Magnesium Technology 2013
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TMS (The Minerals, Metals & Materials Society), 2013

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Influence of Temperature and Rolling Speed on Twin Roll Cast Strip

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Keywords: magnesium, AZ31, twin roll casting, magnesium strip, process parameters

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 aluminum. 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. An alternative, cost-efficient production route for magnesium sheets with improved properties is feedstock production by twin roll casting (TRC). In this paper we report the results of twin roll casting experiments on the magnesium alloy AZ31 (Mg-3Al-1Zn-Mn) and discuss the influence of the process on the microstructure and texture of the strips.

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.

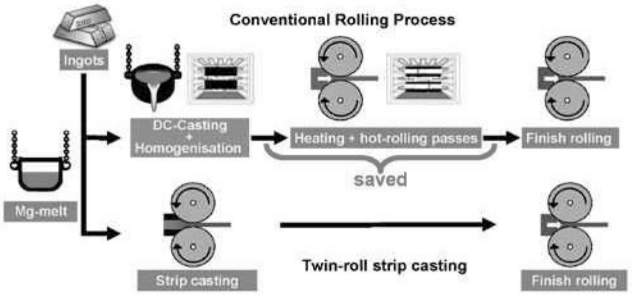


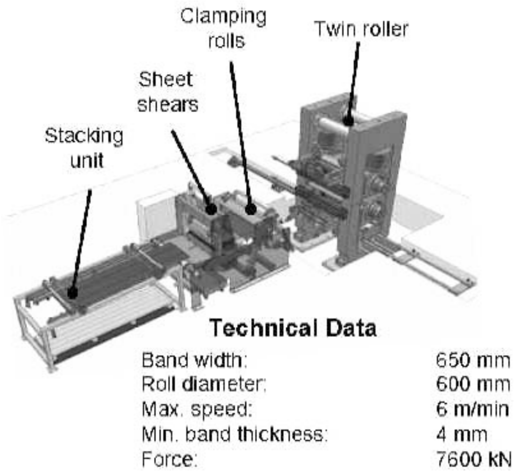
Figure 1: Comparison of the two process chains

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 (Figure 1).

The twin roll casting technology is already well established in for example the aluminum industry. However, applications to 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

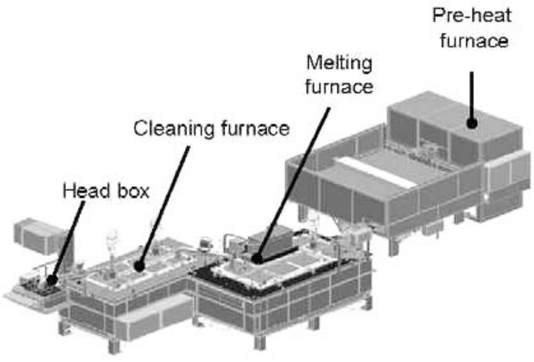
The development of wrought magnesium alloys and their introduction into industrial, structural applications are the main goal of the activities at the Magnesium Innovation Centre MagIC of the Helmholtz-Centre Geesthacht (HZG). The current focus of the research work is on alloy design and the development 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 Figure 2 and Figure 3.



Technical Data

Band width:	650 mm
Roll diameter:	600 mm
Max. speed:	6 m/min
Min. band thickness:	4 mm
Force:	7600 kN

Figure 2: Twin roll caster at HZG and technical data



Technical Data

Max. capacity:	1000 kg/h
Max. temperature:	750 °C
Temperature stability:	+/- 3 °C

Figure 3: Furnace line of the twin roll caster at HZG and technical data

The twin roll casting line consists of a furnace line (Striko-Westofen) (Figure 3) and a twin roll caster (Novelis, Jumbo 3CM) (Figure 2). 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 in 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 fusion in the melting furnace. After pre-heating, the feedstock is transferred to the melting furnace. A transfer tube 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 (Figure 4). The metal exiting the tip solidifies on the rolls into a strip that is further deformed by the rolls. Important features of the strip such as microstructure and texture are influenced by the position of the solidification front.

