Acta Tecnología – International Scientific Journal about Technologies
Volume: 3 2017 Issue: 4 Pages: 1-5 ISSN 2453-675X

Received: 09 Nov. 2017
Accepted: 30 Nov. 2017

THE ISSUE OF THE COMPRESSIVE STRENGTH OF FINE-GRAINED REINFORCED CONCRETE

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Keywords: concrete, high-quality, charts, model
Abstract: To obtain high-quality concrete constructions it is not enough to execute it only in concrete of high class. One of the effective ways to improve the reliability and durability of concrete is its reinforcing by various kinds of fibers. The article presents the researching results of the influence of brands of portland cement and disperse reinforcing by polyethylene terephthalate fibers (PET-fiber) on concrete durability. Standard compression tests of the cubical prototypes of fine-grained sand concrete made of two brands of portland cement – PC400 and PC500 with different percentage of PET-fibers have been conducted. The optimum content of PET-fibe, wherein there is a maximum increase of durability of fine-grained fiber-reinforced concrete, has been set.

1 Theories of the concrete strength

There are three groups of theories of the concrete strength: phenomenological, statistical and structural [1].

Phenomenological theories describe the concrete as a homogeneous isotropic elastic body [2]. Special attention is given to the dependence of the strength on external loads. The laws, by which we can judge about the beginning of the material destruction under the complex stress, about the behavior of material under the simple tension, compression or bending, are set. However, the phenomenological strength theories cannot explain the internal processes in the concrete (deformations of contraction and swelling, ectothermy, etc.).

According to the statistical theories, the existence of continuous isotropic environment and separated air voids and microcracks in concrete is presumed. These theories determine the reasons of the huge differences between the actual strength and the results of theoretical calculations. It is usually determined by the defect structure, although without consideration of the structure. Nevertheless, statistical theories cannot explain the influence of many processing factors not leading to the formation of cracks but significantly changing the stressed state of the material on concrete strength.

The most promising for the technological problems of designing concrete structures is the usage of the structural strength theories based on certain models of the concrete structure [4]. A common feature of all the structural theories is the consideration of the concrete as a polystructural material in which, depending on the nature and mechanism of structure processes, the distinction is drawn between:

- microstructure (the structure of the cement matrix);
- mesostructure. (the structure of the solution in concrete, considered as a two-component system «aggregate – cement stone»);
- macrostructure (the structure of two-component systems «pore space – solution»).

The given division of concrete structure is explained by the fact that the mechanism of formation and properties of macro-, meso- and microstructure are fundamentally different. Each level of structure can be characterized by certain physical parameters defining its peculiar properties. So, the most important technological factors which influence the formation of the cement stone microstructure are the cement brand, its chemical and mineralogical composition, fineness of grinding, water-cement ratio and the conditions of hardening.

2 High-quality concrete producing

As a cementing material for high-quality concrete producing it is recommended to use Portland cement with the brand not lower than 400 and the qualitative characteristics meeting the requirements of GOST 31108-2003 [5]. The usage of cement below the recommended brand leads to its significant overrun. In turn, the increased cement stone content in concrete, which has such negative properties as creep, reduced crack resistance, high shrinkage deformations, causes a decrease in physical-mechanical and operational properties of concrete.

Polystructural character of concrete affects the work of the structures under load. The behavior of concrete is different at different levels of loading. At low load levels processes associated with the redistribution of effort due to technological factors and stress concentration from external influences prevail. These processes lead to the transition of technological microdefects in operating ones. The behavior of concrete at medium levels of loading is characterized by the interaction and development of defects and by combining of them. At loads close to the destructive, the main role is played by the redistribution of forces in the construction and transformation of microcracks into main macrocracks.

Therefore, the execution of the construction only made of high-class concrete will not ensure its fail-safe running as a whole. To improve the resistibility of the artificial stone to compressive, tensile and transverse (bending) stresses, it is recommended to use disperse reinforcing. Disperse reinforcing is a steady distribution of elastic, short (5-20 m) and thin (10-100 micrometer diameter) fibers that can be made of glass, metal, basalt or polymer throughout the volume. The concrete and reinforcing due to the high adhesion ensure the solidity of the construction and its performance as a single integrated material – reinforced concrete.

In the reinforced concrete production it is necessary to set the range of the volume content of fibers ‘μ’ within which brittle fracture is excluded [6]. However, in the range μmin – μmax another characteristic point is of great importance. It corresponds to the moment of fiber cement frame creation ‘μk’, before and after which the behavior of the composite and its properties differ significantly (Figure 1).

