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# Recycling Polypropylene Nonwoven Selvages to Create Far-Infrared Composite Plates

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Recycling Polypropylene Nonwoven Selvages to Create

Far-Infrared Composite Plates

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**ABSTRACT**

In this study, recycled polypropylene (PP) nonwoven selvage was collected and made into PP pellets using a single screw extruder. The recycled PP pellets were mixed with far-infrared PP masterbatch and virgin PP pellets, molded, and formed into various far-infrared/PP composite plates. The virgin PP pellets were added in order to strengthen the

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## 1. INTRODUCTION

The 20th century was an era of rapid industrial development which resulted in massive global resource depletion and environmental crisis. Since 1990, many developed countries have changed their waste management methods and strategies, turning from passive waste disposal to active resource management. Now, they focus on environmental protection and waste reduction, reusing, and recycling.

Recently, the importance and benefits of synthesized polymer recycling

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and reusing have been acknowledged. Because synthesized polymers occupy much more space than other materials with identical densities, techniques to reduce and reuse them have become the priority of many researchers.

The compressible strength of plastic waste is three times stronger than that of concrete if the waste has been processed properly. To establish a procedure including synthesis, manufacturing, utilization, recycling and depolymerization, it is necessary to find a highly efficient and low cost depolymerization technique which requires few resources [1]. Previous research has added far-infrared pellets to polymer; however, seldom has synthesizing the far-infrared pellets and polymer into a composited plate been discussed.

An injection molding machine and a single screw extruder are generally utilized in polymer recycling [2]. M.A. Silva Spinace et al. use a single screw extruder to re-process polyester (PET) pellets three times and discover some significant changes in the mechanical properties and crystallization of the pellets. As the result, they conclude PET is a perfect material to be recycled, re-processed and re-mixed with other substances because of its firm mechanical properties [3].

To ensure the stability of these properties, this research recycles, re-processes, and re-mixes virgin polypropylene (PP) pellets with other substances, changing the mixture's proportions. The virgin PP pellets were mixed with far-infrared PP masterbatch, strengthening the mechanical properties of the composite plate [9-11]. Far-infrared PP masterbatch was used instead of pure far-infrared powder because it more easily disperses as a chip. The aggregate pellets separated easily with sheer force during

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preparation due to the paint or high concentration of filling material. The prepared pellets were put into resin and mixed thoroughly; therefore, the paint and filling material were spread evenly, preventing aggregation [4-8].

In the present study, recycled PP nonwoven selvage was smashed and cut into small particles with a single screw extruder. The pellets were mixed with far-infrared PP masterbatch and then re-processed using the single screw extruder. The dried mixture was injected into a mold of the far-infrared composite plate and, finally, its physical properties were examined.

## 2. EXPERIMENTAL

### 2.1 Preparation of the Material

0.18 ㎜ thick recycled PP selvage, which possessed a melting point of 162.3□ and weighed 30g/m², was supplied by Kang Na Hsing Enterprise Co., Ltd. First, the selvage was crushed by a Universal Powerful Granulator (Wei Sheng Machinery) and then ground into particles with a single screw extruder set at 72rpm. The temperature of the extruder's die was controlled at 200 □ and its tank was set at three temperatures: 170, 190 and 200 □.

0.5μm far-infrared PP masterbatch with a melt flow index (MI) of 106.3g/10min was mixed with the recycled PP pellets. The PP masterbatch was composed of 20% micrometer far-infrared metal powder, supplied by Hao Mao Nano-Tech Co., Ltd. The virgin PP pellets (model: 1035), procured from Formosa Chemicals & Fiber Co., had a melting point of 165□ and an MI of 35g/10min.

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The recycled PP pellets and the far-infrared PP masterbatch were mixed and injected into a mold by a single screw extruder with a running speed of 36rpm, a die temperature of 200□ and the above mentioned three tank temperatures. During the recycling procedure, the mixture was re-processed five times, each time with a different proportion of far-infrared PP masterbatch. The mechanical properties of each final product were then evaluated.

## 2.2 Specimens

In order to examine the effects of the far-infrared PP masterbatch and processing frequency on the mechanical properties of the far-infrared composite plates, the proportion of the virgin PP pellets to the recycled PP pellets was 1:1; in addition, the far-infrared PP masterbatch content of each mixture varied, ranging from 0% to 1%, 3%, 5%, 7% or 9 %. R1-R5 denotes the number of rounds of processing each mixture received.

