RECYCLING PLASTICS IN DEVELOPING COUNTRIES: PROPERTIES OF NOVEL POLYMER-SAND COMPOSITES PRODUCED FROM WASTE PLASTICS

Alexander Kumi-Larbi Jnr[1], Richard Galpin[1], Silva Manjula[2], Zoe Lenkiewicz[3], Christopher Cheeseman[1]
[1]Department of Civil and Environmental Engineering, Imperial College London, SW7 2BU, UK
[2]Department of Materials, Imperial College London, SW7 2AZ, UK
[3]Waste Aid UK, Wye, Kent, UK

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Presenting author's email: alexander.kumi-larbi-jnr16@imperial.ac.uk

INTRODUCTION

Global plastic production has increased from 1.5 million in 1950 to 368 million tonnes in 2019. <20% of plastics are properly managed by recycling (The Economist, 2018). Plastic recycling efforts have increased globally, and many developed countries have advanced recycling and treatment infrastructure including pyrolysis and incineration. Hence, recycling rates in the EU has increased from 8 wt.% in 1990 to 42 wt.% in 2009 (Wilson *et al.*, 2013). It is difficult to implement such advanced treatment processes for waste plastics in developing countries (DCs) due to the financial requirements and strict emission controls (Gu & Ozbakkaloglu, 2016). Improper plastic waste management threatens the environment with ocean plastics being a global concern. Approximately 80% of ocean plastics come from land and particularly coastal DCs (Derraik, 2002). Inadequate waste management infrastructure in DCs result in indiscriminate dumping of plastics into water bodies**.** The uncollected waste plastics block drains resulting in increased flooding with impacts on public health. The need to develop low-cost plastic recycling technologies has inspired using single-use plastics as a binder to form plastic bonded sand (PBS) composites. As shown in **Figure 1**, PBS use in roof tiles and paving blocks has been reported in countries including Gambia and Ghana. However, there is limited research investigating the suitability of using waste plastics to produce polymer sand composites. This research investigates the influence of processing conditions including temperature, binder, and filler properties on PBS properties to establish their use in construction.

Figure 1: Paving blocks from plastic bonded sand (PBS) produced in Gambia.

METHODS AND MATERIALS

PBS samples were produced using polyethylene and sand. LDPE water sachets and HDPE bottle caps were used as the plastic binder. Dried silica sand with a particle density of 2.65 g/cm^3 was used as the filler. The sand was sieved into three different particle sizes (d) in mm of $d<0.30$, $0.30<d<0.60$ and $0.60 <d<1.35$. To produce the test samples, a layered mixture of plastics and sand was heated in a Wild Barefield M253 oven with a temperature sensitivity of ± 5 °C. Stirring was done after 7, 10, and 15 mins of heating to achieve a homogeneous paste. The paste was then cast into steel moulds, pre-heated to at least 150 °C. The paste was then mildly compacted and cooled to room temperature to form PBS samples. The test samples were processed within a temperature range of 250 °C to 375 °C at 25 °C intervals to study the effects of temperature. The effects of sand particle sizes and proportions on the mechanical properties were investigated in samples with varying sand content (50wt.%, 66.7wt.%, 75wt.%, 80wt.%, 83.3wt.%) and sand particle sizes.

A Zwick Roell 1474 test machine was used to conduct compressive strength, plasticity, and elasticity analysis. Compressive loads were applied at a strain rate of 10 mm/min till 10 % deformation or 10 % peak strength was attained after failure. Samples were also subjected to three-point bending tests. Test loads were applied at a crosshead speed of 1 mm/min at a support distance of 30mm ± 1%.

RESULTS AND DISCUSSIONS

The optimum processing temperatures for forming the LDPE bonded sand (LBS) and HDPE bonded sand (HBS) samples were between 250 to 350℃. Higher temperatures reduced LBS and HBS compressive strengths due to polymer degradation and lower temperatures reduced sample homogeneity. Test samples prepared at 375℃ retained >20 % of the ultimate strength at 7.5% strain. At 250℃, samples retained at least 74% of ultimate strength at 24% strain. The compressive modulus of LBS ranged between 0.6 to 0.8 GPa. Two failure modes were observed: samples processed above 325℃ failed along a 45° shear plane. Below 325℃, test samples failed along the compaction layers without disintegrating due to the heterogeneity of the samples. The flexural modulus of LBS processed at <275 ℃ ranged between 0.5 to 0.7 GPa. LBS flexural strengths remained constant within 250 ℃ to 325 ℃. Above 325 ℃, a significant reduction in flexural strength and an increase in brittleness was observed**.**

