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Properties and behavior of light hydrophobic concrete

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Abstract. In concrete mixing plan, we usually encounter a combination of aggregates including sand, the amount of cement, which is actually the criterion of concrete grade, and the volume of water consumed. Changes in the quality and quantity of these components actually create the usual types of concrete. But the attitude that formed the basis of this research is based on the change in the nature of the components of the concrete mixing design. Removal of water and cement from the mixing plan and replacement of polymeric materials as well as the use of mixed LECA aggregates instead of aggregates is the basis of this research. In this paper, by examining and selecting LECA grain style and pre-treatment (hydrophobicity and coupling), in a constant ratio of resin, concrete samples were selected from three dimensional categories. After making the samples, flexural strength test was performed on them and the results were analyzed. Various compounds and processes have so far been proposed in the lightweight concrete mixing scheme. The distinctive point of this study is the use of lightweight expanded clay concrete with heat-treated acrylic polymer (crosslinking constituents) and related coupling agents. It is also important to select and apply the right amount of hydrophobic nanoparticles for hydrophilic surface hydrophobicity. Hydrophobicity was possible due to the non-polar nature of the acrylic polymer and the use of hydrophobic nanomaterials.

Keywords: flexural strength concrete, LECA polymer lightweight concrete, lightweight concrete, nano-hydrophobic concrete, polymer concrete, Scoria polymer lightweight concrete

Изготовление гидрофобного полимерного легкого бетона

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Аннотация. В процессе бетоносмешения обычно используется комбинация заполнителей, включающая песок, некоторое количество цемента, являющегося критерием качества бетона, и объем потребляемой воды. Изменения качества и количества этих компонентов фактически создают традици-

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онные типы бетона. Настоящее исследование основано на изменении характера компонентов конструкции бетоносмешения. В его основе удаление воды и цемента из плана смешивания и замена их полимерными материалами, а также использование смешанных заполнителей типа LECA. Путем изучения и выбора типа зерна LECA и предварительной обработки (гидрофобность и сцепление) в постоянном соотношении полимера были отобраны образцы бетона из трехмерных категорий. После изготовления образцов на них проводились испытания на прочность при изгибе и анализировались полученные результаты. Ранее в схеме смешивания легких бетонов предлагались различные вариации соединения и процессов. Отличительная особенность данной работы заключается в использовании легкого керамзитобетона термообработанным акриловым полимером, скрепляющим компоненты, и сопутствующими связующими веществами. Особое внимание уделено выбору и нанесению нужного количества гидрофобных наночастиц для достижения гидрофобности прежде гидрофильной поверхности. Гидрофобность стала возможной благодаря неполярной природе акрилового полимера и использованию гидрофобных наноматериалов.

Ключевые слова: бетон с прочностью на изгиб, легкий полимербетон LECA, легкий бетон, наногидрофобный бетон, полимербетон, легкий полимербетон Scoria

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Introduction

In the concrete mixing plan, we are usually faced with a combination of aggregates, including sand, the amount of cement, which is in fact the standard of concrete grade and the volume of water used. Changes in the quality and quantity of these materials actually create the usual types of concrete.

But the attitude that formed the basis of this research is based on the change in the nature of the components of the concrete mixing design. Removal of water and cement from the mixing plan and replacement of polymeric materials as well as the use of mixed LECA aggregates instead of aggregates is the basis of this research. In this paper, by examining and selecting the LECA grain style and pre-processing (hydrophobicity and coupling), in a constant ratio of resin, concrete samples were selected from three dimensional categories. After making the samples, flexural strength test on They were performed and the results were analyzed.

Polymer concrete is a composite material where the binder is a thermosetting polymer reinforced with aggregates. It was developed in 1970 responding to the need of a lightweight material with high compressive strength and good chemical resistance [1; 2]. Vibration damping is also another polymer concrete relevant property [3]. There are several uses of precast polymer concrete such as drains, tanks, manholes [3], restoration building [4; 5], pavements [6], and underground utility structures [1], among others. The final properties of polymer concrete depend on its design and production conditions such as the type of binder, the mixing method, and the type and size distribution of the aggregates. The binder of polymer concrete is usually a thermosetting resin; hence, the viscosity and the gel time of the resin are also important preparation factors [7].

