Some Properties of Fiber-Reinforced Road Concrete Using Iron Ore Dressing Wastes

Rasul Akhmednabiev, Lyudmila Bondar, Oksana Demchenko, and Vladimir Shulgin

Abstract The results of studies of fine-grained road fiber-reinforced concrete using iron ore dressing wastes as fillers at the Poltava mining and processing plant are presented. Ore dressing wastes are crushed rocks of the quartzite group, which are not worse in strength than granites. The waste has a rocky torn surface, which contributes to good adhesion to the cement stone. The uniformity of the of polypropylene fibers distribution in the volume of the concrete mixture was assessed by the change in the degree of separation. The dependences of homogeneity of a concrete mixture with different amounts and volumetric concentration and length of polypropylene fibers on the duration of mixing have been obtained. The graphs were built and the optimal duration of mixing the concrete mixture was determined.

The influence of polypropylene fibers on the strength of concrete of different grades has been investigated. The research results indicate that polypropylene fibers do not have an adhesive bond with cement stone and, therefore, cannot significantly increase the strength of concrete in comparison with steel fibers. However, polypropylene fibers can have a positive effect on the crack resistance and dynamic strength of road concretes.

Keywords Iron ore dressing wastes · Polypropylene fibers · Degree of separation · Volumetric concentration of fibers · Homogeneity of concrete mix

1 Introduction

With the development of scientific and technological progress, mankind extracts more and more minerals from the earth. The careers are getting deeper and the environmental impacts are becoming more tangible. As you know, almost all the fossils that mankind extracts from the earth have associated rocks or waste is generated after their use. One way or another, a large amount of waste accumulates on the ground. Some wastes are mineral raw materials suitable for further use in activities

R. Akhmednabiev (✉) · L. Bondar · O. Demchenko · V. Shulgin
National University "Yuri Kondratyuk Poltava Polytechnic",
Pershotravnevyj Ave. 24., Poltava 36011, Ukraine

V. Onyshchenko et al. (eds.), *Proceedings of the 3rd International Conference on Building Innovations*, Lecture Notes in Civil Engineering 181,
https://doi.org/10.1007/978-3-030-85043-2_2

of mankind, for example, ash and slag from thermal power plants, waste of ferrous and non-ferrous metals. In some developed countries, such waste is used almost 100%, and in Ukraine—only about 15%.

On the territory of Ukraine there are six largest mining and processing plants, which form the lion's share in the Ukrainian production of concentrate, pellets and agglomerate.

At Poltava Mining and Processing Plant, dry magnetic separation wastes are sold in the form of crushed stone, and 335 million m^3 of wet magnetic separation waste is stored in a sludge storage facility. Annually, Poltava MPP produces about 11 million m^3 of wet magnetic separation waste, which is currently not used.

Review of Literary Sources. A feature of the large-tonnage waste of mining and processing plants is that technogenic raw materials have crystalline structures and do not contain organic impurities [1]. They are crushed material in which its texture and structure are disturbed, as well as, in many respects, the morphology of individuals and aggregates of minerals. Due to the extraction of ore minerals from the grinding products, the mineral and chemical composition of the dressing wastes differs significantly from the composition of the original ore. The storage of waste in storage facilities is accompanied by gravitational differentiation of the crushed material. As a result, the mineral and chemical composition of stale waste in specific areas of the storage facilities differ markedly [2].

As you know, along with by-products of iron ore mining and finely ground waste of wet magnetic enrichment at mining and processing plants of Ukraine, dry magnetic enrichment units of crushed mass operate in the technological line for crushing ferruginous quartzites, resulting in crushed stone. The main physical and technical properties of crushed stone from dry magnetic enrichment waste of ferruginous quartzite are practically not inferior to granite and therefore it is recommended for use as a coarse aggregate in the preparation of concrete for monolithic structures and as a ballast material in construction and road works [3].

Waste of wet magnetic separation by grain size composition is a finely ground material containing 70 … 75% of grains with a particle size of 0.085 … 0.16 mm and 7.7 … 17.3% of grains with a particle size of 0.16.,.. 3, 0 mm, specific surface area 30 … 40 m^2/l [4].

