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Physical and mechanical properties of pre-bound aggregate composites

Vladimir T. Erofeev[1], **Sergey V. Kaznacheev**[1]✉, **Elena V. Pankratova**[2], **Vyacheslav A. Seleznev**[1], **Tatyana P. Tyuryahina**[1]

[1]*National Research Ogarev Mordovia State University, Saransk, Russian Federation*
[2]*Keramzit LLC, Ulyanovsk, Russian Federation*
✉ kaznacheevsv@mail.ru

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Abstract. New building materials and products in construction and reconstruction, which improve the performance and efficiency characteristics of buildings, reduce material consumption, cost and labor intensity, are always relevant. A promising direction for further development of composite materials is the employment of pre-bound aggregate materials. Their production is a two-stage process, which involves at first creating an optimal aggregate mix and gluing the grains to each other and secondly filling the voids of the obtained aggregate framework with a high-workability matrix. Presented research is an experimental investigation of physical and technical properties of pre-bound aggregate composite materials. Composites with complex binders are also considered in this study. In such cases, the aggregate framework and the grouting matrix were made of binders of different nature, which are incompatible when the components are mixed ordinarily. When studying composites, a complex of physical and mechanical methods was used. Improvement of physical and mechanical properties of framework composites in comparison with composites obtained according to conventional technology has been established. These advantages are identified primarily for such properties as deformability, impact strength, creep.

Keywords: composites, framework structures, framework, matrix, compressive strength, flexural strength, fracture toughness, deformability

Vladimir T. Erofeev, Doctor of Technical Sciences, Professor, Academician of the Russian Academy of Architecture and Construction Sciences, Director of the Institute of Architecture and Construction Engineering, Head of the Chair of Building Materials and Technologies, Director of the Research Institute "Materials Science", National Research Ogarev Mordovia State University, 68 Bolshevistskaya St, Saransk, 430005, Russian Federation; ORCID: 0000-0001-8407-8144, Scopus Author ID: 56662851300, ResearcherID: A-7827-2017, eLIBRARY SPIN-code: 4425-5045; vlalmo@mail.ru
Sergey V. Kaznacheev, Candidate of Technical Sciences, Associate Professor, Associate Professor of the Chair of Building Materials and Technologies, National Research Ogarev Mordovia State University, 68 Bolshevistskaya St, Saransk, 430005, Russian Federation; ORCID: 0000-0002-0053-3160, Scopus Author ID: 55996356400, eLIBRARY SPIN-code: 8890-7601; kaznacheevsv@mail.ru
Elena V. Pankratova, Deputy Director for Science and Technology, Keramsit LLC, 49 Oktyabrskaya St, room 53, Ulyanovsk, 432032, Russian Federation; ORCID: 0000-0001-9164-1759; elenapankratova3@yandex.ru
Vyacheslav A. Seleznev, postgraduate, Chair of Building Materials and Technologies, National Research Ogarev Mordovia State University, 68 Bolshevistskaya St, Saransk, 430005, Russian Federation; ORCID: 0000-0003-1202-9209; vyacheslav.seleznev.00@mail.ru
Tatiana P. Tyuryakina, postgraduate, Chair of Building Materials and Technologies, National Research Ogarev Mordovia State University, 68 Bolshevistskaya St, Saransk, 430005, Russian Federation; ORCID: 0000-0002-0138-5411; kitana1908@mail.ru

Физико-механические свойства каркасных строительных композитов

В.Т. Ерофеев[1], С.В. Казначеев[1], Е.В. Панкратова[2], В.А. Селезнев[1], Т.П. Тюряхина[1]

[1]*Национальный исследовательский Мордовский государственный университет имени Н.П. Огарева, Саранск, Российская Федерация*
[2]*ООО «Керамзит», Ульяновск, Российская Федерация*
kaznacheevsv@mail.ru