Materials and methods

Choose LECA seed style. The specifications of processed structural aggregates must comply with the criteria (ASTM C330) [8]. The volumetric mass of structural aggregates is much less than conventional aggregates. The bulk density of structural aggregates is between 560 and 1120 kg/m^3. While the bulk density of ordinary aggregates varies between 1200 to 1760 kg/m^3. Water absorption of light grains is between 5 and 20% by weight of dry materials [9].

The average specific gravity and water absorption of some types of light grains are given in Table 1.

Table 1

Characteristics of different grain styles

Type of materials	Average bulk density, kg/m^3	Water absorption, %
Beneh Kohol pumice	457	37
Eskandan pumice	730	20
Scoria	850	16
LECA (lightweight expanded clay aggregate)	367	15

An experiment to determine the mass crushing properties of aggregates is called the crushing value test in Part 3 of the Regulations (BS 812 1975) [10]. When considering aggregates with unknown performance (especially in cases where aggregates are suspected of having less power), for example in the case of limestone and some granites and basalts, the value of crushing can be a useful guide. In this test, a force of 400 kN is applied to the piston of the lightweight particles in 10 minutes. The disadvantage of this test is its inaccuracy for the smaller aggregates, which after crushing the larger aggregates, get stuck among the larger aggregates, and this reduces the quality of the test. In the third chapter of the standard, the 10% fine-grained test is presented, which is more accurate. For weaker aggregates, the 10% fine-grained test is more sensitive and gives a more realistic picture of the differences between more or less weak samples. Therefore, this test is valuable for evaluating lightweight materials, but there is no simple relationship between the result of this test and the maximum strength of concrete made with the aggregates tested [11]. The results of the 10% fine-grained test are shown in Table 2.

Table 2

Results of ten percent fine-grained test

Type of materials	Name of materials	Test results	
		Specific weight (aggregates between 1/2 and 3/4 inch sleve)	Force (to create 10% fine grain), kN
Light	Beneh Kohol pumice	453	22
	Eskandan pumice	728	29
	Qorveh Scoria	826	37
	LECA	356	26
Normal	Payam Marand Aggregate	1603	221

Two-component acrylic resins. Two-component hydroxyl acrylic resins hardened by isocyanates have two main characteristics. The first characteristic is the formation of urethane bonds, which are formed by the reaction between hydroxyl acrylics and basic isocyanate polymers. The second characteristic is the ability to produce these resins with different percentages of hydroxyl groups [12].

Flexural strength test methods and equipment. In concrete flexural strength test, the tensile strength of concrete is indirectly evaluated. This test was performed according to the central point load standard [13], which is the same as three-point load. The test diagram is shown in Figure 1.

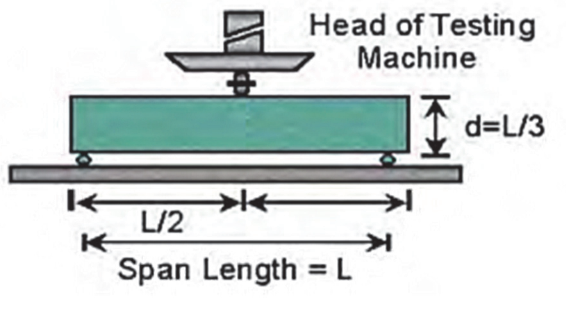

Figure 1. Flexural strength test of a central point or three-point concrete load

Experimental sample size. The Indian standard specifies a sample size of 150 mm in width, 150 mm in depth, and an aperture of 700 mm. The standard also states that if the maximum aggregate size is not greater than 19 mm, it may exceed 100 mm. Width, 100 mm depth and 500 mm aperture used. The British standard specifies a square cross-section of 100 mm or 150 mm and an aperture of four to five times the depth of the specimen. However, this standard also prefers sizes of 150 mm by 150 mm and an aperture of 750 mm. In this research, based on standard 17731, the method of making and processing concrete samples in the laboratory for compressive and flexural tests has been performed by the Iranian Institute of Standards and Industrial Research. In this standard, the dimensions of the sample for flexural strength test are defined as $L \times L \times L \times 3L + 5$ cm. In making the samples of this research, the width and height of 10 cm and therefore the length of 35 cm have been selected for the test.

