Influence of intensive melt shearing on subsequent hot rolling and the mechanical properties of twin roll cast AZ31 strips

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Abstract

In the present investigation, strips were produced by melt conditioned twin roll casting (MC-TRC) process. The strips were homogenized at 400 C for one hour followed by hot rolling (400 C) process. Severe deformation was applied to deform the strip up to 40% by single and two passes. Tensile tests at elevated temperature (200 C) were conducted on TRC, MC-TRC, and hot rolled MC-TRC samples. Single pass hot rolled MC-TRC sample showed excellent tensile strength and ductility compared to the other samples. Detail microstructural studies revealed that fine grain structure can be obtained by giving maximum deformation during the hot rolling process and finer the grain size better is the tensile properties at warm forming temperature.

Keywords: Twin roll casting; Hot rolling; Tensile test; Optical microstructure

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Introduction

Magnesium and its alloys have high specific strength and their sheet products have great potential for applications in the aerospace, automotive, electronics and general engineering sectors [1, 2]. But due to hexagonal close pack (HCP) crystal structure it cannot be deformed at room temperature. However, fine grain structure in Mg-alloys enhances strength and improves ductility by promoting the operation of nonbasal slip systems and restricting twinning. To obtain fine grain structure in Mg-alloys many process have been employed, such as powder metallurgy, rapid solidification and severe plastic deformation. However, only a small quantity of material can be produced by these processes and also they are expensive and consume more energy. Twin roll casting (TRC) has been demonstrated to be a process capable of producing Mg sheets at significantly reduced cost [3, 4]. However, the quality of the Mg sheets produced by the TRC process is limited by the formation of coarse columnar dendritic grains and centreline segregation, which reduces the strength and ductility of Mg-alloys. To encounter such problems, melt condition technique of intensive melt shearing by external field was employed before TRC process [3]. The strip obtained from MC-TRC process had fine equi-axed grain structure without any centreline segregation. A significant improvement in the tensile properties at lower temperature was achieved by the MC-TRC process. TRC samples have several casting defects [5], which has been minimized or eliminated by MC-TRC process. However, MC-TRC process failed to eliminate porosity inside the strips [3]. Such cast defects can be catastrophic during forming process, as it can initiate cracks. Generally, cast structures and pores in the strips are not desirable. These defects can be minimized or eliminated by subsequent hot rolling. Several research works has been reported in recent past on subsequent hot rolling after TRC process [6, 7]. However, multiple passes were required to obtain the desired thickness as the amount of deformation in each pass has been limited due to restrictions in formability of magnesium alloys.

In the present paper the samples were subjected to hot rolling process to improve its mechanical properties by improving microstructure and decreasing cast defects.

Experimental

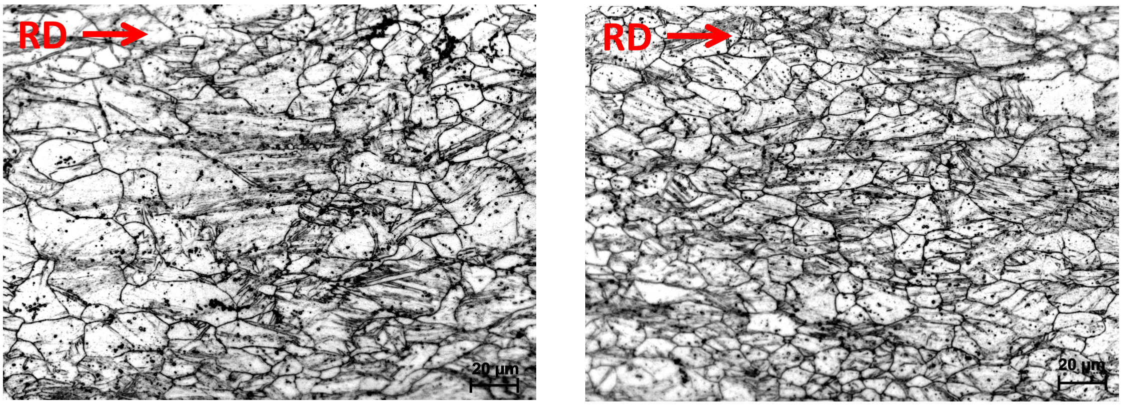
AZ31 (Mg-3.4Al-0.97Zn-0.31Mn, in wt. %) alloy strips were produced by MC-TRC process [3]. The samples were homogenized at 400 C for one hour before hot rolling at the same temperature. The samples were hot rolled from MC-TRC strips (2.8 mm) to desire tensile test sample (1.7 mm) thickness. The reduction was achieved by one and two passes and they have been designated as HR1 and HR2, respectively. The total reduction was approximately 40% of initial thickness. For the two pass reduction, 20% reduction was applied in each pass. The sample was heated at 400 C for 1 hour after first pass. TRC and MC-TRC samples of 1.7 mm strip thickness were also produced for comparison.

