ELASTOPLASTIC PROPERTIES OF ALUMINUM ALLOY AMg6M WITH HIGH STRAIN RATES

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Currently a considerable amount of research on metals and their alloys is revealing an increase in mechanical properties with an increase in strain rate [1, 2]. However, there are materials exhibiting a zero or even negative sensitivity to strain rate. Among similar materials is magnesium-aluminum alloy AMg6 which is used extensively in different structures of new technology. Results of experiments carried out with these alloys in the strain rate range 10^{-4}-10^{1} sec^{-1} indicate a reduction in strength properties with an increase in rate [3]. There are a limited amount of data on the behavior of this alloy with strain of more than 10^{2} sec^{-1} [4-6].

Tests have been carried out using the Kol'skii method by the authors of [4] in testing alloy AMg6 with strain rates of 10^{3} sec^{-1}. Specimens of this alloy were tested in compression in the as-supplied condition and in tension in the annealed condition. As result of this the authors presented deformation diagrams and values for yield strength with different strain rates.

It appeared that deformation diagrams for alloy AMg6 in the annealed condition for strain rates of $2\cdot10^{-3}$ and $1.7\cdot10^{3}$ sec^{-1} coincide with each other, but deformation diagrams for a strain rate of $8\cdot10^{2}$ sec^{-1} are located below these curves. At the same time, tabulated values of yield strength with different strain rates presented in this work contradict these results. The value of yield strength with $\dot{\varepsilon} = 2\cdot10^{-3}$ sec^{-1} is 180 MPa, with $\dot{\varepsilon} = 8\cdot10^{2}$ sec^{-1} it is 190 MPa, but with $\dot{\varepsilon} = 1.7\cdot10^{3}$ sec^{-1} it is 205 MPa. This nonconformity of the test results may be a result of the fact that, during testing, the strain rate does not remain constant and varies sharply.

Examples of testing alloy AMg6M obtained by us in a device with a Hopkinson split rod and presented in Fig. 1 (b are curves for the change in strain rate for loading schedules 1 and 2, and a are deformation diagrams relating to them) indicate how the nature of change in strain rate affects the deformation curve. It can be seen that the path of the deformation diagram depends strongly on a change in strain rate during dynamic testing. In addition, with certain loading schedules in a Hopkinson split rod system, strain pulses may form, modeled by high-frequency oscillations, which during subsequent treatment by one method or another are smoothed out [7]. This may also mask the true behavior of a material with high-speed deformation.

Also presented in [5, 6] are test results for alloy AMg6 carried out using a modified impact machine method. In these works studies were carried out on the effect on mechanical properties of both strain rate [5] and the history of its change [6]. In [5] a reduction was obtained in strength properties up to a strain rate of $5\cdot10^{2}$ sec^{-1}. Results in [6] made it possible to establish the effect on alloy behavior of the history of change in strain rate. Previous static loading of specimens leads to the situation that their deformation diagrams at higher rates are located above static diagrams. Values of "upper" and "lower" yield strengths were given in [6] for alloy AMg6. Normally the development of these limits with high speed loading is connected with presence of a flow platform for the material during static tests. It is possible to suggest that development of "lower" and "upper" yield limits for alloy AMg6 with a monotonic static deformation diagram at strain rates of $5\cdot10^{2}$ sec^{-1} is connected either with high-frequency oscillations which accumulate on the force record, or with a sharp change in strain rate coming in the initial section of the deformation diagram with a changeover of the specimen material from the elastic condition to the plastic condition, where, as tests show, there is the strongest effect of a change in the strain rate on the path of the deformation diagram. Unfortunately, it is not possible to draw a more definite conclusion on the basis of the data presented since in the works listed, the nature of change in forces and strain rate with time is not indicated. Development of these oscillations

