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Effect of polypropylene-grafted-maleic anhydride content on physical properties of carbon fiber reinforced polypropylene composites

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Abstract

Polypropylene-grafted-maleic anhydride (PP-g-MAH) is known as an excellent interface modifier that can improve the interface between carbon fiber (CF) and PP. In this study, the effect of PP-g-MAH content on the physical properties of PP composites containing long-fiber CFs was investigated. It was confirmed that PP-g-MAH acted as an interface modifier between the interface between CF and PP, and when an appropriate amount of 10 wt% was incorporated, the tensile strength, tensile modulus, Izod impact strength, and heat deflection temperature were improved by 110%, 50%, 86.7% and 12.7%, respectively. On the other hand, the blending effect of PP-g-MAH, which is a low molecular weight, was greater than the compatibilizing effect when the PP-g-MAH content was mixed above the appropriate content, thereby reducing the physical properties. Therefore, the content of PP-g-MAH as the interface modifier must be designed to be the optimum content considering the CF content to be mixed in order to optimize the physical properties of the composite material.

1. Introduction

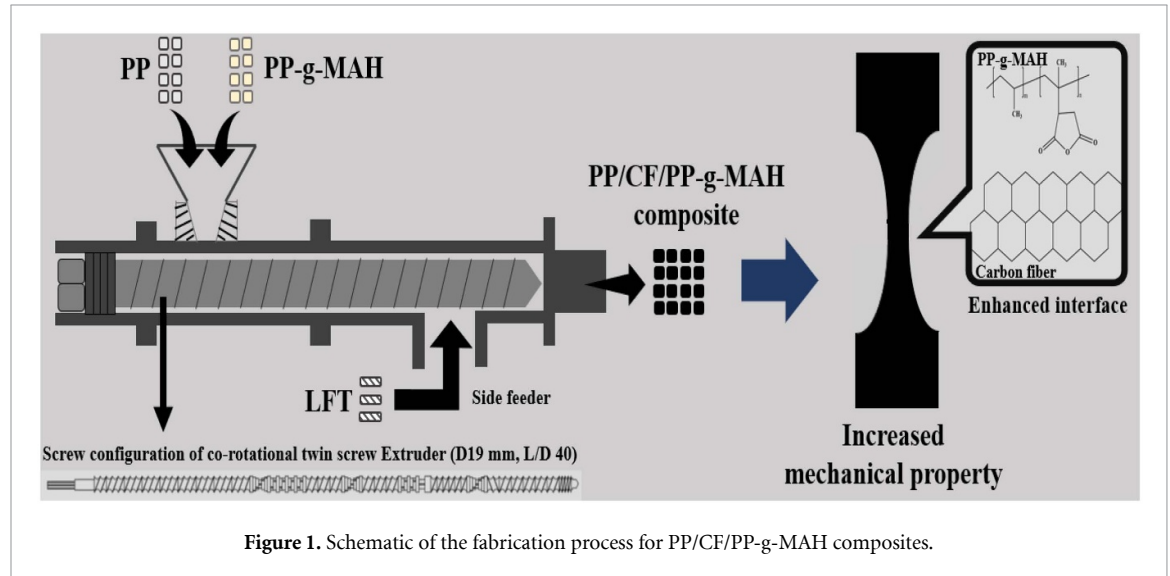
Carbon fiber reinforced plastics (CFRPs) are attracting attention as lightweight structural materials that replace metals because they exhibit excellent mechanical properties compared to density [1–5]. In particular, they are used in various fields that require weight reduction, from leisure goods to automobiles and space aircrafts [6–8]. The CFRP can be classified into thermosetting and thermoplastic CFRPs according to the type of used resin [2, 9, 10]. In addition, depending on the shape of the filler, it can be classified into continuous fiber, long fiber, and short fiber filled CFRPs [11–13].

