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Microstructure and Texture of MX20 after Conventional Rolling and Rolling from Twin Rolled Cast Strip

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Abstract. Two main impediments are currenty discussed with respect to the industrial application of magnesium sheets. First, the low formability of magnesium sheets requires many rolling passes to roll cast slabs to final gauge, which leads, second, to high costs for the production of magnesium sheets. An alternative cost-saving process chain for magnesium sheets with enhanced properties is the feedstock production by twin roll casting (TRC). In the TRC process, liquid metal proceeds from a furnace over a pipe into a crucible and then flows between a pair of counter rotating, internally cooled rolls. The metal solidifies upon touch with the cooled rolls and gets rolled to a strip.

This paper refers to the comparison of the two processing routes on the example of the aluminum-free magnesium alloy MX20 (2 wt% Mn and 0.5 wt% Ca). Both kinds of production processes like casting and twin roll casting have an influence on the microstructure and texture of the feedstock material for the subsequent rolling process. The paper reports on the results of casting and twin roll casting experiments of this alloy. Furthermore, rolling trials are conducted and the deformation behavior of the sheets are presented and discussed with respect to the developed microstructures and textures. The different morphology of precipitates in the cast and twin roll cast feedstock material is used to improve the ductility of the magnesium alloy MX20.

Introduction

Principally, the comparably low formability of magnesium sheets is caused by a lower number of active deformation mechanisms, at least in comparison to metals with a cubic crystal structure like steel. The low formability [1, 2] of magnesium crystals has a substantial influence on the processability during massive deformation. It has been found that the addition of rare earth elements improves the properties of magnesium sheets like formability, strength and corrosion resistance [3]. Magnesium sheets with an addition of rare earth elements form a weaker texture and fine-grained microstructure [4-6].

The commercial alloy ME21 is an aluminum free magnesium alloy and therefore avoids low-melting eutectic transformations in contrast to classical aluminum-containing magnesium alloys. It reveals high strength at higher temperatures and high creep resistance in comparison to other magnesium alloys [7]. However, alloying with rare earth elements is problematic, because of their strategic importance for many industrial applications and the tight supply situation. Therefore, they are classified as a critical resource group whose supply is associated with high costs and leads to economic dependences on imports of these elements. Additionally, their fabrication requires high industrial efforts and causes environmental issues. Thus, the usage of rare earth elements is supposed to be avoided along with newer material selection approaches. Adding Ca as a substitute to rare earth to Mg-Zn-based alloys leads to similar texture evolution and texture behavior as RE containing alloys [7, 8]. Because of this, in these experiments Ca replaces the rare earth elements in the Mg-Mn base alloy.

Experimental Procedure

For the conventional sheet rolling process the alloy MX20 (2 wt% Mn and 0.5 wt% Ca) was cast in cubic billets (120 mm x 70 mm x 270 mm) at HZG using a modified gravity casting process. The billets were homogenized at 450 °C for 16 h to reduce the amount of precipitates. In parallel, strips of MX20 were received from twin roll casting experiments from the Institute of Metal Forming at the TU Bergakademie Freiberg. For this material a homogenization heat treatment was applied at 460 °C for 8 h. For the rolling trials, the billets were machined to slabs with dimensions 20 mm x 100 mm x 200 mm. Strips were prepared to plates with dimensions of 330 mm x 600 mm x 5 mm. Slabs and strips were both rolled to sheet thickness using a Danieli rolling mill with roll diameter of 360 mm and a width of 500 mm. The different feedstock were rolled at a temperature of 450 °C and the rolling procedure consisted of two rolling schedules of 8 resp. 19 passes with different degrees of deformation between $\varphi = 0.1$ and $\varphi = 0.2$, leading to a final gauge of approximately 1.5 mm.

