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Influence of Process Parameters on Twin Roll Cast Strip of the Alloy AZ31

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Abstract. Reducing vehicle weight and emissions by lightweight design is a major goal of the automotive industry. Magnesium as the lightest structural metal offers a significant weight saving potential compared to steel and aluminium. Cast magnesium components are widely used, e.g. as engine blocks or gear box housings. The application of magnesium sheets is currently hampered by the low formability of magnesium which means that a large number of rolling passes is required to roll a DC cast slab to final gauge sheet. This large number of rolling steps is the main reason for the high cost of magnesium sheets.

Twin-roll casting (TRC) is an alternative, economic production process for the generation of fine-grained feedstock materials that subsequently can be warm rolled to thin sheets. It therefore receives attention in actual research and development projects for the application of magnesium alloys as prospective light metal solutions. This production process for thin strips combines solidification and rolling into one single production step and therefore saves a number of rolling and annealing passes in comparison to the conventional rolling process. The main goal of the activities at the Magnesium Innovation Centre MagIC of the Helmholtz-Centre Geesthacht (HZG) is the development of wrought magnesium alloys and their introduction into industrial, structural applications. The current focus of the research work is on alloy design and their processing for magnesium sheets produced by twin roll casting. In order to understand the influence of process parameters on the microstructure and texture the first twin roll casting experiments were performed with the alloy AZ31 (Mg-3Al-1Zn-Mn) as benchmark. As an example, the influence of melt temperature on the microstructure of the strip is presented and discussed with respect to arising material properties. Optimisation of process parameters of twin roll casting and the subsequent rolling of the sheets, offers the possibility to produce high quality sheet material.

Introduction

At present, magnesium alloys used in the automobile industry are mainly processed by die casting. This technology allows components with a complex geometry to be manufactured. However, the mechanical properties of die cast materials often do not meet essential requirements with regard to endurance, strength, ductility, etc. A promising alternative for thin, large area parts, such as automotive body components is to utilize sheet material. Sheet metal formed parts are characterized by superior mechanical properties and high quality surfaces without pores in comparison to die cast components. Substitution of conventional sheet materials such as steel or aluminum by magnesium sheets could lead to significant weight savings. However, it will be necessary to produce sheet material with competitive properties in an economic production process.

Twin-roll casting is an economic production process for the generation of fine-grained feedstock materials that can subsequently be warm rolled to thin sheets. This production process for thin strips combines solidification and rolling into one single production step. Thus, it saves a number of rolling and annealing passes in comparison to the conventional rolling process. The twin roll casting technology is already well established in for example the aluminium industry. However, applications for magnesium alloys are in their infancy at present [1]. There are worldwide a small number of industrial or laboratory scale twin roll casters installed at universities, companies and research facilities. Initial results from these activities on conventional wrought and cast alloys have shown promising sheet properties [2-6].

Twin Roll Casting Trials

The development of wrought magnesium alloys and their introduction into industrial, structural applications are the main goal of the activities at the Magnesium Innovation Centre MagIC of the Helmholtz-Centre Geesthacht (HZG). The current focus of the research work is on alloy design and the development of processing technologies for semi-finished magnesium products. In the particular case of sheet materials, it has been recognized that the feedstock for the warm-rolling process needs to be in the form of thin bands as they are produced via twin roll casting, if thin magnesium sheets are to become competitive industrial products. For this purpose HZG has installed the twin roll caster shown in Fig. 1.

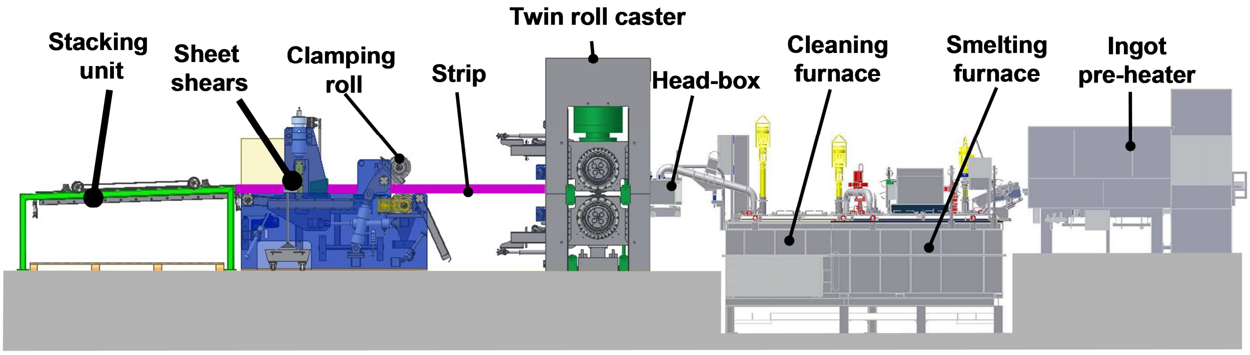

Fig. 1. Twin roll casting equipment at HZG.

