IN-SITU STUDY OF THE INFLUENCE OF THE STRAIN PATH CHANGE ON THE DEFORMATION PROCESSES IN MAGNESIUM

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Abstract

The twinning activity and internal stress evolution in random textured polycrystalline magnesium were studied as a function of strain path changes using in-situ neutron diffraction method. The pre-deformation to different stresses in compression and tension, respectively was followed by application of load with opposite sign. The results indicate that the deformation behavior significantly depends on the level of the pre-deformation.

Keywords: Magnesium, neutron diffraction, twinning, detwinning

1. INTRODUCTION

The unique properties of magnesium alloys predestine them for use in many applications, especially in transport industry. Nevertheless, the insufficient understanding of deformation mechanisms in its hexagonal close packed structure precludes their wider usage. Basal slip <a> is the system with the lowest critical resolved shear stress (CRSS), followed by prismatic <a> and pyramidal <a> [1]. All these systems together can provide 4 independent slip systems. Consequently, the Von Mises rule, requiring five independent slip systems for homogeneous plastic deformation is not fulfilled [2]. Thus activation of other deformation mechanisms is necessary. At room temperature $\{10\bar{1}2\}\langle 10\bar{1}1\rangle$ tensile twinning has been identified as the most easily activated mechanism [3].

Owing to its polar nature different grains undergo twinning during tensile and compressive deformation. Tensile twinning causes reorientation of crystal lattice by 83.6° and causes changes in the texture of the material. When the loading direction change the sign, two possibilities can occur - nucleation of new twins in favorably oriented grains, which are usually different than that from the precedent loading direction or detwinning takes place, during which the twinned crystal lattice reorients back to the initial orientation of the parent grain [4].

In the present paper the influence of the strain path change on the twinning evolution is studied using in-situ neutron diffraction technique. The main advantage of this method is in its capability to examine large sample volume owing to the deep penetration length of thermal neutrons. Furthermore, the intensity changes of particular diffraction peaks characterize the twinning and shift of diffraction peaks provides information about lattice deformation and internal stresses [5-6].

2. EXPERIMENTAL TECHNIQUE

Cast polycrystalline magnesium with 1 wt.% Zr content was used for the experiment. Zirconium was added to stabilize the grain size to the value of 110 μm. The monotonic compression and tensile tests were applied at room temperature at a strain rate of $\cdot 10^{-3}$ s^{-1}. The test was stopped on the predetermined values of stress and loading with opposite sign was applied. Three different levels of pre-deformation were applied in compression - 40 MPa, 60 MPa and 80 MPa (C40, C60, C80) than deformed in tension to the same level of stress. Similarly two pre-deformations in tension 50 MPa and 70 MPa (T50, T70) were applied and consequently deformed up to the same level of stress in compression. The test was stopped for approx. 10 min in order to collect the neutron diffraction data. During this time, stress relaxation occurred. This is the reason, why stresses in figures do not correspond exactly to the stopped stresses, but are lower due to the relaxation. The SMARTS engineering instrument at LANSCE was used for collecting the diffraction pattern. The diffraction patterns were measured using two detector banks at ± 90° to incident beam. The angle between the incident beam and the loading direction is 45°. This setup provides diffraction measurement of planes perpendicular to the loading direction and parallel to it.

3. RESULTS

3.1 Deformation curves

The measured true stress - true strain curves are shown in **Fig. 1**.

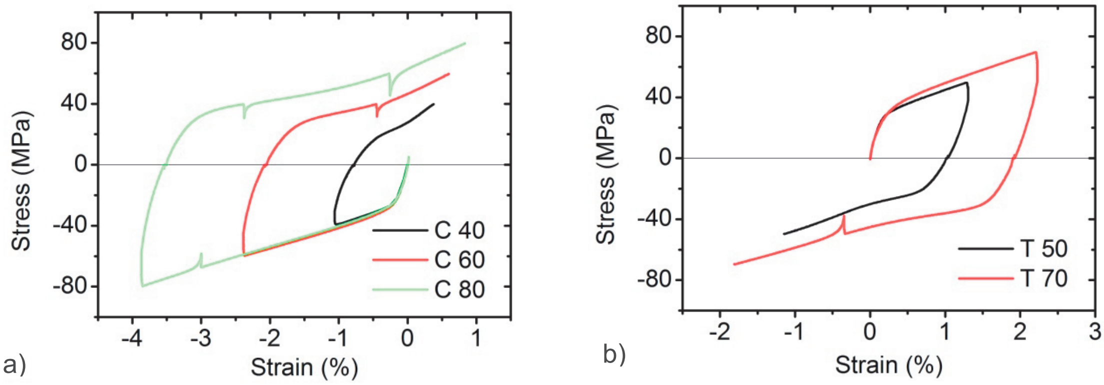

Fig. 1 Experimental stress strain curves with pre-deformation a) in compression b) in tension