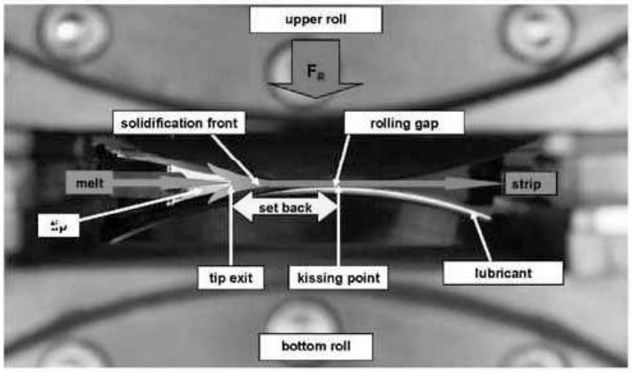


Figure 4: Principle and parameters of the twin roll casting process

The position of the solidification front is controlled mainly by the melt temperature, the set back (distance between exit of the tip and kissing point of the rolls), the height of the rolling gap and the strip speed.

The solidification starts when the magnesium melt enters the rolling gap and is in contact with the surface of the cooled rolls, the melt temperature drops to the solidus temperature at the strip surface (Figure 5). Ongoing along rolls surface, more heat flows from the strip in the rolls as it fully solidifies.

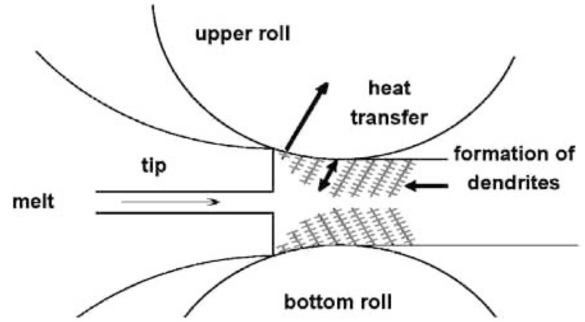


Figure 5: Solidification of the metal during twin roll casting

Then the heat is extracted to the solid strip. If the contact time of the melt at the rolls increases or the melt temperature decreases the solidification starts earlier and the solidification front is located near the exit of the tip. Its position influences the degree of deformation in the strip.

If the solidification front is located closer to the exit of the tip, the degree of deformation increases because the strip is fully solidified before entering the rolls (Figure 6a). If the solidification front moves towards the kissing point of the rolls due to changes in the processing parameters, the strip is not completely solidified and the degree of solid-state deformation decreases (Figure 6b).

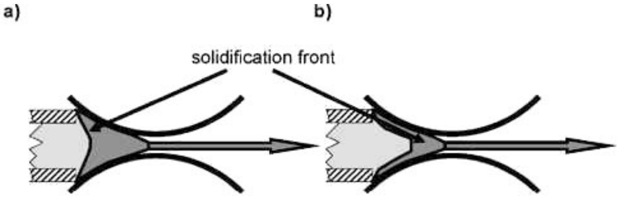


Figure 6: Position of the solidification front

All twin roll cast experiments were performed with the above mentioned equipment. The trials were carried out at melt temperatures between 650 - 710 °C. The rolling speed was varied stepwise between 1.4 m/min and 2.7 m/min. The setback and the rolling gap were constant. In these initial trials, the commercial magnesium alloy AZ31 was used and strips cast with 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]. Texture measurements were performed on the sheet mid-planes using a Panalytical X-ray diffractometer setup and CuKα radiation. 6 pole figures were measured up to a tilt of 70° which allowed recalculation of full pole figures based on an MTEX software routine [8] The (00 2) and (10 0) pole figures are used in this work to present the texture of the strips at midplane.