## 2.3 Methods

### 2.3.1 Tensile Strength Test

The tensile strength test was conducted in accordance with ASTM-D 638 and the injected plastic was treated as described in ASTM-D 618. The specimen was put in an environment with a temperature of 23±2□ and a relative humidity of 50±5% for 40 hours. The distance between the upper and lower clamps on the tensile tester was 25mm; the pulling speed was 5mm/min. Samples of each specification were tested five times.

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### 2.3.2 Impact Test

The impact test was conducted in accordance with ASTM-D 256. A 63.5×12.85×3㎜large "V" shape was cut 0.25R±0.5㎜into every specimen. Samples with each specification were examined five times.

### 2.3.3 Melt Flow Index (MI)

The MI was conducted in accordance with ASTM D 1238. The composite plate was dried at 90□ for 1 hour and the tester was pre-heated to 230□. The material of the composite plates had excellent fluidity; therefore, the thermal temperature was adjusted to 220□ to reduce unnecessary heat. The composite plate was fed into the cylinder and then heated for 7 minutes, after which a piston weighing 2.16kg pushed the melted material in the cylinder. If the viscosity of the material was high, it flowed slowly, resulting in a smaller amount of extrusion. Samples were taken every 15 seconds and weighed as soon as they cooled down. Three samples for each specification were weighed and the mean was taken as the final result.

### 2.3.4 Differential Scanning Calorimeter

A differential scanning calorimeter (DSC) was used to examine the far-infrared/PP composite plate's thermal property. The tester's temperature changed at 20℃/min the first time, increasing from 26℃ to 200℃ and decreasing from 200℃ to 26℃; the second time the temperature

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changed at 10℃/min. The specimens tested weighted ~5-10mg. Nitrogen was released at 20 CC/min.

### 2.3.5 Far-infrared Emissivity

The far-infrared emissivity (ε) test was conducted by the Laboratory of Sensing Elements in the Department of Electrical Engineering at the National Taiwan Ocean University. The experiment required a constant temperature of 60□.

Emissivity (Formula 1) is the ability of a substance's surface to emit energy through radiation. At a constant temperature, emissivity is the comparative ratio of the energy radiated by a certain material to the energy radiated by a black body. The black body's ε is equal to 1; thus, the emissivity from any object should be between 0 and 1, or 0<ε<1. The closer ε is to 1, the better the thermal energy absorbed is transformed into electromagnetic waves. A black body is noted for its ability to transform all the thermal energy it absorbs into electromagnetic waves. Furthermore, no energy loss occurs during the transition.

$$\text{Emissivity }(\varepsilon) = \frac{\text{Material's electromagnetic waves}}{\text{Black body's electromagnetic}} \quad \ldots\ldots(\text{Formula 1})$$

### 2.3.6 Scanning Electron Microscope

A scanning electron microscope (SEM) was used to examine the distribution of the far-infrared powder in a cross section of the

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far-infrared/PP composite plate. Before observation, the specimen was gilded with gold for two minutes. An accelerating voltage of 15KV was then used to magnify the image 3000-5000X.

## 3. RESULTS AND DISCUSSION

### 3.1 Tensile Property

Figs. 1 and 2 give the tensile strengths of the far-infrared/PP composite plates with different amounts of far-infrared PP masterbatch content. From Fig. 1, it can be seen that the increase in processing frequency does not reduce the plate's tensile strength. In fact, the PP matrix was immune to thermal degradation; therefore, re-processing five times hardly weakened the composite plate's tensile strength. Likewise, the increase in far-infrared powder did not enhance the plate's tensile strength either. It remained around 29-33MPa. The results indicate that the far-infrared mineral powder did not significantly improve the plate's tensile strength due to the insufficient amount of powder.

Fig. 2 reveals that when the plate is processed one and two times, the extension at break rate of the plate containing 1% far-infrared PP masterbatch decreased 100%, much more than the composite plate without masterbatch. Force produced a concentration of stress on the interface between the far-infrared powder and the PP, leaving cracks on the surface. Increasing force continuously widened the cracks until the material finally broke.

When the far-infrared PP masterbatch made up 3% of the composite plates processed one and two times, the extension at break rate of the plates

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reached 223%. The far-infrared PP masterbatch had a high MI of 106.3g/10min. As a result, only the PP stayed on the surface of the composite plate and acted as a carrier, which in turn caused bottlenecking (see Fig. 3 a and b). However, no apparent bottlenecking or variation in the extension at break rate was observed in the plates processed three times. The far-infrared PP masterbatch was evenly spread, so the PP did not congregate on the plate's surface. Consequently, the far-infrared/PP composite plates seldom broke.