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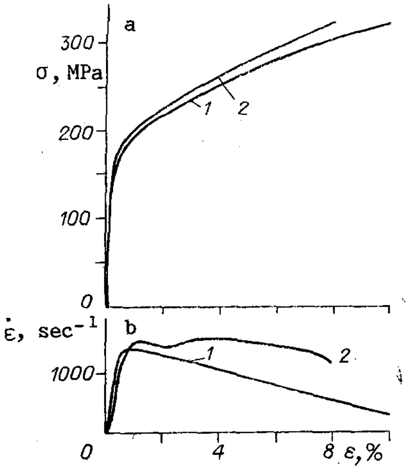

Fig. 1

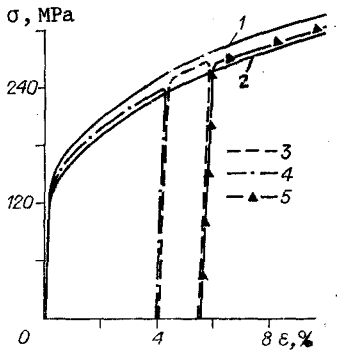

Fig. 2

with certain deformation regimes is connected with the loading system and it is characteristic of impact testing [8].

Thus, from an analysis of [4-6] it can be seen that the behavior of alloy AMg6 with high-speed deformation is complex in nature. Therefore, further studies are necessary for the behavior of this alloy with different loading histories for strain rates of 10^3 $\sec^{-1}$.

In the present work results are presented for testing alloy AMg6M at room temperature in two strain rate regions: quasistatic and dynamic. Testing of specimens with quasistatic loading regimes was carried out in a UMÉ-10T test machine, and dynamic testing was carried out by the Kol'skii method in a unit using the Hopkinson composite rod [9]. A detailed description of the unit is given in [10].

Specimens 9 mm in diameter and 4.5 mm high were prepared from a flattened ring and annealed at 593 K for 1 h followed by air cooling. Specimen dimensions were selected proceeding from conditions for minimizing the effect of inertial forces on the deformation diagrams obtained [11].

Tensile test results for alloy AMg6M for quasistatic loading regimes are given in Fig. 2. In the experiments, apart from testing with constant strain rates, there were tests in which the strain rate was varied directly during specimen deformation. In this case a specimen was first loaded at a rate of $1.4 \cdot 10^3$ $\sec^{-1}$ to a strain of 4.5%, after which it was unloaded and loaded anew at a rate of $1.4 \cdot 10^{-4}$ $\sec^{-1}$ to a strain of 6%. Then the specimen was unloaded and loaded at a rate of $3 \cdot 10^{-3}$ $\sec^{-1}$. Different strain rate regimes were governed by the movement rate of the active grip and they were prescribed by means of a reducer for the test machine EMÉ-10T. Lines 1 and 2 in Fig. 2 are deformation diagrams obtained with continuous loading regimes with rates of $1.4 \cdot 10^{-4}$ and $3 \cdot 10^{-3}$ $\sec^{-1}$, and lines 3-5 are deformation diagrams obtained with cyclic loading with rates of $1.4 \cdot 10^{-4}$, $1.4 \cdot 10^{-3}$, $3.0 \cdot 10^{-3}$ $\sec^{-1}$.

Thus, in the range of lower strain rates an increase in strain rate leads to a reduction in material strength properties, i.e., the deformation diagram with a greater strain rate is located below diagrams with a lower strain rate. A feature of cyclic loading is that sections of the deformation diagram with a changeover from one strain rate to another do not coincide with diagrams obtained with the same constant strain rate. Test results (see Fig. 2) point to the effect of the history of change in strain rate on the mechanical properties of alloy AMg6M, which agrees with the data in [6].

Two series of dynamic experiments were also carried out. In the first series the strain rate was maintained almost constant over the whole test. This was provided by loading measurement rods with uniform strikers 50-400 mm long accelerated in the barrel of a ballistic device [12]. In the second series tests were carried out with a jumpwise change in strain rate. In this case compression pulses of compact shape were excited by impact of special strikers composed of materials with different acoustic stiffnesses [13, 14]. Composite rod strikers were placed in relation to each other either without a gap or with a gap, and the gap between rods was fixed by flexible readily deformed clamps. Clamp length prescribed the time for delay between loading cycles, which was varied from test to test in relation to the aims of the test and the material reaction to cyclic dynamic loading. A typical oscillogram for strain