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Аннотация. Применение при строительстве и реконструкции зданий и сооружений различного назначения новых строительных материалов и изделий, обеспечивающих улучшение их эксплуатационных показателей, повышение эффективности, снижение материалоемкости, стоимости и трудоемкости изготовления, является актуальной задачей. Перспективным направлением дальнейшего развития строительных композитов представляется получение и внедрение материалов каркасной структуры. Технология их изготовления включает предварительное создание оптимальных смесей заполнителей и склеивание зерен друг с другом с последующим заполнением пустот полученного каркаса высокоподвижной матрицей. Исследование посвящено экспериментальному изучению физико-технических свойств каркасных композиционных материалов. В качестве исследуемых объектов рассматривались композиты, составленные на различных связующих, в том числе на комплексных. В последнем случае каркас и пропиточная матрица изготавливались на связующих различной природы, порой несовместимых при обычном смешивании компонентов. При исследовании композитов использовался комплекс физико-механических методов. Установлено улучшение физико-механических свойств каркасных композитов при сравнении их с композитами, полученными по общепринятой технологии. Данные преимущества выявлены в первую очередь для таких свойств, как деформации, ударная прочность, ползучесть.

Ключевые слова: композиционные материалы, каркасные структуры, каркас, матрица, материалы, армированные волокнами, прочность на сжатие, прочность на изгиб, ударная вязкость, деформативность

Introduction

From the many types of composite materials for aggressive environment, polymer concrete and other polymer-based composites are considered to be the most effective [1–7]. However, despite the growing use of polymer concrete, some aspects of its structure formation and mechanical properties are poorly explored [8; 9]. The modern technology of polymer concrete production is based on the conventional method of manufacturing cement concretes and products, which leads to increased consumption of the expensive synthetic resin. Making and casting polymer concrete are still substantially labor-intensive operations, which are especially difficult to perform in case of high-viscosity mixtures [10–12]. In this regard, pre-bound aggregate composites have a lot of potential. Their production involves two stages: making an optimal mix of coarse aggregate and binding it into a framework as a first stage and then filling the voids of the aggregate framework with a high-workability

Ерофеев Владимир Трофимович, доктор технических наук, профессор, академик РААСН, директор Института архитектуры и строительства, заведующий кафедрой строительных материалов и технологий, директор НИИ «Материаловедение», Национальный исследовательский Мордовский государственный университет имени Н.П. Огарева, Российская Федерация, 430005, Саранск, ул. Большевистская, д. 68; ORCID: 0000-0001-8407-8144, Scopus Author ID: 56662851300, ResearcherID: A-7827-2017, eLIBRARY SPIN-код: 4425-5045; vlalmo@mail.ru

Казначеев Сергей Валерьевич, кандидат технических наук, доцент, доцент кафедры строительных материалов и технологий, Национальный исследовательский Мордовский государственный университет имени Н.П. Огарева, Российская Федерация, 430005, Саранск, ул. Большевистская, д. 68; ORCID: 0000-0002-0053-3160, Scopus Author ID: 55996356400, eLIBRARY SPIN-код: 8890-7601; kaznacheevsv@mail.ru

Панкратова Елена Васильевна, заместитель директора по науке и технологии, ООО «Керамзит», Российская Федерация, 432032, Ульяновск, ул. Октябрьская, д. 49, п. 53; ORCID: 0000-0001-9164-1759; elenapankratova3@yandex.ru

Селезнев Вячеслав Алексеевич, аспирант, кафедра строительных материалов и технологий, Национальный исследовательский Мордовский государственный университет имени Н.П. Огарева, Российская Федерация, 430005, Саранск, ул. Большевистская, д. 68; ORCID: 0000-0003-1202-9209; vyacheslav.seleznev.00@mail.ru

Тюряхина Татьяна Павловна, аспирант, кафедра строительных материалов и технологий, Национальный исследовательский Мордовский государственный университет имени Н.П. Огарева, Российская Федерация, 430005, Саранск, ул. Большевистская, д. 68; ORCID: 0000-0002-0138-5411; kitana1908@mail.ru

matrix [11; 13–15]. When using pre-bound aggregate technology for floorings, their manufacturing and casting is simplified and it is possible to produce other materials with specified properties and products for various purposes on their basis [11].

The fundamental theory of pre-bound aggregate composites, which are effective as floorings in buildings with aggressive environments, textile industry in particular, is presented in papers [16–20].

This article is devoted to experimental investigation of physical and technical properties of pre-bound aggregate composite materials.

