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Performance of structural concrete with recycled plastic waste as a partial replacement for sand

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HIGHLIGHTS

- Eleven concrete mixes tested with plastic as partial replacement for sand.
- Target compressive strength of 54 MPa to replicate structural concrete.
- Control of particle size distribution minimises change in compressive strength.
- PET fragments graded as sand can be used at a replacement ratio of 10%.
- Save 820 Mt sand per year by replacement with waste plastic.

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ABSTRACT

Environmental concerns arising from the over-dredging of sand have led to restrictions on its extraction across India, with direct economic impacts on concrete construction. A suitable environmentally friendly alternative to sand must be found to match the huge demand from the concrete construction industry. At the same time, waste plastic is rarely recycled in India, with as much as 40% left in landfill. The dumping of such materials which degrade at extremely low rates meaning they persist in the environment is a long-term environmental concern.

To tackle both issues, it is proposed to process waste plastic to create a partial replacement for fine sand in a novel mix for structural concrete. In this paper eleven new concrete mixes are evaluated to study five plastic material compositions, three groups of particle sizes, three different aspect ratios, and two chemical treatments and establish an appropriate choice of material to act as partial replacement for sand.

The results show that replacing 10% sand by volume with recycled plastic is a viable proposition that has the potential to save 820 million tonnes of sand every year. Through suitable mix design the structural performance of concrete with plastic waste can be maintained. This preliminary work was supported through funding from the British Council under the UKIERI (United Kingdom India Educational Research Initiative) programme for the project 'Development of structural concrete with the help of plastic waste as partial replacement for sand'.

1. Introduction

Cement manufacture in India reached 280 Mt in 2014 [1], second only to China. India exports only small volumes of cement, with internal demand for concrete being driven by a growing economy, growing population, and rising living standards [2]. Mass extraction of sand, usually via river dredging, has been a problem in India for a number of years and is mainly fed by construction demand. A high court ruling in 2011 has virtually eliminated sand dredging [3] with the consequence of supply problems within India.

The Indian central pollution control board CPCB) reported in 2008 that approximately 15,000 tons of plastic waste is dumped every day in India [4]. Non-biodegradable plastic waste is inert and breaks down very slowly once buried in landfill. Even if all of this plastic could be recycled, by-products of the recycling

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process such as polyethylene terephthalate (PET) sand are still required to be sent to landfill.

A solution to both of these problems is proposed by substituting fine sand in concrete mixes with processed waste plastic, which would otherwise remain as waste in landfill. This would not only encourage the collection and use of waste, but would provide alternative sources of fine material in place of sand in novel concrete mixes

2. Plastic as a replacement for sand in concrete

Initial research on the effects of plastic aggregate substitution on concrete compressive strength was undertaken by Al-Manaseer and Dalal [5], who explored the effect of an increasing proportion of angular waste plastic particles on cylinder strength for three different water to binder ratios. It was found that compressive strength decreased with an increase in plastic aggregate content, with this loss in strength attributed to poor bonding between the plastic and cement paste (Fig. 1). The plastic was able to pull out, rather than to split in tension, during compressive testing of the concrete.

Saikia and de Brito [6] tested concrete mixes containing three different sized and shaped particles: 1) large (10–20 mm length) particles; 2) shredded flaky fine particles (2–5 mm length); and 3) cylindrical pellet shaped particles (3 mm length). Each of these was tested over a series of replacement ratios, ranging from 0% to 15% of the sand. It was found that the higher the replacement ratio, the lower the concrete's compressive strength, attributed to the lack of interaction between the PET aggregate and cement paste (Fig. 1). This study concluded that the interfacial transition zone in concrete containing PET aggregate is weaker than that of standard concrete.

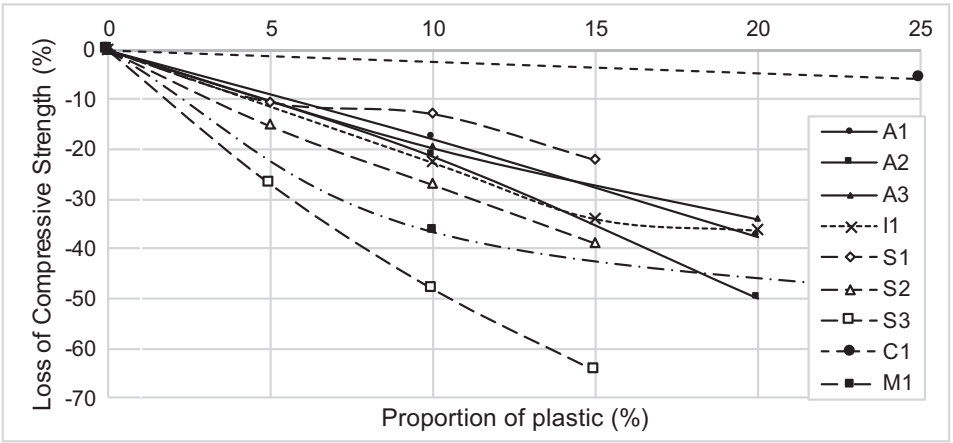
Albano et al. [7] used irregularly shaped PET particles between 2.6 mm and 11.4 mm in replacement quantities of 10% and 20% with two different w/c ratios (0.50 and 0.60). It was found that the compressive strength reduced with increases in the proportion of plastic, implying that plastic particles acted as defects within the internal structure of the concrete. Mix designs containing only larger plastic particles were substantially weaker compared to mixes containing only smaller PET particles, as illustrated in Fig. 1. The formation of a honeycomb of cavities and pores was observed and attributed to the low workability affecting the compaction of the concrete.

Frigione [8] used granulated PET that was graded very similarly to the siliceous sand that was to be replaced in the mix. It was found that while the compressive strength of the mix decreased, the reduction was less than 2% when a replacement ratio of 5% was used. This is favourable when compared to the 12% loss seen by Saikia and de Brito [6] when 5% sand was replaced with larger plastic pellets. This indicates that although the use of plastic may cause a decrease in compressive strength because of a poorer bond to the surrounding matrix when compared to sand, the loss can be limited by appropriate mix design and choice of plastic.

Ismail and Al-Hashmi [9] tested concrete with a mixture of PET and polystyrene as sand replacement. Subsequent reductions in compressive strength were attributed to a decrease in adhesive strength between the surface of the waste plastic and the cement paste as plastic is a hydrophobic material (Fig. 1). Therefore movement of the water required for cement hydration is hindered, leaving isolated volumes of unhydrated cement within the bulk volume.

Albano et al. [7] demonstrate that both larger particles, and higher replacement percentages, cause significant reductions in tensile strength due to an increase in voids present within the concrete. This is supported by Frigione [8], where 5% replacement by volume of sand using granulated PET led to only a 2% loss in tensile strength.

Saikia and de Brito [6] found that as with compressive strength, there was a loss of tensile performance when plastic aggregate was introduced into the concrete, and the more plastic added, the greater the loss. The loss of tensile strength was attributed to the



	A = Albano et al. (2009)	**I** = Ismail and Al-Hashmi (2008)	**S** = Saikia and de Brito (2014)	**C** = Choi et al. (2005)	**M** = Al-Manaseer and Dalal (1997)
1	All small particles	PET and polystyrene	PP — cylindrical pellets	PET coated in GBFS	Angular particles
2	All large particles	N/A	PF — flaky fine particles	N/A	N/A
3	50/50 mix of particles	N/A	PC — large coarse particles	N/A	N/A

Fig. 1. The relationship between plastic replacement and loss in compressive strength.