

# DEVELOPMENT OF ROLLING TECHNOLOGY FOR TWIN ROLL CASTED 1500MM WIDE MAGNESIUM AZ31 ALLOY

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## Abstract

Magnesium alloy AZ31 sheets of 4.5-6.5mm thick and 1500mm width were produced by twin roll strip casting first time in Turkey. Afterwards, sheets were hot and cold rolled down to less than 1mm both by laboratory and industrial scale rolls. Microstructure of the sheet was analyzed by optical microscope and transmission electron microscope. In addition, pole figures have been obtained by XRD studies. Mechanical properties were investigated by tensile tests and also hardness measurements. Annealing heat treatments were performed on the produced sheets.

## Introduction

Magnesium alloys have been considered as advanced materials for many applications, especially for transportation, aerospace and electronic industries. Other than being the lightest structural metal (density: 1.74 g/cm<sup>3</sup>), it has high specific strength, excellent damping capacity, good machinability and good electromagnetic shield properties [1]. Moreover, magnesium wrought alloys have good mechanical properties compared to other alternative traditional structural metals. There is a high demand of using magnesium alloy for transportation, aerospace and electronic industries. However, application of magnesium wrought alloy sheets for these industries is limited due to the cost of the magnesium material [2]. Decreasing the magnesium sheet prices can be met through twin-roll casting [2]. There is a wide range of application of twin-roll casting technique on magnesium alloys [3-14]

Recently, an industrial scale magnesium twin roll casting plant has been set up in Turkey. 1500mm wide magnesium alloy AZ31, AZ61, AZ91, AM50 and AM60 sheets of 4.5-6.5mm thickness have been successfully casted [15,16]. To our knowledge, these are the widest magnesium alloy sheets that have been produced by this method in the world so far. Afterwards, sheets were hot and cold rolled down to less than 1mm both by laboratory and industrial scale rolls.

## Experimental Procedure

The reason for choosing AZ31 alloy in the present study is that it is the most common wrought Mg alloy. The chemical composition of magnesium alloy AZ31 sheets are listed in Table 1.

**Table 1.** The chemical composition of magnesium alloy sheets.

Sample	Al	Zn	Mn	Mg
AZ31	2.7	1.03	0.31	bal.

The magnesium AZ31 alloy strips were cut to 5cmx20cm size samples. Sheet samples were homogenized at 400°C. After homogenization, sheets have been warm/hot rolled using a laboratory scale rolling mill. Prior to the rolling, the rolls were heated by gas flame. The samples were preheated in a furnace for approximately 20 minutes before rolling. The temperature was controlled by a FLIR Systems ThermoCAM thermal camera and a thermocouple (Figure 1). Magnesium alloy AZ31 sheets were rolled at 300°C with 25% deformation at a single pass. In another trial, samples were hot rolled at 450°C and a maximum deformation amount of 50% has been reached in one rolling pass.

The experience and knowledge obtained from the laboratory scale rolling have been adjusted to industrial scale rolling. An electrical resistant furnace has been put next to 1600mm wide horizontal rolling system (Figure 2). Before rolling, homogenization heat treatment was applied on the twin roll casted Magnesium AZ31 sheets at 400°C. Rolling procedure was performed just after heating the sheets at 400°C in the furnace. Final sheet thickness of 1.0mm was achieved after approximately 10 passes rolling. Twin roll casting direction and rolling direction were the same orientations.

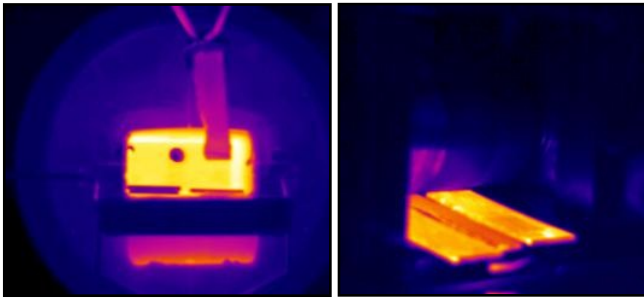
Metallographic samples were prepared to observe the microstructure in the length, width and thickness directions. The samples were mounted and polished starting with SiC paper, followed by diamond slurry and colloidal silica. Etching was done using acetic picral acid solution (4.2g picric acid, 10ml acetic acid, 70ml ethanol, 10ml water) face up for 5 seconds immediately followed by washing with ethanol. Heyn Lineal Intercept procedure (ASTM E112-96 standard) is applied for measuring the size of the grains.

