MECHANICAL PROPERTIES OF HOMOGENIZED TWIN-ROLL CAST AND CONVENTIONALLY CAST AZ31 MAGNESIUM ALLOYS

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Resume

The improvement of mechanical properties of magnesium alloys nowadays is very important, because of the variety of industrial applications. For this goal, the number of casting techniques and further treatments were developed. Among the continuous casting techniques, which allow producing long strips of the alloys, is twin-roll casting. Using this process one can get the magnesium alloy with finest microstructure and higher specific strength. In this paper the comparison of tensile properties of conventionally cast and twin-roll cast AZ31 magnesium alloys was made. Tensile tests were carried out with constant strain rate 10^{-3} s^{-1} at temperatures ranging from 100 to 300 °C. Both materials were tested in as-cast state and after homogenization treatment at 450 °C for 10 hours. The investigation showed that there are no significant changes in ductility of AZ31 conventionally cast alloy even after heat treatment, while the ductility of twin-roll cast alloy increases.

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1. Introduction

Magnesium alloys are well-known structural materials, which are now widely spread in automotive industry [1 - 4]. The future trend in automotive industry is a reduction of the weight of car components, so the magnesium and aluminium, which are ones of the lightest metals, are becoming more and more popular. Since Mg-Al-based alloys have high specific strength and stiffness, low density and good thermal and electrical conductivities in future they could replace some steels and cooper cast alloys [5]. They are also perspective for the electronics and computer components production [6].

The influence of the alloying elements is crucial for final properties of the alloy. Many investigations of the impact of the Al, Zn, Ca, Sn, Sr and Zr on mechanical properties were made in order to control the manufacturing process and improve it [7 - 11].

Different casting techniques are used to produce Mg alloys with the definite properties and to meet specific requirements. Among them are die casting and twin-roll casting (TRC) followed by hot extrusion or hot rolling. Each of the processes affects the texture and microstructure and therefore the mechanical properties of the alloy [12 - 14].

Of the variety of the AZ commercial alloys, the AZ31 is very popular and represents good properties such as strength, ductility and low cost. However, to apply AZ31 alloy as a car component (for example, car roof) there is a need to produce thin sheets that might be successfully produced from TRC materials. The thickness of the alloy as-cast strip before further rolling could go down to 5 mm [15]. But there are still many open questions in the manufacturing process. Among them is the role of the inhomogeneity of the as-cast structure on the properties of the final product.

In this paper the microstucture and mechanical properties of AZ31 prepared by two different cast techniques, conventional casting (CC) and TRC, were studied. In order to examine the effect of the inhomogeneous structure on mechanical properties during heat treatment the specimens in the as-cast and homogenized states were prepared for structural, microhardness and tensile tests.

2. Experimental

In the present study the investigations of AZ31 CC ingot and 5.6 mm thick AZ31 TRC strip were performed. The chemical composition of AZ31 magnesium alloy is given in Table 1.

Table 1

Chemical composition (in wt. %) of the AZ31 magnesium alloy.

Al	Zn	Mn	Cu	Ca	Fe	Mg
3.45	0.98	0.28	0.002	0.002	0.004	Balance

Two sets of samples were used: 1) as-cast AZ31 magnesium alloy and 2) alloy after homogenization treatment at 450 °C for 10 hours. Specimens were annealed in an air furnace and quenched in oil.

In order to distinguish the resulting microstructure and compare it with the as-cast state the standard metallographic specimens with dimensions 10 mm × 10 mm × 5.6 mm were prepared and then etched with 5 % picric acid. The microstructure images of the AZ31 alloys were obtained by Olympus GX51 optical microscope using NIS-Elements AR 3.0 software. The same specimens were used for Vickers microhardness tests on QNess Q10 machine. The applied load was 100 g. The mapping of the 5 mm × 8 mm cross-section for TRC material was performed in transverse direction (TD) of the specimens.

The 1 mm thick dog-bone shaped coupons for tensile tests were machined from both CC ingot and TRC strip. The specimens of TRC alloy had their tensile axes parallel to the RD and had a length of 6 cm. Tensile properties of AZ31 magnesium alloys were investigated on the INSTRON 5228 machine with the constant strain rate 10^{-3} (s^{-1}). The samples were heated up to 100, 150, 200, 250, and 300° C respectively and held at the temperature for 10 min before the tensile test at the given temperature started.