## 3.2 Impact Test

Fig. 4 reveals the influence of the far-infrared PP masterbatch content and the processing frequency on the impact strength of the composite plates. In Fig. 4, there is no obvious change in the impact strength of plate, despite the increase in far-infrared PP masterbatch and processing frequency, and the impact strength remained between 19-26 J/m. If the micron (same as above) far-infrared metal powder did not have any surface modification, it tended to cluster, which caused a concentration of stress between the interface of the powder and PP that reduced the flexibility and impact strength of the plate. When the content of the filling material (far-infrared masterbatch) was at a maximum amount of less than 10%, the properties of the plate remained unchanged. Therefore, the increase in far-infrared mineral powder significantly changed the impact strength of the far-infrared/PP composite plate.

### 3.3 Melt Flow Index (MI)

Fig. 5 displays the MI of far-infrared/PP composite plates with different amounts of far-infrared PP masterbatch content (0, 1, 3, 5, 7 and 9 wt%), each processed various times. With an increase in far-infrared PP masterbatch content, the MI increased from its original 30g/10min to 47g/10min. The far-infrared mineral powder untangled the intricate molecular chains, allowing them to slide more easily; consequently, the MI was higher. Additionally, an increase in the number of times processed also caused a slight increase in the MI. The repeated processing also straightened out the molecular chains and the weight of the molecules decreased; thus, the MI grew.

### 3.4 Far-Infrared Ray Emissivity

As can be seen in Fig. 6, the average far-infrared emissivity is over 0.85 ($\varepsilon$) when the wavelength is 1-15$\mu$m, the range in which the tester can detect the waves. When thermal electromagnetic waves shine upon an atom, the atom is irritated due to the absorbed energy and must release the extra energy in order to return to its original state. The active vibration between the atom and molecule is thus slowed down by the emission of far-infrared rays.

The emissivity test compares the emitted energy between the tested material and the black body. When the emissivity is above 0.8, the emission is determined to be efficient. In this study, all of the composite plates had an emissivity that reached 0.85, proving a more than adequate far-infrared ray emission by the composite plates.

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### 3.5 Differential Scanning Calorimeter

As Figs. 7 and 8 show, the virgin PP crystallized at 105□, which is 13 degrees lower than the far-infrared/PP composite plate. Multiple processing increased the plate's crystallization rate. The molecular weight was reduced due to splitting and decomposition. Generally, low molecular processes stimulate the activity of molecule chains and increase the speed of crystallization. As a result, the far-infrared/PP composite plate crystallized faster and displayed higher temperatures at its crystallization peak.

With the same percentage (5%) of far-infrared PP masterbatch, it was found that when the composite plates were processed one, three, and five times, there was a 3 degree temperature decrease for crystallization. In fact, the added far-infrared PP masterbatch acted as the nucleating agent, increasing the amount of heterogeneous nucleation within the PP and stimulating crystallization. The composite plate's crystallization rate increased, and its crystallization temperature rose as well. However, there was no significant change in the melting point or thermal resistance of the plate; the average melting temperature remained ~164□ [6-8].

### 3.6 Scanning Electron Microscope

Figs. 9.1-9.7 show SEM images of composite plates with a variety of far-infrared PP masterbatch content (0, 1, 5, 9 wt%), processed one, three and five times. The dispersion degree of the far-infrared mineral powder does not change significantly with the increase in processing frequency (Figs. 9.5-9.7). Because the far-infrared metal powder was in the form of

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far-infrared PP masterbatch, the metal powder did not cluster within the composite plates, and thus did not add stress concentration or distribute unevenly on the plates. The far-infrared PP masterbatch had excellent distribution that was not influenced by the increase in processing frequency.

## 4. CONCLUSIONS

In this study, recycled PP nonwoven selvage was mixed with far-infrared PP masterbatch to produce a far-infrared/PP composite plate. The mechanical properties of the plate were not influenced by the far-infrared PP masterbatch or the frequency of processing, even when the plate was processed five times. When processed five times, the tensile strength of the composite plate was between 29-33MPa, while the impact strength was from 19-26J/m. When processed once and twice, the extension at break of the composite plate with a 3% far-infrared PP masterbatch content changed significantly, compared to one without masterbatch content, which reached a peak of 223%. After being processed three times, the extension at break decreased to between 15-20% without any sign of bottlenecking.

