Plastics Research Online

10.2417/spepro.006491

De-inking paper sludge as a potential reinforcement for recycled plastics

Ahmed Elloumi, M. Makhlouf, A. Elleuchi, and Ch. Bradai

The addition of de-inking paper sludge into recycled high-density polyethylene composites improves their tensile strength and stiffness, but is detrimental to their ductility and toughness.

Plastic and paper wastes are significant sources of pollution, and in the face of new environmental, economic, and petroleum considerations, the scientific community is increasingly being forced to deal with the recycling of such waste. An efficient way of recycling waste plastics, for instance, is through the development of blends and composites.[1] Furthermore, the European paper industry generates about 11 million tonnes of waste annually, 70% of which originates from recycled paper production (e.g., paper sludge that comes from paper mills and recycling factories).[2] In particular, production of tissue paper from recycled paper generates up to 150kg of dry solids/tonne of 'de-inking paper sludge' (DPS).[3] At most paper mills, this kind of sludge is disposed of through burning, landfill, and land application.[4] As landfill becomes more scarce and expensive, however, sludge is increasingly being incinerated[5] and alternative recycling approaches are required.

Instances of sludge being used as an additive for the manufacture of building materials,[6] e.g., cement,[7] bricks, ceramics, and concrete, have previously been documented. The high moisture content of DPS, however, makes it difficult for it to be reused in value-added applications. Indeed, for most applications, the sludge must be de-watered or dried. This limits the value of upgrading the sludge because of the associated drying costs and energy consumption. Paper mill sludge has also been tested as a raw material in the manufacture of wood polymer composites (WPCs), i.e., as an alternative to wood flour.[8,9] Moreover, it has been demonstrated that polymeric composites reinforced with DPS exhibit superior physico-mechanical properties to those reinforced with paper sludge.[10]

In our work,[11] we are searching for a new alternative for recycling of paper sludge and plastics in the production of composites, for several potential applications (e.g., the automotive industry and for windows, doors, and decking). We have thus investigated the potential of using DPS and recycled high-density polyethylene (RHDPE) for biocomposites. DPS consists of a mixture of organic matter (total 41%) and a high content of inorganic matter. The organic material is mostly cellulose (23.0±1.84%), whereas the inorganic part is mainly aluminum, magnesium, and calcium oxides (e.g., calcium carbonate and kaolin). Other elements are also present at lower concentrations. Such a composition makes DPS a promising candidate for use as a biofiller in thermoplastic composites. Indeed, the organic content of DPS means it should have a substantial impact on the mechanical properties of DPS-reinforced composites. In addition, the low density of DPS (1.924g/cm^3) makes it an interesting reinforcing agent for the polymeric matrix.

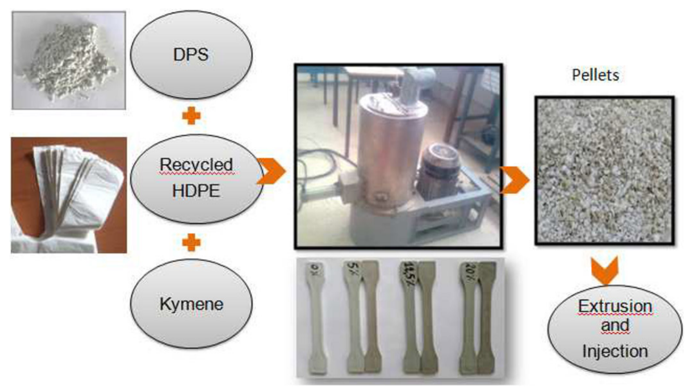

Figure 1. *Schematic illustration of the melt compounding manufacturing process for the de-inking paper sludge/recycled high-density polyethylene (DPS/RHDPE) pellets. Different DPS loadings (0–20wt%) and compatibilizer contents (0–4wt%) are used for different formulations, and Kymene—a commercial paper wet-strength agent polyamideamine-epichlorohydrin (PAE) resin—is used as the DPS binder.*

We used a melt compounding method to produce a set of DPS/RHDPE pellets for injection molding (see Figure 1). These

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samples contained different DPS loadings (0–20wt%) and compatibilizer contents (0–4wt%). In addition, we used a commercial paper wet-strength agent polyamideamine-epichlorohydrin (PAE) resin (Kymene) as the DPS binder. We could thus study the effects of DPS composition and PAE content on the performance of RHDPE/DPS biocomposites.

