OPTICAL MEASUREMENT OF THE MAGNESIUM ALLOY AZ31B STRAIN DISTRIBUTION AT THE HIGHER TEMPERATURES

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Abstract

During the last decades there is continuous tendency to lower the weight of cars and thus automotive industry is trying to find other metal (or e.g. plastic) materials suitable to produce lighter car-bodies. As one of these materials can be taken also magnesium alloy AZ31B-0 that is suitable for forming. Among advantages of magnesium belong mainly its low specific weight, availability and relatively inexhaustibility of its sources. As a disadvantage there is mostly low Young´s modulus and crystallization in the hexagonal-closed-packed lattice which causes limited ductility of the magnesium at room temperature. Metal forming technologies for the magnesium alloys respect this specification about hexagonal-closed-packed lattice of the basic solid solution and its microstructure. Low ductility at the temperature of 200 °C is caused by the low number of the slip system which takes place only on the basal planes. At temperatures over 225 °C there are already acting more slip planes. This paper deals with the experiment where were (with the help of the contact-less optical system ARAMIS) determined strain distributions and their maximal magnitudes in the fracture vicinity under the uni-axial loading at different temperatures. Eventually new grains creation and development of the recrystallization was examined by the optical metallography.

Keywords: AZ31B-O, crystallographic texture, hot forming, strain distribution, optical system ARAMIS

1. INTRODUCTION

Formability of the magnesium alloys depends mostly on the magnesium material properties, on the forming temperature and on the friction between punch and magnesium sheet. Among the most important material properties that influence the magnesium alloys formability belongs the dimensional stability of the mechanical properties, slip systems of the hexagonal lattice, critical resolved shear stress (τ_{CRSS}) and formation of twinning in material. Because magnesium crystalizes in the hexagonal close-packed (HCP) crystallographic lattice, slip can occur only in the basal planes and that is why its formability at the room temperature is strictly limited. However, just slightly elevated temperature can make active also the other slip systems which results in much more higher formability of the magnesium alloys. In this paper was measured major strain φ_1 (1) distribution on the sample surface that was uni-axially loaded at different temperatures.

2. HCP lattice slip systems and temperature influence

As was already mentioned before, dominant slip system at the room temperature is termed as basal <a> slip and is activated in the planes with the highest planar density {0001} - thus planes that are parallel to the slip directions of the highest linear density $<11\bar{2}0>$.This slip system is a preferred one and is shown in **Figure 1a)**. Among the other slip systems which can be activated under the higher temperatures, there are prismatic planes $\{10\bar{1}0\}$ and pyramidal planes {1111}. Both of these slip systems are in the slip directions $<11\bar{2}0>$ and are illustrated in **Figures 1b)** and **1c)**, respectively. Additionally (again under the very strong dependence on the temperature) there are activated pyramidal slip planes $\{10\bar{2}2\}$ in the slip directions $<11\bar{2}3>$ [3]. These slip systems are illustrated in the last image about the slip systems for magnesium alloys - see **Figure 1d)**.

Basal <a> and prismatic <a> slip of the HCP lattice under the room temperature reveal only two independent slip systems. Accordingly pyramidal slip reveals only four independent slip systems. In all mentioned cases there is not fulfill von Mises conditions for polycrystalline materials that $\tau_{RSS} \geq \tau_{CRSS}$ (τ_{RSS} is the resolved shear stress), because it is valid only when crystal lattice has at least five independent slip systems. If it hasn´t, there won´t be polycrystals homogeneous plastic deformation without fracture (e.g. fracture along the grain boundaries). Moreover, slip system in <a> direction perpendicular to c axis can´t perform deformation which is parallel with this axis [1, 2].

Activation of the pyramidal <a + c> slip systems in $\{11\bar{2}2\}$ planes and $\langle 11\bar{2}3 \rangle$ directions of the second order is the only one possibility to perform motion of the dislocations along axis c. Pyramidal <a + c> slip systems reveal over five independent slip systems. However, these systems are difficult to be activated at the room temperature because τ_{CRSS} has to be higher by two orders than shear stress necessary to activate basal <a> slip systems. Regarding the reality that τ_{CRSS} for activation pyramidal <a + c> slip systems in much higher than τ_{CRSS} for twining, it is possible to observe that approx. till 200 °C the twining mechanism of plastic deformation prevails over the activation dislocations motion in <a + c> systems axis [1, 2].