In general, thermosetting CFRPs mainly using epoxy resins are relatively excellent and stable in terms of various physical properties. However, they have disadvantages in that the processing time is relatively long and recycling is not easy [2]. On the other hand, thermoplastic CFRPs are somewhat disadvantageous in general properties, especially thermal stability, but are attracting attention recently because they can be recycled and processed quickly [2]. Conventional CFRP market is based on aircrafts and sporting goods, which is sensitive to safety issues and less sensitive to production time or parts cost [14]. In recent years, in contrast, since the CFRP is applied as an automobile material that is sensitive to production time and parts cost, interest in the thermoplastic CFRP is increasing due to the recycling issue [15].

One of the most important factors influencing the mechanical properties of CFRP is the shape of CF. It is known that the longer the length of the filler, i.e. in the order of continuous fiber > long fiber > short fiber, the better the reinforcing effect. On the other hand, the longer the CF length, the more restrictive the processability. Therefore, it is required to select a suitable filler in consideration of the application purpose. In particular, in order to be used as an automobile material that is sensitive to unit cost and processing time, not only the characteristics of the material but also the processing time must be considered [2].

Table 1. Composition of the fabricated composites.

Sample	PP (wt%)	CF (wt%)	PP-g-MAH (wt%)
PP/CF/PP-g-MAH 0 wt%	97	3	0
PP/CF/PP-g-MAH 5 wt%	92	3	5
PP/CF/PP-g-MAH 10 wt%	87	3	10
PP/CF/PP-g-MAH 15 wt%	82	3	15

**Figure 1.** Schematic of the fabrication process for PP/CF/PP-g-MAH composites.

Polypropylene (PP) is a general thermoplastic resin that is used not only for clothing, toys, industrial parts, etc but also for automobiles. However, since PP and CF show poor miscibility, interfacial properties could be limited when manufacturing a composite material. As one method to solve this problem, it has been reported that by introducing maleic anhydride (MAH) into PP, the interfacial properties between the CF and the PP matrix can be improved [16].

Cho *et al* [17] investigated the co-crystallization behavior of blends of PP and PP-g-MAH and reported that the phase separation between the PP and PP-g-MAH molecules was observed when the cooling rate was very slow in the case of non-isothermal or the crystallization temperature was relatively high in the case of isothermal. Razak *et al* [18] observed the best tensile and flexural strength of the PET/PP-g-MAH blend when 4 phr of PP-g-MAH was incorporated. Järvelä *et al* [19] summarized the relationship between the morphological characteristics and dynamic mechanical properties of homo PP and PP-g-MAH blends. Karsli and Aytac [20] reported that the introduction of PP-g-MAH improves the tensile strength, modulus and hardness of short CF reinforced PP composites.

Relatively few papers have been reported to identify the effect of PP-grafted (g)-MAH content on the physical properties of PP filled with long fiber-type CFs. In this study, the effect of PP-grafted (g)-MAH content on the physical properties of PP filled with long fiber-type CFs that can secure the processability while exhibiting satisfactory properties was investigated. When the optimum content of MAH was incorporated, it was confirmed that physical properties such as tensile strength, tensile modulus, Izod impact strength, and heat deflection temperature (HDT) were improved.

2. Experimental

2.1. Materials

PP-impregnated long fiber thermoplastics (LFT, PP1350, Lotte Chemical Co., Seoul, Korea) based on CFs which can improve the physical properties were used as reinforcement. Commercial PP (J-160H, Lotte Chemical Co., Seoul, Korea) was prepared as matrix and PP-g-MAH (Adpoly PH200, MAH content of 5 wt%, Lotte Chemical Co., Seoul, Korea) which is made from MAH grafting onto the PP using reactor polymerization method was used as an interface modifier to enhance the interfacial property between the reinforcement and the matrix. Melt flow index of the commercial PP and PP-g-MAH was 16 and 100 g 10 min⁻¹, respectively, according to ASTM D1238.