As to the melt flow index (MI), it was enhanced by greater far-infrared PP masterbatch content and more times of processing. The far-infrared PP masterbatch content raised the plate's MI from 30g/10min to 47g/10min.

DSC results showed that the frequency of processing lowered the crystallization temperature by 3 degrees, from 117℃ to 114℃. However,

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larger far-infrared PP masterbatch content raised the crystallization temperature by 13 degrees, from 105℃ to 118℃.

The average far-infrared emissivity was 0.85 with a wavelength between 1-15μm. It was not affected by the quantity of the far-infrared PP masterbatch or the processing frequency.

The SEM results signify that using far-infrared PP masterbatch, rather than far-infrared metal powder alone, is conducive for optimal far-infrared metal powder distribution. All of these results indicate that processing the plates three times provides the optimal conditions for manufacturing far-infrared/PP composite plates with outstanding mechanical properties.

## Acknowledgment

## REFERENCES

[1] Aurrekoetxea, J., Sarrionandia, M.A., Urrutibeascoa, I. and Maspoch, M.Ll. (2001). Effects of Recycling on the Microstructure and the Mechanical Properties of Isotactic Polypropylene, *Journal of Materials Science*, 36: 2607-2613.

[2] Mancini, S.D. and ZANIN, M. (2000). Consecutive Step of PET Recycling by Injection: Evaluation of the Procedure and of Mechanical Properties, *Journal of Applied Polymer Science*, 76: 266-275.

13

[3] Silva Spinace´, M. A. and DE PAOLI, M. A. (2001). Characterization of Poly (ethylene terephtalate) after Multiple Processing Cycles, *Journal of Applied Polymer Science*, 80: 20-25.

[4] G'Sell C., Bai, S. L. and Hiver, J.M. (2004). Polypropylene/Polyamide 6/Polyethylene–Octene Elastomer Blends. Part2: volume dilatation during plastic deformation under uniaxial tension, *Polymer*, 45(17):5785–5792.

[5] Rezaei, F., Yunus, R. and Ibrahim , N.A. (2009). Effect of fiber Length on Thermo Mechanical Properties of Short Carbon Fiber Reinforced Polypropylene Composites, Materials and  Design, 30(2): 260–263.

[6] Josefina Lozano-González,MA., Teresa Rodriguez-Hernandez, MA., Gonzalez-De Los Santos, E. A. and Jesus, V.O. (2000). Physical-Mechanical Properties and Morphological Study on Nylon-6 Recycling by Injection Molding, *Journal of Applied Polymer Science*, 76: 851–858.

[7] La Mantia, F. P., Curto, D. and Scaffaro, (2002). R. Recycling of Dry and Wet Polyamide 6, *Journal of Applied Polymer Science*, 86(8): 1899-1903.

[8] Maspoch , M. L., Ferrando, H. E. and Velasco, J. I. (2003). Characterisation of Filled and Recycled PA6, *Macromolecular Symposia*, 194: 295-303.

[9] Naficy, S. and Garmabi, H. (2007). Study of the Effective Parameters on Mechanical and Electrical Properties of Carbon Black Filled PP/PA6 Microfibrillar Composites, *Composites Science and Technology*, 67: 3233-3241.

[10] Tocháček, J., Jančář, J., Kalfus, J., Zbořilová, P. and Buráň, Z. (2008).

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Degradation of Polypropylene Impact-Copolymer During Processing, *Polymer Degradation and Stability*, 93(4): 770-775.

