

Mechanical Properties of Fly Ash Polymer Concrete with Different Fibers

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The experimental results obtained by studying the influence of different types of fibers on the mechanical properties of fly ash polymer concrete are presented in the paper. The general demand of using wastes found applicability in building material industry because some of them are beneficial in improving concrete properties. The waste additions type fly ash and fibers were incorporated in polymer concrete. The study focused on fibers type glass, polyester, metallic and cellulose. The mechanical properties such as compressive strength, flexural strength and split tensile strength were investigated having in view the type, dosage and length of fibers. The results show that fibers improved mechanical properties in comparison with that of polymer concrete without fibers, the test results being differently influenced by the factors which were considered.

Keywords: Fiber reinforcement, flexural strength, polymer concrete, compressive strength, tensile strength, fly ash

Building materials industry has developed a lot of new materials which must respond to the modern requirements from construction field and to the necessities related to the environment protection [1- 3]. A great number of construction materials are obtained with/from wastes, which are an important problem in environment pollution and storage costs [4]. The concrete is one of the most used products in construction industry and it is often associated to wastes of different types: powder, fibers, granules, nano-particles, etc.[5-8]. As addition or replacement of cement in concrete and cement component are used many wastes, such as: silica fume [9-11], fly ash [12], ground granulated blast furnace [13, 14], sludge [15, 16], waste ferrochromium [17], tire wastes [18, 19], bagasse ash [20], rice husk ash [21], bamboo leaf ash [22, 23], ceramic waste [24], etc.

The effects of fibers on cement concrete and composite materials have been studied and reported in articles by numerous researchers [1-3, 22-29]. In reinforcing polymer concrete a lot of types of fibers can be used: glass, carbon, boron, steel, polyester, polypropylene, etc. or natural fibers like: hemp, coconut, banana fibers, sugar cane bagasse, cellulose. The mechanical properties depend on the type and dosage of fiber [3, 30, 31]. Most of studies reported that glass fibers, carbon and metallic fibers improved the post-peak behavior of polymer concrete [3, 32, 33]. The strength and toughness also increased with addition of fibers [34]. In the paper [35] authors reported that textile fibers do not increase polymer concrete flexural and compressive strength but their addition to the mixture eliminates the signs of brittleness behavior of unreinforced polymer concrete. In paper [36] is reported a study which evaluates the use of recycled fibers from carpet industrial waste. Significant increases in shatter resistance, energy absorption and ductility were observed. The uses of natural fibers, as reinforcement are economical for increasing their tensile strength, shear strength, toughness and/or combinations of these [37]. An investigation of the mechanical characterization (flexural strength, fracture toughness and fracture energy) of epoxy polymer concrete reinforced with natural fibers (coconut,

sugar cane bagasse, and banana fibers) had shown that these properties can be increased and also the flexural strength can be slightly increased by using coconut fiber only [38]. In this study the mechanical characteristics such as compressive strength, flexural strength and split tensile strength were investigated on polymer concrete made with fly ash and different types of fibers wastes.

Experimental part

Research Significance

A significant amount of wastes of different types is disposed worldwide. They are not only an environmental concern, but also by using them the resources can be protected. This paper completes the knowledge referred to the characteristics of polymer concrete made with wastes. This type of polymer was not sufficiently studied in the last years because the high costs of polymer [39, 40]. Using wastes for obtaining the polymer concrete is a possibility of obtaining this material at lower prices. The research study presents the mechanical properties of new products obtained with fly ash and different fibers wastes in order to determine their usefulness. New studies are required in this field for promotion and use of these materials in construction industry.

Materials

For studying the influence of fibers on mechanical properties of fly ash polymer concrete the following components were used: epoxy resin, fly ash as filler and two sorts of aggregate (0-4 mm and 4-8 mm). To the witness mix different types of fibers were added: glass fibers, (GF), polyester fibers, (PesF), metallic fibers (MF) and cellulose fibers (CF) (table 1).

The polymer was type epoxy resin, called ROPOXID, made in Romania by POLICOLOR Bucharest [41]. The hardener was type ROMANID 407, also made by POLICOLOR Bucharest [41].