To homogenize the microstructure of sheets, a heat treatment of 1h at 450 °C was applied after rolling. After all processing steps, the microstructures of the materials were examined by using optical microscopy. Standard metallographic sample preparation techniques were applied and an etchant based on picric acid was used to reveal grains and grain boundaries [9]. Texture measurements were carried out on the sheet mid-planes using a Panalytical X-ray diffractometer setup. The pole figures were measured up to a tilt angle of 70°, which allowed the recalculation of full pole figures by using an open source software routine MTEX [10]. Subsequently, Erichsen Tests were conducted to see how the different processing routes influence the formability of the sheets.

Properties of the Sheets Rolled from the Cast Billet

Figure 1 shows the microstructure of the cast MX20 billet in the as cast condition and after the heat treatment. The cast billet displays coarse dendritic grains and a relatively homogeneous grain size distribution. Furthermore, some coarse Mn containing precipitates can be detected in the grains by EDX analysis (figure 2). Besides, finer Ca containing precipitates are observed along the dendrite arms. The heat treatment of 16 h at 450 °C decreases the number of precipitates at the grain boundaries. The dendritic microstructure disappears also in the grains.

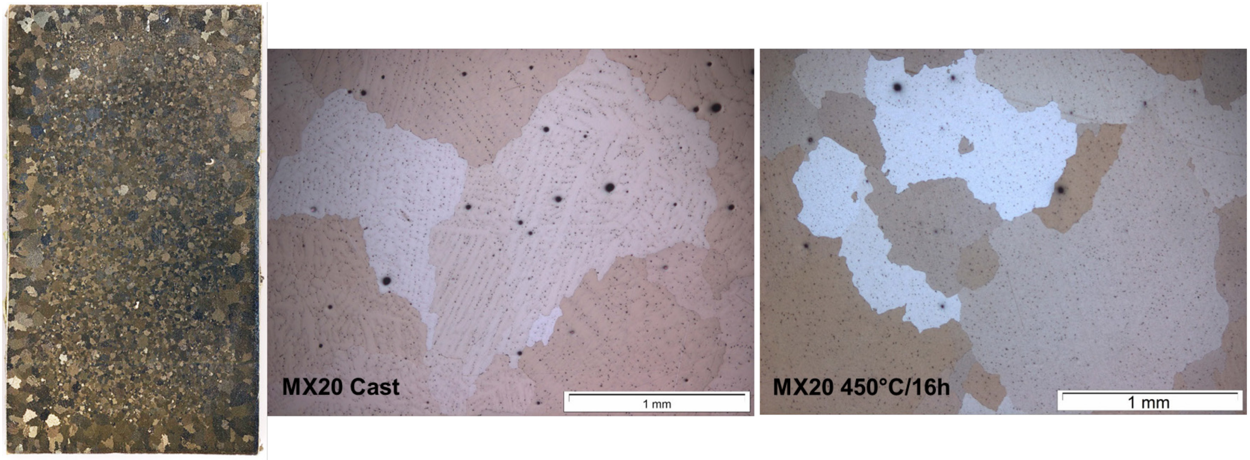
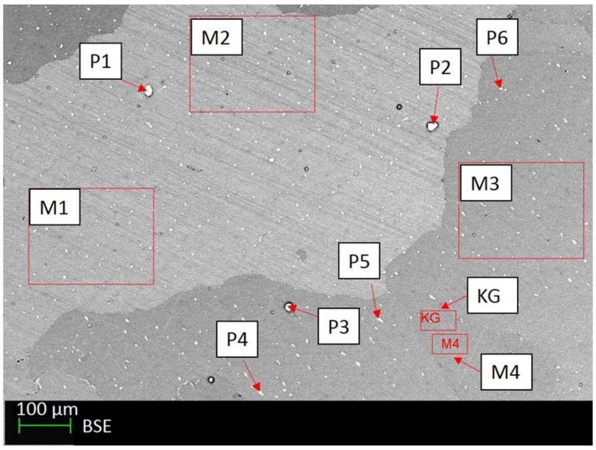
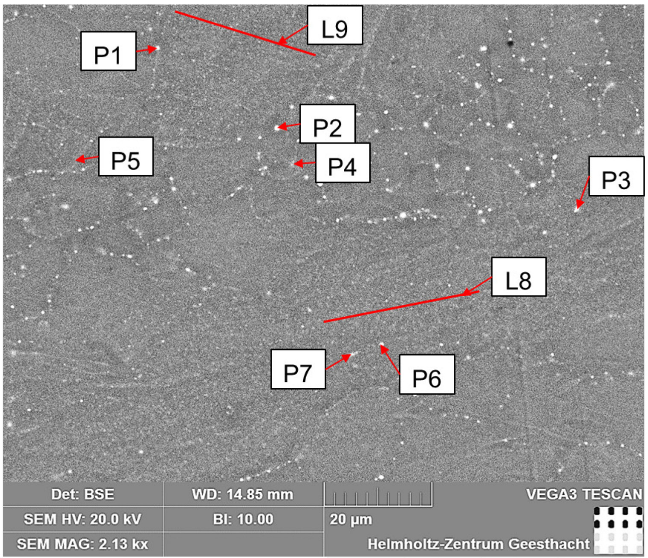