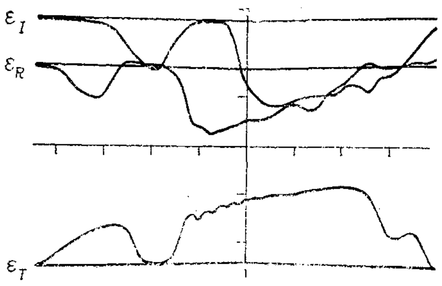

Fig. 3

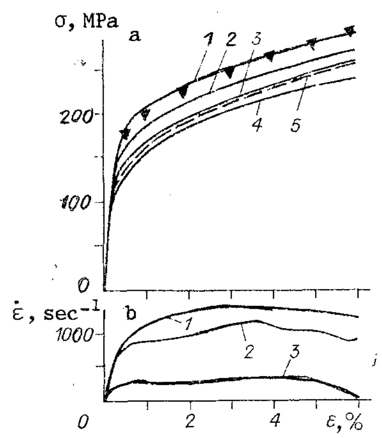

Fig. 4

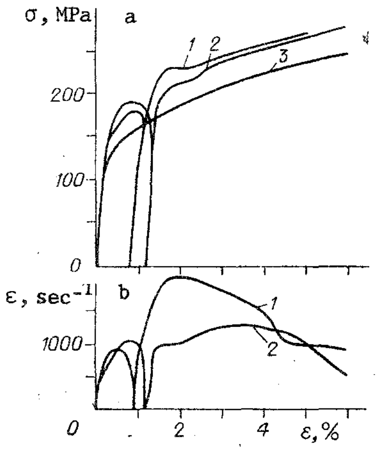

Fig. 5

pulses obtained with loading a composite Hopkinson rod by this striker is shown in Fig. 3. Dynamic testing of specimens was carried out both in tension and in compression. Treatment of data in accordance with the Kol'skii equations [9] and construction of deformation diagrams was carried out by means of a set of programs in an SM-4 computer. The error in determining stresses and strains did not exceed 5%, with a confidence level of 0.95.

Results of treating high-speed test data are presented in Fig. 4 where each of the diagrams is averaged for the results of three tests, and the scatter of results for repeated tests did not exceed 3%. Shown in Fig. 4a and b are deformation diagrams with tension for aluminum alloy AMg6M and the rule for the change in strain rate obtained in the first series of tests (curves 1-3, respectively). Shown here by triangles are data for dynamic compression found with strain rates of $1.5 \cdot 10^3$ sec^{-1}. Curve 4 in Fig. 4a (static deformation diagram in compression with $\dot{\varepsilon} \sim 10^{-4}$ sec^{-1}) was submitted by us as an original curve within the interbranch basic experiment "Dinamika" [15]. Deformation diagram 5 (broken line) was obtained by us for static tensile loading.

From the results provided, it follows that the deformation diagram with a strain rate of $2 \cdot 10^2$ sec^{-1} (curve 3) coincides within the test limits with static diagram 5. Dynamic deformation curves 1 and 2 for strain rates of 10^3 and $1.5 \cdot 10^3$ sec^{-1} are located above the static curve.

Experimental data found with a jumpwise change in strain rate during compression testing are shown in Fig. 5 (curve 3 corresponds to curve 4 in Fig. 4). In similar experiments with a sharp change in strain rate, variations in stresses, if these are observed, are a direct measure of the effect of strain rate on material mechanical properties. It can be seen from Fig. 5 that unloading specimen material after the first loading stage with a rate of 10^3 sec^{-1} is elastic with an elasticity modulus equal to the original Young's modulus. The next loading with a nominal rate of $2 \cdot 10^3$ sec^{-1} is elastic with the same modulus. A changeover of specimen material into a plastic condition in the second stage occurs with a higher stress than that achieved at the start of unloading.

Thus, the experiments carried out and the qualitative data from them point to the fact that with strain rates of more than 10^3 sec^{-1}, elastoplastic properties of alloy AMg6M increase with an increase in strain rate.

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