Methods

A great variety of binders and aggregates allows to obtain pre-bound aggregate composites with different physical and mechanical properties. Binders and aggregates of different nature were used for the manufacturing of samples. Aggregate size was taken as 5–10 mm. Aggregate was glued into a framework by filler-free binders, meanwhile its grouting was performed using filled compounds. Quartz powder was used as filler in the grout matrices. The main studied mechanical characteristics of the materials were strength and elasto-plastic properties. These properties were determined by testing 4×4×16 cm sample pieces according to the modern techniques.

Results and discussion

Compression tests of the samples indicate high strength of pre-bound aggregate composites (Figure 1). This parameter varies widely depending on the strength, shape and surface roughness of the coarse aggregate. Higher compressive strength corresponds to composites based on epoxy binders and granite aggregate. Pre-bound aggregate composites exhibit high flexural strength. In the tests of beams by a single concentrated force, the values of 18.0, 15.0 and 7.2 MPa were obtained for composites based on epoxy, polyester and cement binders. The prototypes of pre-bound aggregate composites – composite materials (CM) of regular structure – showed 10% lower flexural strength. Higher strength values of pre-bound aggregate composites relative to regular composites are also observed in tensile tests. The strength of standard briquettes based on polyester binders with granite and expanded clay aggregates amounted to 9.0 and 5.9 MPa for the pre-bound aggregate composites and 5.2 and 4.54 MPa for the regular composites respectively. Increased strength of pre-bound aggregate composites is explained by higher adhesion of the grout to the aggregate.

When comparing the properties of polymer concrete with epoxy and polyester framework and polymer concrete obtained with regular mixing of components, the former is apparently at advantage. The polymer concrete test-pieces were made according to the procedure in[1], but injected with Portland cement instead of quartz fine-dispersion filler.

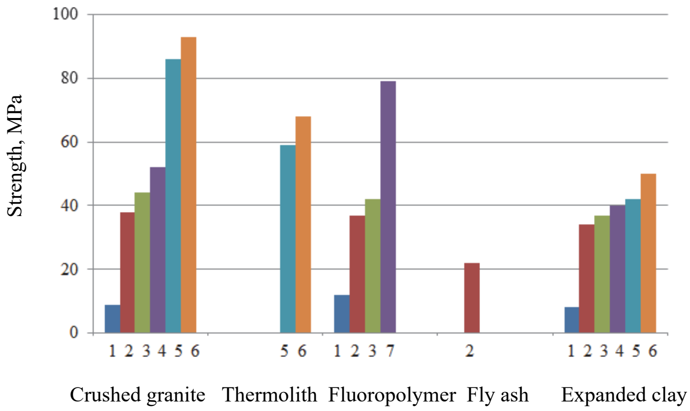

Figure 1. Compressive strength of pre-bound aggregate composites versus filler and binder type:
1 – gypsum; *2* – portland cement; *3* – polymer cement; *4* – urea-formaldehyde resin;
5 – multipurpose polyester resin (grade PN-1); *6* – epoxy-diane resin (grade ED-20); *7* – EPILOK epoxy resin

Pre-bound aggregate concrete strength may be increased by using complex binders and reinforced frameworks. Concrete with a complex binder is obtained when the aggregate framework and the matrix are made with

[1] Instructions on the technology of preparation of polymer concrete and products made from them. CH 525-80. Moscow: Stroyizdat Publ.; 1981.

different binder types. For example, gypsym matrix and cement or polymer framework, cement matrix and polymer cement framework, etc. These kinds of combinations allow to increase the strength and other characteristics of the composites. Thus, the flexural strength of the gypsym and cement concretes with polymer framework and granite aggregate rises from 4.0 to 5.2 MPa and from 6.7 to 7.8 MPa respectively. Moreover, the best effect is achieved by using polymer compounds, which harden in wet environments, for gluing the framework simultaneously with the cement matrix [11].

The main parameter that characterizes elasto-plastic properties of materials under external load is the modulus of elasticity. Elastic modulus of pre-bound aggregate composites depends on the strength and deformability of the matrix, framework glue and aggregate. The tests of concrete samples with crushed brick aggregate and various binders show higher elastic modulus values for cement materials (Figure 2). Polymer concrete based on epoxy resin demonstrates a twice larger value of the elastic modulus relative to the one based on polyester resin. Pre-bound aggregate bitumen concrete is characterized by high deformability and has the lowest elastic modulus values.

