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Evaluation of fiber surface treatment on the interfacial behavior of carbon fiber-reinforced polypropylene composites

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ABSTRACT

Carbon fiber reinforced polypropylene (CFRPP) has been widely used in many engineering fields because of its high specific strength and stiffness. However, polypropylene (PP) does not adhere well with carbon fibers because it has a low free surface energy. In addition, high viscosity in the melted phase causes poor impregnation. In this study, surface treatment methods, i.e., coupling agents with plasma treatment on carbon fibers, were applied to increase the interfacial strength between the carbon fibers and the PP matrix. The modified carbon fiber surfaces were analyzed by X-ray photoelectron spectroscopy (XPS) and scanning electron microscopy (SEM). To analyze the effectiveness of the surface treatment method, the interlaminar shear strength (ILSS) was measured using the three points bending test. From the test results, the ILSS of the specimens treated with the silane coupling agent after the plasma treatment increased by 48.7% compared to those of the untreated specimens.

1. Introduction

As environmental awareness gradually increases, thermoplastic polymers attract increased attention as a matrix for composite materials because of their recyclability and easy processability. The range of application for these polymers is also increasing, finding applications in everything from automobile parts to sports equipment [1–3]. Among various thermoplastic polymers, polypropylene (PP) is one of the more promising materials for the matrix because of its high flexural strength, low density and low price [4–6]. Carbon fiber reinforced PP (CFRPP) has been widely used in many engineering fields because of its high specific strength and stiffness. However, PP exhibits poor interfacial adhesion with carbon fibers (CF) because of low surface energy and a chemically inert surface. In addition, in its melted phase PP is very viscous and has difficulty impregnating dry fiber structures, such as fabrics. In that case, interfacial debonding is occurred by weak interfacial strength between the carbon fiber (CF) and PP. Therefore, various approaches have been investigated to increase the interfacial adhesion between the CFs and PP [7–9].

The functionalization of PP with polar molecules is the most attractive method to improve adhesion and compatibility [10–12]. However, the functionalization of PP such as maleic anhydride grafted PP leads to a decrease of the molecular weight. If the molecular weight of the PP becomes too low, the functionalized PP becomes quite brittle with reduced strength and stiffness [13].

The surface treatment of the fiber is another way to increase the interfacial adhesion except the functionalization of resin. Several techniques for surface treatments on fibers have been applied to improve the interfacial strength such as wet oxidation, sizing, whiskerization, thermal treatments, and coupling agent treatments. These surface modification methods either enhance the number of reactive functional groups or increase the surface roughness of the fiber to increase the physical bonding with the matrix. Coupling agent treatment is one of the most common methods for fiber surface treatment [14–16]. Silane coupling agents (CAs) improve interfacial strength between the glass fibers and the matrix. Cho et al. found that the interlaminar shear strengths of glass fabric/nylon 6 composites sized with various silane coupling agents were significantly improved compared with that of the commercially sized composites [17]. Gironès et al. investigated the effect of silane CAs on the properties of pine fibers/polypropylene composites [18]. Silane CAs form alkoxysilane groups, which, after hydrolysis, are capable of reacting with hydroxyl groups on the surface. There is a wide range of available functionalities for the organofunctional group. This organofunctional group is responsible for improving the compatibility between the reinforcing material and the polymer matrix, and can also establish covalent bonds between them. The interpenetrating polymer network that is formed between the organofunctional group of silane and the polymer matrix increases the interfacial strength in the case of thermoplastic resin, which is a difficult chemical-bonding material. An interpenetrating polymer network is defined as a blend of two physically cross-linked polymers. Fig. 1 shows interpenetrating polymer network structure created by the silane CA at

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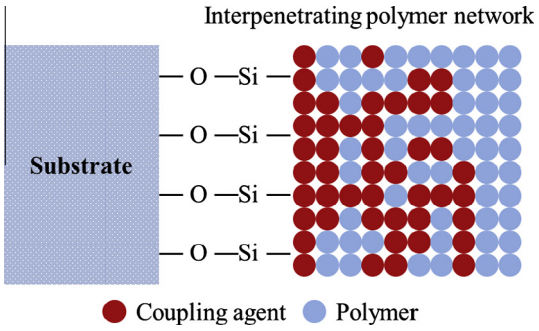

Fig. 1. Interpenetrating polymer network structure created by the silane CA at the interphase between the substrate and the polymer matrix.

the interphase between the substrate and the polymer matrix. It does not necessarily involve cross-linking of the silane or other coupling agent and the polymer matrix [19].

