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STUDY ON POLYMER CONCRETES WITH WASTE OF POLYSTYRENE GRANULES

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Abstract

This paper presents the results of experimental tests on polymer concrete prepared with different wastes. Two types of polymer concrete mixes were compared. The control polymer concrete was obtained with epoxy resin, natural aggregates in two sorts (0-4 mm and 4-8 mm) and fly ash waste used as filler. To the control mix, both sorts of natural aggregate were replaced in different dosages by polystyrene granules waste. The influence of polystyrene granules as substitution of aggregate on density, compressive strength, flexural strength and split tensile strength was analyzed in comparison with the properties of control polymer concrete. All mixes with aggregate substitution had densities of lightweight concrete, smaller than that of control mix. The compressive strength and flexural strength presented smaller values than that of control mix. The split tensile strength presented two values higher than the control mix. The values of mechanical properties decreased with increasing the substitution dosage of aggregate with polystyrene granules.

Key words: epoxy resin, fly ash, mechanical properties, polymer concrete, polystyrene granules waste

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1. Introduction

The problem of wastes is today of great importance because they generate environmental pollution. Wastes can be of different types, in form of powder, granules, fibers etc. (Cazacu et al., 2017, Golestaneh et al., 2010; Kou and Poon, 2013; Jawaid et al., 2013; Weena and Thiru, 2013) and can be used as components of building materials being an opportunity of replacing natural raw materials or, in some cases wastes can improve building material properties (Bărbuță et al., 2015; Bolden et al., 2013; Ciocan et al., 2017; Garbacz and Sokolovska, 2013; Jnyanendra et al., 2016; Serbanoiu et al., 2017).

Eco-polymer-concretes (EPC) are prepared with different types of wastes which can replace polymers, aggregates or are added as filler (Benosman et al., 2017; Mahdi et al., 2010; Martinez-Barrera et al., 2013; Saribiyik et al., 2013). The natural aggregates can be replaced by aggregates obtained from wastes and generally they are obtained at lower costs than the natural aggregates. Using different types of wastes, such as: chopped PET bottles, polystyrene granules, saw dust, glass etc. as substitution of natural aggregate, concretes with new properties are obtained (Jo et al., 2008; Kaya and Kar, 2016; Sayadi et al., 2016; Tonet and Gorninski, 2013; Xin at al., 2016).

In this paper, we analyzed the experimental results regarding the preparation of polymer concrete with wastes of polystyrene granules type used as substitute for natural aggregates. The effects of this alternative on the density, workability and mechanical

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strengths of polymer concrete were investigated by testing different mixes in which aggregates were replaced by waste polystyrene granules in dosages ranging between 25% and 100%.

2. Experimental

2.1. Materials

The following materials were used for preparing a control mix (CPM) of polymer concrete with usual density: epoxy resin in a dosage of 12.4 wt%, fly ash (FA) as filler in a dosage of 12.8 wt%, and natural river aggregates of two sorts (sand and gravel 4-8 mm), both in the same dosage of 37.4 wt%. Epoxy resin is a Romanian product and is activated by the hardener. FA is a waste from Electric Power Plant Holboca Iasi, Romania. It has a grey colour, in the form of round particles with size ranging from 0.01 to 100 μm, the specific surface is between 4800-5200 m^2/m^3, the density is between 2400 and 2550 kg/m^3. FA contains oxides, hydroxides, carbonates, silicates, and sulfates of calcium, iron and aluminum (Bucur et al., 2014). Waste of expanded polystyrene granules (EPS) of round shape is used in two sorts: 2-4 mm (EPS1) with bulk density of 16.34 kg/m^3 and 5-8 mm (EPS2) with bulk density of 10.9 kg/m^3.

Experimental mixes PPM1 to PPM4 were prepared by substitution of sand with (EPS1) in dosages of 25%, 50%, 75% and 100%. The experimental mixes PPM5 to PPM8 were prepared by substitution of gravel with (EPS2) in dosages of 25%, 50%, 75% and 100%. The concrete was prepared by mixing together the components: aggregates, fly ash and polystyrene granules which were firstly introduced in the epoxy resin combined with hardener and then in the mix. The samples of cubic form of 70 mm and prisms of 210x70x70 mm sizes were poured and demoulded after 24 hours. After 14 days of hardening in laboratory conditions at 20°C, the samples were measured, weighed and tested. The density of hardened concrete, compressive strength (f_c), flexural strength (f_{ti}) and split tensile strength (f_{td}) were determined on three samples for each test, according to standard prescription (ASRO, 2005a, 2005b, 2009, 2011).

