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Improving the mechanical behavior of polypropylene nanocomposites

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The addition of smectite-based nanoclays with appropriate compatibilizers can enhance the mechanical properties of polypropylene matrices.

The potential of layered silicates to increase the strength, toughness, thermal stability, thermal conductivity, and flame retardancy of polymers has drawn significant interest in recent years. For nanoclays to be used as additives in nonpolar polymer matrices, compatibilizers (which act as a bridge between nanoclay and polymer matrix) are required.[1,2] Montmorillonite (MMT), phlogopite, and hectorite are the most commonly used smectite-type layered silicates for the preparation of polymer nanocomposites (PNCs). Due to its high cation exchange capacity, surface area, and surface reactivity, smectite is a valuable mineral class for industrial applications (e.g., oil well drilling and the filtering and decolorization of oils) and in civil engineering (e.g., for impeding water movement).[3]

Due to its technological simplicity, compounding by melt mixing represents the most appealing industrial method for the preparation of PNCs. From an economical point of view, the use of a co-rotating twin-screw extruder for continuous processing is preferable to melt mixing in a discontinuous kneader because of the enhanced throughput rates it allows.[4] At the Kunststoffmesse 1998, Krauss Maffei presented the injection-molding compounder (IMC) for the first time.[5] The characteristic feature of this IMC is a twin-screw extruder that is directly integrated into an injection-molding system. The injection-molding compounding process combines two processing steps: material compounding and injection molding.[6–8]

By adding various smectite-based nanoclays with different compatibilizers, we have been able to evaluate the enhancement of the mechanical properties of polypropylene matrices. These PNCs were produced using the polymer nanocomposite injection-molding compounder (PNC-IMC). We performed material compounding and subsequent injection molding directly with only one plasticizing process, using a heated melt line and a melt accumulator. As a compatibilizer, we used copolymer- and homopolymer-based polypropylene grafted maleic anhydride (CP and HP PP-g-MA) and then measured the yield stress and Young's modulus to evaluate the influence of different nanoclays in the polypropylene (PP) matrices.

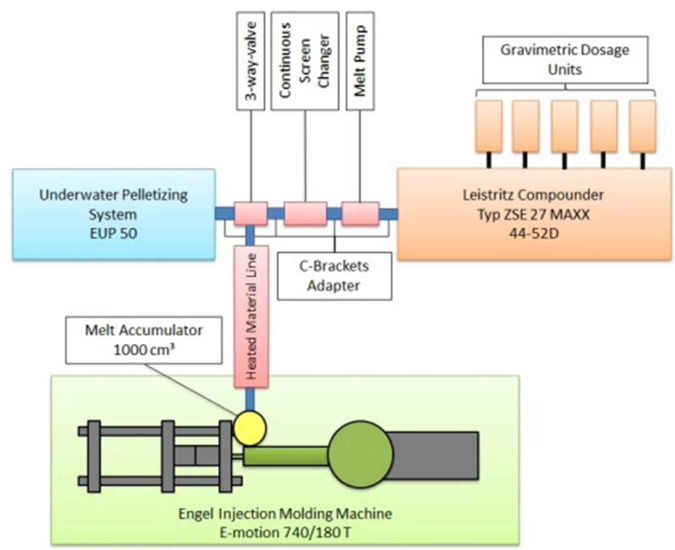

Figure 1. *The polymer-nanocomposite injection-molding compounder (PNC-IMC).*

We produced the PNCs using the PNC-IMC shown in Figure 1. PP and compatibilizer were fed upstream through the main hopper, and the nanoclay was fed downstream at the fourth extruder barrel by separately controlled gravimetric dosage units. The PP was kept constant at 85wt%, and the amount of compatibilizer and nanoclay were both varied between 5 and 10wt%. The melt pump is not used in the conventional way in this method, acting instead as a throttle to generate shear stress and residence time.

Continued on next page

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Table 1. Physical properties of the polypropylene grafter maleic anhydride (PP-g-MA) compatibilizers used. MAL: Maleic anhydride. HP: Homopolymer. CP: Copolymer. MFR: Melt mass flow rate.

