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Synthesis and characterization of high density polyethylene/peat ash composites

Zhi Cao [a], Michael Daly [b], Luke M. Geever [a], Ian Major [a], Clement L. Higginbotham [a], Declan M. Devine [a, *]

[a] Materials Research Institute, Athlone Institute of Technology, Athlone, Ireland
[b] Mergon International, Castlepollard, Westmeath, Ireland

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ABSTRACT

A new type of polymer composite was synthesized from peat ash which was obtained as industrial waste. This was added to high density polyethylene (HDPE) at varying mixing ratios and the resulting products were characterized using different experiments which included Fourier transform infrared spectroscopy (FTIR), scanning electron microscopy (SEM), melt flow index (MFI), density, wettability, tensile test, flexural test and cost analysis. The effects of various ash loadings and the use of the maleic anhydride grafted high density polyethylene (HDPE-g-MA) compatibilizer on the physical and mechanical properties of composites were investigated. It was observed that the utilization of peat ash significantly increased the tensile strength and the flexural modulus, where also reducing raw material cost. Incorporating (HDPE-g-MA) in the composites formulation led to further increases in tensile and flexural properties. Conversely, there was a significant decrease of impact strength found for all composites in comparison to the virgin HDPE. And the impact strengths generally decreased as peat ash content increases. Microstructural analyses showed that surface treated peat ash particles appeared to be well-incorporated into the HDPE matrix, as intimated polymer/peat ash contact was observed. In addition, the melt flow index of the composites decreased remarkably with an increase in peat ash content. No significant water uptake effect was detected on peat ash composites indicating that these materials could be used as a direct replacement for HDPE in applications where impact strength is not a critical factor. Furthermore, the use of peat ash increased the composite density in comparison to virgin HDPE. Nevertheless, as peat ash reinforcement does offer increased tensile and flexural properties, this may make the end product lighter as lower wall thickness parts can be used to fulfil the same function. From this study, it was concluded that the utilization of the peat ash from peat fired power stations has proved to have significant value-added potential as a filler material in polymer composites.

1. Introduction

Peat ash is an industrial waste produced by burning peat primarily for the generation of electricity. Peat is an organic fuel formed through natural atrophy and incomplete disintegration of dead plants under excess humidity and limited air supply conditions [1,2]. Peat fuel has many economic and environmental benefits include: (1) energy values equivalent to coal and so it can be used directly as a substitute for coal in power generating stations [1]; (2) low sulphur content and virtually no mercury; (3) cheaper than oil and natural gas and price competitive with other biofuels [1–3]. In Finland, peat is used for power generation at power plants ranging in size from 20 to 550 MW, contributing to a total output of over 7000 MW. Similarly, in Russia, more than 6000 MW electric power is produced from peat [2]. In Ireland, peat was the source of heating and cooking for centuries. Peatlands or bogland cover 1.03 million hectares about 15% of the Republic of Ireland. In 2009, 38% of the energy supply was accounted by indigenous fuels like peat [4].

The disadvantage of peat fuel is that it produces large amounts of ash as a waste product [5] and massive amount of peat ash is produced each year [6,7]. Peat ash constitutes a major waste problem and the traditional practice mostly involves disposing of it

* Corresponding author. Materials Research Institute, Athlone Institute of Technology, Dublin Road, Athlone, Co. Westmeath N37 F6D7, Ireland. Tel.: +353 879187012.
E-mail address: ddevine@ait.ie (D.M. Devine).

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in landfill sites [6,8]. However, due to the rise in the cost of waste disposal via landfill and the strengthening of regulations designed to avert an increasing toxic threat to the environment, new trustworthy and environmentally friendly disposal methods are urgently needed [8,9]. To date, although enormous efforts have been made on peat ash deposition reduction and utilization [2,5,10], an economical, widely accepted technology for the recycle and reuse of peat ash has yet to be developed.

Polymer compounding, chemical and coupling agent treatment technologies has recently attracted increasing attention as a viable solution to reusing and recycling industrial ash wastes, which provides a sustainable alternative to landfill of ash, where ash composites have shown beneficial in a variety of applications [11–13]. For example, Deepthi et al. [14], studied the mechanical and thermal characteristics of HDPE-fly ash *cenospheres* composites. It was noticed that such composites could be used as potential fire retardants materials. Wang et al. [15] investigated the effects of lightweight fly ash on the microstructure and properties of silica-based composites. From this study, it was reported that the density of the samples decreased as the content of fly ash *cenospheres* increased, while the strength increased inversely when the content was lower than 50 wt.%. Alfaro et al. [16] studied the ionizing radiation effects on polypropylene/20% of rice husk ash composites. It was shown that the properties decreased by increasing irradiation dose due to chain scission. The common conclusion by various researchers on polymer–fly ash composites can be formulated: "The content of conventional fly ash in polymer composite compositions enhances their mechanical properties and chemical resistance, in a limited range – exceeding the limit content values (about 12–15% of composite mass for compressive/flexural strength and elasticity modulus where 20% loading has a detrimental effect on tensile strength and workability) [17]."

