

THE STRENGTH AND STIFFNESS OF VAPOR-GROWN CARBON FIBER/THERMOPLASTIC COMPOSITES

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INTRODUCTION

Vapor-grown carbon fibers (VGCFs) are produced catalytically on metallic (typically iron) particles from gaseous hydrocarbons [1]. It is known that the catalytically grown filament is quite graphitic (over 80% of the (002) X-ray peak at 0.335 nm), while the pyrolytic carbon subsequently deposited around the filament core is less graphitic (20% at 0.335 nm) [2]. This fact as well as indirect measurements made on the fiber [3] indicate that VGCFs possess a quite high modulus. Furthermore, direct measurements on fibers grown to macroscopic dimensions (which should be less graphitic than their microscopic counterparts) yield a strength value of 2.92 GPa and a tensile modulus of 240 GPa [4]. Therefore, there has been recent interest in investigating the potential of VGCFs as composite reinforcements [5,6].

In order for these fibers to be grown economically, the catalyst particles, and thus the fibers, must flow through the reactor with the reacting gas [7]. As a result of this continuous processing, the fibers emerge from the reactor in a highly entangled state. Furthermore, the bulk density of the mass of fiber that emerges is very low. For these reasons, conventional composite fabrication techniques can be difficult or impossible to apply to VGCFs.

EXPERIMENTAL

The fibers used in this study were approximately 0.2 μm in diameter and were formed by iron catalyst particles in a methane atmosphere. Fibers of two types were used; "As-grown" fibers were not heat-treated in any way after removal from the reactor and, therefore, contained condensed poly-aromatic hydrocarbons on their surfaces, while "Baked" fibers were heated in flowing nitrogen at 500°C to remove most of this condensed material and provide a cleaner surface.

Injection molding of mini-tensile specimens (ASTM Test Method D638 Type V) using VGCF/nylon and

VGCF/polypropylene (PP) was performed using a benchtop CSI MiniMAX Molder. The apparatus is equipped with a rotor which may be submerged into a 12.7 mm diameter heated cup. Mixing is imparted by the rotary as well as by the vertical motion of the rotor. The cup temperature was maintained at 310°C for nylon and 230°C for PP. The mold was held at 200°C for nylon and at room temperature (23°C) for PP samples to inhibit crystallization. The resulting specimens were mounted in the grips of an MTI tensile testing machine and were stretched at 1 mm/min until failure occurred.

RESULTS AND DISCUSSION

Figure 1 illustrates the dependence of tensile strength and modulus on fiber content for the two types of VGCF in nylon. The results show a distinct drop in tensile strength with increasing fiber fraction. The tensile modulus appears largely unaffected by the addition of fibers. The results also indicate only a slight improvement when fibers with a cleaner surface are used. The results for VGCF/PP composites are much more encouraging (Figure 2). The addition of 11.5% fiber approximately doubles the tensile modulus of pure PP, without the drop in strength that was observed for VGCF/nylon specimens. Again, no great improvement was noticed in the properties of samples made from fibers with a relatively clean surface.

These results indicate that the nylon was not able to completely infiltrate the network of VGCF under the conditions of these experiments. This argument was supported by SEM micrographs showing dry areas of fiber on the fracture surfaces of VGCF/nylon specimens. Polypropylene, by contrast, seems to be more easily dispersed in the VGCF, yielding composites with considerably improved modulus.

CONCLUSIONS

These results underscore the importance (and difficulty) of adequately dispersing the molten polymer throughout VGCFs prior to injection molding of thermoplastic composites. This problem seems significantly more severe with nylon than with PP. This infiltration effect overshadows any influence of fiber surface condition on the composite properties. Thus, in order to produce composites with optimal properties, careful attention must be given to the method of mixing the fiber and polymer.

