



Red mud/polypropylene composite with mechanical and thermal properties

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Abstract

Polypropylene (PP) based composites containing 0, 5, 10, 15, 20, 30, and 50 wt% red mud are granulated by twin-screw extrusion and injection molding. Their mechanical properties such as tensile strength, flexural strength and modulus, impact strength, and thermal properties are determined. After filling with red mud, the flexural strength and modulus, thermal deformation temperature, and Vicat softening temperature increase, whereas the impact strength decreases with increasing red mud contents. The maximum tensile strength is observed from the PP doped with 15 wt% red mud. Scanning electron microscopy (SEM) is used to investigate the dispersion of red mud in the PP matrix.

Keywords

red mud, polypropylene, composite, mechanical properties, thermal properties

Introduction

Red mud is a by-product arising from caustic leaching of bauxites during the production of industrial alumina. About 1–2 tons of red mud residues are produced for each ton of alumina and millions of tons of red mud have hitherto been accumulated with most of them being stored or released to the sea with very little reutilization. Storage of red mud in wetlands poses serious environmental issues due to the high alkalinity leading to soil alkalization and water pollution. Furthermore, dry storage can produce dust galore and pollute the atmosphere, and direct release to the sea contaminates seawater undermining the fishery industry. Hence, better clean-up processes are urgently needed¹ and recycling of red mud has aroused much interest. For instance, it can be used as building materials^{2,3} but the value added tends to be low. Unsintered brick can be produced from red mud, fly ash, sand, and other materials with relatively low emission of gaseous pollutants and energy consumption.⁴ Jute/sisal composites reinforced with red mud possess favorable chemical, mechanical, and fire-resistant properties, making them promising substitutes to timber.⁵ Red mud is rich in Si, Al, Fe, and Ti and can be used to recover Al, Fe,³ Ti,⁶ and scandium.^{7–9} It can also be used as radio-opaque materials in ceramic processing using phosphate bonding.¹⁰ However, the natural radioactivity poses

problems related to safe utilization of these building materials.¹¹

Having active anion-absorbing capability, red mud can be used in water treatment as a coagulant, adsorbent, or catalyst to remove pollutants¹² such as phenol,¹³ cadmium,¹⁴ phosphate,^{15,16} fluoride,¹⁷ copper,¹⁸ arsenic,¹⁹ and dyes.²⁰ Red mud has also been found to remove As, Pb, and Zn efficiently from acidic mine sites²¹ and even absorb acidic gases.²² Like other adsorbents, the adsorption of As(III) and As(V) on red mud followed Langmuir isotherm.^{23–25}

Red mud is also used as a reinforcing phase in polymeric materials such as polyvinyl chloride (PVC),²⁶

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polyethylene/polypropylene (PE/PP),^{27,28} PVC/PE, PVC/PP, and PVC/PS (PS, polystyrene).²⁹ However, the red mud affects negatively the tensile and flexural strength properties.³⁰ In this study, red mud is incorporated into PP to improve the mechanical and thermal properties. Our results are positive suggesting an effective way to recycle red mud and alleviate environment impact.

Experimental

PP was purchased from SINOPEC Beijing Yanshan Petrochemical Co., Ltd. The red mud was supplied without charge by Shandong Weiqiao Pioneering Group Co., Ltd. The massive red mud was rubbed and then dried at 140°C, whereas the PP was dried at 80°C before use. The red mud particle size distribution was measured by a laser particle size analyzer (BT-9300) with a average size of 4 μm. A series of red mud/PP composites with red mud contents of 0, 5, 10, 15, 20, 30, and 50 wt% were prepared. The red mud and PP mixture were granulated by a twin-screw extruder ($\phi 35$) and the L/D ratio was 40:1. The granules were dried and injection-molded to standard samples using an injection-molding machine (HD-90). The samples were stored at a relative humidity of 50% at 23°C for 24 h before the mechanical properties were evaluated.