3. Results and Discussion

3.1 Microstructure

It is well known that AZ31 magnesium alloys contain mainly α-Mg phase and secondary β-$Al_{12}Mg_{17}$ phase [16]. However the distribution of the phases in the materials produced by different techniques varies. In the Fig. 1 the microstructure images of CC and TRC AZ31 magnesium alloys are shown. As can be seen on Fig. 1c, the as-cast TRC material is characterized by smaller particles of the secondary phase as to compare with much larger ones in the master CC AZ31 alloy. The particles are distributed within the whole α-Mg matrix in both alloys. The grain size in the bulk of TRC alloy is about 200 μm, while for CC alloy the grains have size of about 300 μm. Moreover, during to the TRC the areas near the surface are subjected to the higher deformation than the middle part of the strip.

Thus, grains are smaller in the areas near the surface where the grain size can archive 50 μm. After aging at 450 °C for 10 h (Fig. 1d) the slight coarsening of the microstructure of CC material is observed. On contrary, in TRC alloy significant refinement of the microstructure occurs, the grain size decreases down to 50 μm. Perez-Prado et. al.

[17] showed that the normal grain growth is observed in the mid-layer of AZ31 Mg sheet while the recrystallization process starts at elevated temperatures in the surface layers. Thus, the refinement of the microstructure in the TRC AZ31 magnesium strip is related to the full recrystallization of the microstructure which takes place after long-term heat treatment. Furthermore, after aging (Fig. 1b, d) secondary β-$Al_{12}Mg_{17}$ phase in the CC alloy partially dissolves and only few β-phase particles were observed inside the grains. In the TRC alloy dissolving of β-phase accompanied by a decrease of the grain size is observed, while the grain size of the CC material slightly increases and is often accompanied by the abnormal grain growth. The size, quantity and distribution of secondary phases affect the mechanical properties of alloys [18, 19], as well as the inhomogeneous structure of the material. It was reported [16] that according to the TRC processing parameters such as rolling speed, temperature, etc. the deformation of the outer regions occurs.

Depending on the cooling rate the segregation zone in the centre of the TRC sheet, which may contain pores and different defects, can be also observed (Fig. 2a). Fig. 2b and c show that particles in the central segregation zone remain in the TRC alloy even after aging. The grain size is uniform in all areas along the specimen's cross-section. Most probably, it is the presence of the 0.28 wt. % of Mn which is together with other impurities responsible for the formation of the segregation. It is known [6, 20 - 23], that Mn has very poor solid solution solubility in Mg. In Mg-Al alloys, manganese combines with iron and precipitates as a $Al_5(Mn,Fe)_2$ intermetallic [15, 20]. TRC AZ31 is characterized by the dendritic structure typical for Mg-Al alloys, as it is shown in Fig. 2a, b. The $Al_{12}Mg_{17}$ eutectic phase precipitates along the grain boundaries and is clearly visible in as-cast alloy (white arms in the Fig. 2a). The α-Mg solid solution is located in the interdendritic regions and is presented by dark areas on the SEM image. After homogenization dendritic structure is almost eliminated (Fig. 2b).