[11] Tan, H., Li, L., Chen, Z., Song, Y. and Zheng, Q. (2005). Phase Morphology and Impact Toughness of Impact Polypropylene Copolymer, *polymer*, 46(10): 3522-3527.
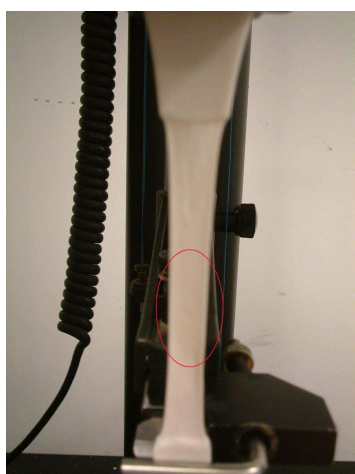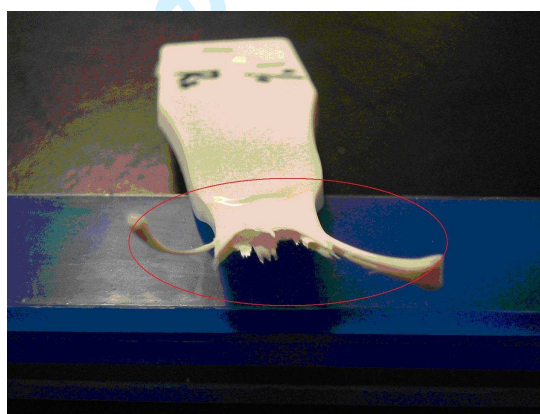
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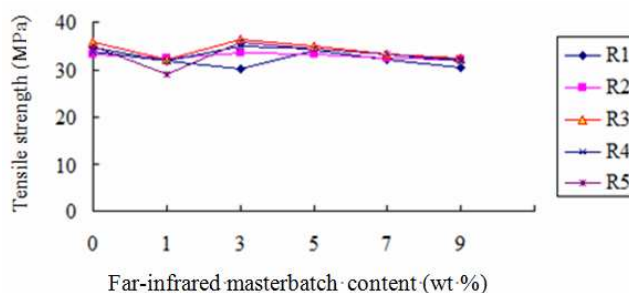


**Figure 1.** The tensile strength of the recycled far-infrared/PP composite
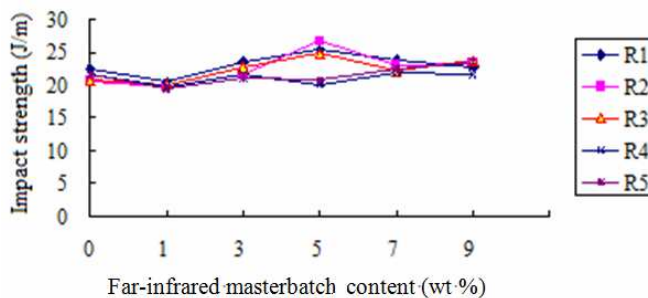
plates, processed for 1-5 rounds.
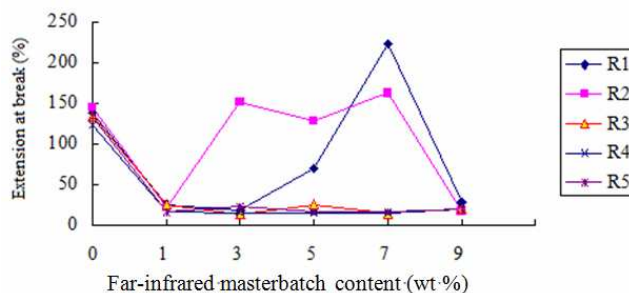


**Figure 2.** The extension at break rates of the far-infrared/PP composite
plates processed for 1-5 rounds.



**Figure 3.** (a). Bottlenecking in the

tensile strength test.



**Figure 3.** (b). The broken
bottlenecking.

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**Figure 4.** The extension at break rates of the far-infrared/PP composite plates.
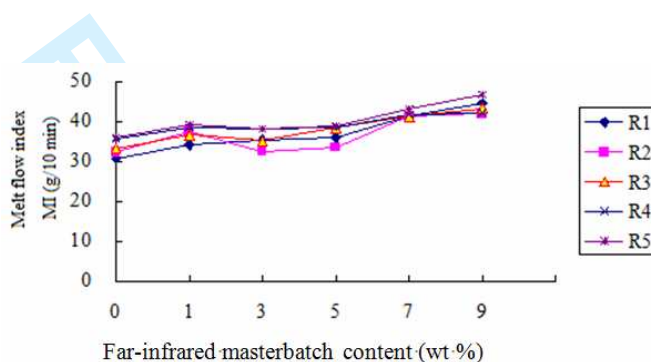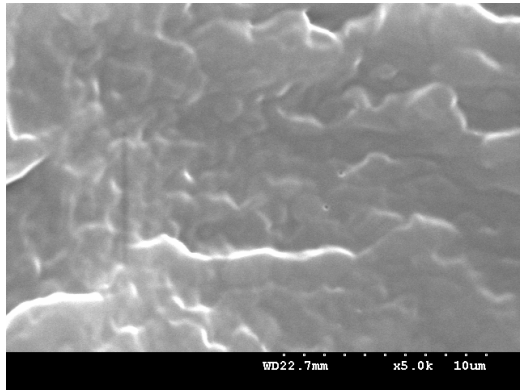


