EXPERIMENTAL INVESTIGATION OF THE DEFORMED STATE OF THERMALLY LOADED SAMPLES OF REFRACTORY MATERIALS

G. A. Gogotsi, A. G. Gashchenko, and A. A. Kurashevskii

UDC 620.172/178.4/.6

Since refractory materials, and especially coarse grained ones, differ substantially from the model of a solid body assumed in the theory of elasticity, whose formulas are normally used in the treatment of experimental results, a study on this basis of the thermal and thermally stressed or deformed states of thermally loaded samples during tests for thermal stability used at the present time by the majority of investigators [1-4] is insufficient for a reliable estimation of the thermal stability of the investigated materials.

In connection with this, we carried out an experimental investigation of the deformed state of this type of materials both in the process of thermal loading of the samples and during the development of fracture cracks in them. We developed a method using wire strain gauges and an increase in the accuracy of measuring the temperature. Tests for thermal stability were carried out on the TS-4 apparatus with the modernized measuring and control circuit shown in Fig. 1. The electric supply was through two parallel thyristors type VKDU-150 in series with which was a silit heater of diameter 12-18 mm and length 320 mm. The maximum rate of heating of samples was up to 1200 deg/min (without including a regulator) and up to 800 deg/min (programmed rate of heating) with maximum temperature at the internal surface of the samples of up to 1200°C.

Automatic programmed control by the heater was carried out by the system PRT-1 [5], including a programmed device RU5-02 and an electronic potentiometer ÉPP-09 connected with a platinum–platinorhodium thermocouple attached to the internal surface of the sample. The temperature distribution was measured by six thermocouples (including the control) placed along the radius of the sample. The readings of the five thermocouples were recorded by double coordinate potentiometers PDS-021 m. Synchronization of recording of all temperatures was achieved by a rheostat device on the potentiometer ÉPP-09 of the system PRT-1.

At temperatures 20-400°C we used copper–constantan thermocouples of diameter 0.1 mm which were calibrated at two datum points. The beads of all the thermocouples were placed in holes of diameter 0.4 mm and depth of up to 1 mm pierced in the samples on an ultrasonic machine. In order to achieve thermal contact of the thermocouples with the sample material, tin was poured into the hole. At higher temperatures, platinum–platinorhodium thermocouples were used with thermoelectrodes of diameter 0.2 mm.

The cold junctions of all the thermocouples were thermostatically controlled in a Dewar vessel filled with melting ice.

The fairly high value for the thermal electromotive force of copper–constantan thermocouples (about 0.04 mV/deg) and also the measurement on a scale of 0-5 mV with a 250 mm instrument achieved a threshold of sensitivity of the measuring circuit of not less than 0.8°C, which is extremely important for determining the temperatures in the region of the positions of the thermally sensitive wire strain gauges. In spite of the lower accuracy of the potentiometers PDS-021, they were used because of their multirange capability, making it possible to use graduated thermocouples corresponding to measured temperatures, to

Institute of Strength Problems, Academy of Sciences of the Ukrainian SSR, Kiev. Translated from Problemy Prochnosti, No 4, pp. 112-115, April, 1972. Original article submitted May 6, 1971.

TABLE 1

Material	D, mm	d, mm	H/D	θ, deg/min	ε_θ center	ε_θ end	ε_z center	ε_z end
			0,9		0,08	0,20	0,03	—
Chamotte (KhPI)	75	25	0,66	400	0,09	0,21	—0,1	—
			0,4		0,14	0,24	—0,07	—
Magnesite	75	25	0,4	400	0,06	0,1	—0,04	—
Zirconium dioxide	50	25	3	1200	0,06	0,09	0,06	—
			0,5		0,08	—	0,03	—
Pressed corundum	100	50	1,5	1200	0,04	0,08	0,04	0,03
			1		0,045	0,12	0,03	—
			0,5		0,04	0,1	—0,06	—0,03
			0,4		0,04	0,06	—0,04	—
			0,3		0,05	0,08	—0,005	—
			0,2		0,07	—	0	—