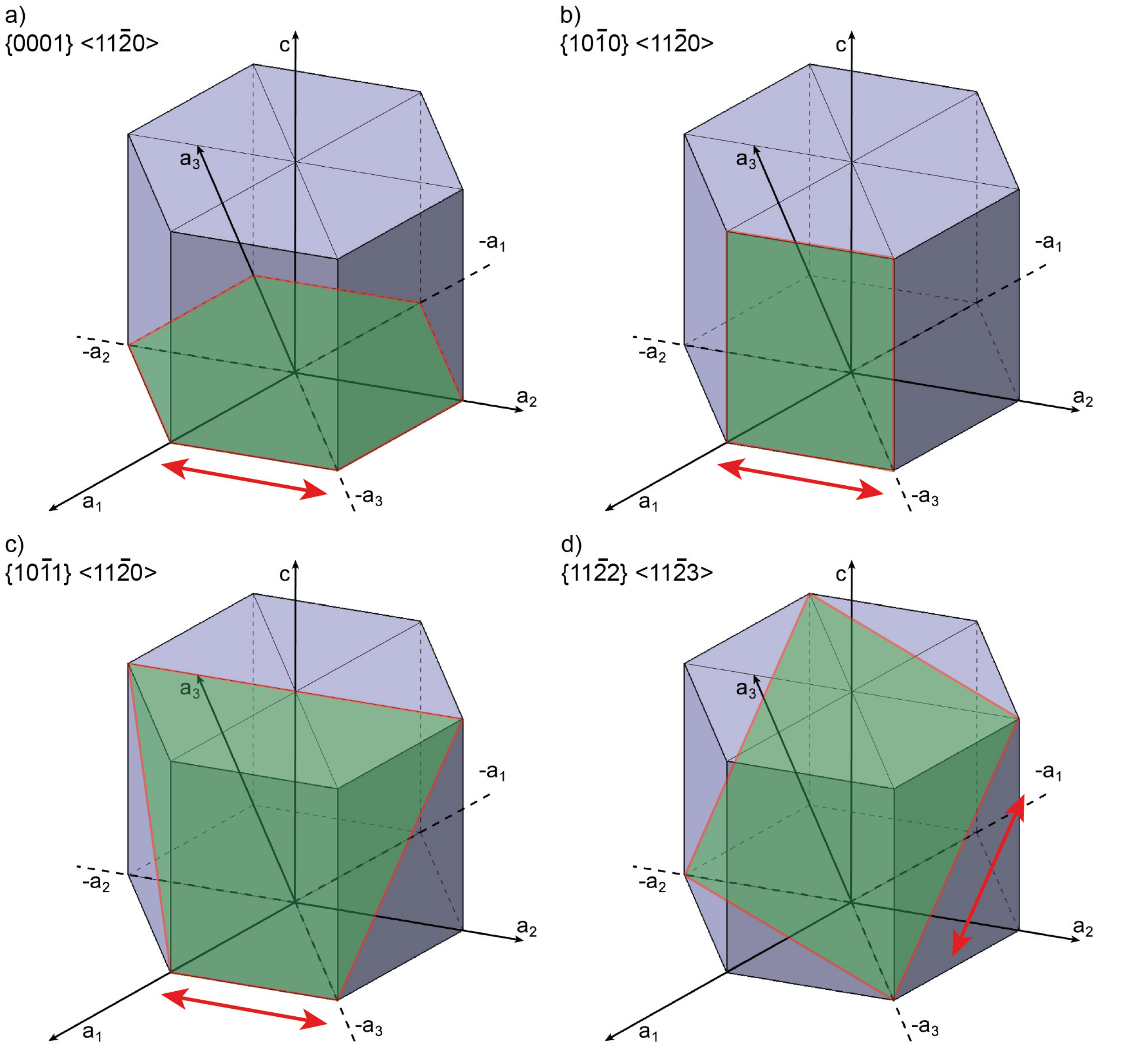

Figure 1 Slip systems of the magnesium alloys [4]

