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Recycling plastic waste in cement composites: An analysis

23 April 2019

Gurbir Kaur and Sara Pavía explore the possibility of raising the amount of recycled plastic (34%) by replacing sand with plastic waste in mortars and concretes, as this would not only reduce plastic incineration and landfill but would also lower raw material extraction with the consequent economy in fuel and carbon emissions

Plastics that have received little or no attention were targeted in this research including polycarbonate (PC), acrylonitrile-butadiene-styrene (ABS), acrylonitrile-butadiene-styrene + polycarbonate (ABSC) and polyoxymethylene (POM).

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Gurbir Kaur and Sara Pavía.
Dept. of Civil Engineering. Trinity College Dublin.
gurbir.kaur@thapar.edu; pavias@tcd.ie

Introduction

At current and predicted production levels, plastics are a vast problem. If current production, use and waste management trends continue, the amount of plastic dumped in landfill or polluting nature by 2050 will be 12 billion tonnes [1]. According to statistics, Ireland is the top plastic waste producer in Europe; generating c.61kg per person every year [2, 3]. C.34% of this plastic is recycled while 39% is incinerated and 31% landfilled [3]. We are in a particularly dire situation following China's ban on importing waste plastics from Europe. In 2016, China took c.95% of Ireland's plastic waste [4] however, this is no longer an option therefore, there is an urgent need to handle plastic waste in a sustainable way. Various regulations have been implemented or are being developed in Ireland to handle the increasing plastic waste and achieve sustainability. This research explores the possibility of rising the current amount of recycled plastic (34%) by replacing sand with plastic waste in mortars and concretes. This, not only would reduce plastic incineration and landfill but would also lower raw material extraction with the consequent economy in fuel and carbon emissions.

Use of plastic waste in construction

In recent years, the use of waste plastic as aggregate in construction has gained widespread attention. Plastic is lightweight, durable, airtight and decay resistant. Plastic waste can be washed, shredded and used as aggregate partially replacing natural sand in

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mortars and concretes. The performance of plastic composites depends on replacement levels, type of plastic, particle size, grading and surface treatment. The structural performance of concrete containing plastic waste can be maintained with a suitable mix design [5]. Plastics such as polyethylene terephthalate (PET), high-density polyethylene (HDPE) and low-density PE (LDPE) have attracted much attention over the last years however, they have not yet been widely adopted in construction.

Research on waste plastic composites

Plastic aggregates (PAs) generally lower the material's density due to the low density of the plastic [6, 7]. Authors generally agree that strength lowers with increasing PA; and attribute the strength drop to the low bond and lessened cement hydration at the interface due to the hydrophobic nature of plastic [6, 7]. The PA morphology and particle size have been linked with strength. Cordoba et al. [8] state that the compressive strength improves when smaller PET particles are used at low concentrations. However, some authors have reported PAs increasing strength: 5% fine aggregate replacement with PET improves the compressive strength of concrete by c.9-12% [9]. Saikia and Brito [10] also report strength enhancement with heat-treated PET pellet content up to 15%. The elastic modulus (E) of PA concrete is generally lower than that of conventional concrete; and the decrease becomes more significant when the PAs are less uniform in shape or have a low E themselves [7, 11]. The incorporation of PAs lowers the peak load of concrete but ductility improves (the corresponding strain and ultimate strain rise) and the material absorbs greater load improving toughness. Saikia and De Brito (2012) claim that PET concrete is less brittle than reference concrete but withholds a greater deformation while still keeping its integrity.

Plastics that have received little or no attention were targeted in this research including polycarbonate (PC), acrylonitrile-butadiene-styrene (ABS), acrylonitrile-butadiene-styrene + polycarbonate (ABSC) and polyoxymethylene (POM)-figure 1. PET and standard portland cement mixes were also included as references. Sixteen mixes were prepared with 5, 15 and 20% plastic replacing natural sand. A laboratory testing program and microstructural analyses were carried out using petrographic microscopy, Scanning Electron Microscopy and physical tests to measure density, hygric, mechanical and thermal properties and durability. Some of the results are shown below. The last phase of the investigation involved treating the aggregates chemically. Hot mixing trials for geo-engineering applications are also in progress.

Figure 1: Particle properties of the plastics investigated.

(a) ABS: Erratic morphology: flat, angular to cylindrical-smooth and rounded, rough-surfaced.

(b) PC: Varying morphology, similar to ABS with more sub-rounded particles and less fines.

(c) PET: Flat, angular particles with smooth surfaces.

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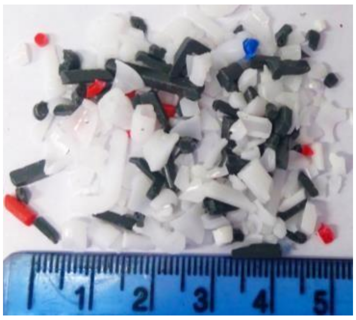

(d) POM: Randomly shaped particles from elongated to rounded and flat, angular. All smooth surfaces.

(e) ABSC: Coarse, smooth to rough surfaces, occasionally scored. Mix of elongated and sub-rounded to angular.

Results

Physical properties of the plastic aggregate materials

The dry density of the plastic mixes ranges from 1664 to 2136 kg/m³; c.15% lower than the standard cement mix (at 20% replacement). Most mixes are under 2000 kg/m³ (maximum density required for structural lightweight concrete by RILEM) which highlights their lightweight applications.

The incorporation of plastic slightly lowers workability and increases porosity and water absorption (by immersion and capillarity) however, the increase by PC, ABS and ABSC is not significant. The ABS materials show the lowest porosity and absorption closely followed by the PC and ABSC, while POM and PET present the maximum values. The PC and PET are the least permeable to water vapour (greatest diffusion resistance) and POM the most permeable however, the differences are not significant and the values close to the control.

