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Recycling and reuse of waste from electricity distribution networks as reinforcement agents in polymeric composites

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ABSTRACT

Of the waste generated from electricity distribution networks, wooden posts treated with chromated copper arsenate (CCA) and ceramic insulators make up the majority of the materials for which no effective recycling scheme has been developed. This study aims to recycle and reuse this waste as reinforcement elements in polymer composites and hybrid composites, promoting an ecologically and economically viable alternative for the disposal of this waste. The CCA wooden posts were cut, crushed and recycled via acid leaching using 0.2 and 0.4 N H_2SO_4 in triplicate at 70 °C and then washed and dried. The ceramic insulators were fragmented in a hydraulic press and separated by particle size using a vibrating sieve. The composites were mixed in a twin-screw extruder and injected into the test specimens, which were subjected to physical, mechanical, thermal and morphological characterization. The results indicate that the acid treatment most effective for removing heavy metals in the wood utilizes 0.4 N H_2SO_4. However, the composites made from wood treated with 0.2 N H_2SO_4 exhibited the highest mechanical properties of the composites, whereas the use of a ceramic insulator produces composites with better thermal stability and impact strength. This study is part of the research and development project of ANEEL (Agência Nacional de Energia Elétrica) and funded by CPFL (Companhia Paulista de Força e Luz).

1. Introduction

Electricity distribution companies generate large amounts of waste from the transmission and distribution electricity network. Wooden posts treated with chemical preservatives and ceramic insulators make up the majority of the waste that is difficult to recycle and potentially harmful to human health and the environment when disposed of improperly.

Chemical treatments are applied to the wood to increase its service life by protecting against insects and fungi. Consequently, the chemicals used in these treatments are toxic to organisms and may be harmful if discharged into the environment. Chromated copper arsenate (CCA) is the most frequently applied chemical treatment for wooden posts used in power distribution networks, and the most common CCA formulation is type C, comprising 19% copper(II) oxide (CuO_2), 50% chromium(VI) oxide (CrO_3) and 31% arsenic(V) oxide (As_2O_5) (Janin et al., 2009). Because of this metal content, CCA-treated wood has been difficult to manage as solid waste and it's considered as a hazardous waste because of the leachability of arsenic and chromium (Jambeck et al., 2007). The toxicity of copper, chromium and arsenic is highly dependent on the specific form present. Hexavalent chromium and pentavalent arsenic are carcinogenic and mutagenic. Copper in the free ionic state above trace levels is toxic; thus, copper losses from treated wood are of high concern due to its potential for environmental contamination (Kartal, 2003).

Several alternative methods for the disposal of CCA-treated wood waste have been studied, including recycling and recovery, chemical extraction, bioremediation, electrodialytic remediation and thermal destruction (Christensen et al. 2006; Helsen and den Bulck, 2005; Kartal, 2003; Kakitani et al., 2006; Janin et al., 2009; Helsen et al., 1998; Mercer and Frostick, 2012).

Lignocellulosic materials can be used as fillers or reinforcements for thermoplastic polymers in industrial applications. Their biodegradability, renewability, low cost, UV resistance, and machining properties are some of their advantages over plastic (Hosseinaei et al., 2012).

Wood–plastic composites (WPCs) have emerged as an important family of engineering materials. WPCs have many applications in construction, including in decking, docks, landscaping timber, and fencing, partially due to the need to replace pressure-treated solid lumber (Faruk and Matuana, 2008; Ashori and Nourbakhsh,

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2009). The increasing acceptance of WPCs is due to their low moisture absorption, resistance to biological attack, dimensional stability, combination of high specific stiffness and strength, relatively low abrasion during processing, low density and moldability (Valente et al., 2011). So far, various thermoplastics, including polyethylene (PE), polypropylene (PP) and poly(vinyl chloride) (PVC), have been used as host material with a wide range of wood flour content for the research and development of WPC manufacturing (Ndiaye et al., 2008).

The key point leading to WPC of acceptable properties is the compatibilization between vegetable fiber (wood) and polymer host matrix. Since wood is hydrophilic in nature (high surface tension), its compatibility with hydrophobic polymeric material (low surface tension) is reduced, so the use of compatibilizing agents is generally required during composite preparation (Ndiaye et al., 2008). The function of the compatibilizing agent is to promote covalent chemical bonds and/or secondary acid–base links or hydrogen bonding between the phases of the matrix and fiber, and may even alter the vegetable fiber energy surface effective to allow wetting of the fiber by the polymer matrix. Maleic anhydride (MA) grafted onto the polymer matrix is one of the most widely used compatibilizing agents in WPC manufacturing due to its low cost and fair efficiency (Adhikary et al. 2008; Dányádi et al. 2010; Li and He, 2004).

Kamdem et al. (2004) studied the properties of compression-molded WPCs made from recycled HDPE and wood flour from CCA-treated pine wood and virgin wood, observing that the composite made from CCA-treated wood exhibited higher mechanical properties than that made from virgin pine wood (Kamdem et al., 2004).