3. EXPERIMENTAL PART

As a tested material there was used the magnesium sheet AZ31B-O of thickness 1.4 mm from the company MgF Magnesium Flachprodukte GmbH which is a subsidiary company of the Thyssen-Krupp AG. There was carried out common static tensile test (thus uniaxial tensile stress state) at device TIRAtest 2300. Evaluation of all tests was made by software LabNET. For contact-less deformation measurement through the whole test was used optical system ARAMIS v6.1.1-2 from the German company GOM. This system in based on the principles of photogrammetry and is able to measure true (or engineering) strain during the whole testing procedure. Simultaneously there was also measured force F (N) and cross-bar displacement (mm) for evaluation the static tensile test. It was not possible to use the common length gauge because of heating samples in the temperature chamber. That is why samples were always measured in light of length before and after the static tensile test. Initial length was l_0 = 80 mm. Edges of samples were also machined by milling. Material was tested in different rolling directions as following: 0°, 45° and 90°. Due to the system ARAMIS there was possible to always evaluate moment right before the first fracture occurrence. As testing temperatures there were selected four different temperatures as following: 20 °C (*RT* - room temperature), 100 °C, 230 °C and 280 °C. Because of system ARAMIS, there was necessary to use hardened glass in place of the door (thus the temperature chamber was not completely isolated). To achieve the proper heating of samples, keeping time in the chamber for every sample was 8 min. As a result from this test there were magnitudes of the major strain φ_1 (1) for the moment right before the fracture. Finally there were made scratch patterns from the deformed samples which were inspected at the microscope OLYMPUS GX71 to determine occurrence of twins and creation of new grains (via recrystallization).

3.1. Results of the static tensile test

After proper heating on the required temperature was sample placed into the temperature chamber and clamped by jaws (**Figure 2** - left). It was also necessary to apply stochastic pattern on the sample surface for the subsequent deformation measurement by system ARAMIS (**Figure 2** - in the middle). In **Figure 2** (left) it´s also possible to see the hardened glass. With higher temperatures also increased the material ductility A_{80mm} (%) and was needed to use, under these higher temperatures, programmed file for data scanning frequency because the number of images for one test is limited. Due to this reality there was also necessary to modify the loading velocity v_L (mm·min^{-1}) on the magnitude as: v_L = 20 mm·min^{-1}. Major strain φ_1 (1) was determined from the last image before the fracture. This situation is illustrated in **Figure 2** (right) where is shown already computed sample at following parameters: temperature 280 °C and rolling direction 0°.