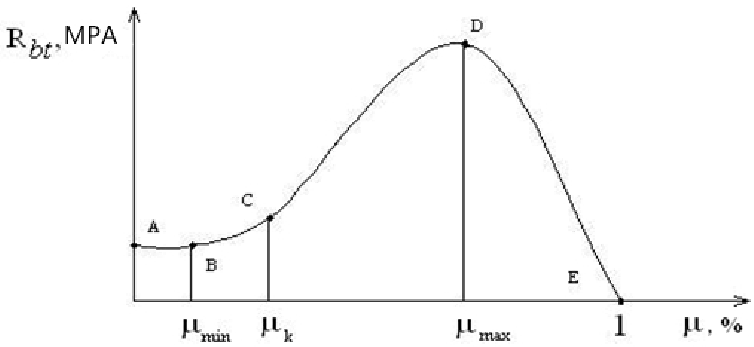

Figure 1 The character of strength changing of reinforced concrete depending on the volume concentration of fibers

The AB phase is characterized by small saturation when the fibers are removed from each other on a considerable distance («zone of diffused reinforcing»). The strength of reinforced concrete is characterized by the strength of the matrix and does not differ from it. The BC phase is «the area of concentrated reinforcing». When the matrix cracks, fibers are able to take the load and ensure the bearing strength of reinforced concrete. Point C is the moment of merging of the contact areas of fiber – matrix and creation of fiber-cement framework. Further and more intensive increase of strength of reinforced concrete takes place on the CD phase. It is the result of compaction of the cement stone between the fibers. Point D corresponds to a maximum strength of reinforced concrete. The DE phase is characterized by the strength reduction due to the thickness reduction of the matrix layer so the material shows a tendency to segregation even at low loads.

Experimental researches have been done to determine the optimal volume content of fibers ‘μ’ for fine-grained reinforced concrete. The composition of fine-grained sand concrete with a compressive strength of B5 was designed previously. It was used in the creation of 7 series of experimental cubic prototypes, made of reinforced concrete of two portland cement brands – PC400 and PC500, with various percentage content of polyethylene terephthalate fibers relative to the total fiber mass from 0 to 0,9 %. The ultimate saturation of reinforced concrete by similar types of fiber is 0,9 % [7]. When the concentration of fiber exeeds 0,9 % the widespread reduction in all strength parameters is observed. Secondary polyethylene terephthalate fibers (PET fiber) received by means of vertical blowing and produced by "PET" LTD Tchaikovsky was used for concrete reinforcing. The diameter of the fibers is 10-20 microns, length is up to 20 mm. The prototypes were tested on the axial compression to the limit state in accordance with GOST 10180-90.

According to the results of experiments the functional dependence of the strength of reinforced concrete under axial compression from percentage of reinforcing by PET fiber and brand of portland cement was built. The obtained diagrams are presented in figure 2.

Compared to the chart (Figure 1) the behavior of the material to the point ‘μk’ is multiple-valued. Obviously there is an influence of some technological factors that require additional researches. The zones of increasing of strength of reinforced concrete are practically the same, although their locations are slightly different: μmax ≈ 0,7 % (PC400); μmax ≈ 0,55 % (PC500).

3 Mathematical model and factors of concrete structure formation

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The plotting of a mathematical model of the standards for evaluation of different physico-mechanical and performance properties of reinforced concrete based on the influence of several factors allows to judge the progress of the process of structure formation more accurately. The more factors are considered, the more accurate the model is. The results of the experiments allowed us to build the model of evaluation standard of the strength of reinforced concrete. According to this model, the chart depending on the concentration of PET fibers is ploted (Figure 3):

$$P = P(x) \quad (1)$$

$$P_1 = 6307 + 93366 \cdot x - 417604 \cdot x^2 - 227204 \cdot x^3 + 3206947 \cdot x^4 - 4495654 \cdot x^5 + 1827215 \cdot x^6; \quad (2)$$

$$P_2 = 18067 + 305367 \cdot x - 4058509 \cdot x^2 + 18392384 \cdot x^3 - 37018022 \cdot x^4 + 34498333 \cdot x^5 - 12199867 \cdot x^6, \quad (3)$$

where:
P1, P2 – the values of the strength (failure loads) for PC400 and PC500 respectively (kg/cm2), x – the fiber content (%).