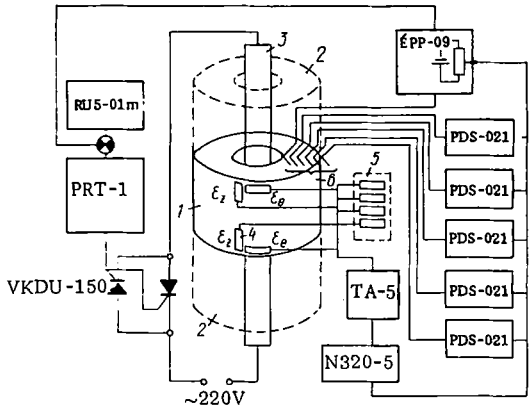

Fig. 1

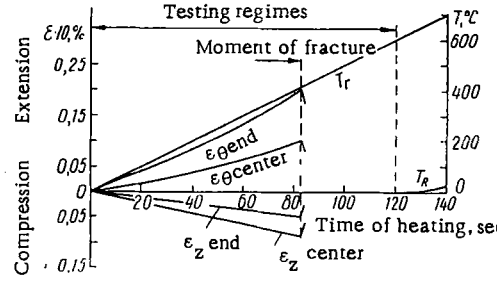

Fig. 2

Fig. 1. Measuring circuit for the experimental apparatus: 1) investigated sample; 2) lining samples; 3) silit heater; 4) working strain gauges; 5) compensation strain gauges.

Fig. 2. Change in temperature and deformation of sample: $\varepsilon_{\theta\,\text{center}}$ and $\varepsilon_{\theta\,\text{end}}$) surrounding surface deformation in the central plane of the sample and at 3 mm from the end; $\varepsilon_{z\,\text{center}}$ and $\varepsilon_{z\,\text{end}}$) relative axial surface deformation in the central plane of the sample and at 7 mm from the end; T_r and T_R) temperature of the internal and external walls of the sample.

regulate a "zero" instrument, and to have an expansion region which during the experiment could be used to change the limit of measuring and therefore to work at the maximum sensitivity of the instrument.

Deformation was measured with the help of wire strain gauges 2PKB-10-100GB, having a coefficient of strain sensitivity K-2.21 and a nominal resistance of about 100 Ω. The signal of the strain gauges was intensified by a 4-channel tensometric amplifier TA-5 working on the limit of measurement $0.25 \cdot 10^3$ relative units, to the outputs of which was connected a 5-channel rapidly-acting milliammeter N-320-5 through a suitable arrangement. On the fifth channel of this milliammeter, there was the synchronizing signal (proportional to the temperature of the internal surface of the sample) entering from the rheostat device.

Measurement of deformation was carried out in conditions when the surface of the sample had the same temperature as the room. Therefore the regime of thermal loading for the samples was selected in such a way that the fracture occurred before an increase in temperature on the external surface (Fig. 2). This testing regime differed considerably from that used earlier, which was a linear heating regime [2]. With such heating, there is no thermal exchange on the external surface of the sample which increases the reliability of the results because of the exclusion of the chance influence of cooling currents of air. In several cases, this regime may be close to the conditions of operation of certain components.

In selecting the base for the strain gauges we started from the condition of requiring a mean deformation of individual grains and binding agent of the investigated material [6, 7]. Since the grain size was about 1-1.5 mm, we took strain gauges with a base of 10 mm, i.e., 7-10 times greater than the size of the individual grains. The adhesion and thermal treatment of the strain gauges and also their calibration was

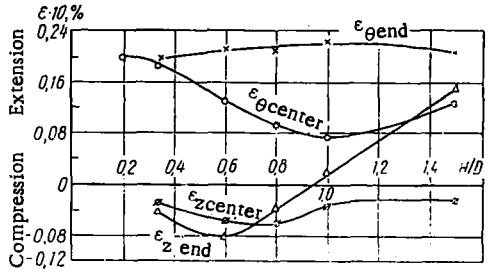

Fig. 3

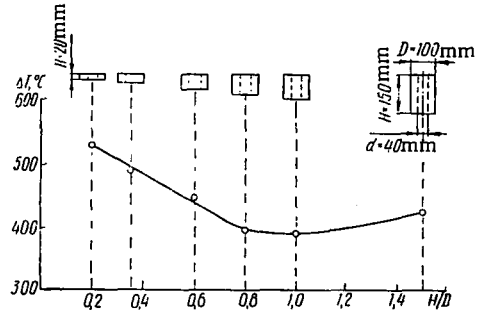

Fig. 4

Fig. 3. Surface deformation of samples at fracture.

