FRACTURES AND ENERGY OF FRACTURE OF TENSILE AND IMPACT TEST SAMPLES

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The energy of fracture in tensile tests and impact tests was investigated on samples of titanium alloy OT-4. Annealed and normalized alloys of this type are two-phase, with a fine lamellar second phase. After quenching, the alloy has a fine acicular martensitic structure. In both cases one observes large platelets of second phase and martensite needles, which leads to averaging of the mechanical properties within the limits of a single grain [1]. Also, due to the smaller ratio of the axes of the hexagonal close-packed lattice in titanium there is a large variety of crystallographic planes with different probabilities of slip [2].

Alloy OT-4 was annealed, normalized, and quenched from different temperatures. Samples for standard tensile tests and impact tests were turned from the heat treated pieces.

The tensile test samples were tested in a machine with recording of the elongation, from which the force of fracture \( P_{\text{fail}} \) was determined, the force at which necking began \( P_{\text{even}} \), and the deformation corresponding to these forces. Let us take the energy of fracture as the work of average force at a distance corresponding to elongation of the sample from the beginning of necking to failure:

\[
E = \frac{1}{2} (P_{\text{fail}} + P_{\text{even}})(\ell_{\text{fail}} - \ell_{\text{even}}).
\]

The impact strength was determined in an impact testing machine. The variation of the specific energy of fracture in tensile and impact tests with the heat treatment conditions was plotted from the test results (Fig. 1). On cooling from the intermediate region the plasticity of OT-4 increases due to redistribution of impurities, while with cooling from the homogeneous region it decreases due to formation of martensite.

![Fig. 1. Energy of fracture in tensile and impact tests of alloy OT-4 as a function of heat treatment. a) Water quenched; b) cooled in air. ○) Impact; ×) static tension.](image)

In both cases the variation of the energy of fracture with the type of structure is the same.

To determine whether there is a relationship between the similar energies of fracture in the two cases we compared the fractures of tensile and impact test samples [3]. Figure 2 shows light micrographs of carbon replicas from ductile and brittle fractures of both types of samples. It can be seen that the type of fracture does not depend on the type of test but on the heat treatment.

The results indicate that the energy of fracture in tensile and impact tests not only varies in the same way with the heat treatment but is also similar in absolute value. The similarity of the mechanism of fracture in both cases is indicated by the similarity of the fracture surfaces.

In determining the energy of fracture it is necessary to take into account three basic values — the energy of plastic deformation around the focus of fracture, the energy of elastic deformation of the sample as a whole, and the energy of formation of new surfaces. The first varies.

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mainly with the plasticity of the material, i.e., is proportional to the dislocation density and the length of the free path. Elastic energy accumulates in the sample, since there is overall elastic deformation of the sample, i.e., after failure of the sample, when there is no longer any elastic deformation of the entire sample, the elastic energy is spent on formation of the fracture surface. Elastically stressed sections may also be formed, remaining after failure, maintained in this condition by the surrounding plastically deformed material. However, if we use a fairly rough method of calculating the energy of fracture the elastic energy of these sections is not taken into account.

The energy of formation of new surfaces is proportional to the fracture surface [4], which varies with the degree of coincidence of the optimal crystallographic direction of cleavage and the direction of the most favorable crack development [5, 6]. In single crystals or textured samples with directions of optimal cleavage common to the entire sample the direction of the acting force is different in tensile and impact tests. Of course, the surface and the energy of fracture will differ. In a polycrystalline material, particularly with a lamellar phase or martensitic structure (alloy OT-4, for example), one finds a statistical averaging of the crystallographic directions with regard to the direction of the acting macroforces so that the size of the fracture surface no longer depends on the type of load. Thus, the energy of fracture for polycrystalline samples with fairly small grains will be similar when subjected to different types of load.

**CONCLUSIONS**

1. The change in the energy of fracture is similar in absolute value for samples of titanium alloy OT-4 subjected to tensile and impact bending tests and varies with the structural condition of the material.

2. The fracture surfaces of samples fractured by different methods are similar and vary with the heat treatment, and not with the type of test.