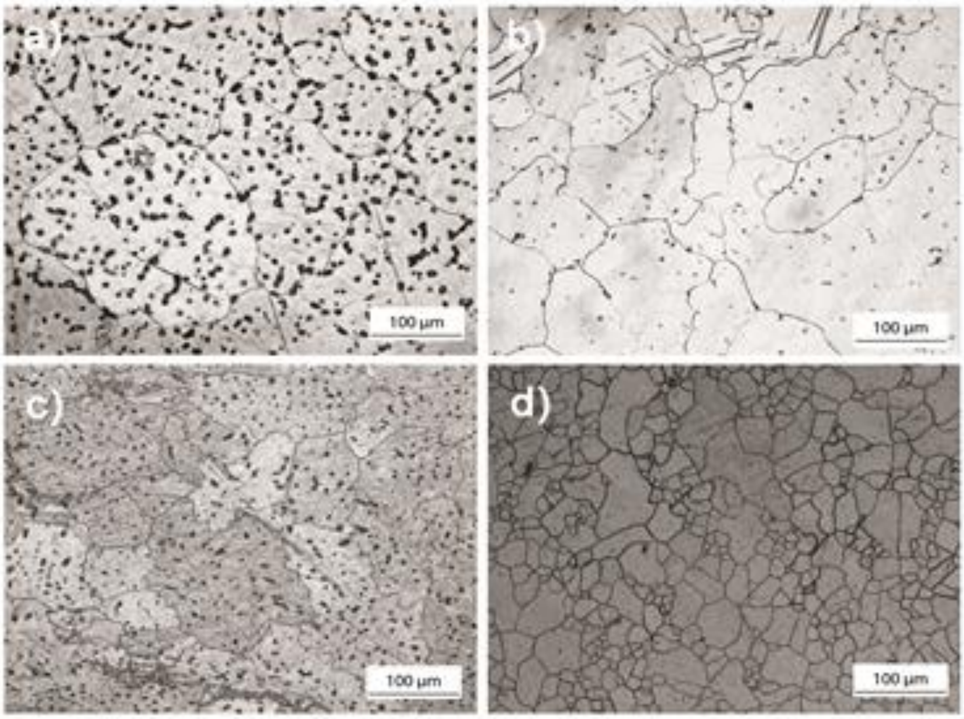

Fig. 1. Microstructure of AZ31 magnesium alloys: a) CC as-cast, b) CC after homogenization annealing at 450 °C for 10 hours, c) TRC as-cast, d) TRC after homogenization annealing at 450 °C for 10 hours.