Concrete flexural testing equipment:

1) steel or iron molds or molds of any other non-absorbent material measuring 100 mm by 100 mm by 350 mm;
2) impact rods two large rods (16 mm in diameter and 600 mm long) and one small bar (10 mm and 300 mm long);
3) a test machine capable of applying loads evenly and without interruption;
4) small shovel;
5) trowel;
6) scales with an accuracy of 1 kg;
7) electric concrete mixer;
8) vibrating table.

Research related standards. Various components are involved in the manufacture of lightweight polymer concrete with hydrophobic properties. Each of these components is effective in determining the final concrete properties: ASTM C1228. Standard practice for preparing coupons for flexural and washout tests on glass fiber reinforced concrete [14]; ASTM C642. Standard test method for density, absorption, and voids in hardened concrete [15]; ASTM C78. Standard test method for flexural strength of concrete (using simple beam with third-point loading) [16]; ASTM C293. Standard test method for flexural strength of concrete (using simple beam with center-point loading [17] and central loading (three-point) [18].

Sample making steps:

1. *Pre-treatment of lightweight aggregates with water repellent nanomaterials.* One of the objectives of this research is to achieve light polymer concrete with hydrophobic properties. To achieve this goal, two solutions are considered. First, polymer concrete is made using the appropriate ratio of components and then superficially by one of a variety of methods of waterproofing and surface hydrophobicity, this feature should be provided. It should be noted that the types of polymers used in the manufacture of polymer concretes such as polyester resins, epoxy, acrylic, polyurethane, etc., are inherently waterproof, but what makes the nano-hydrophobic process is the nature of waterproof resins have different levels depending on each other and the water resistance performance of most resins changes over time and the desired performance decreases. On the other hand, mixing aggregates with resin in such a way that all surfaces of aggregates are completely covered by resin will not happen in practice and uncovered ducts will be the path of water penetration and in the manufacture of products that, in addition to the surface, the depth of work is also in the water, such as blocks and porous floors with water permeability, cannot be completely waterproof and will not be responsible for durability. Because the relationships we create between lightweight aggregates and polymer chains are predicted by temporary Van der Waals forces.