3. Results and discussion

3.1. Workability of polymer concrete

The dosage of polystyrene granules influenced the workability of fresh concrete. With the increasing of polystyrene dosage a better flow and workability of concrete was observed.

3.2. Density of hardened concrete

The density of hardened epoxy resin concrete with polystyrene granule of both type (EPS1 and EPS2) as aggregate substitution was smaller than that of control mix, and varied between 1656 and 1336 kg/m^3, indicating a lightweight concrete (Fig. 1).

The values of densities were close for both types of polystyrene granules and this characteristic is not dependent on the size of polystyrene granules but only on the dosage of substitution (Fig. 1).

3.3. Compressive strength

The values of compressive strength for all mixes are represented in Fig. 2a. The values of compressive strength of polymer concrete with polystyrene granules as aggregate substitution were smaller than that of control mix in both cases of substitution. The decrease of f_c in comparison with control mix was bigger in the case of polymer concrete with substitution of aggregate sort I (0-4mm). The highest value of compressive strength f_c= 35.3 MPa was obtained for polymer concrete with substitution of aggregate sort 4-8 mm (PPM5). The smallest value of f_c=11.9 MPa was obtained for polymer concrete with substitution of aggregate sort 0-4 mm (PPM4).

Generally when increase the dosage of aggregate substitution, the compressive strength of polymer concrete will decrease.

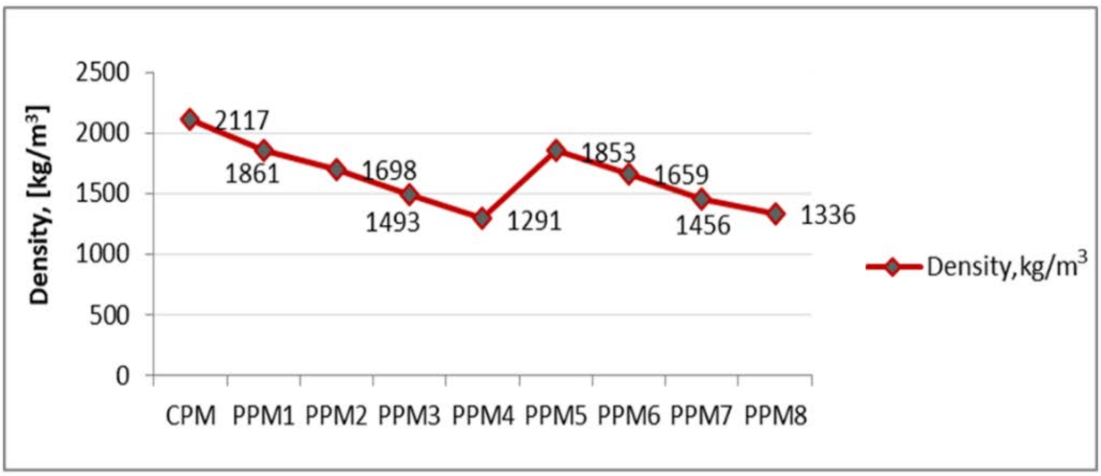
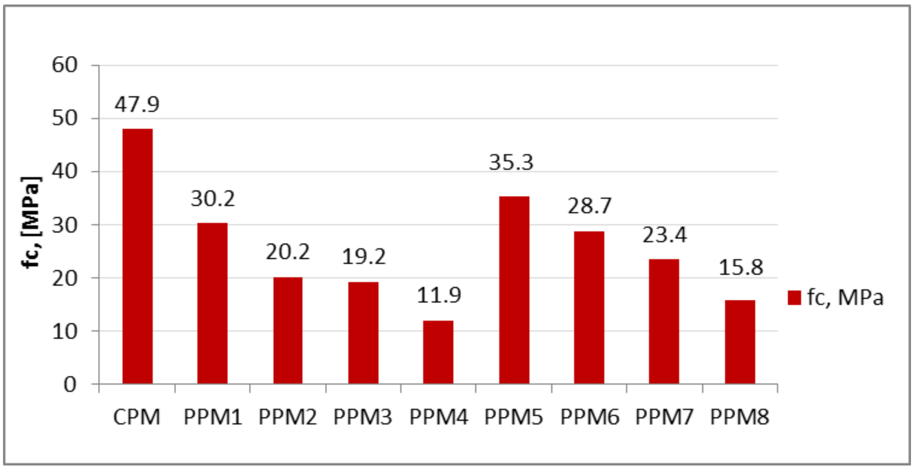
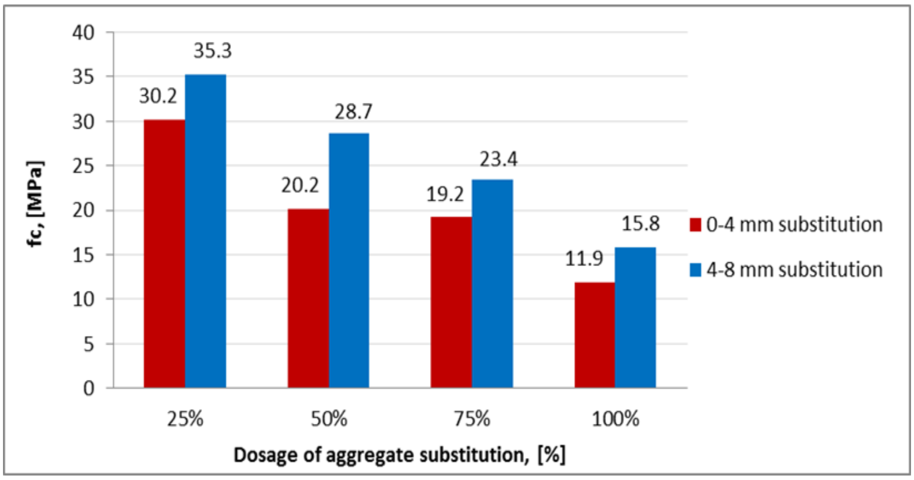