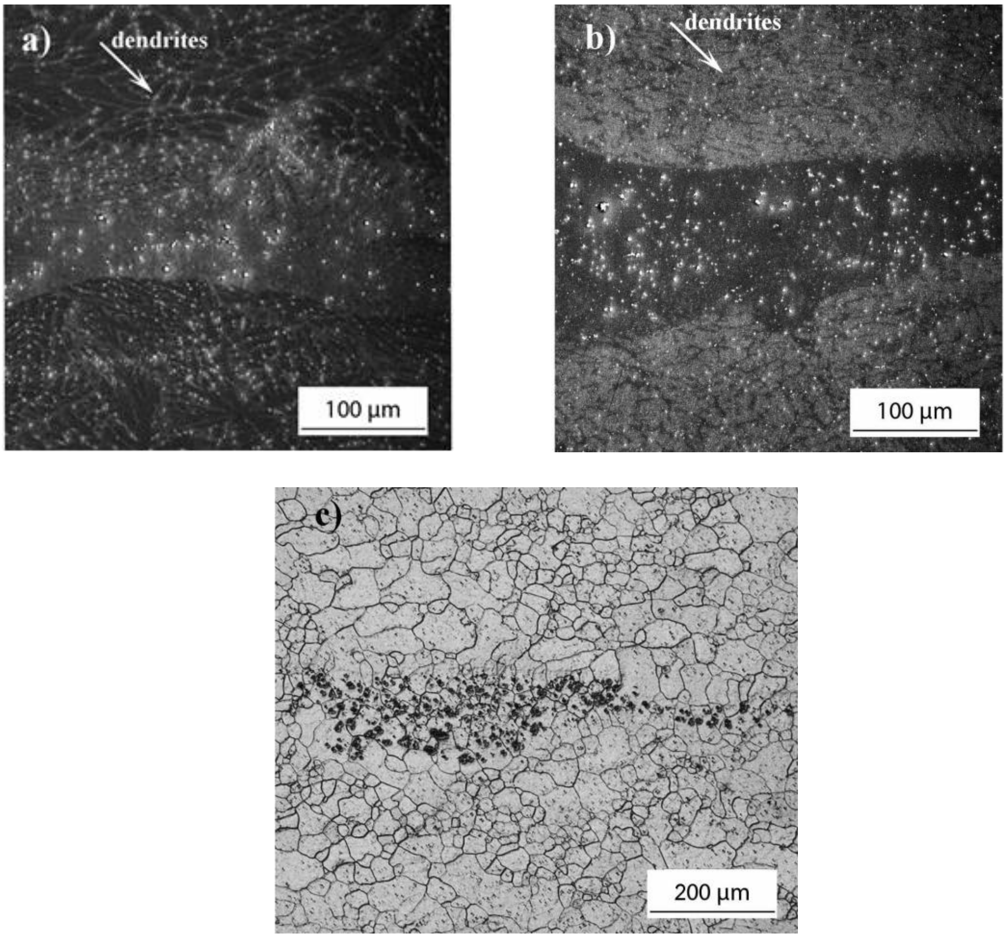

Fig. 2. SEM images of the dendritic structure and central segregation zone in TRC AZ31 magnesium alloy: a) as-cast, b) after aging at 450 °C for 10 h and c) image made by light microscope after aging at 450 °C for 10 h.

3.2 Microhardness

The metallographic studies showed the inhomogeneous structure of the as-cast TRC alloy, which disappears after homogenization. The inhomogeneity of the microstructure also leads to different values of Vickers hardness along the strip. As shown in Fig. 3 and 4, the 5.6 mm TRC AZ31 strip is harder in the middle and near the surfaces. Generally, surface regions are more deformed than the rest of the material [15], which can explain the high hardness values in the as-cast TRC sample near the strips surface. The elevated hardness values in the central zone (Fig. 3 and 4c) reflect the presence of the central segregation, where the finer grains and higher Al and Mn supersaturation are observed.

The refinement of the grain structure after homogenization annealing is accompanied by softening of the TRC alloy due to the recrystallization of the material and removal of the deformed substructure (Fig. 4d). The influence of the β-phase dissolution also could not be excluded. Microhardness drops down to 50 HV0.1 after aging and approaches to the values observed in the CC material. This process is governed mainly by the solid solution concentration.

The as-cast CC alloy did not exhibit any significant changes of the microhardness and grain structure along the cross-section. Nevertheless, redistribution of solutes from coarse particles and solid solution enrichment take place.

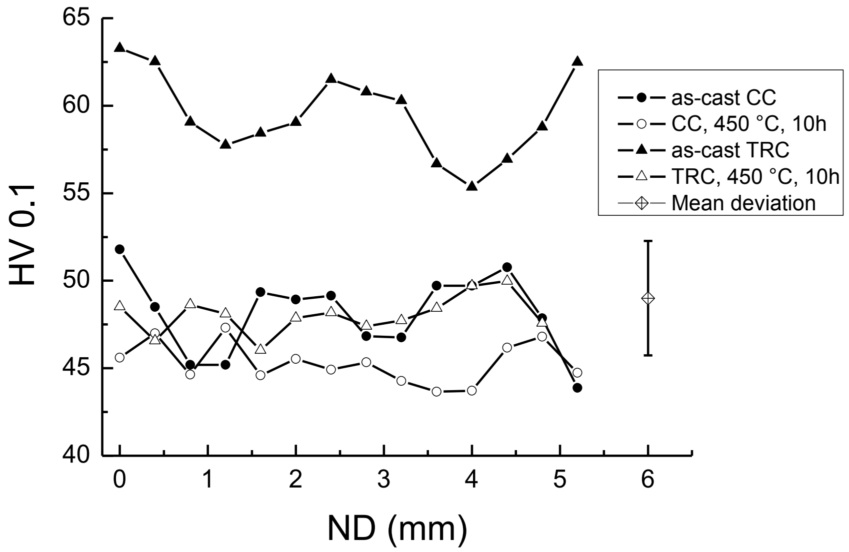

Fig. 3. Evolution of inhomogeneity in AZ31 magnesium alloys during heat treatment.

