

# The Effect of Carbon Fibre Reinforced on Polyamide1012

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## Abstract

A series of composites of carbon fibre-reinforced polyamide1012 (PA1012) were prepared which the carbon fibre content was from 5% to 40%. Their thermo-mechanical properties and fracture morphology were characterized by means of thermogravimetric analysis (TGA), a microcomputer-controlled electronic universal tester, and Scanning Electron Microscopy (SEM), respectively. The results showed that the initial decomposition temperature of the composite was above 400C. With the increase in carbon fibre content, the tensile strength and elastic modulus of the composites were improved. When the carbon fibre content was 15%, it was found that the maximum values of tensile strength and elastic modulus were 87.01 MPa and 438.31 MPa, respectively. The images of SEM showed that the surface modified carbon fibre was superior to original carbon fibre. It was also observed that the surface of modified carbon fibre had some particles that may have contained the ester group, which could have improved the interfacial bonding strength.

*Keywords:* Carbon Fibre; PA1012; Composite; Thermo-mechanical Properties

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## 1 Introduction

PA1012, which has a high-carbon alkyl group, was used to replace the metal material because of its numerous advantages, such as lower water absorption, stable size, high strength and good toughness. It is widely used in machinery, automobiles, the military, aerospace and other fields [1]. Thus, improving its mechanical properties was the main focus of current research. Zhou et al. [2] used acrylate polymer, grafted by glycidyl methacrylate (ACR-g-GMA), to improve the toughness of PA1012. When the ACR-g-GMA content was 9%, the notch impact strength reached the maximum value which was 3.8 times as high as that of PA1012. But the tensile strength decreased by about 18%. Xu et al. [3] used styrene-maleic anhydride (SMA) to reinforce the copolymer PA1012 and acrylonitrile butadiene styrene (ABS). The blends were prepared by using melt blending method. It was found that when the content of SMA was 5% and ABS content

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was 50%, the PA1012/ABS/SMA blend had the optimal impact strength. With the increase of the SMA content, the crystallization temperature of the blend would increase and then decrease. There are hardly fibre materials which were used to reinforce the PA1012.

Carbon fibre is a new type of material, which has high strength and modulus. It also has other excellent properties, such as like low density, low coefficient of thermal expansion and good heat resistance. Carbon fibre is usually used as reinforced material because of its outstanding performance in aircraft manufacturing, national defence, military industry, automobile, medical equipment, sport equipment and so on [4]. The surface of original carbon fibre is non-polar because of the copious presence of inert graphite crystallite [5, 6]. This structure resulted in bad wetting properties and interfacial bonding properties with the resin. There were three ways to modify the surface of carbon fibre. One was to introduce active functional groups, such as carbonyl, carboxyl and hydroxy, to enhance the wetting properties and bonding capacity [7]. The second was to sculpture some groove on the surface of the carbon fibre to increase the specific surface area for the sake of forming a mechanically interlocked structure with the resin [8]. The third was to remove the weak interface layer on the surface of the fibre. Yang et al. [9] used carbon fibre, modified by a silane coupling agent, to reinforce the epoxy and found that the interlaminar shear strength increased by about 42%, and the wetting properties were also improved. Yu et al. [10] used potassium peroxydisulphate ( $K_2S_2O_8$ )/silver nitrate ( $AgNO_3$ ) to treat the surface of the carbon fibre. The results showed that the interlaminar shear strength increased by 62.5%, while the surface was not destroyed. This was a pleasing outcome.

The thermoplastic resin reinforced by carbon fibre is one of the main materials of interest to current researchers all over the world [11, 12, 13, 14]. The composite can also be recycled because of the thermoplasticity of the resin. Zhang et al. [15] used carbon fibre to reinforce the PA6T/66 copolymer. The composites were prepared by the melt blending technology using a twin-screw extruder. The results revealed that carbon fibre reinforcements enhance the tensile strength and bending strength.

Fibres used to reinforce materials have been significantly applied in many fields [16, 17, 18]. In our study, we used carbon fibre, whose surface was modified to reinforce PA1012, with a view to obtaining some composite materials (C/PA1012). We wanted to find the influence factors of the thermal and mechanical properties of these reinforced materials.

## 2 Experimental Section

### 2.1 Materials

Carbon fibre (T700) modified by polyvinyl acetate (PVAc) was purchased from the Toray Company in Japan. PA1012 was procured from Shandong Guangyin New Material Company. Aluminium foil was obtained from Tianjin Angesi Steel Trade Company.

