DEVELOPMENT OF HIGH-STRENGTH/LIGHTWEIGHT HEATING COMPOSITE BOARD MADE OF CARBON FIBER WASTE

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Abstract
In concerning of superior mechanical properties and good electrical conductivity of carbon fiber, we try to mold the high-strength/lightweight heating composite board by extruding molding method. The waste of carbon fiber was used as a raw material for molding. The strip-shaped composite board was obtained by extruding molding and the mechanical properties and heat generation property were examined by bending test and temperature measurement, respectively. From the results, it was cleared that the bending strength and modulus increases with increasing the content of carbon fiber and take peak values at 30~40wt% of carbon fiber content. Meanwhile, the electrical resistance decreases suddenly at 20~30wt% of carbon fiber content and the notable temperature rise occurs above this content value under the condition of turning-on-electricity state.

1. Introduction

In recent years, increased emphasis has been placed on developing recycling techniques for industrial and post consumer wastes, with the goal of protecting the environment. For example, textile and plastic industries have taken a growing interest in developing a system for recycling the waste plastics (including composite materials) and textile products [1,2]. However, because of lack of effective recycling technique, most of these wastes are currently destroyed by fire or buried underground.

Meanwhile, to meet a wide variety of recent engineering requests, research has focused on the development of new materials. In particular, much attention has been focused upon developing of fiber-reinforced multifunctional composites such as CFRP (carbon fiber reinforced plastics). And also the attention has been shifting from thermosetting composites to thermoplastic composites because of the higher recyclability of thermoplastic matrix resins [3].

In this report, we paid our attentions to the superior mechanical properties and good electrical conductivity of carbon fiber. Namely, we tried to mold the high-strength/lightweight heating composite board by extruding molding from the carbon fiber and PP (polypropylene). Here, the carbon fiber may reinforce PP resin and enhance the mechanical properties of obtained board may increase. And also, with certain content of carbon fiber, the board may be electro conductive material, so it may produce heat of turning-on-electricity state. And also, taking the construction of recycling system in mind, the waste of carbon fiber was used for the one of source materials for molding.

In order to evaluate obtained samples, the mechanical properties and heat generation property were examined by bending test and temperature measurement by infrared thermometer, respectively.

2. Experiments

2.1. Molding materials

Because the carbon fiber is mainly used for reinforcement of resin, it is also assumed that the waste carbon fiber mainly comes from the separation process of used CFRP into resin and fiber. On the other hand, the timber offcuts obtained from the producing process of carbon-fiber prepreg also generated at large quantities. Therefore, we used the timber offcuts of carbon fiber prepreg weaving. Fig. 1 shows the aspect of the carbon fiber. The average length of carbon fiber is 52 mm. In general, the waste of carbon fiber is obtained as a state of discontinuous fiber and can be used as the reinforcement at the process of injection molding and extruding molding. PP resin was used for the matrix material. Moreover, in order to improve adhesiveness between carbon fiber and PP, maleic anhydride modified PP (Umex1001, Sanyo chemical industries, Ltd.) is used.

Figure 1. Aspect of carbon fiber as molding material.

2.2. Molding method of composites

In the molding process, the waste of carbon fiber was pre-treated by carding machine to make well-dispersed fiber web. The carbon fiber web and PP resin was mixed by kneading machine. Then the mixture was cooled and crushed to make mixed pellet. Fig. 2 shows the aspect of mixed pellet. Then the mixed pellet was introduced in extruding molding machine and the strip shaped carbon fiber/PP composite board was obtained. Fig. 3 shows the aspect of composite board. The board may produce heat by applying voltage on the board, so it may be high-strength/lightweight heating composite. However, as mentioned above, the carbon fiber is discontinuous in the composite. Therefore, it is supposed that there is lower limit of carbon fiber contents at which almost no current can be carried on the board. So, the content of carbon fiber was varied from 0wt% to 45wt% in the experiments to evaluate the relationship between material properties and the content of carbon fiber. Moreover, the samples in which 5wt% of Umex1001 is mixed at kneading process were also molded. Here, the carbon fiber in the board may shorten by shearing force during kneading and extruding process. So the length of carbon fiber in the board was measured by dissolving PP matrix of composite board by hot xylene and microscope measurement of 1000 fiber. Fig. 4 shows the distribution of carbon fiber length in composite board. The average of fiber length was 77.8 μm.