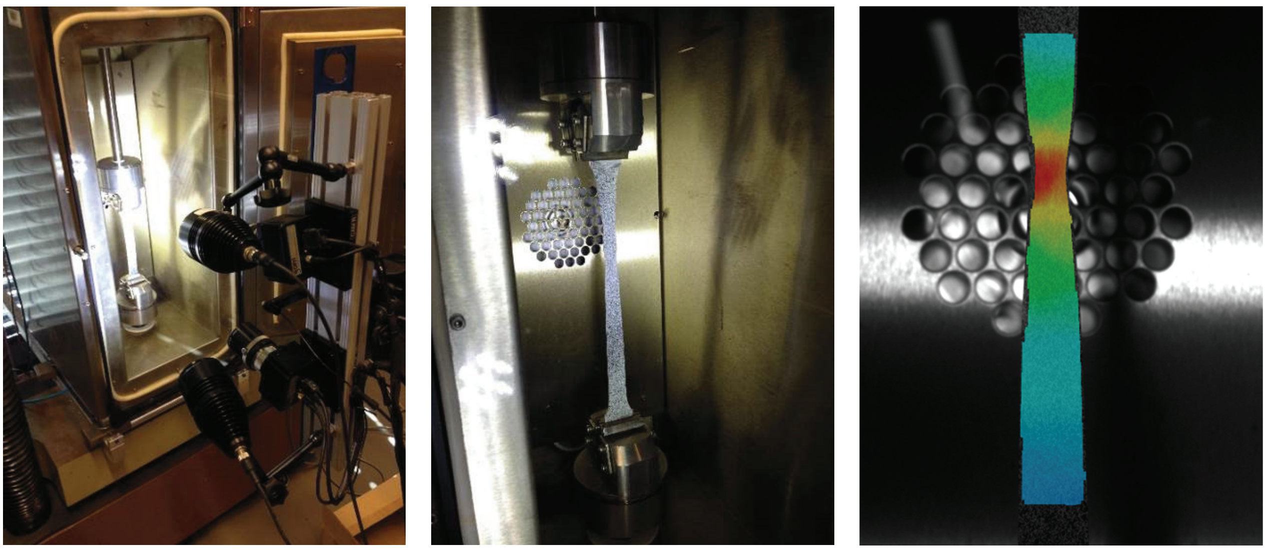

Figure 2 Lay-out of the static tensile test (left), tested sample (in the middle) and computed sample (right)

In **Figure 3** are shown dependences of the major strain φ_1 (1) on the testing temperatures *T* (°C) in light of the rolling directions. As a magnitude of the major strain φ_1 (1) there were taken magnitudes right before the fracture (see **Figure 2**). There is also used straight connection between measured points because connection via spline curves can be a little bit confusing in this graph due to the possible maxims between points.

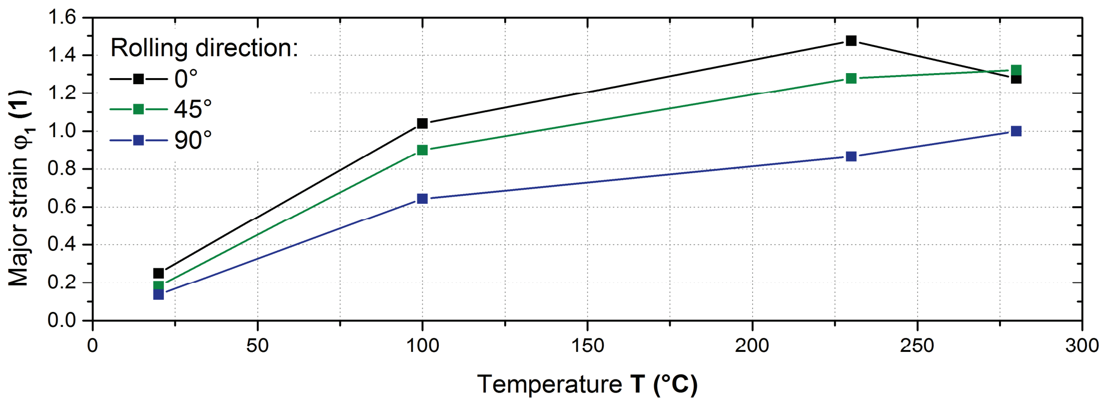

Figure 3 Major strain φ_1 (1) vs temperature T (°C) in light of rolling directions

Figure 4 connects two possible outputs from the optical system ARAMIS. In the upper part there is a graphical distribution of the major strain φ_1 (1) in the moment right before the fracture (temperature 280 °C and rolling direction 0°). The lower part illustrates its distribution along the section 0 via the line graphs. The maximum magnitude of the major strain in this case was φ_1 = 1.312.