The experience of crushed stone use and sand of ore dressing wastes as concrete aggregates shows that they allow, in many cases, to increase the strength and density of concrete, its frost resistance, impact and abrasion resistance, in comparison with traditional aggregates [3, 5].

Several authors investigated the possibility of using other industrial waste in the technology of building materials production [6, 7].

Concretes with the use of aggregates from iron ore dressing wastes have an increased density due to the presence of iron residues in their compositions. Such concretes are more suitable for road construction. However, road concretes must be able to maintain their operational characteristics under conditions of constant exposure to dynamic loads and corrosive environments inherent in roads.

Since the beginning of the last century, a method has been known to increase the dynamic strength of concrete by introducing fibers into their composition. This method is called fiber reinforcement. At present, experience has been accumulated in the use of various types of fibers, both steel and polymer, and even of plant origin, for fiber reinforcement of concrete.

Materials Used in the Work. Portland cement PC 500 of Ivano-Frankivsk plant was used as a binder. As a fine aggregate—waste of wet magnetic separation of the Poltava Mining and Processing Plant with a modulus of 1.01; as a large aggregate, crushed stone of 5–10 mm fraction from dry magnetic separation waste of the same plant. As a fiber reinforcement—polypropylene fibers with a diameter of 0.1 mm of various lengths. A superplasticizer based on modified polycarboxylates "Fluid Premia 196" was used in the work.

Research Methods: The properties of mineral aggregates were investigated by standard methods. The activity of the cement was determined according to the DSTU method.

It is known that the greatest difficulty in the technology of dispersed concrete reinforcement is the provision of a uniform distribution of fibers in the volume of the material. Some researchers have developed special equipment for feeding fiber into a mixer, as well as mixers for mixing dispersion-reinforced mixtures. In this work, the uniformity of fiber distribution in the volume of the mixture was estimated by the change in the degree of separation, which is determined by the equation.

$$S = \left(\frac{1}{V}\right)\left(\frac{1}{\rho_{m.a}}\right)\sum\nolimits_n \sum\nolimits_m [\rho_i - \rho_{i.a}] \cdot \Delta V_i \tag{1}$$

where $\rho_{m.a}$—the average density of the concrete mix, kg/m^3; ρ_i—density of component $\boldsymbol{i}$, kg/m^3; $\rho_{i.a}$—density of component i in the entire volume of the mixture, kg/m^3; V—the total geometric volume of the mixture, m^3; $\boldsymbol{m}$—the number of samples; $\boldsymbol{n}$—the number of mixes. In this case, the fibers were considered a component of the mixture.

The study of the effect of fiber length and their number on the concrete properties was carried out using mathematical design of the experiment. In this case, the fiber length varied from 10 to 30 mm, and its volume content—from 1 to 2%. the amount of superplasticizer varied within 1 … 2% of the cement mass. Experimental conditions are shown in Table 1.

All the studies were carried out on the same composition of the concrete mixture: cement—500 kg; crushed stone 1120 kg; sand (iron ore dressing waste) 640 kg; water—200 *l*. Compressive strength of concrete 54.3 MPa.

Research Results. It is known, the degree of separation is a value equal to the specific average deviation of the density of the mixture components from their average density and characterizing the uneven distribution of the components in the entire volume of

Table 1 Experimental conditions

Factors		Levels of variation			Interval of variation
Natural view	Coded view	−1	0	1	
Fiber length, mm	X_1	10	20	30	10
Volume content, %	X_2	1	1,5	2,0	0,5
Additive content, %	X_3	0,8	1,2	1,6	0,4

the mixture. The change in the degree of separation or mixing process over time is expressed by a decaying exponent.

$$S = a + (S_{max} - a)e^{-kt} \tag{2}$$

where ***a, k***—parameters depending on the nature of the components, on the design of the mixing equipment, the mixing mode and to be determined by the least squares methods***;*** ***t*** is the mixing time of the mixture, s; S_{max}—some value of the degree of separation corresponding to the initial stage of the mixing process. When the components occupy a separate volume, and the deviation of the density of these components at a given place from their average density in the entire volume is maximum.

$$S_{max} = 2[1 - 1/V(\sum_m \rho_i V_i^2 / \sum_m \rho_i V_i)] \tag{3}$$

where V—the total volume of the mixture components, m^3;
ρ_i—density of component ***i,*** kg/m^3; V_i—the volume of component ***i,*** in the mixture, m^3; ***m***—the number of components in the mixture.