Figure 2. Carbon fiber/PP mixed pellet

Figure 3. Carbon fiber/PP composite board

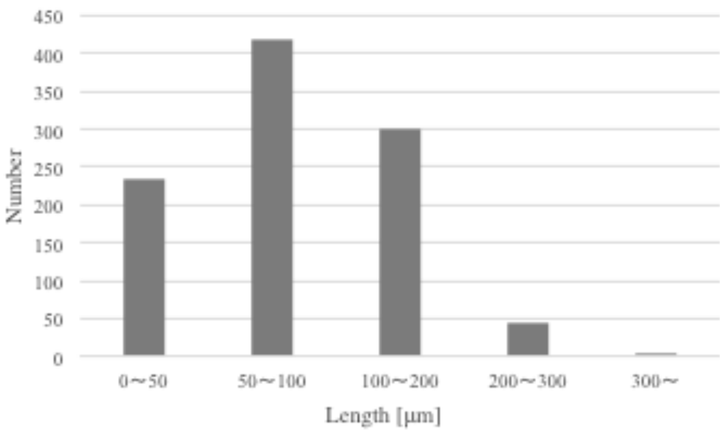

Figure 4. Distribution of carbon fiber length in composite board

2.3. Mechanical property test and heat generation property test

The strip shaped carbon fiber/PP composite board was cut into the size of 200×19×4 mm and the bending properties were evaluated by three-point bending test with the span length of 32 mm and testing speed of 1.0 mm/min.

Moreover, The specimen was clumped by metal electrode with conductive grease. Then voltage of 30.5 V was applied for 40 min and current was measured by constant direct-current power supply system (DP-3005, CUSTOM corporation). In addition the temperature on the center of surface of specimen was measured by thermo camera (TH3102MR, NEC san'ei co. ltd.).

3. Result and discussion

3.1. Mechanical properties

The relationship between the content of carbon fiber (W_f) and bending strength (σ) and bending modulus (E) was shown in Fig. 5. These graphs indicate that σ and E increase with increasing W_f between 0~30 wt%. At 30~40wt % of W_f, σ and E take maximum value. In especial, it is notable that σ improves by using Umex1001. Fig. 6 show SEM images of the fracture cross-section of carbon fiber/PP composite board with and without Umex. From these images, it is clarified that the adhesion between carbon fiber and PP improves with Umex. Therefore it can conclude that the improvement of σ is caused by the improvement of adhesion reinforcement fiber and matrix resin. Even though, E shows almost no improvement by using Umex.

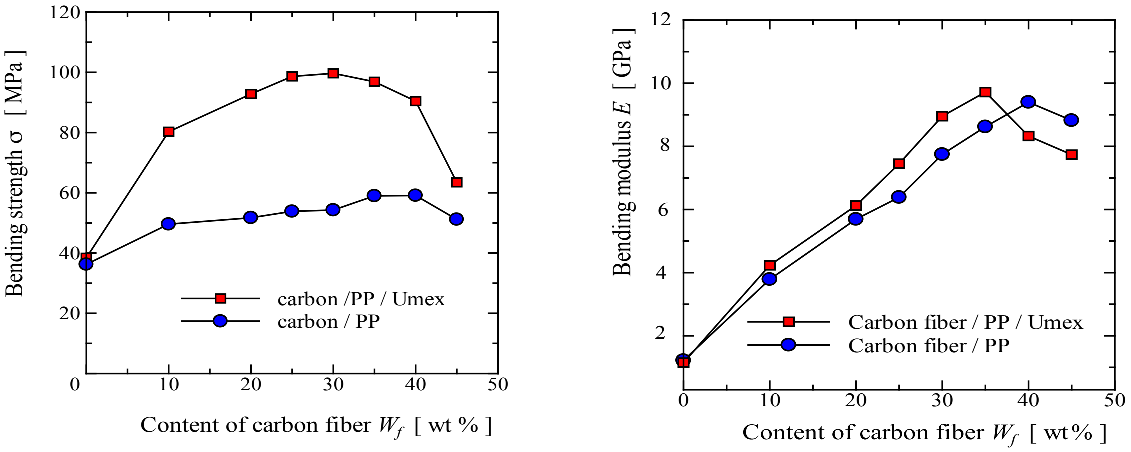

Figure 5. Bending strength and modulus of carbon fiber/PP composite board

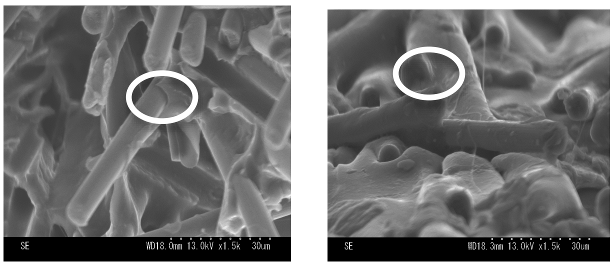

Figure 6. SEM image of fracture cross-section of carbon fiber/PP composite board without Umex (left) and with 5 wt% of Umex (right). White circles show improvement of adhesion between carbon fiber and PP.