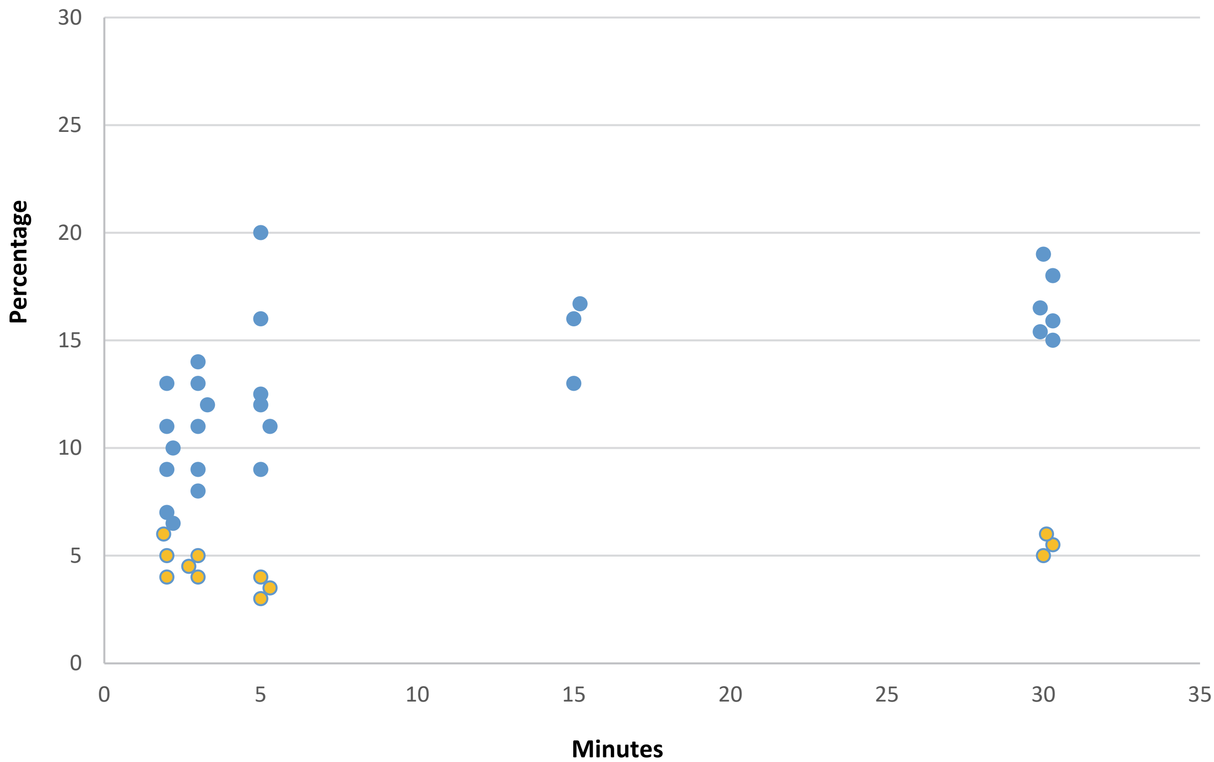

Figure 2. Percentage of water absorption per minute:
yellow circles – 5 to 10 mm; *blue circles* – 10 to 20 mm

In the second case, using nano-hydrophobic concrete, first the lightweight aggregates are immersed in the hydrophobic solution so that the entire surface of the aggregates is covered by hydrophobic materials. After this work and drying of light grains, mixing with resin is done. In this method, all the aggregates are completely covered due to the dispersion and very high surface coverage of the nanomaterials, and due to the covalent bonds between the hydrophobic nanoparticles and the aggregates, the hydrophobic action will be permanent. On the other hand, nanomaterials due to their structure, which are polar on the one hand and non-polar molecules on the other. They are connected from the polar side to the building materials, which here are the same as Leica ores, and from the other side to the non-polar resin chains. In fact, the hydrophobic nanomaterials in Inch play a role as binders (coupling agents).

We mixed light grains (LECA) with ratios of 1, 3 and 5 wt.% of nanomaterials (dissolved in a ratio of 1 to 15 in water). After 24 hours and completing the reaction of Ibn Nanomaterials and granules (LECA), 100 g of lightweight aggregates (LECA) from all three samples containing 1, 3 and 5% of hydrophobic nanomaterials were poured into the container separately. Plastic mesh was placed on the light grains so that they would not float on the surface of the water. Then 500 ml of water was added to each container. After 72 hours, light grains (LECA) were removed from the containers and weighed by a digital scale with an accuracy of 0.01 g. Figures 2, 3 & 4 shows the water absorption values by granules (LECA).

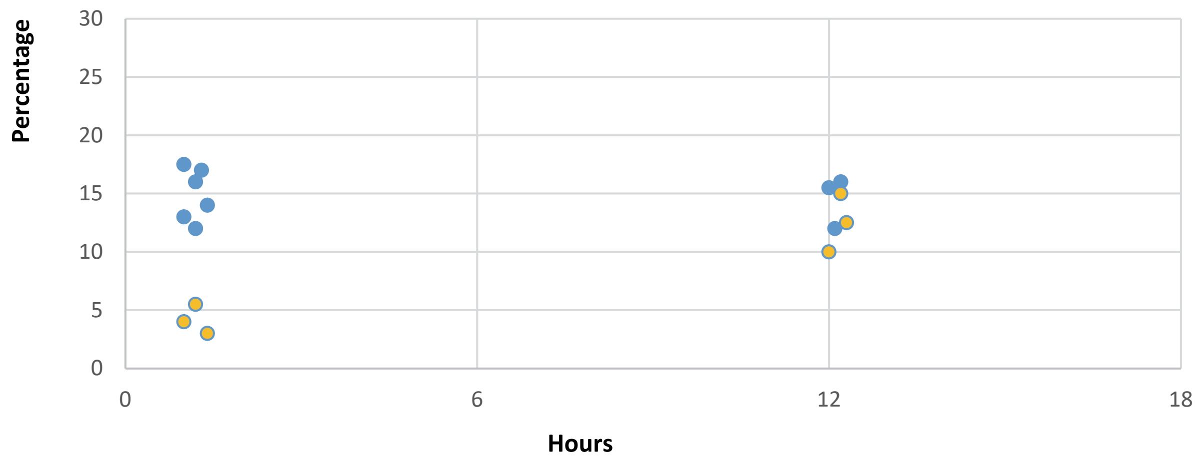

Figure 3. Percentage of water absorption per hour:
yellow circles – 5 to 10 hours; *blue circles* – 10 to 20 hours

