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THE OWN STRESSES INFLUENCE ON SCALE EFFECT IN CONCRETE

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The experimental technique and the experiment results on the influence of own stresses unevenly distributed over cross section on materials strength and on scale effect are presented. The reasons for the occurrence and distribution of such influence are analyzed. Based on the experiments results on fragile duralumin samples, the inevitability of influencing on scale effect in concrete during compression stresses, which are caused by unevenly shrinkage over cross section was proved. Possible reasons for the different (sometimes opposing) results of experimental studies of various authors on scale effect in concrete in compression are explained. The influence of own stresses unevenly distributed over cross section on scale effect in concrete during compression, depending on samples size and concrete age, is analyzed in detail.

Keywords: scale effect, own stresses, concrete strength, shrinkage, creep

ВПЛИВ ВЛАСНИХ НАПРУЖЕНЬ НА МАСШТАБНИЙ ЕФЕКТ В БЕТОНІ

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У роботах різних авторів результати експериментальних досліджень масштабного ефекту при випробуванні бетонів, розчинів та інших пористих матеріалів на стиск носять різний, іноді досить суперечливий, характер. Спроби пояснення отриманих результатів досліджень масштабного ефекту привели до необхідності врахування різноманітних факторів, до яких, безперечно, можна віднести вплив нерівномірно розподілених по поперечному перерізу власних напружень. Наведено методику проведення експерименту та результати дослідів по впливу власних напружень, нерівномірно розподілених по поперечному перерізу, на міцність матеріалів та на масштабний ефект. Проаналізовано причини виникнення протилежних за знаком полів власних напружень, нерівномірно розподілених по поперечному перерізу зразка, та їх можливий вплив на масштабний ефект при випробуванні зразка на стиск. Спираючись на результати дослідів з крихкими дюралюмінієвими зразками доведено неминучість впливу на масштабний ефект у бетоні при стиску напружень, викликаних нерівномірною по поперечному перерізу усадкою. На основі результатів експериментів інших дослідників по зміні міцності бетону повітряно-сухого зберігання у часі обґрунтовано зміни нерівномірності розподілу власних напружень по поперечному перерізу внаслідок нерівномірної усадки і повзучості бетону в поперечному перерізі. Поява різних за знаком полів нерівномірно розподілених по поперечному перерізу власних напружень у різні проміжки часу не тільки впливає на міцність бетонних зразків при стиску, а й проявляє в різній мірі масштабний ефект. Пояснені можливі причини різноманітних (іноді навіть протилежних) результатів експериментальних дослідів різних авторів щодо масштабного ефекту в бетоні при стиску. Детально проаналізовано вплив нерівномірно розподілених по поперечному перерізу власних напружень на масштабний ефект у бетоні при стиску в залежності від розмірів зразків і віку бетону.

Ключові слова: масштабний ефект, власні напруження, міцність бетону, усадка, повзучість

Introduction

The scale effect is substantiated by the statistical theory of strength: the larger sample size, the greater probability of a destructive defect [1-6]. At the same time, various results of experimental studies were obtained (especially for concretes, mortars and other porous materials): in some experiments in larger sizes samples obtained less strength; in other experiments in larger samples there was greater strength; in some cases, in samples of different sizes there was almost no difference in strength [7, 8, 9, 10, 11].

Such experimental results led to necessity to consider various factors influencing scale effect. One of such factors can be considered as influence of unevenly distributed own stresses over section.

Review of the research sources and publications

The first experiments on own stresses influence (unevenly distributed over cross section) were performed on samples of epoxy resin [1]. Cylindrical samples with a height of 60 mm and a diameter of 30 mm were made of epoxy resin in layers in three stages. Samples each series consisted of two groups, which differed from each other in the sign of their own stresses fields. Samples of the first group were made starting from the inner layers. First, the first inner layer of sample was filled, and then it hold time for 10 days. After attainment of sufficient strength inner layer, it was loaded with compressive force and the next second layer was filled around it. After 10 days, both layers (inner and middle) were loaded with a larger compressive force. Thereafter, last third outer layer was filled. Subsequently, first series samples had gained strength for 10 days, and then central compression was tested.