The samples were ground, polished and etched before microstructural observation. The microstructural examinations were carried out by optical microscope. All the microstructures presented in this paper were taken from longitudinal section of the strip. The grain sizes were measured from the optical microstructures. The equivalent grain diameter was calculated from the area of the selected grain. For accuracy in measuring grain diameter, more than hundred readings were taken for each grain size data.

Tensile tests were conducted on a Gleeble 3800 thermo-mechanical simulator, which can heat a specimen by direct resistance heating at a rate as high as 1000 K/s. Tensile tests were performed to failure at 200 C after the specimens had been soaked at the target temperature for 1 minute. The tests were carried out at constant strain rate of 1 /s, representative of typical strain rates in hot forming processes. The vertical cross-section of the fractured surface was studied using an optical microscope.

Results and discussion

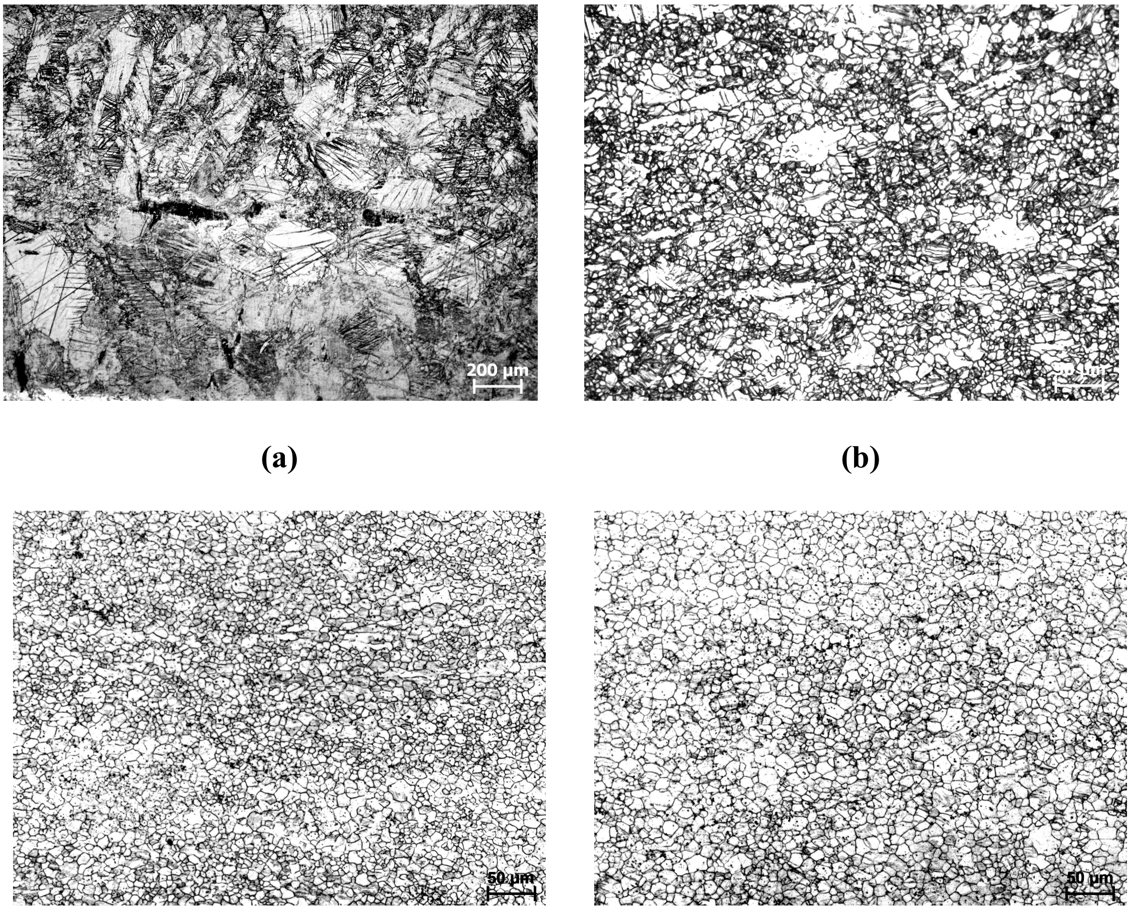
The optical microstructure of the samples prepared by TRC and MC-TRC processes are shown elsewhere [3]. The microstructures showed cast dendritic structure in both the cases. However, TRC and MC-TRC samples showed large columnar and fine equiaxed dendritic structure, respectively. The microstructures of hot rolled MC-TRC samples are shown in Fig. 1. As mentioned in previous section 40% deformation in one pass was successfully achieved on MC-TRC samples. It can be attributed to the fine uniform equiaxed grain structure obtained during MC-TRC process. Due to heavy deformation cast dendritic structure has been completely eliminated (Fig. 1). Deformation bands parallel to the rolling direction (RD) was observed in all the hot rolled samples. The average micro-hardness values for HR1 and HR2 were 76.83±1.26 and 73.72±1.16 HV5, respectively. HR1 showed higher hardness compared to HR2 samples. It can be correlated to the amount of deformation, higher the amount of deformation more is the hardness value [8]. Hence, HR1 had more stored energy compared to HR2 in the form of internal stresses due to deformation.



