Lecture 8. Mechanical Properties of Grown Vapor-Grown Carbon Fiber (VGCF). Transport Properties of VGCF. Applications of VGCF

The purpose of the lecture: to give information about the mechanical properties of grown vapor-grown carbon fiber (VGCF), transport properties and applications of VGCF.

Expected results: to be able to explain the mechanical properties of grown vapor-grown carbon fiber, its transport properties and applications.

Carbon fibers customary fail in a brittle fracture. The mode of fracture of the as-produced VGCF is very much like the brittle failure of PAN and pitch based carbon fibers. During this fracture the fiber may even explode in the microtensilometer, and special precautions are necessary to preserve the remainder of the sample in order to examine the mode of fracture. However, the nested basal plane structure of VGCF, particularly when the fibers are graphitized above 1100°C, may slow down the fiber with a “pull out” failure observed in a vapor-grown fiber heat treated to 2200°C. Figure 1 shows tensile failure of the VGCF graphitized to 2200°C. Under the applied tensile load, a surface-initiated crack that is arrested after penetration only a short distance in the fiber may rapidly propagate around the circumference. A series of such events may conclude with thin cylinders of graphite telescoping to increasing length, gradually decreasing the load-bearing capability of the fiber under slowly increasing applied strain. After complete shearing of the fiber, the nesting layers may wedge together as further strain is applied, and continue to support some load.

VGCF has desirable mechanical properties, although it is produced at the relatively low temperature of around 1100°C. The product has almost the same properties whether it is made from benzene or methane. Figure 2 presents the dependence of the tensile strength and modulus of elasticity of the methane-derived VGCF on fiber diameter. Its tensile strength is comparable to that of commercial carbon fibers, and it can be enhanced to as high as 7 GPa when the fiber is graphitized at 2200°C.

Transport Properties of VGCF

VGCF has higher electrical and thermal conductivity than any other fiber; its electrical resistivity at room temperature is 10 Ч 103 μΩ.cm. When it is heat treated at 3000°C, its thermal conductivity at room temperature is about 4 times higher than that of copper.

Electrical Conductivity

Figure 3 shows measurements of the electrical resistivity of as-produced VGCF and also heat treated at 2000°C and 3000°C, respectively. The resistivity of the 1100°C material as grown, 2 Ч 10–5 Ω.m, is virtually independent of temperature. It is therefore not surprising that the electrical industry has used vapor-deposited carbon resistors for many years.

Heating the fibers at higher temperature results in the expulsion of heavier hydrocarbons, near 2000°C when graphitization begins resulting in an increase in conductivity. At higher temperatures these plots approach the behavior of single-crystal graphite with a 300 K resistivity of about 5 Ч 10–7 Ω.m. According to Hermans the fibers are semimetal with equal numbers of electrons and holes and a 40 meV overlap between the electron and hole band.

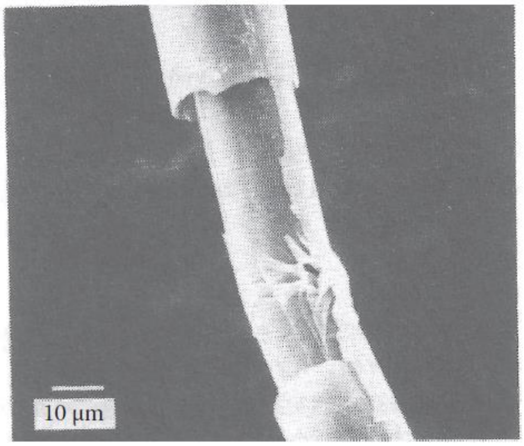

FIGURE 1. Fracture behavior of VGCF. Unlike PAN and pitch-based carbon fiber, which has britle failure, the VGCF that has been heat treated to 2200°C instead shows “sword and sheath (pull out)” noncatastrophic failure due to its annular microstructure

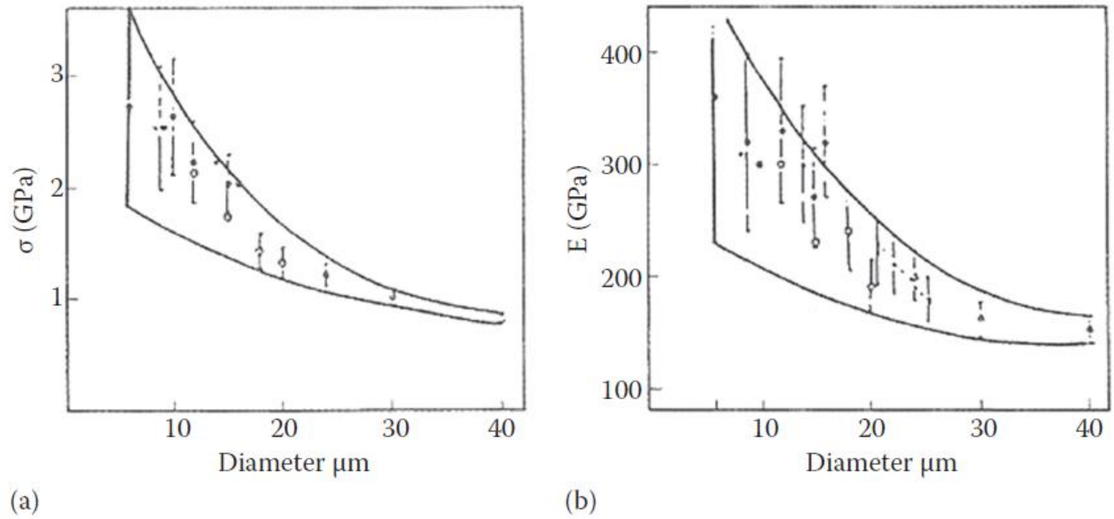

FIGURE 2. Dependence of tensile strength (σ) and (b) modulus of elasticity (E) of VGCF on fiber diameter

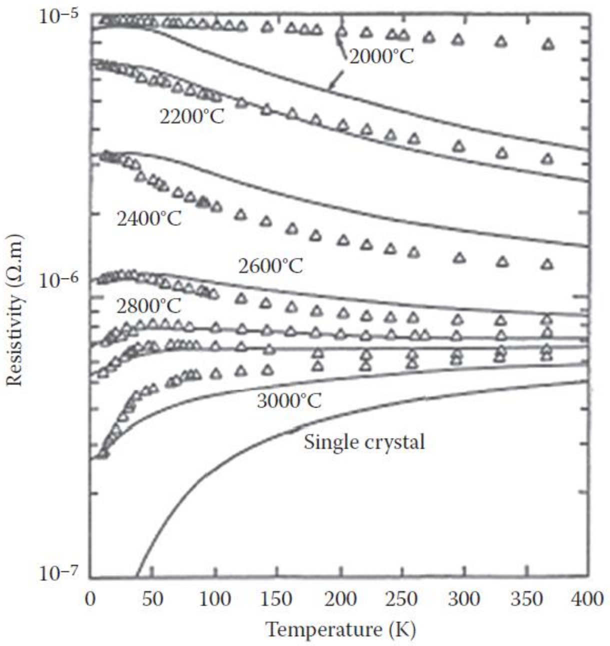

FIGURE 3. Model (solid lines) and experiment (points) for temperature-dependent resistivity of carbon fibers HTT at various temperatures. The bottom solid line is the calculated curve fitted to the resistivity of single-crystal graphite.