The influence of electric current pulses on jump-like deformation of industrial alloy AMg-6

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The paper studies the influence of pulses, electric current to jump-like deformation of industrial alloy AMg-6 at T = 300 K. Critical current density at which the suppression of the jump-like deformation occurs was defined. The effect of electric current density on the strength of characteristics of the industrial alloy AMg-6 was studied.

Keywords: jump-like deformation, tensile strength, plasticity resource, the electric current density, electric current pulses, the suppression of jump-like deformation.

У роботі вивчений вплив імпульсів електричного струму на стрибкоподібну деформацію промислового сплаву АМг-6 при T = 300 K. Визначено критичне значення густини струму, при якому відбувається придушення стрибкоподібної деформації. Вивчено вплив щільності електричного струму на характеристики міцності промислового сплаву АМг-6.

Ключові слова: стрибкоподібна деформація, межа міцності, ресурс пластичності, густина електричного струму, імпульси електричного струму, придушення стрибкоподібної деформації.

В работе изучено влияние импульсов электрического тока на скачкообразную деформацию промышленного сплава АМг-6 при T=300 K. Определено критическое значение плотности тока, при котором происходит подавление скачкообразной деформации. Изучено влияние плотности электрического тока на прочностные характеристики промышленного сплава АМг-6.

Ключевые слова: скачкообразная деформация, предел прочности, ресурс пластичности, плотность электрического тока, импульсы электрического тока, подавление скачкообразной деформации.

Introduction

Mechanical properties of metal are determined by its structure state (presence and behavior of lattice defects) and by deformation conditions (strain rate, temperature). However, its structure properties (at other different conditions) not the only key factor. Recent studies have shown that dislocations motion are affected by phonons and conductivity electrons. First studies showed that at low temperatures the electrons influence increases, because of "freezing" of the other mechanisms. Some facts about a possibility to speed-up the dislocations moving using an electron flow were found too.

On graphs, during a crystal deformation with a constant strain rate, we can see a leaps of deforming stress (single or multiple). It was called "jump-like deformation". During the plastic deformation of metal under electron, neutron radiation we can also see energy dissipation of moving dislocations on the conductivity electrons [1, 6].

Aluminum magnesium alloys are classic materials, which plastic deformation can show us different modes of plastic flow, Portevin-Le Chatelier effect for example [2, 6-10].

Theoretical models of appearing and evolution of plastic flow instability usually based on two approaches of avalanche-like overcome of potential barriers by dislocations and its accumulations, in the way of force (athermal affect) and thermic excitation of crystal lattice [9]. However, incompleteness of research of this phenomenon do not give us a possibility to choose any of these mechanisms, which controls moving of dislocations on microscopic level, as correct.

Researching results of impact of electronic irradiation on the process of plastic deformation of AMg-3 are listed in [3-5]. Obtained experimental results of researching the plastic deformation of AMg-3 alloy can be summarized in the next way: jump-like deformation is going parallel to general deformation hardening of crystal lattice; short (~ 1s) and long electron irradiation are suppressing the jump-like deformation; decreasing of deforming stress and increasing of plastic resource at the same time are

observed. Emergence of jump-like deformation with general deformation hardening let us to observe the plastic flow of AMg-3 alloy like consisting of two simultaneous processes. The first one is determined by generation, moving and interaction of defects, and the second one by specific behavior of dislocation system. Earlier was shown [2], that the starting mechanism of emergence of jump-like aluminum deforming stress decreasing, can be collective force (athermal) overcome of potential barrier by a big group of dislocations (due to the high level of internal stresses). Emergence of deforming stress leaps with a sharp increasing of plastic flow speed in local volume [2], which is in 105 times higher than uniform plastic deformation speed, explained by deallocation of dislocation accumulation from atoms of impurities and intermetallic ejections. Increasing of experiment temperature are making these relations weaker and, due to this, increasing the amount of dislocations, which are overcoming the barrier, what we can observe by increasing of leap amplitude. Due to high-energy electrons flow impact, suppression of jump-like deformation occurs and decreasing of deformation stress level due to changes in defect structure and behavior of single dislocations interactions and their accumulations with impurities.

Research of electric current impact on jump-like deformation and comparing it with experiments of electronic irradiation impact on this effect [3] is crucial for understanding the mechanism of jump-like deformation suppressing.

Experiment and research objects

Using of standard and original equipment allowed reaching following technical characteristics and parameters of experimental machines: creation stresses on the specimen up to $2 \cdot 10^3$ with ultimate sensitivity of registration 10^{-2} N; registration of elongation during active loading with relative elongation $5 \cdot 10^{-2}$ %.

The specimens were made of industrial alloy AMg-6. Stress, temperature and electric current pulses implemented the impacts on it.

The specimens were made by cutting a 10-20 mm length pieces from cylinder of industrial alloy AMg-6, which had 20 mm diameter. Then the piece was made thinner by rolling it in 2-3 stages and annealed it in 320 ˚C. This process was repeated until 0,9 mm thickness was reached. Then the specimens were cut using templates with thickenings for deformation machine holders. The sizes of specimens working part were 4x30x0,9 mm.

