THERMAL CONDUCTIVITY OF POROUS SINTERED IRON

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During the machining of porous iron-base materials, as well as during their operation in friction pairs, their residual porosity gives rise to a number of phenomena which are difficult to explain unless the specific structural characteristics of this type of material are taken into account. It has been demonstrated [1], for instance, that the deformation properties of porous materials cannot be assessed on the basis of the usual assumption that the volume of a metallic specimen in compression remains unchanged. The volume of specimens from porous materials decreases during compression by an amount which is approximately equal to their controlled porosity. Similarly, microhardness measured under ordinary conditions cannot be utilized for evaluating the physicomechanical state of material in a stressed-strained form [2], because the behavior of a porous material in such a case is analogous to that of any elastic-plastic medium. The thermal conductivity of porous sintered iron-base materials also markedly affects the behavior of parts from such materials operating in contact with mating parts (in machining and applications involving friction). Thermal conductivity essentially determines the extent of heating of very thin surface layers of materials and, consequently, the intensity of wear of the tool or friction-pair components. Data on the thermal conductivity of porous iron are given in [3], but only for materials with a porosity of up to 17%. Materials with porosities which are most commonly required in practice (20-30%), however, have not as yet been investigated in this respect.

This report presents the results of an investigation into the thermal conductivity of iron specimens with porosities ranging from 24 to 48%.

Compacts for the investigation were prepared from PZh1M1 iron powder (to GOST 9849-61 standard), obtained by the reduction of mill scale with converted natural gas. Specimens 20 × 2 mm in size were pressed and sintered in a dried-hydrogen atmosphere at a temperature of 1150°C for 2 h. Their porosity was checked by hydrostatic weighing after sintering.

The thermal conductivity of porous iron was determined by the method of steady dynamic heating-up of material [4]* over the temperature range from 20 to 250°C. An apparatus utilizing this principle has been constructed and is shown diagrammatically in Fig. 1. The test specimen S was coated with heat-resistant silicone oil. The reference standard R was placed on top of it, after which it was heated together with a duralumin block by means of the heating element H (of 30-Ω resistance). The voltage supplied to the heating element was regulated with an SN-220 ferroresonance-type stabilizer. The rate of change of the specimen temperature and the change of the temperature at the specimen/heating element junction were recorded with an EPP-09 recording potentiometer. During testing, the temperature drop in the test specimen was 3–5°C. The reference standard was 22 mm in diameter and 15 mm high, and was made of fused quartz [5]. Relative error of measurement did not exceed 3–5%.

In a general case, heat transfer in porous materials is effected through thermal conduction in the metallic skeleton, as well as through convection and radiation in the gas present in the pores of the materials.

Convective heat transfer will be absent, according to [6], when Gr·Pr < 10^3, where Gr and Pr are the Grashof and Prandtl numbers, respectively. A calculation taking into account this condition demonstrated that, at a pore diameter of less than 5 mm and a temperature drop of 10°C, convective heat transfer may be ignored.

* The term "steady dynamic heating-up" was first used in [4].

Fig. 1. Diagrammatic arrangement of apparatus for thermal-conductivity measurement. Descriptions in text.

Fig. 2. Temperature dependence of thermal conductivity for porous iron: 1-4) after [3]; 5-8) results of present investigation. 1) St.0 (low-carbon) steel. Porosity: 2) 5%; 3) 11%; 4) 17%; 5) 24%; 6) 30%; 7) 39%; 8) 48%.

Eucken [7] has been able to demonstrate that, for a porous material from aluminum oxide (maximum pore diameter 1.46 mm) at up to 500°C, neither its porosity nor temperature significantly affects heat transfer in the material by radiation. The pore size of the iron investigated did not exceed 0.2 mm, and therefore it was reasonable to assume that the thermal conductivity of this material at temperatures up to 500°C was essentially due to heat transfer in the metallic skeleton, although heat transfer due to gas radiation could in this case play a certain part.

The experimentally-determined values of thermal conductivity as well as relevant literature data [3] are shown in Fig. 2, from which it can be seen that, as the porosity of porous iron is increased at any temperature, the thermal conductivity of the material decreases. This may be attributed to the fact that the surface area of contacts between adjacent particles decreases with increasing size of the air layers separating the particles.

The thermal conductivity of iron decreases with rise in temperature. This is characteristic of all pure metals, in the over-all thermal conduction of which thermal conduction due to "free" electrons plays a much greater part than phononic thermal conduction, which is caused by elastic vibrations of the lattice atoms. Nevertheless, it follows from the data of Fig. 2 that, for porous sintered iron, this reduction is less pronounced than for the bulk material, particularly at high porosities. This phenomenon is presumably due to the presence of gas in the pores of the sintered material. With rise in test temperature, heat transfer due to gas radiation is intensified, and the drop in the over-all thermal conductivity of the material is less marked.

As temperature is raised, porous materials become oxidized, the extent of this reaction being the greater the higher the initial porosity [8]. The thermal conductivity of oxides is invariably lower than that of the pure metal [9]. As can be seen from the curves presented, however, the presence of oxides does not affect the integral value of thermal conductivity, presumably because of the presence of air in the pores.

The relationship between the thermal conductivity and porosity of sintered iron, illustrated in Fig. 3, is of considerable interest. The same graph contains also a theoretical curve of thermal conductivity, calculated by the method proposed in [10]. The very close similarity of the two curves will be noted. The difference between these curves could undoubtedly be ascribed to discrepancy between the actual and stoichiometric compositions of the porous iron, as well as to possible nonuniformity of pore distribution within