The twin roll casting line consists of a furnace line (Striko-Westofen) and a twin roll caster (Novelis, Jumbo 3CM). The twin roll caster is designed to produce thin strips of magnesium with a maximum width of 650 mm and a thickness in the range of 4-12 mm at a maximum rolling speed of 6 m/min. The furnace line is configured to allow manual loading of raw materials as ingots and the possibility to vary the alloy composition, i.e. cast strips can be made from different alloys. The furnace line includes an ingot pre-heater to remove humidity from the ingots and accelerate melting in the melting furnace. After pre-heating, the feedstock is transferred to the melting furnace. A second transfer device conveys the molten metal to the cleaning furnace. From the cleaning furnace the melt is transferred to the head-box which is connected to the tip. The liquid metal flows by gravity through the tip into the gap of the rolls of the twin roll caster (Fig. 2). The metal exiting the tip solidifies on the rolls into a strip which is then deformed by the rolls. Important features of the strip such as microstructure and texture are influenced by the position of the solidification front.

The position of the solidification front is controlled mainly by the melt temperature and the strip speed. Its position influences the degree of deformation in the strip. If the solidification front is located at the exit of the tip, the degree of deformation increases because the strip is fully solidified before entering the rolls. If the solidification front moves to the kissing point of the rolls, the strip is not completely frozen and the degree of solid-state deformation decreases.

All twin roll cast experiments were performed with the above mentioned equipment. The melt temperature was 715 °C and 650 °C. In these initial trials the commercial magnesium alloy AZ31 was used and the strips cast had a width of 350 mm. After twin roll casting, the microstructure of the strips was analyzed using optical microscopy. Standard metallographic sample preparation techniques were employed and an etchant based on picric acid was used to reveal grains and grain boundaries [7].

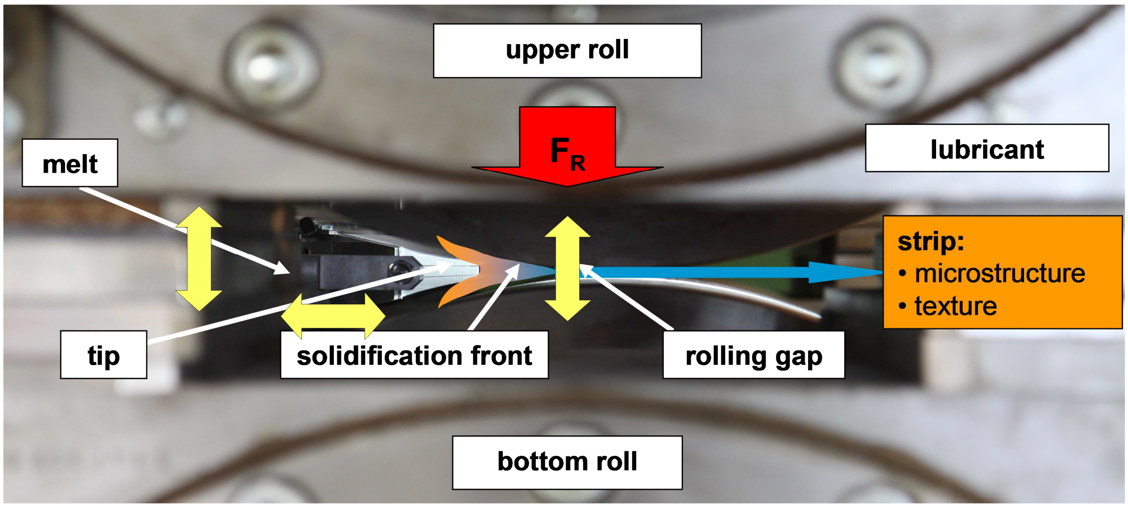

Fig. 2. Principle and parameters of the twin roll casting process.

Texture measurements were performed on the sheet mid-planes using a Panalytical X-ray diffractometer setup. The (002) and (100) pole figures were measured and used to calculate the complete orientation distribution which allows the recalculation and presentation of complete pole figures.