3.2. Conductivity and heat generation property

Fig. 7 shows the relationship between W_f and electric resistance R of composite board. From the figure, it was revealed that R decreases rapidly with increasing W_f. It seems that discontinuous carbon fibers dispersed in the composite board can easily contact each other when W_f. increases and it causes the decreasing of R. The left of Fig. 8 shows typical image of specimen under the condition of turning-on-electricity state observed by thermo camera. By measuring the center spot of specimen, the maximum temperature increase (ΔT) during electric applying (40 min) was calculated. The right of Fig. 8 shows the relationship between applied electric power (E) and maximum temperature increase (ΔT). From the result, it was revealed that ΔT increases with increasing W_f even at the same electric power supplying. Fig. 9 shows the content of carbon fiber and surface temperature (T_s) of composite board. This figure also shows that the temperature increasing with increasing W_f. In addition, it is clarified that there is a threshold of content of carbon fiber that is critical to temperature increasing and the value is 20~30 wt% for the specimen of this study. The value of 20~30 wt% is almost same with the value W_f of rapid R decreasing in Fig. 7. So it seems that electric resistance of material largely affects the heating property of carbon fiber/PP composite board.

Next, the influence of Umex on heating property of composite board was investigated. Fig. 10 shows the relationship between content of Umex1001 and surface temperature of composite board. It is obvious that T_s decreases with increasing content of Umex and T_s becomes almost constant over about 3 wt% of Umex. From careful observation of fracture cross-section of specimens in Fig. 6, it can be shown that the PP matrix sticks around carbon fiber with Umex on the contrast of without Umex. Therefore, it is concluded that the improved adhesiveness between carbon fiber and PP prevent direct contact of discontinuous carbon fibers each other in composite board by intercalating PP resin between them. From Fig. 4, the carbon fiber is shortened to be under about 200 μm during molding process of composite board. This value is about 1000 times smaller than 200 mm of electric current path (i.e. the long side of specimen). Therefore the direct contact between carbon fibers may be essential for electrical resistance and surface temperature of composite board.

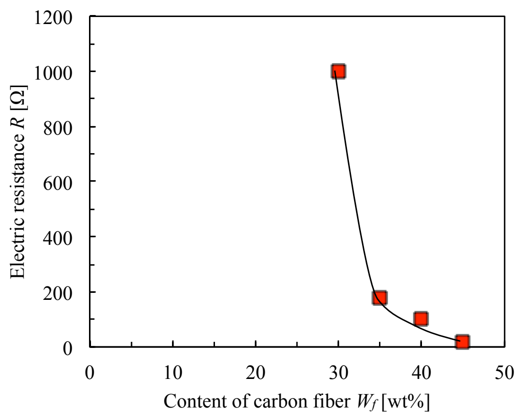

Figure 7. Content of carbon fiber and electric resistance of carbon fiber/PP composite board

