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THE EFFECT OF IRRADIATION WITH AN INTENSE PULSED ELECTRON BEAM ON MECHANICAL PROPERTIES OF TECHNIALLY PURE ALUMINUM

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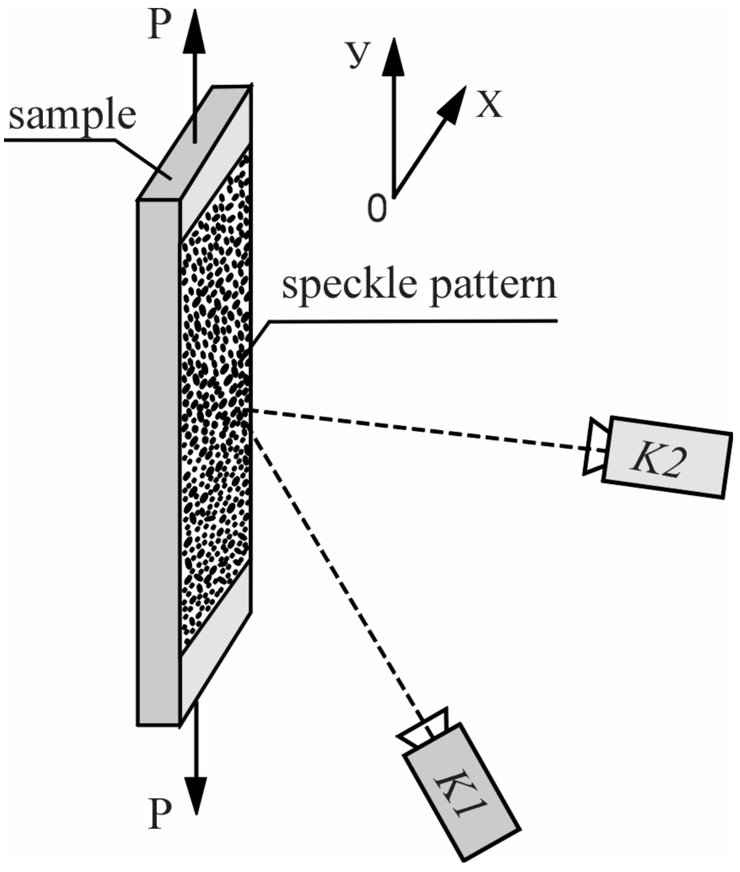
- The paper is devoted to studying the effect of irradiation in the melting mode of a thin (30, 40 μm) surface layer with a high-current intense pulsed electron beam on mechanical properties of technically pure aluminum A7. The deformation curves have been produced by tensile deformation of irradiated and unirradiated flat samples of aluminum A7. The analysis of the occurrence of stages of deformation curves has been carried out based on construction of deformation diagrams in the σ–ε coordinates.
- The presence of four stages on the deformation curve has been established: the transition stage T and stages III, IV, and V. It has been established that plastic deformation on samples of A7 aluminum irradiated with a high-current pulsed electron beam begins at higher stresses than on unirradiated samples.
- The occurrence of stages of the plastic flow on deformation curves for aluminum samples irradiated with a high-current electron beam has not changed fundamentally: the same number of stages are observed in the irradiated metal as on unirradiated metal with a somewhat broadened transition stage T.
- The evolutionary features of the distribution of deformation fields on the surface of the samples at a macroscopic scale have been established during uniaxial tension deformation based on the use of the Vic-3D digital optical system. It has been found that a transition from the transition stage T to stage III is observed when stresses are reached above the elastic limit, which is accompanied by merging of small deformation zones into larger ones in distribution patterns of longitudinal ε_{YY} relative deformations on the sample surface.

- **The purpose of the paper** is to study the effect of irradiation with an intense pulsed electron beam on mechanical properties and the evolution of distributions of deformation fields on the surface of technically pure aluminum A7 samples under tension.

MATERIAL AND METHODS

- Technically pure aluminum A7 was used as the research material (0 A7 (0,16 Fe, 0.15 Si, 0.01 Cu, 0.04 Zn, 0.01 Ti the rest was Al, wt.%). For mechanical testing, samples from technically pure aluminum A7 were prepared in the shape of thin plates in the form of double-sided blades with the dimensions of the working part 17×9.6×3.8 mm.
- Speckle patterns on the surface of the samples were produced .
- Displacement fields were recorded in the near-surface layers of the samples during deformation using the VIC-3D optical measuring system . The displacement fields, as a result of calculations, are projections of displacements of local surface areas along three axes: OX and OZ are transverse directions of the deformation ε_{xx} and ε_{zz}, respectively; OY is the longitudinal direction of the deformation ε_{yy}.