Fig. 1. Variation of density for polymer concrete with polystyrene granules as aggregate substitution



(a)



(b)

Fig. 2. Compressive strength of polymer concrete with polystyrene granules: a) compressive strength for all mixes; b) compressive strength depending on the polystyrene granules size – Sort I, Sort II

The size of polystyrene granules influenced the compressive strength. For the same aggregate substitution percentage, the polymer concrete with higher size of polystyrene granules (EPS2) presented higher values of compressive strength for all dosages of substitution. The increase in f_c of polymer concrete with EPS2 comparative to polymer concrete with EPS1 is relatively the same for all substitution dosages, between 1.16% and 1.4% (Fig. 2b). The compressive strength is dependent on the density as it is presented in Fig. 3, decreasing with density.

The type of failure of cubic sample is not a typical brittle failure as that of polymer concrete without any addition. After the maximum force in compression is reached, the cracks occurred on lateral surfaces of the cube and an elastic shortening and a swelling of the samples were observed and profound cracks were slowly developed without complete degradation of the sample. The failure was gradual, and high elastic shortening of the cube of polymer concrete was observed (Fig. 4a). In the concrete mass the matrix was not completely destroyed and polystyrene granules presented a good adherence to the binder (Fig. 4b).

3.4. Flexural strength

The experimental values obtained for flexural strength of concrete with polystyrene granules as aggregate substitution are represented in Fig. 5. In the case of flexural strength, a decreasing in value was observed with increasing the substitution dosage, for both types of polystyrene granules, as in the case of compressive strength. All values of f_{ti} are smaller than that of control polymer concrete (Fig. 5). Better values of f_{ti} were obtained for substitution of aggregate with bigger size granules (EPS2), and they were smaller than the control value with percentages between 18% and 58.1% in comparison with values of f_{ti} obtained in the case of (EPS1), which were smaller than the control value with percentages between 32.3% and 67%. The highest value f_{ti} was obtained for concrete with 25% polystyrene granule of higher size (PPM5) and the smallest value of f_{ti} was for the mix with maximum replacement of aggregate, and smaller size of granule (PPM4). The type of failure of samples is similar to that of concrete without wastes addition. The sample was separated in two pieces but more slowly.