### 2.2 Preparation and Characterization

The composite materials of carbon fibre and PA1012 were prepared by a two-step process. First, carbon fibre and PA1012 were mixed in the Haake Rotational Rheometer (RheoDrive 7), which was purchased from ThermoFisher Scientific Co., Ltd., for about 10 min by varying the percentage

of carbon fibre content by 5%, 10%, 15%, 20%, 30% and 40% respectively. The temperature of the Banbury mixer was set at 210 °C and the rotate speed was set at 30 r/min. In subsequent steps, the mixture was put into the tablet press, which was obtained from Shanghai Xima Weili Rubber and Machinery Co., Ltd., to cut it into a tablet under 30 MPa of pressure. Then, the composite tablet was cut into a standard spline whose effective length, width and thickness were 20 mm, 5 mm and 1 mm, respectively.

The mechanical property of the composite materials were tested with a stretching rate of 50 mm/min using the WDW-20E Microcomputer-controlled Electronic Universal Testing Machine, manufactured by Jinan Shidai Shijin Testing Machine Group Co., Ltd. The TGA of the PA1012 and composite materials were performed by using a TG 209F1 from Netzsch Scientific Instruments Trading (Shanghai) Ltd. The samples were run at 10 K/min for the heating rate and 20 K/min for the cooling rate in an ambient temperature up to 600 °C, under the atmosphere of which the shielding gas and sweeping gas were respectively 20 mL/min and 50 mL/min. The Infrared absorption spectrum of original and modified carbon fibre were tested by Fourier transform infrared spectroscopy (FTIR) Tensor-27 instrument produced by Buker Optics Company in Germany, and the diffuse reflection method was used. The microcosmic surface and cross section of the carbon fibre and composites were observed using the JSM-6510LV SEM, manufactured produced by Questar China Ltd.

### 3 Results and Discussion

#### 3.1 Mechanical Properties of Composites

The mechanical properties of C/PA1012 composite materials containing various percentages of carbon fibre were shown in Fig. 1. From the graph (a) and (b) in the Fig. 1, it could be seen that the tensile strength and elastic modulus of the composite materials were increased along with the increase in carbon fibre content at the beginning. When the percentage rose beyond 15%, there was no remarkable improvement. The tensile strength and elastic modulus were increased 30% and 40%, compared with pure PA1012. Thus, the optimum result was found with regard to 15% of carbon fibre in C/PA1012. However, when the content of the carbon fibre rose beyond 15%, the tensile strength and elastic modulus were decreased sharply. Thus, we could say the tensile

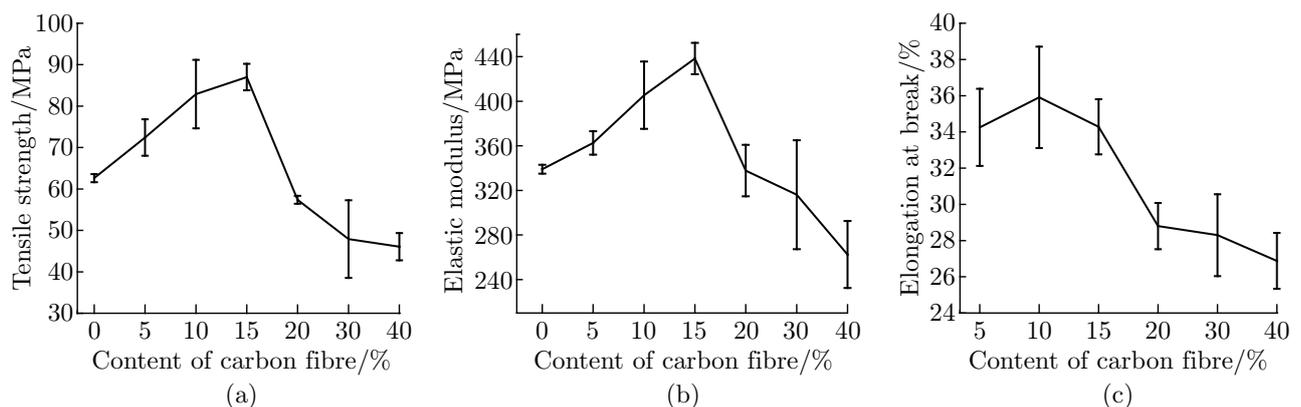


Fig. 1: The mechanical properties of C/PA1012 composite materials

strength and elastic modulus were poorer than for pure PA1012 when the content of the carbon fibre was over 15%. The dispersion uniformity and the saturability of the bonding became poor when the resin was filled with lots of carbon fibre. The space between the carbon fibres lacked the resin for sufficient bonding. This caused micro crack defects in the composites. When under a tensile force, the extension of the micro crack led to decreasing afford ability. The result observed at the macro level was a decrease in tensile strength and elastic modulus. As for elongation at the break, the value of this physical quantity also decreased with the increase in carbon fibre content. The toughness of the composite material declined indirectly.

