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The analysis of the compression strength of concrete modified with rubber granules SBR and polyethylene terephthalate

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ABSTRACT:
Worn out car tires and plastic from food wrappings constitute a problematic waste. They pollute the environment and management of such waste is important both ecologically and economically as it protects the environment, and reduces the costs of acquiring components to produce different materials. In this article, the results of testing modified concrete are shown. The concrete was modified with a mixture of supplements in the form of the pre-mentioned materials. The car tires provided, upon processing, rubber granules SBR of the following fractions: 0÷1 mm, 0.8÷2 mm, 2÷4 mm. Plastics of polyethylene terephthalate were used in the form of PET flakes. Six concrete series were generated where 10% of the cement mass was replaced with the supplement mixture. Tests of the texture and compression strength of a modified concrete mixture were conducted after 7, 14, and 28 days. All the series of concrete shared satisfactory homogeneousness of decomposition in the particular components. The strength tests proved that the application of rubber granules SBR and PET flakes in the form of a supplement mixture obtains a concrete strength of about 40 MPa.

KEYWORDS:
plastics; rubber granules; concrete

1. Introduction

The need to manage rubber waste from car tires or plastic waste from used packaging is a global problem. A highly worrying phenomenon is the presence of this waste in legal and illegal landfills, where it may spontaneously ignite, causing environmental pollution in the form of toxic smoke, soil degradation, and groundwater pollution. Solutions to reduce the storage of this waste and, at the same time, utilize it to obtain cheap components for the production of various materials have been sought for many years. The legal basis for limiting waste deposits are, among others:

- The directive of the European Parliament and Council (EU), which requires European Union countries to implement and ensure the possibility of managing waste in the form of recycling or subjecting it to other forms of recovery [1].
- OJ The Act of 24 May 2018 on waste, which orders manufacturing plants to prevent the formation of waste, and if it arises, orders it to be recovered [2].
- The National Waste Management Plan 2022, which defines the forecast of changes in waste management [3].

Car tires do not decay, and plastic decomposes, depending on the composition, within 100 to 1000 years. This waste can be used entirely or, after processing into individual components, for the production of various materials in various branches of the economy. The management of

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waste should strive for the so-called “circular economy”, which is the basic premise of the 2018 Directive of the European Parliament and Council.

After processing used car tires into pellets and plastics into PET flakes, they are used as individual components, for example, as an additive to the production of materials, improving their adhesion, plasticity and thermal resistance. Rubber granulate, due to its damping properties, perfectly suppresses mechanical interactions in media related to wave propagation and is most often used in road, land, or water construction [4-7].

Another example is the addition of processed waste in the form of SBR rubber granules and PET flakes to concrete mixes as a partial substitute for aggregates. SBR rubber granules obtained from used car tires and PET flakes obtained from food packaging waste can be a valuable addition to cement matrix materials. Guneyisi et al. [8] confirmed that for concretes containing granulate or fine rubber, strength decreases proportionally with the content of rubber. They confirmed that it is possible to produce concrete even with a strength of 40 MPa, in which 15% of rubber waste was used as a substitute for aggregate. Biel and Lee [9], performing strength tests of modified concrete with rubber granules, determined the maximum use of rubber granules up to 17% of cement mass. In testing concrete mixes, Aiello and Leuzzi [10] replaced fine and coarse aggregate with hyphae from tires. They found that the size of the individual rubber particles used in the concrete has an impact on the compressive strength of the concrete. By using thick shreds of rubber waste, the compressive strength is significantly reduced when compared to using smaller fractions of rubber waste.

Another addition used in modified concretes is polyethylene terephthalate in the form of PET flakes. It was noticed that concretes with this addition are characterized by high compressive strength [11] and are definitely a lighter replacement for partial aggregate. In [12-14] it has been shown that polyethylene terephthalate in the form of PET flakes can be used as an additive to cement concrete composites, partly replacing sand. There are few studies in the literature that test concretes modified with two additions simultaneously: polyethylene terephthalate and SBR rubber granulate. This article presents modified concretes in which additive mixtures were used, using fine fractions of SBR rubber granules with sizes: 0÷1 mm, 0.8÷2 mm, and 2÷4 mm, and polyethylene terephthalate in the form of PET flakes.

2. The scope of tests for modified concretes

The developed research program was aimed at the simultaneous use of SBR rubber granulate and PET flakes in concrete. SBR rubber granulate was obtained from the fragmentation of used car tires. Granules with fractions: 0÷1 mm, 0.8÷2 mm, 2÷4 mm were used. Polyethylene terephthalate was obtained from cutting plastic packaging and was colloquially referred to as PET flakes. Both waste materials were added to concrete in the form of a mixture of additives.

The additive mix for the modified concretes was used in the amount of 10% cement weight while subtracting the same amount of aggregate by volume. The percentage of SBR rubber granules of individual fractions and PET flakes in the additive mixtures is presented in Table 1.