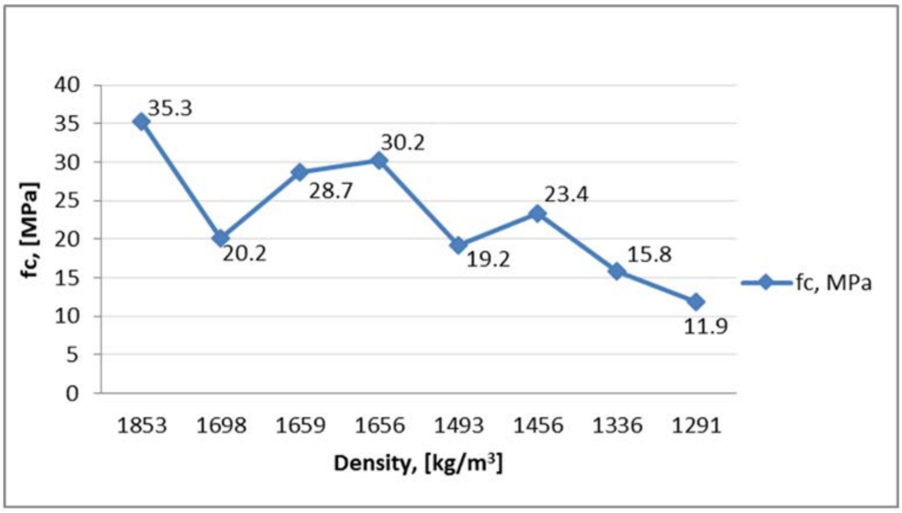


Fig. 3. Variation of compressive strength for different densities

(a) (b)

Fig. 4. Failure of samples with polystyrene granules waste as aggregate substitution: a) elastic shotening of sample; b) cube degradation in compression

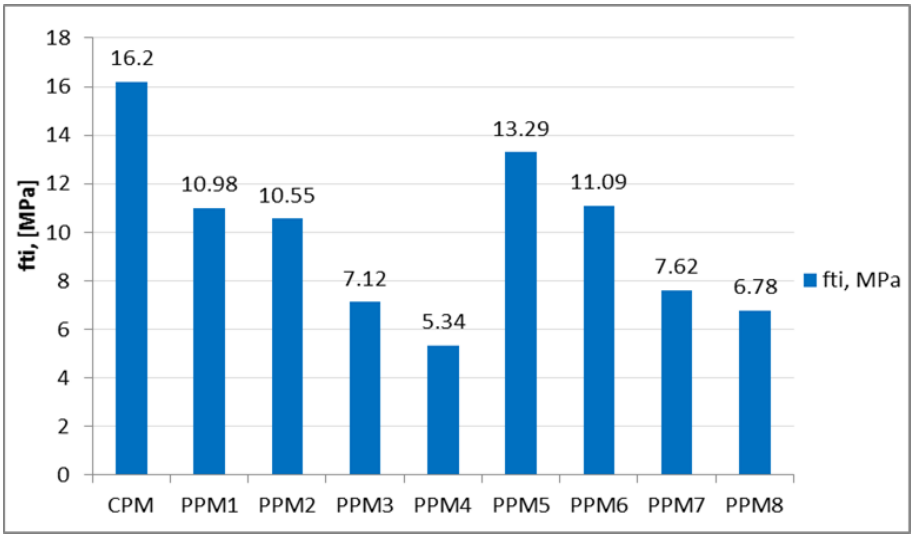


Fig. 5. Flexural strength of polymer concrete with polystyrene granules

In the structure of the polymer concrete the distribution of polystyrene granules was influenced by the dosage of aggregate substitution (Fig. 6a). The distribution is not uniform, so the value of flexural strength depends on the presence of polystyrene granules in the tested section, granules that probably has a negative influence on the behaviour in flexure. Also on the failure surface there are a big number of alveoli which indicate that the granules were detached from the matrix at failure.

