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PHYSICAL INTERACTION OF POINT DEFECTS WITH CRACKS IN THE SOLID

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The problem of vacancy during healing of cracks in metal is considered as a part of the structural and diffusion mechanism of interaction between defects and cracks in the solid state. Dependence of the diffusion coefficient of defects on temperature is noted. It has been shown that the activation energy of the diffusion pores in metal significantly affects the rate of fractures healing.

Introduction. Defects in solids, particularly in metals, may be of various types and origins. The defect structure of solids is formed at the stage of producing material. In the manufacturing process of products and during the operation of finished products, the defect structure can be transformed. This may change the number of the defects and may cause their reformation with the formation of new types of violations. The most typical defects in the crystal structure are [1]:

– point defects (vacancies, interstitial atoms);
– linear defects or dislocations which can exist both separately and combined into the loop, that leads to distortion of the crystal lattice;
– surface defects (grain and twins boundaries, stacking faults);
– volume defects (voids and inclusions).

During the machining processing of the material such defects as cracks, voids, inclusions can be seen. The destruction process begins with the formation of cracks, their increasing and ends with the macroscopic destruction of the material into separate parts. In materials science of metals the surface state and the emergence of cracks in many ways determines resistance to deformation and destruction of materials. Under certain conditions cracks in metals can heal (decrease its volume), which leads to improved performance characteristics of the material.

In this paper, the possible outcome of cracks healing within the model of structure-diffusion mechanism is considered which was proposed by the authors [2].

The model of pores and cracks interactions. Cracks are sinks for point defects and micropores in the solid. The process of healing (overgrowing) is connected with the flow of the micropores (vacancies) from the crack (to the crack). It was established [2] that the vacancy concentration near the surface of small cracks (pores) higher than the vacancy concentration of large cracks, and therefore the flow of vacancies comes from small cracks to large cracks. There is the healing of small cracks. The flow of micropores on the surface of cracks of unit length is calculated by the formula [2]:

$$f = \frac{\gamma n_1}{R}\sqrt{\frac{D}{n_2}}\frac{K_1(z)}{K_0(z)}, \text{ where } \gamma = \frac{2\alpha\Omega}{kT}, \; z = R\sqrt{\frac{n_2}{D}},$$

R – radius of the crack;
D – the effective diffusion coefficient for this type of defect;
n_1, n_2 – constants;
α – specific surface energy;
Ω – typical volume of micropores (defect);
T – absolute temperature;
$K_i(z)$ – MacDonald's cylindrical functions of the i-th order.

Take into account that the temperature dependence of the diffusion coefficient of the defects can be described as well-known ratio:

$$D = D_0 e^{-\frac{E_a}{kT}},$$

where E_a – activation energy for diffusion of the defect;
D_0 – constant;
k – Boltzmann constant.

In this way the flow of micropores is a complex function of many parameters: temperature, diffusion coefficient, surface energy, crack radius.

Consider the diffusion of micropores in volume adjacent to the open crack of cylindrical shape. Then the change of volume of crack ΔV (length h in a time t) is defined by the formula:

$$\Delta V = 2\pi R h f t \Omega .$$

In assessing crack healing process it's necessary to determine the relative change of crack volume (relative rate of crack healing): $\varepsilon = \Delta V / V$.

Results, their discussion and perspectives. Figure 1 shows the dependence of the relative change in the volume of crack on the temperature for different values of activation energy of micropores diffusion. It is known [3, 4] that activation energy for the vacancies in metals is in the range 0,9–2,0 eV.

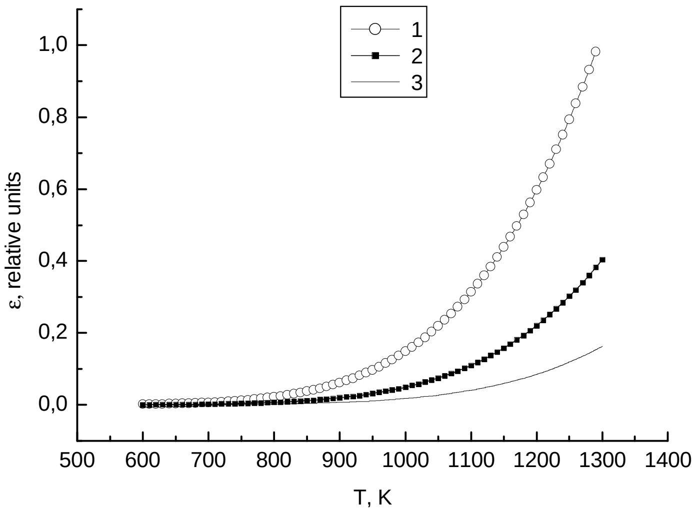

Fig. 1. The dependence of the relative change in the volume of crack on the temperature at different activation energies of pores, eV: 1 – 1, 2 – 1,13, 3 – 1,25. $D_0 = 5\cdot 10^{-6}$ m^2/s, t = 20 h.