In order to evaluate the deformation behavior of the AZ31B sheet, tensile tests were performed. Tensile samples were machined via EDM (Electric discharge machining) in accordance with ASTM standard B557M. The samples were subsize specimens. A Zwick Z250 tensile testing machine at a strain rate of 1x10<sup>-3</sup> s<sup>-1</sup> was used for tensile testing. Vickers microhardness measurements were performed with a 200g applied load using a Zwick ZHV10 device.

For X-ray diffraction (XRD) texture studies, specimens were polished to third quarters of sheet thickness. Texture measurements were performed by PANalytical X'Pert Pro operated at 45kV and 40mA.

For transmission electron microscopy (TEM) studies, specimens were cut; 3mm diameter discs were punched and ground to a thickness less than 80µm. Punched specimens were dimple ground with Gatan 656 Dimple Grinder. Specimens were ion polished at 3kV with Gatan 691 Precision Ion Polishing System

(PIPS). The foils were examined with a JEOL 2100 TEM with a LaB<sub>6</sub> filament operated at 200kV.



**Figure 1.** Thermal camera pictures during hot rolling.



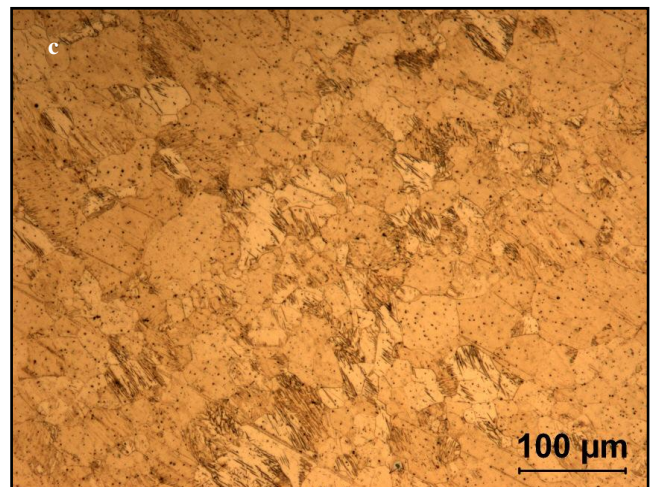
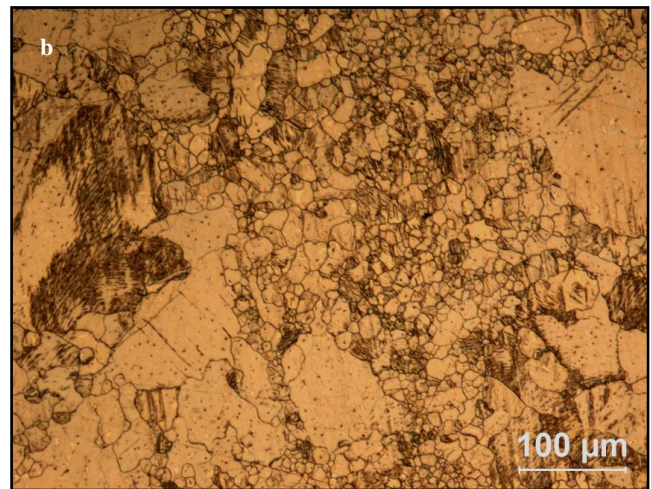
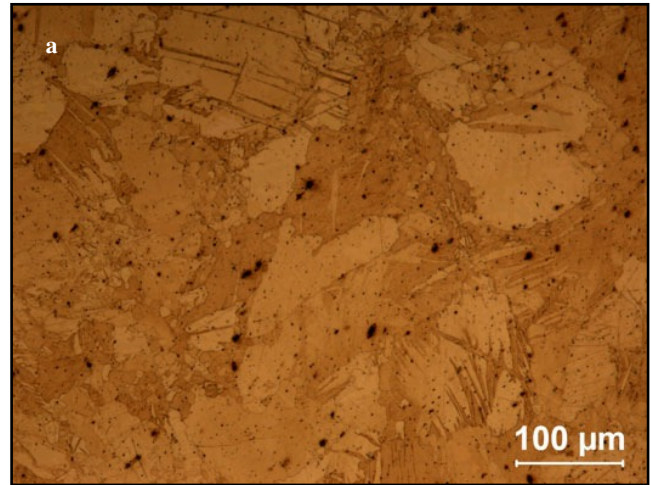
**Figure 2.** Photograph of industrial scale rolling mill system and furnace used for hot rolling.