Fig. 1: MX20 macro section and microstructure in the as cast condition (left side) and the microstructure after the heat treatment at 450°C for 16 h (right side)



	Mn	Ca	O
P1 - P3	80,0	0,05	13,0
P4 - P5	0,35	7,50	8,0
P6	59,0	0,10	19,0
M1 - M4	0,70	0,30	1,75
KG	0,80	0,30	1,70



	Mn	Ca	O
P1	1,83	0,19	0,97
P2	7,47	0,52	2,42
P3	0,74	0,35	1,33
P4	0,85	0,72	1,47

	Mn	Ca	O
P5	0,64	0,80	1,30
P6	0,69	0,11	1,44
P7	0,89	0,29	1,42
L8	1,61	0,22	0,45
L9	1,65	0,23	0,44

Fig. 2: EDX analysis of the cast MX20 billet after heat treatment of 450 °C for 16 h (left) and of the twin roll cast strip after heat treatment of 460 °C for 8 h (right)

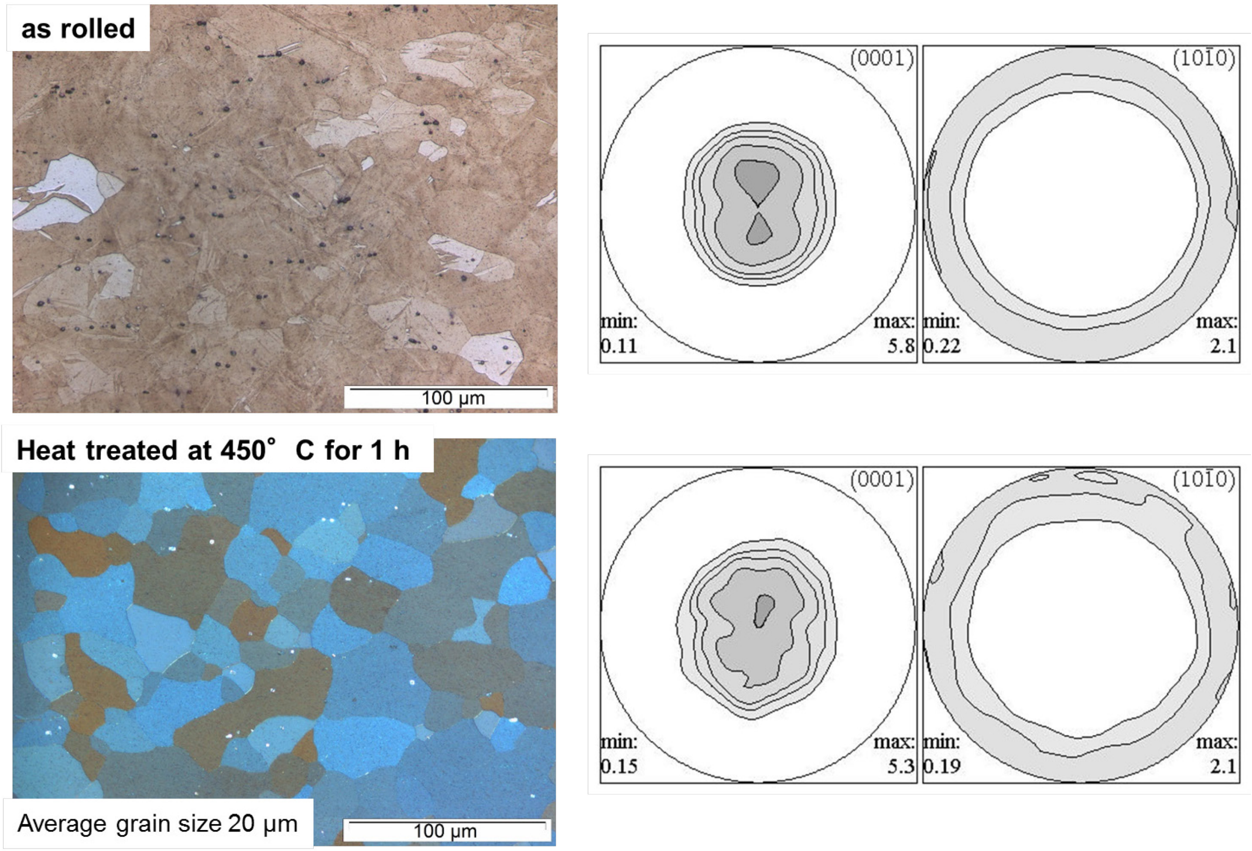


Fig. 3: Microstructure of a MX20 sheet rolled from the cast slab

The microstructure of the sheet rolled from slabs is shown in figure 3 in the as rolled condition and after the heat treatment. The microstructures of the as rolled sheets are in a basically unrecrystallized but deformed condition. After the heat treatment the sheet exhibits a fully recrystallized microstructure with an average grain size of 20 µm. Besides, in the sheet rolled from the cast slabs Mn containing precipitates are aligned in small lines, so called stringers. These stringers are associated with particles from the original cast billet structure that also underwent deformation, i.e. they did not form during rolling procedure.

The basal and prismatic pole figures of the sheet rolled form the slab, after rolling and after heat treatment are also presented in figure 3. In general, an alignment of basal planes parallel to the sheet plane is found, however, highest intensities are in split peaks