Influence of Melt Temperature on the Strip

In a first set of casting trials the influence of the melt temperature on the microstructure of the twin roll cast strip was investigated. Figures 7 to 9 display micrographs of strip cast at a constant rolling speed of 1.8 m/min and varied melt temperatures (700 °C, 690 °C and 680 °C). It can be observed that the strip cast at 700 °C reveals a columnar structure where grains grow from the surfaces towards the central region of the strip. The central region itself reveals equiaxed grains in a band with certain thickness (Figure 7).

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 large amount of columnar grains is an indicator that the solidification front was located closer to the kissing point of the rolls and thus, the degree of deformation was small during the rolling operation due to incomplete solidification.

Figure 7 also displays (10 0) and (00 2) pole figures of the strip which both exhibit low intensities. A very weak alignment of basal planes parallel to the strip plane still gives hints to active deformation mechanisms which start to form of a typical sheet texture. Interestingly, components with alignment in RD and TD are also found with low fraction.

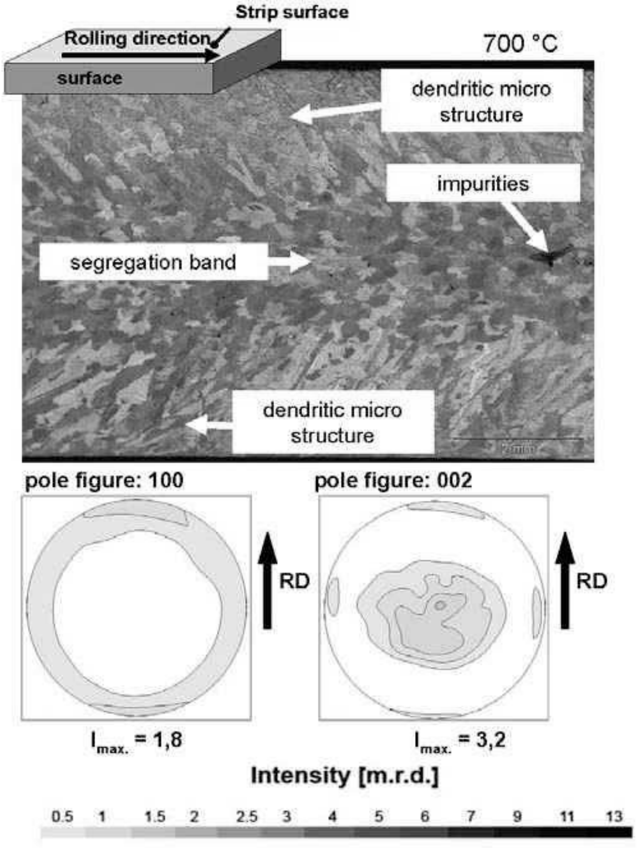


Figure 7: Microstructure and texture after twin roll casting with a melt temperature of 700 °C at a rolling speed of 1.8 m/min and a thickness of 5 mm

Figure 8 shows the same results as Figure 7 but for a casting temperature of 690°C. The columnar type microstructure is found to be less significant if compared to Figure 7 at 700°C and grains are more equiaxed.

Nevertheless, the strip cast at 690 °C is also characterized by a clear segregation band with a large amount of impurities at the centreline. The higher proportion of equiaxed grains in the microstructure indicates that the solidification front moves slightly towards the tip exit and the degree of deformation is somewhat higher than in the strip cast at 700 C.

Figure 8 also shows the (10 0) and (00 2) pole figures of the strip. The result is very similar to that shown in Figure 7 which indicated comparable features in the centreline. It is noted that this position in the through-thickness consideration most likely is the least part influenced by active deformation.

