Atlantis Highlights in Material Sciences and Technology (AHMST), volume 1
International Symposium "Engineering and Earth Sciences: Applied and Fundamental Research" (ISEES 2019)

Investigation of the Coefficient of Linear Temperature Expansion of Composite Rods and Heavy Concrete

Kychkin A.K.
Institute of Physical-Technical Problems
of the North of the V.P. Larionov Siberian Branch
of the Russian Academy of Sciences
Yakutsk, Russia
kychkinplasma@mail.ru

Lebedev M.P.
Institute of Physical-Technical Problems
of the North of the V.P. Larionov Siberian Branch
of the Russian Academy of Sciences
Yakutsk, Russia
m.p.lebedev@prez.ysn.ru

Kychkin A.A.
Institute of Physical-Technical Problems
of the North of the V.P. Larionov Siberian Branch
of the Russian Academy of Sciences
Yakutsk, Russia
icen.kychkin@mail.ru

Matveeva O.I.
Yakut State Design Research Studies Institute of Construction
Yakutsk, Russia
yapniis@mail.ru

Marachovskii P.S.
All-Russian Scientific Researh Institute of Aviation Materials (VIAM FSUE)
Moscow, Russia
petrbmstu@mail.ru

***Abstract* – This paper presents the data of changes in the coefficient of thermal expansion of composite reinforcement and heavy concrete in a wide temperature range. Studies allow not only to justify the high stability of the BPA in terms of thermal expansion, but also to assess the subtle effects of measured parameters for parallel samples in the initial state and after climatic tests in Yakutsk. We identified the optimum relations of heavy concrete with limestone rubble of 60 % and gabbro-dolerite - 40 %, providing high degree of compatibility of temperature expansion with composite armature, for increase of crack resistance and excluding crack formation at temperature changes. The results allow to determine the optimal formulation of concrete reinforced with composite reinforcement for their possible use in the creation of new structural materials.**

Keywords – linear thermal expansion coefficient; composite reinforcement; crushed stone; concrete.

I. INTRODUCTION

The world practice shows that the solution of the durability problem of concrete reinforcement is one of the main tasks in the modern construction industry.

Wide distribution of reinforced concrete as a building material for structural solutions of typical and unique construction objects is promoted by its main advantages: high mechanical strength, environmental safety, durability, high fire resistance. Nevertheless, reinforced concrete, as the main building material of load-bearing structures, has certain drawbacks: a significant weight of the building structure, weak tensile strength of concrete, formation and opening of cracks in the stretched area of the reinforced concrete structure's cross-section, a significant difference in the coefficient of linear expansion of steel reinforcement and concrete, which leads to the formation of cracks in the protective layer of concrete under the influence of temperature cycles and subsequent corrosion of steel reinforcement, and then leading to the consequent loss of structural integrity.

A modern and promising product for steel reinforcement replacement is composite reinforcement made of plastic reinforced with various types of continuous fibers - aramid fibers, carbon fibers, glass fibers, basalt fibers, packed in a polymeric matrix.

The main advantages of composite reinforcement in relation to metal reinforcement are:

- increased strength values (1.5-2 times higher than steel);
- lower weight (3.5-4 times lighter than steel));
- high modulus of elasticity with a small coefficient of relative elongation, high resistance to stress loads; - excellent rheological characteristics;
- resistance to corrosion, very little change in its mechanical properties under the influence of acids, salts and alkalis;
- electromagnetic characteristics - is a dielectric, radio-transparent, magnetoinert (the change of strength

properties under the influence of electromagnetic fields is excluded);

- immunity to ultra-low temperatures (does not lose its strength properties);
- 100% adhesion with concrete and linear expansion coefficient equal to concrete, which excludes gusts of reinforcement and cracking in the protective layer of concrete under the influence of temperature cycles.

The world experience in the use of composite reinforcement as an effective substitute has more than 30 years. A number of countries have adopted normative documents on the application and calculation of fiberglass reinforcement in construction [1-5].

Composite basalt-plastic reinforcement (BPA) is a new, innovative building material with unique properties in comparison with traditional materials.