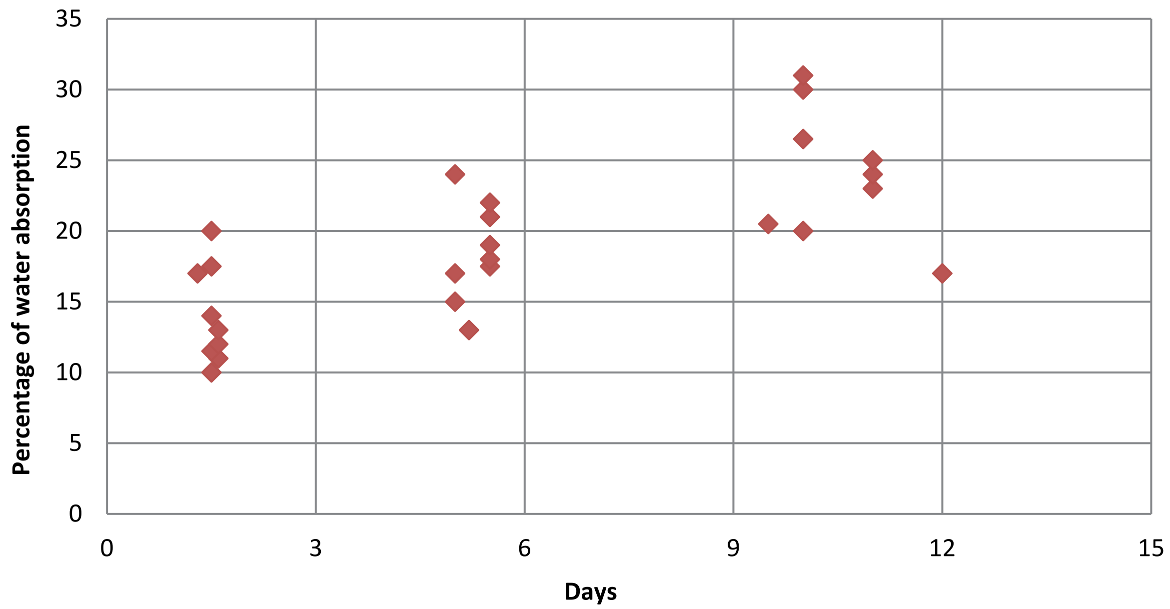

Figure 4. Percentage of water absorption per day

Refereeing Table 3, three groups of lightweight LECA with sizes of 0–4, 4–10, 10–25 mm were prepared. After light grain processing (mixing process with hydrophobic nanomaterials) and after a certain time to complete the surface reaction between LECA aggregates and nanomaterials, it is time to mix with resin.

The tested samples were from medium-sized LECA grains with a light grain size of 4 to 10 mm, which in fact had the highest surface area compared to other grading sizes. First, 100 g of LECA light grain was placed in the container as a control in the same way as the hydrophobic samples, and after placing a plastic net and adding 500 mg of water to the container and 72 hours passed, the LECA sample was weighed.

The water absorption rate of light grains was 18% based on the standard test ASTM-C 642 according to the following formula

$$\text{Percentage of water absorbed} = \frac{m-m_0}{m_o} \times 100,$$

where M – wet sample weight; M_0 – dry sample weight.

2. *Meshing and making samples of LECA and resin.* The strength of polymer concrete is directly related to the size of the aggregate and the optimal ratio of resin consumption. First, the optimal size of the aggregate has been determined.