3.5. Split tensile strength

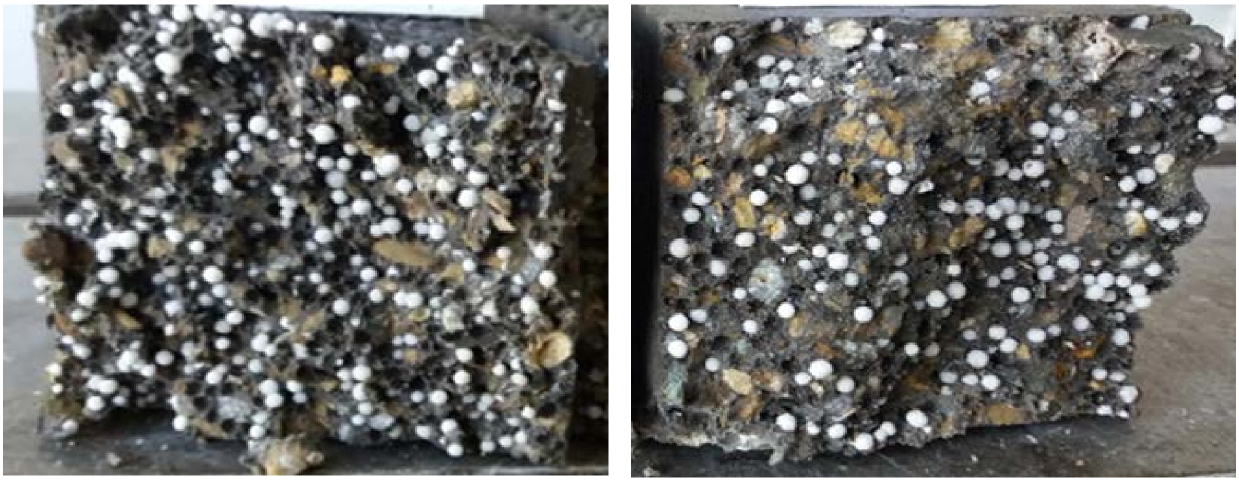
The experimental results obtained for f_{td} had shown that all values of polymer concrete with sand replaced by polystyrene EPS1 were smaller than that of control concrete (Fig. 7).

In the case of polymer concrete with EPS2, two values of f_{td} were bigger than the value of control mix. The highest value was obtained for polymer concrete with 25% polystyrene (PPM5), the increase in strength being of 16.6%. The smallest value of f_{td} was for the mix PPM4 with 100% replacement of sand, the decrease being of about 68.6%. The biggest value in the case of polymer concrete with sand replacement by polystyrene was obtained for PPM1 with 25% aggregate substitution. Fig. 6b shows the failure surface in splitting test. At failure the samples presented the same type of failure as in the case of ordinary concrete without any addition, with only one plan of failure in the section with maximum splitting force and aggregate degradation. It can clearly observe that the bond between polystyrene granules and matrix is destroyed.

The variation of split tensile strength (f_{td}) with cube compressive strength (f_c) was represented in Fig. 8. It can be observed that with decreasing of tensile strength the compressive strength is also decreasing. The first graph of Fig. 8 is representing the variation of split tensile strength with cube compressive strength in the case of aggregate sort I with 0-4 mm substituted with EPS1 and the second graph in the case of sort II substituted with EPS2.

As it can observe in both cases of aggregate substitution, the compressive strength is depending on the split tensile strength and an equation of variation can be expressed for each type of polystyrene substitution (Equations and R-Squared values are given in Fig. 8).

From the studied mechanical strengths, the highest decrease had the compressive strength. For tensile characteristics the values were closed to that of the control mix, which indicated a good behavior in tension. Concretes with high dosage of aggregate substitution with EPS are recommended to be used as non-structural concrete.



(a) (b)

Fig. 6. Failure surface of polymer concrete with polystyrene granule: a) failure in flexure, b) failure in splitting

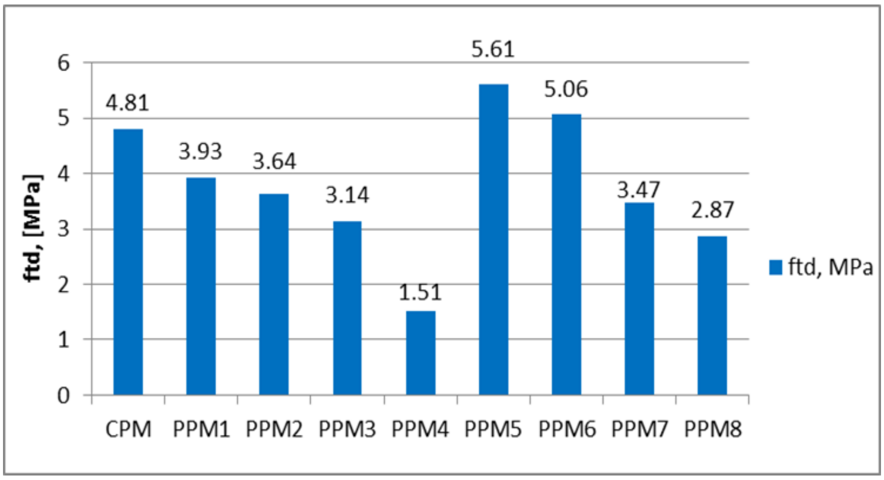


Fig. 7. Variation of split tensile strength of concrete with polystyrene granules