Strength and Elastic Modulus

The PC, ABS and ABSC at 5% replacement improved the compressive strength of the standard cement mix by 9, 15 and 11% respectively while the POM and PET marginally reduced strength by 5-8%. The PC, ABS and ABSC materials with 15% plastic marginally reduce strength by 3, 8 and 15%. The POM and PET mixes at 20% replacement are the worst performers reducing strength by c.40%. All the plastics slightly enhanced the standard flexural strength (5% plastic) except for the POM. Similarly to the compressive strength, the declining flexural strength with increasing plastic is likely due to the occasional disruption of the plastic-cement interface, triggered by the hydrophobic nature of the plastics. In spite of the flexural strength drop at the highest plastic content, the post peak performance improved significantly as the materials were able to carry the load for a few minutes after the peak load and prior to failure, indicating an improved ductility.

Microstructure of the plastic aggregate materials

The microstructural analyses focused on the interfaces of the plastic aggregates. The improved performance of PC, ABS and ABSC mortars in compression and flexure is attributed to the rough surface of their particles resulting in a continuous bond as determined by SEM and petrographic analyses (figures 2-5).

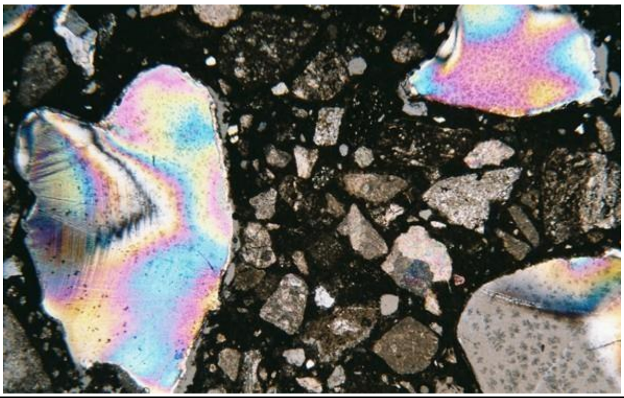

Figure 2. Detail of polycarbonate aggregate (iridescent) well attached to the cement matrix. 2X polarised light. Field of view 7 mm.

Figure 3. Coarse PET (jagged) and limestone aggregate (left) showing a good bond with the hydrated matrix (opaque). 2X natural light.

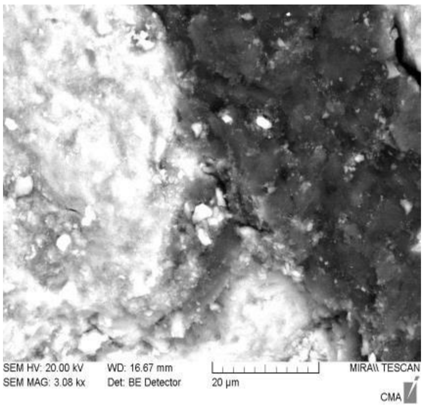

Figure 4. SEM micrograph of the ABSC aggregate interface. Field of view 0.08 mm.

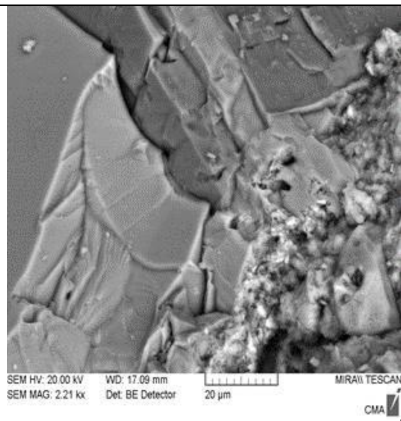

Figure 5. SEM micrograph of the PET aggregate interface. Field of view 0.1 mm.

Durability

No significant differences were evidenced between the standard cement and the plastic aggregate composites following durability tests except for the PC following salt crystallization cycling. The speed at which the specimens deteriorated, indicates that polycarbonate is vulnerable to sulphate attack.

A slight mass reduction was observed for all specimens in all durability tests however, the drop is not significant and can be caused by aging plastic since drying temperature was 105°C.

For up to 15% aggregate replacements, the strength loss after durability cycling (thermal/moisture, frost and salt action) was insignificant (<2% of the original strength). The PC and PET mixes were more susceptible to frost damage than the other plastic aggregate materials. Salt attack caused hair cracks in some specimens. However, most of the plastic aggregate materials showed less hair cracks than the control mix (figure 6).

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Figure 6. A representative sample of specimens after salt-crystallization cycling showing superficial hair cracks. Left-20% PET. Right-control mortar.

Thermal properties

The inclusion of plastic lowers the thermal conductivity of the materials as expected given the low thermal conductivity of plastic. Therefore, the plastic mixes display better insulation properties. The lowest thermal conductivity was observed for the 20% PET. The specific heat capacity of the plastic mixes lowers as expected from the inclusion of a low density solid however, the variation is not significant, and the values are still typical of high thermal mass materials.

Conclusions

The properties and performance of plastic materials at replacement levels up to 15% are not significantly different to those of a standard cement mixes. The plastics can improve cement materials for certain applications such as light-weight and insulation purposes, while preserving a mechanical resistance similar to a standard cement mix. Plastics can also increase the ability of cement composites to absorb stress and deform without failure as well as adjust internal humidity. Therefore, plastic waste can partially replace sand; and plastic composites be used for structural or non-structural applications. This would reduce plastic incineration and landfill as well as raw material extraction and associated fuel consumption and carbon emissions.

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