Second group samples were made in reverse order. The first was filled with outer layer of cylindrical sample. After 10 days, after reaching outer layer of sufficient strength attainment, it was loaded with compressive force and then filled middle layer. After 10 days, both layers were loaded with compressive force and last inner layer was filled.

After unloading, own stress field was created in samples of first group where sample internal part (core) was compressed and outer layers were stretched. The field of own stresses arose with opposite signs in second group samples: outer layers were compressed, and inner, on the contrary, stretched. It should be noted, strength of all layers in each sample was different due to different terms of their hardening during manufacture.

The disadvantages of the experiment, which are caused by manufacturing technology of samples and could insignificantly affect experiments results, include stepwise (layer-by-layer) own stresses field creation. In addition, epoxy resin is an aging material, and in different layers there were different hardening periods of epoxy resin.

Despite these disadvantages, experiments results confirmed the effect of their own unevenly distributed cross-sectional stresses on material strength. First group samples strength was larger than strength of the second group samples, despite the fact that outer layers of first group samples have less strength than second group samples due to different hardening periods [1].

Later, experiments were performed on effect of unevenly distributed cross-sectional stresses on second series samples strength, which completely eliminates first series disadvantage. Experiments to determine influence of own stresses on material strength were performed on cylindrical samples made of fragile (silicate) aluminum alloy with a diameter of 30 mm and a height of 60 mm. Samples of one group were made by ordinary technology: cast in steel molds and their cooling began with outer layers. Thus, after equalizing temperature with complete cooling in cross section of samples, outer layers were compressed and inner stretched.

Second batch samples were made in steel molds of same size as the previous ones. Steel tubes with a diameter of 6 mm were mounted on samples axis. The molds were located in cylindrical asbestos thermal insulators in the middle of which were electric heating coil mounted. Before a duralumin was filled, an electric heating coil had turned on and the steel mold had been heating to the duralumin melting point. During casting of duralumin and further sample cooling, water was supplied through the tube and, therefore, sample cooling had begun from middle layers. Thus, after complete sample cooling, its inner layers were compressed and outer stretched.

The experiments confirmed own stresses effect on the strength of duralumin: samples strength cooled from the central layers was on average larger than 20% of samples strength of ordinary (natural) cooling [12]. Considering that in large-sized samples own stresses (unevenly distributed over cross section) would have larger values than in smaller ones (and, as a consequence, the decrease in strength is more intense), it could be drawn conclusions about influence of own stresses on scale effect.

To confirm own stresses influence on the scale effect, experiments were performed on different sizes samples with opposite signs fields of own stresses. The experiments were performed on cylindrical samples with diameters of 30 and 50 mm and a height of 60 and 100 mm, respectively, made of fragile aluminum alloy.

After filling molds were cooled from middle, which provided own stresses field, which is opposite to stress field in samples of ordinary cooling. The experiments results confirmed logical justifications for own stresses influence on the scale effect: in samples with opposite natural distribution of own stresses over cross section, samples with a larger diameter showed larger strength [3].

Definition of unsolved aspects of the problem

Thus, the influence of unevenly distributed cross-sectional own stresses on scale effect in concrete has not been studied.

Problem statement

The goal of the research is to determine own stresses effect (unevenly distributed over cross section) on scale effect in concrete.

Basic material and results

The appearance and change of own stresses (unevenly distributed over cross section) in concrete are much more difficult than in metals.

The difficulty of unevenly distributed cross-sectional stresses caused by shrinkage on concrete strength studying effect is that intensity and shrinkage distribution in cross-section largely depends on concrete sample's storage conditions.

When storing samples in an air-dry environment, shrinkage begins and flows much more intensely on sample surface and gradually spreads to its inner layers. With greater reduction due to more intense concrete shrinkage in sample's outer layers the on its surface there are shrinkage tensile stresses, which in turn compress concrete in sample's inner layers (core) and create conditions for cracks on the sample surface.