The experimental values of the degree of separation were determined from the equation

$$S = \left(\frac{1}{V}\right)\left(\frac{1}{\rho_{a.m}}\right)\sum_n \sum_m [(\rho_i - \rho_{i.a})] \cdot \Delta V_i \tag{4}$$

where $\rho_{a.m}$—is the average density of the concrete mix, kg/m^3;
ρ_i—density of the i-th component, kg/m^3;
$\rho_{i.a}$—is the average density of the ***i***-th component in the entire volume of the mixture, kg/m^3;
V—the total geometric volume of the mixture, m^3;
n—the number of mixes;
m—the number of samples taken from the mixture.

Fiber was loaded into a laboratory compulsory-type concrete mixer along with the components of the concrete mixture. The effect of fiber length on the uniformity of distribution was determined at a volume content of 2%. The effect of the volumetric content on the uniformity of distribution was determined with a fiber length of 20 mm.

At certain time intervals according to the experiment, the mixture was unloaded from the mixer into a laboratory flat bucket with an area 1 m^2. Samples were taken from the mixture in a checkerboard-nesting manner. The samples were weighed and the volume was measured, after which the cement was washed out of the samples with water. The remaining mass was dried and separated into individual components. Thus, the data necessary to assess the uniformity of fibers distribution in the mixture were determined.

Taking the degree of separation as a random variable, to determine the position of the found values of S, the method of mathematical statistics was used and the numerical characteristics were found.

- mathematical expectation

$$M = \sum\nolimits_{i=1}^{m} \frac{S_i}{m}, \tag{5}$$

- standard deviation

$$\sigma = \sqrt{D} = \sqrt{\sum\nolimits_{i=1}^{m} (S_1 - M)^2/(m-1)}, \tag{6}$$

- the coefficient of variation

$$\varphi = \left(\frac{\sigma}{M}\right) \cdot 100 \tag{7}$$

The calculation results are shown in Table 2.

Based on the results of mathematical processing of the obtained data, the graphs the separation degree dependence on the length of the fiber (Fig. 1) and the volumetric content of the fiber (Fig. 2) were constructed.

Analysis of the graphs shows that fiber length has a significant effect on the uniformity of fiber distribution in the volume of the mixture. With increasing fiber length, the degree of separation increases.

Obviously, with increasing fiber length, the number of contact points between them increases, which leads to the formation of lumps.

The graphs in Fig. 2 demonstrate the nature of the change in the degree of separation depending on the volumetric fiber content. As can be seen, with an increase in the volumetric content of fiber, the degree of separation increases.

Analysis of the graphs in Figs. 1 and 2 shows that the change in the degree of separation over time is expressed by a decaying exponential and an increase in the mixing time does not improve the homogeneity of the concrete mixture above a certain value.

Three periods of mixture formation can be distinguished on the graphs: the first period is characterized by a sharp decrease in the degree of separation, the second—by the stabilization of the mixing process in time, the third period is characterized by a slight increase in the degree of separation, i.e. a decrease in the homogeneity of

Table 2 Results of mathematical processing of data for experimental determination of the degree of separation

