The American Journal of Engineering and Technology
(ISSN – 2689-0984)
**Published:** November 29, 2020 | **Pages:** 67-74
**Doi:** https://doi.org/10.37547/tajet/Volume02Issue11-11

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2020: 5. 32
OCLC - 1121105677




# Study Of The Effect Of Heating On The Strength And Deformation Properties Of Concrete

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## ABSTRACT

This article presents the results of experimental studies of cubic, prismatic strength, elastic and plastic deformations, as well as deformations of thermal expansion of conventional heavy concrete and heat-resistant concrete on alumina cement when heated.

## KEYWORDS

Ordinary heavy concrete, heat-resistant concrete on alumina cement, strength, deformability, compression, tension, heating temperature, thermal deformation, modulus of elasticity.

## INTRODUCTION

To perform calculations of the strength, crack resistance and stiffness of reinforced concrete structures operating in a dry hot climate, high and high technological temperatures, as well as to determine the fire resistance limit, it is necessary to know the physical, mechanical and deformative properties of concrete when heated. For this purpose, special experimental studies were carried out.

Research methodology. The experiments were carried out on samples - cubes with an edge of 10 cm and prisms with dimensions of 10x10x40 cm, made in metal molds from ordinary heavy concrete and heat-resistant concrete on alumina cement. The composition of ordinary heavy concrete is adopted as follows: Portland cement M400 - 360 kg / m3, granite crushed stone of fraction 5-20 mm - 1100 kg / m3, quartz sand with Mcr = 2.25-760 kg / m3, water - 162 kg / m3; the consumption of materials per 1 m3 of heat-resistant concrete is the following: alumina cement M500 - 400 kg, chamotte crushed stone of fraction 5-20 mm - 720 kg, chamotte sand of fraction 0-5 mm from chamotte class B-720 kg,

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water - 280 kg. The concrete mixture was laid in layers and vibrated with deep vibrators. Samples - cubes and prisms after 7 days of storage in the conditions of the production workshop were decomposed and placed in a normal hardening chamber, where they were stored for 28 days. Subsequently, the samples were stored in a production workshop. The prototypes were tested at normal temperature and at temperatures of 70, 100, 150, 200, 300, 400, 500, 600, 700 and 800 ° C in accordance with the requirements of the standards. The samples were heated in electric muffle furnaces at a rate of 100-150 ° C / hour. After reaching the specified temperature, the sample was kept at this temperature for 4 hours, then loaded. Appropriate equipment, instruments and installations were used to control the temperature in the furnace, measure the deformation of concrete, and load [1-14].

Research results. At normal temperatures, the concretes had the following strength and deformation characteristics:

| Concrete | Curing conditions | Age (days) | R MPa | $R_b$ MPa | $R_{bt}$ MPa | $E_b \circ 10^3$ MPa | $\varepsilon_{bu}$ $1 \circ 10^{-5}$ | $\nu_b$ | w % |
|---|---|---|---|---|---|---|---|---|---|
| Normal heavy | Natural hardening | 28 | 42 | 36 | 4,1 | 37 | 215 | 0,84 | 3,6 |
| | | 240 | 48 | 39,5 | 4,35 | - | - | - | 3,0 |
| | Dried | - | 46 | 38 | 4,1 | 32,5 | 240 | 0,76 | - |
| Heat resistant on alumina cement | Natural hardening | 28 | 40,5 | 35 | 3,6 | 24,7 | 280 | 0,69 | 5,8 |
| | | 125 | 41 | 35 | 3,6 | - | - | - | 4,9 |
| | Dried | - | 30 | 26 | 2,4 | 20,6 | 320 | 0,62 | - |

The cube strength of ordinary heavy concrete of natural humidity after heating to 70 and 100°C decreases by 16 and 25%, respectively, and after heating to 150 and 200°C it increases by 5 and 14%, respectively. After heating to 300°C, the cube strength of ordinary concrete is reduced by 4%. With a further increase in temperature to 800°C, the cube strength decreases by 83%.

The cube strength of dried conventional heavy concrete at (heating to 200°C does not decrease) when heated to 200°(strength) increases by 5%, after heating to 300°, 400° and 500°C, decreases by 7, 18 and 36%, respectively (Pic. 1, a).

