Multicycle electroimpulse fatigue of amorphous metallic alloys

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Multicycle electroimpulse fatigue of amorphous metallic alloys

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Abstract. The changing of the physical and mechanical properties of the Co-based alloys, appearing in consequence of multicycle electroimpulse fatigue, has been researched. It has been established that the Co-based specimens with different composition have practically the similar fatigue characteristics. It has been shown that the electroimpulse impact changes ambiguously the stress limit of alloys while increasing the pulse number. Herewith a linear increasing of Young's modulus, coming up to 10% from initial value at 10⁴ pulse number, exists. Influence of the electroimpulse impact on failure time of the AMAG-186 alloy has been measured during double increasing of the current density and triple increasing of the mechanical stress in the alloy.

1. Introduction

The electroplastic effect, observing in the various materials, is been the point of active investigations during few decades [1-3]. This effect is observed in the amorphous Co-based alloys too [4-7]. The amorphous Co-based alloys are perspective materials of the new generation and they are intensively used in the different areas of the industry. The devices with the amorphous metallic details work in the different electromagnetic fields, particularly, at the influence of the electroimpulse electrical current. In this context, the changing of the physical and mechanical properties of the amorphous Co-based metallic glasses is investigated after the multicycle electroimpulse fatigue.

2. Materials and methods

The ribbon Co-based amorphous specimens with the sizes 55×3.5×0.01 mm³ are the objects of investigations. The elemental composition of the specimens has been represented in the table 1.

Table 1. The elemental composition of the specimens.

| Alloy   | Co (%) | Fe (%) | Ni (%) | Si (%) | Mn (%) | B (%) | Cr (%) |
|---------|--------|--------|--------|--------|--------|-------|--------|
| AMAG -170 | 70.42  | 4.72   | 10.46  | 9      | 2.1    | 2     | 1.3    |
| AMAG -179 | 78.1   | 3.31   | 8.19   | 5.48   | 1.61   | 2     | 1.31   |
| AMAG -180 | 78.65  | 4.03   | 4.73   | 7.22   | 1.88   | 2     | 1.49   |
| AMAG -183 | 82.69  | 2.21   | –      | 7.77   | 4.19   | 2     | 1.14   |
| AMAG -186 | 85.41  | 2.27   | –      | 5.15   | 4.07   | 2     | 1.1    |

The methodic and the electrical schematic of the current pulsing through the specimens of the amorphous metallic alloys have been developed and realized (see figure 1).
Figure 1. The scheme of the experimental equipment: 1 – computer, 2 – electromechanical machine, 3 – specimen, 4 – electronic impulse counter, 5 – relay, 6 – surge current generator.

We carried out the experiments for an axial strain by the Instron-5565 electromechanical machine for the static experiments with the traverse speed 0.1 mm/min. A specimen had been loaded preliminary to 100 MPa. Then the loading process had been stopped and the electrical impulses, whose form was shown on the insertion of the figure 1, were passed with the discharge of the condenser. We used the surge current generator and the electronic impulse counter for control of a current duration and a frequency. The current density ($j$) was equal to $\sim 10^8$ A/m$^2$. The pulses had duration $\tau \sim 250$ ms, and they were applied with the frequency $\nu = 0.5$ Hz.

In the first experimental series, the fixed count of the impulses had been passed through the specimens, and then the current process was stopped. Afterwards, the specimen had been loaded to destruction and the stress limit of the investigated materials was determined. The passing of the impulses was accompanied by the drops of the mechanical stress with their following elimination. In the second experimental series, the specimens had been tested so long as destruction appeared under the influence electrical impulse current, and failure time with the correspond number of the impulses was registered. The temperature of the specimens was controlled with the laser pyrometer Testo-845 during the experiment.

Investigations of the relation between microhardness of an amorphous alloy AMAG-180 and the count of the electrical impulses with their magnitude have been carried. We carried out three experimental series in this part of the investigations. In the first experimental series, we passed the fixed number of the impulses from 1 to 12 with the time interval 5 ms. In the second experimental series, the count of the impulses was fixed from 5 to 30 with the time interval 25 ms and 10-60 impulses with interval 50 ms was fixed in the third series. Herewith the specimens were not destruct at these experiments. The impulse parameters are following: the current density $j=9.5 \cdot 10^8$ A/m$^2$ and duration $\tau = 5$ ms. We determined the microhardness of the investigated specimens by the automatic hardness machine DM8 with the Vickers pyramid at the indentation load 25 g.

We also investigated the influence of the current magnitude and the mechanical load on the variation of the failure time interval for the specimen AMAG-186. The method of this experimental part is analogous to the algorithm of the tests with destruction, caused by the electrical impulse current. Herewith the magnitude of the mechanical stress, loaded preliminary, was equal to 1000–1500 MPa and the $j$ was equal to $2 \cdot 10^8$ A/m$^2$. 

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3. Discussion of results
It has been experimentally established that the stress limit of the investigated alloys changes at the multiple impulse impact. The changing of the mechanical stress of the AMAG-186 alloy after the preliminary treatment by the multicycle impulse impact has been shown on the figure 2.