corresponding to a tilt of the c-axis out of the normal direction towards the rolling direction. Prismatic poles are visualized as randomly distributed parallel to the normal direction in both cases. The differences between the as-rolled condition and after the heat treatment are very small. Thus, to distinct texture development is revealed for this alloy.

Properties of the Sheets Rolled from the TRC Strip

Figure 4 presents the microstructure of the twin roll cast strip. The material shows a typical microstructure of a twin roll cast strip, with some elongated, columnar grains in the top and bottom area and equiaxed grains in the center. Nevertheless, most grains in the top and bottom area are also equiaxed, because of the deformation received after solidification. Compared to the cast and heat treated billet the microstructure in the heat-treated twin roll cast strip is much finer. Additional EDX analysis of twin roll cast strip validates that the precipitates in the microstructure are mainly located at the grain boundaries and the precipitates are much finer, compared to the cast material (figure 2).

Figure 5 presents the microstructure of the sheet rolled from the TRC strip also as rolled and heat-treated. The microstructure of the sheet is mainly un-recrystallized after the rolling process. However, the homogenized sheet exhibits a fully recrystallized microstructure. The sheet rolled from the TRC-strip shows a very fine and homogeneous microstructure with an average grain size of 13 µm. In comparison to the sheet rolled from the cast slab the precipitates in this sheet are mainly located at the grain boundaries (figure 5).