The prismatic strength of ordinary heavy concrete of natural humidity when heated to 300°C is less than the strength at normal temperature, while the greatest decrease is observed when heated to 100°C. When heated to 70, 100, 200 and 300°C, the prismatic strength of ordinary concrete decreases, respectively, to 15, 24, 10 and 18% (Pic. 1, a).

When heated to 70 and 100°C, the tensile strength of ordinary heavy concrete of natural moisture decreases by 15 and 20%,

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respectively. After heating to 200°C, the tensile strength of conventional heavy concrete was slightly higher than that at 100°C, although it did not reach its original tensile strength at normal temperature. When heated to 150 and 200°C, the tensile strength decreased by 13 and 10%, with a further increase in temperature to 800°C, the tensile strength of ordinary heavy concrete decreases by 92% (Pic. 2, a).

Short-term heating to 100°C causes a sharp decrease in the compressive strength of heat-resistant concrete on alumina cement of natural moisture. The cube strength of concrete after heating to 100°C is reduced by 53%. After heating to 200°C, the cube strength decreased by 37% and after heating to 300°C - 60%. The reason for such a sharp decrease in the strength of refractory concrete is the endothermic effects observed when hydrated alumina cement is heated at temperatures close to 100 and 300°C, associated with the loss of free and bound water by the cement stone and structural disturbance due to the difference in temperature deformations of the aggregate and cement stone.

In the temperature range of 400-700°C, the cube strength of refractory concrete on alumina cement of natural moisture content is 43-52%, and after heating to 800°C it was 36% of strength at normal temperature (see Pic. 1, a).

The cube strength of dried heat-resistant concrete on alumina cement when heated to 500°C decreases smoothly and to a lesser extent than that of concrete of natural moisture.

The prismatic strength of refractory concrete on alumina cement when heated has approximately the same character of change as the cubic strength. When heated to 100°C, the prismatic strength decreases by 56%, and at 300°C - by 49%. When heated to 700 and 800°C, it decreases by 56 and 59% (see Pic. 1, b). The Rbtem / Rt ratio for heat-resistant concrete on alumina cement when heated to temperatures of 100, 300, 450, 700 and 800°C was 0.85, 1.04, 0.79, 0.88 and 0.97, respectively, which indicates a decrease in the difference between prismatic and cubic concrete strength at high temperatures.

The tensile strength of heat-resistant concrete on alumina cement after heating to temperatures of 100 and 300°C decreases by 54 and 65%, respectively. In the temperature range 400 - 600°C, the tensile strength remains almost unchanged, it averages 42% of the reference strength at normal temperature. Heating to 700 and 800°C causes a decrease in the tensile strength of heat-resistant concrete on alumina cement by 66 and 68% (Pic. 2, a).

The modulus of elasticity of conventional heavy and heat-resistant concretes on alumina cement upon heating was obtained from the results of tests of prisms 10x10x40 cm for compression in a heated state at a stress level of 0.3 Rbtem (Pic.2,b).

When heated, the compressive and tensile deformations of conventional heavy and heat-resistant concretes on alumina cement increase. When heated to 300°C in ordinary heavy concrete, elastic deformations increase by 2.25 times, plastic - almost 8 times, and total - 3.2 times compared to deformations at normal temperature (Picure 3.4), while the ultimate deformations compression increases by an average of 3 times. The increase in plastic and total deformations of ordinary heavy concrete occurs to a greater extent than an increase in elastic deformations, as a result of which the coefficient of elasticity ν of concrete decreases from 0.84 to 0.66.