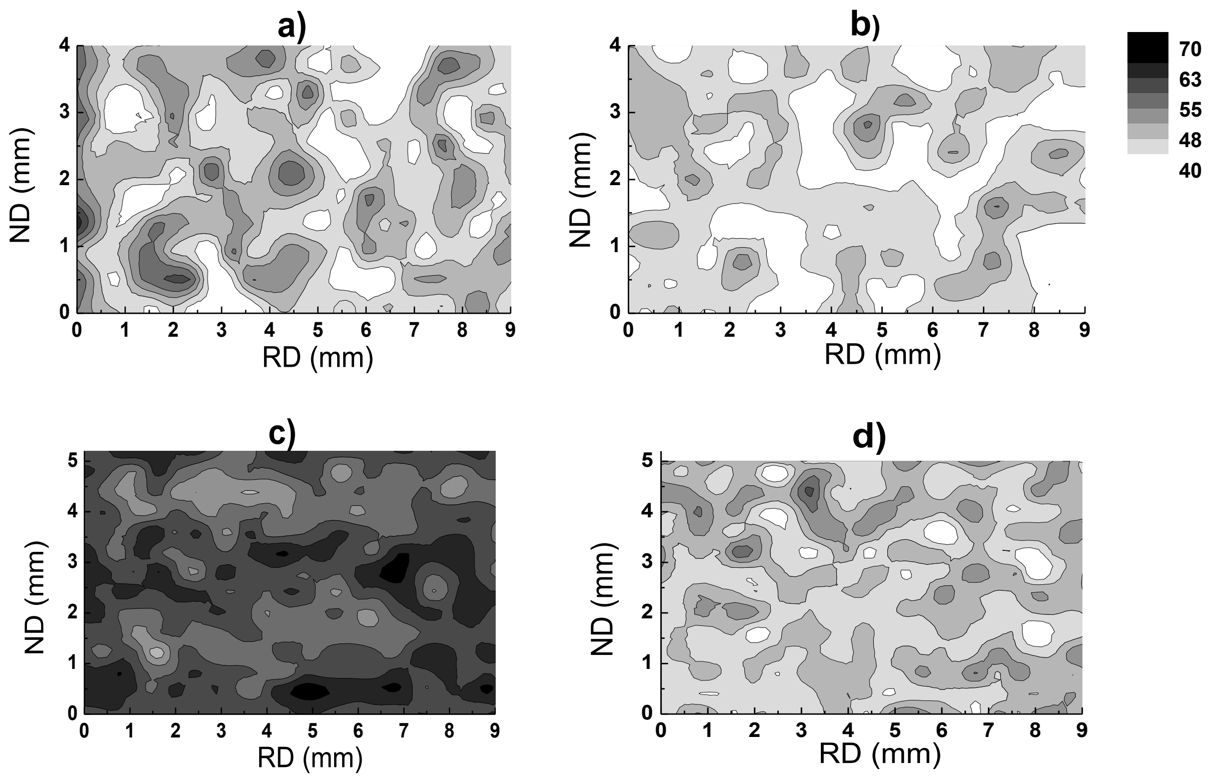

Fig. 4. Microhardness mapping (in MPa) of the cross-section of AZ31 magnesium alloys: a) as-cast CC AZ31 alloy, b) CC alloy after homogenization annealing at 450 °C for 10 h, c) as-cast TRC alloy, d) TRC alloy after homogenization annealing at 450 °C for 10 h.

The investigation of Hay et al. [24] showed that the microhardness of β-$Al_{12}Mg_{17}$ phases is higher than the one of the α-Mg matrix, the composite contribution of the β-phase prevails over the solid solution hardening in the homogenized CC specimen. Therefore, slight 10 % decrease of microhardness of the homogenized CC material was observed.

The changes of the microhardness along the cross-section of the TRC and CC specimens are presented in Fig. 3. The mean standard deviation responds to the fact that the structure in the TRC material is inhomogeneous not only through the thickness of the strip but also along the rolling direction (RD).

3.3 Tensile Properties

Tensile properties are greatly influenced by the microstructure. Fig. 5 shows the typical stress-strain curves of AZ31 Mg alloys during straining at 100, 150, 200, 250, and 300 °C. For the CC alloy tensile test did not show any important changes or even improvement of mechanical properties after homogenization (Fig. 5a, b).

The ductility of both types of CC specimens is less than 15 % and slightly decreases after homogenization while the yield stresses remain almost unchanged as is shown in Fig. 6a. This decrease of ductility is most probably connected with coarser and less uniform grain structure of the homogenized CC material, as well as with the dissolution of the secondary phase particles, which are obstacles for the dislocation movement may result in the enhancement of the strain localization.

