USE OF RECYCLED PLASTIC WASTE IN CONCRETE

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Abstract Substantial growth in plastics consumption over the last decades has contributed to an increasing amount of plastic waste being deposited in landfills and in natural environments such as the oceans. The production of new materials from recycled plastics appears to be one of the best solutions for the management of plastic waste. The aim of this paper is to investigate the adequacy of using various recycled plastic waste in concrete. The effects of waste plastic aggregates or fibers on the physical, mechanical, thermal and durability properties of concrete have been investigated. In addition, several recommendations for future studies are provided.

Keywords: recycling plastic, concrete, physical properties, mechanical properties, durability

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1 Introduction

The world is on the edge of a global plastic calamity and our collective action over the next decade will determine the future of our planet. If current trends in production and waste management continue, around 12,000 million tonnes of plastic waste will end up in landfills or in natural environments such as the oceans by 2050 (Geyer et al., 2017). The UN Environment Programme estimated that for every square mile of ocean, there are 46,000 pieces of floating plastic (Silverman, 2007). The production of new materials by recycling plastic waste seems to be one of the best solutions for the disposal of plastic waste.

Concrete is the most widely used material and is available at low cost. The main raw materials consist of cement, water, and aggregates. Approximately 65-80% of the concrete volume is taken up by aggregates, which strongly influence the general workability, durability, permeability, and strength of concrete. The use of recycled plastics as fine aggregates can eliminate large amounts of waste material while solving problems associated with aggregate mining, waste disposal and lack of aggregates on construction sites (Almeshal et al., 2020). The use of a lightweight plastic aggregate as an alternative to natural aggregates usually reduces the weight of concrete and offers many advantages, such as lower costs, enhanced thermal insulation performance and better handling. Overall, the use of waste material in concrete production is considered to be environmentally and economically beneficial (Faraj et al., 2020).

The aim of this paper is to investigate the appropriateness of using recycled plastics in concrete mixes. The influence of the commonly used recycled plastic aggregates or fibers on the physical, mechanical, thermal and durability properties of concrete has been extensively investigated. Furthermore, several recommendations for future studies are provided.

2 Different types of waste polymers in concrete

Generally, plastic is incorporated into concrete in the form of plastic aggregates as an alternative to natural aggregates or as a fiber that is intended to reinforce the concrete. The most commonly used recycled plastics in concrete are (PP) plastic particles (Faraj et al., 2019), PP fibers (Madhavi et al., 2014), high-density polyethylene (HDPE) particles (Badache et al., 2018), polyvinyl chloride (PVC) pipe (Gupta, 2013), polyethylene terephthalate (PET) plastics fibers, particles and bags PET (Sulyman et al., 2016), expanded polystyrene (EPS) foams (Dissanayake et al., 2017), high impact polystyrene (PHIS) granules (Olofinnade et al., 2020), high toughness poly-propylene (PPHT) fibers (Ikai et al., 2010), polyethylene (PE) granules (Chen et al., 2019), and shredded recycled plastic waste (Jain et al., 2020). The properties of the most commonly used plastic waste polymers in concrete, such as tensile strength (σ), modulus of elasticity (E) and thermal conductivity (λ), are shown in Table 1. All types of plastic waste have much lower young moduli and thermal conductivities than those of concrete mixes.

Table 1: Properties of commonly used waste plastic polymers in concrete materials (Jacob-Vaillancourt and Sorelli, 2018).

Material	σ/MPa	E/GPa	λ /(W/m.K)
PET	55–80	2.1–3.1	0.15
PVC	50–60	2.7–3.0	0.17–0.21
PS	30–55	3.1–3.3	0.105
PP	25–40	1.3–1.8	0.12
PE	18–30	0.6–1.4	0.33–0.52
Natural aggregate	/	70	2.29–2.78
Cement*	/	36–40	1

*cement paste with w/c = 0.5

3 Properties of concrete containing plastic waste

The effects of the addition of plastics on the properties of concrete in the green state, the mechanical properties in the cured state, durability and thermal properties are discussed in this section.