Fig. 4. Change in fracture temperature drop in relation to the ratio of height to external diameter of sample.

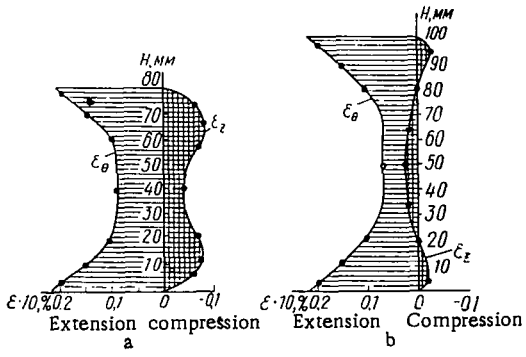

Fig. 5

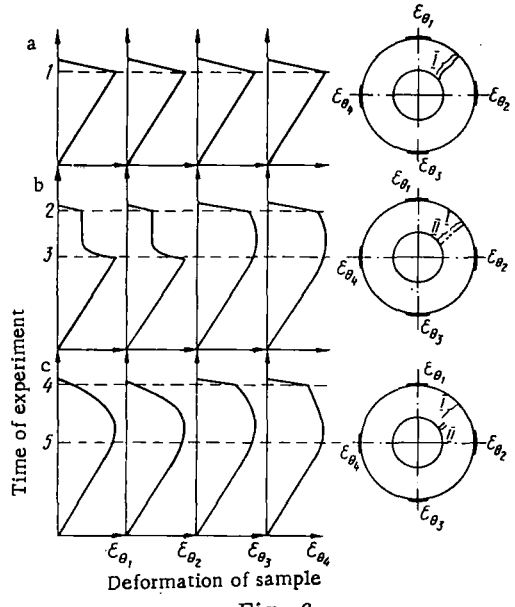

Fig. 6

Fig. 5. Diagram of the relative surface external ε_θ and axial ε_z deformations of samples having H = 80 mm, D = 100 mm; H_D = 0.8 (a) and H = 100 mm; D = 100 mm; H_D = 1 (b)

Fig. 6. Diagram of change in relative peripheral surface deformation during thermal loadings: 1, 2, 4) moment of formation of continuous crack; 3, 5) beginning of fracture [I, II) stages of fracture].

carried out by the usual method [6]. For the investigations we used chamotte and magnesite samples with an external diameter D = 75 mm and internal d = 25 mm prepared in KhPI [8]; corundum, samples of sintered aluminum oxide (D = 100 mm and d = 50 mm) containing 99.37% Al_2O_3 with a porosity 29.8% and specific gravity 2.66 g/cm^3 and samples of ZrO_2 (charge P-47) prepared on the experimental works UNIIO. In addition, from stopper tubes 2SP117, having D = 100 mm and d = 40 mm with length 300 mm, we cut cylindrical samples with a diamond wheel of height 20, 35, 60, 80, 100, and 150 mm. For investigations connected with a study of the character of the fracture of materials we also used samples of zirconium dioxide stabilized by yttrium and also from chamotte prepared in KhPI [8].

The results of deformation measurements at the moment of fracture of the samples of chamotte and corundum are given in Table 1 and the samples cut from the stopper tubes with a rate of heating of 300 deg/min in Fig. 3. From the figure it can be seen that for cylinders of low height ($H/D \leq 0.2$) and fairly "long" ($H/D = 1.5$), the obtained relationships correspond to deformation of samples under conditions of plane-stressed and plane-deformed states of a hollow cylinder. The obtained results for intermediate values of H/D should be examined carefully. In this range, the relative axial deformation ε_z with $H/D = 1.5$, equal to the relative external deformation ε_θ, not only decreases to zero but also changes to the reverse

sign. This may be explained by the fact that the ends of the samples are deformed, taking the shape of a funnel [9].