Advantages of polymeric materials reinforced with basalt fibers in terms of mechanical parameters, cost, resistance to aggressive environments, biological resistance are discussed in a number of works [6-16].

In [7] it is shown that basalt-plastics are resistant to water and chemically active solutions. After 250 days in these environments at room temperature, the tensile strength limit and modulus of elasticity change by 10-20%. According to [9], the plates and compressed layers of impregnated basalt fiber are resistant to dry and wet climate, but their mechanical parameters are unstable and fluctuate within the range of up to 30-40%. In work [10] durability and destruction of basalt plastic are compared with similar indicators for fiberglass plastics and carbon plastics after being in a wet environment and chemically active solutions. It is shown that the systems reinforced with basalt fibers have high resistance to these aggressive influences. A similar comparison is made in [11-13] and it is shown that the tensile, bending and shear strength limits and modulus of elasticity are not inferior to GRP in their resistance. In [14-16] the resistance of basalt-plastic materials to low, high temperatures and thermocycles has been investigated and the stability of these materials to the specified effects has been shown. In works [17,18] similar conclusions about high stability of BPA to influence of aggressive environments are received after estimation of influence of water, saline and alkaline solutions at normal and raised temperatures on mechanical properties of rods in diameter of 11-12 mm. Basalt-plastic samples based on polyester matrix according to [19] sorbed up to 2% of normal and sea water at room temperature. Tensile, bending and impact strength were reduced by 50-60%, especially for samples with basalt fibers treated with H2SO4 and NaOH solutions before composites were manufactured.

Similar mechanical properties of basalt plastics reinforced with finely cut roving, fabrics or uniaxially oriented continuous fibers are compared with carbon plastics and fiberglass plastics on the basis of unsaturated polyesters, epoxy phenol-formaldehyde and epoxyphenolic matrices [20]. It is shown that for 12 months of climatic tests in the South Caucasus there is a decrease in strength, depending on the type of polymeric matrix and the value of the applied tensile stress. Notably, the aging processes develop on the surface of the samples, but there is no experimental evidence of this statement.

A topical issue in the use of BPAs in construction is the confirmation and justification of the preservation of properties at a high level in the process of long-term operation in a variety of climatic conditions. However in all listed works [6-20] there is no information on change of properties of construction machinery under the influence of natural climatic conditions of different zones.

In this connection, we carried out an experimental assessment of the change in the linear expansion coefficient (LLTR) of the BPA after exposure in the extremely cold (Yakutsk) and the choice of the concrete formulation close to these values of LLTR.

II. Methods and Materials

We manufactured BPA for climatic tests, which is a unidirectional basalt-plastic rods of periodic profile with diameters of 6 and 8, on the technical line "Struna", on the basis of basalt roving RBN 13-2400-4C, manufactured by LLC "TBM" (Yakutsk), according to TU 2296-001-86166796-2013 "Fittings non-metallic composite of basalt-plastic". The initial binder based on epoxydianic resin ED-22 cured with isomethyltetrahydrophthalic anhydride (iso MTGFA) in the presence of accelerator 2,4,6-tris(dimethylaminomethyl) phenol (UP-606/2) was prepared according to the formulation RTP-SP2-20994511-1999T.

Measurement of KLTR samples was carried out on the thermomechanical analyzer TMA 202 "NETZSCH-Geratebau GmbH" with the heating rate of 5 K/min in the medium of helium duct with the speed of 70 ml/min.

Measurements were made in accordance with the national standard ASTM E 831 "Determination of the temperature coefficient of linear expansion of solid materials by thermomechanical analysis" in the temperature range of -100 to + 150 0C.

Parallelepipeds with a height of 20 mm and a cross section of 4x4 mm were cut out of the presented rods. The ends of the samples were ground on the butting saw to a deviation from the flatness of no more than 0.1 mm.

Concrete samples were measured in accordance with the national standards ASTM E831 for the temperature range from -60 to 60 ° C.