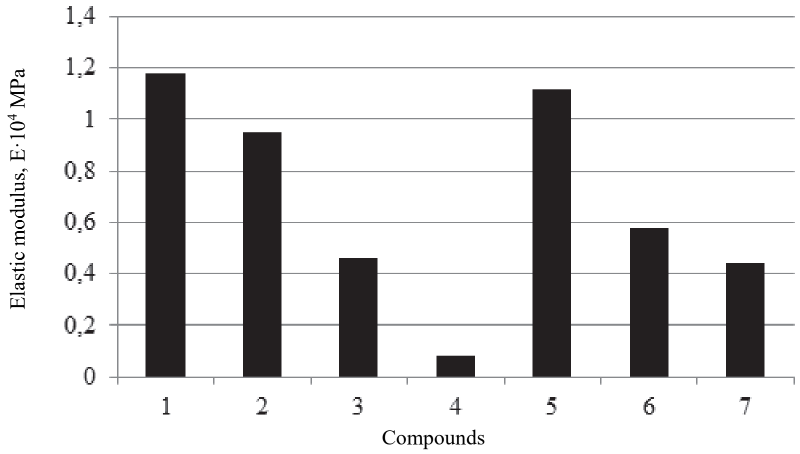

Figure 2. Elastic modulus of pre-bound aggregate composites based on crushed brick versus binder type and of epoxy polymer concretes versus filler type:
1 – cement; *2* – epoxy-diane resin (grade ED-20); *3* – multipurpose polyester resin (grade PN-1); *4* – bitumen; *5* – granite framework; *6* – thermolith framework; *7* – expanded clay framework

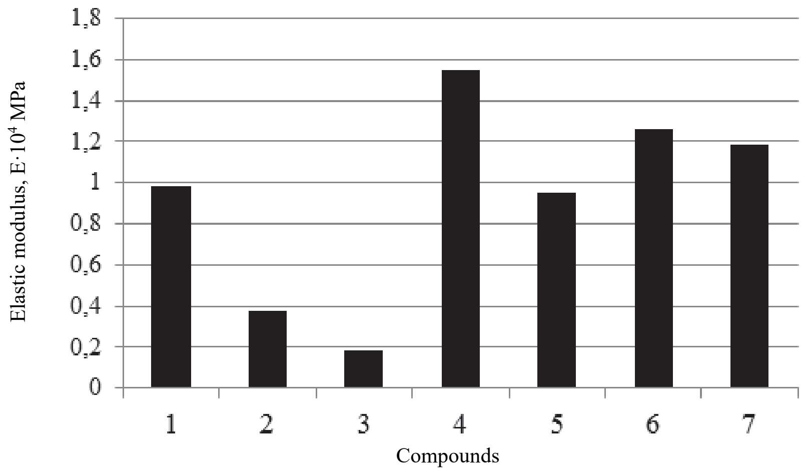

Figure 3. Elastic modulus of pre-bound aggregate composites versus aggregate, glue and matrix type:
1 – cement framework glue, grade ED-20 epoxy-diane resin matrix; *2* – grade PN-1 multipurpose polyester resin framework glue, epoxy-diane resin matrix; *3* – bitumen framework glue, epoxy-diane resin matrix; *4* – granite aggregate and carbon fiber framework; *5* – granite aggregate and plasticizing binder framework; *6* – granite aggregate and quartz filled binder framework; *7* – granite aggregate framework, quartz powder filled matrix

Pre-bound aggregate composite is a highly filled concrete. This allows to obtain concretes with different modulus of elasticity by controlling the aggregate stiffness. Figure 3 illustrates that the modulus of elasticity decreases by more than twice when using expanded clay as coarse aggregate instead of crushed granite aggregate.

Deformability is also controlled by the matrix and the glue layer of the framework (Figure 3). Stiff glue allows to obtain composites with increased elastic modulus; viscoelastic glue allows to produce materials with a lower modulus of elasticity. This can be observed from the data of epoxy concretes based on cement and bitumen frameworks respectively. The stiffness of pre-bound aggregate composites may be increased by introducing fiber reinforcement and silica sand into the framework compound and also by adding quartz filler into the matrix. In such case, the best effect is achieved by introducing stiff carbon fiber in the amount of 2.5% from the filler mass. By adding plasticizing agents into the framework or matrix, the modulus of elasticity becomes lower.