- The deformation curve was produced based on registration of deformations on the basis of an extensometer installed within the working part of the test sample from the center of the sample to the bottom clamp of the testing machine. A synchronous recording of images from two cameras was performed during the test using the VicSnap software. Stereo images were processed using the digital image correlation method.



- Deformation of the samples was carried out on using the INSTRON 3386 testing machine with a constant speed of 0.3 mm/min.

- Some samples were irradiated from both sides with a pulsed electron beam at the SOLO plant (ISE SB RAS) with the following parameters: electron energy was 18 keV, electron beam pulse duration was 150 μs, number of pulses was 3, pulse repetition rate was 0.3 s^{-1}, energy density of the electron beam was 15 and 25 J/cm^2. The surface irradiation with an intense pulsed electron beam have led to modification of the surface layer of the aluminum sample in the melting mode of a thin surface layer with a thickness of 30–50 μm.

RESULTS AND DISCUSSION

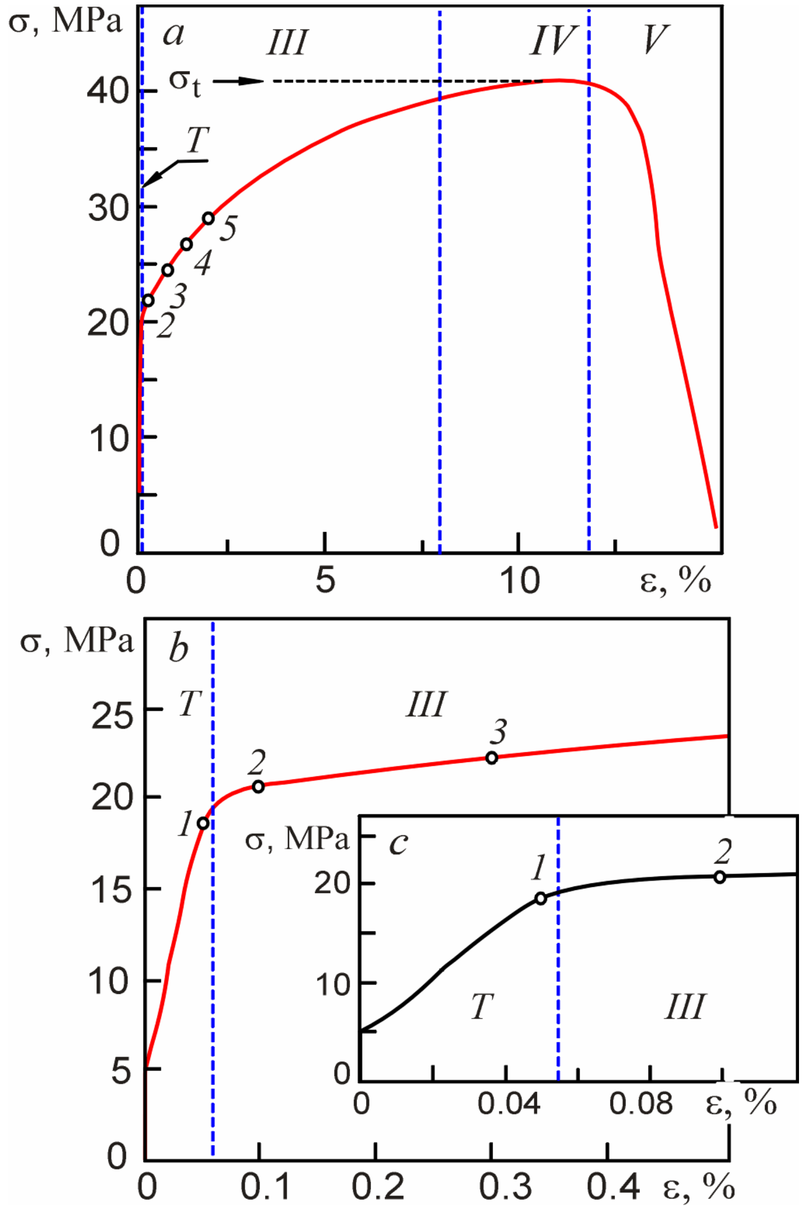
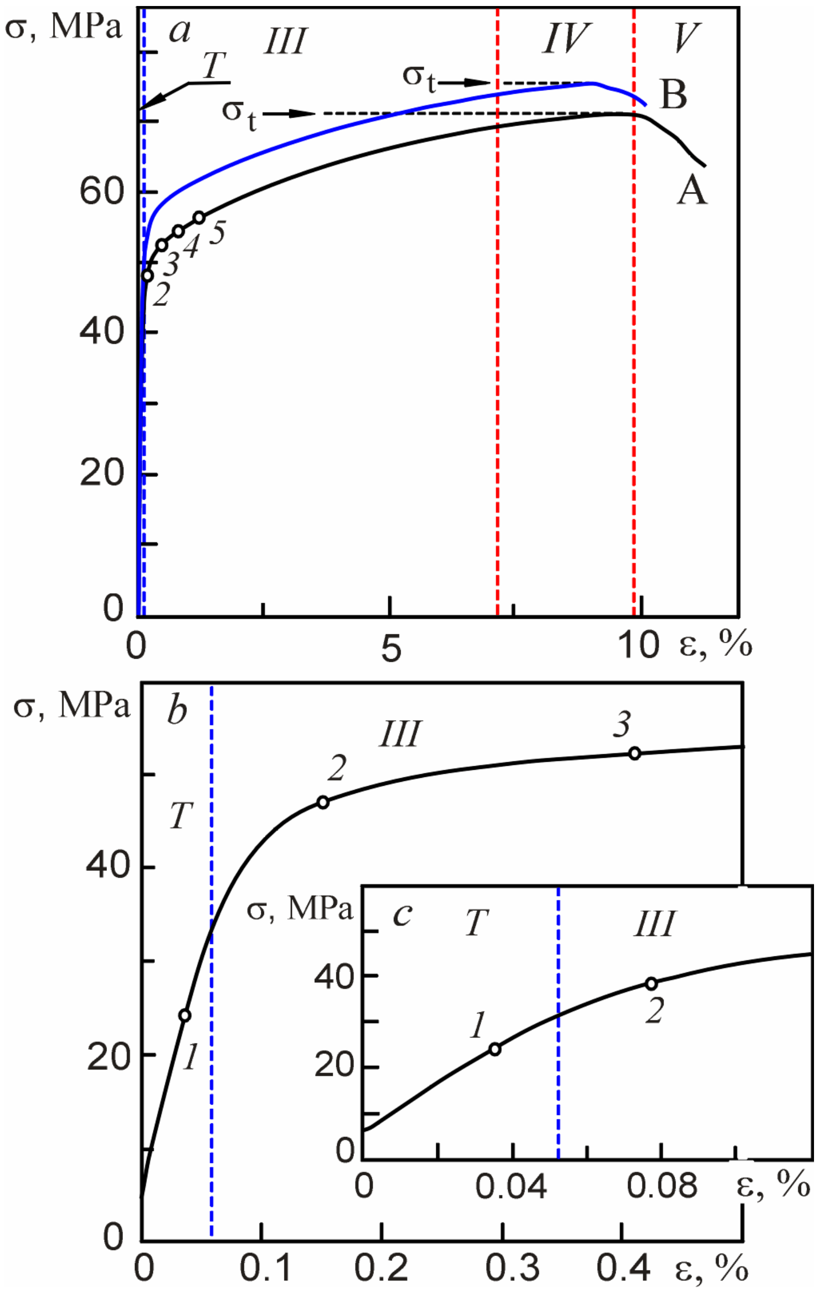