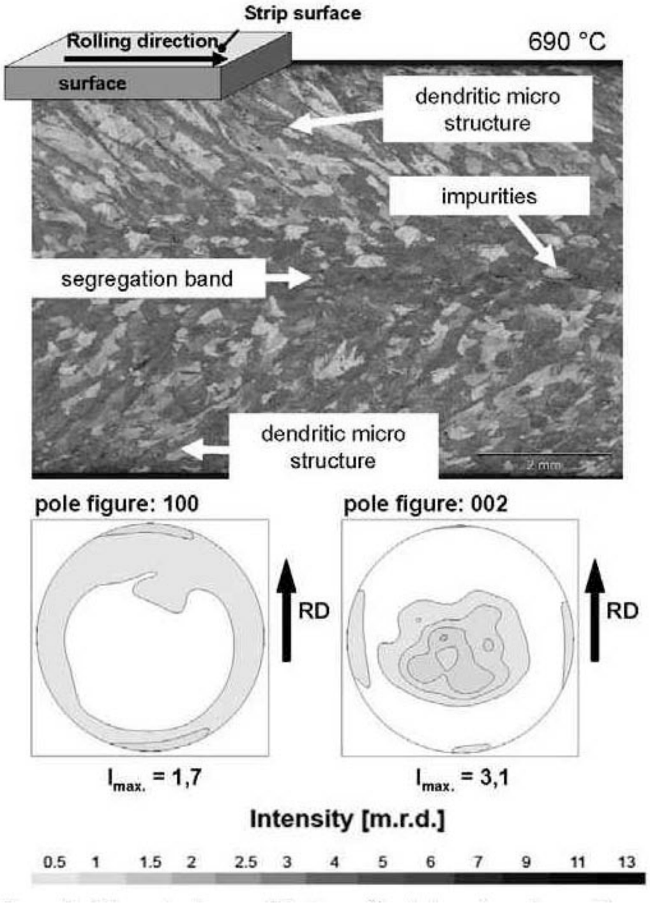


Figure 8: Microstructure and texture after twin roll casting with a melt temperature of 690 °C at a rolling speed of 1.8 m/min and a thickness of 5 mm

During casting the melt temperature was reduced to 680 C. The microstructure and texture of this twin roll cast strip are shown in Figure 9. This microstructure differs from the microstructures of the other two strips. 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 a deformed material. Still some features of a strip cast microstructure as shown above are visible.

The respective pole figures of this strip are shown in Figure 9. Again, the main feature is a weak alignment of basal planes in the sheet plane accompanied by a component tilted 90° to the RD as well as to the TD. Interestingly, there is no clear difference in the texture if compared to the results at higher casting temperature which is a counterintuitive finding with respect to the consideration about the amount of realized deformation during strip casting and concurrent rolling. However, the measurement of the texture at midplane position only gives respect to the condition in the finally solidified fraction of the microstructure which can be identified as a separate region in Figure 9. Haßlinger et al. [9] showed that the development of an alignment of basal planes in the sheet plane is the result of continuously increasing deformation with increasing number of passes. At low degree of deformation comparable weak textures with alignment of basal planes in the sheet plane have been found. Thus, the resulting texture reveals that the amount of deformation realized in this central part of the strip does not vary significantly with the casting temperature..