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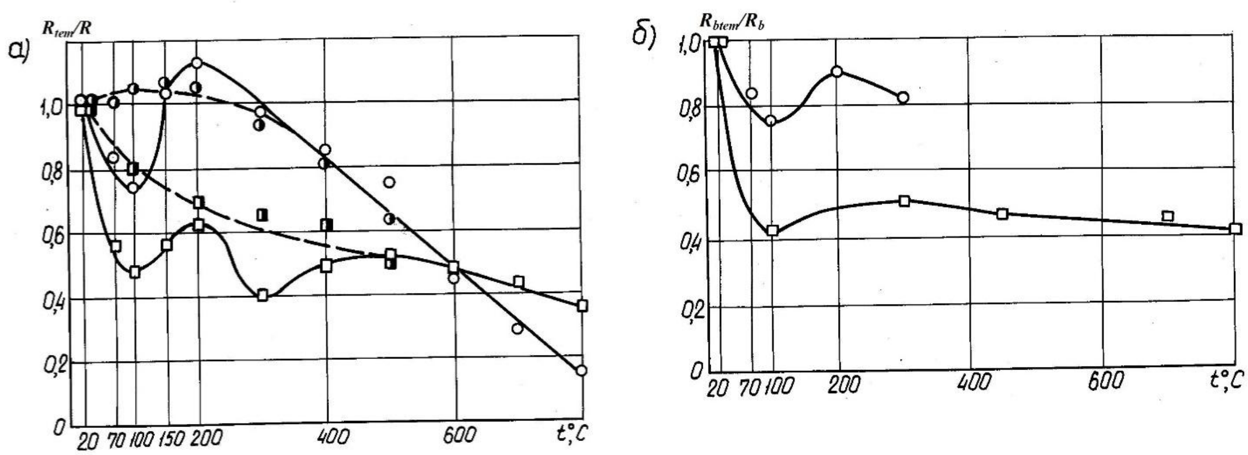
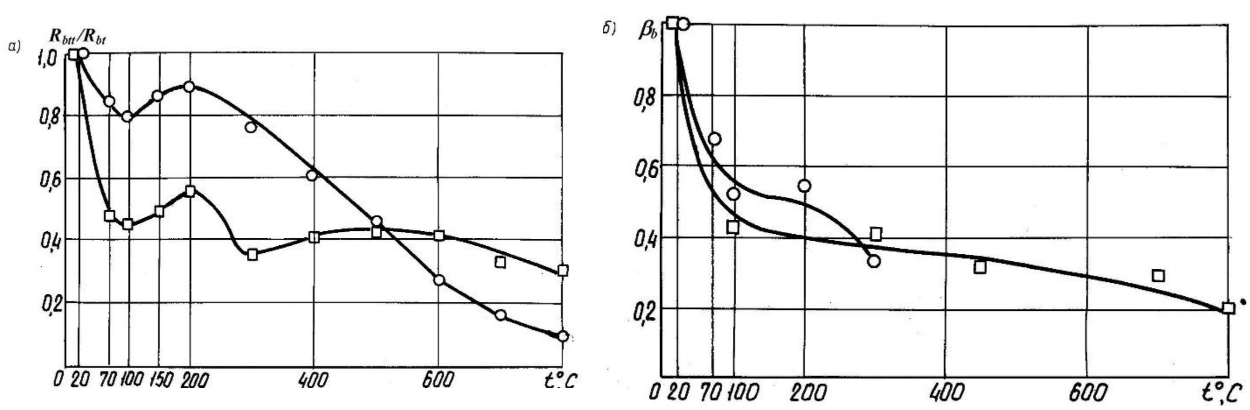
Increased deformability and a decrease in prismatic strength during heating leads to a sharp decrease in the modulus of elasticity of conventional heavy concrete. When heated to temperatures of 70, 100 and 300°C, the modulus of elasticity of concrete decreases by 33, 48 and 66%, respectively.



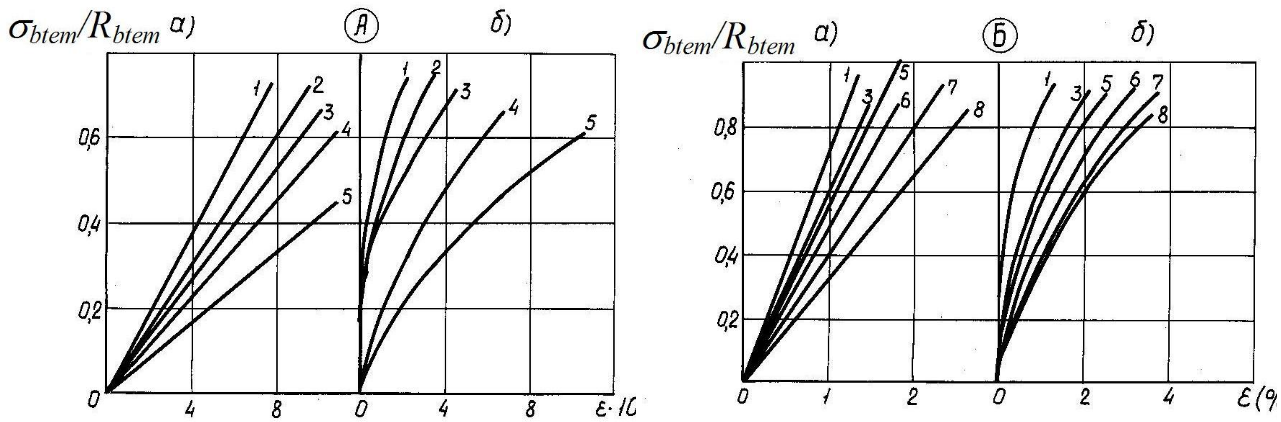

picture: 1. Relative compressive strength of concrete when heated: a - cubic;

б - prismatic; ○, ◑ ordinary heavy concrete, respectively natural hardening and dried at 110°C;

□, ◧ - heat-resistant concrete based on alumina cement, naturally hardened, and dried at 110°C.

