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# The Macroscopic Phenomena During The Development Of Mechanical Twins In Titanium Under Concentrated Intensive Load

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Abstract**-** The effect of a concentrated load, obtained by pressing a diamond pyramid into the plane (0001) of polycrystalline titanium BT1-0 on the formation of residual mechanical twins and acoustic emission (AE) is studied. The increasing loads in the same print were used for their obtaining. We studied the relationship between the released AE energy and the parameters of mechanical twins using the Pearson correlation.
Keywords: titanium, intensive deformation, twinning, mechanical twins, acoustic emission.

## Introduction

The development of a microstructure in metallic materials with a hexagonal close-packed (HCP) lattice in order to improve the mechanical properties may be performed by intensive plastic deformation (IPD), namely by pressurized torsion [1], an equal channel angular extrusion [2], screw extrusion [3], accumulating rolling [4] etc. However, using the IPD, it is practically impossible to investigate the evolution of a deformed structure and the stages of changes taking place in a structure.

A convenient material to study the changes in a crystal structure is titanium, which allows for an experiment to perform plastic deformation and obtain reliable information on the changes made in it within a temperature environment suitable for testing. The deformation of pure or commercially pure titanium of VT1-0 grade at a room temperature is carried out by four independent systems of basic slip in the direction perpendicular to the axis "C" and is accompanied by twinning. This property of titanium allows to select a desired field of study for an experimenter.

Twinning occupies an intermediate position between micro-and macroscopic processes according to the scope of involved phenomena occurring in the crystals. During the twin entities development large internal surfaces, affecting the kinetics of many physical processes are formed in material. Depending on its orientation, mechanical counterparts may serve as a reinforcing factor and the cause of a noticeable softening [5].

The search for practical possibilities of mechanical twinning to increase the real strength and ductility in technologically important materials, despite the presence of considerable theoretical and experimental data are still relevant today.

## Material, equipment and study methods

The material of the study is technicaly pure titanium BT1-0. In order to relieve internal stress, the samples underwent full recrystallization annealing in a vacuum oven for one hour at the temperature of 700 C.

The concentrated power was applied as a determining factor of the twinning process appearance to produce wedge-shaped twins [6]. The diamond pyramid Vickers of microhardness meter DM-8B served as the source of a concentrated load. The maximum stress of a shear modulus order G acts at the point of a sample contact with the top of the pyramid during the indentation [7].

The grains with the orientation in the basal plane (0001) on the surface of the sample were chosen for indentation using the microscope Quanta 3D, which corresponds to a favorable orientation for the exit of twins on a sample surface. The size and the shape of the residual wedge twins on the surface of the sample was studied using an optical microscope «Olympus GX51» and a scanning probe microscope «Ntegra Aura».

In the test samples stress concentrators have grouped wedge twins, and speed their tops reaching ~ 5000 m/s, generates acoustic emission signals.

The obtaining of residual wedge twins was carried by a traditional method of a single indentation, which allows to perform re-indentation in the selected grains in identical conditions.

**Experiment results and analysis**

The experiment was carried out by a consistent loading with the load weight of 10-200 g. and 15 second delay in the selected grain sample. The twins formed around an imprint as a result of a concentrated load, have a clearly defined borders and a wedge shape with gradually decreasing thickness from the mouth to the top (Table 1).

Table 1. Parameters of twinning layers under the influence of an increasing load at the same grain

| № i/n | Load value, g. | Twin length L, mcm. | Twin thickness h, mcm. | h/L |
|---|---|---|---|---|
| 1 | 10 | 7.4 | 0.76 | 0.102 |
| 2 | 25 | 15.5 | 1.42 | 0.092 |
| 3 | 50 | 23.2 | 1.89 | 0.081 |

Under the influence of an applied loading wedge layers appear from multiple systems of intersecting planes. However, even with equal loads on an indenter in various grains with the same orientation the number and the location of mechanical twins is different (Figure 1). Since the mechanical twinning is a regular re-orientation of a crystal lattice under the influence of an external force, it may be assumed that there is an uneven distribution of local internal mechanical stresses which affect the further development of twinning and its accompanying sliding in the vicinity of twin boundaries [8].

The experimental data showed that the appearance of the twins and their number cannot be predicted in advance. Their origin is activated obviously by random stress concentrators, the presence and the amount of which depends on a defect structure. Since the twin end profile remains sharp, you can assume a low defect density, which allows to move a twin from a mouth under the action of concentrated stress.