The melt flow index (MFI) of the composites was determined by a melt flow rate measurer (μ PXRZ) according to GB/T3682-2000. The tests were conducted under standard test conditions (2.16 kg, 230°C). The tensile and flexural properties were investigated using an electronic tensile machine (DXLL-1000). The tensile property was determined from dumbbell-shaped specimens according to GB/T1040-1992 at a cross-head speed of 5 mm/min. At least five samples were tested for each set of conditions to determine the average values. The flexural specimens were prepared to the required size of $80 \times 10 \times 4 \text{ mm}^3$ as stipulated in the GB/T9341-2000 protocol. The tests were carried out at a loading rate of 2 mm/min and stopped to record the values when the deformation quantity of the sample was 6 mm.

The impact strength was studied using a XJJ-50 impact machine according to GB/T1043-93, and Izod impact experiments were conducted on a XJU impact machine as specified by GB/T1843-1993. The thermal deformation and Vicat softening points were determined according to GB/T1634-79 and GB/T1633-79 using a XRW-300 machine. The tests were stopped when the deformation quantity was -1.000 mm for thermal deformation and -0.350 mm for Vicat softening point. The morphology of the red mud and fractured surface on the specimens after tensile tests was

examined by a scanning electron microscope (Hitachi S-450, Japan) at an accelerating potential of 25 kV after a thin gold layer was sputter-coated onto each sample to circumvent sample charging.

Results and discussion

The fluidity which is related to how well the red mud is dispersed in the PP matrix is measured by the MFI. Figure 1 shows the influence of the red mud contents on the MFI of the composites under standard testing conditions. The MFI decreases sharply with increasing red mud concentration and so proper processing conditions are needed, especially for high red mud contents.

The relationship between the tensile strength and red mud content in the composites in Figure 2 shows that the tensile strength increases when the red mud

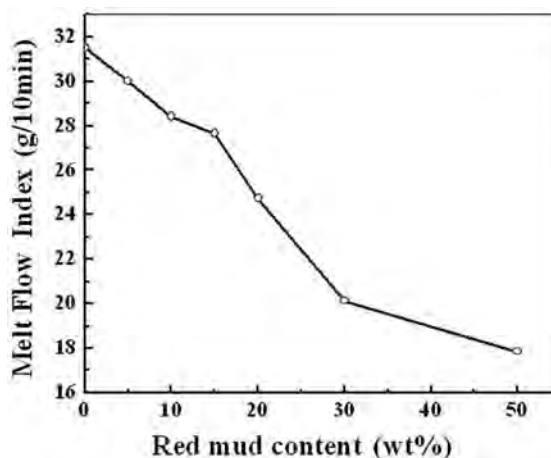


Figure 1. Effects of red mud contents on the MFI of the red mud/PP composites.

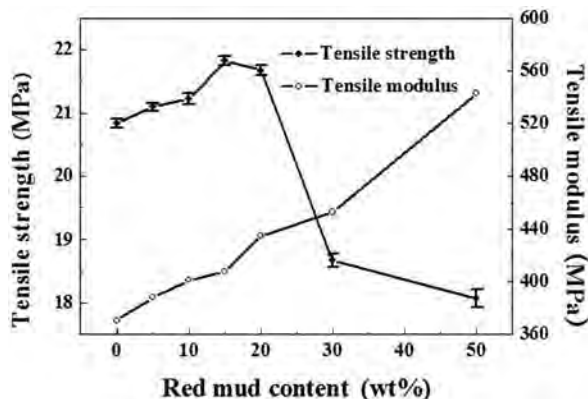


Figure 2. Effects of red mud contents on the tensile strength and modulus of the red mud/PP composites.