In order to accentuate the influence of the pre-deformation on the deformation properties, in **Fig. 2** we slightly modified the curves. The pre-deformation parts were cut off; the origin of the subsequent deformation steps was shifted to the zero point and compared with not pre-deformed material (**Fig. 2**).

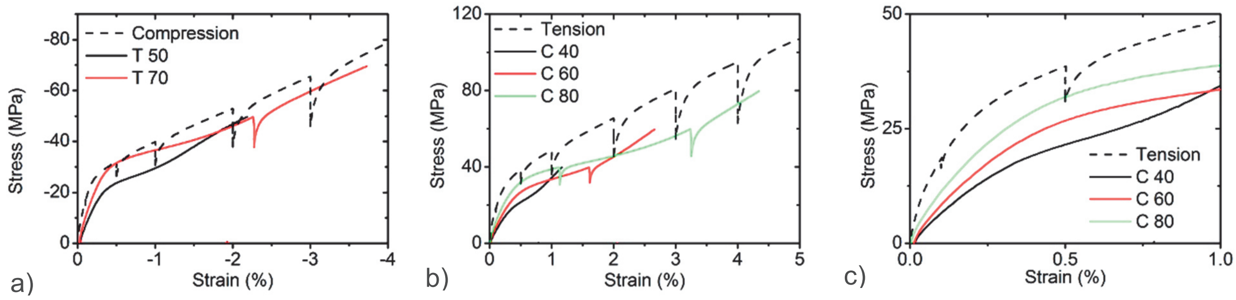

Fig. 2 Experimental stress strain curves a) in compression, b) in tension, c) in tension, zoom of the initial part of b). The dashed curve represents the simple tensile and compression curves, respectively, without pre-deformation

It is obvious that pre-deformation significantly influences stress-strain curve. **Fig 2c)** shows that the stress necessary for achieving a certain level of strain depends on the level of pre-deformation. Nevertheless, the dependence is ambiguous, since up to 0.8 % of applied strain this stress increases with increasing level of pre-deformation. On contrary, above this level an opposite dependence can be observed. The shape of the deformation curve also differs. Unlike the convex tension, the pre-deformed samples exhibit additional hardening caused by activation of non-basal slip systems.

The above described behavior for lower strains could be explained in terms of detwinning phenomenon. As it was discussed in our recent work, in compression twin nucleation takes place at the beginning of the straining followed by rapid twin growth [7]. That means that the twin size in the point, where the strain path is reversed depends on the stress level. As it was shown by Dobron et al. [8], the extent of the detwinning is size dependent, i.e. small twins can completely vanish, and the large ones only slightly shrink. In the consecutive tensile step the twins are suitable oriented for further tensile twinning. It seems that such a secondary twinning takes place easier in small twins, so the (micro) yielding takes place at lower stresses for C40 than that for C80. On the other hand the secondary twins consume their parents (i.e. primary twins) faster in C40, simply for the reason of the smaller size of the primary twins. If the secondary twinning mechanism is exhausted, a new slip system has to be activated for accommodation of the plastic strain. The dislocation density increases and additional hardening takes place. The onset of this mechanism is clearly shifted to higher strains for C60 and C80 samples owing to the larger size of primary twins.