For this purpose, three groups of LECA light grains with sizes of 0–4, 4–10, 10–25 mm were prepared from LECA company. Since the simultaneous supply of lightweight concrete and being in the range of light to medium concrete is the desired structure, and according to information sources, it is predicted that LECA granules with 0–4 mm granulation will have better results to ensure, 9 samples of the three granulation groups were made and tested with a higher amount of resin. The test results proved the equality of the predictions and the obtained results.

Table 3

Special weight of LECA grading

	Grading	Special weight (average)	Special weight (max)
1	0–4 mm	510 kg/m^3	560 kg/m^3
2	4–10 mm	320 kg/m^3	370 kg/m^3
3	10–25 mm	250 kg/m^3	300 kg/m^3

Three groups of lightweight LECA with sizes of 0–4, 4–10, 10–25 mm were prepared. After light grain processing (mixing process with hydrophobic nanomaterials) and after a certain time to complete the surface reaction between LECA aggregates and nanomaterials, it is time to mix with resin. Since the maximum amount of resin used against 50% aggregate can be and above this the nature of the material composed of composite material and polymer will be more commonly known as polymer, therefore, the highest percentage of resin, which is 50% by weight relative to lightweight, was selected. First, we weigh the grains that are completely dry and dried in the oven. The mold was made of high-strength Hilux plates and smooth surfaces to prevent the resin from adhering to the mold body, in dimensions of 35×10×10. The mold was lubricated with paraffin oil before loading. After weighing the lightweight aggregate and resin, mixing was performed. It should be noted that at each stage of the work, after mixing the resin with the reactant in a ratio of 3 to 1, 1% of the saline coupling agent was added to the resin. This allows the resin to bond better to the surface of the aggregates, in fact the coupling agent prevents cracking of the polymer concrete, which includes mineral and organic components. When the light mix of grain and resin is done, we mold the sample. After an hour, open the mold and put the sample in the oven at 80 degrees for 6 hours for baking. After cooking the samples, we turn off the oven and let the sample lose its temperature. Sudden exit of the sample from inside the oven to the outside space can cause small cracks in the resin connecting the grains.

Probation. After making the samples, in order to perform flexural strength tests, precise loading devices were used in the form of three-point loading or central loading. Samples with a length of 350 mm were made. According to the standard 17731 flexural strength test, the distance between the two supports was 3 or 300 mm. The loading speed of 200 kg/s was defined for the test device. The test method was the same for all samples in different stages. Before flexural strength tests, the weight of the specimens was accurately measured. By calculating the exact dimensions of the specimens, the volumetric weight of each specimen for placement in the formula was obtained. The method of breaking the sample with Leica 10 to 24 mm grain style is shown in the Figures 5 and 6.

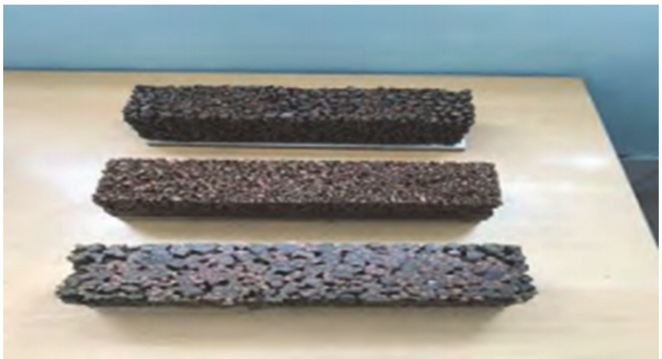

Figure 5. Examples of lightweight polymer concrete with different grain styles

Figure 6. Sample failure method with Leica 10–25 mm grain style

After fabrication of the specimens and fracture strength test, the flexural strength of each specimen has been calculated. For each specimen fabricated, its dimensions in three directions were accurately measured with a caliper. After that, the weight of each sample was determined accurately using a digital scale. Then, from these two components, volumetric weight was obtained. Loading at a rate of 200 kg/s was performed by a device with high accuracy of flexural and tensile strength in the laboratory. For flexural strength tests, the distance between the two supports to the edge of the sample is 25 mm on each side according to the standard was calculated. The calibration values of the device were calculated by the operator of the device. Then the values of flexural strength were calculated based on the obtained information. The Standard of Flexural Strength Test Method of Concrete Using a Simple Beam with Point Loading in the Center of the National Standard Organization of Iran [14] has been used for the test method and calculation of rupture modulus:

$$R = \frac{3PL}{2bd^2},$$

where R – the modulus of rupture, in terms of 2; P – the maximum applied load, indicated by the test device, in terms of 4; L – mouth length, in millimeters; b – average test width, in failure time in millimeters; d – average test height, at the time of failure, in millimeters.

