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EFFECT OF PARAMETER OF FIBRES IN DISPERSED REINFORCEMENT OF CONCRETES AND SULFUR CONCRETES

The problems of concrete and crack resistance under cyclic repeated power, temperature and moisture effects are of great significance for road, transport, irrigation and other structures, especially in the regions with increased day temperatures. These effects accelerate the processes of concrete failure to a great extent, but their influence on concrete endurance and crack resistance is insufficiently studied. A lot of various concretes differing in structure, kind and modified state of binders, kind and properties of fillers and aggregates have appeared lately. The paper deals with the results of experimental investigations of cement and sulfur concrete endurance, including concretes reinforced with glass fibre under the action of repeated load and variable humidity.

Key words: cement and sulfur concrete, fibre.

Проблеми тріщиностійкості бетону за багаторазового повторного навантаження, вологостійкості та впливу температур мають велике значення для спорудження автошляхів, транспортних споруд, зрошувальних систем та інших будівель, особливо в районах зі збільшеним діапазоном зміни температури протягом доби. Це істотно прискорює процеси руйнування бетону, проте вплив цих факторів саме на витривалість та тріщиностійкість бетонів вивчено недостатньо. Останнім часом з'явилось багато видів бетонів, що відрізняються за структурою, видами в'яжучих, видами та властивостями заповнювачів та наповнювачів. Наведено результати експериментальних досліджень витривалості цементних та сірчаних бетонів, зокрема армованих фіброю зі скловолокна, під дією багаторазового повторного навантаження та змінної вологості.

Ключові слова: цементні та сірчані бетони, фібра.

Introduction

Cyclic and repeated effects of external loads and repeated cycles of damping-drying, heating-cooling from environment contribute to accumulation of internal stresses in concrete and reinforced concrete structures.

Reduction of strength under external loads and effects of medium results from accumulation and time development of micro- and macro cracks in the structure and corresponding relaxation of stresses in the material [1]. The amount of concrete strength reduction depends on a lot of factors, concrete grade, its structure and state of moistening being the determinative ones.

Investigations [2, 3] found that humidity exercises substantial influence on mechanical properties of concretes, especially on their endurance. It can be explained by the fact that water molecules present in capillaries diffuse quickly into micro cracks arising from fatigue and accelerate their spreading. A fatigue crack arising and quickly spreading in water- saturated layer is a concentrator of stresses and it contributes to specimen's failure. Even greater influence on endurance is exercised by alternate concrete damping and drying. Repetition of these processes and overlapping of temperature strains causes the loosening of the structure of concretes, especially coarse ones, in consequence both static and fatigue strength falls [3].

Investigations [4, 5] found the process of crack formation in sulfur concretes to differ considerably from similar process in cement concretes. It is explained by the difference in their structure, character and value of own stresses in materials. Absence of capillary-porous structure, chemical processes connected with cement hydration, chemically bound and free moisture in sulfur mastics and concretes imposes its own features on the mechanisms of their failure.

Aims, objects and materials for investigation

The aim of this investigation was studying the influence of humidity conditions, compositions and structure on the endurance of cement and sulfur concretes differing in manufacturing process.

The main disadvantage of sulfur as a concrete binder is high brittleness and presence of high residual temperature stresses taking place after the completion of sulfur concrete structure formation. In the process of exploitation such concretes are sensitive to temperature effects and it results in their rather low crack resistance under loading. Therefore the technology of obtaining high quality durable products made of sulfur concrete is based on the process of elementary sulfur modification.

Sulfur modification eliminates to a great extent shortcomings typical for sulphur concretes, but a lot of their properties remain not fully studied, insufficiently safe to be applied in structures exposed to alternative loads in working conditions, e.g. in road surfaces and airfield pavements, railroad sleepers, bridge and overbridge members.

Specimens sized 4x4x16 cm manufactured by vibrocompression method were the object studies. Specimens made of sulfur concrete were manufactured according to hot technology. During this process sulfur melted at 150°C and mixed with mineral fillers and aggregates dried and heated to this temperature. Specimens were shaped in metal forms heated to the temperature of sulfur melt.

Specimens made of cement stone were kept up under normal hardening conditions for 28 days and then–under air-dry laboratory conditions. Specimens on sulphur binder hardened in the open air after manufacturing and were kept under air-dry conditions afterwards.

Starting materials for manufacturing concretes were as follows: portland cement with activity 48 MPa, technical sulfur of 9920 gradeand sulfur modified by 5% dicyclopentadiene (DCPD), grinded limestone sulfuric ore containing about 28% of elementary sulfur as binders; grinded silica and limestone flour (specific surface 3,000 cm^2/g) and mineral component in the composition of sulfuric ore as fillers; quartz fine- grained sand (size modulus 1.38) and limestone sand as fine aggregates; granite siftings of 3…8 mm fraction obtained after grinding granite chips, and granite chips of 5…10 mm fraction as coarse fillers.