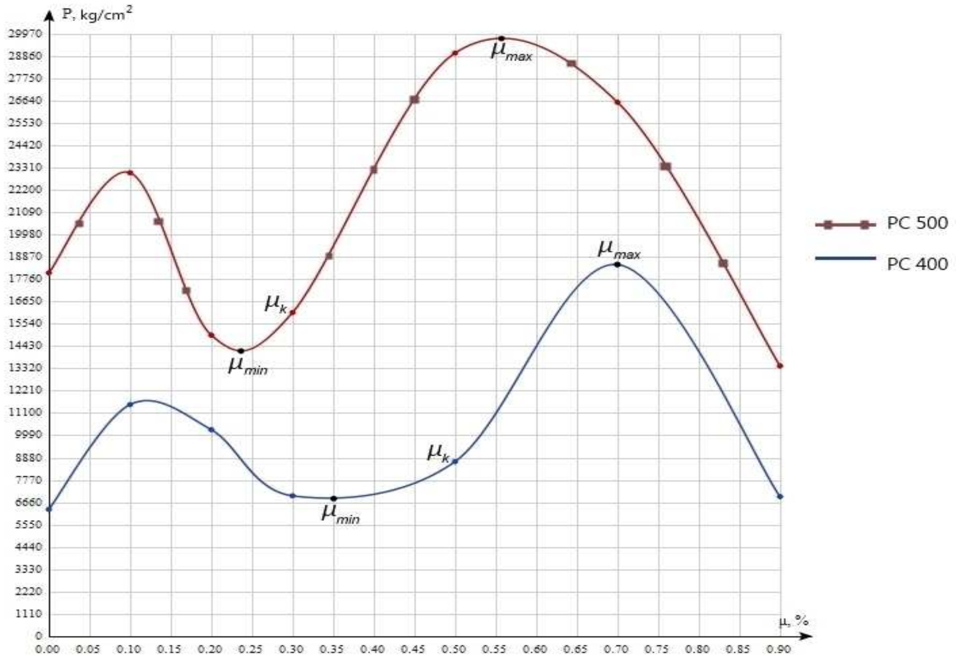

Figure 2 The dependence of the strength of reinforced concrete under axial compression from the reinforcing ratio of PET fiber and brand of portlandcement

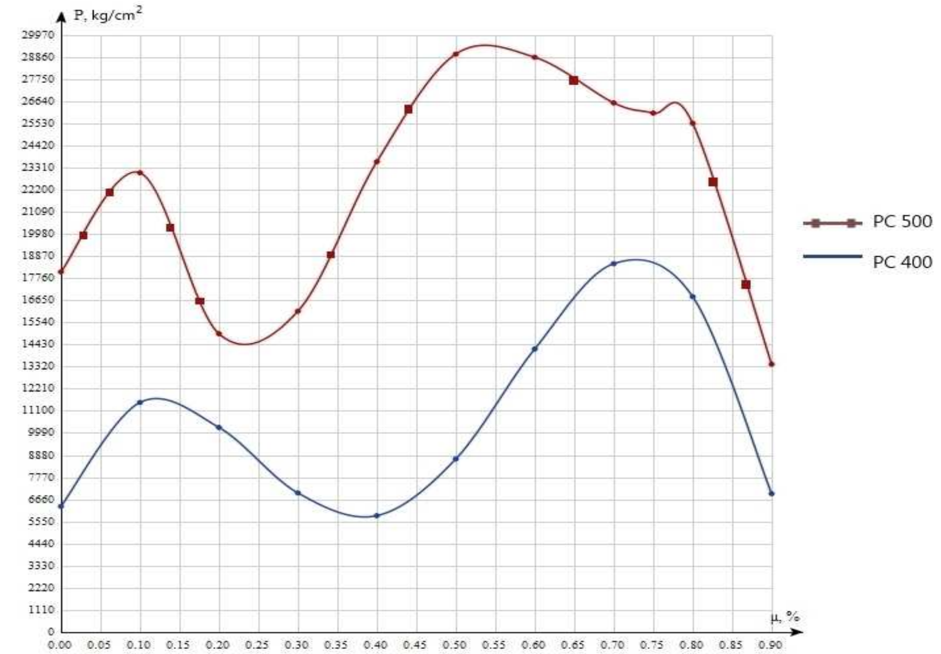

Figure 3 Chart prediction of bearing capacity of fine-grained reinforced concrete

To determine the effect of brand of portland cement on strength of fine-grained reinforced concrete the values of the strength chart were compared (Figure 4). Here a÷g is a difference in strength of reinforced concrete samples on the basis of PC400 and PC500.