Thermophysical properties of heavy concrete were investigated by preparing samples with dimensions of 10x10x10 cm on the basis of cement+sand matrix, in the amount of 6 pieces of each composition with different content of limestone and gabbro-dolerite crushed stone with the size of fractions of 5-20 mm. Precipitation of the cone of concrete mixture with limestone crushed stone was 18 cm, with gabbro-dolerite crushed stone - 5 cm.

Exceptional systematic errors have been taken into account when calibrating relative dilatometers as a standard measure. The relative measurement error was 3% at a confidence level of 0.95 over the entire operating temperature range. The arithmetic mean of CLTR observations was taken as the result of the measurement, which was preliminary corrected to exclude systematic errors.

To estimate the CLTR change of the periodic profile BPA rods of 6 and 8 mm diameter, were exhibited for 51 months on the open stands in the extremely cold climate of Yakutsk. The average annual air temperature in Yakutsk is -10.2°C. Yakutsk is located in the zone of sharply continental climate with very cold winters and relatively hot and short summers. The minimum registered temperature is -64.4°C. The annual temperature amplitude between the highest and lowest values exceeds 100°C. In winter in Yakutsk at temperatures below -40°C all water vapor contained in the air crystallizes and forms fogs. The average wind speed is 1.8 m/s. The average annual relative humidity is 68%. Precipitation corresponds to 237 mm per year. The annual total solar radiation dose in Yakutsk is 3680 MJ/m2. The daily temperature difference in the autumn - spring period is 250C with crossing the zero point.

III. RESULTS

Results of measurements of average CLTR in a range of temperatures from -50 to +100 samples of basalt-plastic armature are resulted in Table 1.

TABLE I. Average CLTR of BPA samples

Temperature range (20 - T_i), °C	CLTR of the original BPA samples				BPA samples after 54 months			
	Average arithmetic value, $\bar{\alpha}_{av}\cdot10^6$, 1/K		*Standard deviation, $S\cdot10^6$, 1/K*		*Average arithmetic value, $\bar{\alpha}_{av}\cdot10^6$, 1/K*		*Standard deviation, $S\cdot10^6$, 1/K*	
	Ø6	Ø8	Ø6	Ø8	Ø6	Ø8	Ø6	Ø8
-50	5.9	6.7	0.09	0.32	5.76	6.00	0.15	0.36
0	6.8	6.9	0.15	0.24	6.05	6.37	0.05	0.30
50	7.0	7.0	0.22	0.25	6.38	6.64	0.01	0.34
100	7.1	7.1	0.32	0.35	6.44	6.65	0.16	0.49

Figure 1 shows the areas of increase and decrease of CLTR of initial (1) and after 51 months of exposure of 6 mm diameter (2) and 8 mm diameter (3).

Temperature dependences of relative thermal expansion $\Delta L/L_0$ along the direction of reinforcement of BPA samples in the initial state and after exposure in Gelendzhik [21] and Yakutsk are shown in Fig. 2. To estimate the reproducibility of the results, measurements were made on three parallel samples in each state. Colored bands indicate variances $\Delta L/L_0$.

The reason for the observed increase in $\Delta L/L_0$ and $\bar{\alpha}$ is the prevalence of the effect of attenuation of polymeric matrix stresses at the interface with basalt fiber over the effect of additional hardening of polymeric matrix of BPA. Similar regularities were observed earlier at climatic aging of VPS-7 fiberglass based on epoxy binder EDT-10P [22]. Similar regularities were observed earlier at climatic aging of VPS-7 fiberglass based on epoxy binder EDT-10P [22].