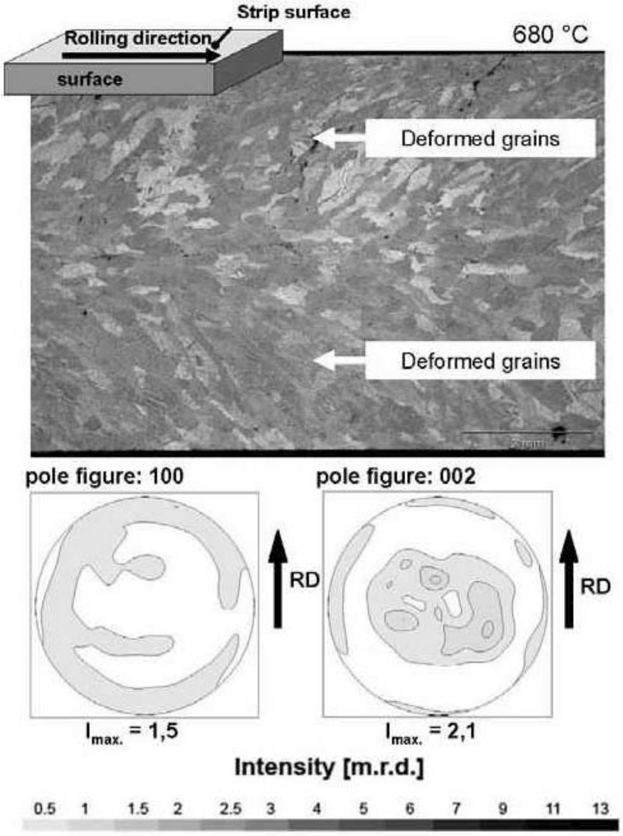


Figure 9: Microstructure and texture after twin roll casting with a melt temperature of 680 °C at a rolling speed of 1.8 m/min and a thickness of 5 mm

Influence of Rolling Speed on the Strip

Figures 10 and 11 depict the microstructures and textures of samples extracted from strips produced with the same temperature of 710 °C but varied rolling speeds of 2.7 m/min and 1.6 m/min, respectively. Again, both figures show the longitudinal sections of the strips. Figure 10 illustrates a clear columnar structure which is even more pronounced if compared to the result shown at intermediate speed but same casting temperature in Figure 3. Furthermore, the distinct segregation band containing a large amount of impurities at the centre-line of the strip is found.

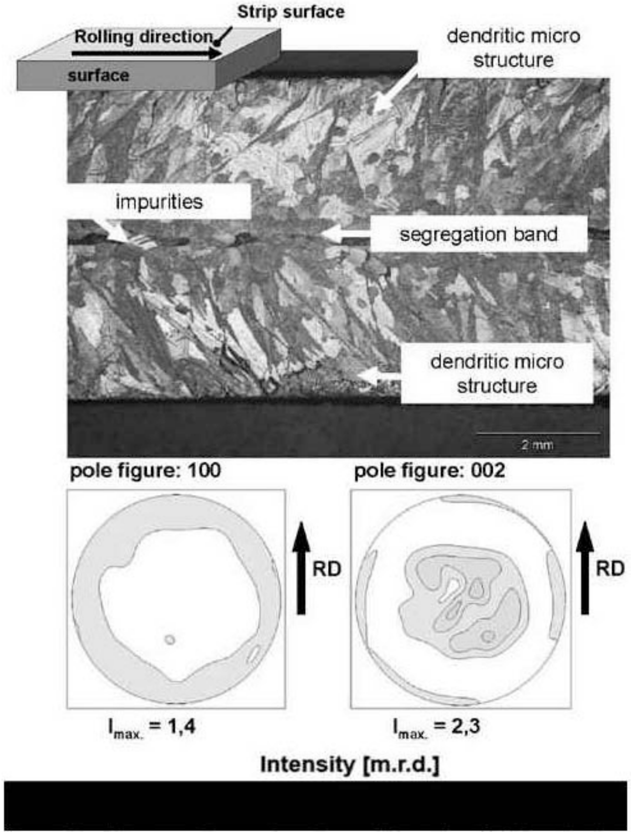


Figure 10: Microstructure and texture of the alloy AZ31 after twin roll casting with a melt temperature of 710 °C at a rolling speed of 2.7 m/min and a thickness of 5 mm

Again, the large number and the significance of columnar grains in the upper and lower surface region of the strip is an indicator for a low degree of deformation during the rolling operation. The texture of this sheet measured at midplane does not hint towards a different development compared to that explained in the previous section.

In Figure 11 results are shown after decreasing the rolling speed to 1.6 m/min. This strip also exhibits a columnar microstructure. In comparison to the one shown in Figure 10 no significant differences are revealed in the microstructure and texture of this strip. It is also characterized by a clear segregation band with a large amount of impurities at the centreline.