In initial period of shrinkage when sample is loaded with compressive force, sample outer layers are not compressed until the external load reaches a value that can compensate for their own tensile stresses.

The sample internal part, compressed by its own stresses until an external force is applied, has higher total stresses when loaded with compressive force than outer layers, since self-stresses in inner layers consist of stresses from the action of the compressive external load with same sign. Therefore, strength of whole sample should determine its more intense inner part. However, inner part, although overloaded, is located in a clip made by underloaded outer layers.

As a result, in general, such sample should withstand more external compressive load than the sample without own stresses field. Well-known and confirmed by numerous experiments, there is the effect of increase in strength during concrete drying, associated with a more intense manifestation of above own stress distribution over sample cross section.

In the stressed state of concrete sample, in the above, there is a concrete creep in tension outer layers, which leads to their elongation and in inner layers of creep from compression, which reduces them. In parallel, the shrinkage gradually moves to sample's inner layers and eventually reaches the sample central part. During this period, shrinkage intensity in outer layers decreased compared to initial, and the concrete surface of sample increased in size due to creep from tensile stresses.

Sample inner layers (core), continuing to shrink from shrinkage in size, compress the outer layers, and themselves gradually move to a stretched state. Characteristically, this process is enhanced by the resulting reduction of sample's inner part due to creep during compression in shrinkage initial period.

During this period, when loading such a sample with compressive force, outer layers are overloaded, and total load in them consists of its own stresses and stresses caused by action of compressive external load. The outer layers have no clamps and, therefore, naturally, sample collapses at a lower load than sample without its own stresses.

Based on the changes in distribution of own stresses in the cross section over time due to the shrinkage and creep of concrete, it is possible to draw a conclusion about the possible decrease in concrete strength over time. This conclusion is confirmed by the experimental results by S.A. Mironov, shown on the Figure 1. A temporary decrease in strength of concrete is observed for concretes of both natural hardening and steaming [13].

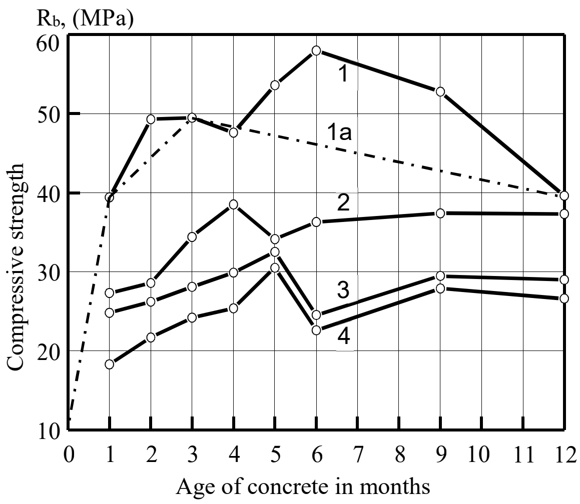

Figure 1 – Changes over time concrete strength in the experiments of S.A. Mironov

After some time, concrete shrinkage attenuates throughout cross section, after which relaxation of its own tensile stresses in the sample middle (core) and compressive stresses in its outer layers begins to appear. Thus, the difference between stresses values in outer and inner layers is reduced and, as a consequence, negative effect of unevenly distributed own stresses over cross section on compressive concrete strength is reduced. During this period there is increase in concrete strength.

Diagrams of the change in cubic compression strength of some samples concrete are shown in Figure 1. Repeated decrease in concrete strength can also be additionally caused by relaxation of structural own stresses [14]. Such a decrease may not be at all or it may be insignificant depending on tested samples concrete properties: gravel size, water-cement ratio, hardening conditions, storage conditions, etc.