### 3.2 TGA

The temperature of the initial decomposition in pure PA1012 and 15% C/PA1012 was about 400 °C. In Fig. 2, compared with pure PA1012, which the maximum decomposition temperature was 450.2 °C, and the mass loss was 96.57%, the maximum decomposition temperature of 15%C/PA1012 was raised to 467.1 °C, while the mass loss was 87.93%. Hence, the maximum decomposition temperature was improved a little by adding carbon fibre. Thus, carbon fibre improved the heat resistance of the composite material.

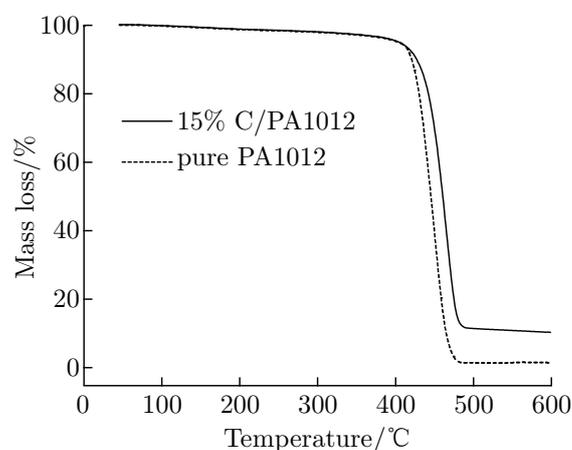


Fig. 2: The TGA of pure PA1012 and 15%C/PA1012

### 3.3 FTIR Analysis

The FTIR spectrum of the original and modified carbon fibre is shown in Fig. 3. A strong absorption peak was observed at  $1662.34\text{ cm}^{-1}$ , which refers to the strong stretching vibrations of the carbonyl (C=O) functional group. The band at  $1,230.36\text{ cm}^{-1}$  was identified as stretch vibrations of the C—O—C bond, while the bands at  $2917.77\text{ cm}^{-1}$  and  $2850.27\text{ cm}^{-1}$  were respectively identified as stretch vibrations of methyl (—CH<sub>3</sub>) and methylene (—CH<sub>2</sub>). As for the absorption peak at  $3357.46\text{ cm}^{-1}$ , this represented the characteristic absorption band of hydroxy (—OH) in the water contained in the fibre. The original carbon fibre was modified by the polyvinyl acetate (PVAc). IR spectroscopic study confirmed the existence of PVAc in the modified fibre.

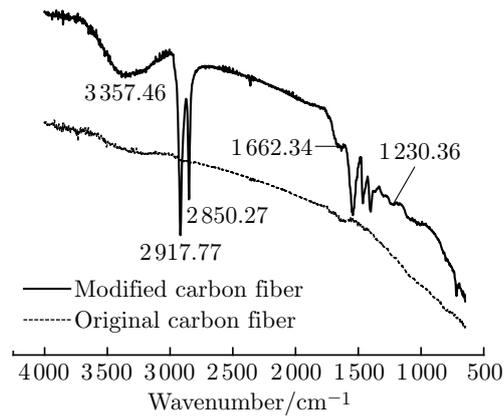


Fig. 3: FTIR spectrum for original carbon fibre and carbon fibre modified with polyvinyl acetate

### 3.4 Surface Morphology

The surface morphology of pure carbon fibre and surface-modified carbon fibre were shown in Fig. 4. It was already known that carbon fibre must be modified by a surface treating agent before being added to the resin. In Fig. 4, there were many small particles in the modified fibre's surface, compared to the carbon fibre that was without modification by PVAc. The particles were adhered to the surface of the carbon fibre, which contained PVAc with an ester group. This was performed in order improve the interfacial bonding strength and relieve the internal stress. This different structure could be observed in Fig. 4, which showed that many modified fibres were bonded together.

