CARBON FIBER / EXPANDED POLYPROPYLENE COMPOSITE FOR ISOTROPIC CONDUCTIVITY

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1 Introduction
Lightweight and multifunctional materials are of interest in many industrial fields [1-15]. Electrical and thermal conductivities can be useful for applications such as the heat sink or electromagnetic wave shielding. Multifunctional materials can be made by mixing two or more materials, or by structural inducement [1-3, 10-30]. To obtain isotropic properties, powder type fillers, for example, carbon black, carbon nanotube, and graphene have been used. The fillers of powder form are easy to realize isotropic properties. However, it also has a disadvantage which is the difficulty in filler dispersion in the matrix. Rod shape fillers may result in better properties than the powder type fillers. However, it may result in anisotropic properties after the molding process because the rod-shaped filler having a high aspect ratio will inevitably assume orientation depending on the direction of the flow. Consequently, electrical or thermal conductivities of the composite in the flow direction may become quite different from the conductivity in the perpendicular direction [21-30]. In order to enhance the conductivity in the perpendicular direction and thus to realize isotropic conductivity, expanded polypropylene (EPP) and carbon fiber were used in this study. The EPP has the characteristic of secondary expansion during the fusion-bonding process. As illustrated in Fig. 1 and Fig. 2, expansion of the EPP beads may force the carbon fibers to be oriented along the gaps between the beads which induces the isotropic property. In this investigation, carbon fiber/EPP composite was made and its electrical and thermal conductivities were evaluated.

2 Experimental details
2.1 Materials

![Fig. 1. Illustration of carbon fibers positioned between the EPP beads.](image1)

![Fig. 2. Illustration of orientation mechanism of carbon fiber through the thickness direction.](image2)
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The following materials were used in the preparation of the samples: EPP (B 4.5P grade, Howtech Co., Ltd.) was used for the matrix. For the reinforcement, a 6 mm length chopped carbon fiber (T700SC, Toray Corp.) was used. The density of the EPP was decreased to 0.138 g/cm³ from 0.2 g/cm³ by the secondary expansion during the fusion-bonding process. The densities of the EPP and the carbon fiber/EPP composite are shown in Table 1. The thermal conductivities of the EPP and the carbon fiber are 0.061 W/mK and 9.408 W/mK, respectively [31, 32]

Table 1 Densities of the EPP and carbon fiber/EPP composites after secondary expansion.

<table>
<thead>
<tr>
<th>Items (volume percent)</th>
<th>density</th>
</tr>
</thead>
<tbody>
<tr>
<td>EPP (100%)</td>
<td>0.138 g/cm³</td>
</tr>
<tr>
<td>carbon fiber (4.2%) / EPP (95.8%)</td>
<td>0.207 g/cm³</td>
</tr>
<tr>
<td>carbon fiber (5.2%) / EPP (94.8%)</td>
<td>0.224 g/cm³</td>
</tr>
<tr>
<td>carbon fiber (7.3%) / EPP (92.7%)</td>
<td>0.260 g/cm³</td>
</tr>
<tr>
<td>carbon fiber (8.5%) / EPP (91.5%)</td>
<td>0.280 g/cm³</td>
</tr>
</tbody>
</table>

2.2 Preparation of the Samples

Prior to the molding process, dry mixing of the chopped carbon fiber and EPP was conducted by using a treadmill at 200 rpm for 30 min as shown in Fig. 3. Then, the mixture was molded in a mold cavity as shown in Fig. 4. In order to achieve a high fusion-bonding efficiency of the EPP beads and secondary expansion in the mold cavity, the molding of the EPP beads in the mold cavity was done using steam at an elevated temperature with a higher saturation vapor pressure. Prior to setting the mixture in the mold, the mold was preheated to 125°C. Then, the mixture was set in the preheated mold cavity. After closing the mold, steam at 130°C with a pressure of 640 kPa was injected into the bottom of the mold. When the pressure gauge on the bottom mold indicated 400 kPa, the vent on the bottom of the mold opened immediately. The vent remained open until the pressure dropped to 100 kPa. After the vent was closed, the steam was injected into the upper mold until the pressure gauge on the upper mold indicated 440 kPa. The pressure reached was maintained for 4 seconds without opening the vent on the upper mold. Then, the vent of the upper mold opened partially until the pressure reached 200 kPa when the vent on the upper mold was fully
opened. Cool water (20°C) was subsequently injected into the mold to cool the product. After the water in the mold drained, the product was taken out of the mold. The product was then dried in a forced convection oven (Model FC-1D-2, Universal Scientific Co., Ltd.) at 55 °C for 24 hours.