The coefficient of lateral deformation has a great practical value in regards to CM. This parameter, similar to the modulus of elasticity, describes the material elastic properties. Given the value of the coefficient of lateral deformation, one may calculate the change in volume when the material is loaded. Studies of pre-bound aggregate composites showed the relationship between this coefficient and the type of coarse aggregate and binder. The coefficients of lateral deformation of the composites based on epoxy binder and granite, thermolith and expanded clay aggregates were 0.32, 0.28 and 0.2 respectively.

Building materials and products are subjected to dynamic loads when in service, which may lead to, for example, early failure of metalworking machine frames, road and fly ground pavements, floors of heavy-duty industrial buildings, etc. The conducted tests demonstrate high resistance of pre-bound aggregate composites to impact load (Table 1).

Table 1

Composite impact resistance, kJ/m²

Aggregate	Impact toughness of pre-bound aggregate composite				Relative impact toughness of regular polymer concrete
	Epoxy framework	Polyester framework	Cement framework	Bitumen framework	
Crushed granite	4.2	2.10	1.90	2.00	1.30
Expanded clay	4.73	2.31	2.15	2.20	1.45

Impact toughness was taken as the criteria of pre-bound aggregate concrete resistance to impact, which was determined by testing 4×4×16 cm sample blocks using a Charpy machine. Impact toughness of pre-bound aggregate polymer concrete appeared to be a lot higher than of regular polymer concrete. The best results were achieved in the case of expanded clay filler due to its high adhesion with the binder. Increased impact toughness of pre-bound aggregate composites arises possibly from the following: polymer concrete framework creates an interlinked arrangement of the bound aggregate grains, which redistribute the applied load between each other; the structural stress at the filler-binder interface, which leads to microfracturing, decreases. A substantial increase of impact toughness is achieved by introducing reinforcement fiber, which improves the combined action of the framework and the matrix.

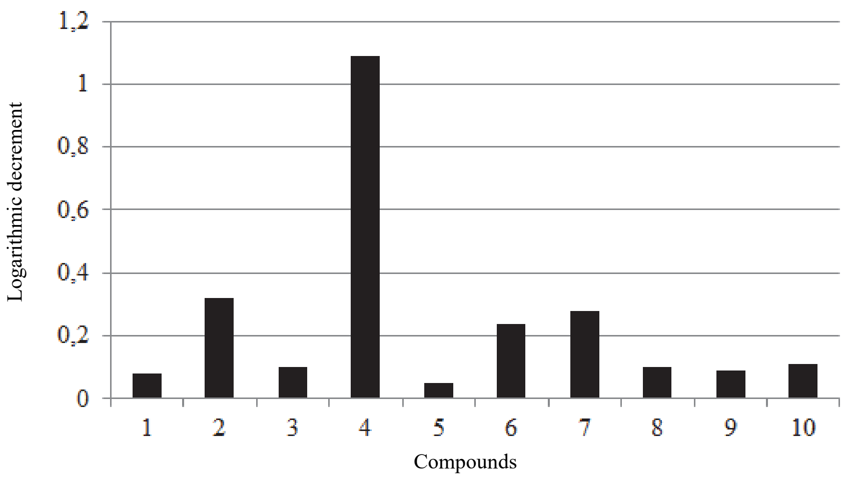

Figure 4. Damping ability of pre-bound aggregate composite versus compound:
1 – grade ED-20 epoxy-diane resin and crushed brick; *2* – grade PN-1 multipurpose polyester resin and crushed brick; *3* – cement and crushed brick; *4* – bitumen and crushed brick; *5* – cement framework glue, crushed brick aggregate, epoxy-diane resin matrix; *6* – multipurpose polyester resin framework glue, crushed brick aggregate, epoxy-diane resin matrix; *7* – bitumen framework glue, crushed brick aggregate, epoxy-diane resin matrix; *8* – granite aggregate and epoxy-diane resin; *9* – expanded clay and epoxy-diane resin; *10* – thermolith and epoxy-diane resin

Another dynamic resistance parameter of a building material is damping – the ability to absorb cyclic deformation energy. Materials with high damping ability reduce the vibration amplitude, soften the impact and, hence, lead to the decrease of stress in structures [21]. Pre-bound aggregate technology is advantageous in this regard: the damping properties are controlled at the micro- and macrostructure levels. The tests of pre-bound aggregate concretes based on various binders and fillers were conducted. The damping ability was evaluated by the logarithmic decrement, which was calculated based on the resonance peak width of 4×4×16 cm cantilever samples according to the common procedure [21]. The concrete compounds and the test results are presented in Figure 4.