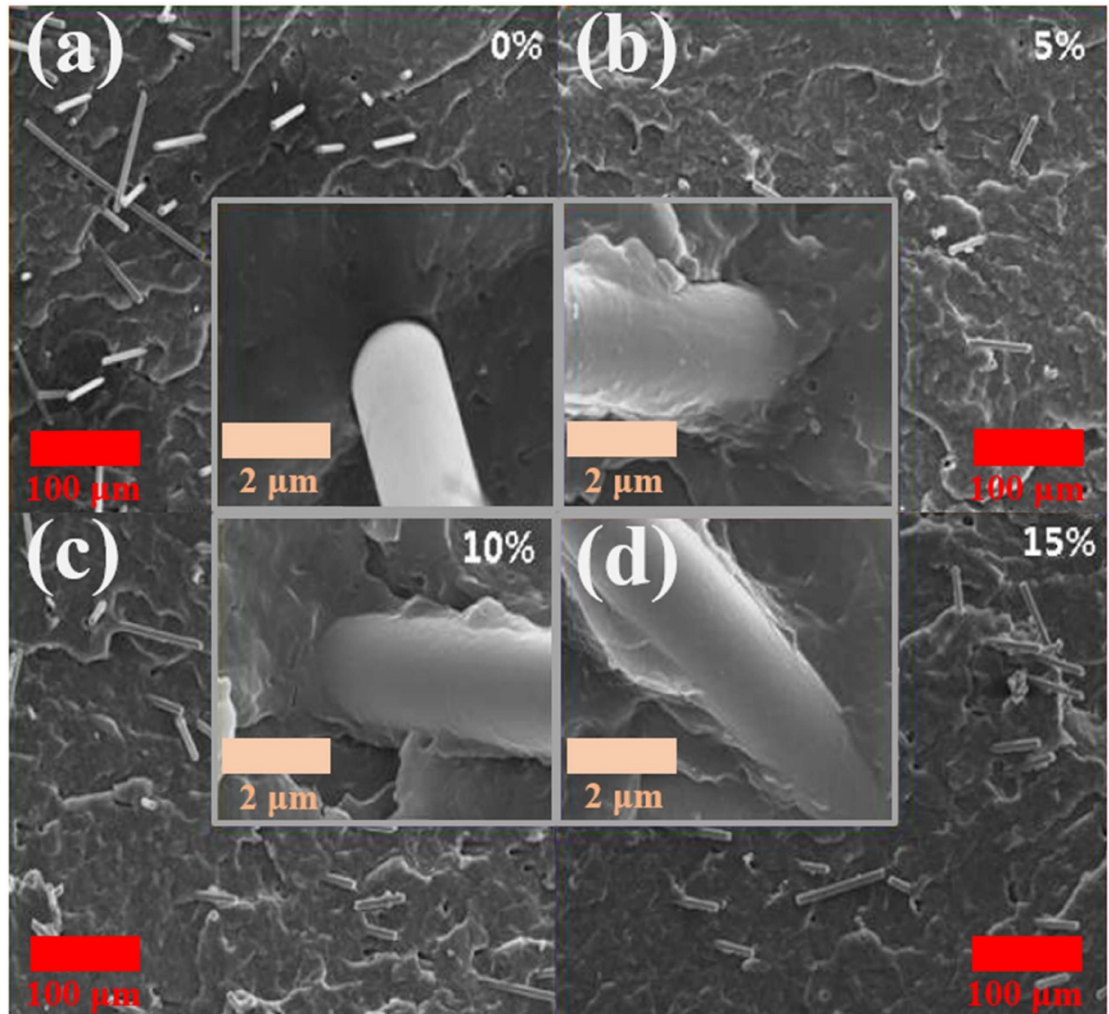


Figure 2. FE-SEM images of PP/CF/PP-g-MAH composites (a) without PP-g-MAH and incorporated with (b) 5 wt%, (c) 10 wt% and (d) 15 wt% of PP-g-MAH.

2.2. Composite fabrication

The resin and interface modifier were mixed to target content ratio, listed in table 1, using a twin screw extruder (L40/D19, Bautek CO, Uijungbu, Korea) at the temperature of 230 °C and a screw speed of 100 rpm with side feeding of LFT, as shown in figure 1. The prepared compounds were fabricated as specimens for analyzing physical properties using a heating press (D3P-20J, Dae Heung Science, Incheon, Korea) or lab-scale injection molding machine (CS-183 MMX, Custom Scientific Instruments Inc., Easton, PA, USA) at a pressure of 15 MPa for 10 min at 200 °C.