### Results

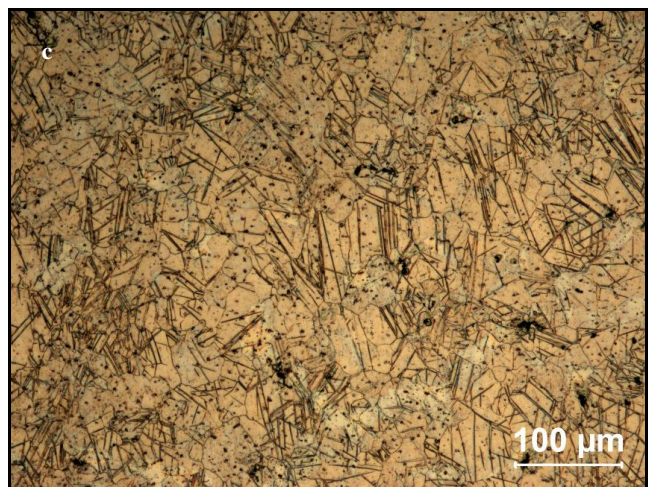
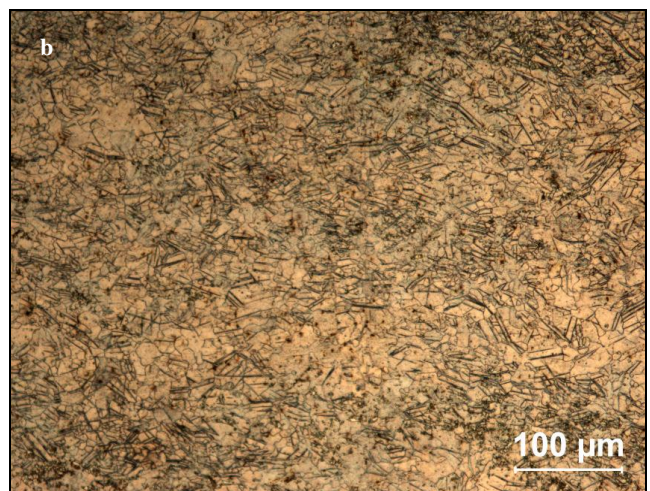
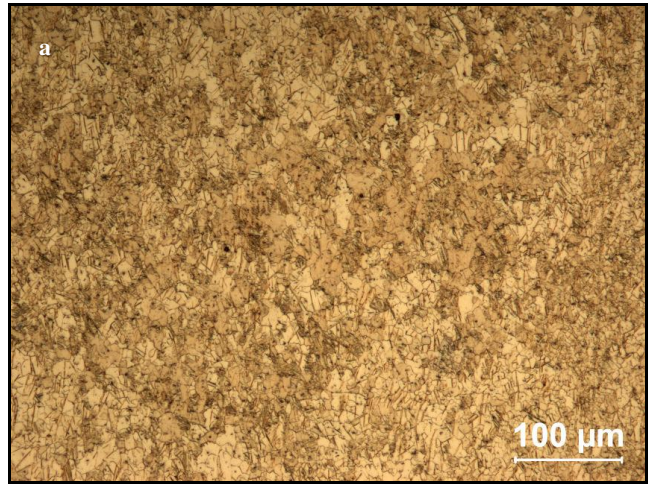
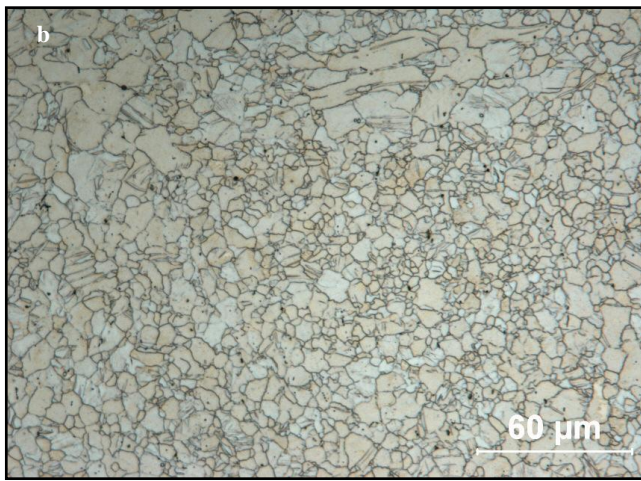
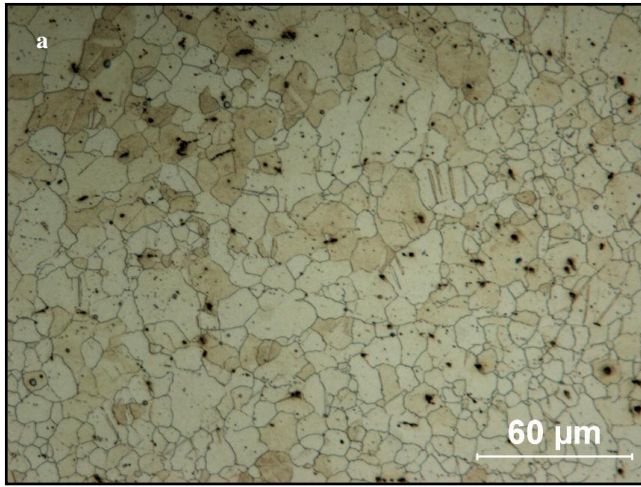
Homogenization heat treatments were applied on the produced Mg AZ31 sheets. As a beginning, heat treatment was performed between 350-450°C for 1-2-4-6hr in laboratory scale furnace. Figure 5 shows plan view microstructures of TRC 6.5mm AZ31 magnesium alloys after homogenization at 350°C, 400°C and 450°C for 2hr.