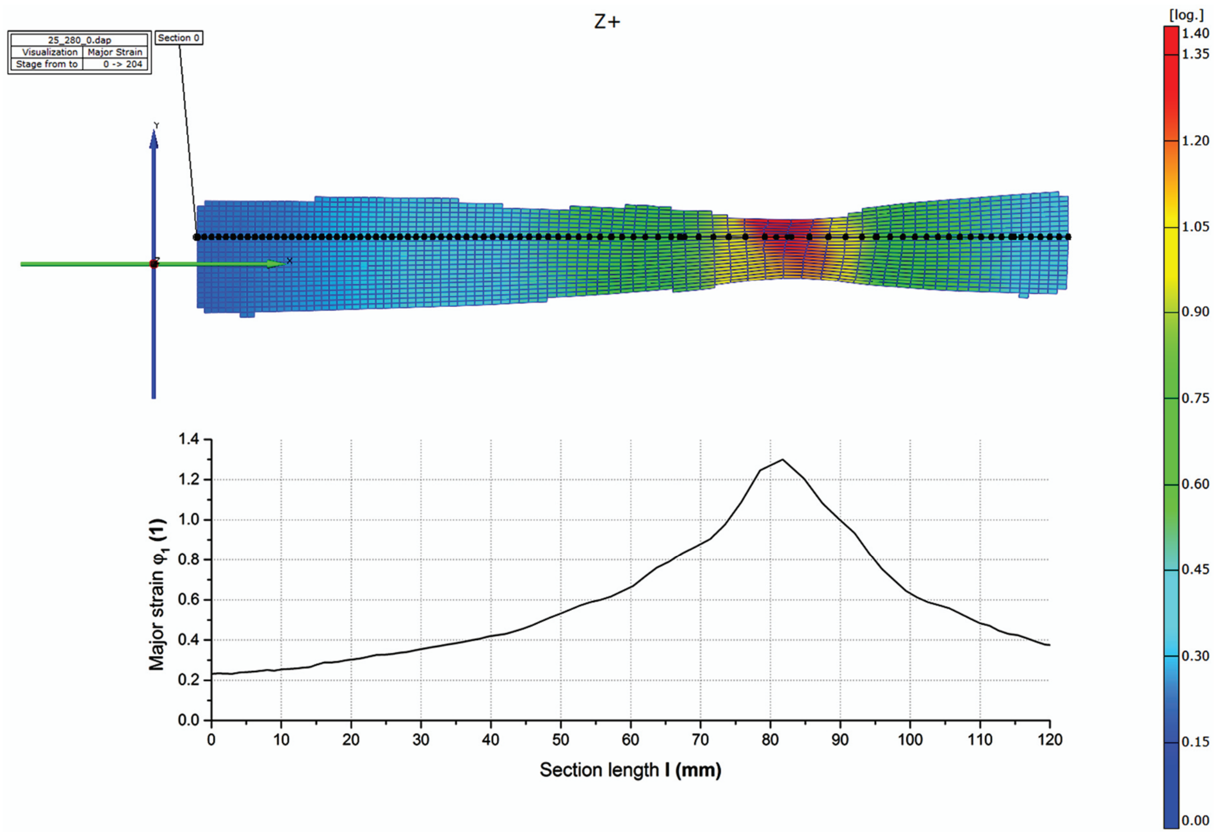

Figure 4 Moment right before the fracture with φ_1 (1) values - temperature 280°C; rolling direction 0°

3.2. Metallographic analysis

After static tensile test (so uni-axial stress state) were from surface of the deformed material taken samples for the subsequent metallographic scratch patters samples. All samples were embedded into the epoxide and after the polishing they were etched by the mixture of picric acid (5 ml of acetatic acid, 6 g of picric acid, 10 ml of water and 100 ml of ethanol). Own evaluation of the structure was done by the metallographic microscope OLMYPUS GX71 with the graphic instrument. Beside the plastic deformation by slip is, on the measured scratch patterns taken from the formed sheet at room temperature and at temperature 100 °C (see **Figure 5**), evident the hardening of structure by twinning that is typical of magnesium alloys.

There is not slip of dislocations at plastic deformation by twinning, but both parts of crystals moved in such manner that they reveal the mirror symmetry along the certain twinning plane (see **Figure 5**). Orientation of twin is in the direct reflection regarding the parent crystal on the twinning plane. Under this deformation type are atoms in the every atomic plane moved by the same distance compared with the atoms in the adjacent planes. From the acquired images at the elevated loading temperature 230 °C and 280 °C (**Figure 6**) is evident a very fine-grained structure. That is due to influence of the heating and the uni-axial tensile loading where recrystallization occurred. With the increasing temperature was not possible to observe the twins creation, thus there weren´t monitored the expressive plastic deformation by twinning.