Summarizing the analysis stresses shrinkage effect unevenly distributed over cross section on concrete compressive strength, it can be concluded that the intrinsic stresses first increase the strength of concrete, then there may be temporary decrease in strength, followed by increase in compressive strength. After the attenuation of its own stresses and the gradual attenuation of deformations caused by creep, there may be a gradual decrease in the concrete strength, over time. These conclusions are fully confirmed by the experiments of S.A. Mironov and others.

The diagrams could have a different form depending on the timing of determining concrete strength during experiments. When constructing diagrams on four points (and not on eight points, as in the experiments of S.A. Myronov) according to the results obtained in the experiments of V.I. Sytnyk and Yu.A. Ivanov [15] repeated increase in strength concrete is not observed in

Figure 1 (1a). Such conclusions are confirmed experimentally. In the experiments of V.I. Sytnyk and Yu.A. Ivanov, in all considered concretes, mortars and cement stone, the strength gradually decreases over time after reaching the maximum (Fig. 2).

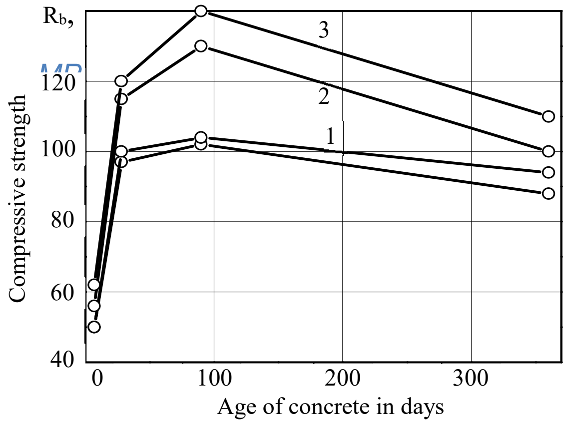

Figure 2 – Changing concrete strength (1), mortar (2) and cement stone (3) over time in the experiments V.I. Sytnyk and Yu.A. Ivanov [15]

In almost all experiments, when the concrete reaches maximum strength, a temporary slight decrease in strength is observed. In the future, strength increases slightly, then slowly and gradually decreases over time [13].

The opposite effect will occur at water saturation of concrete samples, because process begins with moisturizing outer layers. Swelling of concrete causes, respectively, appearance of compressive stresses in sample's outer layers and tensile stresses in inner layers. During this period, when compressing such a sample, outer layers that are not in holder will be overloaded and therefore sample will begin to collapse from outer layers. As a result, strength of the water-saturated concrete sample will be less than strength of same sample without its own stresses caused by swelling.

When storing samples in an air-dry environment, the gradual decrease in concrete compressive strength after reaching the maximum value; in smaller sizes samples begin earlier than in larger sizes samples due to the fact that shrinkage in samples of smaller sizes is more quickly aligned over the cross section.

The graph of the change in concrete strength over time in different sizes samples is shown in Figure 3.

Figure 3 clearly shows different variants of the strength ratio in the different sizes samples depending on concrete age in which the tests were performed.

The numbers that indicate curves in graphs correspond to edges size of the tested cubes in centimeters. The age numbering of concrete in which test sample were tested corresponds to the numbering given in Table 1 and Figure 3.