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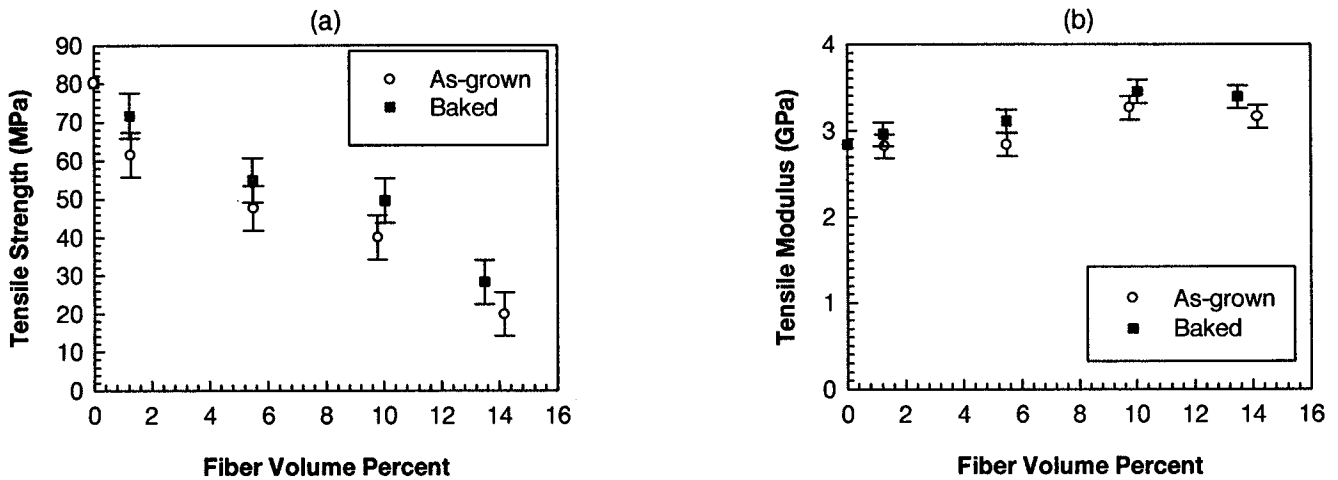


Figure 1. (a) Tensile strength and (b) tensile modulus vs. fiber volume percent of VGCF/nylon composites.

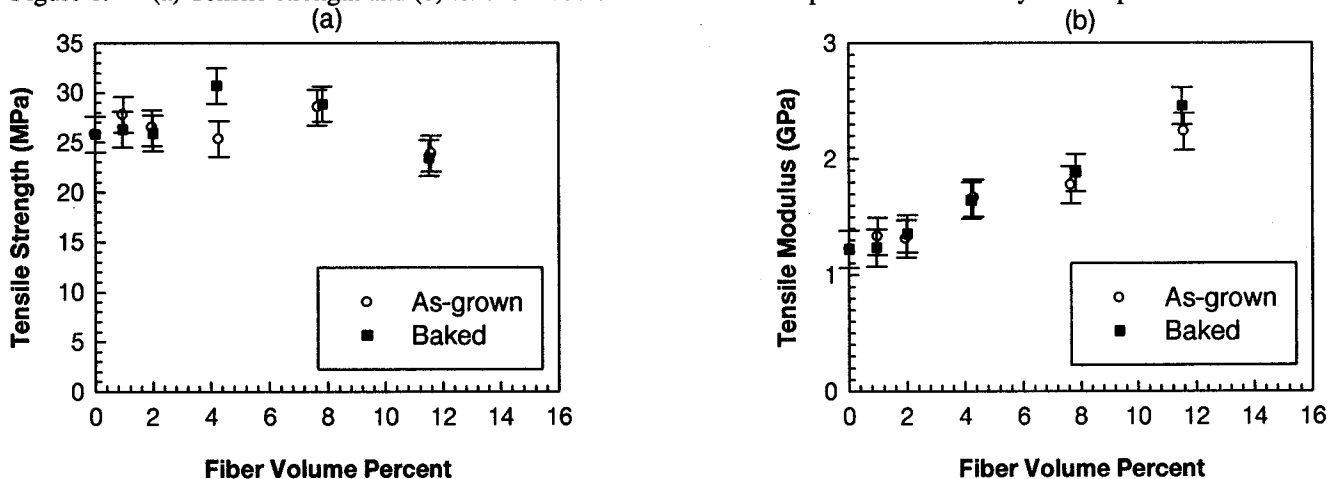


Figure 2. (a) Tensile strength and (b) tensile modulus vs. fiber volume percent of VGCF/PP composites.