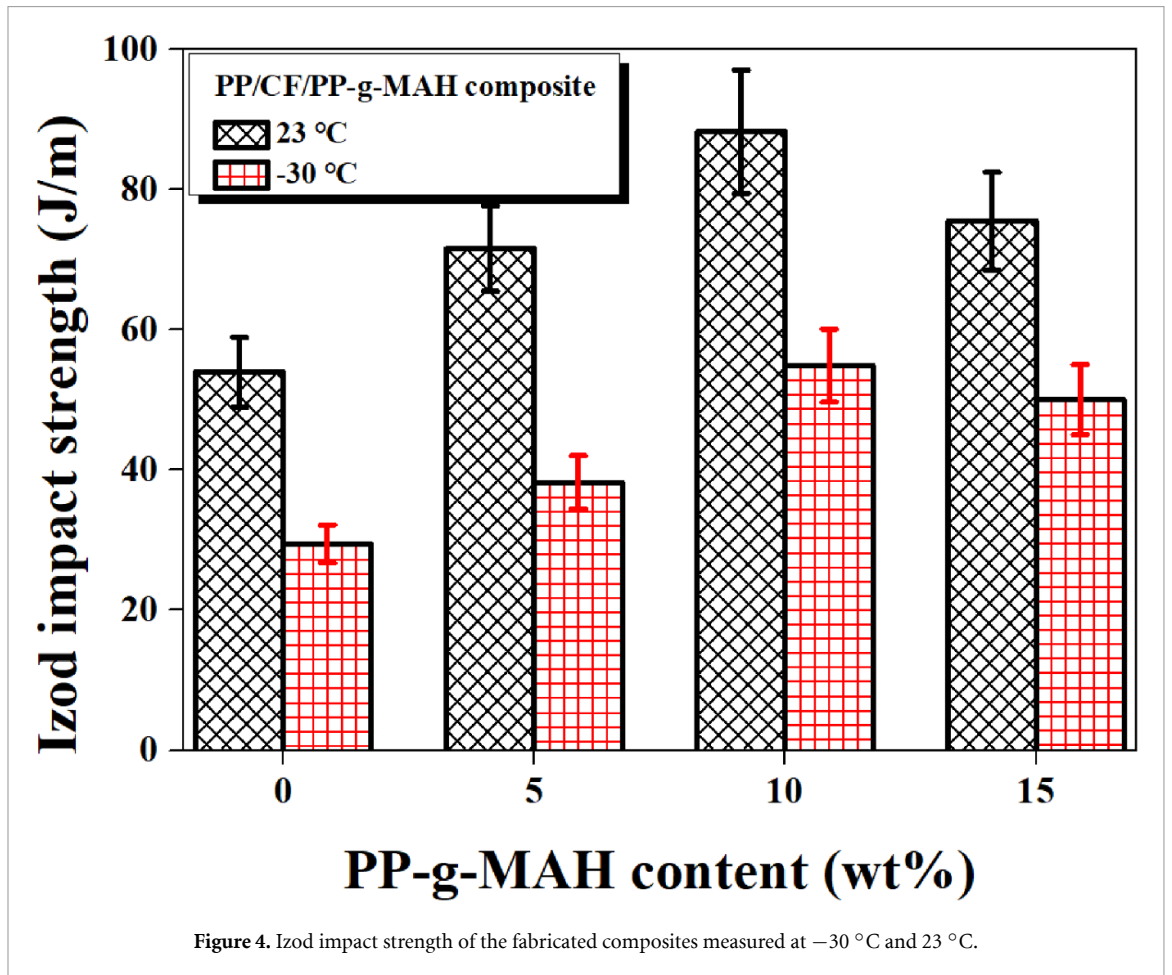