The fly ash (FA), a waste from the power plant CET Holboca Iasi was added to the aggregates [42]. Fly ash was type F ash, with a gray color, small particles ranging in size from 0.01 to 100 μm and its chemical composition

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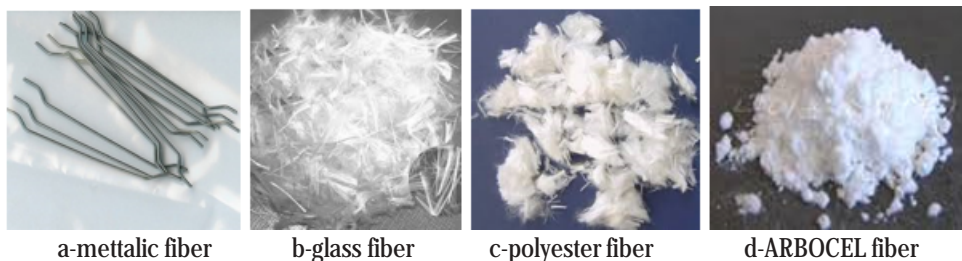


Fig. 1. Type of fibers

Sample	Epoxy resin %	Fly ash %	Aggregate %		Fibers						
			Sort I	Sort II	GF		PesF		MF		CF %
					L (mm)	%	L (mm)	%	L (mm)	%	
PC - witness	12.4	-	43.8	43.8	-	-	-	-	-	-	-
PCGF1	12.4	12.8	37.4	37.4	50	0.5	-	-	-	-	-
PCGF2	12.4	12.8	37.4	37.4	30	0.5	-	-	-	-	-
PCGF3	12.4	12.8	37.4	37.4	10	0.5	-	-	-	-	-
PCPesF1	12.4	12.8	37.4	37.4	-	-	50	0.5	-	-	-
PCPesF2	12.4	12.8	37.4	37.4	-	-	30	0.5	-	-	-
PCPesF3	12.4	12.8	37.4	37.4	-	-	10	0.5	-	-	-
PCMF1	12.4	12.8	37.4	37.4	-	-	-	-	50	2	-
PCMF2	12.4	12.8	37.4	37.4	-	-	-	-	25	2	-
PCMF3	12.4	12.8	37.4	37.4	-	-	-	-	50	7	-
PCFM4	12.4	12.8	37.4	37.4	-	-	-	-	25	7	-
PCCF1	12.4	12.8	37.4	37.4	-	-	-	-	-	-	0.25
PCCF2	12.4	6.4	40.6	40.6	-	-	-	-	-	-	0.25

Table 1
COMPOSITION OF
POLYMER
CONCRETE WITH
WASTES

with oxides, hydroxides, carbonates, silicates, and sulfates of calcium, iron and aluminum [41].

The aggregates were used in two sorts: 0-4 mm (sand) and 4-8 mm, with continuous granulosity, obtained from crushed river gravel.

The glass fibers (fig. 1 b) were wastes from industry which were cut at different lengths: 10 mm, 30 mm and 50 mm. the characteristics of glass fibers type Glass fiber 2040 dtex are: yarn tensile strength 72.64 N and tenacity 66.98 cN/tex [42]. The glass fibers were used in a dosage of 0.5% from the mix weight.

The polyester fibers (fig. 1 c) are also wastes which were cut at 50 mm, 30 mm and 10 mm. The characteristics of Polyester fibers type PES HT 110 dtex are: yarn tensile strength 42.21 N and tenacity 20.69 cN/tex [43].

The glass and polyester fibers were used in a dosage of 0.5% from the mix weight.

The metallic fibers (fig. 1 a) had different lengths, of 50 mm and 25 mm (these were half of long fibers).

The ARBOCEL fibers (fig. 1 d) were natural cellulose fibers, produced by J. Rettenmaier & Sohne GMBH. The ARBOCEL cellulose fibers had the mean fiber length of 10 μ m. The fiber dosage was of 0.25% from the mix weight.

Experimental samples

The mixes presented in the article were chosen from previous experimental results effectuated on each type of fiber with more types of components dosages, table 1. The criterion for chosen samples was the value of compressive strength obtained experimentally which was considered with maximum value. In the case of glass fibers and polyester fiber are analyzed the mixes with different lengths and maximum dosage of fiber. In the case of

metallic fibers are analyzed the mixes with different lengths and dosages (because a dosage of 7% from the weight is not maximum). In the case of cellulose fiber was analyzed the mixes with maximum and minimum dosage of fly ash dosage which allow the same dosage of 12.4% of epoxy resin, with the fiber with maximum dosage and the same length.

The glass fibers and polystyrene fibers were of three sizes: 50 mm, 30 mm and 10 mm. For glass fiber polymer concrete, the notations were: PCGF1 for 50 mm length, PCGF2 for 30 mm and PCGF3 for 10 mm length and for polyester fiber polymer concrete the notations were: (PCPesF1) for 50 mm, PCPesF2 for 30 mm and PCPesF3 for 10 mm length. The proportion used in polymer composition was of 0.5% from the mix weight (this was the maximum dosage of fiber imposed from the workability condition).