An observed development of a twin means that  that a twin did not choose a dislocation layer completely and encountered the obstacles, and the process under certain conditions, fits into the scheme of pure twinning staging. Such twins may be described sufficiently by a well-known dislocation model [9,10].

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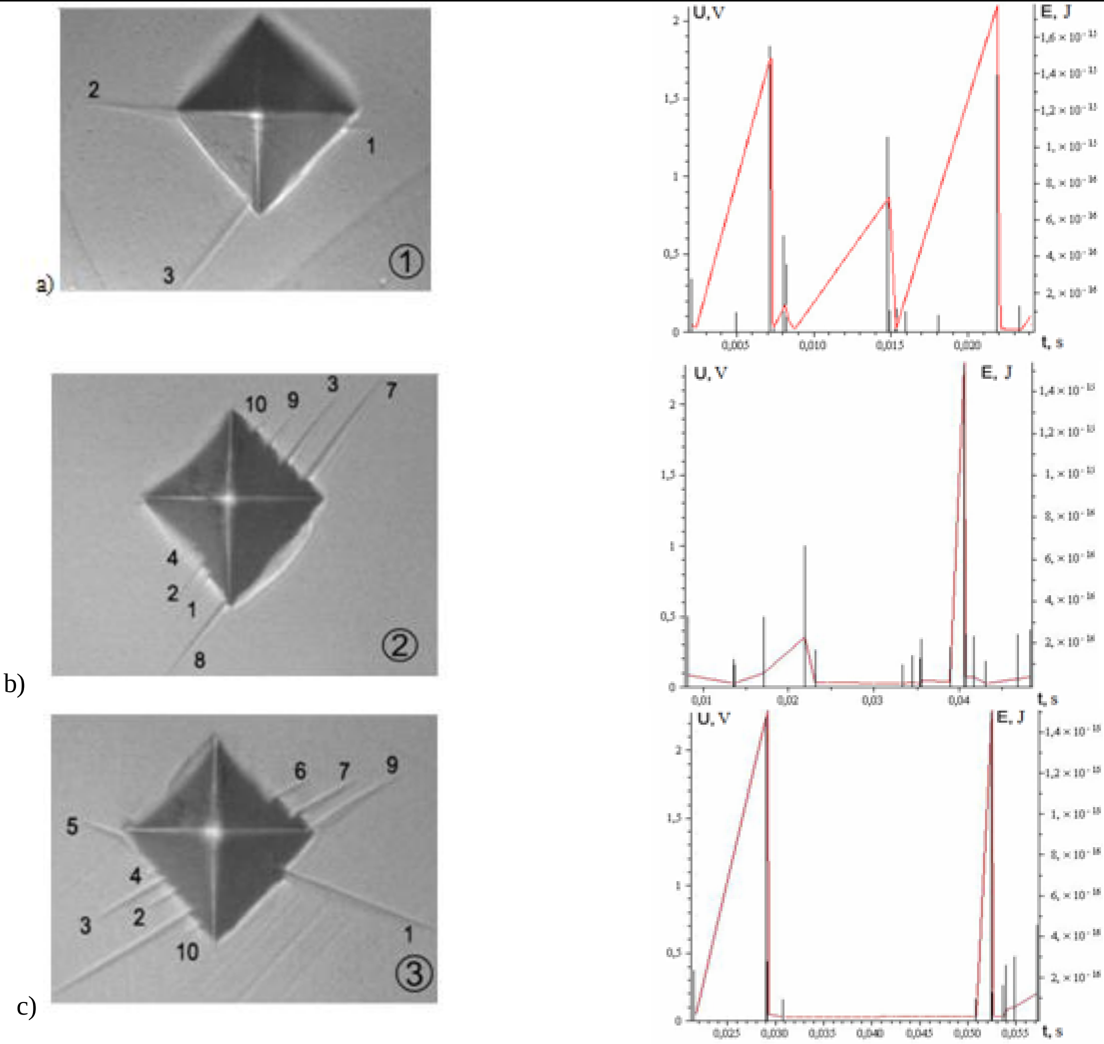


Fig. 1. The state of residual mechanical counterparts during the impact on the indenter with the load of 50g x 1500. U - pulse value of AE, E - AE electrical pulse energy, t - loading period.

The emergence of the twinning process in metals is preceded by slip that accompanies twinning at all stages of its development (Fig. 2, d). An intensive slip along the basic planes of a parent crystal leads to the formation of accommodation bands before the rise of a twin beyond its edge (Fig. 2, b).