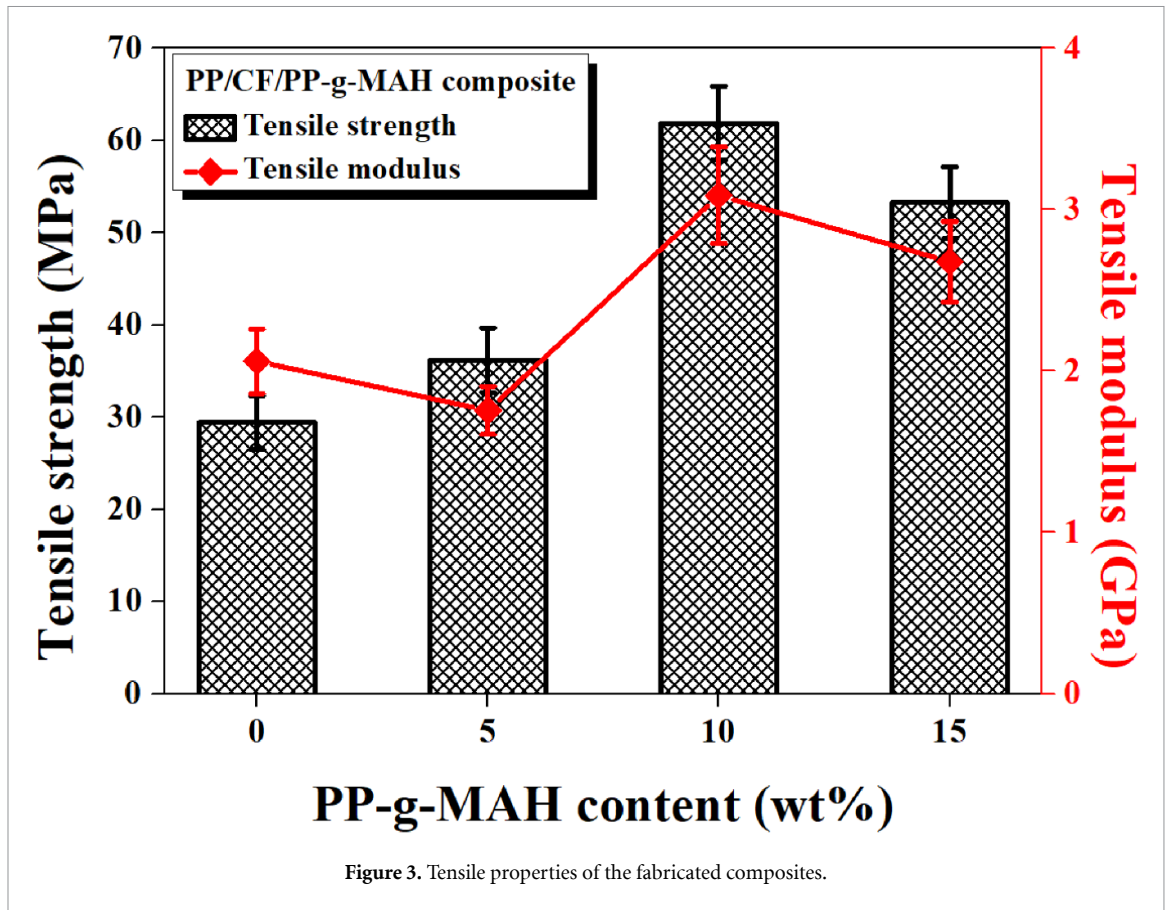
2.3. Characterization