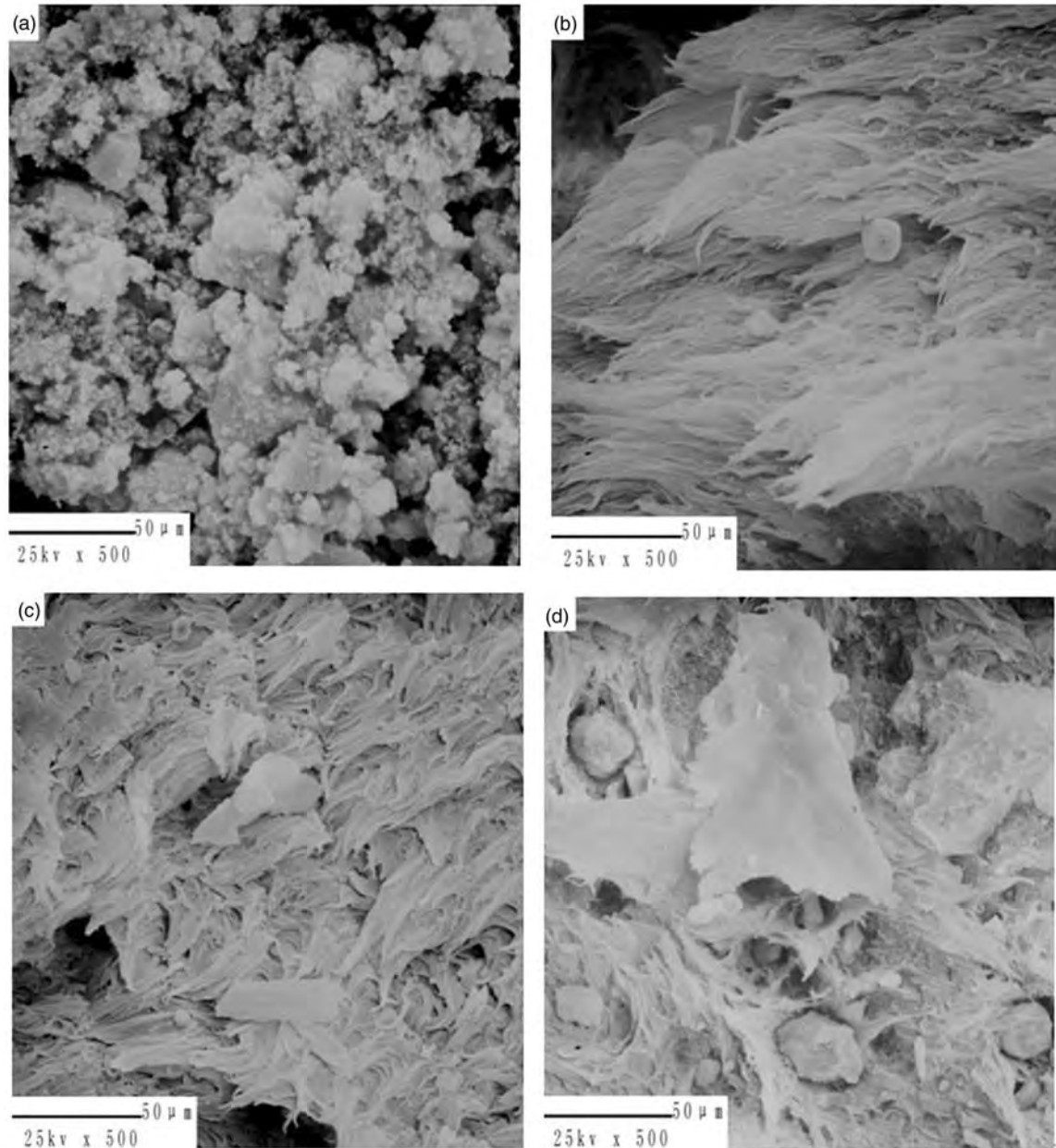


Figure 3. SEM photographs of red mud particles and red mud/PP composites with different red mud contents: (a) pure red mud, (b) 10 wt% red mud/PP, (c) 20 wt% red mud/PP, and (d) 30 wt% red mud/PP.

concentration increases from 0 to 15 wt%, but in a red mud content of above 20 wt%, the tensile strength drastically decreases. The tensile strength reaches a maximum value of 21.82 MPa which is about 4.75% higher than that of pure PP (20.83 MPa) when the red mud concentration is 15 wt%. Although the tensile strength decreased with the increase of red mud content, the tensile modulus increased as a result of the higher rigidity of red mud particles.