Electric current pulses generator up to 1 kA with 400 V voltage.

The scheme of machine, which generating single or multiple consecutive pulses up to 1 kA current, ~$10^{-5} – 10^{-4}$ s length and 60 – 450 V voltage are described. Discharger with a 400 – 1250 Hz frequency.

For making experiments of annealed lattice defects in pulsed regime, getting a big drifting speeds of electrons and other tasks we need to have a current like $10^3 – 10^4$ A/mm^2 density for a $10^{-4} – 10^{-6}$ s of time.

Electric scheme of it is shown on fig 1. It has the next nodes:

1 – control block; 2, 3 – thyristors; 4 – inductor; 5 – specimen; 6 – capacitor bank; 7 – voltmeter; 8 – resistance standard 1 mOhm; 9 – oscilloscope; 10 – load resistor; 11 – capacitor bank 20 mF; 12 – supply 220 V; 13 – transformer; 14 – diode bridge.
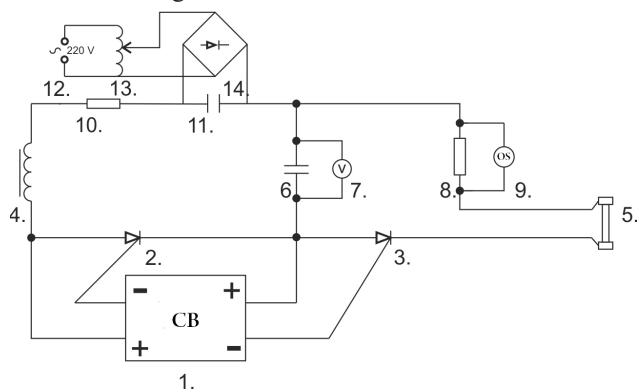

Fig. 1. Electric scheme of the pulse machine.

Relation of current and time shown on fig. 2 is regulating by changing the voltage on supply. Calibration of pulses by amplitude and duration is realizing by Rigol DS1052D oscilloscope. Signal on is going from resistance standard and allow us to make a measurement with a 5% error.
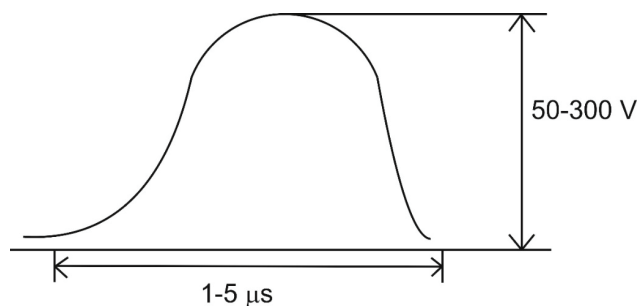

Fig. 2. Single pulse curve in time-voltage cords

Main scheme characteristics: $(0,1 – 10) \cdot 10^3$ A current; 60 – 450 V working current; $(1,4 – 18) \cdot 10^{-5}$ pulse duration; Bell-shaped pulse; Steepness of the front and slope are $4 \cdot 10^6$ and $2 \cdot 10^5$ kA/s respectively; smallest duty cycle in automatic turning on regime 1 s.

Results and discussion

Let's consider the affect of current pulses on jump-like deformation of AMg-6 specimen with 400 Hz frequency. Deformation curves of specimens are shown on figure 3.

