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Recycling waste plastics in developing countries: Use of low-density polyethylene water sachets to form plastic bonded sand blocks

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ABSTRACT

In many developing countries low-density polyethylene (LDPE) sheets, bags and water sachets are a major waste problem because local collection and recycling systems do not exist. As a result, LDPE has no value and is dumped causing aesthetic, environmental and public health issues. A relatively simple technology has been developed in the Cameroon that produces LDPE-bonded sand blocks and pavers. The application of this technology is an example of a community-driven waste management initiative that has potential to impact on the global plastics waste crisis because it can transform waste LDPE and other readily available types of plastics into a valuable local resource. In this research, waste LDPE water sachets have been melted and mixed with sand to form LDPE-bonded sand blocks. The effect of sand particle size and sand to plastic ratio on density, the compressive strength and water adsorption are reported. Optimum samples have been further characterised for flexural strength and thermal conductivity. LDPE-bonded sand is a strong, tough material with compressive strengths up to ~27 MPa when produced under optimum processing conditions. The density and compressive strength increase as the particle size of the sand decreases. The potential for using this simple technology and the materials it produces to transform LDPE plastic waste management in developing countries is discussed.

1. Introduction

Developing countries (DCs) typically have inadequate solid waste management, with low waste collection rates, disposal primarily by dumping and limited outlets for reusing potentially recyclable materials (Wilson et al., 2015). However, waste materials in DCs can provide livelihoods to a highly entrepreneurial informal sector (Wilson et al., 2006). The management of wastes, and particularly waste plastics, has become a high profile, environmental and public health issue. Recycling infrastructure for these materials often does not exist in DCs, and as a result, waste plastics have little or no value, resulting in uncontrolled disposal as shown in Fig. 1. Dumping into waterways has severe adverse effects on local communities. Waste plastics are not only unsightly, but they block urban drainage systems and sewers, causing flash floods, as well as providing a fertile breeding ground for mosquitos and other waterborne diseases.

Plastic waste has become so ubiquitous that it is now a serious threat to marine ecosystems and biota. It has been estimated that between 4.8 and 12.7 million metric tonnes of plastic waste was added to the oceans in 2010 (Jambeck et al., 2015). Oceans are downstream from waterways, 60–80% of marine litter is plastic and poor waste management in DCs is a major cause and contributor to plastics in the oceans (Grantham Institute, 2016).

Despite the low biodegradability of plastics and the associated potential for long-term adverse environmental impacts, single-use polyethylene drinking water sachets such as those shown in Fig. 2 are very widely used throughout much of Africa. These are used in enormous numbers because water sold in sachets has higher quality than the local tap water. As a result, water sachet use has increased to such an extent that they are now a major environmental issue in many parts of Africa, as reported for the Accra-Tema Metropolitan Area in Ghana (Stoler et al., 2012). Uncontrolled and indiscriminate dumping of plastics into water bodies is very common in DCs because there is often no local recycling infrastructure. It is estimated that 15–40% of waste plastic is dumped into water bodies and this contributes to the estimated 5.25 trillion pieces of plastic debris currently in the oceans (Crawford and Quinn, 2017; Sebille et al., 2016).

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Fig. 1. Photographs showing waste plastics including water sachets blocking urban drainage in Ghana.

Fig. 3. Typical block paver made in the Cameroon using LDPE and sand.

Fig. 2. Single-use LDPE drinking water sachets that are widely used in Africa.

Previous research has reported on the re-use of waste plastics as construction materials in developing countries. Polyethylene terephthalate (PET) bottles filled with sand or earth have mechanical properties suitable for use in walls and in slab construction (Mansour and Ali, 2015). Plastic bottles can also be filled with plastic food wrappers to form eco-bricks (Lenkiewicz and Webster, 2017). Lightweight concrete has been produced by using waste plastics as aggregate (Gu and Ozbakkaloglu, 2016; Ismail and Al-Hashmi, 2008). Plastic coated aggregates have been used to form asphalt and this allows a 10% reduction in bitumen usage (Vasudevan et al., 2012). Plastic fibres have been used in concrete to provide a cost-effective, corrosion resistant reinforcement option (Gu and Ozbakkaloglu, 2016). PET fibres have also been used to improve the compressive strength and energy absorption capacity of soils (Consoli et al., 2002).

Plastic-bonded sand paver blocks as shown in Fig. 3 were first produced using waste plastics in the Cameroon by Pierre Kamsouloum in 2006. This has now become a leading example of a community-driven waste management initiative that has had an impact on local communities and local waste management (Lenkiewicz and Webster, 2017). By turning wastes into potentially valuable resources it also has the potential to contribute to solving the global waste crisis. However, the manufacturing process and the mechanical properties of the materials formed have not previously been reported in the scientific literature to date and these technologies will benefit from the type of laboratory-based systematic research reported in this paper (Wilson and Webster, 2018). The aim of this research was therefore to optimise the production process at laboratory scale and determine the properties of these materials in order to provide guidance to those working in the field on the key production parameters that determine performance. In this work the effect of the sand particle size and the sand to plastic ratio in LDPE-bonded sand is reported. The optimum samples have been further characterised for stress-strain behaviour during loading to failure in bending. The thermal conductivity of samples is also reported.

2. Materials and methods

LDPE water sachets from Ghana were used in these experiments (Space Poly Product Limited, Ghana). LDPE is a thermoplastic that can be moulded and remoulded repeatedly when heated. It is a highly flexible material because it contains numerous side chains that increase the distance between the main C-C chains, reduced packing and intermolecular attraction. It typically has a density in the range of 0.91–0.94 $g \cdot cm^{-3}$.

Commercially available silica sand with a particle density of 2.65 $g \cdot cm^{-3}$ was used as an inert filler. This was dried and used as-received and also sieved to give four different size fractions with particle sizes (d) in mm of $d < 0.5$, $0.50 < d < 1.00$, $1.00 < d < 2.36$ and $2.36 < d < 4.75$. These four size fractions were assumed to have average particle sizes of 0.25 mm, 0.75 mm, 1.68 mm and 3.55 mm.

The mix designs of LDPE bonded sand samples used to investigate the effects of sand particle size and sand to plastic ratio are shown in Table 1. The process flow diagram used to produce LDPE-bonded sand samples is shown in Fig. 4. The water sachets were first heated in a saucepan on a hotplate (Jenway 1000 series hotplate) with the temperature of the mix measured using an infrared thermometer (RayTemp 3). The water sachets softened between 110 and 150 °C and when they had an appropriate consistency the sand was added. The sample were then continuously mixed until a homogenous blend of sand and LDPE had formed. The mix was then cast into three gang 50 × 50 × 50 mm cube steel moulds that had been coated with a silicone-based release spray. The moulds were pre-heated to approximately 100 °C as this allowed the hot samples to be compacted and formed into shape before cooling to room temperature.

The density of samples was determined using the Stable Micro Systems (SMS) industrial specific gravity balance (model SG/30). The water absorption of samples was determined after 24 h immersion in distilled water at room temperature, as described in ASTM D570.