The average size of the red mud particles is about 4 μm . Moreover, it is observed from Figure 3(a) that the size distribution is heterogeneous and there are particles

as large as 50 μm . It is because red mud has a tendency to agglomerate even under low humidity. As shown in Figure 3(b), red mud is better dispersed in the matrix showing little agglomeration when the concentration is 10 wt%. Figure 3(c) indicates that in spite of more agglomeration at a concentration of 20 wt%, the tensile strength is still much higher than that of the polymer matrix. However, further raising the red mud content to 30 wt% results in excessive agglomeration, poor dispersion, and consequently reduced the tensile strength, as shown in Figure 3(d). Hence, introduction of fine red mud particles at a relatively small concentration

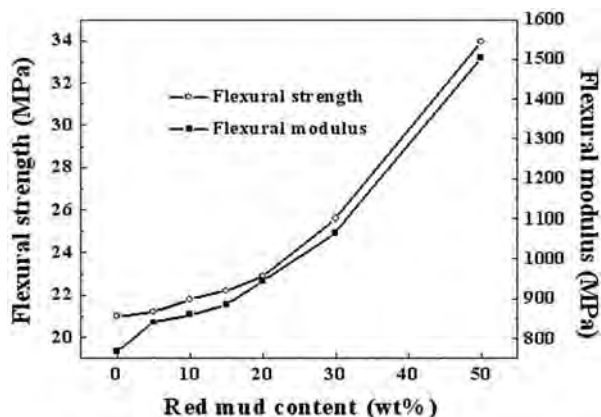


Figure 4. Effects of red mud contents on the flexural strength and flexural modulus of the red mud/PP composites.

effectively improves the tensile strength and the red mud content should not be larger than 20 wt%, otherwise calls for proper compatibilization.

Figure 4 shows incorporation of red mud changes the flexural properties of the composites. Both the flexural strength and modulus increase with higher red mud contents. The flexural strength reaches 33.96 MPa at 50 wt% and it is 61.7% higher than that of PP. At the same time, the flexural modulus is 1504 MPa and 95.8% higher than that of pure PP. The rigidity of red mud plays a key role in the flexural properties. Although agglomeration becomes more prevalent at high red mud concentrations (Figure 3), the flexural properties of the red mud/PP composites are improved obviously.

Figure 5 shows that the Izod impact strength of the composites decreases with increasing red mud contents. Similar to the Izod impact strength, the Charpy impact strength diminishes with red mud contents as well. The results indicate that introduction of red mud negatively affects the impact properties. The low interaction between the PP matrix and red mud fillers is one of the key factors influencing the impact properties. The reason why the introduction of red mud into PP degrades the impact properties of the composites is that the two phases are joined by weak van der Waals force. The decrease of tensile and impact strengths has shown worse interface and dispersion at higher loading, which result in the decrease of the stressed area, making the tensile and impact strength decrease. While on the bending stress, the rigid red mud particles are useful to support the matrix, hampering its movement, makes the flexural strength increase. Nonetheless, to reap the overall benefits, the red mud concentration should be low, at which compromise in the impact properties is well compensated for by enhancement in other properties.