In Fig. 5c, d the stress-strain curves of the as-cast and aged TRC alloy are shown. The behavior of the TRC material is entirely different when compared with the CC material. The ductility of the TRC specimens significantly increases at all deformation temperatures, especially at 300 °C, when the ductility riches 36 %. The yield strength, on the contrary, is significantly reduced by ~ 50 % as is shown in Fig. 6a. These remarkable changes are connected with the full recrystallization of the TRC material. The formation of homogeneous fine-grained structure results in a more uniform deformation of the material, while the elimination of the dislocation substructure formed during TRC leads to significant drop of the yield strength in the homogenized specimen.

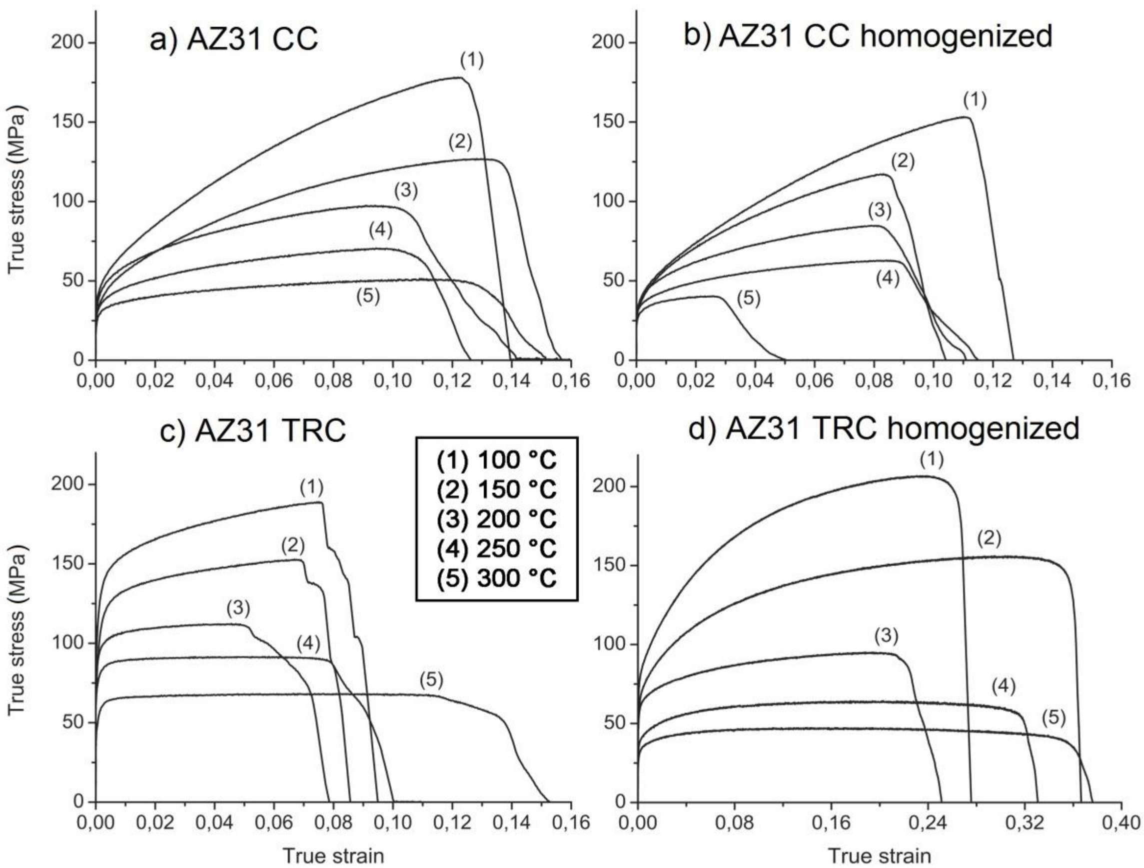

Fig. 5. Stress-strain curves for AZ31 magnesium alloys during annealing at temperature range from 100 °C – 300 °C: a) as-cast CC, b) CC after homogenization annealing at 450 °C for 10 hours, c) as-cast TRC, d) TRC at 450 °C for 10 hours (note the scale on the figure 5d).