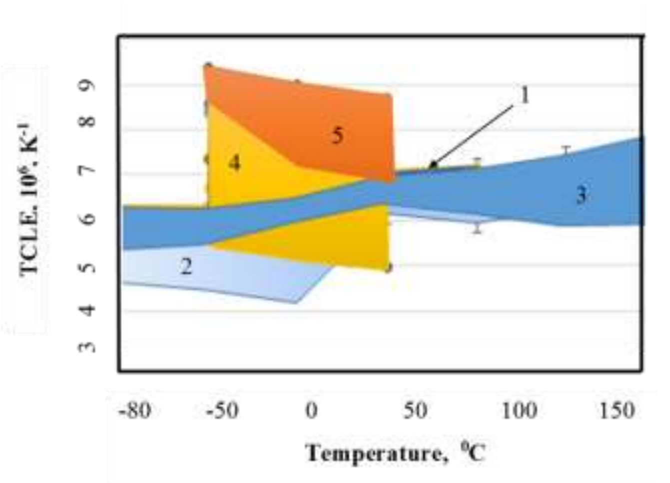

Fig. 1. Areas of increase and decrease of CLTR in the initial state - 1, after 51 months of diameter 6 mm -2, after 51 months of diameter 8 mm, concrete with limestone rubble -4, concrete with gabbro-dolerite rubble

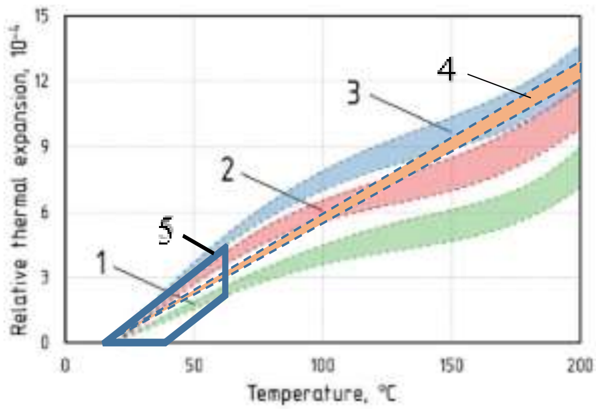

Fig. 2. Temperature dependences of relative thermal expansion along the direction of BPA reinforcement in the initial state (1), after 30 months of exposure in Gelendzhik (2), 28 months of exposure in Yakutsk (3) and 51 months of exposure in Yakutsk (4), concrete on the basis of limestone rubble (5).

The results of measurements given in Fig. 2, allow not only to justify high stability of the BPA in terms of thermal expansion, but also to evaluate the subtle effects of measured parameters for parallel samples in the initial state and after climatic tests in Gelendzhik [21] and Yakutsk. The results of thermal expansion measurements of BPAs are shown in Table 2. Calculation of CLTR $\bar{\alpha}$ is made under the assumption of linear increase $\Delta L/L_0$ at $T < T_g$ и $T > T_g$ (where, Tg – the glass transition temperature).

In order to carry out investigations of the thermal and physical properties of heavy concrete, were obtained samples of 6 pieces of each composition with marking:

Composition No. 1 - ratio of initial materials by sand-cement mixture C:P=1:1,2 on the basis of limestone crushed stone are presented in table 3. Precipitation of concrete mixture cone -18 cm, mixture of crushed stone fractions - 5-20 cm.

TABLE II. Effect of exposure on linear thermal expansion of BPAs

Climate test conditions	**Relative thermal expansion in the temperature range 25–200°C, $(\Delta L/L_0) \cdot 10^{-4}$**	**Linear thermal expansion coefficient $\bar{\alpha} \cdot 10^{-6}, K^{-1}$**	
		$T < T_g$	$T > T_g$
Initial state	7–9,3	5,0–6,3	5,6–5,9
30 months of exhibiting in Gelendzhik [21]	9,1–13	7,1–7,4	9,8–12,5
28 months of exhibiting in Yakutsk [21]	12–14	7,7–9,3	7,5–9,5
51 months of exhibiting in Yakutsk	9,8–13,5	7,6–8,2	9,5-10,6

Composition No. 2 - ratio of initial materials by sand-cement mixture C:P=1:2,2,2 on the basis of gabbro-dolerite crushed stone are presented in table 4. Precipitation of concrete mixture cone -5 cm, mixture of crushed stone fractions - 5-20 cm.