The composition and properties of ash depend on the type and origin of the fuel used as well as the combustion conditions. Peat as an intermediate product in the formation of coal contains both types of ash formers, namely mineral grains and organically associated ions [18–20]. Therefore, the use of coupling agents and chemical treatment to increase the adhesion between fillers and matrix are often necessary [12]. Simple surfactants such as stearic acid can be used as coupling agents in filled polymer systems [12,21]. Yao et al. [13] investigated polymer-stearic acid coated fly ash composites. Their study shows that dispersion of fly ash particles in the composites were improved after stearic acid coating due to a reduction in the hydrophilicity of the ash. Sengupta et al. [22] studied the usage of a coupling agent for improving the mechanical and thermal properties of fly ash-recycled PP composites. They concluded that low cost chemicals like stearic acid can be used as an effective coupling agent for fly ash. It has also been reported in literature that the interfacial adhesion between matrix and fillers can also be enhanced by using polymeric coupling agents such as HDPE-g-MA [23–25]. Ayswarya et al. [26] concluded that the usage of a compatibilizer consisting of HDPE-g-MA greatly improves the mechanical properties of rice husk ash–HDPE composites and that a compatibilized blend was found to have a more homogeneous structure.

Generally, different types of ash waste products are a possible source for polymer composite production. In fact, a great number of ash waste products have been studied as fillers for composite production, including fly ash [14,15,17], rice husk ash Alfaro et al. [16], bean pod ash [27], oil palm ash [28], carbonized bone ash particulate [29], and bagasse ash [30]. More importantly, the fillers play a significant role in the polymer–filler interactions and affect the physical and mechanical properties of the final composite products [31]. Therefore, one of the primary research efforts in the past has been devoted to identifying different source materials for polymer composites production and to characterize the properties of the composite products for potential practical applications.

This paper presents an experimental study on the synthesis and characterization of a new type of ash polymer composite derived from an industrial waste, peat ash. The main objectives of this paper were (1) to investigate the potential utilization of the peat ash as reinforcement filler for thermoplastic composite production, and (2) to characterize the composition, density, melt flowability, moisture level, mechanical properties and cost of the resulting composite products. The effects of various ash loadings and the use of the compatibilizer (HDPE-g-MA) on the physical and mechanical properties of composites were also investigated. This study intends to convert industrial wastes into thermoplastic composite for use in automotive parts (see Fig. 1).

2. Experimental

2.1. Materials

HDPE [Marlex® HHM 5502BN] used in this study was supplied by Chevron Phillips Chemicals International N.U. Belgium. Raw peat ash was obtained from a Peat-fired power station. The raw ash was subsequently sieved through 355 μm-sieve to remove the large particles and any non-combusted materials. Stearic acid (SA), Sodium hydroxide (NaOH) (99.99% purity), Dicumyl peroxide (DCP) (98% purity) and maleic anhydride (MA) (95% purity) were purchased from Sigma Aldrich (Ireland) and used as received.

2.2. Peat ash surface treatment

In this study, 1.5 wt.% of SA was used to surface treated peat ash particles. In order to do this, two separate suspensions were prepared. Suspension 1 contained 250 ml of 0.01 mol SA and 250 ml 0.014 mol of NaOH. These suspensions were mixed at 75 °C until the SA had totally dissolved.

The second suspension consisted of 500 ml of distilled water which 100 g of peat ash was added at a temperature of 75 °C. Subsequently, these two suspensions mixed together at 75 °C for 15 min. The resultant suspension was filtered and the filtrate dried in the oven at 50 °C for 12 h and stored in an airtight container until required. This process was repeated until enough SA treated peat ash was produced.

2.3. Synthesis of HDPE-g-MA compatibilizer

2 wt.% MA and 0.006 wt.% DCP were mixed and ground to a fine-powder using a pestle and mortar. This powder was hand mixed

Fig. 1. Utilization of ash waste filled polymer composites for automobile applications.