3.2 Neutron diffraction

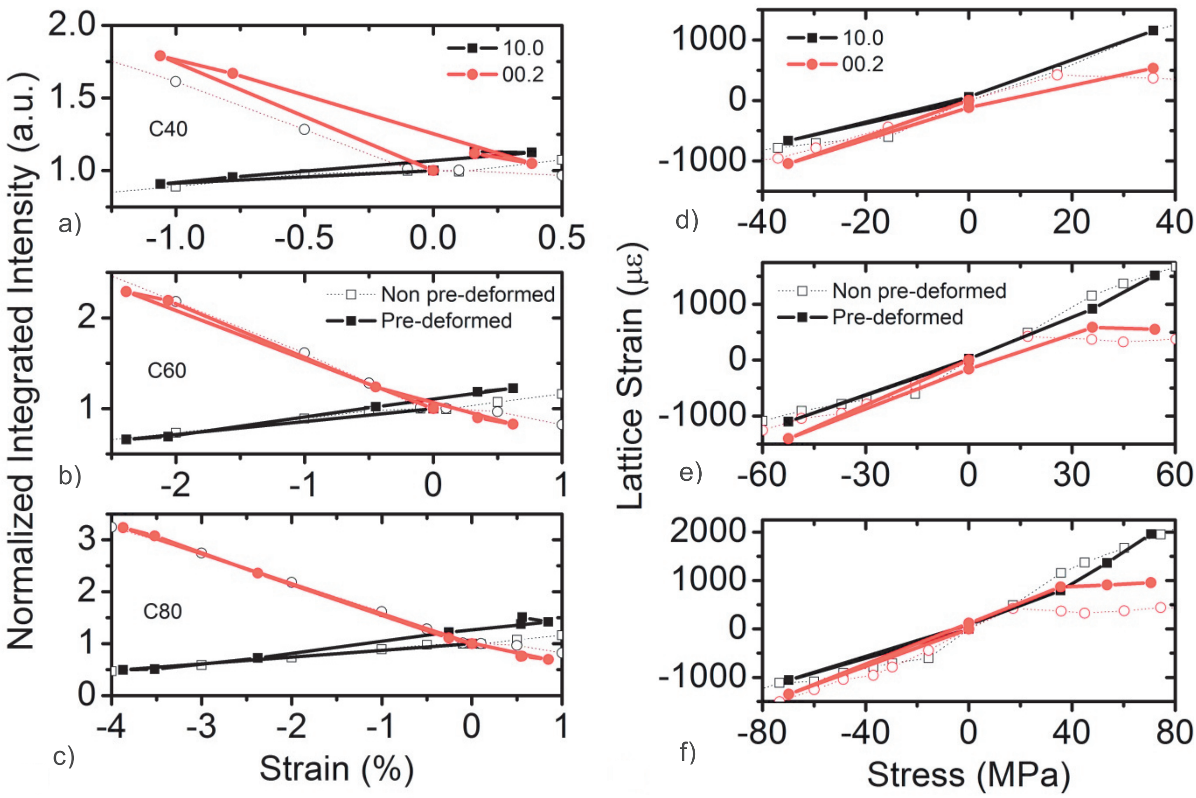

Fig. 3 Change of the a-c) relative intensity, d-f) lattice strain in axial direction in samples pre-compressed to a), d) 40 MPa, b), e) 60 MPa, c), f) 80MPa

The measurements clearly show that integrated intensities vary with strain. Owing to the applied diffraction geometry, the (00.2)-(10.0) intensity pair is the most sensitive on the twinning process. It is noteworthy that different behavior was found for the two strain paths [5]:

1) During compressive pre-deformation the reorientation of the lattice by twinning causes increase of (00.2) peak and decrease of the “parent” (10.0) peak [9]. When the strain path is reversed, opposite behavior

can be observed. It is obvious from **Fig. 3a)**, where normalized integrated intensities vs. strain are plotted for both pre- and non pre-deformed specimens that twin volume at a given strain level does not depend on the strain history at all. Similarly, the lattice strain of 10.0 planes does not depend on pre-deformation. On contrary, significant difference appears for 00.2 planes, where the lattice strain is higher for higher stress of pre-deformation. This effect can be caused by joint impingement of detwinning and secondary twinning. As mentioned above in C40 sample many twins recombine during the tension cycle. Therefore instead of secondary twins new primary ones nucleates, which takes place at the same stress level as in simply tensioned specimen. On contrary, in C60 and C80 specimens the detwinning is moderated. Thus the secondary twinning is more pronounced. The activation stress of secondary twinning seems to be size dependent. Nevertheless, this assumption needs further theoretical and experimental validation.