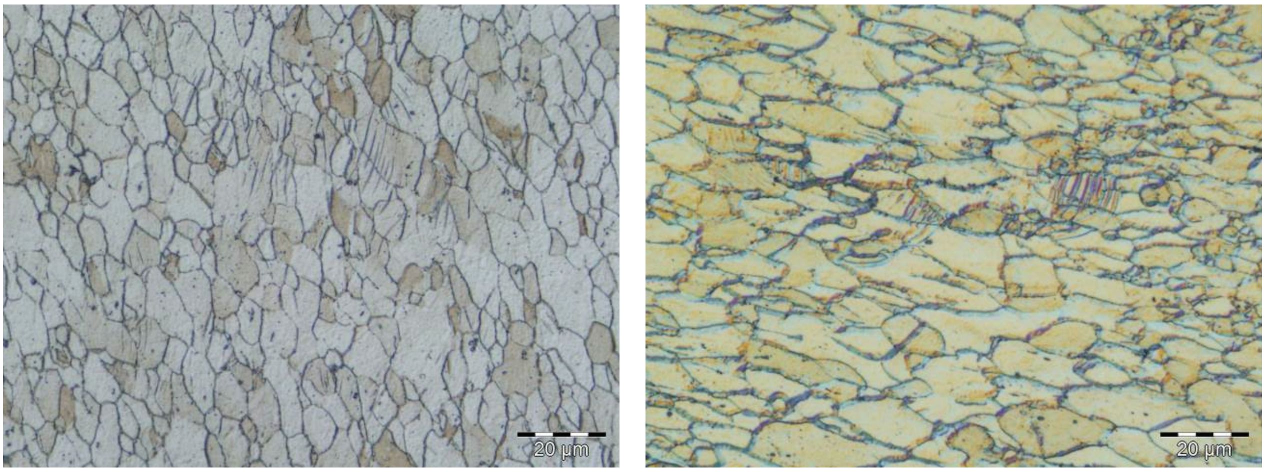

Figure 5 Images from microscope OLYMPUS GX71, etched, polarized light;
left - room temperature, rolling direction 45°; right - 100 °C, rolling direction 0°

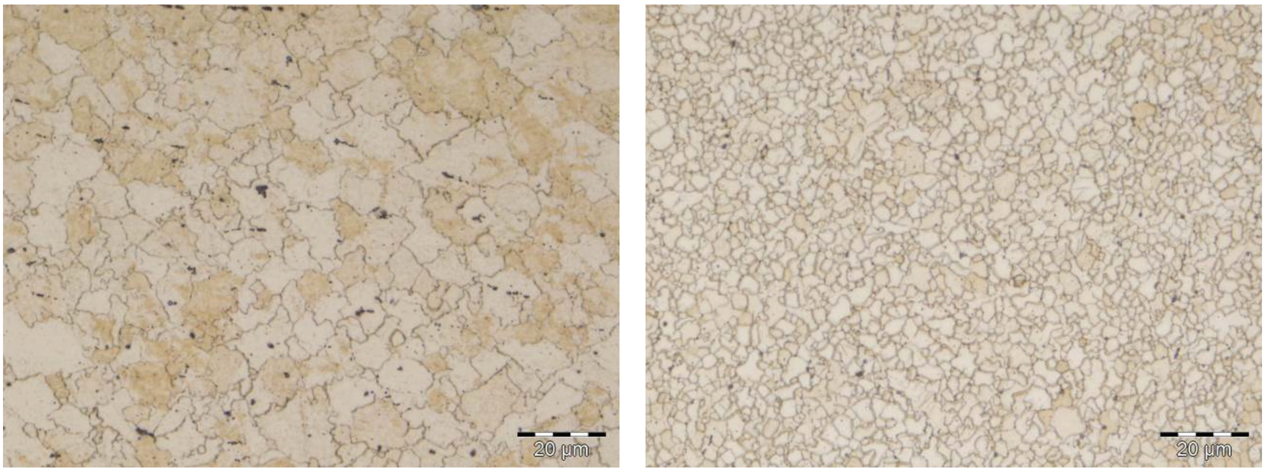

Figure 6 Images from microscope OLYMPUS GX71, etched;
left - 230 °C, rolling direction 0°; right - 280 °C, rolling direction 0°