In the first part of our study, we examined the physico-chemical properties of DPS. Our scanning electron microscope images of the DPS (see Figure 2) show its irregular, cracked, and short fibers, mixed with aggregates of the mineral particles. We also found that some of the organic fibers in the DPS had been broken down to a powder because they had been recycled several times, whereas other fibers maintained their original shapes.

Our mechanical tests reveal that the Young's modulus (i.e., rigidity) of our composites increased with addition of DPS. This is because the samples contained an increased amount of the rigid component. Our measurements also indicate that the tensile strength of the samples increases with DPS addition, and reaches an optimum level at a DPS content of 12.5% (see Figure 3). In contrast, we find that the elongation of the samples reduces with increased DPS content. This may occur because the composites with higher DPS contents exhibit many defects (i.e., abundant mineral aggregates) and low homogeneity. Indeed, the more heterogeneous compositions provide the most complicated results (because of the synergetic effect between the organic and inorganic components).

In summary, our characterization of de-inking paper sludge has revealed its mineral- and cellulose-rich nature. This composition means it can serve as a potential lignocellulosic biofiller in high-density

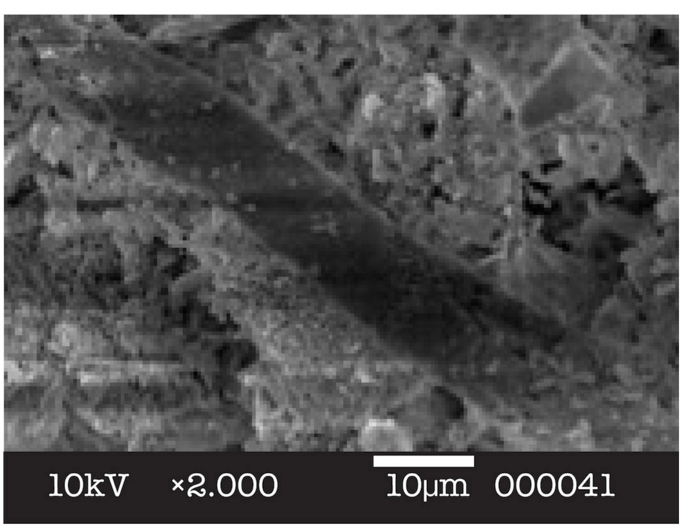

Figure 2. *Scanning electron microscope image of DPS that shows the irregular, cracked, and short fibers mixed with mineral aggregates.*

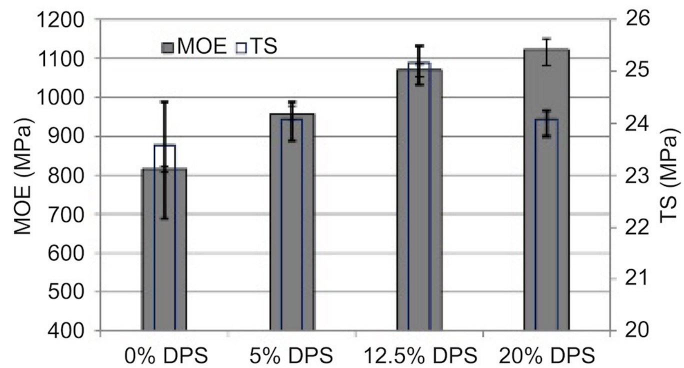

Figure 3. *The effect of DPS, and a 2% PAE content, on the tensile strength (TS) and elastic modulus (MOE) of the DPS/RHDPE composites.*

polyethylene composites. Our mechanical tests on DPS/RHDPE samples show that the incorporation of DPS into the composites improved their tensile strength and their stiffness. The large particle size of DPS and poor filler dispersion, however, had a negative effect on the ductility and toughness of the composites. We have also found that the addition of Kymene improved the interfacial interaction between DPS and RHDPE, but was detrimental to the ductility of the samples. In our future work we will focus on the use of high DPS contents for WPCs and for particle-board production in construction applications. We also hope to extend our study to other polymeric matrices with high contents of DPS and commercial compatibilizers.

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