

Effect of Compounding Method on the Mechanical Properties of Polypropylene-Clay Nanocomposites

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ABSTRACT

This study investigates the effects of direct melt compounding, masterbatch dilution and compatibilizer addition on the mechanical, thermal and morphological properties of organoclay nanocomposites. Nanoclay reinforced polypropylene composites manufactured using melt mixing with and without adding polypropylene-graft-maleic anhydride (PP-g-MA). These composites were compared with nanoclay reinforced polypropylene materials with similar compounds diluted from commercial masterbatches. All compounded materials were prepared at 2, 4, 6, 8, and 10 wt% nanoclay. Series of tensile, flexural, and impact tests were conducted to evaluate mechanical properties.

Key words: polypropylene, mechanical properties, nanocomposites, masterbatch dilution

1. Introduction

During the last decade, nanoreinforced polymer composite materials have received great attention both in academia and industry due to their superior mechanical properties, and relatively low cost. Due to their high aspect ratio, nanoparticles/fibers provide better mechanical properties by enhancing the bonding between the matrix and the filler, and therefore providing a better load transfer between the matrix and the reinforcement [1-15]. Clay is one of the most studied nanofillers among researchers because of its availability, relatively easy surface modification and low price among nanofillers [1, 2]. Clay is naturally a hydrophilic material and increasingly used for reinforcement of polymeric materials [1-3]. Hydrophilic structure makes clay difficult to exfoliate in a polymer matrix especially polyolefin based matrices because of their strong hydrophobicity. This contraction is overcome by the surface treatment of clay to render its surface more hydrophobic and by using adhesion promoters to make the matrix and clay more compatible [1-3]. It is very well documented that the mechanical properties of PP/nanoclay nanocomposite is directly related to the degree of exfoliation of the nanoclay particles [4-7]. Prior studies have extensively focused on studying the clay exfoliation and reported successful attempts in achieving full exfoliation of clay particles by using a mixture of stearyl ammonium-exchanged montmorillonite, maleated

polypropylene (MAPP), and PP homopolymer [2, 4-15]. In recent years, specific efforts have been devoted to the development of melt-compounded polypropylene (PP) based Polymer nanocomposites with organically modified fillers in which coupling agents, such as polypropylene-graft-maleic anhydride (PP-g-MA), were used to improve both the nano-fillers' dispersion and particle-matrix adhesion [16, 17]. Most studies have shown that Young's modulus and tensile strength increase in nanocomposites as compared to neat PP [2-19]. However, in some cases, the impact resistance of nanocomposites decreased when a coupling agent is used [2, 8, 12, 15].

Melt compounding is one of the most used techniques to produce nanocomposites especially at the industrial scales [20, 21]. Melt compounding has mainly concentrated on twin-screw extrusion, however several work has been reported using laboratory scale batch mixers and microextruders. Batch mixers are conventionally utilized in preparation of masterbatches, but twin-screw extruder is very common and increasingly used nanocomposite formation process [1, 2]. Despite the importance of this topic, few studies has focused on investigating the effect of compounding method, screw rotation and masterbatch dilution on the mechanical and thermal properties of nanocomposites [2, 15, 20-22]. Previous studies [1, 2] have shown that using masterbatches lead to more effective dispersive mixing, which is more uniform and show better exfoliated structure, and enables more precise control of filler concentration in the final compound in comparison with direct mixing .

In this study we seek to investigate the effects of direct melt compounding, masterbatch dilution and compatibilizer addition on the mechanical of nanoclay reinforced PP matrix.

2. Experimental Procedure

The polymer used in this study was polypropylene impact copolymer (FHR Polypropylene AP5135-HS) from Flint Hills Resources, LP. It has a melt flow index of 35 g/10 min and a density of 0.9g/cm³. The polypropylene-graft-maleic anhydride (PP-g-MA) used had a molecular weight equal to 9100 and was purchased from Sigma-Aldrich. The nanoclay Nanomer I.44P was supplied by Nanocore and it has a quaternary ammonium chemistry based surface modification and an average particle size 15-20 micrometer. The commercial masterbatches nanoMax®-