Results of the Twin Roll Casting Trials

Figs. 3 & 4 depict the microstructures and textures of samples extracted from strips obtained from three different twin roll casting trials. Each figure shows the longitudinal and transverse sections of the strips. Fig. 3 illustrates a clear dendritic structure growing from the upper and bottom surfaces of the strip towards the centre, with a region containing equiaxed grains at the centre.

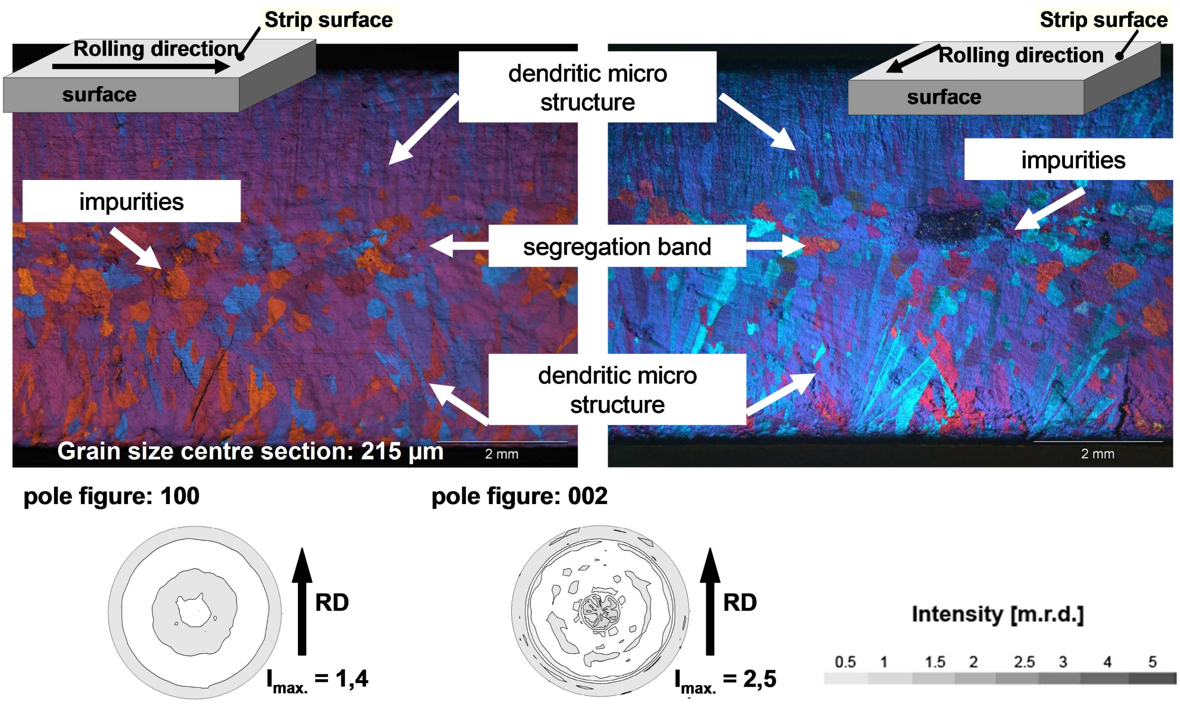

Fig. 3. Microstructure and mid-plane texture of the alloy AZ31 after twin roll casting with a melt temperature of 715 °C and a thickness of 6 mm.

A remarkable feature is the strong segregation band containing a large amount of impurities at the centre-line of the strip. Such segregation is a common effect in this type of processing. The formation of this segregation band can only be avoided by optimisation of the process parameters:

casting speed, roll gap and melt temperature which influence the thermal gradient. The large number of dendritic grains in the upper and lower regions of the strip is an indicator for a low degree of deformation during the rolling operation. Fig. 3 also shows recalculated (100) and (002) pole figures of the strip which both exhibit low maximum intensities (I_{max} = 1.4 and I_{max} = 2.5 respectively). A very weak alignment of basal planes parallel to the strip plane corresponds to a low degree of deformation.

The microstructure and texture of a twin roll cast strip with a melt temperature of 650 °C and a thickness of 5 mm are shown in Figure 4. This microstructure differs significantly from the microstructures of the previous strip. It consists of smaller equiaxed grains, which are elongated in the rolling direction in the near-surface regions of the strip. This microstructure is typical for deformed material. Both the (100) and (002) pole figures shown in Fig. 4 are characterised by higher maximum intensities (I_{max} = 2.6 and I_{max} = 4.1 respectively) than in the other two strips and a distinct basal character of the texture. A remarkable feature is that the angular distribution of basal planes is broader towards the transverse direction rather than to the rolling direction. This is a different texture compared to typical textures of conventionally rolled magnesium sheets of this alloy where a broader angular distribution is typically found towards the rolling direction, if any. However, Haßlinger et al. [8] were able to show that such textures as observed in this work during twin roll casting can also occur during the course of rolling if the degree of deformation is still low. In general, these results demonstrate that the strip cast at 650 °C experienced more deformation than that cast at 700 °C.

