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The use of Polymer Recyclates in the Technology of Concrete Composites Production

PIETRZAK Alina[a*]

Czestochowa University of Technology / Faculty of Civil Engineering, Poland

[a] alina.pietrzak@pcz.pl

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Abstract. The paper presents a short literature review related to the possibility of using various types of post-production or post-use waste in concrete technology. The main focus was on polymer waste, namely polyethylene terephthalate, polyethylene and polypropylene, and rubber waste.

Introduction

In modern construction, concrete, a composite material with a cement matrix, is used on a large scale. Its use allows for the construction of durable and aesthetic objects. The concrete mix components, i.e. cement, aggregate and water, are environmentally friendly. Unfortunately, the growing demand for this type of material causes enormous exploitation of the above-mentioned natural resources, which in turn causes a heavy burden on the surrounding environment. Over the past few decades, there has been a growing interest in reusing by-products from various industries. The range of used mineral additives for concrete has been extended with new raw materials and waste types. It takes into account the components that make up the concrete mix. According to the literature review, domestic and industrial waste [1], fly ash, silica dust, ground blast furnace slag, biofuel ash [2-8], sanitary waste and ceramics [9, 10], CRT glass is used for the production of concrete mix. [11, 12], recycled glass sand [13] and slag aggregate [14]. The article focuses on using various types of polymer recyclates in the production of concrete.

Polyethylene terephthalate materials

The literature reports show that polyethylene terephthalate (PET) is one of the most studied waste management [15-22]. The use of polyethylene terephthalate waste in concrete is presented in Table 1. The recyclate obtained from PET waste was used for concrete as a replacement for aggregate or in the form of fibers as reinforcement. The method of PET recyclate preparation and shape significantly impacts the produced concrete's parameters. Recycling with a smooth, spherical surface has a lesser effect on concrete workability than recycling with a non-uniform shape. The addition of PET waste material to concrete, as demonstrated by most authors, reduces the compressive strength, tensile and bending strength of concrete and the modulus of elasticity, regardless of the tested consistency and water-cement ratio. Research on polymer recyclates utilization as substrates involved in the production technology of mortars and concrete mixtures is significant in the ecological aspect.

Materials Made of Polyethylene and Polypropylene

For over fifty years, modifiers in the form of polymers have been used in concrete to improve its quality. The plastic fibers added to the fresh concrete mix act as micro-reinforcement, reducing plastic shrinkage and limiting the formation of shrinkage cracks in the hardened concrete. However, after the concrete has achieved the designed strength and the appropriate modulus of elasticity, these fibers cease to function, then the stress is transferred by the concrete itself or the main reinforcement. The research was also conducted on using waste recyclate made of polyethylene and polypropylene as a replacement for aggregate or concrete reinforcement (Table 2).

Table 1. *Utilization of polyethylene terephthalate waste in concrete*

recycling methods	size, shape recyclate	properties of recyclate	dosing	ref.
shredded PET bottles combined at 250ºC with powdered GBFS blast furnace slag	round and smooth particles ≤ 0.15 cm	PD = 1390 kg/m3	round and smooth particles ≤ 0.15 cm	[15]
PET bottles shredded in the melting process	fibers of length 30 and 40mm	SG = 1.34 g/cm^3 TS = 450	fiber 0.3 - 1.5% by volume	[16]
mechanically shredded PET bottles combined at 250ºC with powdered river sand	round and smooth particles 0.15-4.75 mm	PD = 1390 kg/m^3 BD = 840 kg/m^3 FM = 4,1	fine aggregate 25-75% by volume	[17]
3 types of artificial aggregates Pc, Pf - shredded, Pp - thermal treatment	Pc ≤ 11.2 mm Pf ≤ 4 mm Pf, Pc - scaly shape Pp ≤ 4 mm - irregular granules	P_c: BD = 261 kg/m^3 SG = 1.3 g/cm^3 P_f: BD = 438 kg/m^3 SG = 1.28g/cm^3 P_p: BD = 739 kg/m^3 SG = 1.31g/cm^3	Pc - coarse grained and fine aggregate 7.5% by volume Pf, Pp - fine aggregate 7.5 and 15% by volume	[18]
3 types of artificial aggregates Pc, Pf - shredded, Pp - thermal treatment	Pc ≤ 11.2 mm Pf ≤ 4 mm Pf, Pc - scaly shape Pp ≤ 4 mm - irregular granules	P_c: BD = 351 kg/m^3 SG = 1.34 g/cm^3 P_f: BD = 555 kg/m^3 SG = 1.34 g/cm^3 P_p: BD = 827 kg/m^3 SG = 1.34 g/cm^3	Pc - coarse grained and fine aggregate 5, 10 and 15% by volume Pf, Pp - fine aggregate 5, 10 and 15% by volume	[19]
shredded PET bottles	fibers length 25 mm	SG = 1.34 g/cm^3	fiber 0.5-3% by weight of cement	[20]
shredded PET particles	< 7 mm	PD=464 kg/m^3 SG=1.11 g/cm^3	fine aggregate (sand) 5, 10 and 15%	[21]
shredded PET bottles (melted and extruded fibers)	fibers A, length 40 mm (straight, smooth profile) B fibers 52 mm long (crimped, notched profile)	A: SG = 1.34 g/cm^3 TS = 550 B: SG = 1.34 g/cm^3 TS = 274	fiber 1% by volume	[22]