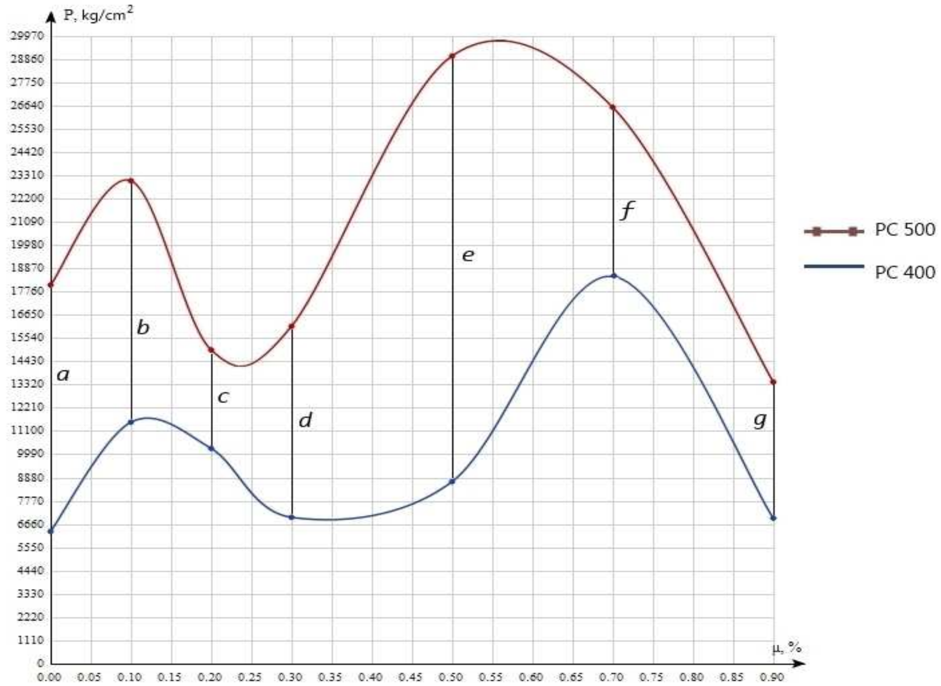

Figure 4 The interdependence of the strength of reinforced concrete based on different brands of portland cement

Having compared the values of the strength of reinforced concrete based on different brands of portland cement with different concentration of the same PET fiber, we built the function curve of the effect of type of cement and its graph (Figure 5):

$$Y_{изм} = a + b \cdot x + c \cdot x^2 + d \cdot x^3 + e \cdot x^4 + f \cdot x^5 + g \cdot x^6 \ ; \quad (4)$$

$$Y_{изм} = 11760 + 11524 \cdot x + 4701 \cdot x^2 + 9115 \cdot x^3 + 20311 \cdot x^4 + 8068 \cdot x^5 + 6498 \cdot x^6 . \quad (5)$$

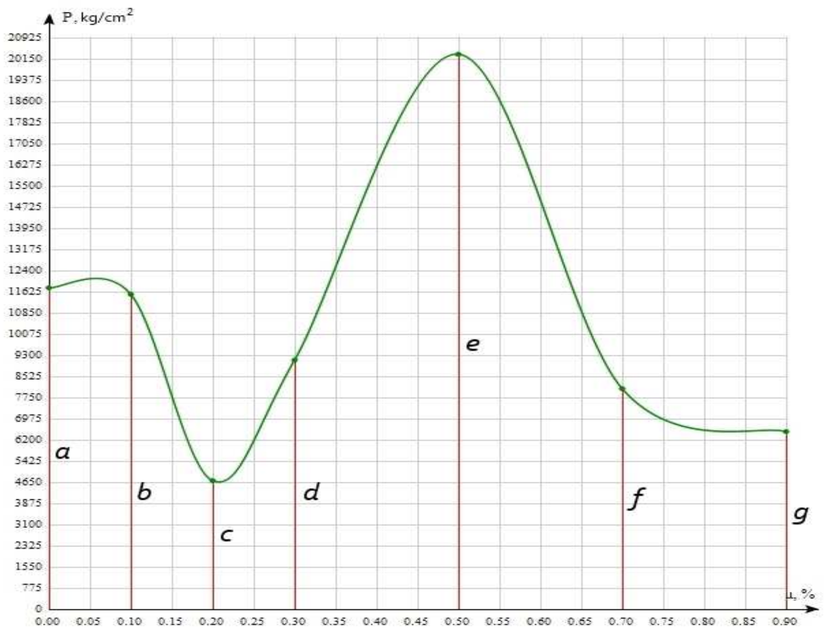

Figure 4 The graph of the function curve of the effect of cement type on the strength characteristics of reinforced concrete

4 Conclusion

Thus, the model of evaluation standard of the strength of reinforced concrete constructions is:

$$\left.\begin{aligned} P_1 &= 6307+93366\cdot x-417604\cdot x^2-227204\cdot x^3+3206947\cdot x^4-4495654\cdot x^5+1827215\cdot x^6 \\ P_2 &= 18067+305367\cdot x-4058509\cdot x^2+18392384\cdot x^3-37018022\cdot x^4+34498333\cdot x^5-12199867\cdot x^6 \\ Y_{изм} &= 11760+11524\cdot x+4701\cdot x^2+9115\cdot x^3+20311\cdot x^4+8068\cdot x^5+6498\cdot x^6 \end{aligned}\right\} \quad (6)$$

This model allows to carry out a design test and to make additional experiments on its basis to refine the mathematical model and exact laws of structure formation. Also, it can be argued that the reinforcing by polyethylene terephthalate fibers allows to reduce the probability of brittle fracture, to increase the ability to bear various loads and also to solve partly a relevant environmental problem of our time.

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Review process

Single-blind peer reviewed process by two reviewers.