Fig. 1 and 2 exhibit "stress-deformation" curves $\sigma = f(\varepsilon)$ under tension of technically pure aluminum A7 samples in the initial state and after irradiation with a pulsed electron beam. It can be seen that electron-beam irradiation of the surface has led to an increase in the tensile strength of the samples σ_t.

Fig. 1. A complete tensile deformation curve of technically pure aluminum A7 (*a*) and fragments of the deformation curve at the initial stage of deformation (*b, c*). The numbers 1 – 3 correspond to the position on the curve of the patterns of deformation structures in Fig. 3. *T, III, IV, V* are stages on the deformation curve



Unirradiated and irradiated samples of technically pure aluminum A7 demonstrate a smooth plastic flow of metal with hardening. Fragments of deformation curves have been constructed at different scales. It can be seen that complete curves $\sigma = f(\varepsilon)$ and their fragments produced from unirradiated and irradiated aluminum samples A7 are similar.

Fig. 2. Complete deformation curves of irradiated aluminum samples A7 (*a*). Fragments of the deformation curve at the initial stage of deformation (*b*, *c*) of the sample irradiated by electrons with an energy density of E_S = 15 J/cm^2. Curves A and B are samples irradiated at E_S = 15 J/cm^2 and 25 J/cm^2, respectively. The numbers 1 – 3 correspond to the position on the curve of the patterns of deformation structures in Fig. 4. *T, III, IV, V* are stages on the deformation curve

The deformation diagram in the coordinates σ–ε was used in the analysis of the stage occurrence based on the deformation curves produced during the study (Fig. 3). The transition from deformation diagrams in the coordinates σ from ε to diagrams σ from √ε allows distinguishing boundaries of the stages quite well: transition stage T and stages III, IV V. It has been found that the nature of deformation curves in the coordinates σ from √ε, reflecting the stage occurrence of the plastic flow for aluminum samples irradiated with a pulsed electron beam, had not undergo a fundamental change.

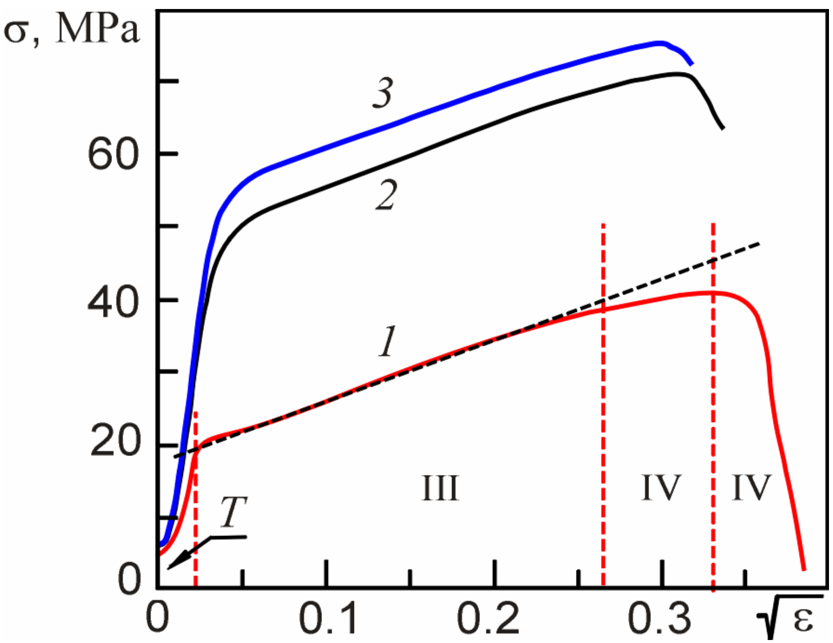


Fig. 3. Deformation diagrams in the coordinates σ – √ε. Curve 1 is the tension of technically pure aluminum A7. Curves 2 and 3 are the tension of aluminum A7 samples irradiated with an electron beam with energies E_S = 15 J/cm^2 and 25 J/cm^2, respectively. *T, III, IV, V* are stages on the deformation curve

The use of the optical measuring system VIC-3D for registration of displacement fields in near-surface layers of the samples has allowed revealing, at the macro level, features of the redistribution of deformation fields on the surface of aluminum samples during deformation at the transition from one stage to another (Fig. 4)