From this graph, we can see that the pulses of current suppress the jump-like deformation in the AMg-6 specimen. We can see an increase of the specimen toughness as well
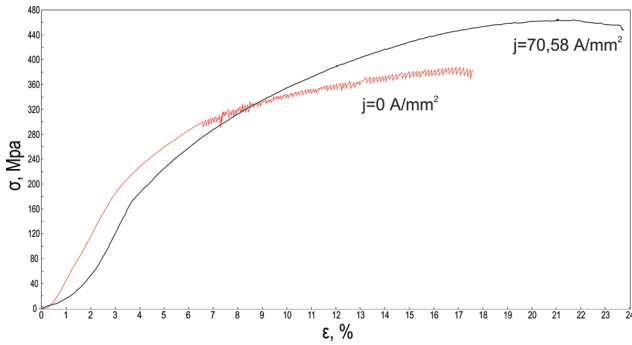
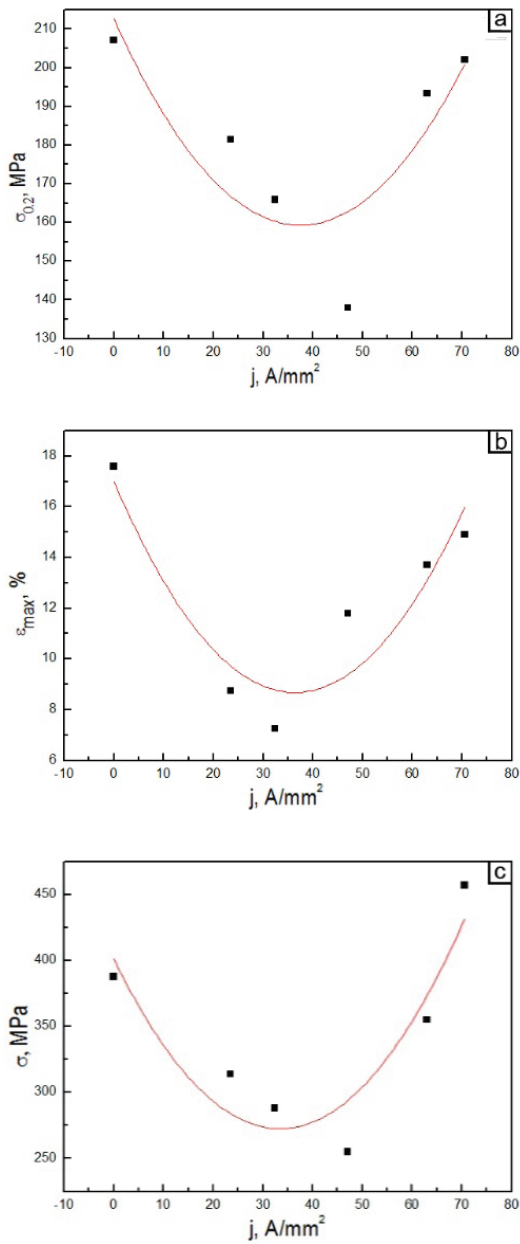*Fig. 3*. Deformation curves of AMg-6 alloy, which deformed without current (red) and with it (black).

as plastic resource.

The effect of current pulses with different density on toughness properties of material and suppressing of the jump-like deformation was observed.

The influence of the pulses density on toughness properties of material during deformation are on the figure 4.

From these graphs we can see a decreasing of toughness, plastic resource and yield stress of specimens after increasing the current density to 45-50 A/mm². If we continue the increasing, these values will rise.

The relations of relative elongation and stress, which starts the jump-like deformation are shown on the figure 5.
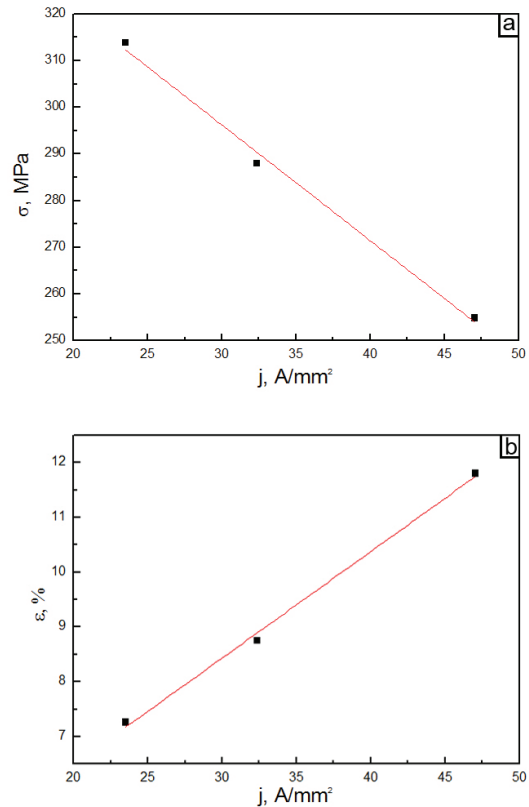

Fig. 5. Relation of starting point of jump-like deformation for different current densities and: a – applied stress, b – relative elongation.

As we can see, due to the increase of electric current density, the starting point of jump-like deformation moves to larger values of elongation, on top of that decrease of stress is observed.

Increasing of current more than j = 70 A/mm² supp0ress the jump-like deformation. This influence on dislocation movement cannot be explained only by thermal impact. Review of the temperature increasing showed that the temperature grows only for 6-15 K depending on electric current density. On the temperature growing like this, the area of starting the jump-like deformation are moves to larger values of elongation, but not completely

Fig. 4. Relation of toughness properties: a – yield stress, b – relative elongation, c – ultimate tensile stress, and electric current density.

suppress it, and thus the reduction of potential barriers during the dislocation movement are not primary. It may be, that during the current pulses passing through, the breathing model [5] appears, as well as during the specimens irradiation by high-energy electrons.

Conclusions

1. The influence of electric current pulses on jump-like deformation of the specimens made of industrial alloy AMg-6 at a 300 K temperature was studied.

2. It was found, that due to electric current density increase, the starting point of jump-like deformation are moves to larger values of elongation.

3. It was showed, that the electric current pulses absolutely suppress the jump-like deformation on the specimens at the values more than critical value ($j_{cr} = 45\text{-}50$ A/mm^2) of electrical current density, and also increases its plasticity and decreases ultimate tensile stress.

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