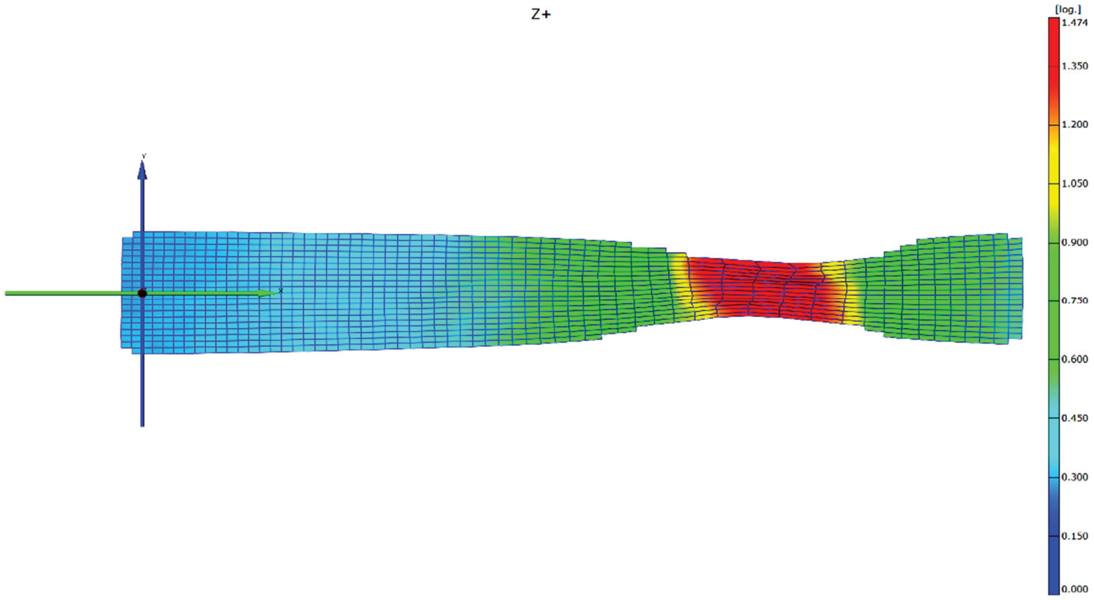

Figure 7 Major strain φ1 (1) distribution right before the fracture - temperature 230 °C; rolling direction 0°

4. CONCLUSION

This paper deals in the strict extent about the uni-axial (tensile) loading of magnesium sheet from the alloy AZ31B-O and its deformation measurement and evaluation by contact-less optical system ARAMIS. In the broad extent is this paper about the magnesium sheet mechanical properties, their anisotropic behavior and temperature dependences. From the measured results it obvious strong dependence of the major strain on the temperature. The higher testing temperature, the higher deformability of the magnesium alloy (see **Figure 3**). Under the temperature 280 °C was major strain φ_1 (1) increased five-times in comparison to its magnitude at the room temperature (*RT*). The highest major strain φ_1 (1) was measured for sample at temperature 230 °C with the rolling direction 0° (see **Figure 7**). Such deformation behavior is in some references termed as the superplasticity. From the metallographic scratch patterns can be already observed twins created during the deformation. Moreover at temperature 280 °C it is obvious the change in grain size. It is because of recrystallization, nucleation and growth of new strain-free and equiaxed grains. Simultaneously with increasing temperature there was lowered the creation of twins i.e. that slip occurred only on the non-basal prismatic and pyramidal planes. In these cases magnesium sheet revealed a very fine-grained structure.

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