3.1 Physical properties

Workability, which determines the concrete homogeneity, is the most important property of concrete in the green state. The slump test is normally applied to the measured workability. The addition of waste material can greatly influence workability. (Guendouz et al., 2016). Increasing the substitution level of fine plastic aggregates decreases slump and consequently the workability of concrete (Batayneh et al., 2007). In order to prevent poor mixture consistency and to increase workability, the use of superplasticizers is therefore recommended (Faroug et al., 1999). The incorporation of plastic waste reduces the density of the concrete. The use of lightweight plastic paving concrete has many advantages. For example, the risk of earthquakes is greatly reduced because the force of earthquake depends linearly on dead building weight (Akçaözoğlu et al., 2010).

3.2 Mechanical properties

Compressive and flexural strength are the most important properties that verify the behavior of concrete (Fig. 1) Among them, splitting tensile strength, pulse velocity, triaxial strength and elastic modules are frequently investigated.

The quality of concrete depends on the compressive strength. The results of the 28-day compressive strength of concrete with plastic waste are shown in Fig. 2. An increase in the volume fraction of plastics by up to 40% reduced the compressive strength (Fig. 2a). However, the addition of a limited amount of plastic to the concrete can lead to small improvements in mechanical properties (Fig. 2b). Similarly, the flexural strength of concrete, which was evaluated by the three-point loading of the four-point loading test, decreased with increasing the volume fraction of plastics. The addition of a small percentage of plastics can improve the ability to resist failure in bending (Fig. 3b).

The factors that can negatively affect the compressive and flexural strength of concrete containing plastic waste are: hydrophobic nature of the plastics, which can cause a cement hydration reaction, low strength between the cement paste and the surface of plastic waste aggregates, high porosity, reduced modulus of elasticity and deterioration of the plastic aggregates (Gu and Ozbakkaloglu, 2016).

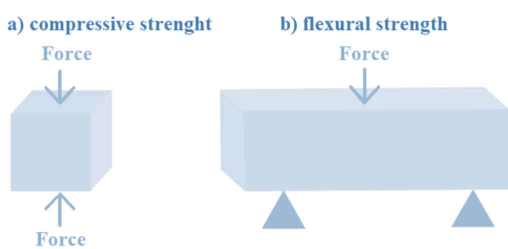

Figure 1: Compressive and flexural strength are influenced to a great extent by the addition/replacement of various forms of plastics.

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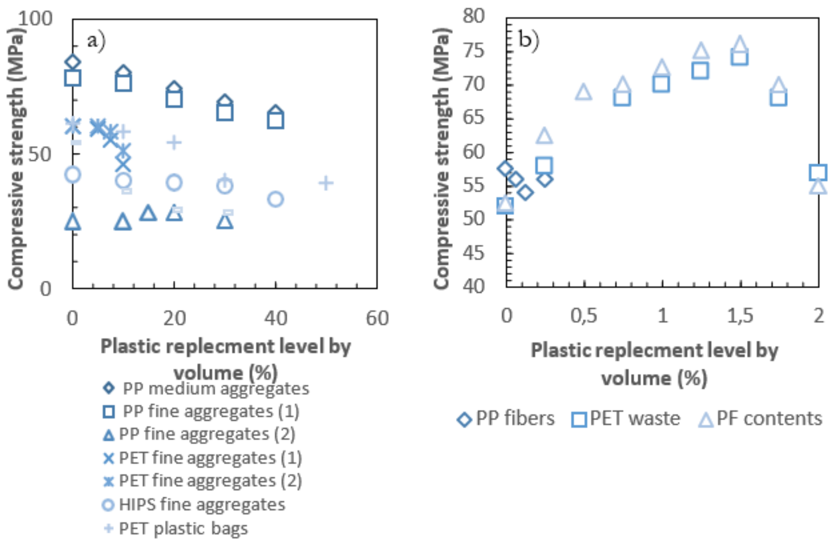

Figure 2: Variation of compressive strength of concrete with varying plastic content: PP medium aggregates (Faraj et al., 2019), PP fine aggregates 1 and 2 (Yang et al., 2015), PET fine aggregates 1 end 2 (Hama and Hilal, 2017), HIPS fine aggregates(Chunchu and Putta, 2019), PET plastic bags (Safi et al., 2013), PP fibers (Aslani et al., 2019), PET waste and PF contents (Al-Hadithi and Hilal, 2016).