Concrete damping ability depends on the nature and the properties of the matrix and the aggregate; besides, the logarithmic decrement value is mostly affected by the properties of the matrix, which fills framework voids, framework glue characteristics, and also the interaction of the aggregate with the glue and the glue with the matrix.

The most optimal filler in terms of damping is thermolith, the next are crushed granite and expanded clay. Test results show low ability of cement concrete in absorbing vibration. For this reason, it has little utility for making road pavements, which are subjected to impact load. For example, according to the service background of roadways, vibration in cement concrete pavements leads to the displacement of the unbound components of the road bed, deterioration of pavement slab smoothness and its early failure. Damping efficiency of epoxy polymer concrete is also poor. Cement concrete and epoxy concrete are brittle materials. Special treatment in terms of improving the viscoelastic characteristics needs to be provided for advancing their damping properties [21].

Introduction of fillers into polymer compounds led to the decrease of their damping ability. For example, by introducing graphite and Portland cement powders into multipurpose polyester resin (grade PN-1), the logarithmic decrement reduced by factors of 1.9 and 1.7 respectively relative to the unfilled compound. Meanwhile, EPILOK epoxy resin decreased the damping properties by factors of 1.3 and 1.6 when filled with cement and silica sand respectively.

The tests established that by using polyester and bitumen binders instead of cement and epoxy ones, the logarithmic decrement increases by factors of 3.8 and 14.4 respectively. Dynamic properties of pre-bound aggregate concrete improve by binding the framework grains with elastic and viscoelastic glues. Thus, by using polyester and bitumen glues instead of cement for binding the framework, the damping properties increase by factors of 3.6 and 5.3 respectively (Figure 4).

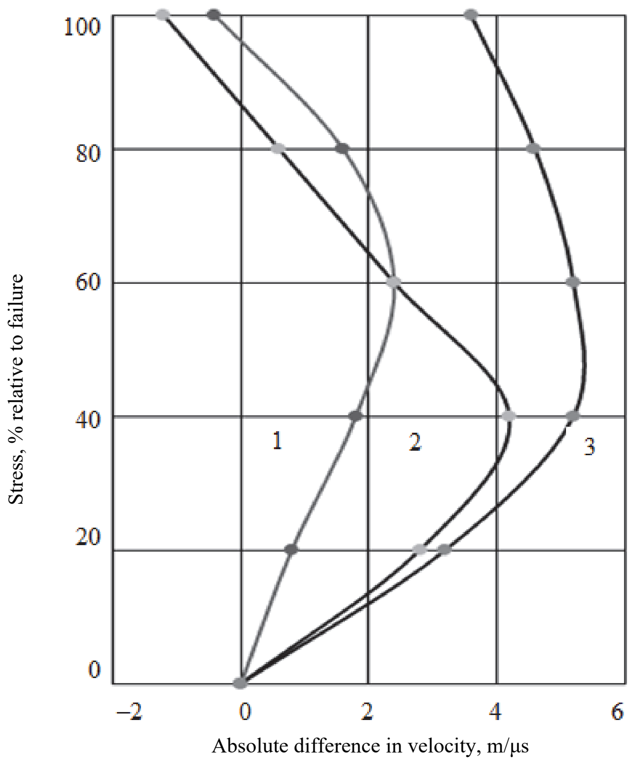

Figure 5. Ultrasonic velocity difference in pre-bound aggregate composite versus applied stress:
1 – polymer concrete; *2* – cement concrete; *3* – bitumen concrete

Crack resistance is also an important characteristic of composite materials. The reference data for evaluating crack resistance of CM are the experiments, which demonstrate the change in volume in the loading process. This parameter may be used to establish microfracture boundaries. In this regard, tests of pre-bound aggregate concrete samples with polymer, cement and bitumen binders and crushed brick were conducted. Ultrasonic transmission time was measured in the process of loading the samples (Figure 5).