Slip deformation distorts severely an original structure of the crystal and cannot provide a local identity of conditions for the development of twinning layers within one and the same crystal. The accompanying of the twinning process by slip is easily visible on the crest of a twin rib (Fig. 2, d), and the change of a slope angle confirms the proposed scheme of a twinning staging (Fig. 2, b, c).

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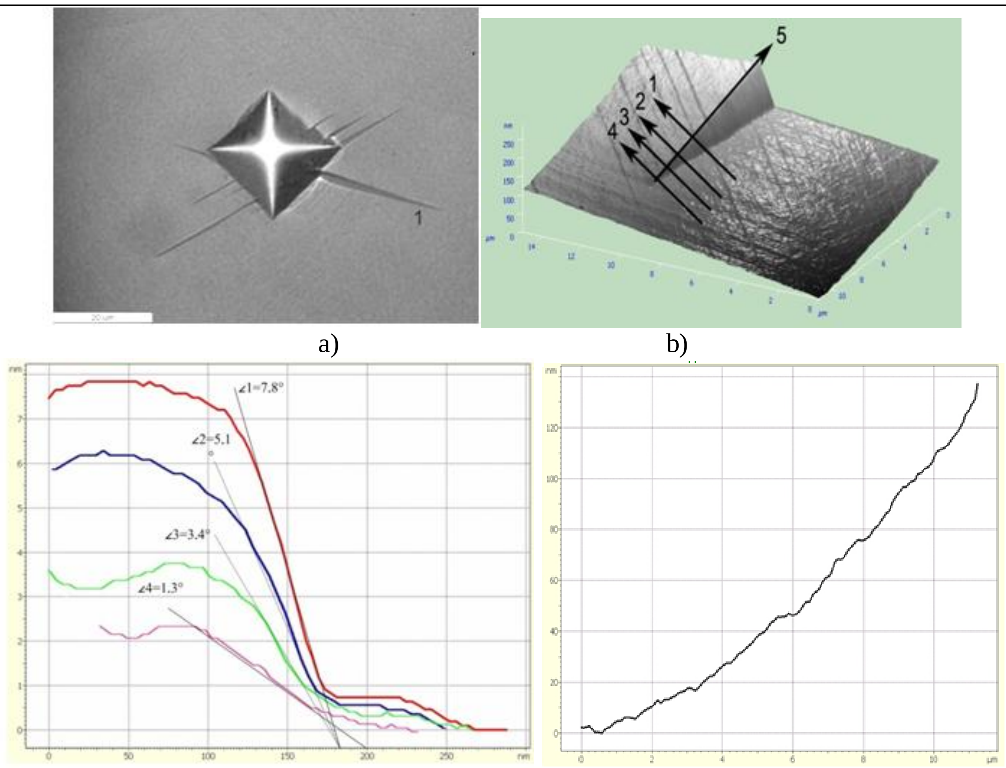


a) b) c) d)

Fig. 2. The position of formed twins around a print (a); twin layer form from the mouth to the top (b); angular section profile along the lines 1,2,3 and 4 (c); profile section along the twin layer edge - line 5 (d).

The fact that twins appear in the most deformed areas of a crystal by slip is an indisputable one.

The authors of the work [11] support the hypothesis of the initiation of deformation twin appearance by the slide before twinning. However, a significant variation of the quantitative twinning characteristics in the grains of the same orientation with respect to the sample surface (Fig. 1), the difference in time and energy parameters of an occurring acoustic emission (Figure 1) and the parameter h/L (Table 1) are dependent on load. The latter fact suggests that with the load and the depth of the pyramid increase various sign processes of a crystal lattice restructuring may take place - twinning and detwinning.

In order to enhance the understanding of the occurring processes in titanium under the influence of an intensive concentrated load the additional statistical experimental studies were performed.

In order to display the relations of variables between released AE and the parameters of developed mechanical twins Pearson correlations were used [12]. The obtained correlating parameters are presented graphically on Fig. 3,4,5.