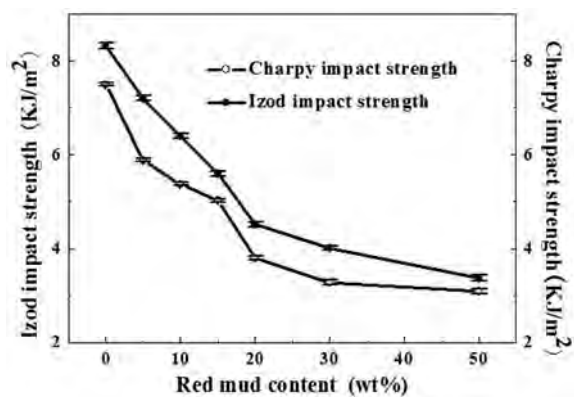


Figure 5. Effects of red mud contents on the Izod impact strength and Charpy impact strength of the red mud/PP composites.

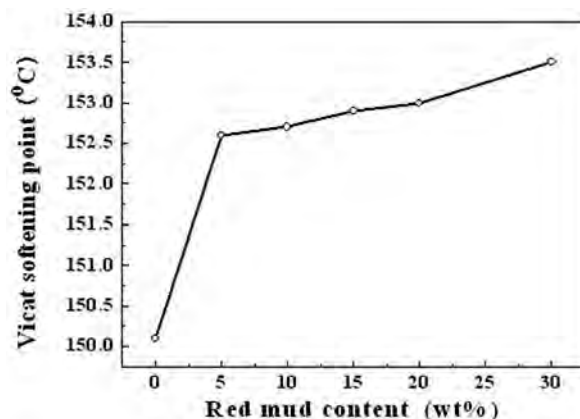


Figure 6. Effects of red mud contents on the Vicat softening point temperature of the red mud/PP composites.

Figure 6 shows that the Vicat softening point temperature of the composites increases slightly with red mud content and it is 3.4°C higher than that of PP when the red mud concentration is 30 wt%. But there is a step variation observed when only a 5 wt% of red mud is added to the PP and further addition does not seem to be equally effective in producing changes on the Vicat point. As shown in Figure 7, the thermal deformation temperature is also improved evidently by incorporating red mud. It is about 26.3°C higher at a red mud concentration of 30 wt%. The introduction of high-melting point red mud particles plays an important role in supporting the molecular chains in the matrix when the samples start to soften. The underpinning capability increases at high red mud concentrations and so the temperature of Vicat softening point and thermal deformation increase. This improves the thermal stability and usable temperature range of the materials.

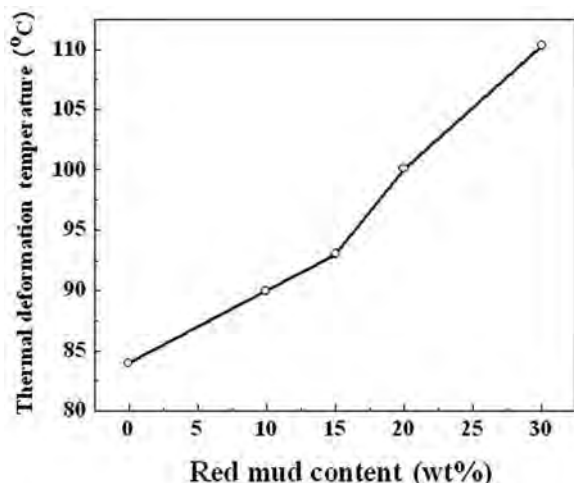


Figure 7. Effects of red mud contents on the thermal deformation temperature of the red mud/PP composites.

Conclusion

In this article, a series of PP-based composites containing different red mud contents are prepared. The mechanical and thermal properties of red-mud/PP composites are investigated. Addition of red mud to PP improves the tensile strength, flexural characteristics, and thermal properties of the composites. The tensile strength reaches a maximum value at a red mud concentration of 15 wt%, but the impact property degrades with increasing red mud contents. Red mud/PP composites with better overall mechanical and thermal properties can be achieved at relatively lower red mud contents. This suggests an effective way to recycle red mud and alleviate environmental impact.

Acknowledgments

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