Characteristics of random variables	Mixing duration, min					
	1	2	3	4	5	6
Fiber volume content 1% with a length of 10 mm						
M	9.4	4.2	3.2	2.6	2.67	2.71
σ	1.34	0.47	0.32	0.23	0.28	0.30
φ	14.0	11.2	10.0	8.09	10.5	11.07
Fiber volume content 1% with a length of 20 mm						
M	11.9	7.6	5.0	4.1	4.18	4.2
σ	1.98	0.98	0.61	0.43	0.46	0.465
φ	16.8	12.9	12.2	10.4	10.7	10.8
Fiber volume content 1% with a length of 30 mm						
M	13.4	10.2	7.9	5.7	6.9	7.0
σ	2.52	1.43	0.96	0.63	0.84	0.85
φ	18.8	14.1	12.4	11.09	12.1	12.29
Fiber volume content 1.5% with a length of 20 mm						
M	11.8	6.3	5.4	4.65	4.68	4.71
σ	1.77	0.94	0.69	0.52	0.59	0.63
φ	15.4	14.7	12.7	11.1	12.6	13.35
Fiber volume content 2% with a length of 20 mm						
M	13.6	8.3	7.5	6.55	6.61	6.63
σ	2.34	1.3	0.97	0.81	0.95	0.96
φ	17.3	15.8	13.06	12.36	14.05	14.47

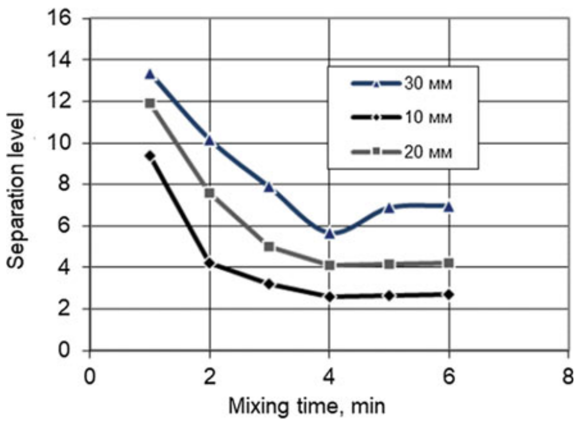

Fig. 1 Change in the degree of separation of concrete mixture depending on the mixing

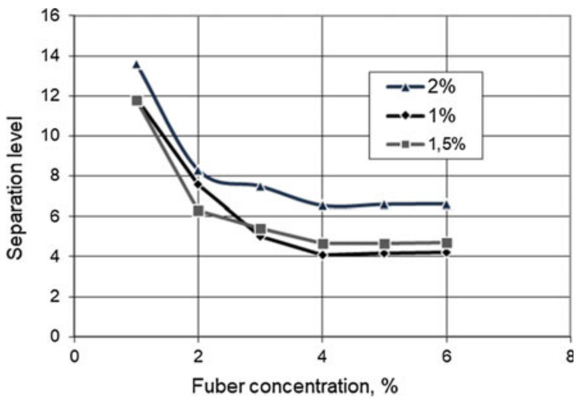

Fig. 2 Variation of separation degree depending on fiber concentration and mixing time

the mixture. Obviously, with prolonged mixing, the process of formation of lumps from fibers is enhanced. Therefore, the mixing time of the components of the mixture should be limited to the second period.

The paper studies the effect of the amount and length of fiber on the strength of heavy concrete. In the study, the method of mathematical planning of the experiment was applied. The conditions for planning the experiment are given in Table 1. The studies were carried out on cube specimens with an edge size of 100 mm and prisms with dimensions of 10 × 10 × 40 cm. The specimens were made in metal molds and stored in laboratory conditions for 28 days. The components of the concrete mixture were loaded into a forced action concrete mixer of the following sequence: crushed stone, sand, fiber, cement, water with an additive. The mixing of the concrete mixture lasted 5 min.

After solidification, cubic specimens were tested for compressive strength, and prisms for bending.

The test results were processed by the STATISTICA-10 program and are shown in Fig. 3.

The graph shows that with an increase in the fiber length within the experiment, the concrete strength first increases and then decreases. decreases. Obviously, polypropylene fibers, although they do not have adhesion strength with a cement matrix, contribute to an increase in strength due to friction forces at the fiber-cement stone interface. It should be noted that the reduction in strength is only 5–7% compared to unreinforced concrete.