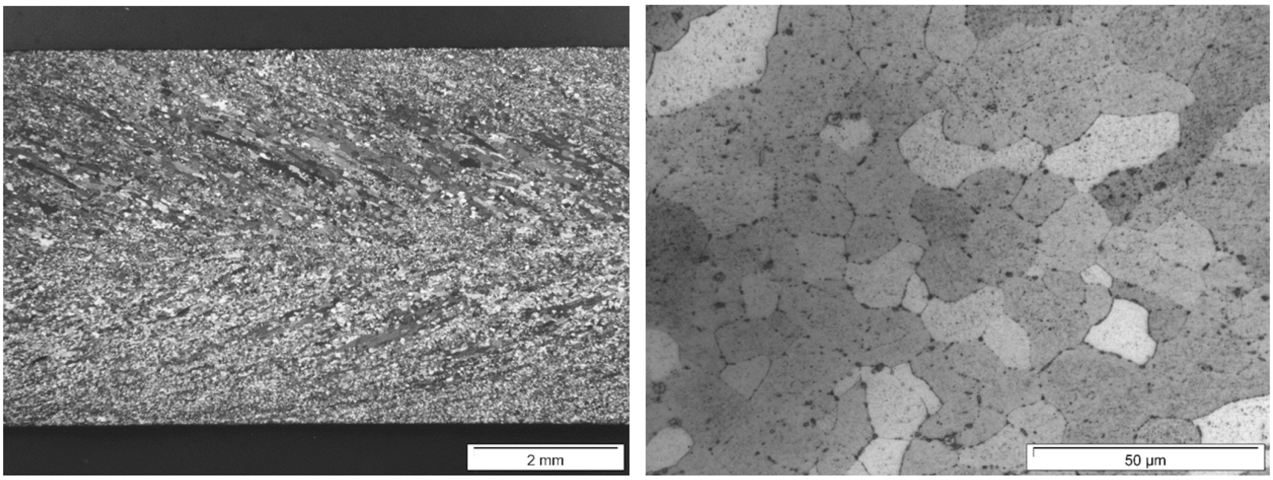


Fig. 4: MX20 twin roll cast and heat-treated at 460°C for 8 h left side overview of the strip, right side center area with higher magnification

Besides, figures 5 shows the basal and prismatic pole figures, after rolling and after heat treatment. The texture is very similar to the the ones of the sheets rolled from cast slab but somewhat weaker. Still, the split peak component is clearly visible in both conditions. In this case annealing also seems to contribute to some texture weakening as visualized in the maximum pole intensities.