**Figure 5.** The MI of the far-infrared/PP composite plates.
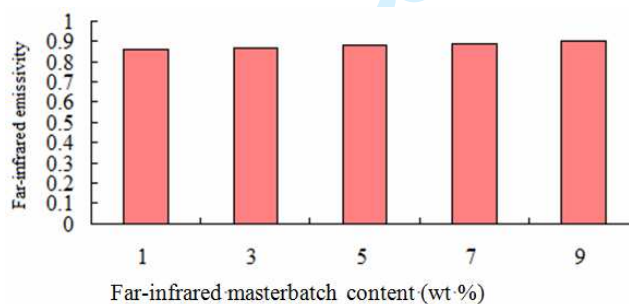


**Figure 6.** The far-infrared emissivity of composite plates with various masterbatch chip contents (0, 1, 3, 5, 7 and 9 wt %), each processed 5 times.
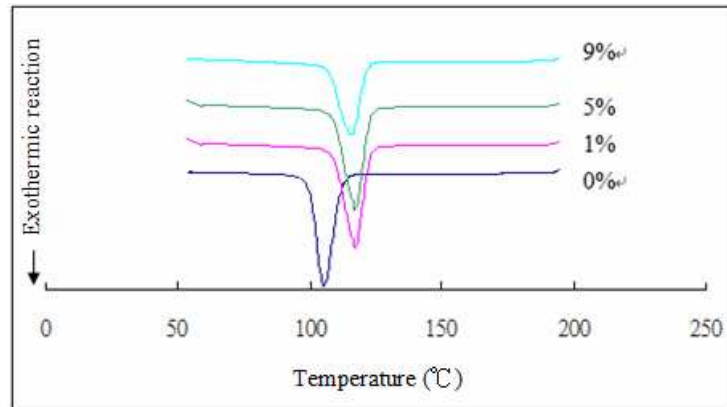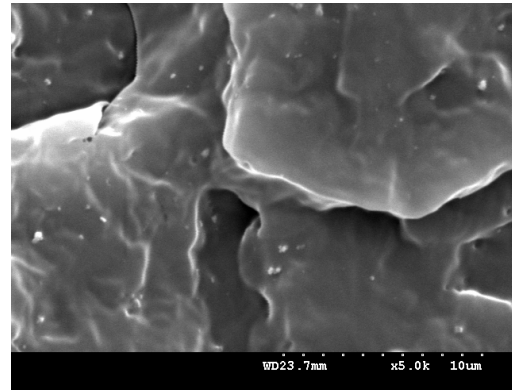
**Figure 7.** The crystallization temperature (cooling rate) of the far-infrared/PP composite plates with different far-infrared PP masterbatch content (0, 1, 3, 5, 7 and 9 wt %).
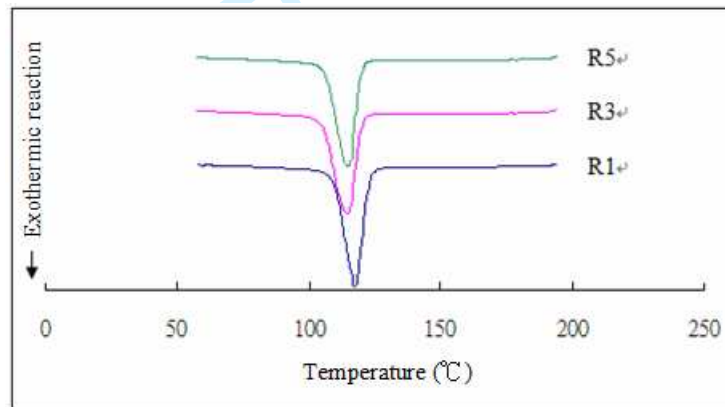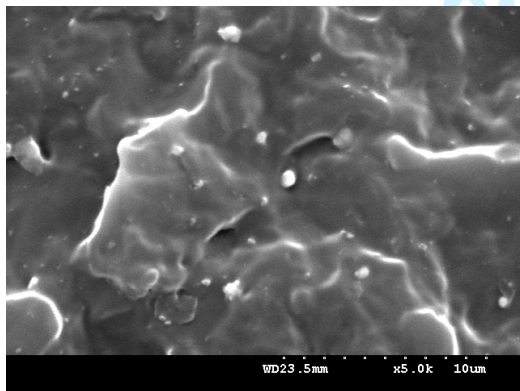