The concentration of fiber in the bulk of concrete, within the experiment, has an even smaller effect on the strength of concrete. Although it should be noted that with an increase in the volume concentration of fiber, the strength of concrete, within the experiment, decreases. So, for example, with an increase in the volumetric fiber concentration from a minimum 0.8% to a maximum 2.0%, the strength of concrete decreases by 5.0 MPa from unreinforced concrete, which is almost 10%.

From the point of view of the theory of composite materials, polypropylene fibers cannot increase the strength of concrete, since the strength of polypropylene is an

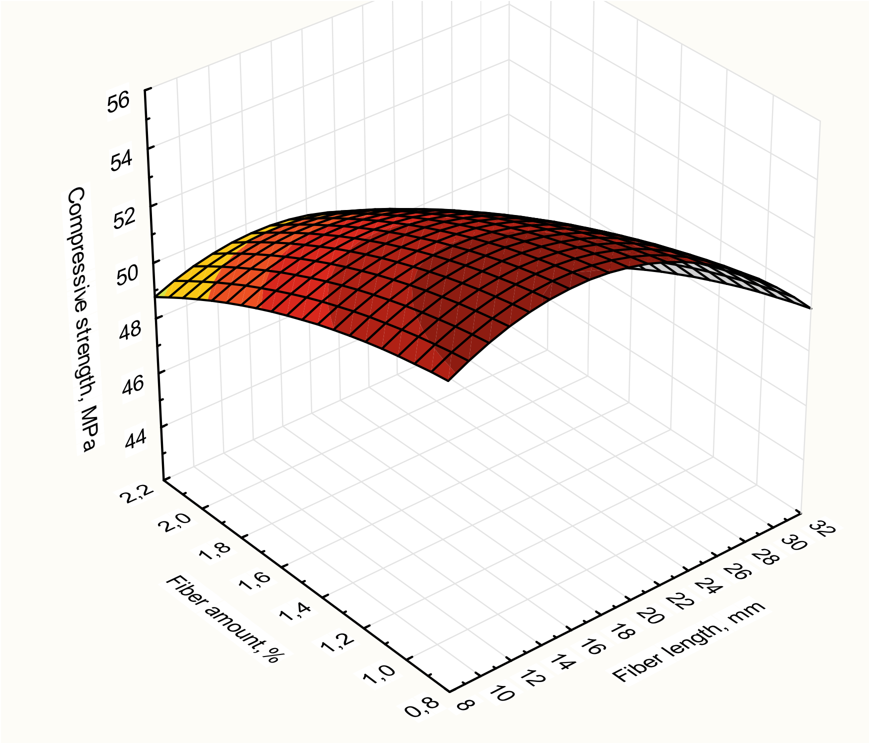

Fig. 3 Surface of influence of length and fiber content on concrete strength

order of magnitude lower than the strength of the concretes under study [8]. Insignificant fluctuations in the strength of concrete with the introduction of polypropylene fibers can be explained by the small work of the forces of friction of the surface of the fibers against the surrounding cement stone. As you know, polypropylene is not wetted with water, i.e. it is a hydrophobic material, in addition, it is absolutely inert material in relation to the environment of cement hardening. Proceeding from this, there can be no question that adhesion forces similar to steel reinforcement can arise between propylene fibers and cement stone. All interactions between these materials are based solely on frictional forces. It is obvious that the use of polypropylene fibers for dispersed concrete reinforcement aims at increasing the crack resistance and resistance of concrete to dynamic loads.

It is known that under the action of repetitive loads in the body of brittle materials, which are especially road concretes, microcracks appear, which, with prolonged exposure to dynamics, combine into a macrocrack, which leads to the destruction of structures [9–15]. The theory of composite materials also gives us a mechanism for the occurrence and development of microcracks in materials, in particular in brittle materials. The more brittle the material, the smaller the radius at the crack mouth and the higher the stress concentration. If the crack encounters an obstacle that increases the radius of curvature at the crack mouth, then the stress concentration decreases sharply and additional work of external forces will be required to achieve the same stress concentration. In this aspect, the use of polypropylene fibers for concrete reinforcement makes sense. But it should be noted that the fibers should not lead to a significant decrease in the strength of concrete.

However, such studies are carried out in this work and their results will be published in future publications.