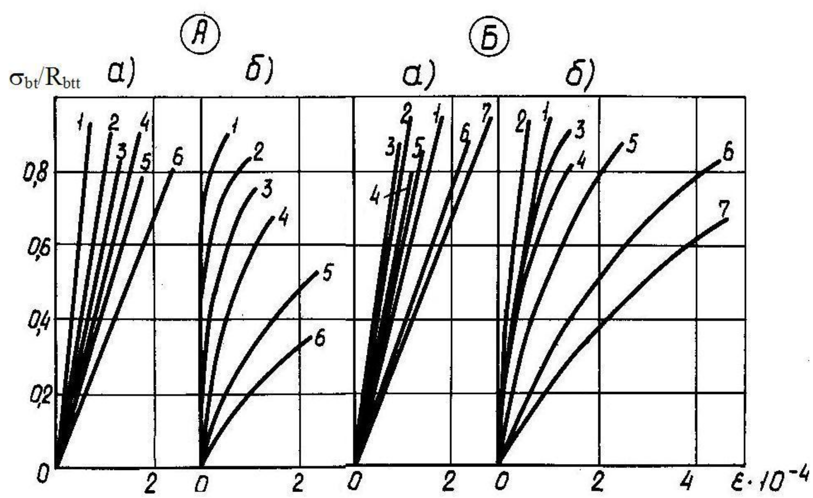



picture: 2. a is the relative tensile strength of concrete of natural moisture when heated; b - change in the relative modulus of elasticity of concrete of natural moisture when heated: ○ - ordinary heavy concrete, □ - heat-resistant concrete on alumina cement.




picture: 3. Deformations of ordinary heavy (A) and heat-resistant concrete on alumina cement (Б) during short-term heating: a-elastic; b-plastic; 1-20°C; 2-70°C;

3-100°C; 4-200°C; 5-300°C; 6-450°C; 7-700°C; 8-800°C.




picture: 4. Elastic (a) and plastic (б) tensile deformations of conventional heavy concrete on Portland cement (A) and heat-resistant concrete on alumina cement (Б)

for short-term heating: 1-20°C; 2-100°C; 3-200°C; 4-300°C; 5-500°C;

6-800°C; 7-1000°C.

Elastic deformations of heat-resistant concrete on alumina cement when heated to temperatures of 300, 700 and 800°C increase by 1.25, 1.67 and 2 times, respectively, plastic - by 1.8, 3.5 and 4 times, and full - by 1, 4, 2.25 and 3 times. Ultimate compressive deformations of concrete on alumina cement when heated to temperatures of 100, 700 and 800°C were, respectively, 1.5, 2.3 and 2.7 times greater than at normal temperature.

The coefficient of elasticity ν of heat-resistant concrete on alumina cement when heated to 800°C decreases from 0.69 to 0.50.

An increase in elastic deformations and a significant decrease in compressive strength

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leads to a sharp decrease in the elastic modulus of refractory concrete on alumina cement when heated. When heated to temperatures of 100, 700 and 800°C, the modulus of elasticity of concrete on alumina cement decreases by 57, 70 and 80%, respectively.

When ordinary heavy concrete of natural humidity is heated to 300°C, the temperature deformations of concrete change nonlinearly, the removal of water causes shrinkage deformations of concrete. The coefficient of thermal deformation of ordinary concrete on granite crushed stone at 20°C is 12x10-6 deg-1, at 300°C 8.75x10-6 deg-1.