For reinforcing sulfur concrete glass fibre of aluminoborosilicate composition 10, 30 and 50 mm long was applied.

Methods of investigation

Material endurance limit is a strength characteristic under the actions of repeated load. As well as dynamic (impact) strength it is a specific characteristic of material, and it brings about methodical and theoretical difficulties when carrying out experiments on estimation of the results obtained.

In order to standardize the method of investigation it is common practice to take endurance limit (fatigue strength) R_{end} as the strength of material with 50% reliability level when testing specimens on the basis of 1 million cycles of loading changing according to sinusoid law, i.e.if endurance limit is equal to R_{end} it means that after 2 mln. cycles of loading $P_0 \sin \omega t$ half the specimens will fail. Of course, this example is of simplified character as under natural conditions structures are effected by periodic loads or periodic loads with multiple harmonics, but nevertheless this approach gained wide application as it simplifies the process of carrying out experiments.

Force alternating in value and direction are created by pulsation and vibration setups, the latter ones being the simplest. They create alternating forces by rotating eccentrics. The main parameters of the setups are frequency of excitation force, their maximum and minimum value (static and variable) and range of loading characteristics at which vibrator operates.

Cycle characteristic is value ρ equal to the ratio of minimum and maximum load in cycle $\rho=P_{min}/P_{max}$. The most common range of values is $\rho=0.1…0.6$. At $\rho<0.7$ repeated load is close to constant loadin its action. At $\rho<0$ concrete and natural stone materials have low strength, that's why their application under alternate loads is limited.

Fatigue tests were carried out at specially designed vibration setup. Alternate forces were created by 4 eccentrics on two shafts rotating in opposite directions. Static load was created by extra loads in the form of the steel discs 1/3 of specimen’s bearing length.

Mean stress on the lower side was created by the mass of extra loads vibrator P_{st} making

$$s = \frac{P \cdot l}{6 \cdot W} = 0.1875 \cdot P\,, \qquad (1)$$

Maximum value σ_{max} was composed of stresses from static load P_{st} and variable P_d:

$$s_{\max} = 0.1875 \cdot (P_{st} + P_d)\,, \qquad (2)$$

where P- variable load created by unbalances equal to:

$$P_d = 4 \cdot w^2 \cdot m \cdot e\,, \qquad (3)$$

where m- mass of unbalances;

ω- frequency of unbalance rotation equal to 2;

e- eccentricity.

Minimum stress σ_{min} on the lower side of the specimen made:

$$s_{\min} = 0.1875 \cdot (P_{st} + P_d)\,, \qquad (4)$$

Then the characteristic of load cycle makes:

$$r = \frac{P_{st} - P_d}{P_{st} + P_d}\,, \qquad (5)$$

At ρ=0.5, $0.5P_{st}$=1.5 P_d and P_{st} =3P_d. The above dependence allows us to determine the amplitude of a variable by known static load.

Relative fatigue strength was used in the investigation. It was a ratio of maximum cycle load to concrete static strength. Testing of specimens’ bending tension was carried out at frequency 50 Hz, characteristic of stress cycle 0.5 and number of load repeating $2x10^6$ cycles.

Accepted method of determining fatigue strength in order to reduce the number of specimens is described below. The specimen was loaded with relative loading level known to be lower than the coefficient of endurance $\gamma_{C,fat}$, equal to 0.25 and tested at $1x10^5$ cycles etc. Afterwards if the specimen didn’t fail another one was loaded by previous loading level and tested up $1x10^6$ cycles. If the specimen didn’t fail after that the load was increased by 0.02 and $1x10^6$ cycles were applied again. Future on the step of load change remained the same, bur residuary specimens were tested by the whole basic amount of cycles. This approach made it possible to quickly determine the tentative level of relative endurance limit using only 2…3 specimens for this purpose and to make it more accurate during further experiments.

Results of experiments and their consideration

At the first stage of investigations the specimens’ behavior under repeated load in air- dry state was analyzed. Relative endurance limit at bending of specimens on cement binder made 0.45…0.60, on sulfur binder – 0.28…0.36. Reduction of relative endurance of specimens on sulfur binder in comparison with cement binder can be explained by the presence of multitude of local heterogeneities in its structure. They are intensively revealed under repeated load provoking the origination of micro cracks, their development and transformation into macro cracks, resulting into failure.

The reason for arising heterogeneities is the process of sulfur recrystallization during sulfur mastic cooling, hardening and structure formation leading to high internal stresses and thermal shrinkage strains. It is intensified by the lack of the process of crack “self- healing” taking place in cement systems.