Table 1
Percentage of SBR rubber granules and PET flakes used in modified concrete

Additives	Series					
	A1	A2	A3	A4	A5	A6
Rubber granules 0÷1 mm	36%	36%	36%	22.5%	22.5%	22.5%
Rubber granules 0.8÷2 mm	54%	54%	54%	22.5%	22.5%	22.5%
Rubber granules 2÷4 mm	–	–	–	45%	45%	45%
Flakes PET	10%	10%	10%	10%	10%	10%

In three series of the modified concretes A1, A2, A3, SBR rubber granulate with fractions: 0÷1 mm and 0.8÷2 mm and PET flakes were used as a partial sand replacement. In the next three series A4, A5, A6, SBR rubber granules with fractions: 0÷1 mm and 0.8÷2 mm and PET flakes were used as a partial sand replacement and SBR rubber granules with a fraction 2÷4 mm as a partial gravel replacement. In this way, six series of modified concretes were obtained, in which the following components were used: CEM I 32.5 R cement, fraction gravel 2÷8 mm; sand 0÷2 mm, tap water, Stacheoplast 202N superplasticizer, SBR rubber granules with fractions: 0÷1 mm, 0.8÷2 mm, 2÷4 mm, PET flakes. The modified concretes were compared with the designed A0 control concrete composed of: CEM I 32.5 R cement, fraction gravel 2÷8 mm; sand 0÷2 mm, tap water, Stacheoplast 202N superplasticizer. The compositions of concrete are shown in Table 2.

Table 2

Compositions of modified concrete with a mixture of additives: SBR rubber granulate and PET flakes and control concrete A0 [kg/1 m^3; l/1 m^3]

Series	C/W	Sand [kg/m^3]	Gravel 2÷8 mm [kg/m^3]	Cement CEM I 32.5 R [kg/m^3]	Water [kg/l]	Stacheoplast 202N [kg/l]	Rubber granules SBR [kg/m^3]			Flakes PET [kg/m^3]
							0÷1 mm	0.8÷2 mm	2÷4 mm	
A1	2.1	287.0	1256.0	416.0	198.1	4.99	13.2	19.7	–	3.6
A2	2.0	301.0	1320.0	402.0	201.0	4.82	13.8	20.7	–	3.8
A3	1.9	310.0	1360.0	349.2	183.8	4.19	14.3	21.4	–	3.9
A4	2.1	314.4	1228.6	416.0	198.1	4.99	8.2	8.2	16.4	3.6
A5	2.0	330.0	1291.2	402.0	201.0	4.82	8.6	8.6	17.3	3.8
A6	1.9	339.7	1330.3	349.2	183.8	4.20	8.9	8.9	17.8	3.9
A0	1.9	481.0	1319.0	459.0	235.5	5.50	–	–	–	–

In all series of modified concrete and control concrete, cubic samples with a 15 cm edge were used in accordance with PN-EN 206 [15], strength tests were carried out in accordance with PN-EN 12390-3 [13]. The consistency of the concrete mix was tested using the fall cone method in accordance with PN-EN 12350-2 [16].

In individual series of the modified concretes, an even distribution of the additive mixture was observed throughout the entire volume of concrete, as shown in Figures 1 and 2.

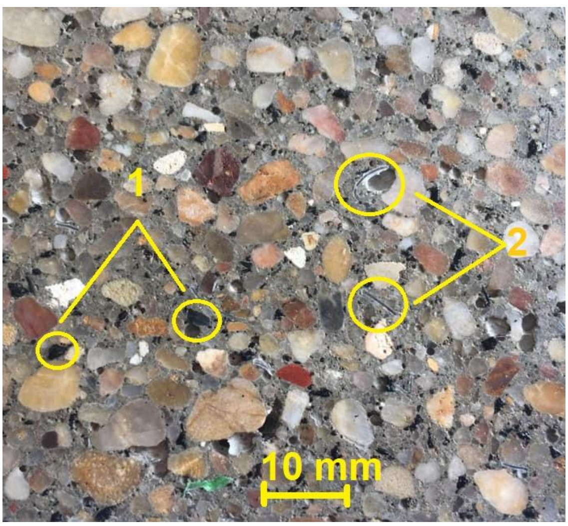

Fig. 1. Cross-section of a modified A1 series concrete sample, 1 - SBR rubber granulate with a fraction of 0.8÷2 mm, 2 - PET flakes

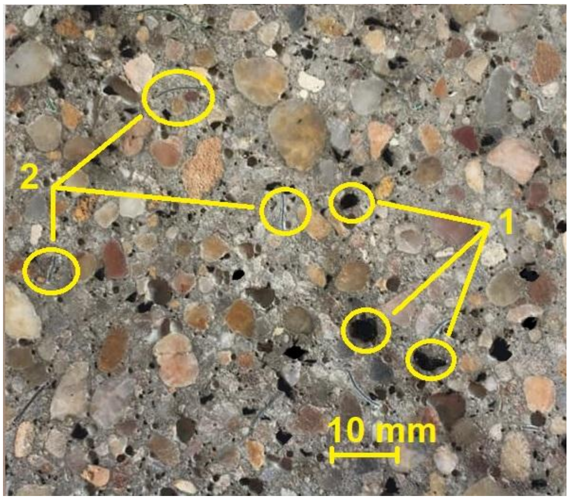

Fig. 2. Cross-section of a modified A5 series concrete sample, 1 - SBR rubber granulate, 2÷4 mm fraction, 2 - PET flakes

3. Research results

The consistency of the concrete mix was tested in accordance with PN-EN 12350-2 [16]. Compressive strength tests after 7, 14, 28 days were carried out in accordance with PN-EN 12390-3 [17]. The results obtained are summarized in Table 3.