2.3.1. Morphology

Fracture surface of the composite was coated with platinum in a vacuum for 100 s using a sputter coating machine (Ion Sputter E-1030, Hitachi High Technologies Co., Tokyo, Japan). The prepared specimen was observed for analyzing interface between CF and matrix with a field emission scanning electron microscope (FE-SEM, Nova NanoSEM 450, FEI Corp., OR, USA) at 10 kV.

2.3.2. Mechanical properties

Tensile strength and elongation at break were measured to ASTM D638 standard using a universal testing machine (Instron 5982, Instron Co., Norwood, MD, USA). Izod impact strength was measured according to ASTM D256 using an Izod impact test machine (Model 892, Tinius Olsen, Horsham, PA, USA). Flexural modulus was measured according to ASTM D790 standard, and HDT was analyzed according to ASTM D648 standard.



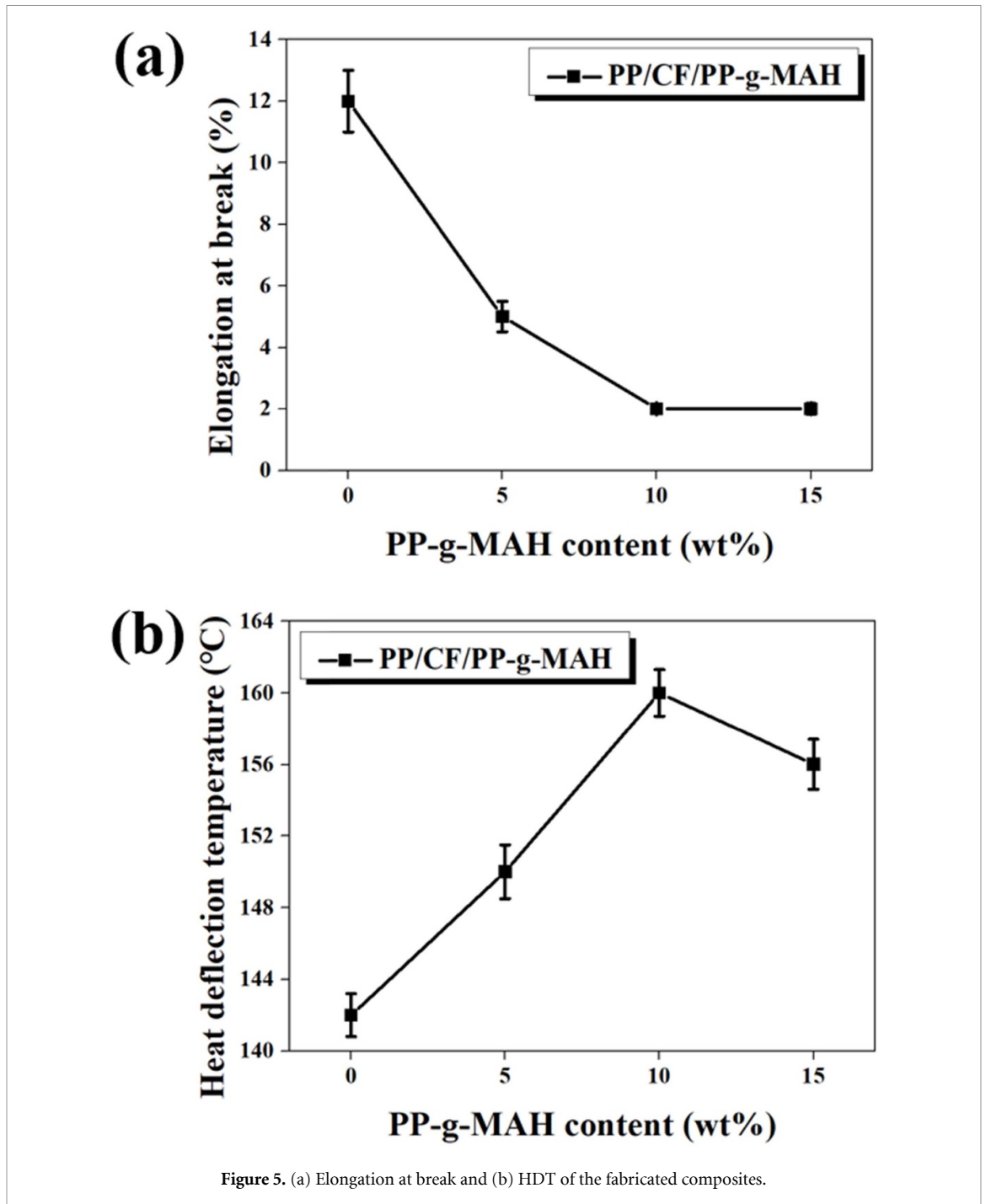


Figure 5. (a) Elongation at break and (b) HDT of the fabricated composites.