2.3 Measurement of Electrical Conductivity

The electrical conductivity of the carbon fiber/EPP composite specimens was measured according to ASTM D4496 with a multi-meter (Fluke 187, Fluke Corp.) in the directions of 3 axes as shown in Fig. 5. A specimen was machined with a water jet cutter. Prior to the measurement, all surfaces of the samples were trimmed using a razor to create a flat surface. The samples were kept in a forced convection oven (Model FC-1D-2, Universal Scientific Co., Ltd.) at 55°C for 24 hours. Silver paste was then painted onto their surfaces to ensure good contact between the surfaces of specimen and the copper electrodes. Due to the large deviation in electrical conductivity at different points on the surface of a specimen from the four-terminal measurements, the DC volume electrical resistivity in this study was measured using the two-terminal technique. The electrical conductivity was recorded after a 5-minute wait to obtain a stationary value. The volume electrical resistivity was calculated using the following equation:

\[ \rho_v = \frac{RLW}{t} \]  

where \( \rho_v \) is the volume electrical resistivity, \( R \) is the measured resistance, \( L \) is the length of the specimen, \( W \) is the width of the specimen and \( t \) is the thickness.

2.4 Measurement of Thermal Conductivity

The thermal conductivity of the carbon fiber/EPP composite was measured by a thermal conductivity analyzer (Mathis TCI, C-Therm Technologies Ltd., Fig. 6) which was the modified transient plane source technique. As illustrated in Fig. 7, three-dimensional thermal conductivities of the specimen were tested at the room temperature. The measurements were done five times per point in each direction. The specimen was in the analyzer as shown in Fig. 8.
2.5 Observation of Surface Morphology

In order to assess the orientation of the carbon fibers along the gaps between the beads, the morphologies of the cross-sections of carbon fiber/EPP composite were observed by FE-SEM (JSM-6700F, JEOL).

3 Results and Discussion

3.1 Electrical Conductivity

The volume electrical resistivity of the specimens was measured and the results are shown in Fig. 9. The average volume resistivity of the specimen tends to decrease with increase of the amount of carbon fibers. The volume resistivity of the Z-axis (thickness direction) was generally lower than that of the other directions. An average volume resistivity of 169 Ω cm and volume resistivity of 303, 110, and 94 Ω cm for the X-axis, Y-axis, and Z-axis, respectively were obtained for carbon fiber volume fraction of 8.5% in this study.

3.2 Thermal Conductivity

By adding carbon fibers in the composite, the thermal conductivities of three axes were enhanced. As shown in Fig. 10, they had similar values with each other. The thermal conductivity of the composite containing a fiber volume fraction of 4.2% has 10 times increased thermal conductivity in the direction of X-axis compared to the neat EPP. In the directions of the Y-axis and the Z-axis, the thermal conductivities are increased 8.8 times and 11.5 times, respectively. By increasing the volume amount of
carbon fiber in the composite, the thermal conductivity was increased accordingly. At a fiber volume fraction of 8.5%, the thermal conductivities are enhanced 13.2 times, 13.4 times and 15.9 times, respectively, along the axes of X, Y, and Z. Consequently, the thermal conductivities of the carbon fiber/EPP composite could be enhanced to about 0.8 W/mK by using the carbon fiber of 8.5 Vol.% and the isotropic thermal conductivity could be realized.

### 3.3 Surface Morphology

Numerous cells are observed on the cross-section of the neat EPP as shown in Fig. 11 (A). Low thermal conductivity of the neat EPP is attributed to the insulation effect by these walls. By utilizing this characteristic, the carbon fiber could be oriented along the gaps between the beads along the X-Z plane and Y-Z plane. The cross-sectional view (X-Y plane) of the carbon fiber/EPP composite with a fiber volume fraction of 8.5% shows oriented carbon fibers along the gaps between the beads as shown in Fig. 11 (B). This could be interpreted as a reason for the increase of electrical conductivity in the thickness direction of the specimen (Z-axis).
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4 Conclusion

The manufacturing process of carbon fiber/EPP composite was introduced and its semi-isotropic electrical and thermal conductivities were observed. A randomly mixed mixture of EPP having a spherical shape and carbon fibers having a cylindrical rod shape could make the carbon fibers positioned along the gap between the expanding EPP beads. Therefore, the secondary expansion which occurs during the fusion-bonding process of EPP could be an effective way to realize the isotropic conductivities. Through the addition of carbon fibers, the average volume electrical resistivity could be lowered to 169 Ω cm and the thermal conductivity was enhanced isotropically in this study.

Acknowledgments

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References


Fig. 11. The surface morphologies of the cross section of the EPP and the carbon fiber/EPP composite; (A) EPP, (B) carbon fiber/EPP composite, (C) magnification of (A), (D) magnification of (B).


[31] www.howteck.co.kr