The results of the investigation give an idea of compaction and decompaction processes during the loading of test samples. Compaction takes place at the load values of 0.3, 0.7 and 0.5 of the failure load for the polymer, cement and bitumen composites respectively. By loading to the specified values the ultrasonic velocity increases. Higher loads decrease the velocity, which indicates the beginning of the decompaction process, and therefore provides evidence of the formation of the first microfailures. This point is referred to by Berg as the first parametric point, which defines the lower microfracture boundary ($R_о^т$). Further load increase causes the ultrasonic velocity to decrease to the original value (second parametric point). This point indicates the beginning of volume increase and defines the upper microfracture boundary ($R_у^т$). According to Berg, stress $R_у^т$ establishes the transition from linear to the non-linear creep. It corresponds to the absolute fatigue limit of concrete subjected to repetitive load [22].

Material resistance to crack formation and propagation is evaluated with the help of the stress intensity factor (K_1), the surface energy coefficient (γ) and also the crack width in its blunt end part (δ). These quantities are related by the following expressions:

$$\gamma = \frac{K_1^2}{2E};\ \delta = \frac{K_1^2}{\sigma E}.$$

The stress intensity factor depends on the sample size and the initial crack length and it was determined according to [18] by the formula

$$K_1 = \frac{PV(l)}{b\sqrt{h}},$$

where P – the failure load; l – the crack width; b – the width of the sample; h – the height of the sample.

Function $V_{(l)}$ that relates the crack length to the height of the sample has the following form:

$$V_{(l)} = 3\frac{l}{b}\left[1{,}93\left(\frac{l}{h}\right)^{0,5} - 3{,}07\left(\frac{l}{h}\right)^{1,5} + 14{,}53\left(\frac{l}{h}\right)^{2,5} - 25{,}11\left(\frac{l}{h}\right)^{3,5} + 25{,}8\left(\frac{l}{h}\right)^{4,5}\right].$$

The stress intensity factor, the surface energy coefficient and the crack width in its blunt end were determined experimentally for epoxy composites with crushed granite, thermolith and expanded clay aggregates. These composites have the following ultimate strength and elastic modulus values in MPa: 11.5 and 8120 for crushed granite, 9.5 and 4750 for thermolith, 9.0 and 4050 for expanded clay respectively. Crack resistance characteristics of pre-bound aggregate composites with different coarse aggregates are presented in Table 2.

Table 2

Crack resistance of pre-bound aggregate composites

Aggregate type	Crack length, mm	Crack resistance parameters		
		K_1, MPa·cm^{0,5}	γ, MPa·cm	γ, cm
Crushed granite	10	54.7	0.184	0.032
	20	52.1	0.167	0.029
Thermolith gravel	10	32.9	0.114	0.024
	20	32.4	0.110	0.023
Expanded clay	10	38.3	0.181	0.040
	20	32.6	0.131	0.029

Analysis of the results indicates that coefficients K_1, γ and δ depend significantly on the aggregate type and the crack length.

Conclusion

The benefits of manufacturing pre-bound aggregate composite building materials are demonstrated.

The results of the investigation of elastoplastic properties and strength of composites based on various binders and aggregates are presented.

High performance of materials based on polymer binders with crushed granite and expanded clay aggregates was established.

References

1. Solomatov V.I., Bobryshev A.N., Himmler K.G. *Polymer composite materials in construction* (V.I. Solomatov, ed.). Moscow: Strojzdat Publ.; 1988. (In Russ.)

2. Bazhenov Yu.M. *Betonopolymers.* Moscow: Strojzdat Publ.; 1983. (In Russ.)

3. Lipatov Yu.S. *Physical chemistry of filled polymers.* Moscow: Himiya Publ.; 1977. (In Russ.)

4. Hozip V.G. *Strengthening of epoxy polymers.* Kazan: Dom Pechati Publ.; 2004. (In Russ.)

5. Sokolova Yu.A., Gotlib E.M. *Modified epoxy mixtures and coatings in construction.* Moscow: Strojzdat Publ.; 1990. (In Russ.)