After laboratory scale warm/hot rolling processes the grain size of less than 10µm has been achieved in some regions as shown in Figure 4. With industrial scale rolling mills, AZ31 sheets have been rolled down to 1.0mm. Figure 5 and 6 shows three examples of the rolled sheets: 2.0, 1.5 and 1.0mm thick in the as-rolled condition from plan-view and cross-sectional views. Figure 7 shows a TEM picture of the as-rolled AZ31 sheet with lots of twins and dislocations.

Annealing heat treatments were applied to the as-rolled Mg AZ31 sheets between 350-450°C for 1-2-4-6hr in laboratory furnace. In Figure 8, microstructures are given for three Mg AZ31 rolled sheets after homogenization heat treatments at 400°C for 6hr. The twin structure is changed to equiaxed grains in most places. Grain sizes of less than 20µm are achieved. Homogenization processes are under investigation for longer times for industrial scale sheets.



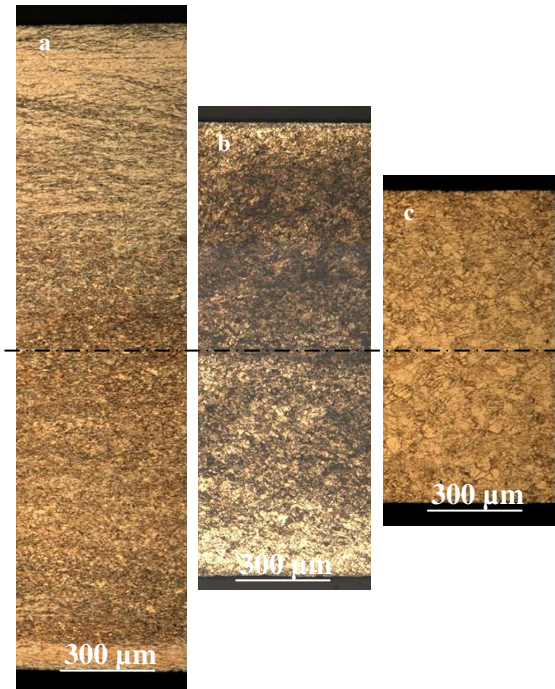
**Figure 3.** Plan view microstructures of TRC 6.5mm AZ31 magnesium alloys after homogenization at **a)** 350°C-2hr, **b)** 400°C-2hr and **c)** 450°C-2hr.



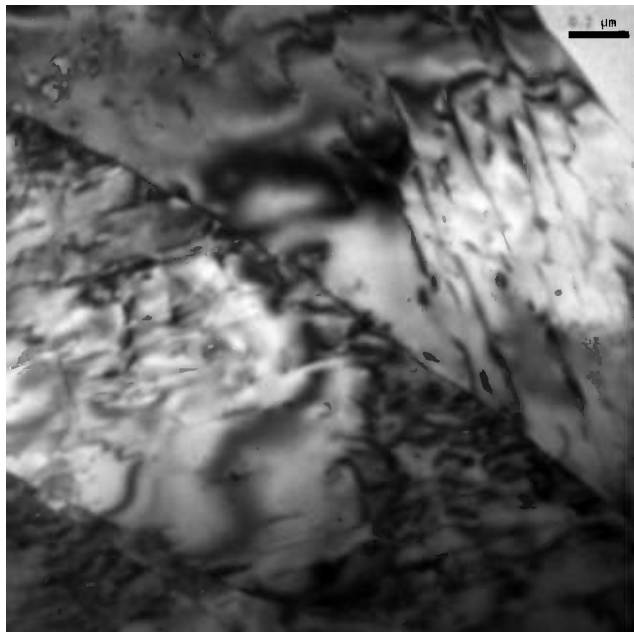
**Figure 4.** Light micrographs showing the microstructures after **a)** rolling at 300°C, and **b)** rolling at 450°C with laboratory scale rolling-mills.

Figure 9 is showing Rolling Direction, RD, and Transverse Direction, TD, sample orientations. From tensile test results of the as-rolled sheets it is observed that UTS values of 300MPa and elongation values of 10% can be achieved (Figure 10). Moreover, by the homogenization heat treatment applied to TRC 6.5mm AZ31 sheets ductility values of more than 20% elongation was achieved (Figure 11). Similar annealing heat treatments performed on as-rolled AZ31 sheets resulted to better ductility compared to the as-rolled condition as shown in Figure 12.