For polymer concrete with metallic fiber (FM) the notations were: PCMF1 for 50 mm length and a dosage of 2% from the mix weight, PCMF2 for 25 mm length (half from the long fiber) and a dosage of 2% from the mix weight, PCMF3 for 50 mm length and a dosage of 7% from the mix weight and PCMF4 for 25 mm length and a dosage of 7%.

For polymer concrete with cellulose fibers the dosage of fiber was the same (0.25% from the mix weight) and the fly ash dosage was 12.8% for PCCF1 and 6.4% for PCCF2.

For studying the influence of fibers on mechanical properties of fly ash polymer concrete the same mix was used (12.4% epoxy resin, 12.8% fly ash and the two sorts of aggregates in equal dosage of 37.4%) for the witness and for the composition with fibers.

The fly ash was mixed with aggregates and then the resin (combined with hardener) was added in the mechanical mixer. During mixing, the fibers were introduced. After complete mixing, the polymer concrete was poured in formworks. The following mechanical characteristics were experimentally tested at 14 days: compressive strength (f_c) on cube samples of 70 mm sizes, flexural strength (f_{ti}) and split tensile strength (f_{td}) on prismatic samples of sizes 210x70x70 mm, according to European standard prescriptions [43-45].

Results and discussions

The results of mechanical properties obtained by laboratory tests according to [43-45] as average of three tests are given in table 2.

The experimental results are compared in the graph presented in figure 2.

Compressive strength

All types of fibers, except cellulose fibers, improved the compressive strength of polymer concrete with fly ash in comparison with that of witness, (table 2, fig. 2). The highest value $f_c=106.85$ MPa, was obtained for polymer concrete which contains glass fiber with 50 mm length and a maximum dosage, in which case the increase in strength was of about 52.8%. All lengths of glass fibers increased the compressive strength with percentages between 33 and 52.8% and the higher lengths results in higher values of the property.

Table 2

MECHANICAL CHARACTERISTICS OF POLYMER CONCRETE WITH FIBERS

	Sample	f_c , MPa	f_{ti} , MPa	f_{td} , MPa
1	Witness	69.93	12.26	6.82
2	PCGF1	106.85	16.73	10.11
3	PCGF2	98.73	16.93	7.78
4	PCGF3	93.03	17.25	8.40
5	PCPesF1	88.03	15.62	11.82
6	PCPesF2	80.6	16.36	7.02
7	PCPesF3	95.54	16.05	12.2
8	PCMF1	88.90	17.1	6.54
9	PCMF2	89.18	15.3	9.10
10	PCMF3	102.41	23.4	6.36
11	PCMF4	85.6	18.78	9.05
12	PCCF1	55.02	14.69	6.92
13	PCCF2	46.41	14.18	6.91

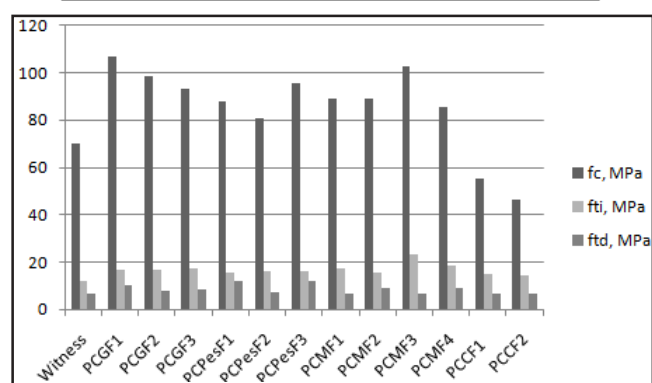


Fig. 2. Variation of mechanical properties of fly ash polymer concrete with different fibers

In the case of polyester fiber the increase in strength was between 15.3 and 36.6% in comparison with that of the witness and with diminishing the length of the fiber the higher values are obtained. The highest value $f_c=95.54$ MPa was for a length of 10 mm and maximum dosage of fiber.

In the case of metallic fibers it appeared that the dosage influenced more significantly. The maximum value $f_c=102.41$ MPa was obtained for a dosage of 7%, which is a huge percent, but it is not the maximum. The increases of strength were between 22.4 and 46.4% in comparison with that of the witness. For the same length of 50 mm, higher f_c was obtained for higher dosage (7%). In the case of length of 25 mm, higher f_c was obtained for lower dosage of 2%. For the same dosage of fiber of 2%, the length had not significantly influenced the compressive strength. In the case of higher dosage of fiber (7%), higher f_c was obtained for higher length. The results were influenced by the ratio between the sizes of the sample and the length of the fiber, having in view that 50 mm is a long fiber in comparison with the size of the sample which was 70 mm. One explanation is the agglomeration of long fibers which can increase the resistant capacity of the polymer concrete.

The compressive strength obtained in the case of polymer concrete with cellulose fibers was smaller than that of the witness, with percentages between 21% and 36.6%, the highest value $f_c=55.02$ MPa was obtained for a bigger content of fly ash.