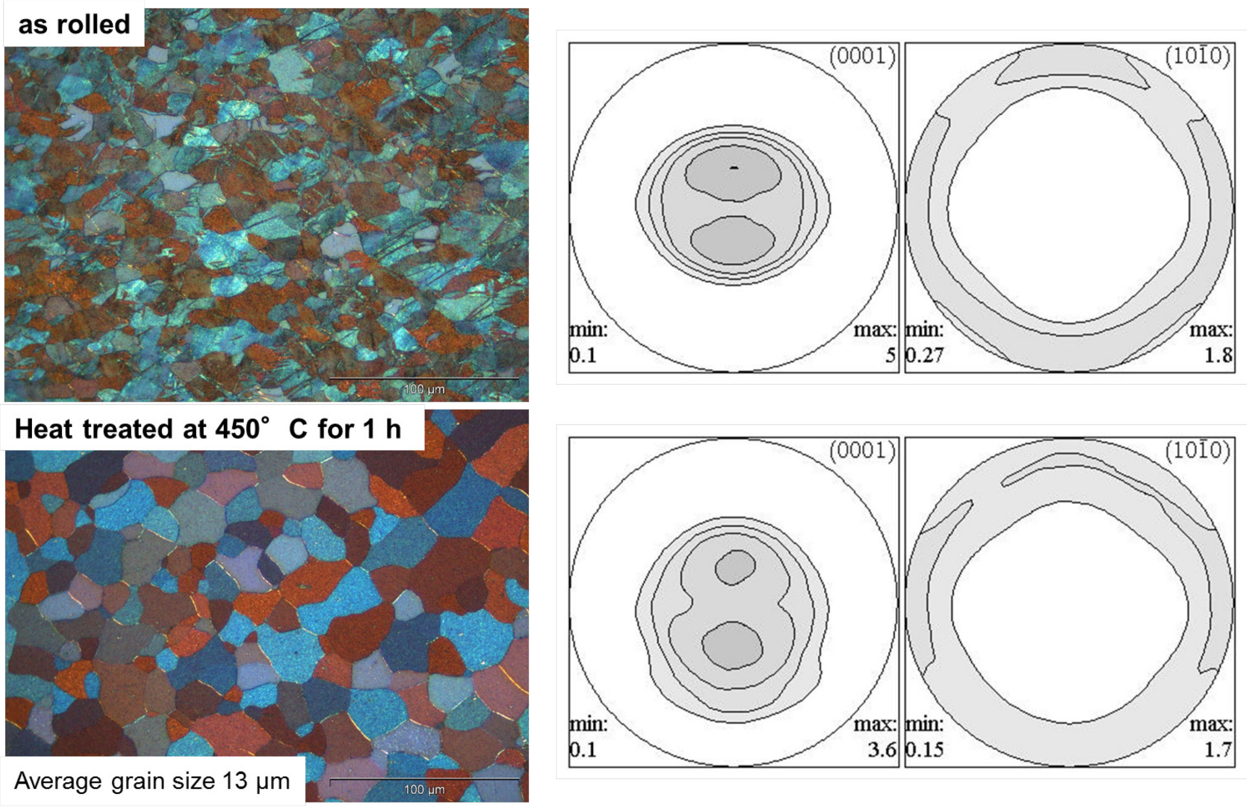
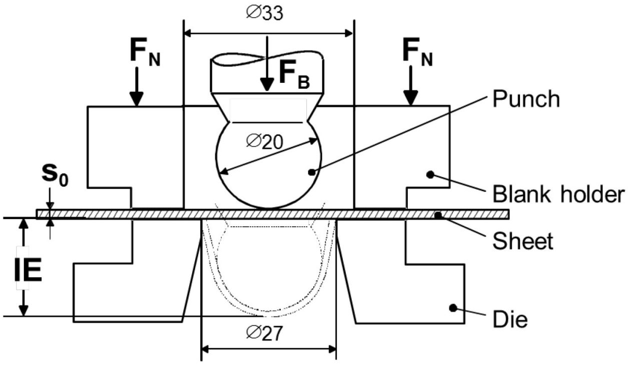


Fig. 5: Microstructure of a MX20 sheet rolled from twin roll cast strip

Comparison of the Formability of Both Sheets

In order to see how the different processing routes influence the ductility of the sheets, Erichsen Tests were performed. The comparative maximum drawing depth, the Erichsen Index (IE) of both sheets are shown in Figure 6. The sheets produced via twin roll casting exhibit higher formability compared to the conventional produced sheets, which corresponds to the different formation of precipitates in the microstructure of the conventional rolled sheets.



Max. draw depth IE [mm]	
MX20 conv. rolled	MX20 TRC
2.2±0.1	6.0±0.4

Fig. 6: Principle and results of the Erichsen Tests

Summary

The results point out that the production process has a significant influence on the properties of the resulting sheets. It can be seen clearly in the Erichsen Tests that the sheet produced via twin roll casting achieves higher formability compared to the one of a conventional production route. This could be seen as a result of the formation of finer precipitates in the twin roll cast strip compared to the conventional rolled material caused by the much higher solidification rate in the TRC process. These finer precipitates in the strip material are also more located at the grain boundaries in the final sheet after rolling. During rolling, coarse precipitates in the cast billets form stringers in the microstructure of sheets, which reduces the ductility and the strength significantly. The minor thickness of the strip material results in a minor total degree of deformation in the sheets, which reduces the risk of defects in the final sheets. Furthermore, in comparison to the conventional rolled sheets those produced by twin roll casting show the same shape of texture but with a less pronounced intensity because of the minor number of rolling passes needed to reach final gauge.

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