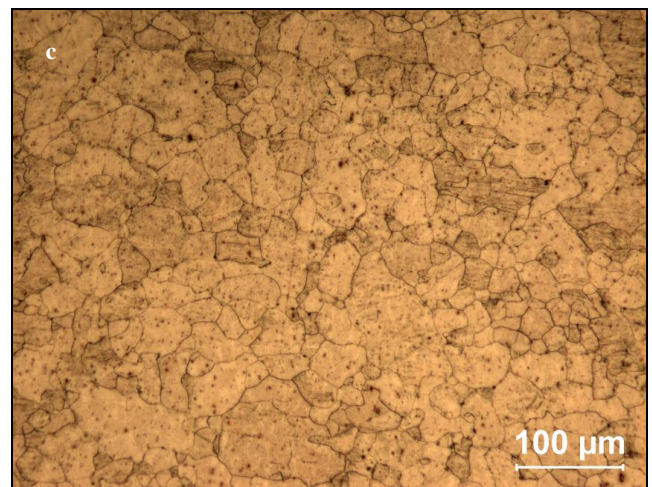
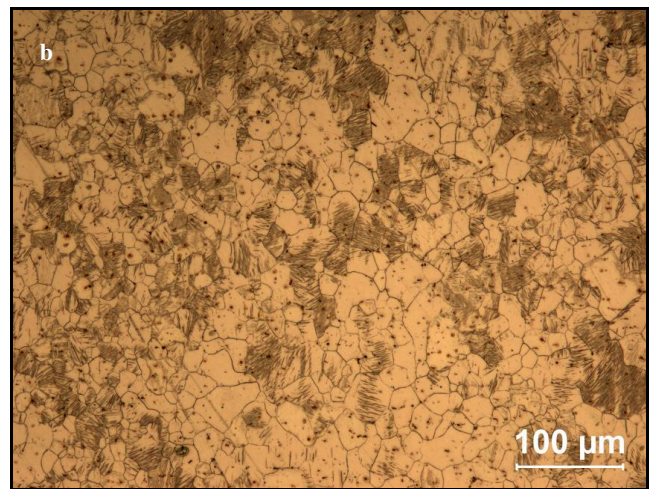
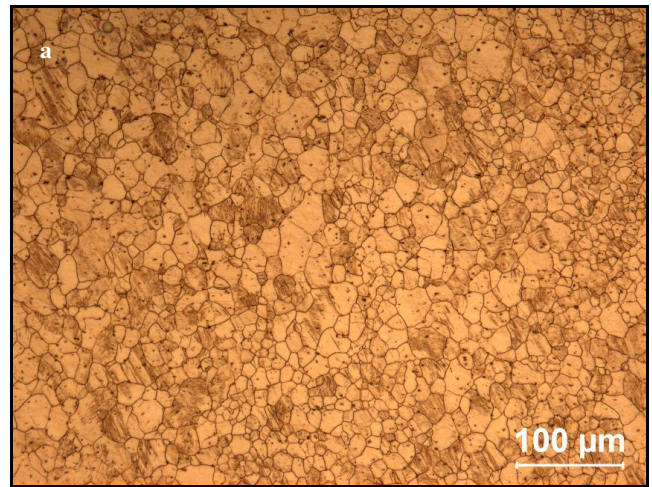
**Figure 5.** As-rolled plan view microstructures of **a)** 2.0 mm, **b)** 1.5 mm and **c)** 1.0 mm AZ31 magnesium alloys.



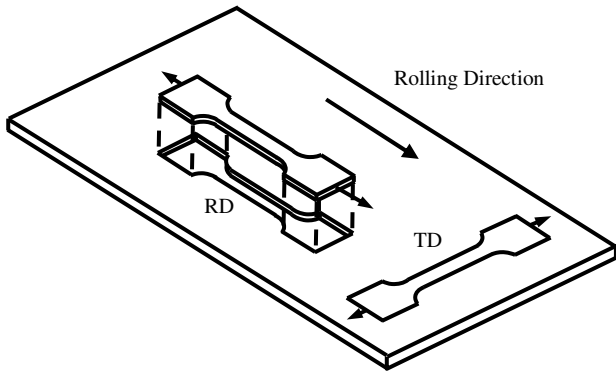
**Figure 6.** As-rolled cross-sectional microstructural views of **a)** 2.0 mm, **b)** 1.5 mm, **c)** 1.0 mm AZ31 magnesium alloys (the dashed line shows the centerline)