TABLE III. Content of limestone-based concrete components

Sample №1	**Sample №2**	**Sample №3**	**Sample №4**	**Sample №5**
Sand and concrete mixture 1:1,2	Crushed stone limestone (15%), sand-concrete mixture 1:1,2(85%)	Crushed stone limestone (60%), sand-concrete mixture 1:1,2(40%)	Crushed stone limestone (85%), sand-concrete mixture 1:1,2(15%)	Crushed concrete

TABLE IV. Content of concrete components based on gabbro-dolerite crushed stone

Sample №6	**Sample №7**	**Sample №8**	**Sample №9**	**Sample №10**
Sand and concrete mixture 1:2.2	Gabbro-dolerite crushed stone (30%), sand and concrete mixture 1:2.2 (70%)	Gabbro-dolerite crushed stone (40%), sand and concrete mixture 1:2.2 (60%)	Crushed gabbro-dolerite stone	Gabbro-dolerite crushed stone (90%) sand-concrete mixture 1:2.2 (10%)

The results of the average CLTR in the temperature range from -60 to +60 of concrete samples are given in Table 5.

TABLE V. Average KLTR of concrete samples

Temperature range Measurements of the average sample CLTR, °C	Average concrete CLTR values				
-60 +60	Sample №1	Sample №2	Sample №3	Sample №4	Sample №5
	11,58	8,50	6,74	5,13	5,05
	Sample №6	Sample №7	Sample №8	Sample №9	Sample №10
	10,43	8,88	7,93	7,71	7,39

Areas of increase and decrease of CLTR of concrete samples on the basis of limestone crushed stone (4) and on the basis of gabbro-dolerite crushed stone (5) are presented in Fig. 1. Temperature dependences of relative thermal expansion of concrete (5) are presented in Fig. 2

IV. CONCLUSION

The results of measurements shown in Figs. 1 and 2, allow not only to justify the high stability of the BPA in terms of thermal expansion, but also to assess the subtle effects of measured parameters for parallel samples in the initial state and after climatic tests in Yakutsk. The reason for the observed increase $\Delta L/L_0$ and $\bar{\alpha}$ is the predominance of the effect of attenuation of polymer matrix stresses at the interface with basalt fiber over the effect of additional hardening of polymer matrix of BPA.

Thus, as a result of the carried out researches we defined optimum relations of heavy concrete with limestone rubble of 60 % and gabbro-dolerite - 40 % that provide high degree of compatibility of properties of CLTR with composite armature, increase of crack resistance and exception of crack formation at temperature change.

Acknowledgment

The work was carried out within the framework of the RFBR Project No. 18-29-05012 "Development of scientific bases for creation of new composite materials under the influence of abiogenic and biogenic factors in the Arctic and subarctic zones of the Republic of Sakha (Yakutia)".

References

[1] The American Concrete Institute (USA): ACI 440.6-08 (2008), ACI 440.5-08 (2008), ACI 440.R-07 (2007), ACI 440.1R-06 (2006) “Guidelines for the Design and Construction of Fiberglass Reinforced Concrete” and ACI's Committee 440, ACI 440.3R-04 (2004) “Composite Fittings Testing Methods”.

[2] Canadian Standards Association (Canada): CAN/CSA-S806-02 “Design and Development of Structures using Composite Fittings”; CAN/CSA-S6-06 “Canadian Bridge and Highway Design Code”.

[3] Japan Society for Civil Engineers: “Recommendation for Design and Construction of Concrete Structures Using Continuous Fiber Reinforced Materials, 1997”.

[4] Italian National Research Council CNR-DT 203/2006 “Guide for the Design and Construction of Concrete Structures Reinforced with Fiber-Reinforced Polymer Bars”.

[5] GOST 31938–2012 “Composite polymeric reinforcement for reinforcement of concrete structures. General specifications”; GOST 32492-2015 “Polymer composite reinforcement for reinforcement of

concrete structures. Methods of determination of physical and mechanical characteristics"; SP 295.1325800.2017 "Concrete structures reinforced with polymer composite reinforcement. Design rules".

[6] V. Dhand, G. Mittal, K.Y. Rhee, S.-J. Park, D. Hui, "A short review on basalt fiber reinforced polymer composites", Composites Part B: Engineering, vol. 73, no. 5, pp. 166–180, 2015.