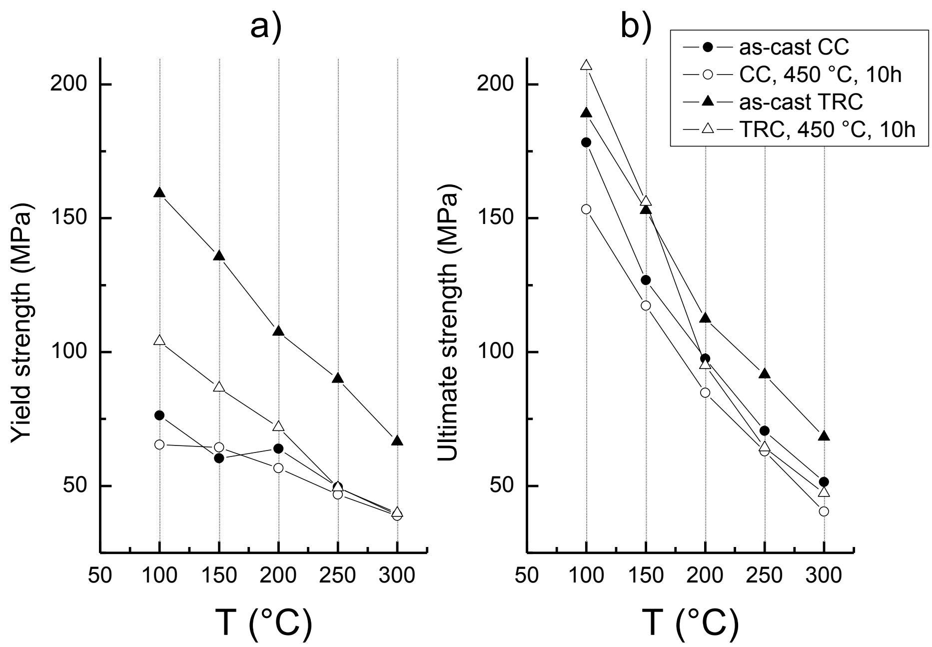

Fig.6. Temperature dependence of the yield (a) and ultimate (b) strengths of the conventionally cast and twin-roll cast AZ31 magnesium alloys before and after aging at 450 °C for 10 h.

The influence of the dislocation recovery also prevails over the Hall-Petch type hardening of the fine-grained structure. The role of the texture of TRC alloy could not be excluded.

The yield stresses and ultimate tensile strengths obtained from the stress-strain curves are summarized in Fig. 6 as a function of annealing temperature. Fig. 6b shows a decreasing of the yield stress and the ultimate strength in all specimens with increasing temperature. The similar rapid decrease of the yield stress was observed by Jager et.al. [25] in the hot rolled AZ31 magnesium alloy during annealing from RT to 350 °C. The highest values of the yield stress were obtained in as-cast TRC material. The homogenized TRC strip after annealing at 300 °C exhibits the largest drop of the ultimate strength of about 80 %.

3. Conclusions

The microstructure and mechanical properties of AZ31 magnesium alloys prepared by different casting techniques were studied in the as-cast and aged states. In the TRC magnesium alloy there are smaller secondary phase particles distributed within the α-Mg matrix than in the CC material. After homogenization at 450 °C for 10 h, β-phase dissolves in both materials and only small amount of β-phase particles inside grains was observed. However, the microstructure of the TRC material is affected more significantly by the heat treatment and originally coarse-grained non-uniform structure is replaced by fine-grained and homogeneous one, except for the central segregation particles that still remain in the material.

It was shown that the originally inhomogeneous structure of the as-cast TRC material which exhibited significant microhardness variations near the surface and in the center of the strip, was replaced by a softer and much more homogeneous one. There are no more systematic regions with higher hardness and the HV values are similar for both alloys after homogenization.

Tensile tests at relatively low strain rate (10^{-3} s^{-1}) revealed improving ductility of the TRC magnesium alloy after homogenization. No significantly changes in tensile properties of the CC cast alloy in the as-cast and aged states were observed.

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