The Potential Use of Waste Cement as a Filler in Polymer Composites

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Abstract. This study explores the potential to use waste cement particles from ready-mixed concrete industry as a low cost filler in polypropylene. Its effects on mechanical and morphological properties were investigated in comparison with commercial cement and calcium carbonate. Mixing and shaping procedures of the polymer composites specimen were conducted by two-roll mill and injection molding, respectively. Next, the effect of filler loading (0, 10, 20, 30, 40, and 50 phr) and filler type on the mechanical and morphological properties of the polymer composites were studied. The results show that when filler loadings increased, the young’s modulus, flexural modulus, impact strength, and hardness of the polymer composites also increased accordingly, while the tensile strength and flexural strength decreased. Moreover, the results show that the waste cement had a greater effect on the enhanced mechanical properties compared to commercial cement and calcium carbonate. Furthermore, the polymer composites’ morphology was studied using scanning electron microscopy. A microstructure analysis was performed to verify and provide a better assessment of the performance properties of the polymer composites.

1. Introduction

Recently, ready-mixed concrete has become widespread and several construction industries in Thailand utilize ready-mixed concrete in building construction. Customers normally receive ready-mixed concrete from the producer using rotating-drum truck mixers on demand and in the specific quantity required. Occasionally these trucks return residues of the ready-mixed concrete back to the producer. That sand, gravel, and cement are then separated and the sand and gravel is reused for ready-mixed concrete processing. However, waste cement is eliminated by landfill, which pollutes the environment and increases costs for the producer. Due to the rise in the amount of waste cement, this study generates alternative uses for waste utilization, specifically proposing waste cement as a filler for polymer composites.

Polymer composites have gained greater attention over recent decades in different technological applications due to their light weight, cost reduction, and improved mechanical properties. Normally, fillers such as calcium carbonate, clay, and talc have been widely selected for use in improving properties and reducing costs in the plastics industry [1-4]. A number of studies have investigated polymer composites prepared using waste material as a filler. Žlebeka T et al. studied the suitable use of waste glass in polymer anchor materials based on epoxy resin. The results led to the selection of a formulation that yielded the best quality of polymer anchor [5]. Meanwhile, Çınar M E and Kar F studied the potential for using marble dust as a reinforced element in composite materials. They
reported that increasing the marble dust ratio improved the bending strength, tensile strength, hardness, and thermal conductivity [6]. Further, Aman A et al. examined the possibility of waste material as a filler for polymeric composite insulation to be environmentally and economically beneficial. Seashells ($\text{CaCO}_3$) and waste glass ($\text{SiO}_2$) were selected to produce an artificial wollastonite (calcium silicate-$\text{CaSiO}_3$) to use as a filler in a polypropylene (PP) matrix. It was found that the chemical compositions of the artificial wollastonite was similar to natural wollastonite [7].

The main aim of the present study was to explore the potential for using waste cement as a filler in polymer composites. Polypropylene (PP)—a commodity plastic—is used as a matrix. The effect of filler content on the mechanical properties were examined. Commercial cement and calcium carbonate were selected for use as a filler to compare their properties with waste cement. The study results show the potential for using waste cement in the plastics industry.

2. Experimental

2.1. Materials

Polypropylene, 1100NK was purchased from IRPC Public Company Limited (Thailand). This had a melt flow index of 11 g/10 min (190°C, 2.16 kg). Waste cement powder derived from ready-mixed concrete was selected from Concrete Products and Aggregate Company Limited (CPAC) (Thailand), which was filtered with a screen panel of 400 meshes. Commercial cement (Ordinary Portland cement-grade) was obtained from Siam Cement Group, Thailand. Calcium carbonate which selected as the commercial filler and was supplied by Kij Paiboon Chemical Limited Partnership (Bangkok, Thailand).

2.2. Preparation of polymer composites

The polypropylene filled with different filler, i.e. waste cement, commercial cement, and calcium carbonate were added at 0, 10, 20, 30, 40, and 50 phr. All the polymer composites were melt compounded in two-roll mill at 190°C for 12 minutes and then pelletized and oven dried.

2.3. Mechanical analysis

An injection molding process was used to prepare the specimens for tensile, flexural, impact, and hardness testing. Tensile testing was conducted using a universal testing machine (model M500-25AT, Testometric). The specimens were made in accordance with ASTM D 638. The instrument was operated at a crosshead speed of 5 mm/min using a 2,500 kgf load cell. The flexural modulus and flexural strength testing of the composite specimens were carried out on a universal testing machine (model M500-25AT, Testometric) in accordance with ASTM D 790 at a crosshead speed of 1.3 mm/min. The notched Izod impact test was determined according to ASTM D 256 using a Ceast impact testing model 6957. The hammer was used to strike the sample with 2.75 J. Hardness was tested by a Shore hardness tester (model Shore D, Desik) in accordance with ASTM D 2240. In each case, the tests were performed at room temperature, with five specimens tested to obtain an average value.