Property	TPPP 2112	TPPP 2112	P 613	P 353
Trade name	Scona	Scona	Fusabond	Fusabond
Abbreviation	S-HP	S-CP	F-HP	F-CP
MAL (%)	0.9–1.2	0.9–1.3	<0.5	1–2
Polymerization	HP	CP	HP	CP
MFR (g/10min)	4–8	3–8	120	470

An overview of the tensile properties of PNCs manufactured with nanoclay phlogopite mica, and four different compatibilizers—S-HP, S-CP, F-HP, and F-CP (S and F represent the trade names Scona and Fusabond), see Table 1—and three different compatibilizer/mica ratios (1:2, 1:1, and 2:1) are shown in Figure 2. The Young's modulus and yield stress of pure PP are 1819.8 and 36.4MPa, respectively, and the addition of nanoclay increases these tensile properties (see Figure 2). There is a strong enhancement of these properties when the ratio of compatibilizer/mica is 1:2, irrespective of which compatibilizer is used. When mica is employed as nanoclay and S-HP PP-g-MA as compatibilizer with a ratio of 1:2, the resultant PNCs show the highest increase in Young's modulus compared to pure PP (65%). We measured similar mechanical properties in the PNCs manufactured using natural unmodified MMT, organically modified MMT (OMMT), and organically modified hectorite (OMHT). We also found the addition of HP PP-g-MA in a compatibilizer/nanoclay ratio of 1:2 to result in the best tensile properties compared to all other nanoclays.

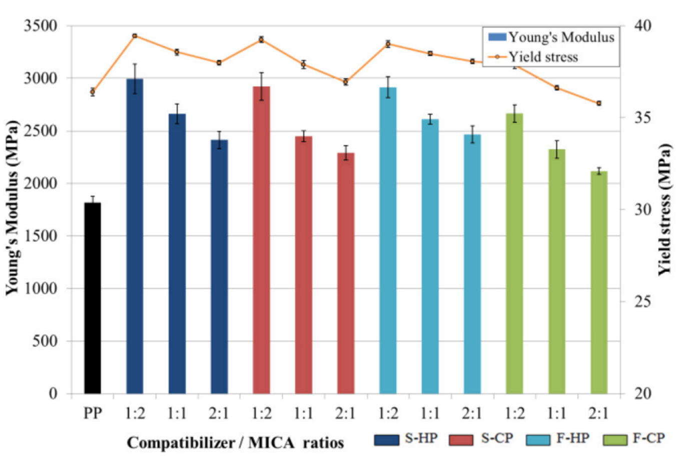

Figure 2. *The effect of compatibilizer and compatibilizer/mica ratios on the Young's modulus and yield stress of PNCs.*

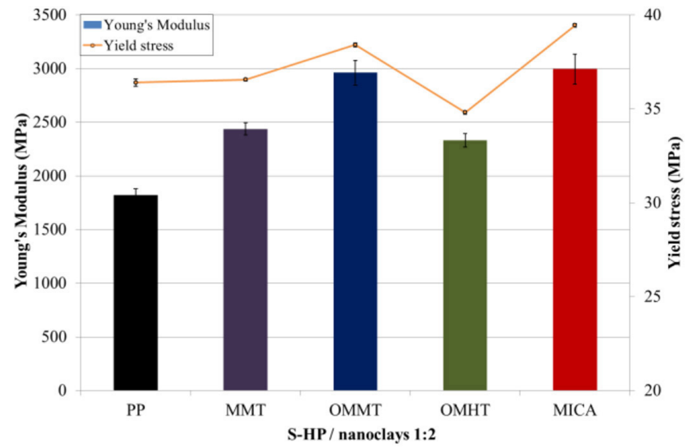

Figure 3. *The effect of different types of nanoclays on the Young's modulus and yield stress of PNCs with 5wt% S-HP compatibilizer and 10wt% nanoclay.*

The effect of nanoclays on the tensile properties of PNCs produced with S-HP as compatibilizer with a compatibilizer/nanoclay ratio of 1:2 is shown in Figure 3. Compared to that of pure PP, the Young's modulus is increased by 28% for OMHT-based PNCs. Although the hectorite nanoclay is organically modified, the MMT-nanoclay-based PNCs showed better tensile properties. The addition of MMT leads to an increase in the Young's modulus of ∼34%, whereas PNCs based on OMMT showed an increase of about 62% over pure PP. This difference occurs due to the larger interlayer spacing in the organically treated MMT, which facilitates better interfacial bonding between the clay platelets and the PP. PNCs based on phlogopite mica also show good tensile properties among the chosen organoclays.

In summary, our results provide insight into the appropriate selection of materials and composite ratios for improving material properties in PNCs produced using the PNC-IMC. We were able to improve the degree of dispersion by incorporating compatibilizers. Furthermore, the addition of nanoclays led to a dramatic increase in the Young's modulus (∼65%). The clay type, compatibilizer, and compatibilizer/nanoclay ratio were determined to be significant factors in relation to the tensile properties of the resulting composites. In future work, we will continue to study the thermal and morphological properties of PNCs developed in this manner and intend to use specially shaped injection-molding nozzles to further improve their tensile properties.

Continued on next page

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