Flexural strength

All types of fibers improved the flexural strength of polymer concrete with fly ash. The highest value was obtained for polymer concrete with metallic fiber, (table 2, fig. 2).

The highest value $f_{ti}=23.4$ MPa, was obtained for polymer concrete which contains metallic fiber with 50 mm length in a dosage of 7%, in which case the increase in strength was of about 90.8%. Comparing the same percentage of fibers and different lengths, it can observe that for a bigger length the flexural strength is higher. Higher dosages of fiber with the same length resulted in higher values of f_{ti} . All polymer concretes with metallic fibers presented higher values of f_{ti} in comparison with the witness, with percentages between 24.8 and 90.8% in comparison with the witness.

In the case of glass fibers it appeared that the length did not significantly influence the strength, a small increase is obtained in the case of short fibers. The maximum value $f_{ti}=17.25$ MPa was obtained for a length of fiber of 10 mm. The increases of strength were between 36.6 and 40.7% in comparison with that of the witness.

In the case of polyester fiber the increase in strength was between 27.4 and 33.4% in comparison with that of the witness. The highest value $f_{ti}=16.36$ MPa was for a length of 30 mm (a medium value).

The flexural strengths obtained in the case of polymer concrete with cellulose fibers were all higher than that of the witness, but smaller than that of polymer concrete with other types of fibers. The increasing percentages were between 15 and 20%, the highest value $f_{ti}=14.69$ MPa was obtained for a bigger content of fly ash.

Split tensile strength

In the case of split tensile strength only PesF, GF and CF increased the strength in comparison with that of witness. The highest value was obtained for polymer concrete with polyester fibers (table 2, fig. 2).

The highest value $f_{td}=12.2$ MPa, was obtained for polymer concrete which contains polyester fiber with 10

mm length. All lengths of polyester fibers increased the split tensile strength with percentages between 3 and 78.9%. In this case it appears that distribution of fibers in concrete matrix is of significantly importance, the length is less important.

In the case of glass fibers the maximum value $f_{td}=10.11$ MPa was obtained for a length of fiber of 50 mm. The increases of strength were between 14 and 48.2% in comparison with that of the witness.

In the case of metallic fiber the highest value $f_{td}=9.1$ MPa was for a length of 25 mm and a dosage of fiber of 2%. Near to this value was polymer concrete with the same length of fiber and a higher dosage of 7%. The lengths of 50 mm for both dosages (2 and 7%) resulted in the decrease of f_{td} in comparison with the witness.

The split tensile strengths obtained in the case of polymer concrete with cellulose fibers were all a small higher than that of the witness. The highest value $f_{td}=6.92$ MPa was obtained for a bigger content of fly ash.

Conclusions

The mechanical properties were differently influenced by the types of fibers used in experimental tests.

In the case of *compressive strength* glass, polyester and metallic fibers, improved the compressive strength of polymer concrete with fly ash. The highest value was obtained for polymer concrete with glass fiber. Glass fibers must be used in maximum dosage and length for obtaining higher f_c . Polyester fibers must be used with minimum length and higher dosage in the case of f_c . Metallic fibers must be used in high dosages for increasing the compressive strength.

All types of fibers improved the *flexural strength* of polymer concrete with fly ash. The highest value was obtained for polymer concrete with metallic fiber in high dosage. Glass fiber must be used with small length to increase the flexural strength.

In the case of *split tensile strength*, glass fibers, polyester fiber and cellulose fiber increased the strength. The highest value was obtained for polymer concrete with polyester fibers which had minimum length. Glass fibers must be used with high length in the case of split tensile strength. Metallic fibers presented high values of f_{td} for minimum length.

In the case of glass fibers, polyester fibers and cellulose fibers the dosage of fibers was maximum from the condition of workability. In the case of metallic fibers the maximum dosage of fibers was not tested because the higher dosage that was used (7% from the mix weight) was sufficiently big.

The split tensile strength is clearly influenced by the distribution of fibers in the concrete structure and consequently the fiber length influences the type of failure.

For some type of fibers, as in the case of cellulose fibers, the mechanical properties can be increased by using a higher resin dosage, but an increase in epoxy resin dosage results in higher costs. The epoxy resin dosage used in all experiments was minimum established from the workability condition.

In the article were analyzed only the influences of type, length and dosage of fibers on the mechanical properties of epoxy resin concrete with fly ash addition.

The mechanical properties are also influenced by the dosage of fiber, the shape of fibers, type of fibers, fiber distribution, preparing technology, pouring, etc. which are necessary to study for a complete characterization of fiber reinforced polymer concrete and determination of its usefulness as building material.

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