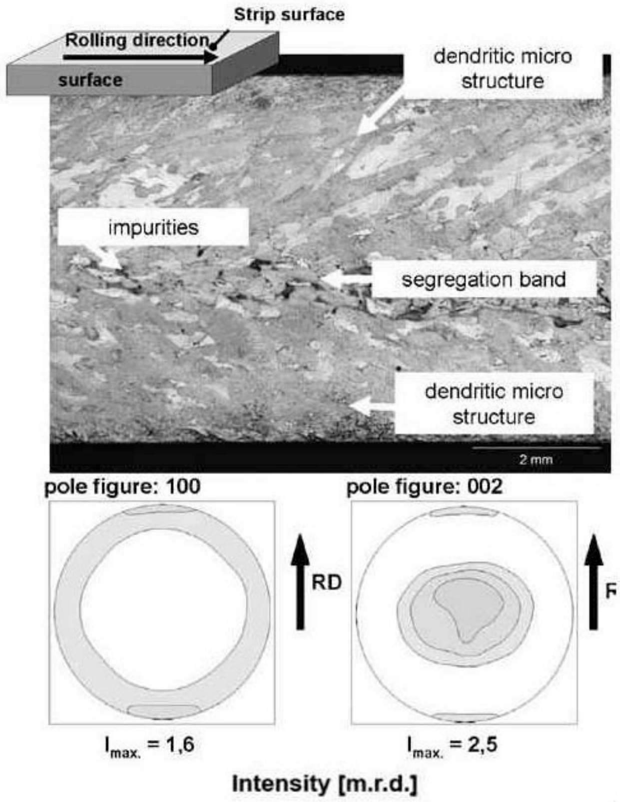


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Figure 11: Microstructure and texture of the alloy AZ31 after twin roll casting with a melt temperature of 710 °C at a rolling speed of 1.6 m/min and a thickness of 5 mm

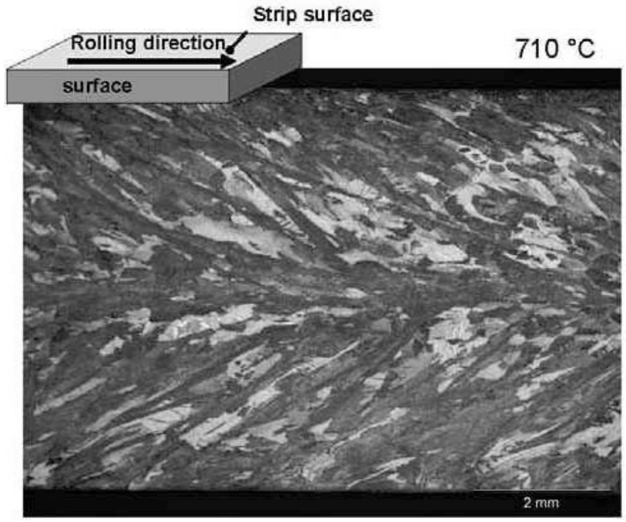

Figure 12: Microstructure after twin roll casting with a melt temperature of 710 °C at a rolling speed of 1.4 m/min and a thickness of 5 mm

At even lower casting speed of 1.4 m/min a variation of the casting temperature was realized by decreasing it from 710 °C down to 700°C and 690°C Figures 12 to 14 show the microstructure of these strips. Fiure 12 shows the microstructure of the strip cast at 710 °C which appears to be a lower casting speed version of the result shown in Fig. 11. No distinct differences were revealed at first sight but thin long structures become visible in this figure. This is also seen in Figure 13 at lower casting speed of 700 °C with even thinner long bands in the regions where originally columnar grains were observed A detailed analysis of these bands, like shown in the lower part of Figure 13 reveals small recrystallized and deformed grains in this bands which have clear similarities to shear bands. The amount of these bands decreases with decreasing temperature down to 690°C. The microstructure of the cast strip at 710 C shows the highest amount of these bands. In the strip cast at 690 °C the bands are more or less disappeared. Thus, an inhomogeneous type of deformation appears to be active at higher casting temperature if the casting speed is low. This feature is less pronounced once the temperature decreases. It might be argued that with lower temperature and low speed more homogeneous deformation is realized during the twin roll casting process and the heterogeneity of deformed regions is less significant. Especially Figure 14 also does not reveal a clear transition between directional solidified columnar grains and a globular central grain structure any more. Thus, also present in a partly deformed condition, the result shown in Figure 14 is the one with the highest homogeneity in this study.