(a) **(b)**

Fig. 1 – Optical microstructures of (a) HR1 and (b) HR2 sample after hot rolling

Fig. 2 shows the homogenized microstructures of all the samples. TRC samples showed large grains (261.08±65.47 m) with centreline segregation (Fig. 2(a)). However, the MC-TRC sample shows fine equi-axed grain (12.6±0.73 m) structure (Fig. 2(b)). The difference in grain structure between TRC and MC-TRC samples after homogenization treatment can be attributed to its solidification and deformation mechanism during the casting processes. The amount of deformation in MC-TRC strip is significantly higher compared to TRC strip during the casting process, which results in finer grain size in the case of MC-TRC samples during homogenization process. The detailed explanation has been reported elsewhere [3]. The centreline segregation is hardly altered by homogenization. Some relatively larger grains were observed in homogenized MC-TRC samples. These grains can be the primary grains, which failed to recrystallize during homogenization process. Fig. 2(c, d) are the homogenized hot rolled microstructure of HR1 and HR2. The grain sizes are much finer in comparison to MC-TRC samples. Also primary grains are not observed in the case of homogenized HR1 and HR2 samples. This can be attributed to the severe deformation during hot rolling process, which enables uniform nucleation of fresh grains. The average grain size HR1 and HR2 are 7.08±2.38 m and 12.05±2.64 m, respectively. Finer grain size of HR1 samples can be attributed to the higher amount of deformation which increases the number of nucleating sites for fresh grains to form.



(a) (b) (c) (d)

Fig. 2 – Optical microstructure of homogenized samples at 400 C for 1 hour after (a) TRC, (b) MCTRC, (c) MCTRC + HR1 and (d) MCTRC + HR2.

Fig. 3 shows tensile test results of all the homogenised samples tested at 200 C. To understand the changes in microstructure during tensile test vertical section of fractured tensile test samples were studied (Fig. 4). TRC sample showed lowest tensile strength and elongation among all. This can be attributed to the coarse and non-uniform microstructure with centreline segregation. The non-uniform microstructure (larger and small grains) is also found in the vertical section of the TRC sample's fracture surface (Fig. 4(a)). However, MC-TRC sample showed better strength and ductility compared to TRC sample. It can be attributed to the uniform and fine grain structure obtained by MC-TRC after homogenization treatment. Fig. 4(b) showed uniform grain structure with grains slightly elongated towards the test direction (TD). HR1 and HR2 samples showed better tensile property compared to TRC and MCTRC samples. This is obvious as hot rolling eliminates several cast defects like porosity [9] and helps to obtain more uniform microstructure. However, the strength and elongation of HR1 sample was significantly higher compared to HR2 sample. This can be attributed to the finer grain structure of HR1 sample. Also the vertical section of the fracture surfaces showed finer grain size in the case of HR1 (7.7±2.38 m) sample compared to HR2 (12.7±4.5 m) sample. This suggests higher deformation by single pass is more effective to obtain finer uniform grain microstructure compared to multiple passes. Hence, finer the grain size higher is the strength and ductility of AZ31 alloy strip.