**Figure 8.** The crystallization temperature (cooling rate) of the far-infrared/ PP composite plates with various processing frequency.
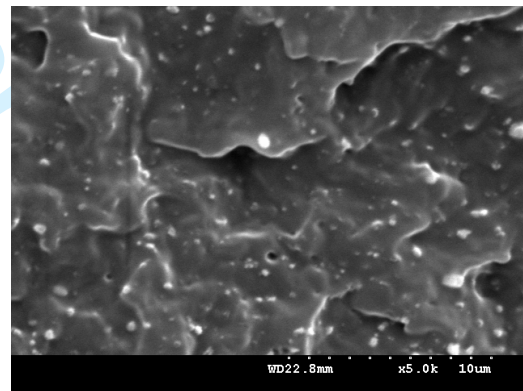
**Figure 9.1.** A cross section image of a virgin PP plate.
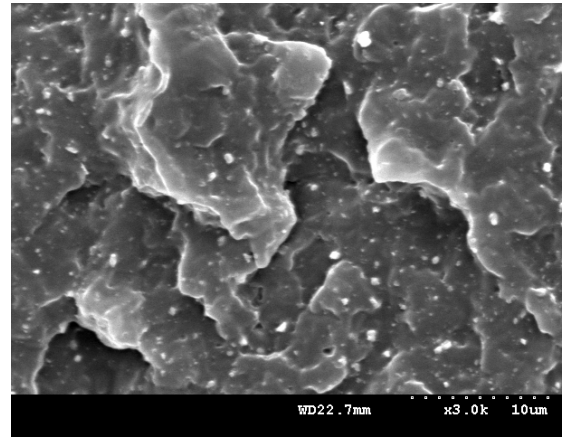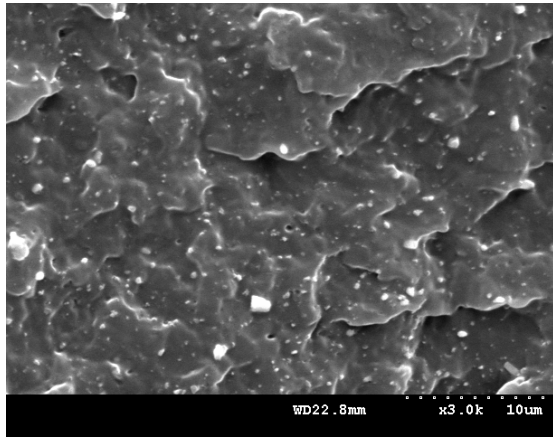


**Figure 9.2.** A cross section image of a far-infrared/PP composite plate with 1% far-infrared PP masterbatch content.



**Figure 9.3.** A cross section image of a far-infrared/PP composite plate with 5% far-infrared PP masterbatch content.
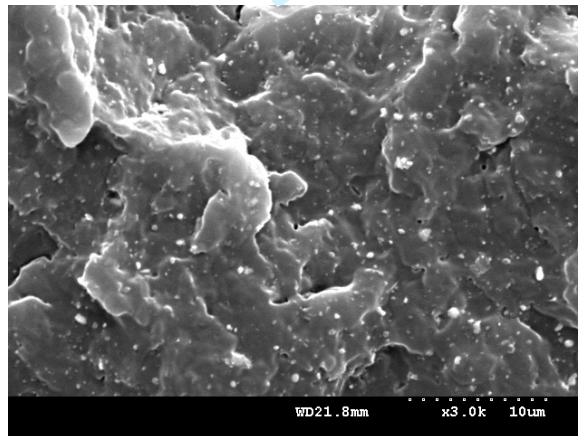


**Figure 9.4.** A cross section image of a far-infrared/PP composite plate with 9% far-infrared PP masterbatch content.

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**Figure 9.5.** A cross section image of a far-infrared/PP composite plate with 9% far-infrared PP masterbatch content, processed once.

**Figure 9.6.** A cross section image of a far-infrared/PP composite plate with 9% far-infrared PP masterbatch content, processed three times.



**Figure 9.7.** A cross section image of a far-infrared/PP composite plate with 9% far-infrared PP masterbatch content, processed five times.