Electrical insulators are used to insulate electrical wires and cables from points of support. These materials are white ceramics and generally composed of quartz, feldspar, clay, and, in some cases, alumina partially substituting quartz. Other substances, such as iron hydroxide, calcium silicate and magnesium silicate, are also sometimes added in small percentages to modify the mechanical and dielectric properties of the insulator. In Brazil, the ceramic insulator manufacturing waste or waste from energy distribution networks are classified according to Associação Brasileira de Normas Técnicas (ABNT) – NBR 10004 as "Class IIB – Inert". Although this waste is inert to environmental deterioration, it is a significant problem in terms of the logistics of its disposal and the disposal volume occupied (Chinelatto and de Souza, 2004).

The reuse of ceramic insulators discarded from industry and energy distribution networks was studied by Senthamarai et al. (2005 and 2011), who proposed their use as coarse aggregates in green concrete, replacing the conventional crushed granite coarse aggregate (Senthamarai and Manoharan, 2005; Senthamarai et al., 2011).

Hybrid composites are materials produced by the combination of two or more different fillers in the same matrix. Hybrid fillers are very useful because they possess properties that cannot be obtained from a single type of reinforcement (Kord, 2011).

Recent studies on filler-reinforced plastic composites have mainly used inorganic and organic hybrid composites. Gwon et al. (2010), studied the effect of the chemical treatment of wood and talc fillers in polypropylene (PP) hybrid composites using a silane-based coupling agent (Gwon et al., 2010). Jiang et al. (2003), studied the mechanical properties of poly(vinyl chloride) with wood flour and glass fiber hybrid composites (Jiang et al., 2003). Valente et al. (2011) studied the development of hybrid recycled glass fiber/wood flour composites made with low-density polyethylene (LDPE) and polypropylene (PP) processed by compression molding (Valente et al., 2011).

Based on the current literature, the possibility of using waste from electricity distribution networks, such as CCA-treated wood and ceramic insulators, in the development of green composites and hybrid composites is very attractive, especially considering the large quantities of this waste generated daily.

2. Methods

2.1. Materials

Polymer matrix: High-density polyethylene (HDPE), grade HF 0144, was supplied by Brasken S.A.

Coupling agent: Maleated high-density polyethylene (HDPEg-MA), grade Polybond 3009, was obtained from Chemtura.

Waste from the disposal of electricity transmission networks: Wooden post and ceramic insulator waste was provided by Companhia Paulista de Força e Luz – CPFL/RGE and removed from service in 2012 in the state of Rio Grande do Sul, Brazil. The wooden posts treated with CCA were from Eucalyptus species and discarded after 10–12 years of application. The low-voltage ceramic insulators were used.

Virgin wood: This wood was collected from the trunk of an *Eucalyptus dunnis* tree species. In order to compare the differences between the virgin wood and the post exposed to weathering besides any loss in physical–chemical properties due to any possible wood degradation resulting from the action of weathering an unweathered wood was used.

2.2. Recycling and characterization of CCA-treated wood and ceramic insulators

The wooden posts treated with CCA were cut and milled in a knife mill (PRIMOTÉCNICA) with a sieve particle size of 8 mm. The extraction methodology of the CCA from the wood was based on Janin et al. (2009), which describes the extraction of Cr, Cu and As by acid leaching with sulfuric acid (H_2SO_4) at concentrations of 0.2 N (treatment A) and 0.4 N (treatment B). The method consists in submerging a mass of 10 g of sieved CCA wood in 200 mL of acid leaching solution in a 500 mL baffled shaker flask coupled with a condenser. The temperature of the leaching test was 70 °C. The decontamination by leaching was performed in triplicate for 2 h each, obtaining a total of 6 h of exposure to acid solution. For each test the wood was filtered and a fresh acid solution was used. After the acidic leaching test the pH of the solution was neutralized with sodium hydroxide (NaOH) and washed with distilled water until the leached liquid was completely removed. The complete leaching tests were performed in triplicate to obtain the mean and standard deviation. Afterwards, the decontaminated (recycled) wood samples were dried at 80 °C for 24 h and milled again in a knife mill with a 1 mm sieve, the 45–150 mesh fraction being retained (Janin et al., 2009).

The Cr, Cu and As concentration in the treated wood, leached liquid and washing water were characterized by atomic emission spectrometry (ICP-AES). The wood was subjected to closed digestion with analytical grade nitric acid (50%, ww^{-1}, 20 mL) and hydrogen peroxide (30%, ww^{-1}, 10 mL). A mass of 1.0 g of dry wood was used in the digestion. Each sample was digested and characterized in duplicate to obtain the average metal concentration.

The ceramic insulators were washed and shredded through a hydraulic press with 40 tons of pressure and separated in particle size fractions of 45–150 mesh.

2.3. Composite preparation

The design of the samples formulations was based on:

- 100% HDPE.
- 68% HDPE, 2% HDPEgMA, 30% virgin wood.
- 68% HDPE, 2% HDPEgMA, 30% recycled wood with leaching treatment A.