Table 3
The results of tests on the modified concretes with a mixture of additives from rubber waste and plastics together with a control concrete

Series	Fall cone [mm]	Class of consistency	Medium compressive strength f_{cm} [MPa]			Grade strength concrete
			After 7 days	After 14 days	After 28 days	
A1	40	S1	34.4	40.9	42.4	C30/37
A2	48	S1/S2	35.8	38.1	42.1	C30/37
A3	30	S1	32.2	38.6	41.6	C30/37
A4	38	S1	36.8	37.9	44.0	C30/37
A5	148	S3	31.8	32.3	39.4	C25/30
A6	40	S1	27.2	31.6	36.0	C25/30
A0	18	S1	41.2	42.3	48.4	C30/37

The results of the strength tests confirmed the legitimacy of using SBR rubber granulate and PET flakes as concrete additives. Tests on all series of the modified concretes resulted in a compressive strength within 40 MPa, after 28 days. The results are presented graphically in Figure 3.

4. Conclusions

Based on the tests performed, it can be noted that:
- SBR rubber granules with fine fractions and PET flakes are good concrete additives, partly replacing the aggregate mix. They reduce the weight of concrete due to the lower specific density of rubber granules and PET flakes when compared to aggregate.

- While using the additions: SBR rubber granulate with fractions: 0÷1 mm, 0.8÷2 mm, 2÷4 mm and PET flakes, C30/37 class concrete can be obtained. Such concrete is widely used in construction and provides an alternative opportunity to manage rubber and plastic waste, improving environmental protection and reducing the cost of components for concrete.
- All the tested series of the modified concretes had good homogeneity, and an even distribution of the additive mixture was obtained throughout the entire volume of concrete.

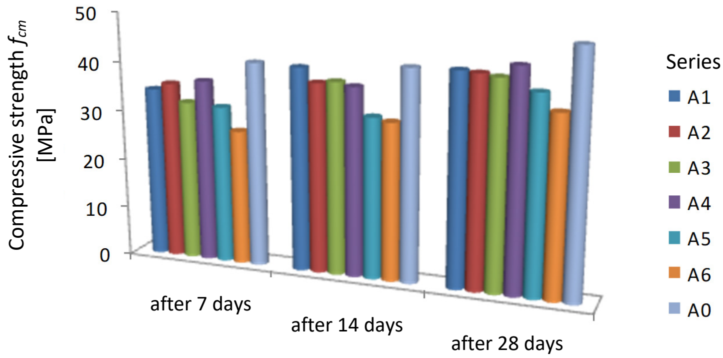

Fig. 3. Average compressive strength of modified concrete and control concrete after 7 days, 14 days, 28 days

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[17] PN-EN 12390-3 Badania betonu - wytrzymałość na ściskanie próbek do badania.

Analiza wytrzymałości na ściskanie betonów modyfikowanych granulatem gumowym SBR i politereftalanem etylenu

STRESZCZENIE:
Zużyte opony samochodowe oraz tworzywa sztuczne po opakowaniach spożywczych są problemowym odpadem; zalegają na różnych składowiskach i zanieczyszczają środowisko. Zagospodarowanie ich ma szeroki aspekt ekologiczny i ekonomiczny. Pozwala chronić środowisko i zmniejszyć koszty pozyskania składników do produkcji różnych materiałów. W artykule przedstawiono wyniki badań modyfikowanych betonów, do których zastosowano mieszankę dodatków jako częściowy zamiennik kruszyw mineralnych. W ten sposób zagospodarowano odpad w postaci zużytych opon samochodowych oraz odpad po zużytych opakowaniach spożywczych z tworzyw sztucznych. Z opon samochodowych wykorzystano pozyskany po przetworzeniu granulat gumowy SBR o frakcjach: 0÷1 mm, 0,8÷2 mm, 2÷4 mm. Z odpadów tworzyw sztucznych w postaci politereftalanu etylenu wykorzystano płatki PET. Wykonano sześć serii betonów, zastępując 10% masy cementu mieszanką dodatków, jednocześnie ujmując objętościowo tę samą ilość mieszanki kruszyw. Dla modyfikowanych betonów wykonano badania konsystencji mieszanki betonowej oraz badania wytrzymałości betonu na ściskanie po 7, 14 i 28 dniach. Wszystkie serie betonów charakteryzowały się dobrą jednorodnością rozkładu poszczególnych składników. Wykonane badania wytrzymałościowe potwierdziły, że zastosowanie granulatu gumowego SBR oraz płatków PET w postaci mieszanki dodatków pozwala na uzyskanie wytrzymałości betonu na poziomie 40 MPa.

SŁOWA KLUCZOWE:
tworzywo sztuczne; granulat gumowy; beton