2 Conclusion

Based on the results of the carried out studies, the following conclusions can be drawn:

Waste from iron ore dressing is a worthy replacement for traditional aggregates of heavy concrete; it was found that the degree of separation of concrete mixtures filled with polypropylene fibers in the initial period drops sharply and then begins to increase; the mixing time of concrete mixtures with polypropylene fibers should not exceed 4–5 min in order to avoid disturbing the homogeneity of the mixture; it was found that polypropylene fibers contribute to a decrease in strength by 5–10% within the experiment.

References

1. Chuikova IL (2011) Increasing the efficiency of building composites using technogenic raw materials by regulating the processes of structure formation. Dissertation for competition Doctor of Technical Sciences/Belgorod
2. Vilkul YG (2013) Processing and complex use of mineral raw materials from technogenic deposits. In: Azaryan AA, Kolosov VA (eds) Girnichiy Visnik, vip, p 96
3. Bondarenko SV (2012) Use of by-products from mining and processing plants. In: Sevastyanova OE, Bondarenko AS Starodubov (eds) Readings
4. DSTU B V. 2.7–33–2001 Quartz-iron sand and fine fraction for construction work on waste mining and processing plants of Ukraine
5. Bolshakov VI Waste from mining and processing plants and their use in construction. In: Bondarenko SV (eds) Dnepropetrovsk , p 96
6. Bondar V, Shulgin V, Demchenko O, Bondar L (2017) Experimental study of properties of heavy concrete with bottom ash from power stations. In: MATEC Web of Conferences, vol 116, p 02007. https://doi.org/10.1051/matecconf/20171160200, Transbud-2017 (Scopus) (Web of Science)
7. Demchenko OV, Shulgin VV, Petrash RV (2018) Experimental study on light concrete properties using bottom ash of thermal power stations. International Journal of Engineering Technology 7(3.2):1–5. (Scopus), https://doi.org/10.14419/ijet.v7i2.26.14366, Article ID: 14366, https://www.sciencepubco.com/index.php/ijet/article/view/14366
8. Croc F, Brautman L (1970) Modern composite materials. Moscow Mir, p 406
9. Storozhenko L, Butsky V, Taranovsky O (1998) Stability of compressed steel concrete composite tubular columns with centrifuged cores. J Constr Steel Res 46(1–3):484. https://doi.org/10.1016/S0143-974X(98)80098-9

10. Piskunov VG, Gorik AV, Cherednikov VN (2000) Modeling of transverse shears of piecewise homogeneous composite bars using an iterative process with account of tangential loads 2. Resolving equations and results. Mech Comp Mater 36(6):445–452. https://doi.org/10.1023/A:1006798314569
11. Piskunov VG, Goryk AV, Cherednikov VN (2000) Modeling of transverse shears of piecewise homogeneous composite bars using an iterative process with account of tangential loads. 1. Construction of a model. Mech Comp Mater 36(4):287–296. https://doi.org/10.1007/BF02262807
12. Onyshchenko VO, Filonych OM, Bunyakina NV, Senenko NB (2020). A new agent for removing concrete residues from the surfaces of polypropylene molds in the manufacture of paving slabs and its advantages. https://doi.org/10.1007/978-3-030-42939-3_67
13. Loburets AT, Naumovets AG, Senenko NB, Vedula YS (1997) Surface diffusion and phase transitions in strontium overlayers on W(112). Zeitschrift Fur Physikalische Chemie 202(1–2):75–85. https://doi.org/10.1524/zpch.1997.202.part_1_2.075
14. Onischenko VA, Soloviev VV, Chernenko LA, Malyshev VV, Bondus SN (2014) Acidic-basic interactions in tungstate melts based on tungsten electroplating out of them. Materialwissenschaft Und Werkstofftechnik 45(11):1030–1038. https://doi.org/10.1002/mawe.201400222
15. S. V. Piddubnyi, H. O. Tatarchenko, V. M. Sokolenko, (2020) Express method for the evaluation of the frost resistance of silicate building materials. Materials Science 56(2):240–246