Explanations: PD - density (kg / m^3); BD - bulk density (kg / m^3); SG - specific weight (g / cm^3); FM - accuracy module; TS - tensile strength (MPa); MP - melting point (ºC); MoE - modulus of elasticity (GPa)

Recycling mixtures of this material are characterized by different quality and mechanical properties [23, 24]. Because the properties of fibers made of pure synthetic material differ significantly from the properties of fibers obtained from recycled material, fibers made of pure polypropylene or polyethylene were used much more frequently in the research [25-27]. Concretes containing polypropylene fibers in an amount up to 1% show higher compressive, splitting, or bending strength compared to concrete without the addition of plastic (normal concrete). Increasing the content of synthetic fibers above this level deteriorates the mechanical properties of modified concretes.

Table 2. *The use of PE and PP waste in concrete*

recycling methods	size, shape recyclate	properties of recyclate	dosing	ref.
industrial waste from mechanically shredded carpets	PP and nylon fibers fiber I, length 12-25mm fiber II, length 3–25mm	-	fiber in quantity 1 and 2% by volume	[28]
shredded HDPE waste	small particles	-	0.5 - 5% for fine aggregate of the total weight	[29]
industrial waste of carpets, shredded mechanically	PP and nylon fibers 12 – 25 mm	-	0.07 – 1.4% volume	[30]
mix of HDPE, PP waste and PVC recycling by grinding	grain size ≤10 mm irregular shape	HDPE: BD = 534 kg/m^3 SG = 1.0 g/cm^3 PVC: BD = 684 kg/m^3 SG = 1.0 g/cm^3	too thick aggregate in a ratio of 1: 0.274 by volume	[31]
ground HDPE waste	grain size ≤ 2.36 mm heated coarse-grained aggregate combined with HDPE powder	BD = 945 - 962 g/cm^3 SG = 1.04 g/cm^3	modifier was added in an amount of 2, 4 and 6% to replace the same amount of cement and sand	[32]
fibers from HDPE waste from pots, buckets, cans, kitchen utensils	fiber length 20 - 100 mm, the ratio of the fiber length to its diameter 20 - 100	SG = 0.9 g/cm3	0.6% by volume	[33]
LDPE waste - bags	grain size ≤2.36 mm	SG = 0.93 g/cm^3 FM = 5.92	for fine aggregate 0.4 - 1% of the total weight	[34]

Explanations: PD - density (kg / m^3); BD - bulk density (kg / m^3); SG - specific weight (g / cm^3); FM - accuracy module; TS - tensile strength (MPa); MP - melting point (ºC); MoE - modulus of elasticity (GPa)

Rubber Waste

There have also been reports on the utilization of rubber waste in concrete production [35-44]. With the increase in the content of rubber waste used as a sand substitute, concrete mixes were characterized by lower [40, 41] or higher [36] workability. Concrete containing the addition of rubber recyclate showed lower values of mechanical parameters than concretes produced without

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the addition of waste [37, 44]. Such an approach may be inspiring for other industrial branches struggling with the problem of recyclates, e.g. packaging [45], steel industry [46],

Summary

Limiting the consumption of mineral resources is particularly important in the construction sector, which consumes large amounts of mineral resources, especially felt and aggregate. The consumption of these raw materials can be reduced by replacing them with, for example, recycled materials. Such activities are consistent with the idea of sustainable development, which is defined as development that meets the needs of the present generation without reducing the ability of future generations to meet their needs. However, replacing mineral materials with recyclates from various types of waste in producing new building materials has several technical and technological limitations, so a series of laboratory tests must precede it. Numerous researchers have attempted to determine the possibilities of using various types of waste, including dust from biomass combustion, ceramics, glass cullet, and some synthetic materials to produce concrete. In the case of plastics, as shown in the literature review, due to their different physicochemical properties (diversified composition of modifying additives and a diverse chemical structure of the primary polymer), their use is tough and it requires each time separate tests for a selected group of plastics. The cited review of the literature presents both research carried out with the use of polymer recyclates produced for the needs of the study and with the use of materials derived from the recycling process. Most studies using recycled plastics concern polyethylene terephthalate and polypropylene. At the same time, there are few reports on the use of other plastics (e.g. PC, PUR) or mixtures of various synthetic materials in the production of concrete.

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