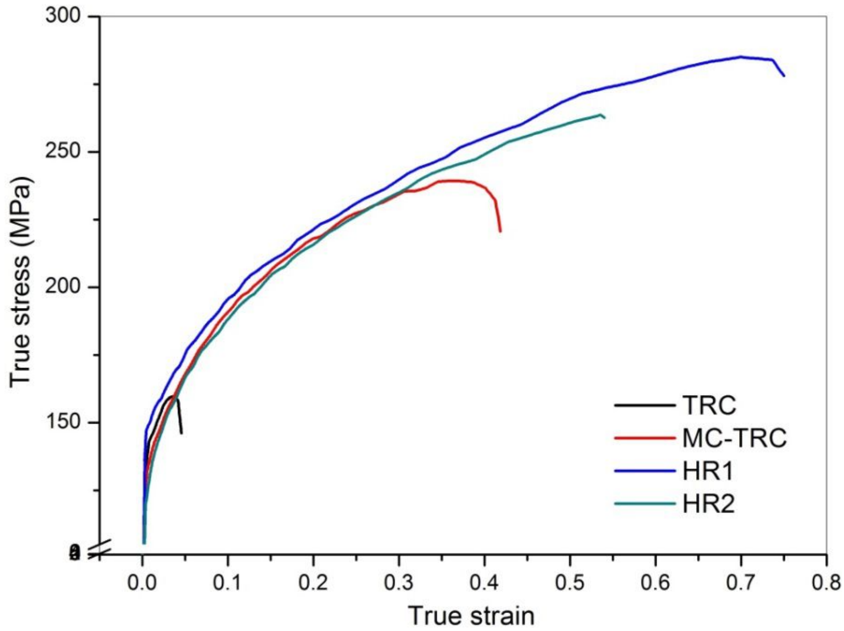


Fig. 3 – Comparison of tensile flow stress curves at 200 C

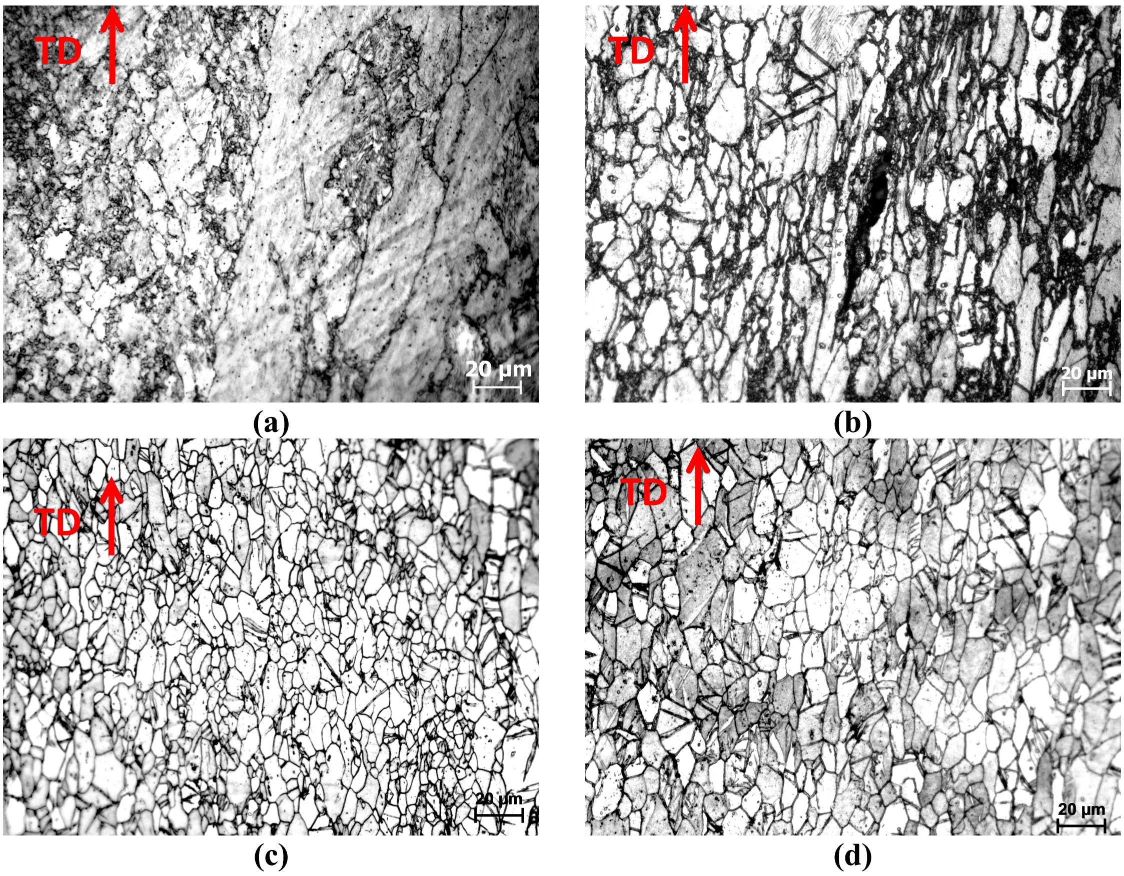


Fig. 4 - Vertical section microstructures of fractured tensile samples of (a) TRC, (b) MC-TRC, (c) HR1 and (d) HR2

Conclusion

Following conclusions can be drawn on the basis of present investigation.

1. AZ31 alloy strips produced by MC-TRC process can be deformed up to 40% by hot rolling in a single pass.
2. Tensile properties of hot rolled MC-TRC samples were much superior to that of TRC and MC-TRC samples at 200 C due to very fine uniform grain structure.
3. Hot rolled MC-TRC sample deformed to 40% by single pass had better strength and ductility compared to two pass reduction (20% in each pass).

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References

[1] Lee S, Chen YH, Wang JY. Isothermal sheet formability of magnesium alloy AZ31 and AZ61. J Mater Process Technol 2002;124:19–24.

[2] Takuda H, Enami T, Kubota K, The formability of a thin sheet of Mg–8.5Li–1Zn alloy. J Mater Process Technol 2000;10:281–286.