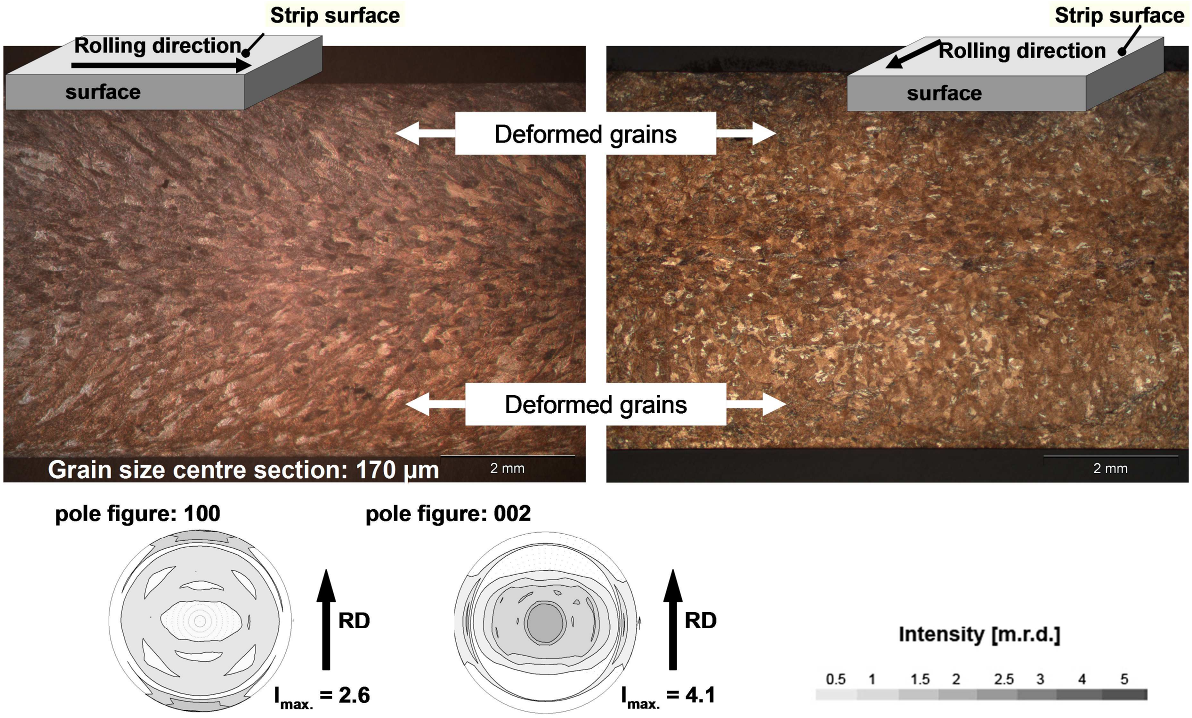

Fig. 4. Microstructure and mid-plane texture of the alloy AZ31 after twin roll casting with a melt temperature of 650 °C and a thickness of 5 mm.

Summary

The results indicate that the processing parameters in twin roll casting have a significant influence on the microstructure and texture of the strips. The degree of deformation in the strip depends on the position of the solidification front. If the solidification front is located near the exit of the tip, the degree of deformation in the strip is increased, because the strip is completely solidified as it enters the rolls and can be deformed more homogenously. If the solidification front is near the kissing point of the rolls, this leads to the effect that the upper and lower regions of the strip are frozen, but the central region is not completely frozen and therefore weak. Deformation during the rolling step is therefore concentrated in the weak central region without any effect on the outer regions of the strip. It could be shown that a melt temperature of 650 °C leads to a more fine-grained microstructure and to a higher texture intensity. Furthermore, the presence of a large amount of impurities in the microstructure indicates that the quality of the feedstock material is a very important issue. Further rolling trials to final gauge sheet will have to demonstrate if a more highly textured feedstock material with a homogeneous microstructure can provide better properties in the final sheet than less strongly textured material with an inhomogeneous microstructure.

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