The nature of the change in temperature deformations of heat-resistant concrete on alumina cement of natural hardening during the first heating in the temperature range of 20-820°C is also non-linear (pic.5). Thermal deformations increase with increasing temperature. When heated above 150°C, deformations of thermal shrinkage begin to appear noticeably, which are practically completed at temperatures of 600°C. Heating above 600°C leads to an intensive increase in temperature deformations of heat-resistant concrete, since shrinkage has already passed in it. At temperatures above 750°C, there is a manifestation of "fire shrinkage" of concrete on alumina cement. The greatest temperature deformations of heat-resistant concrete on alumina cement of natural hardening during the first heating to 820°C were 5.9°C.

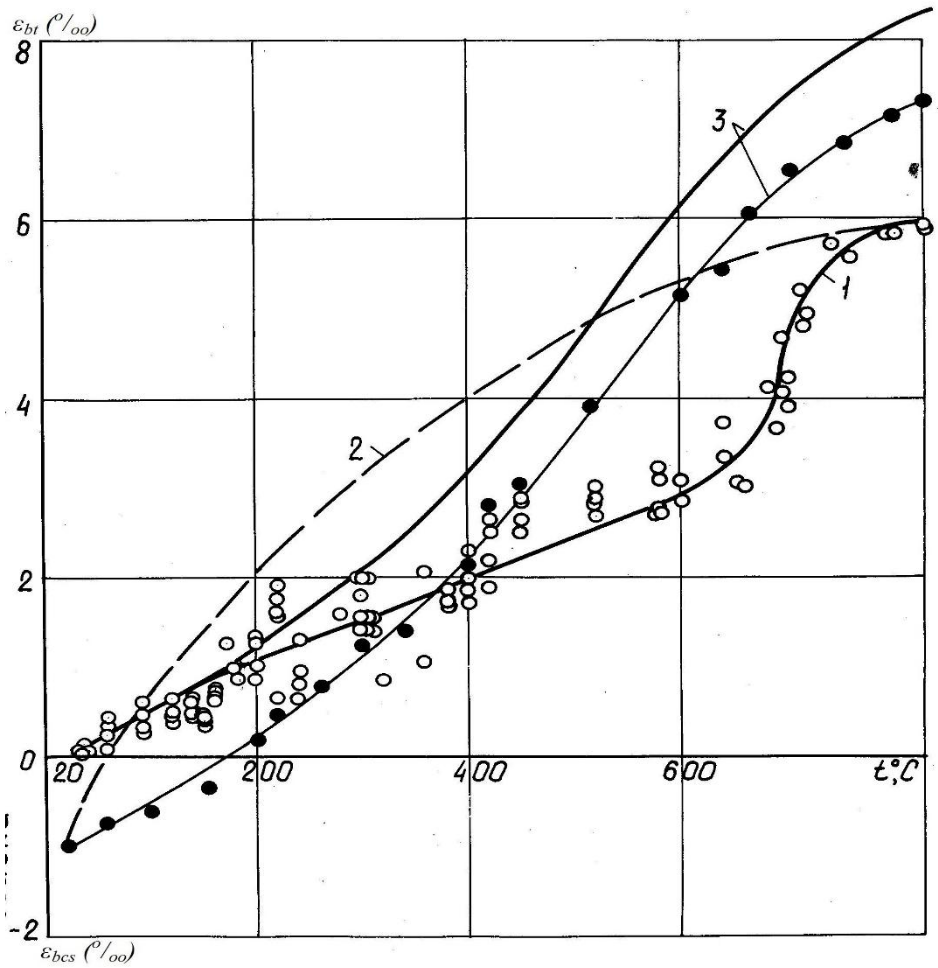
When cooled to 20°C after the first heating, the residual shrinkage deformations of heat-resistant concrete on alumina cement averaged 1°.

The coefficient of temperature deformations of heat-resistant concrete on alumina cement when heated to 100, 620 and 750°C averaged 8; 5.2; 7.6◦10-6 deg-1.

With repeated heating, the deformations of thermal expansion of dry heat-resistant concrete on alumina cement increase with increasing temperature (see pic.5) and they exceed the thermal deformations of the first heating.

## CONCLUSIONS

Studies have shown that the strength and elastic - plastic properties of conventional heavy concrete based on Portland cement and refractory concrete based on alumina cement during heating mainly depend on the heating temperature and must be taken into account when calculating structures.




picture: 5. Thermal deformations of heat-resistant concrete on alumina cement:

1-temperature deformation of natural hardened concrete during the first heating;

2-cooling deformation after the first heating; 3-deformation of thermal expansion during the second heating; o - the first heating of concrete of natural moisture;

● -second heating of dry concrete.

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