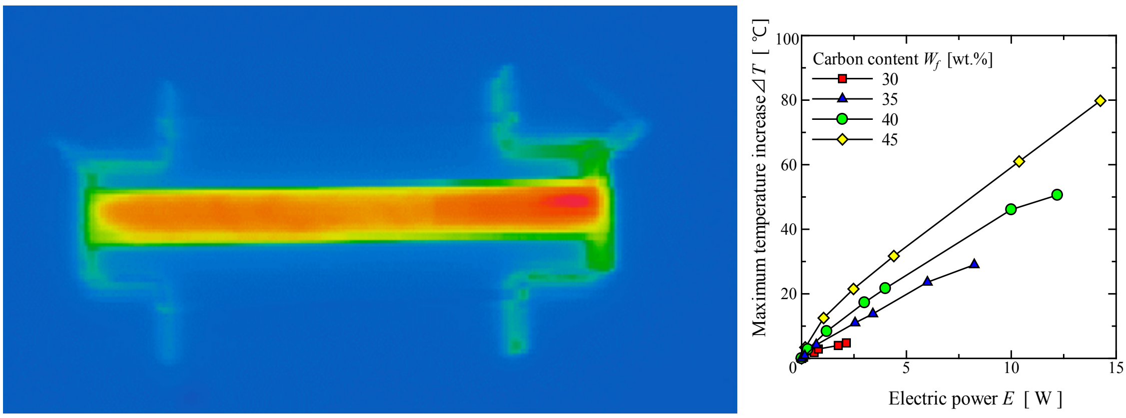

Figure 8. Typical image of specimen observed by thermo camera (left) and the relationship between applied electric power and maximum temperature increase (right)

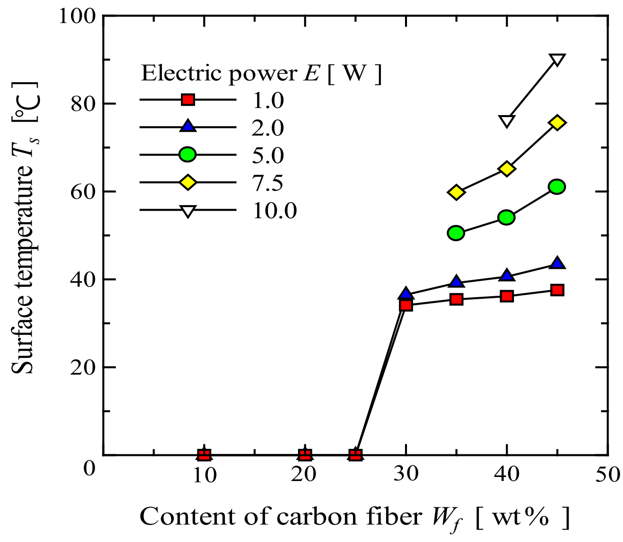

Figure 9. Content of carbon fiber and surface temperature of composite board

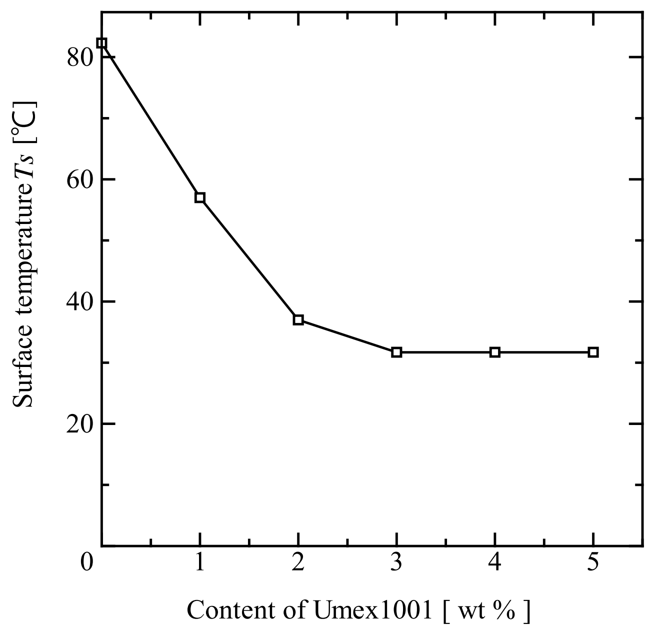

Figure 10. Content of Umex1001 and surface temperature of composite board

4. Conclusion

In this research, high-strength/lightweight heating composite board was tried to mold by extruding molding method from the timber offcuts of carbon fiber prepreg weaving. And the mechanical properties and heat generation property of composite board were examined by bending test and temperature measurement by infrared thermometer, respectively. The content of carbon fiber was varied from 0wt% to 45wt% in the experiments.

From the results, it was cleared that the bending strength and modulus increased with increasing the content of carbon fiber and had peak values at 30~40wt% of carbon fiber content. Meanwhile, the electrical resistance decreased suddenly at 20~30wt% of carbon fiber content and the notable temperature rise occurred after here under the condition of turning-on-electricity state. The surface temperature rose largely for higher content of carbon fiber. Addition of maleic anhydride modified PP cause increasing of bending strength but there is almost no improvement on bending modulus. Moreover, heat generation property of composite board diminishes by adding 5 wt% of maleic anhydride modified PP.

The results suggest that the molding methods described herein shows promise for contributing toward the material recycling of carbon fiber as a multifunctional composite material.

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