In the whole range of studied sizes of samples, their fracture occurred at one level of maximum deformation. The relation between the values ε_θ and ε_z at the moment of fracture was similar also for other materials (see Table 1). The ratio of the measured surface relative deformations of thick walled cylinders of the final length at the end and in the center with H/D = 1.5 was about 2/1 at the moment of fracture. As an example, the deformation on the surface of two samples of different heights prepared from chamotte is shown in Fig. 4.

According to Fig. 5, the change in the fracture temperature drop in relation to heights of the sample ($\Delta T = T_T - T_R$) corresponds to that observed earlier [8, 10]. For H/D = 0.2 and H/D = 1.5, the ratio of the values of the fracture temperature drops was about 4/3.

Visual observation after fracture enabled us to conclude that at heights equal to 0.8 D and higher, fracture begins at the end as was noted earlier [11]. A similar picture of fracture was recorded by strain gauges which were attached at varying heights. The first sharp decrease in deformation began at the end device and after some time (3-4 sec), as the cracks moved to the opposite end, the deformation recorded by all the intermediate strain gauges also decreased.

These investigations (in addition to those earlier [8]) indicate that during tests for thermal stability by thermal loading of cylindrical samples, in those cases when natural conditions are not modelled it is impossible to select arbitrarily the dimensions of the samples, since the type of stressed state caused by thermal loading depends on their dimensions. As follows from the presented data, the redistribution of deformation (and the stresses corresponding to this), connected with change in dimensions of samples, does not enable any kind of conclusions on the influence of the volume of the stressed material on its strength in conditions of thermal loading in the case when the change in parameter is described only as the height of the hollow cylindrical sample.

In order to determine the character of the fracture of the investigated materials on samples with N/D = 0.2, the peripheral deformations were measured by four strain gauges ε_{0_1}, ε_{0_2}, ε_{0_3}, ε_{0_4} (Fig. 6). A varying process of fracture of the investigated samples was shown. In the chamotte and corundum samples the crack proceeded along the body of the samples practically instantaneously (Fig. 6a), in samples of magnesite and chamotte with oriented microcracks the fracture was intermittent (Fig. 6b), and in samples of zirconium dioxide with a monoclinic phase introduced at the beginning of fracture there occurred microcracks on account of gradual exposure with subsequent intermittent movement of the cracks (Fig. 6c). These results indicate the necessity of fixing the initial moment of fracture of the sample because in several materials the period of complete fracture is protracted. There is observed a substantial redistribution of stresses and deformation of the sample in the peripheral direction compared with the redistribution taking place in the model of an axially symmetric deformed hollow cylinder.

LITERATURE CITED

1. E. Henny and M. G. Royston, Trans. Brit. Cer. Soc., No. 10 (1958).
2. G. A. Gogotsi, Avtoref. Kand. Diss. K., IPM Akad. Nauk UkrSSR (1966).
3. V. I. Dauknis, K. A. Kazakyavichus, et al., Electricity from MHD (1968), v. V. International Atomic Energy Agency, Vienna (1968).
4. A. G. Lanin et al., Thermal Strength of Materials and Construction Elements [in Russian], Naukova Dumka (1969).
5. G. A. Gogotsi and Yu. N. Lankin, Probl. Prochnosti, No. 1 (1969).
6. K. K. Perri and L. Lisner, Principles of Strain Gauges [in Russian], Moscow (1955).
7. I. Nemets, Practical Use of Strain Gauges [in Russian], Énergiya, Moscow (1970).
8. G. S. Pisarenko et al., Probl. Prochnosti, No. 3 (1969).
9. S. D. Ponomarev et al., Strength Calculations in Machine Construction [in Russian], GNTI, Mashinostroyeniya (1958).
10. B. Schwartz, J. Amer. Cer. Soc. No. 12 (1952).
11. G. A. Gogotsi, Poroshkovaya Metallurgiya, No. 12 (1967).