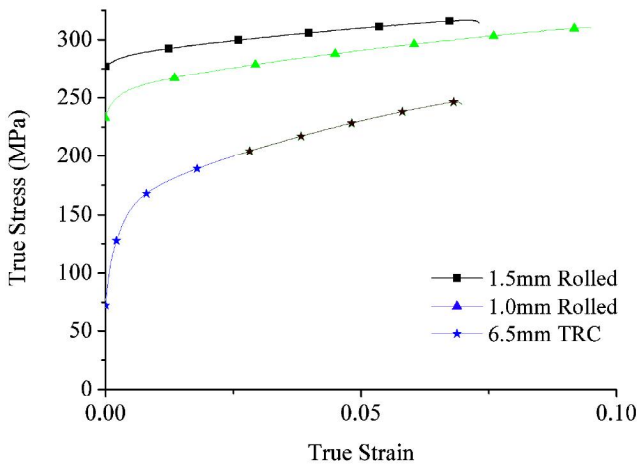
**Figure 7.** TEM picture of as-rolled AZ31 sheet showing twins and dislocations.



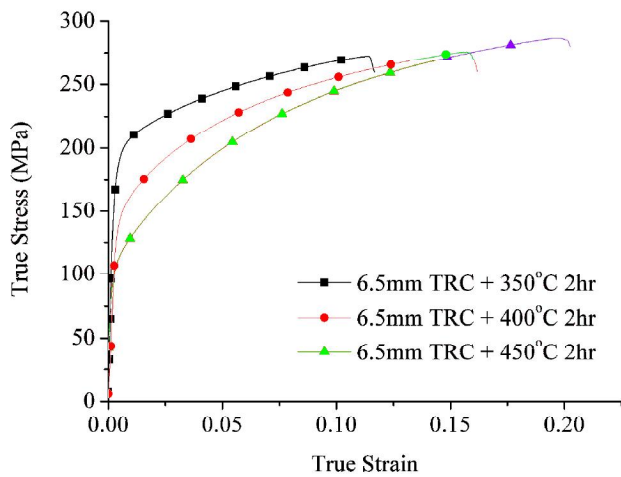
**Figure 8.** Plan views of **a)** 2.0 mm, **b)** 1.5 mm, **c)** 1.0 mm AZ31 magnesium alloys after annealing at 400°C for 6hr.



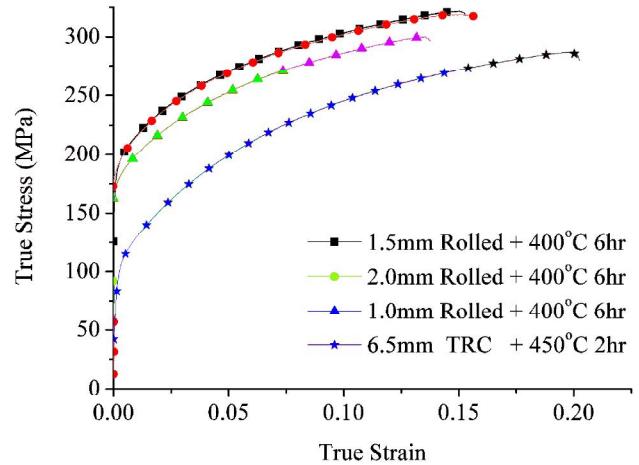
**Figure 9.** Schematic picture showing sample orientations.