Results

Water absorption test results. By performing water absorption test, samples made of LECA polymer concrete with 0–4 mm granulation and weight ratio of 50% of resin, the results mentioned in the Table 4 were obtained. In this test, two components of granulation and the ratio of resin to grain size are considered constant. The difference between the amount of nanomaterials used in the hydrophobicity of grain style has been measured. With increasing the amount of hydrophobic nanomaterials from 1 to 3 and 3 to 5%, the amount of water absorption of Leica light grains has decreased from 18 to 3%. The Table 4 shows the results of water absorption test.

Table 4

Results of flexural strength test of three types of lightweight granulation with 50% resin

Line	Nano hydrophobic percentage	The amount of light grain	Percentage of sample water absorption
1	5	100	3
2	3	100	10
3	1	100	15
4	0	100	18

The results obtained from flexural strength tests on specimens using the same volume of resin and different grain sizes of LECA grain style indicate that the density due to the reduction of grain size grain size leads to an increase in flexural strength in the same ratio of resin.

These results are shown in the Table 5.

Table 5

Flexural strength test of three types of lightweight granulation with 50% resin

Line	Light grain size, mm	Average specific gravity of 3 samples, kg/m^3	Average failure force of 3 samples, kg-f	Average flexural strength of 3 samples, MPa
1	0–4	880	1205	3.76
2	4–10	550	674	2.1
3	10–25	475	481	1.5

By examining the results of flexural strength test for light grain samples of LECA and paying attention to the pictures of the failure sections of the samples, it is revealed that by increasing the volume of light grain, its mechanical strength decreases. Due to the effect of porosity in order to reduce the elastic modulus of concrete, it is predictable that larger grains of lightweight aggregate will reduce the bearing capacity of concrete and flexural strength.

$$10{-}25 > 4{-}10 > 0{-}4.$$

Conclusion

Initially, 1, 3, and 5 percent by weight of LECA lightweights were diluted 15 times with water and nanomaterials. The obtained solution was used for sealing hydrophilic surfaces. Using 5% nanomaterials, the water absorption rate of LECA lightweights decreased from 18 to 3%. Subsequently, a mixture of hydrophobic LECA's was prepared in three groups of 0–4, 4–10 and 10–25 mm and 5% weight resin relative to the weight of the lightweight aggregates. Flexural strength test was performed after molding and curing and passing of time for 72 hours. The 0–4 mm LECA's showed the best flexural strength. After designing and performing different stages of this research, all predetermined goals were achieved. The purpose of this research was to reduce the weight of concrete and at the same time maintain the mechanical strength of hydrophobic lightweight concrete, at least in the range of non-structural lightweight concrete Water absorption has been done. The average results obtained for lightweight polymer concrete with a grain size of 0 to 4 mm are as follows.

Three samples of LECA polymer lightweight concrete blocks with a specific gravity of 880 Kg/m3 on average were tested in the laboratory for flexural strength. The average breaking strength was 1205 kg-f. Then, the flexural strength of each sample was obtained and the average flexural strength was calculated to be 3.76 MPa. Based on the classification of lightweight concrete into three categories of structural, medium and non-structural with specific weights, respectively, the first group, lightweight concrete. Instruments with a specific weight of 1400 to 1900 Kg/m^3, flexural strength is higher than 17 MPa and the second group of lightweight concrete is classified as 800 to 1400 Kg/m^3 and the flexural strength range is 17 MPa and the third group of non-structural lightweight concrete with a specific gravity of 800 to 1400 and flexural strength of 0.31 to 7 MPa are classified. In this study, due to the use of 50% by weight ratio of resin per light weight of grain, the specific gravity of the average lightweight concrete has increased to some extent for this purpose, in a parallel study of this study, 30 to 40 % of the specific gravity of the resin was used. The results and flexural strength tests and failure tests in the sample sections indicate that due to the low failure threshold of light LECA grains compared to resin has little effect on reducing flexural strength.