2.4. Scanning electron microscopy (SEM)

The polymer composites’ dispersion morphology was observed by scanning electron microscopy (model S-4800, Hitachi). The samples were soaked in liquid nitrogen and before being fractured. The test samples were mounted on stubs and then gold coated to avoid electric charge accumulation during examination.

3. Results and Discussion

Figure 1 depicts the tensile properties of polypropylene filled with various filler types at different filler loadings. It is found that the tensile strength decreased with increasing filler content. This means that the addition of organic filler in polypropylene affected the tensile strength, but polypropylene filled with waste cement had an effect that was less than polypropylene filled with commercial cement and calcium carbonate. This may be because in this study, the polypropylene was filled with organic fillers
without any compatibilizer, incompatibility between polypropylene, which non-polar polymer and fillers, which polar material. Therefore, this had a weak interaction effect on the tensile strength reduction. Similar to the tensile strength results, the strain at break decreased with increasing filler content, indicating that the polymer composites became somewhat brittle compared with neat polypropylene. Similar findings are shown in the literature and have been explained by a failure mechanism [8-10]. Under tensile stress, micro-cracks start at the end of the surface of filler particles, due to higher stress concentration at these points. These micro-cracks then move along the particle and spread across the matrix. When the cracks grow to a critical size, fracturing of the composite occurs. This result shows that the failure is closely related to the content of the particle and explains why increasing filler content decreases tensile strength and strain at break values. Although the use of fillers shows no positive effect on the tensile strength of the polypropylene composites, the addition of fillers enhances the tensile modulus. It was found that the tensile modulus of polymer composites increased with increasing filler content from 0 to 50 phr. Interestingly, the comparison between polypropylene filled with different filler i.e. waste cement, commercial cement, and calcium carbonate indicates that the trend of tensile strength and tensile modulus value is the same for polypropylene filled with waste cement and calcium carbonate.

Figure 1. The tensile properties of polypropylene filled with various filler types at different filler loading; (a) tensile strength, (b) tensile modulus and (d) strain at break.

Figure 2 shows the flexural properties of polypropylene filled with various filler types at different fillers loadings. It is found that the flexural strength decreased slightly with increasing filler loading. The slight decrease of flexural strength illustrates the weak interaction between the fillers and the polypropylene matrix. Meanwhile, flexural modulus increased with increasing filler loading. This indicates that the fillers improved the flexural properties of polypropylene. Comparisons between
different fillers show that the waste cement improved the flexural properties of polymer composites more than calcium carbonate, which normally used in industry.

Figure 2. Flexural properties of polypropylene filled with various filler types at different filler loading; (a) flexural strength and (b) flexural modulus.

Figure 3 shows impact and hardness polypropylene filled with various filler types at different filler loadings. It is found that the impact strength and hardness of polypropylene filled with waste cement increased with increasing waste cement loading. For polypropylene filled with calcium carbonate and commercial cement, it was found that the impact strength slightly decreased with increasing filler loading, while the hardness value increased with increasing filler loading. Interestingly, at the same filler content, the trend of impact strength and hardness value of polypropylene filled with waste cement was higher than calcium carbonate.

Figure 3. (a) Impact and (b) hardness properties of polypropylene filled with various filler types at different filler loadings.

This study shows the potential use of waste cement as a filler for preparing polymer composites. Since it improved the mechanical properties of polymer composites, as seen from the SEM micrographs in figure 4, the fractured surface of polymer composites showed a good distribution of waste cement in the polypropylene matrix. This indicates that waste cement improved the properties of polypropylene composites.
Figure 4. SEM micrographs of polypropylene filled with waste cement; (a) 10 phr (x150), (b) 10 phr (x350), (c) 50 phr (x150) and (d) 50 phr (x350).

4. Conclusions
In this research, waste cement was used as a filler for polypropylene and compared with commercial cement and calcium carbonate. The mechanical and morphological properties were examined. From the results, waste cement can improve the properties of polypropylene similar to calcium carbonate, which are normally used as a filler in polymer industries. This observation was supported by SEM micrographs. Therefore, there is potential for waste cement to be used as a filler for prepared polymer composites, which may be useful for waste management from construction industries and to reduce costs.

Acknowledgment
A partial support was received from the Division of Polymer Engineering Technology, Department of Mechanical Engineering Technology, College of Industrial Technology, King Mongkut’s University of Technology North Bangkok.

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