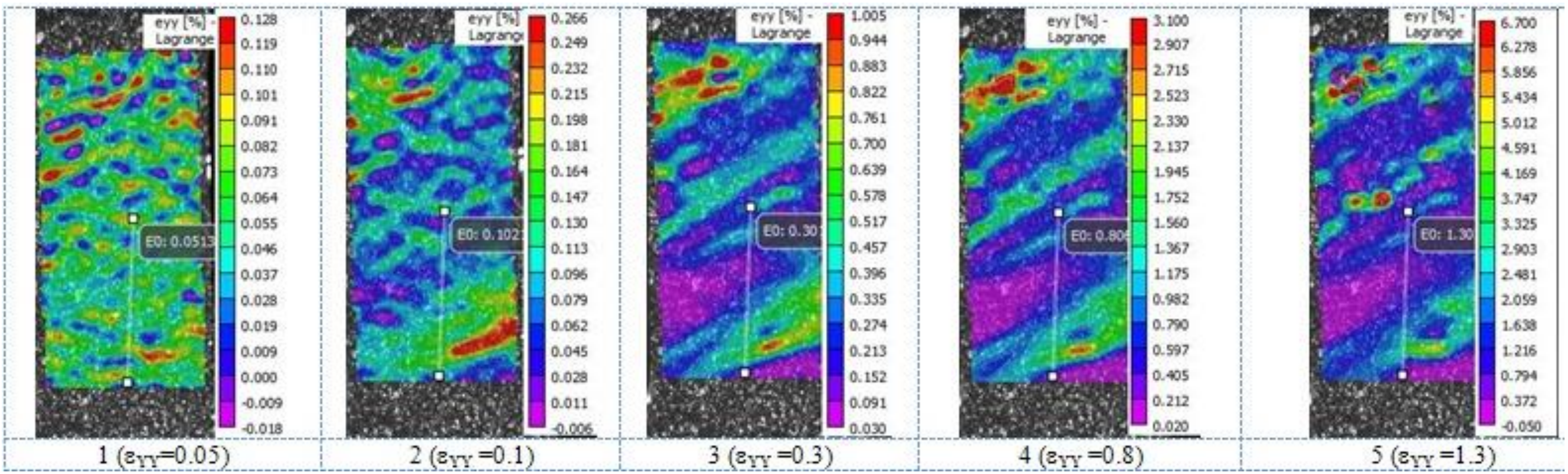
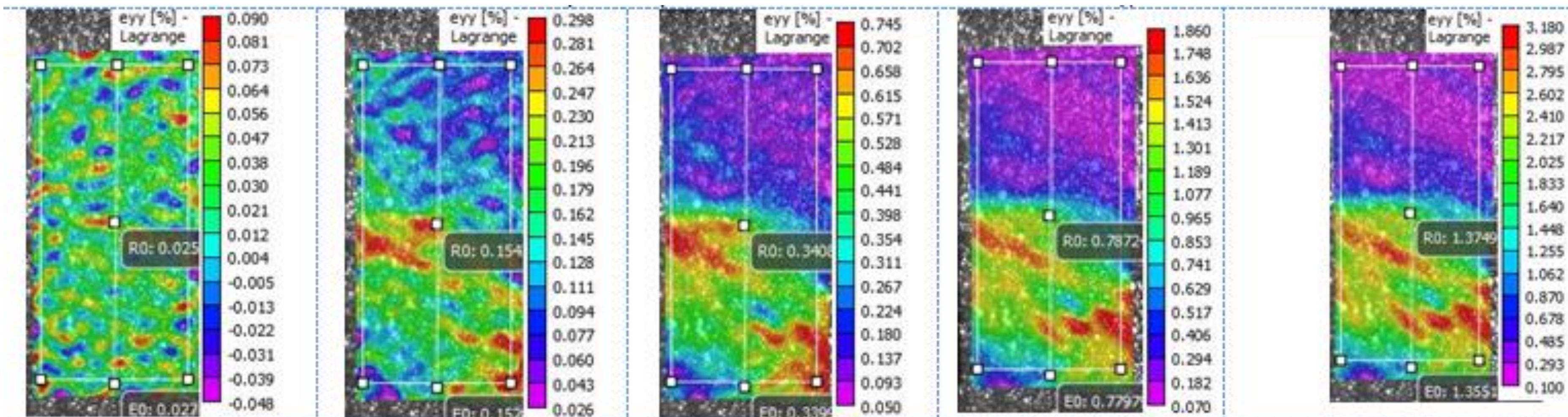


Fig. 4. Distribution patterns of longitudinal ε_{YY} relative deformations on the surface of the initial sample of technically pure aluminum. Patterns 1 – 5 correspond to points 1–5 on the deformation curve in Fig. 1

A transition from stage T to stage III occurs under stresses above the elastic limit, which is accompanied by merging of small deformation zones into larger ones in distribution patterns of the longitudinal ε_{YY} relative deformations on the surface of unirradiated and irradiated samples (Figs. 4 and 5, patterns 2).



1 (ε_{YY}=0.027) 2 (ε_{YY} =0.15) 3 (ε_{YY} =0.34) 4 (ε_{YY} =0.78) 5 (ε_{YY} =1.35)

Fig. 5. Distribution patterns of longitudinal ε_{YY} relative deformations on the surface of the sample of technically pure aluminum irradiated with a pulsed electron beam. Patterns 1 – 6 correspond to points 1–6 on the deformation curve in Fig. 2.

CONCLUSION

The effect of irradiation with an intense pulsed electron beam with an electron beam energy density of 15 J/cm^2 and 25 J/cm^2 on the mechanical behavior of polycrystals of technically pure aluminum A7 under tensile deformation of flat samples has been examined.

It has been found that the analysis of deformation diagrams in the coordinates σ from $\sqrt{\varepsilon}$ allows distinguishing quite well the boundaries of four stages: the transition stage T and stages III, IV V. It has been found that transition from one stage to another is reflected at the macroscale level in the change in distributions of deformation fields on the surface of aluminum samples.

Irradiation of aluminum samples with an electron beam has not change the occurrence of stages of the plastic flow during uniaxial tension of flat samples. It has been found that plastic deformation begins on irradiated samples at stresses 2.5 times higher than on unirradiated samples.

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