PP-HiST were supplied by Nanocore. The nanoclay content in the nanoMax®-PP-HiST masterbatches was 50%. Note that the commercial masterbatches contain additives that are kept trade secret. Nanoreinforced PP composites were prepared by melt mixing PP pellets with nano-fillers using a C.W. Brabender minicompounder. Prior to compounding, the PP and nano materials were oven dried at 70°C for 12 hours. The in-house made compounds were prepared by direct melt mixing. The screw speed, the barrel temperature, and the blending time were kept constant during the manufacturing process at 60rpm, 180 °C, and 20 min, respectively. PP/nanoclay material was produced with and without adding a compatibilizer (PP-g-MA), and with varying the nanofillers loading from 2 wt. % to 10 wt. % using an increment of 2 %. Note that in the case of using a compatibilizer the ratio of the nanofillers to the PP-g-MA was always kept constant at 2:1. The commercial masterbatches (nanoMax®-PP-HiST) containing 50% nanoclay was diluted to achieve 2, 4, 6, 8, and 10 wt. % nanoclay. The nanoMax®-PP-HiST pellets and the PP pellets were premixed using a speed mixer and simultaneously introduced in the hopper of the C.W. Brabender minicompounder. Adding 4wt%, 8wt%, 12wt%, 16wt% and 20wt% commercial masterbatch result in 2, 4, 6, 8, and 10 wt %. All compounded materials were cut into pellets and then oven dried at 70 °C for 12 hours before being injection molded to make mechanical testing coupons. A summary of all compounded materials is shown in Table 1.

3. Evaluation of Nanocomposites

All the tension tests were conducted according to ASTM D 638-03. The tensile behaviors of composites were measured using an Instron 8801 with a 10 kN load cell. All the tension tests were tested at a rate of 0.2 in/min. The flexure tests were conducted according to ASTM D 790-03, using an Instron 8801 with a 4.48 N load cell. The support span was 50 mm. and tests were run at a test speed of 0.05 in/min. The impact tests were conducted according to ASTM D 256-06. The notches were added using a NotchVIS machine manufactured by Ceast.

4. Results and Discussion

Tensile modulus of elasticity and ultimate strength values of all compounded materials are shown in Figure 1 and 2, respectively. The test results showed that the tensile elastic modulus consistently increases when increasing the nanoclay loading in PP-C, PP-C-MAPP, and PP-COMMB. The maximum increase in the MOE was around 60% and it was achieved by adding 6% of nanoclay (Nanomer I.44P) powder to the PP matrix (PP-C-6). Moreover, the results show that adding PP-g-MA to the PP matrix (PP-C-MAPP) leads to lower MOE values when compared to PP-C and PP-COMMB, as shown in Figure 1. This reduction in performance is probably attributed to the macromolecular

modification of the PP matrix caused by the addition of PP-g-MA, a low molecular weight and high grafting content. Examining the ultimate strength data it can be seen that there was not significant improvements in the ultimate strength of PP-C and PP-MAPP-C when adding nanoclay. In contrast, there was clear improvement in the ultimate strength of PP-COMMB which constantly increased when increasing the nanoclay loading. It is important to note that adding more than 2wt% nanoclay resulted in a reduction in ultimate strength, as shown in Figure 2. The maximum increase in the ultimate strength was around 11% and it was achieved by adding 4wt. % nanoclay using commercial masterbatches (PP-COMMB-4).

The flexural modulus of elasticity and ultimate flexural strength of nano-reinforced PP composite are shown in Figure 3 and 4, respectively. The test results show that the elastic modulus consistently increases when increasing the wt% of nanoclay fillers for all types of fillers, as shown in Fig. 3. The maximum increase in the elastic modulus was around 45% and it was seen in PP-COMMB-10. The ultimate flexural strength decreased when adding nanoclay in both PP-C and PP-MAPP-C nanocomposites, and it increased when adding nanoclay to PP-COMMB. For instance adding 4wt% nanoclay resulted in 10% and 12% decrease in ultimate strength of PP-C and PP-MAPP-C, respectively and a 20% increase in PP-COMMB. The maximum increase in flexural strength was about 16% and was obtained when adding 10%wt in PP-COMMB composites, as shown in Figure 4. Similar to the tensile strength results, adding PP-g-MA resulted in lower flexural modulus and ultimate flexural strength. The reduction in performance can be also attributed to the macromolecular modification of the PP matrix caused by the addition of PP-g-MA, as previously explained. In summary, it was shown that PP-COMMB-2 and PP-COMMB-4 nanocomposites exhibit superior tensile and flexural properties as compared to neat PP, PP-C, and PP-MAPP-C nanocomposites.