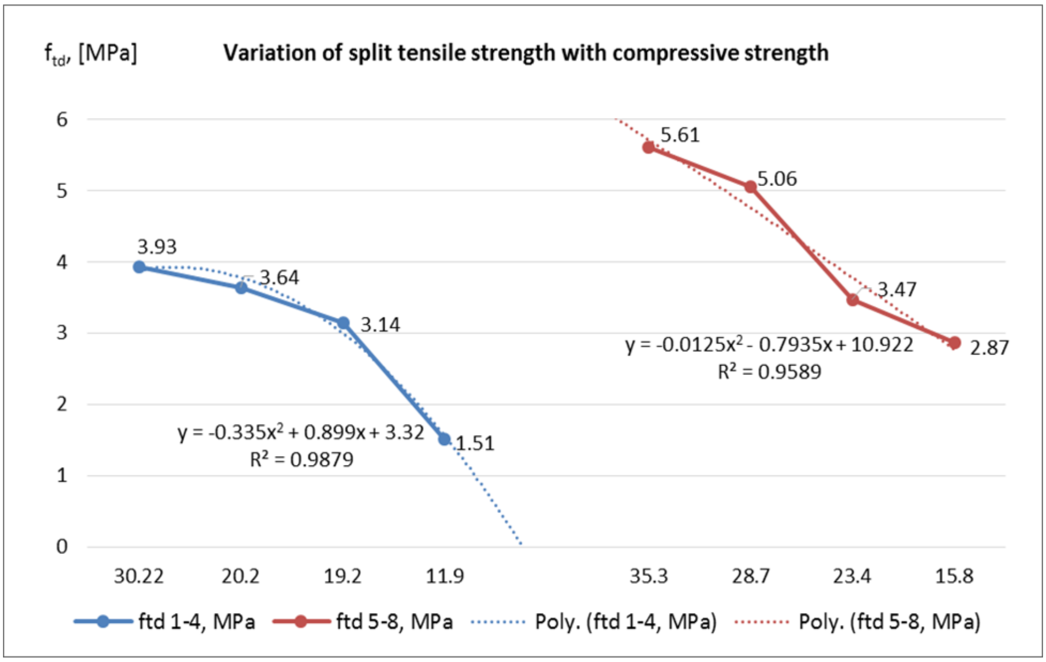


Fig. 8. Variation of split tensile strength with compressive strength

4. Conclusions

The experimental results on polymer concrete with aggregate substitution were analysed in the article.

The density of hardened epoxy resin concrete with polystyrene granule of both types (EPS1 and EPS2) as aggregate substitution was under 2000 kg/m^3, indicating a lightweight concrete.

The values of compressive strength and flexural strength of polymer concrete with polystyrene granules as aggregate substitution were smaller than that of control mix in both cases of substitution.

For the same aggregate substitution percentage, the polymer concrete with higher size of polystyrene granules (EPS2) presented higher values of compressive strength, flexural strength and split tensile strength for all dosages of substitution in comparison with polymer concrete with EPS1.

The values of split tensile strength of polymer concrete with EPS1 were smaller than that of control mix. In the case of polymer concrete with EPS2, two values of f_{td} for PPM5 and PPM6 were bigger than that of control mix.

All mechanical strengths presented highest values for mix PPM5 (with aggregate substitution of 25%).

The failure in the case of polymer concrete with polystyrene granules was more ductile in comparison with the failure of control polymer concrete. Depending on the used domain of polymer concrete with aggregate substitution by waste of polystyrene granules a mix optimization function of the desired characteristic is necessary. The use of polystyrene waste in obtaining polymer concrete results in developing a new material – a lightweight concrete which can be used in construction industry for producing non-structural elements or materials with better thermal or acoustic behaviour than ordinary concrete.

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