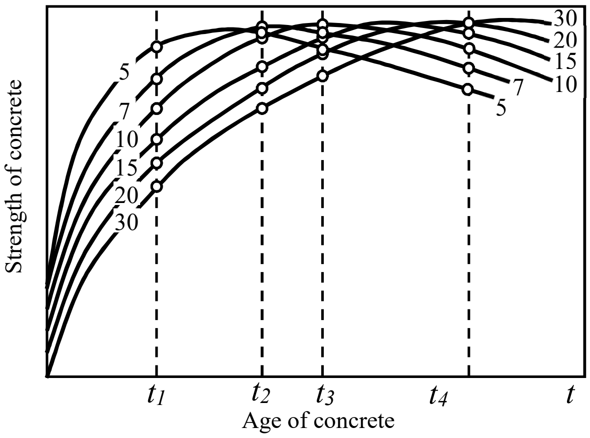

Figure 3 – Characteristic graphs of changes in concrete strength over time

Table 1 – Test results of different sizes cubes for strength in MPa

№	Authors of researchers	Edges of the cube size (cm)					
		5	7	10	15	20	30
1	Skramtaev B.	13	12	11,5	–	10,0	–
2	Kvirikadze O. (1 series)	24,6	25,2	24,4	23,3	22,8	–
3	Kvirikadze O. (2 series)	16,8	17,9	18,1	17,5	16,9	–
4	Lermit R.	–	–	19,8	21,2	21,2	19,3
5	Tsiskreli G.	–	–	–	32,0	32,5	30,0

The own stresses influence on scale effect under compression is confirmed by numerous experiments. Some results of experimental studies are shown in table 1 and for clarity are duplicated in Figure 4.

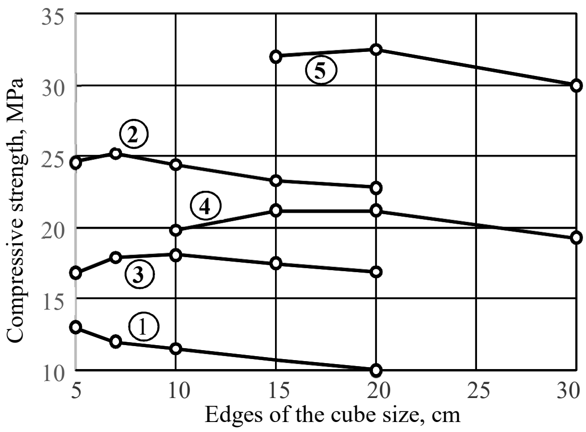

Figure 4 – Experimental data on the influence of scale effect on the concrete compressive strength

At the age of concrete t_1 (Fig. 3) a large-scale effect is maintained: with increasing sample size decreases concrete strength. When testing concrete at the age of t_2, t_3 and t_4 there are strength ratio different variants in samples of different sizes: in some cases, with increasing sample size concrete increases strength, in some there is no effect of sample size on concrete strength). In the age of concrete exceeding the term t_4, the opposite scale effect is observed – with increasing sample size, concrete compressive strength increases.

Some authors have obtained the results of experiments in which concrete strength in cubes with an edge of 5 cm or 7 cm is less than in larger sizes cubes. This phenomenon was most often explained by insufficient compaction of concrete in manufacture of samples or that small samples dry quickly and there is not enough moisture to hydrate cement. At the same time, there are the results of experiments in which strength in cubes with an edge of 10 cm and 15 cm (in the table, the experiments of R. Lermit and G.D. Tsiskreli) is less than in larger samples. These deviations can be explained by own stresses influence on concrete strength (scale effect).

It should also be noted that tabular results do not cover all the ratios of concrete strength in samples of different sizes. For example, in the experiments of I.S. Karol' and others [16] in four series (430 cubes with edge sizes of 20, 15, 10 and 7 cm) of different manufacturing conditions (storage) obtained the lowest strength in samples with edge size of 10 cm. Graphs of concrete strength over time, while maintaining the general shape, can also change the ratio depending on concrete preparation technology, storage conditions, and more.

The various factors influence on the experiments results of scale effect in concrete was analyzed in detail by O.P. Kvirikadze [6]. The analysis was conducted on our own experiments, as well as on different researchers' experiments results. The author gives recommendations on experiments performance on determinate of scale effect of concrete at compression. The influence of own structural stresses (caused by shrinkage or creep) on concrete strength largely coincides with influence of unevenly distributed cross-sectional stresses [14]. It is almost impossible to separate (determine) the influence degree of both stresses.

Conclusions

The influence of unevenly distributed over cross sectional compression stresses on scale effect in concrete is analyzed and substantiates and explains the variety of experimental studies results of concrete, mortars and other porous materials by different authors.

The influence of the scale effect in concrete tensile strength has not been studied enough. The experiments were most often made by bending or splitting. Samples were most often made in a horizontal position, which also negatively affects test results.

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