The impact test results for notched specimens are shown in Figure 5. The impact test results show that the energy absorption of pure PP consistently decreases as the filler content increases. The decrease in the notched impact strength was not surprising since the matrix becomes more crack sensitive by adding fillers. Notched impact behavior is generally controlled to a greater extent by factors affecting the propagation of fractures initiated at predominating stress concentration at the notched tip.

5. Conclusions

In this study, the effects of filler loadings, surface treatments and compatibilizers on the tensile, flexural and impact properties were investigated. The most promising results were shown in PP-COMMB-2 and PP-COMMB-4 nanocomposites which exhibited superior tensile and flexural properties as compared to neat PP, PP-C, and PP-MAPP-C nanocomposites. Adding PP-g-MA compatibilizer to the PP matrix resulted in lower mechanical properties

compared to PP-C and PP-COMMB. The notched impact strengths were lower when adding nanoclay to the PP matrix for PP-C, PP-MAPP, and PP-COMMB. It seems that adding 2 wt% of nanoclay to PP matrix, increases the modulus of elasticity and ultimate strength, of the PP matrix. In general, PP-COMMB nanocomposites show better mechanical properties in comparison with PP-C and PP-C-MAPP nanocomposites.

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7. References

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Nanocomposites	Abbreviation	Method
PP+ clay 2wt%	PP-C-2	Direct melt compounding
PP+ clay 4wt%	PP-C-4	Direct melt compounding
PP+ clay 6wt%	PP-C-6	Direct melt compounding
PP+ clay 8wt%	PP-C-8	Direct melt compounding
PP+ clay 10wt%	PP-C-10	Direct melt compounding
PP+ clay 2wt% + MAPP 1wt%	PP-C-MAPP-2	Direct melt compounding
PP+ clay 4wt% + MAPP 2wt%	PP-C-MAPP-4	Direct melt compounding
PP+ clay 6wt% + MAPP 3wt%	PP-C-MAPP-6	Direct melt compounding
PP+ clay 8wt% + MAPP 4wt%	PP-C-MAPP-8	Direct melt compounding
PP+ clay 10wt% + MAPP 5wt%	PP-C-MAPP-10	Direct melt compounding
PP+ nanoMax®-PP-HiST 4wt%	PP-COMMB-2	masterbatch dilution
PP+ nanoMax®-PP-HiST 8wt%	PP-COMMB-4	Masterbatch dilution
PP+ nanoMax®-PP-HiST 12wt%	PP-COMMB-6	Masterbatch dilution
PP+ nanoMax®-PP-HiST 16wt%	PP-COMMB-8	Masterbatch dilution
PP+ nanoMax®-PP-HiST 20wt%	PP-COMMB-10	Masterbatch dilution

Table 1: Composition and processing history of the nanoclay reinforced PP composites

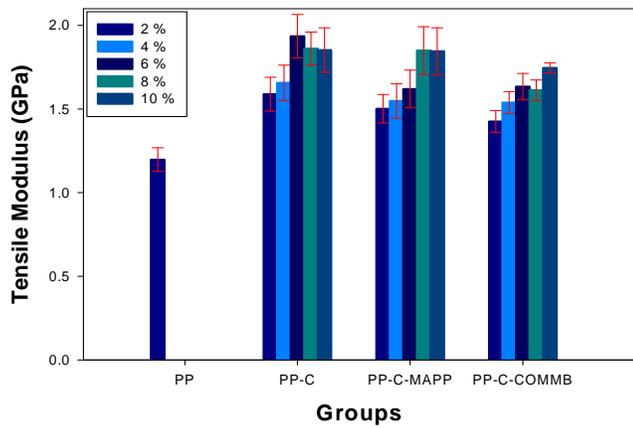


Figure 1. Tensile modulus of elasticity as a function of the filler weight percent