As we can see from the fig. 1, changes of activation energy of pores in a small range of 1-1,25 eV significantly affect the healing option. Additionally, the rate of the healing process depends on the temperature. As the temperature rises the difference in the healing rate in the studied energy range sharply increases.

It is supposed that the flow of impurity atoms in the healing process has to be an order less than the vacancy mechanism since the migration energy for impurities E_a lies in a wide range from 1 to 5 eV. In this way, the main influence of pores on cracks healing is connected with the low value of the activation energy of the diffusion pores. The surface energy of metal has a value on the value of pore flow (fig. 2).

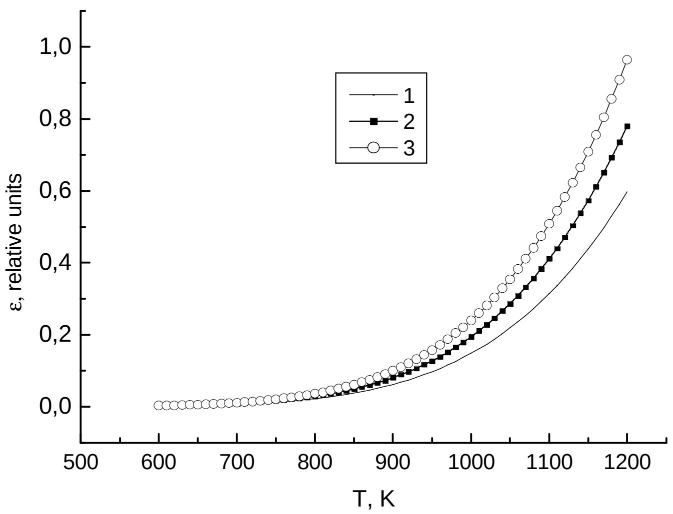

Fig. 2. The dependence of the relative change of crack volume on the temperature at different values of surface energy, J/m^2: 1 – 1,3; 2 – 1,7; 3 – 2,1. $D_0 = 5\cdot 10^{-6}$ m^2/s, t = 20 h.

Figure 3 shows the dependence of time of the total healing of cracks on the temperature. It can be seen, the shortest time of healing is typical for high temperatures 900–1000 K.

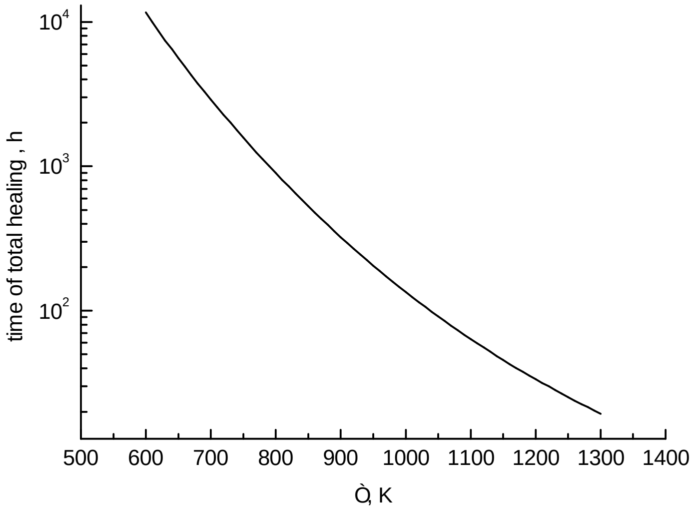

Fig. 3. The dependence of time of the total healing of cracks on the temperature.
E_a = 1 eV, $D_0 = 5\cdot 10^{-6}$ m^2/s.

Conclusion. Within the vacancy mechanism of the cracks healing it was demonstrated that diffusion parameters of micropores significantly affect the rate of the healing of cracks in metal. 25% reduction in the diffusion coefficient leads to a 10-fold decrease in the rate of healing. The time of complete healing at temperatures of 900-1000 K is 100-200 hours.

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