elongation of the epoxy resin increased with increasing temperature; it increased enormously around 80°C because of a gross plastic deformation. That of the CF–epoxy composite, however, remained constant (about 2%) over this temperature range. On the other hand, the stress–strain curve of the CF tow indicated that a filament failure began to occur at about 2% elongation. These results suggest that a gross failure of the CF composite was caused by a fracture of the CF tow. Figure 3 shows the incipient crack propagating from CF tow into resin matrix at 110°C. This photoelastic pattern indicates stress concentrations around the propagating crack tips and the CF fracture points.

The tensile strengths of the CF–epoxy composites were smaller than those of the epoxy resin below 70°C. This result can be explained as follows: As the ultimate elongation of the carbon fiber is even smaller than that of the epoxy resin, a fiber failure occurs prior to the breakdown of the resin, if the bonding between the CF and the resin is sufficiently strong. In other words, a fiber failure generates a crack, which results in the breakdown of the resin matrix. The temperature at which the Young's modulus and the tensile strength of the CF–epoxy composite abruptly varied agreed with the heat distortion temperature of the epoxy resin.

CF–Polyester Composites

Stress–strain curves of the CF–polyester composites indicated that a fracture of the specimens occurred approximately within the elastic limit. At 110 and 130°C, debonding between the CF and

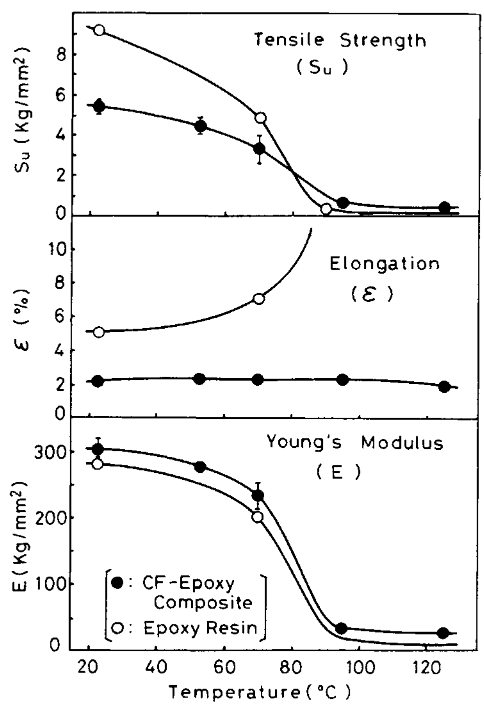

Fig. 2. Effect of temperature on tensile properties of CF–epoxy composites. (●) CF–epoxy composite; (O) epoxy resin.

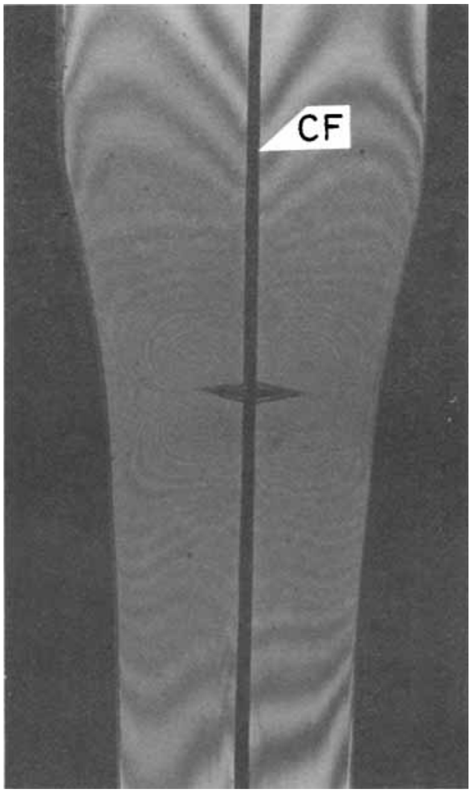

Fig. 3. Photoelastic photograph of CF-epoxy specimen having incipient crack çaused by fracture of CF tow.

the matrix took place, though in the case of the CF–epoxy composite this debonding was not observed. This is due to worse bonding between the CF and the polyester resin than that between the CF and the epoxy resin. Results of tensile tests are shown in Figure 4. The Young's modulus decreased with increasing temperature, and it is recognized that a small amount of CF enhanced the modulus of the CF–polyester composite. The ultimate elongation of the polyester resin increased with increasing temperature, whereas those of the CF–polyester composites remained almost constant (about 2%) over the temperature range from 23 to 130°C, as did the CF–epoxy composites.

The tensile strength of the CF–polyester composite and the polyester resin decreased with increasing temperature. At room temperature, the strength of the polyester resin was similar to that of the CF–polyester composite. It was observed that at 23°C a crack was generated both at the surface of the CF specimen and at the place where the CF was fractured. The temperature dependence of the tensile strength and the ultimate elongation of the CF–polyester composite were quite different from that of the CF–epoxy composite in that the CF–polyester system did not show any abrupt change in mechanical properties as observed in the CF–epoxy system. It was found that the temperature dependence of the tensile strength and Young's modulus was influenced mainly by the properties of the resin.

CONCLUSIONS

The ultimate elongation of thermosetting polymers increased with increasing temperature, but those of CF composites consisting of a single carbon fiber tow in thermosetting resins remained constant independently of temperature. Not only results as described previously, but also the appearances of the fracture surfaces suggested that a failure of the CF composite was initiated by the fracture of the carbon filaments and a crack propagated into the resin matrix from the CF. It was concluded that thermosetting resins are very sensitive to the fracture of the carbon fiber even at higher temperature.

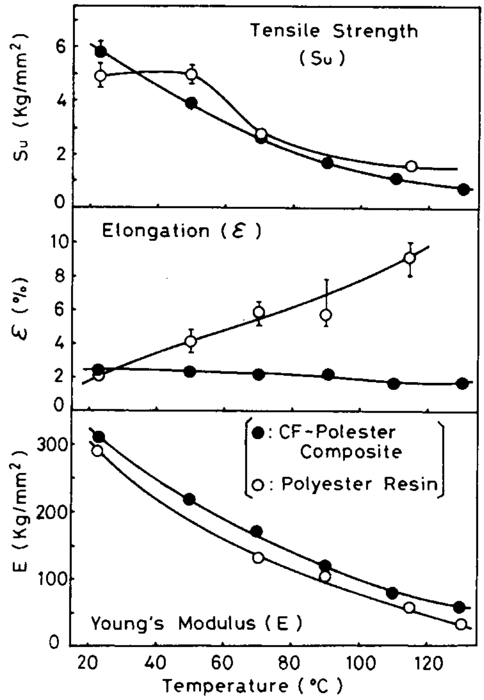

Fig. 4. Effect of temperature on tensile properties of CF–polyester composites. (●) CF–polyester composite; (O), polyester resin.

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