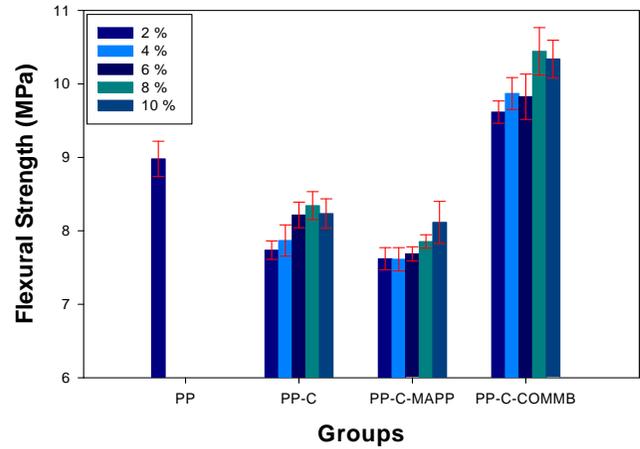


Figure 4. Flexural strength as a function of the filler weight percent

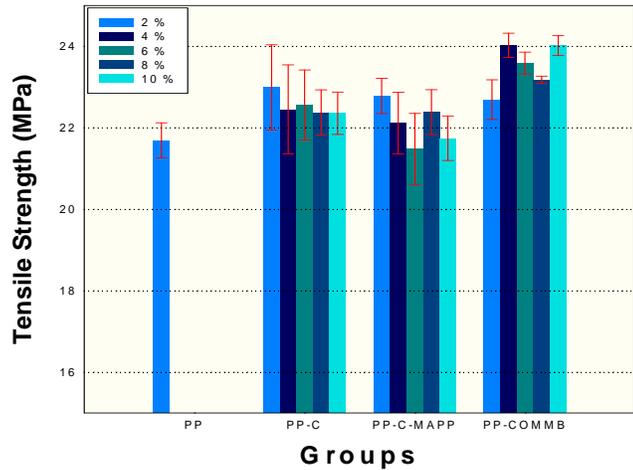


Figure 2. Tensile strength as a function of the filler weight percent.

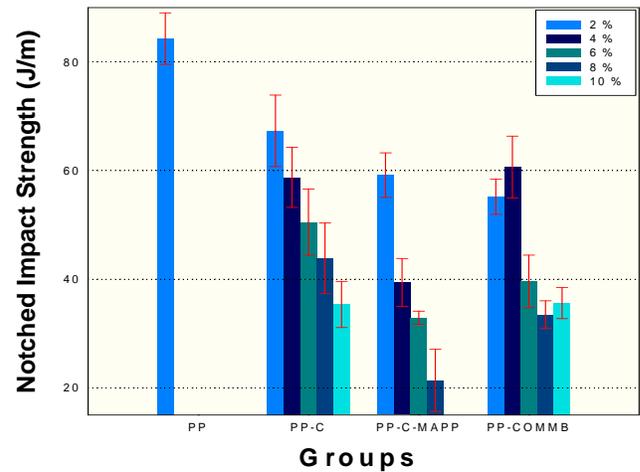


Figure 5. Notched impact strength as a function of the filler weight percent.

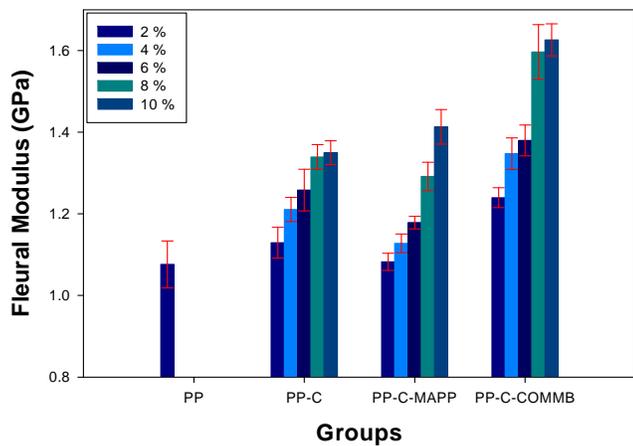


Figure 3. Flexural modulus of elasticity as a function of the filler weight percent.