![Figure 2](image)

*Figure 2.* A relation between the stress limit $\sigma$ of the material and the count $N$ of the impulses, passing preliminary, for AMAG-186 alloy. Each curve point was marked after the plotting of a $\sigma$-$\epsilon$ diagram.

The analogous relations have been observed for all investigated alloys. It is visible that the stress limit increases by 25% before approximately 2000 preliminary passed impulses. Further increase of the count of the impulses leads to decrease of the stress limit, and it comes to the initial magnitude within the measurement accuracy at 1000 impulses. The temperature of the specimens increases not large during the passing singular impulse (in the mean value, on 5 degrees). The temperature of the specimens comes back to the initial magnitude during ~1 s after the impulse passing. As the passing of the impulse electrical current is accompanied by the drop of the mechanical stress, so the drop depends on the count of the impulses, passed preliminary (see figure 3).

![Figure 3](image)

*Figure 3.* A relation between a drop of the mechanical stress $\Delta \sigma$ and the count of the passing impulses for AMAG-186 alloy. The initial magnitude of the mechanical stress is 100 MPa.

This relation is linear, and it is observed up to destruction. The correlation coefficient between the experimental data and the linear function is equal to 0.99. The increase of the drop of mechanical stress is observed during the increase of the count of the passed impulses. It can be caused by the
topological ordering, related to the structural relaxation. The furnace heating leads to the less dropping of the magnitude of the mechanical stress. Young’s modulus of the investigated alloys increases at the increase of the count of the pulses (see figure 4) that can testify about the changing of the structure to the crystalline state.

![Figure 4](image1.png)

**Figure 4.** A relation between Young’s modulus and the count of the passed pulses for AMAG-186 alloy.

It is important to note that the specimens keep X-ray amorphous during the experiments. Consequently, it has been experimentally established that the electroimpulse impact changes the stress limit of the alloys during the increasing of the count of the impulses. Herewith, the linear increase of Young’s modulus, coming to 10% from initial, occurs at $10^4$ impulses.

It was established that Young’s modulus ($E$) had not changed and equal to 148±8 GPa with $j=2.1\cdot10^8\cdot1\cdot10^9$ A/m$^2$ during the investigations of the small count impulse impact on the mechanical characteristics. The stress limit value is in interval 2200±200 MPa at the given parameters of the impulse current. Consequently, the presence of the drop of the mechanical stress for the investigated alloys can be explained not only with the thermal expansion but the structural relaxation. These processes are reversible because the mechanical characteristics are not changes at the impact of the impulse electrical current with the magnitude less than or equal to $10^9$ A/m$^2$.

It has been experimentally established that the hardness changes narrow at the passing of 1-60 impulse electrical current (see figure 5).

![Figure 5](image2.png)

**Figure 5.** A relation between the microhardness and the count of impulses.
The decrease of the hardness is caused by the quenching stress relieving during the primary impulses. Further increase of the microhardness is caused by the stepwise accumulation of the atomic rebuilding, which is the predecessor of the glass transition. The relation between the count of the impulses, passed before the destruction of the specimen, and the mechanical stress is plotted at $j_1 = 10^8$ A/m$^2$ on the figure 6 (the line 1).

![Figure 6. A relation between the count of the cycles of uninterrupted work, and mechanical stress with the current density.](image)

The average value of failure free time decreases linearly at the increase of the mechanical stress. This result caused by the additional electroplastic tension of the ribbon specimens during the passing of the electrical current. The simultaneous impact of these factors leads to the accelerated generation of the shear bands and the cracks, providing the plastic deformation of the structure. The increase of the current density to $2\cdot10^8$ A/m$^2$ leads to the decrease of the failure-free time (the line 2 on the figure 6) that also can be related with the presence of the additional stress at the current impact. The X-Ray investigations argue for the preservation of the amorphous state in the structure at the preset conditions.

Therefore, the multiple impulse current impact leads to the change of the stress limit of the investigated materials. Herewith, the stress limit increases at the initial stage, and it decreases during the increase of the count number of the impulse. Young’s modulus increases linearly. The investigations have shown that the hardness changes narrow that is caused by eliminating of the quenching stresses. The increase of the current density and also preliminary mechanical load leads to the accelerated destruction of the specimens.

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**References**

[1] Spitsyn V I and Troitsky O A 1985 *Electroplastic deformation of metals* (Moskow: Science) p 160
[2] Liu Y Y, Liang Y F, Wen S B and Lin J P 2017 *Materials Science Forum* 898 1236
[3] Ruszkiewicz B J, Grimm T, Ragai I, Mears L and Roth J T 2017 *Journal of Manufacturing Science and Engineering* 139 110801
[4] Stolyarov V V 2016 *Inorganic Materials* 52 1541
[5] Fedorov V, Pluzhnikova T, Sidorov S and Yakovlev A 2014 *Materials Physics and Mechanics* 20 67
[6] Pluzhnikova T N, Fedorov V A, Sidorov S A and Yakovlev A V 2013 *Steel in Translation* 4 59
[7] Fedorov V A, Pluzhnikova T N and Sidorov S A 2013 *Steel in Translation* 12 60