However, the silane CAs are not effective when applied to CFs because the CF does not contain a hydroxyl group [20]. However, the hydroxyl group can be attached on the fiber surface by plasma and wet chemical or electrochemical oxidation treatments. Shi et al. found that short CFs, which oxidized with nitric acid and then treated with silane CA, reinforced PTFE composites had better mechanical properties than untreated CF composite with the same content of CFs [21]. Wet chemical oxidation, however, produces environmental pollutants and the fiber must be thoroughly washed to remove by-products after treatment [20,21]. On the other hand, the plasma treatment is the simplest method and does not generate as many byproducts as the others. The plasma oxidation treatment often leads to the introduction of polar groups. Researchers have confirmed with XPS measurements that this may occur, even when using inert gases [22–24]. Park et al. found that plasma treatment led to a large quantity of reactive functional groups added to the CF surface [25].

In this study, the effect of a combined silane-CA/plasma treatment at atmospheric pressure on CFs in a PP composite matrix reinforced with CF fabrics was investigated. The surface morphology and mechanical properties of CFs treated with plasma and a silane CA surface treatment were characterized by a scanning electron microscope (SEM) and single filament tensile tests. The surface composition change of the CF surfaces with respect to the plasma treatment was investigated by X-ray photoelectron spectroscopy (XPS). The interlaminar shear strength (ILSS) of the

Table 1
Various surface treatments using plasma and silane CA.

Specimen	Surface treatment	
	Plasma	Silane CA
U-0	–	–
U-P30s	30 s	–
U-P1min	1 min	–
U-P3min	3 min	–
S-0	–	1 wt.%
S-P30s	30 s	1 wt.%
S-P1min	1 min	1 wt.%
S-P3min	3 min	1 wt.%

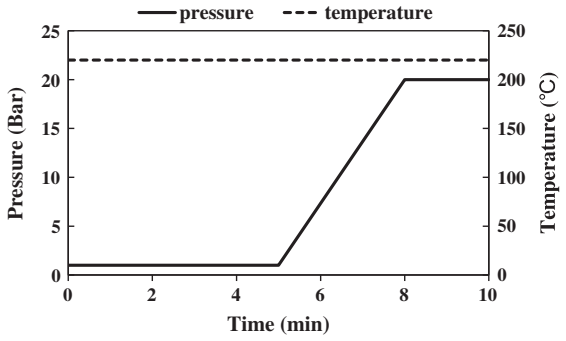

Fig. 3. Pressure–temperature–time diagram of the molding cycle.

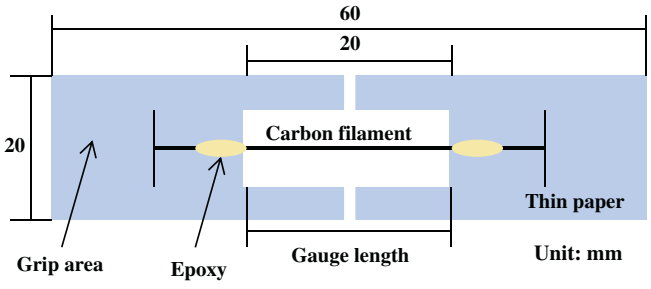

Fig. 4. Single filament tensile test specimen.

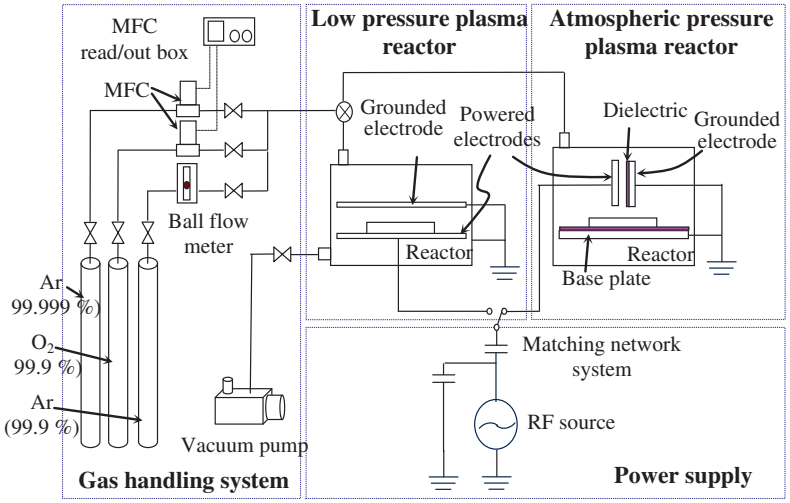

Fig. 2. Plasma surface treatment system.