It was shown above that relative endurance of cement concretes is 30% higher than that of sulfur concretes produced on crystalline sulfur. Modification of sulfur composites with 5% DCPD raised relative endurance greatly. Extra raising of endurance can be reached with the help of reinforcing sulfur concrete with the alkali medium of which fiber corrode with time. In order to study this problem testing of specimens reinforced with fiber 10, 30 and 50 mm long with the percentage of reinforcement μ_f=0;0.5;1.0 and 1.8 was carried out (Table 1).

Table 1

Results of endurance tests of sulfur concretes non - reinforced and reinforced with glass fibre

Fibre length l_r,mm	μ_f,%	Non – modified sulfur			Modified sulfur			Q'_{fat}/ Q_{fat}
		f_{ctk}	$\gamma_{C,fat}$	Q_{fat}	f_{ctk}	$\gamma_{C,fat}$	Q_{fat}	
0	0	12,5	0,38	4,75	21,2	0,50	10,60	2,23
10	0,5	16,8	0,41	6,89	27,8	0,52	14,46	2,10
10	1,0	18,2	0,43	7,83	31,0	0,57	17,67	2,26
10	1,8	19,3	0,45	8,69	33,9	0,60	20,34	2,34
30	0,5	21,0	0,43	9,03	30,6	0,55	16,83	1,86
30	1,0	23,2	0,46	10,67	32,7	0,61	19,95	1,87
30	1,8	25,0	0,48	12,00	35,4	0,65	23,01	1,92
50	0,5	22,5	0,46	10,35	33,2	0,57	18,92	1,83
50	1,0	24,3	0,48	11,66	35,0	0,65	22,75	1,95
50	1,8	25,6	0,50	12,80	37,1	0,67	24,86	1,94

Dispersed reinforcement of matrices with glass fibre effected significantly the strength and endurance of sulfur concrete (Table 1). The nature of specimens' behavior under repeated loading proved Langer's hypothesis about two stages (phases) of work of composition materials in the process on non – stationary accumulation of faults. According to this hypothesis the first stage is characterized by decelerated process of micro fault origination and accumulation. At the second stage their avalanche – like development, joining and transformation of several micro cracks into one trunk crack takes place, as well their as final failure. The duration of this stage depends on the percentage of reinforcing, fibre length, characteristic and number of load cycles the specimen bore. For sulfur concrete this phase is much shorter than for reinforced one, as fibres in the letter decelerate the velocity of micro crack growth making the second stage of material work longer.

The failure of reinforced concrete in comparison with its non – reinforced matrix was of qualitatively different character. Specimens of the former experienced plastic failure, of the later – brittle, almost instantaneous failure. Fibres 10 mm long were pulled out of the matrix, those 30 mm long were partially tom apart, fibres 50 mm long, as a rule, were torn apart. Sulfur modification resulted in even greater plasticity of specimens' failure.

As it should be expected, dispersed reinforcement of modified sulfur matrix increased the endurance coefficient and absolute fatigue strength greatly in comparison with non – modified sulfur matrix. Increase of endurance coefficient made 26-34%, absolute fatigue strength – 1.83…2.34 times. It can be explained not only by the increase of concrete plastic deformation share, but also of adhesive bonds between plasticized sulfur and fibers.

Conclusion

Our investigation showed that endurance of cement concrete decreased with water saturation, especially of small layer in tensile zone. It can be explained by the fact that water – saturated layer actually becomes non – operating. Fatigue crack arising and spreading quickly in it is a concentrator of stresses. This phenomenon isn't observed with the application of sulfur concrete which actually isn't saturated and there are not any processes of alternate damping and drying.

Temperature drops are most dangerous for sulfur concretes. It is connected with high thermal sensitivity of sulfur and its high coefficients of linear and volume temperature expansion in comparison with cements stone.

Fatigue strength of cement and sulfur concretes decreases with rising temperature and has maximum value at humidity corresponding to air – dry state of the specimens.

Lack of active capillary porousness in the structure of sulfur concrete eliminates water saturation, an at low temperatures – ice formation. It brings about high low - temperature resistance in the process of its exploitation under the conditions of normal above – zero temperature.

Alternate influence of positive and negative temperature, especially at great drops, loosen the structure of both kinds of concrete, especially of coarse concretes, raises their heterogeneity ad density. It leads to the reduction of both static and fatigue strength.

The greatest effect on concrete endurance is exercised by cement stone and sulfur mastic micro structure, properties of contact zone with the surface of grains of mineral aggregates, and for sulfur concrete – modified state of sulfur.

Fatigue strength of sulfur concrete is maximum at optimum content of sulfur mastic. The most endurable is concrete produced on carbonate materials and modified sulfur.

Dispersed reinforcement of matrices with glass fibre 20…30 mm long increases sulfur concrete fatigue strength greatly. Further increase of fibre length is less effective and makes even distribution of fibres in the matrix more difficult.

Carried out investigation enables us to assign more substantiated coefficient of fatigue strength when rating design resistance of concretes when endurance of structures is calculated.

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