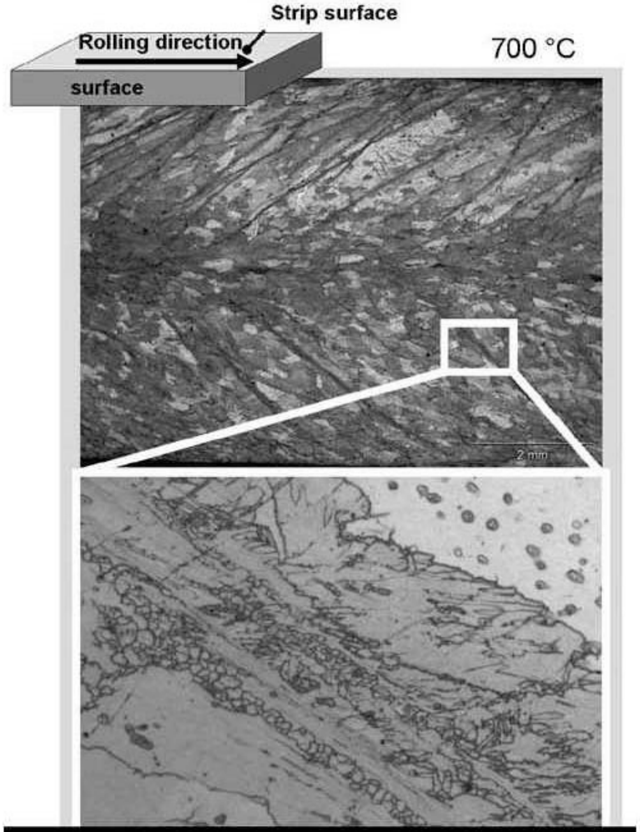

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Figure 13: Microstructure after twin roll casting with a melt temperature of 700 °C at a rolling speed of 1.4 m/min and a thickness of 5 mm

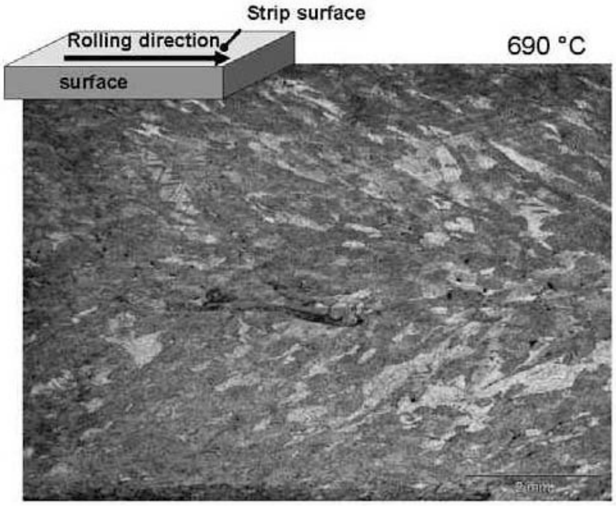

Figure 14: Microstructure after twin roll casting with a melt temperature of 690 °C at a rolling speed of 1.4 m/min and a thickness of 5 mm

Still, a segregation band is also seen in this condition. Further work is needed to optimize the process parameters with respect to the thermal gradient during the process to homogenize the element distribution throughout the strip.

Conclusions

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 solidified, but the central region is not completely solidified and therefore weak. Deformation during the rolling step is therefore concentrated in the outer regions of the strip without any effect on the weak central region. It could be shown that a melt temperature of 690 °C leads to a more fine-grained microstructure. The midplane texture, which corresponds to the globular solidified section of the strips, is basically not influenced by a variation of the processing parameters in the range investigated in this study. 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 in how far the differences in the original strip microstructure have an impact on the performance of the resulting sheets..

Acknowledgements

This research was supported by funding from the German Federal Ministry of Education. The authors are grateful to Novelis for assistance in the twin roll casting trials.

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