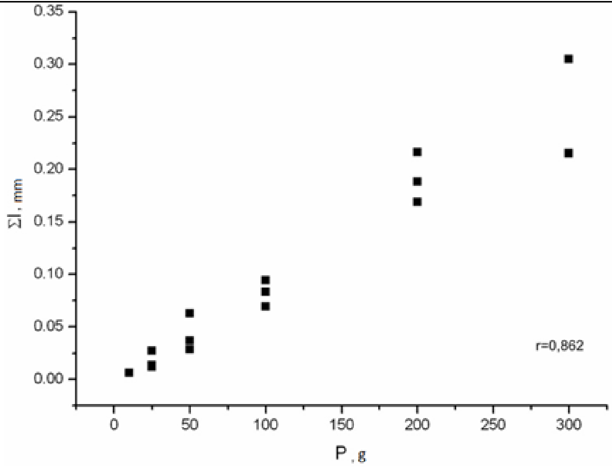


Fig. 3. The dependence of the twin total length of the twin (Σl) on the indenter load (P).

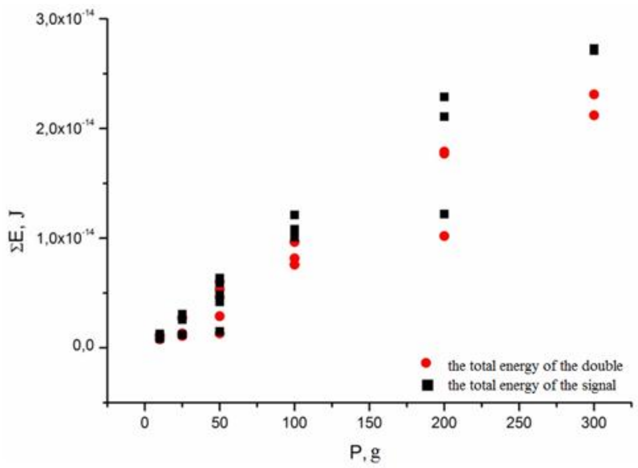


Fig. 4. The dependence of AE TWIN electrical signal total energy (ΣE) on the indenter load (P).

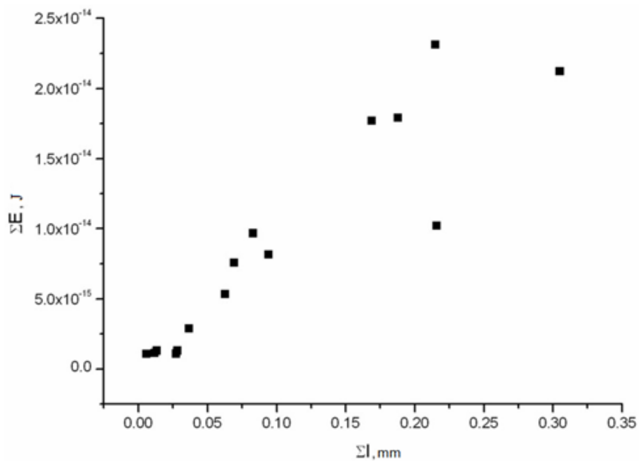


Fig. 5. The dependence of a twin electrical signal AE total energy (ΣE) on the total length of the twin (Σl).

The high correlation between AE parameters and the geometric parameters of a twin shows that a mechanical twin and an acoustic signal can be considered as belonging to a single event. However, with the load increase on the indenter a linear relationship observed between a twin length increase and the total energy of AE electrical signal begins to break down, and is changed to a more complex mathematical relationship with a load increase (Fig. 3, 4). The mere fact of correlation dependence does not give any grounds to assert that one of the variables precedes or causes changes of the other one, or that the variables are related by cause. It is possible here that there is the action of the third factor or a set of factors that influence the final result.

We may assume that other destructive processes are developed with the load increase on the indenter and the increase of a pyramid penetration depth along with the process of slip and twinning, which are excited only in the surface layers [11].

**Conclusion**

1. The study of mechanical twins in the amount of a deformed crystal showed that the sources of twinning dislocations are excited only in the surface layers. Therefore, the assertion that the evolution of titanium BT1-0 microstructure at SPD using the modern methods of [1-4] is associated with the development of the twinning process and requires additional studies.

2. It was found that the use of a concentrated stress by a diamond pyramid in grain oriented along the basal plane (0001) on the sample surface, promotes the phasic development of residual wedge twins, alternating with the stages of slip at the load increase within a crystal section.

3. The detrmined correlation between the geometric parameters of mechanical twins, the load on the indenter and the amount of AE electrical signal energy indicates that a mechanical twin and an acoustic signal may be considered as belonging to the same event.

4. A linear relationship was revealed between the geometric parameters and the twin magnitude and electric AE signal value within the low loads on a diamond pyramid. With the load increase the linearity is disturbed, which may be related to the influence of other factors besides the twinning and slipping.

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