**Figure 10.** Flow curve of as TRC 6.5mm, and as-rolled 1.0mm and 1.5mm AZ31 sheets.

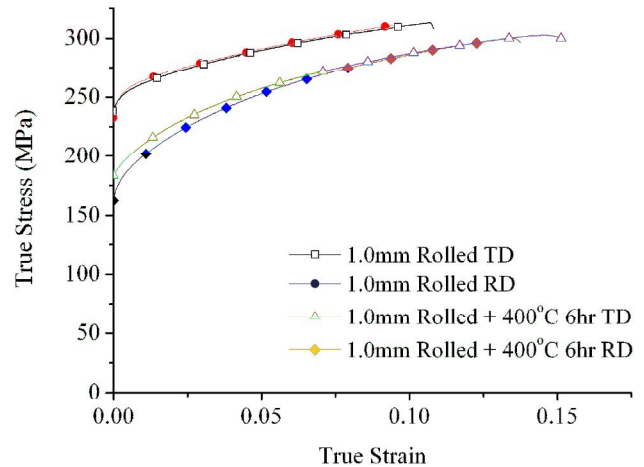


**Figure 11.** Flow curve of TRC 6.5mm AZ31 sheet after homogenized at 350-400-450°C for 2hr for RD samples.



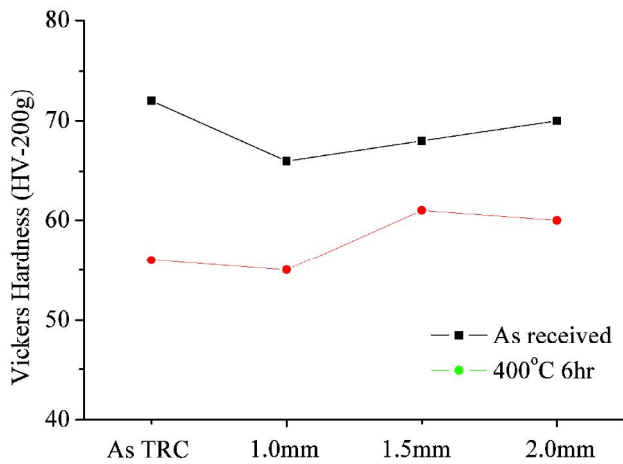
**Figure 12.** Flow curve of TRC 6.5mm, rolled 1.0, 1.5, 2.0 mm AZ31 sheets after homogenization heat treatments.

Figure 13 shows true stress vs. true strain of 1.0mm sheet in the as rolled condition and after annealing at 400°C for 6hr heat treatment conditions for RD and TD directions. It is observed that, for both conditions, strength and strain values are similar for RD and TD. It can be clearly said that, there is less strength and strain anisotropy compared to commercially available magnesium sheets produced by conventional methods [17,18].



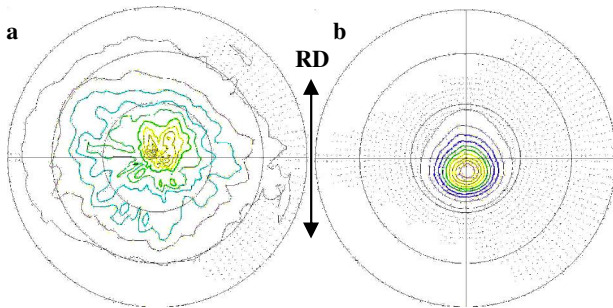
**Figure 13.** Flow curve of 1.0mm sheet in the as rolled condition and after annealing at 400°C for 6hr heat treatment conditions for RD and TD directions.

Micro-Vickers hardness measurements were also performed by applying 200g load on the Mg AZ31 sheets both in the as received (as TRC or as-rolled) conditions and also after annealing at 400°C for 6hr heat treatment conditions as shown in Figure 14. After annealing hardness values decreased as expected.



**Figure 14.** Micro-vickers hardness values of AZ sheets in as TRC and as-rolled conditions, and after annealing at 400°C for 6hr heat treatment conditions.

(0002) pole figures (Figure 15) of the as TRC 6.5mm and rolled 1.0mm AZ31 sheets show that texture is more random compared to commercially available AZ31 sheets produced by conventional methods [17,18].



**Figure15.** (0002) pole figures of **a)** as TRC 6.5mm and **b)** rolled 1.0mm AZ31 alloy sheets.

### Summary and Conclusions

Magnesium alloys Continuous sheet castings of 4.5-6.5mm thick and 1500mm width are easily achievable by TRC method. The conditions employed for thermomechanical processing showed that atmospheric conditions for such processes can be used and that the microstructure and mechanical properties of the produced sheets can be improved significantly. Processing for thinner sheets has been achieved down to 1.0mm with hot rolling. Further processes will focus on cold/hot rolling of different magnesium alloys using the same TRC plant in Turkey.

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