3. Results and discussion

FE-SEM images of the fracture surfaces of the prepared specimens are shown in figure 2. In the CF protruding from the fracture surface of the specimen without PP-g-MAH mixing, it can be observed that the resin is not stained. On the other hand, in the fracture surfaces of the specimens containing 5, 10, and 15 wt% of PP-g-MAH, it can be observed that the resin is embedded on the surface of the CF. These results indicate that PP-g-MAH acted as an interface modifier between the CF and resin, thereby enhancing the interfacial bonding between the CF and resin [20].

Figure 3 shows the tensile properties of the prepared composites. Tensile strength increased when interface modifier was added. In particular, when 10 wt% of PP-g-MAH was added, it was increased by about 110% compared to the control, resulting in 61.9 MPa. Tensile modulus also showed the similar trend. When PP-g-MAH was incorporated in 10 wt%, it was improved by about 50% to achieve 3.09 GPa. These results indicate that PP-g-MAH improved the interfacial bonding as an interface modifier and transfers the external

load applied to the specimen to the CF well, thereby increasing the tensile properties of the composite material.

Figure 4 shows the results of the Izod impact test at 23 °C and −30 °C. Irrespective of temperature conditions, the Izod impact strength was improved with the incorporation of PP-g-MAH. In particular, when PP-g-MAH of 10 wt% was added, compared to the control, the impact strengths were improved by about 63.6% at 23 °C, from 53.9 to 81.8 J m^{−1}, and by about 86.7% at −30 °C, from 29.4 to 54.9 J m^{−1}, respectively. These impact property results were also because the interfacial bonding between the resin and the CF was improved by PP-g-MAH [20].

Elongation at break is shown in figure 5(a). In the case where PP-g-MAH was not mixed, it can be interpreted that the interfacial bonding between CF and the resin was weak, so that it was difficult to transfer the load, resulting in slip at the interface and in high elongation [21]. However, as the content of PP-g-MAH increased, the interfacial bonding between CF and the resin became stronger, so that the load applied to the specimen can be completely transferred and the elongation decreased. Therefore, it was interpreted to show the same elongation after the 10 wt% composition in which the interfacial bond was completely formed. HDT results are shown in figure 5(b) to analyze the thermal properties of the manufactured composite material. Karsli and Aytac [20] reported that the incorporation of interface modifiers increased the heat resistance of the PP matrix and composites. However, when 15 wt% of PP-g-MAH was incorporated, it was observed that it acts as a small molecule in the resin and rather reduces the heat resistance.

From the results of the overall physical properties, it can be observed that as the PP-g-MAH content increases, the physical properties are maximized up to 10 wt% and slightly decreased at 15 wt%. These results can be analyzed that the addition of PP-g-MAH contributed to improving the interfacial bonding between the CF and the resin, and formed the optimum content at 10 wt%. In addition, at 15 wt% content, the blending effect of PP-g-MAH, which is a low molecular weight, was greater than the compatibilizing effect, thereby reducing the physical properties [22].

4. Conclusion

In this study, the effect of PP-g-MAH content on the physical properties of PP filled with LFTs was investigated. As can be seen from the tensile strength, tensile modulus, Izod impact strength, and HDT results, it was confirmed that the physical properties were improved when PP-g-MAH was incorporated. These results imply that the incorporated PP-g-MAH served as an interface modifier between CF and PP matrix. The physical properties of the composites continued to improve until the content of PP-g-MAH reached 10 wt%, but when PP-g-MAH of 15 wt% was incorporated, the physical properties of the composites were reduced. This result was because the blending effect of PP-g-MAH, which is a low molecular weight, was greater than the compatibilizing effect, thereby reducing the physical properties.

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