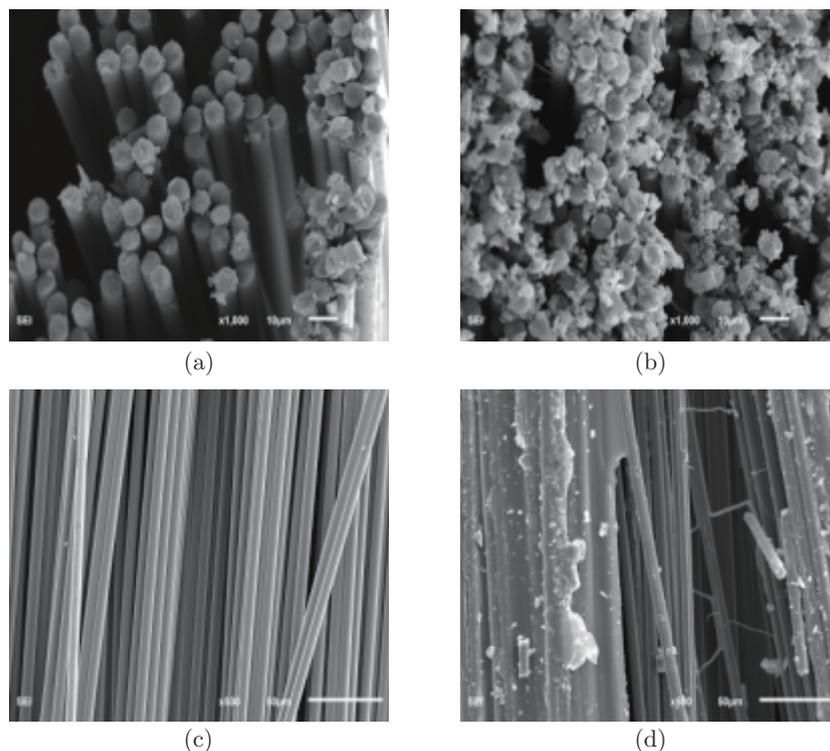


Fig. 4: SEM of carbon fibre: (a) cross section of original carbon fibre, (b) cross section of carbon fibre modified by PVAc, (c) surface of original carbon fibre, (d) surface of carbon fibre modified by PVAc

Fig. 5 demonstrated the SEM of surface and tensile fracture morphology for pure PA1012 and 15% C/PA1012. We observed from Fig. 5(a) that the carbon fibre was tightly packed by the pure PA1012. This explained the smooth surface of the composite material. It was also found that the carbon fibres were arranged irregularly to make a mesh structure within the composites, thus improving the tensile strength and elastic modulus of the composite material. The fracture behaviour of pure PA1012 during the tensile test was shown in Fig. 5(b), which was explained by the orientation of the fibre within the composites stretched during the tensile test. In Fig. 5(c), the carbon fibre was packed by PA1012 in order to improve the performance of the composite. Given the high strength and modulus of the carbon fibre, it could bear higher pressure than pure PA1012. When the composite material was under pressure, the force was transmitted from the matrix to the reinforcement in order to disperse the pressure.

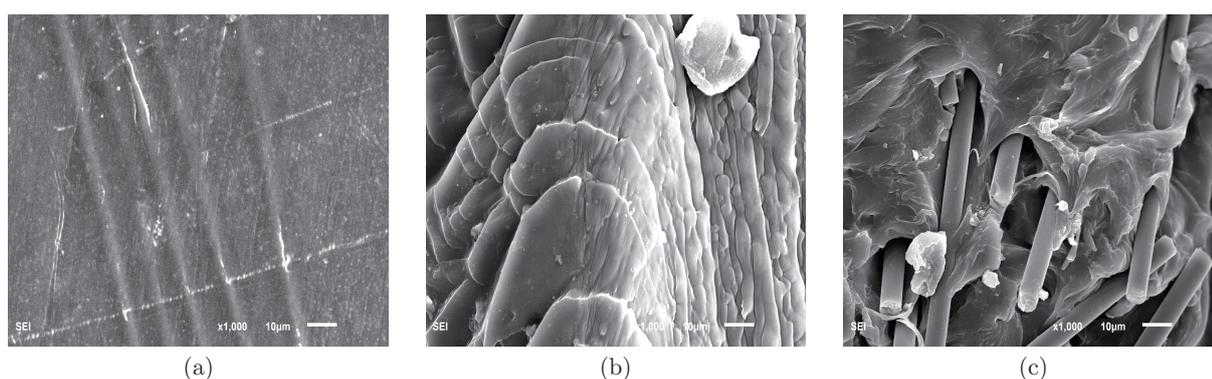


Fig. 5: SEM of pure PA1012 and 15% C/PA1012: (a) surface of 15% C/PA1012, (b) cross section of pure PA1012, (c) cross section of 15% C/PA1012

## 4 Conclusion

The thermal and mechanical properties of C/PA1012 composites were improved by mixing carbon fibre with PA1012 using melt blending method. The experimental data obtained in this work proved that the fastest decomposition temperature of the composite was above 467.1 °C, which was higher than for pure PA1012. It was also found that, with the increase in carbon fibre content, the tensile strength and elastic modulus of the composites increased up to a certain limit. For a 15% carbon fibre content, the maximum values of tensile strength and elastic modulus were found to be 87.01 MPa and 438.31 MPa, respectively, which 30% and 40% higher than for pure PA1012, also respectively. Based on the performances of surface-modified carbon fibre, we can say that PVAc in modified carbon fibre not only improves the interfacial bonding strength, but also relieves internal stress.

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