Therefore, lightweight polymer concrete with a flexural strength of 3.76 MPa for non-structural lightweight concrete and a specific gravity of 880 Kg/m^3 has been completely satisfied and has been in line with the research objectives.

References

1. Fowler D.W. Concrete-polymer materials: how far have we come, and where do we need to go? *International Congress on Polymers in Concrete, Berlin, Germany*. 2018;6:143–195.

2. Fowler D.W. Polymers in concrete: a vision for the 21st century. *Cement and Concrete Composites*. 1999;21(5–6): 449–452.

3. Bedi R., Chandra R., Singh S.P. Mechanical properties of polymer concrete. *Journal of Composites.* 2013;2013: 948745. https://doi.org/10.1155/2013/948745

4. Dimmig-Osburg A. Polymer concrete produced with desert sand – a project of applied research. *Restoration of Buildings and Monuments.* 2014;20(5):361–370.

5. Oertel T., Hutter F., Tänzer R., Helbig U., Sextl G. Primary particle size and agglomerate size effects of amorphous Silica on ultra-high-performance concrete. *Cement and Concrete Composites.* 2013;37:61–67. https://doi.org/10.1016/j.cemconcomp.2012.12.005

6. Lee S.L., Mannan M.A., Wan W.H. Ibrahim. Polishing resistance of polymer concrete pavement using limestone aggregate. *International Journal of Pavement Engineering.* 2018;61(1):1–9. https://doi.org/10.1080/10298436.2018.1489135

7. Kirlikovali E. Polymer/concrete composites: a review. *Polymer Engineering and Science*. 1981;21(8):507–509.

8. *ASTM-C330 standard specification for lightweight aggregates for structural concrete.* American Society for Testing and Materials; 2004. Available from https://www.astm.org/Standards/C330.htm (accessed: 20.02.2021).

9. Naderi M. Comparison of mixing design and compressive strength of lightweight concretes made with LECA. Scoria and Perlite aggregates using torsion method. *Journal of Civil Engineering.* 2012;4(2):203–254.

10. BS 812-1. *Testing aggregates. Part 1. Methods for determination of particle size and shape* (part 3, p. 123–167). London: British Standards Institution; 1975.

11. Kasyap S.S., Li S., Senetakis K. Investigation of the mechanical properties and the influence of micro-structural characteristics of aggregates using micro-indentation and Weibull analysis. *Construction and Building Materials.* 2021;271: 121509. https://doi.org/10.1016/j.conbuildmat.2020.121509

12. Abdollahi S., Khorasani M., Kasiriha M., Nasiri N. Determining the best type of water, based acrylic resin for application in concrete in structures used in the oil and gas industry. *2nd International Conference on Oil, Gas and Petrochemical Tehran, Iran, 2014.* Available from https://civilica.com/doc/346014/certificate/print/ (accessed: 05.03.2021).

13. ASTM C1550. *Standard test method for flexural toughness of fiber-reinforced concrete (using centrally loaded round panel).* West Conshohocken: American Society for Testing and Materials; 2008.

14. ASTM C1228. *Standard practice for preparing coupons for flexural and washout tests on glass fiber reinforced concrete.* West Conshohocken: American Society for Testing and Material; 2015.

15. ASTM C642. *Standard test method for density, absorption, and voids in hardened concrete.* West Conshohocken: American Society for Testing and Materials; 2013.

16. ASTM C78. *Standard test method for flexural strength of concrete (using simple beam with third-point loading).* West Conshohocken: American Society for Testing and Materials; 2018.

17. ASTM C293. *Standard test method for flexural strength of concrete (using simple beam with center-point loading).* West Conshohocken: American Society for Testing and Materials; 2002.

18. Kharun M., Koroteev D.D., Dkhar P., Zdero S., Elroba S.M. Physical and mechanical properties of basalt-fibered high-strength concrete. *Structural Mechanics of Engineering Constructions and Buildings.* 2018;14(5):396–403. (In Russ.) https://doi.org/10.22363/18155235-2018-14-5-396-403