[3] Das S, Barekar NS, Fakir OE, Wang L, Rao AKP, Patel JB, Kotadia HR, Bhagurkar A, Dear JP, Fan Z. Effect of melt conditioning on heat treatment and mechanical properties of AZ31 alloy strips produced by Twin Roll Casting. Mater Sci & Engg A 2014;620:223–232.

[4] Bayandorian I, Huang Y, Fan Z, Pawar S, Zhou X, Thompson GE. The impact of melt conditioned twin-roll casting on the downstream processing of an AZ31 magnesium alloy. Metall Mater Trans A 2012;43:1035-1047.

[5] Yun M, Lokyer S, Hunt JD. Twin roll casting of aluminium alloys. Mater Sci & Engg A 2000;280: 116–123.

[6] Kim KH, Suh BC, Bae JH, Shim MS, Kim S, Kim NJ. Microstructure and texture evolution of Mg alloys during twin-roll casting and subsequent hot rolling. Scrip Mater 2010;63:716-720.

[7] Masoumi M, Zarandi F, Pekguleryuz MO. Microstructure and texture studies on twin-roll cast AZ31 (Mg-3wt.%Al-1wt.%Zn) alloy and the effect of thermomechanical processing. Mater Sci & Engg A 2011;528:1268-1279.

[8] Zi A, Palkowski H. Direct strip casting and hot rolling of an AZ31 magnesium alloy. Mater Sci & Engg A 2010;528:559–565.

[9] Shukla AK, Kumar RS, Murty SVSN, Mondal K. Enhancement of high temperature ductility of hot-pressed Cu–Cr–Nb alloy by hot rolling. Mater Sci & Engg A 2013;577:36–42.