[7] R. Parnas, M. Shaw, Q. Liu, "Basalt fiber reinforced polymer composites", Technical Report NETCR63. Institute of Materials Science, University of Connecticut, 133 p., 2007.

[8] G. Alaimo, A. Valenza, D. Enea, V. Fiore, "The durability of basalt fibres reinforced polymer (BFRP) panels for cladding", Materials and Structures, vol. 49, no. 6, pp. 2053–2064, 2016.

[9] G. Wu, X. Wang, Z. Wu, Z. Dong, G. Zhang, "Durability of basalt fibers and composites in corrosive environments", Journal of Composite Materials, vol. 49, no. 7, pp. 873–887, 2015.

[10] Q. Liu, M.T. Shaw, R.S. Parnas, A.-M. McDonnell, "Investigation of basalt fiber composite mechanical properties for applications in transportation", Polymer Composites, vol. 27, pp. 41–48, 2006.

[11] H. Li, G. Xian, M. Ma., J. Wu, "Durability and fatigue performances of basalt fiber/epoxy reinforcing bars", Proc. of 6th Int. Conf. on FRP Composites in Civil Engineering, Rome, Italy, pp. 8, August 2012 [6th Int. Conf. on FRP Composites in Civil Engineering, Rome, Italy, 2012].

[12] Y. Xie, K. Guan, L. Lai, "Effect of chloride on tensile and bending capacities of basalt frp mesh reinforced cementitious thin plates under indoor and marine environments", International Journal of Polymer Science, vol. 2016, pp. 7, 2016.

[13] M.A. Ammar, "Bond durability of basalt fiber-reinforced polymers (BFRP) bars under freeze-and-thaw conditions", Thesis, Quebec, Canada, 105 p., 2014.

[14] M. Najafi, S.M.R. Khalili, R.E. Farsani, "Accelerated heat aging study of phenolic/basalt fiber reinforced composites", Mechanics of Advanced Composite Structures, vol. 3, no. 1, pp. 1–7, 2016.

[15] S.M.R. Khalili, M. Najafi, R.E. Farsani, "Effect of thermal cycling on the tensile behavior of polymer composites reinforced by basalt and carbon fibers", Mechanics of Composite Materials, vol. 52, no. 6, pp. 807–816, 2017.

[16] A.E. Refai, "Durability and fatigue of basalt fiber-reinforced polymer bars gripped with steel wedge anchors", Journal of Composites for Construction, vol. 19, no. 5, pp. 0401–4078, 2014.

[17] A.E. Refai, F. Abed, A. Altalmas, "Bond durability of basalt fiber–reinforced polymer bars embedded in concrete under direct pullout conditions", Journal of Composites for Construction, vol. 18, no. 7, pp. 0401–3006, 2013.

[18] A. Pandian, M. Vairavan, W.J.J. Thangaiah, M. Uthayakumar, "Effect of moisture absorption behavior on mechanical properties of basalt fibre reinforced polymer matrix composites", Journal of Composites, vol. 2014, article ID 587980, 8 p., 2014.

[19] N.M. Chikhradze, L.A. Japaridze, G.S. Abashidze, "Properties of basalt plastics and of composites reinforced by hybrid fibers in operating conditions", Composites and their applications, pp. 243–268, 2012.

[20] D. Matykiewicz, K. Lewandowski, B. Dudziec, "Evaluation of thermomechanical properties of epoxy–basalt fibre composites modified with zeolite and silsesquioxane", Composite Interfaces, vol. 24, no. 5, pp. 489–498, 2017.

[21] V.O. Startsev, M.P. Lebedev, A.K. Kychkin, "Influence of moderately warm and extremely cold climate on properties of basalt plastic armature", Heliyon, vol. 4, no. 12, pp. e01060, 2018.

[22] O.V. Startsev, A.S. Krotov, P.D. Golub, "Effect of climatic and radiation ageing on properties of glass fibre reinforced epoxy laminates", Polymers and Polymer Composites, vol. 6, no 7, pp. 481–488, 1998.