Optimised PBS compares favourably with C20/25 concrete. However, it has approximately 2-2.5% of concrete stiffness. Optimised LBS and HBS samples met the standard requirements for paving blocks, roof tiles, and partition wall applications. The stress-strain relationships of the samples revealed that LBS was more ductile with lower compressive strengths and toughness than HBS. Fracture energies of LBS and HBS samples ranged between 0.6 to 2.3 MJ/m^3 and 1.0 to 2.1 MJ/m^3 respectively, depending on sand proportions and sizes. **Figure 2** shows the effect of sand proportions and sizes on the compressive strength of LBS and HBS. The optimum sand proportions that gave the highest compressive strengths in LBS and HBS ranged between 65 to 75 wt.% and 65 to 80wt.% respectively. LBS with d<300µm, 300µm<d<600µm, and 600µm<d<1.35mm produced a maximum compressive strength of 27.2 MPa, 21.8 MPa, and 20.1 MPa respectively. Optimum sand proportions for compressive strength decreased with decreasing sand particle sizes in LBS. HBS recorded maximum compressive strengths between 31.4 MPa- 37.1 MPa depending on sand particle size. The compressive strength of LBS with ≤75 wt.% sand decreased with increasing sand particle sizes. Increasing sand particle size till d=500µm increased the compressive strength of LBS with >75 wt.% sand. Further increase in sand particle sizes decreased LBS compressive strength. In contrast, HBS compressive strength decreased with increasing sand particle sizes irrespective of sand proportions.

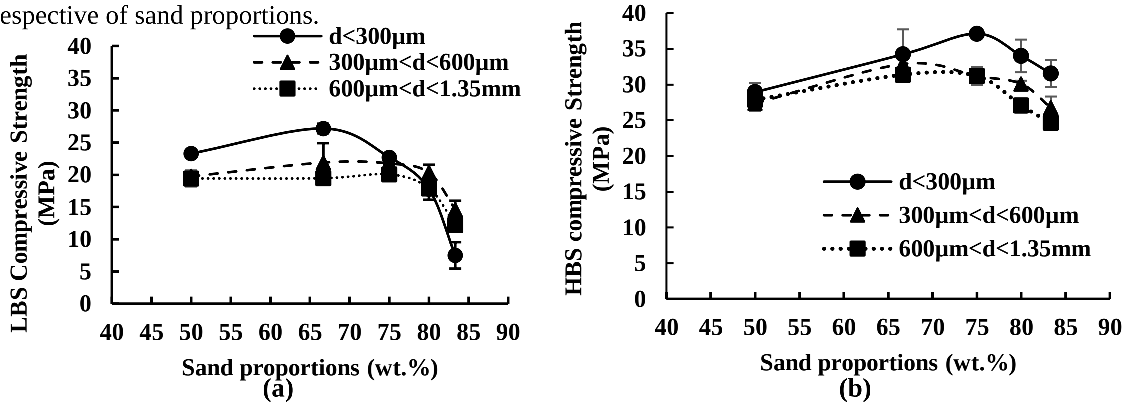

Figure 2: The effect of varying sand proportions and particle sizes on the compressive strength of (a) LDPE bonded sand (LBS) and (b) HDPE bonded sand (HBS).

CONCLUSION

Waste packaging plastics have adverse public health and environmental impacts because there are limited recycling options for the materials in Developing Countries (DCs). Waste plastics can be recycled into durable LDPE bonded sand (LBS) and HDPE bonded sand (HBS) construction composites using inexpensive processes with low energy and water requirements. This develops a sustainable circular economy for waste plastics particularly in DCs. LBS and HBS are durable and suitable for paving, roof tiles, and partition walls. Optimised LBS and HBS have maximum compressive strengths of 27 MPa and 37 MPa respectively, which is comparable to C20/25 concrete and higher than sandcrete. They are tough and have higher ductility than concrete. The compressive strength of LBS and HBS ranged between 5 to 27 MPa and 22 to 37 MPa respectively. Processing temperature and time need to be controlled to prevent polymer degradation. The optimal processing temperature for PBS production was 250°C-325°C. Higher temperatures reduced material toughness, flexural and compressive strengths due to thermal degradation. Lower temperatures produced heterogenous samples with reduced strengths due to inefficient mixing. The structural arrangement of the plastic binder and filler in the composite matrix affects LBS and HBS properties. Recycling waste plastics into PBS is a resource efficient alternative with significant environmental and public health benefits compared to the existing disposal options in DCs.

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