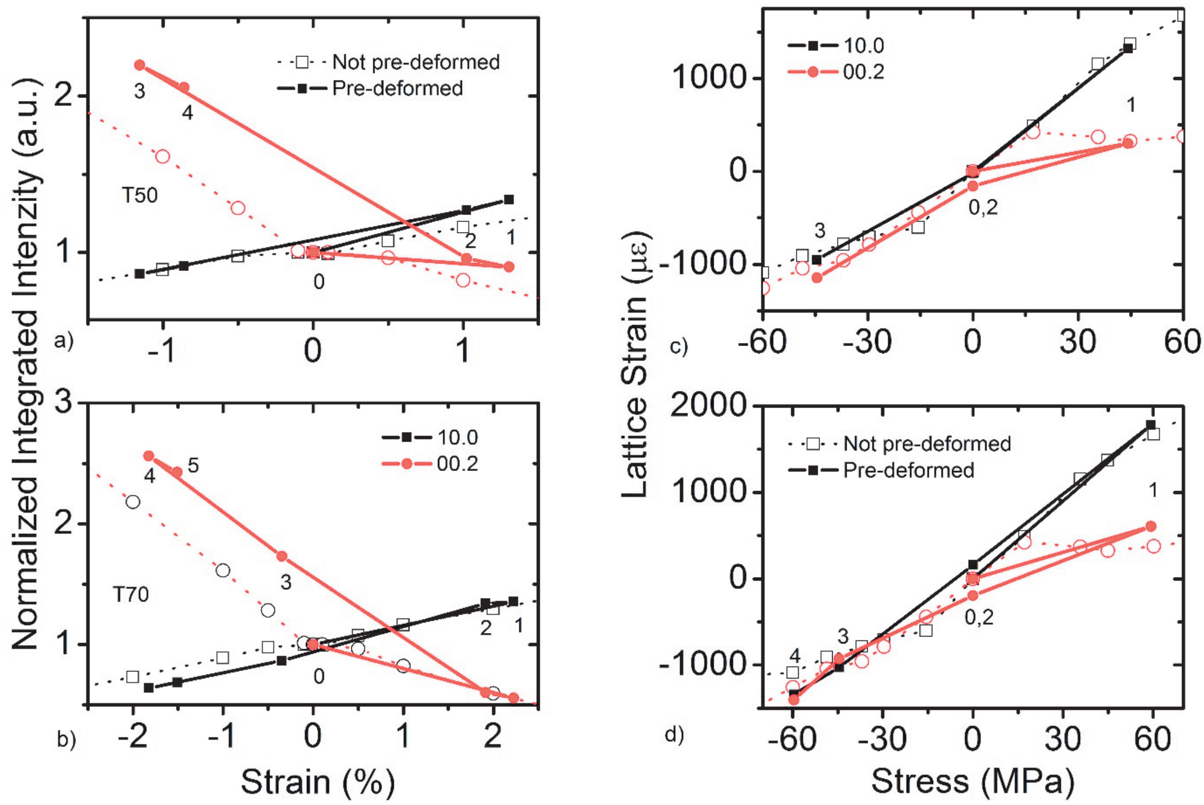

Fig. 4 Change of the a), b) relative intensity, c), d) lattice strain in axial direction in samples pre-tensed to a), c) 50 MPa, b), d) 70 MPa

2) Samples pre-deformed in tension exhibit different behavior. The normalized integrated intensity of the reflection 00.2 shows rapid growth immediately after the onset of the compression stage. Nevertheless, the slope of the increment is almost the same as for simple deformation, as well as the lattice strains. The reason for this behavior is most probably given by initial texture of the specimens. As it was shown by Agnew [10], in the random textured material there are more grains favorable oriented for $\{10\bar{1}2\}\langle 10\bar{1}1\rangle$ twinning in compression than in tension. It means that during pre-tension only a small number of grains undergo twinning. Consequently, during the compression stage the secondary twinning mechanism cannot cover the requirements for strain accommodation and primary twinning take place in virgin grains.

CONCLUSION

The influence of the strain path change of texture-free cast magnesium on the twinning evolution was studied by neutron diffraction method. It was shown that the shape of deformation curves significantly depends on the pre-deformation level. The reason can be rationalized in terms of size dependency of detwinning and secondary twinning. The smaller twins can more easily detwin and be completely consumed by secondary twinning. The neutron diffraction measurements reveal that in the case of pre-compressed samples the twin volume at a given strain level does not depend on the strain history. Pre-tensed samples exhibit rather primary twinning in new grains than detwinning and secondary twinning.

ACKNOWLEDGEMENTS

The work was founded by the Czech Science Foundation under the contract P204/12/1360. Jan Čapek acknowledges the support from the Grant Agency of Charles University under contract Nr. 513512.

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