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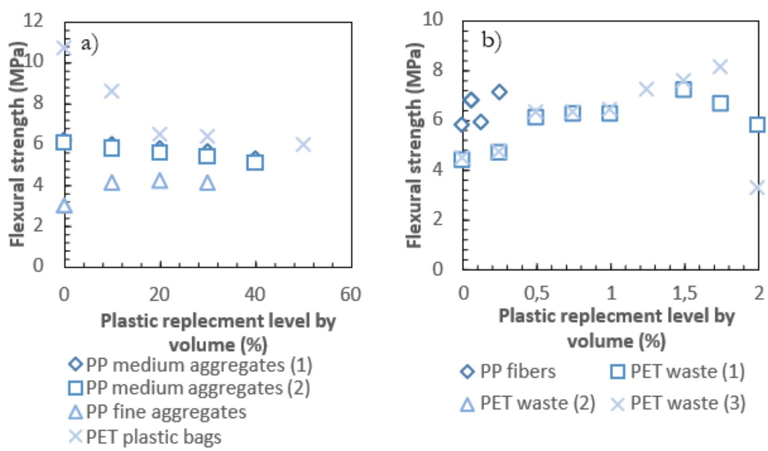

Figure 3: Variation of flexural strength of concrete with different plastic content:: PP medium aggregates 1 and 2 (Faraj et al., 2019), PP fine aggregates (Yang et al., 2015), PET plastic bags (Safi et al., 2013), PP fibers (Aslani et al., 2019), PET waste 1, 2, 3 (Gesoglu et al., 2017).

Source: own.

3.3 Durability

The durability performance of concrete is usually assessed on the basis of water absorption properties, air and water permeability, chloride migration, carbonization, shrinkage, and freezing/thawing resistance.

Water absorption increases as the exchange ratio of sand to plastic waste aggregates increases (Coppola et al., 2018). This indicates that mixing natural aggregates and plastics leads to more porous concrete. The water and air permeability increases with the content of plastic waste in the concrete. More voids in the concrete matrix lead to greater chloride ion penetration and higher carbonation of the cement-like composite (Silva et al., 2013). During the carbonization process, calcium hydroxide $Ca(OH)_2$ reacts with carbon dioxide (CO_2) from the atmosphere and has a negative effect on the mechanics of concrete.

In case of shrinkage, plastic waste has a higher drying shrinkage compared to conventional concrete. In general, the shrinkage stress of plastic-containing cement paste decreases (Bendimerad et al., 2016). The freeze and thawing resistance of concrete containing waste plastics meets all the standards for safe usage. In some cases, increasing plastic waste content in concrete even enhance frost resistance and durability (Kan and Demirboğa, 2009).

3.4 Fire resistance and thermal properties

Fire resistance is an important property of concrete that ensures general building safety. The fire resistance of concrete is characterized by the cement paste and the aggregate. When exposed to fire, concrete heats up 50 times slower than steel. However, replacing natural aggregates with waste plastic aggregates can create holes in the concrete at 400 °C to 600 °C, which reduce its flexural strength and produce toxic smoke (Sayadi et al., 2016). The thermal conductivity of concrete containing plastic waste decreased considerably. The recycling of plastics in concrete leads to improved thermal insulation properties and higher energy efficiency of buildings (Dweik et al., 2008).

4 Conclusions

Plastics can easily be used in concrete in certain proportions. The following conclusions are:

- the workability of concrete containing recycled plastic is reduced. To increase the workability of concrete in the green phase, superplasticizers should be used,
- the inclusion of plastic in concrete does not effectively improve the mechanical properties of concrete. The strength of concrete should be balanced with reactive materials such as silica fume, metakaolin and iron slag to create an additional pozzolanic reaction,
- the durability of concrete containing plastic waste is severely impaired. Water absorption increases as the exchange ratio of sand to plastic waste aggregates increases,
- More voids in the concrete matrix leads to more chloride ion penetration and higher carbonation,
- replacing natural aggregates with plastic waste aggregates can create holes in concrete at 400 °C to 600 °C, which impairs the bending strength,
- freeze and thawing resistance of concrete containing waste plastics meets all the standards for safe usage.

In order to make concrete containing recycled waste more attractive and better accepted by the construction industry, future studies should focus on economic efficiency, social acceptance, material properties such as adhesion, triaxial failure, abrasion and impact resistance, rheological properties, thixotropy, durability properties such as sulfate resistance and general long-term resistance to environmental exposure. The outcomes of this paper show that the use of recyclable plastics in concrete leads to more sustainable building materials in the construction industry.

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