6. Elshii I.M. *Polymer concrete in hydraulic engineering construction.* Moscow: Strojzdat Publ.; 1980. (In Russ.)

7. Potapov Yu.B., Solomatov V.I., Korneev A.D. *Polyester polymer concrete.* Voronezh: Izd-vo Voronezhskogo Universiteta Publ.; 1993. (In Russ.)

8. Solomatov V.I., Selyaev V.P., Sokolova Yu.A. *Chemical resistance of materials. 2nd ed., reprint. and add.* Moscow: RAASN Publ.; 2001. (In Russ.)

9. Perlin S.M., Makarov V.G. *Chemical resistance of fiberglass.* Moscow: Himiya Publ.; 1983. (In Russ.)

10. Koshkin V.G., Figovskij O.L., Smolin V.F., Nebratenko L.M. *Monolithic epoxy, polyurethane and polyester floor coverings*. Moscow: Strojzdat Publ.; 1975. (In Russ.)

11. Erofeev V.T. *Frame building composites* (Dr of Technical Sciences dissertation' abstract). Moscow; 1993. (In Russ.)

12. Erofeev V.T., Kruglov V.M., Vatin N.I., Al-Dulaimi S.D.S. Intelligent composites and their use for self-healing concrete. *Russian Journal of Transport Engineering*. 2019;6(4):11. (In Russ.) https://doi.org/10.15862/12SATS419

13. Erofeev V., Shafigullin V., Bobrishev A. investigation of noise – vibration-absorbing polymer composites used in construction. *IOP Conference Series: Materials Science and Engineering.* 2018;463(4):042034. https://doi.org/10.1088/1757-899X/463/4/042034

14. Startsev V.O., Molokov M.V., Blazno A.N., Zhurkovskii M.E., Erofeev V.T., Smirnov I.V. Determination of the heat resistance of polymer construction materials by the dynamic mechanical method. *Polymer Science – Series D.* 2017;10(4):313–317. https://doi.org/10.1134/S1995421217040141

15. Startsev O.V., Makhonkov A., Erofeev V., Gudojnikov S. Impact of moisture content on dynamic mechanical properties and transition temperatures of wood. *Wood Material Science and Engineering.* 2017;12(1):55–62. https://doi.org/10.1080/17480272.2015.1020566

16. Bobryshev A.N., Erofeev V.T., Voronov P.V., Bobryshev A.A., Gavrilov M.A., Barmenkov A.S. Kinetic modes of swelling and dissolution of composites. *Fundamental Research.* 2016;(6–1):29–35. (In Russ.)

17. Erofeev V.T. Fundamentals of technology theory of production, calculation physical and mechanical properties and indicators chemical and biological properties of frame building composites. *Structural Mechanics of Engineering Constructions and Buildings.* 2022;18(4):283–296. (In Russ.) http://doi.org/10.22363/1815-5235-2022-18-4-283-296

18. Erofeev V.T., Al-Dulaimi S.D.S., Fomichev V.T. Chemical aspects of the process of concrete cracks elimination with the help of bacteria. *Russian Journal of Transport Engineering.* 2018;5(3):12. (In Russ.) https://doi.org/10.15862/13SATS318

19. Erofeev V.T., Al-Dulaimi S.D.S., Smirnov V.F. Bacteria for self-healing concretes. *Russian Journal of Transport Engineering.* 2018;5(4):7. (In Russ.) https://doi.org/10.15862/13SATS318

20. Erofeev V.T., Tyuryahin A.S., Tyuryahina T.P., Tingaev A.V. Effective modules of two-phase construction composites with grain filler. *Structural Mechanics of Engineering Constructions and Buildings.* 2019;15(6):407–414. (In Russ.) http://doi.org/10.22363/1815-5235-2019-15-6-407-414

21. Solomatov V.I., Cherkasov V.D., Fomin N.E. *Vibration-absorbing composite materials*. Saransk: Izd-vo Mordovskogo Universiteta Publ.; 2001. (In Russ.)

22. Berg O.Ya., Shcherbakov E.N., Pisanko G.N. *High-strength concrete*. Moscow: Strojzdat Publ.; 1971. (In Russ.)