IMPURITIES SEGREGATION IN TWIN-ROLL CAST Al-Mg-Sc-Zr MATERIAL

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Abstract

Twin-roll casting (TRC) is a modern method of preparation of aluminum alloys. The distinctive feature of TRC is the combination of rapid metal solidification and subsequent plastic reduction in a single combined processing step. As a result of intensive heat extraction to the coolant via caster rolls, the melt solidifies and undergoes plastic reduction similar to the rolling process. However, some specific microstructural features of twin-roll cast strips, which restrict applications of this technology, are known. These are localized centre line segregation, surface and near-surface microsegregation and microstructural inhomogeneity. These features lead to the deterioration of mechanical properties of the strips, in particular strength, formability and corrosion resistance and can only be eliminated during a complex thermomechanical treatment. In the present contribution segregations in TRC Al-Mg-Sc-Zr alloy were studied by means of light optical microscopy, electron microscopy and 3D X-ray computer tomography. The spatial distribution was succesfully detected and morphology was described.

Keywords: Twin-roll casting, aluminum alloy, segregation, computer tomography

INTRODUCTION

Twin-roll cast (TRC) aluminum strips can suffer from macrosegregation of impurities in a form of central eutectic segregates or near-surface microsegregation [1]. The formation of these defects usually leads to a premature fracture and reduced strength and can influence the fatigue behavior [2]. The segregations consist of intermetallic particles and phases of alloying elements with aluminum [3-5]. Due to a higher hardness in comparison with the surrounding material and low diffusivity of impurities, the segregations are very difficult to diminish and remove during the subsequent thermomechanical treatment [6]. The segregation fraction grows with increasing casting rate [1, 7, 8]. Since the presence of mushy zone until the sheet passes through the roll nip is responsible for the occurrence of segregation during TRC, there have been several efforts to reduce the size of mushy zone and accordingly the degree of segregation by the control of casting parameters such as melt temperature, casting speed, etc. Optimization of the casting process and further thermomechanical treatment is based on a detailed knowledge of the composition and morphology of segregates. The main objective of the present study is to explore the occurrence of segregation in a twin-roll cast laboratory Al-Mg-based alloy with small additions of Sc and Zr.

1. EXPERIMENTAL DETAILS

Strip from AlMg-base alloy with a thickness 5 mm and composition shown in **Table 1** was studied. Twin-roll casting was realized in a caster with a vertical operation plane. No release agents were applied on the rolls surface before or during the process. The caster is equipped with two on the inside water-cooled rolls with outer steel sleeves diameter of 370 mm and barrel length of 200 mm. More detailed description of applied experimental equipment is given elsewhere [9]. Material was melted in a resistance furnace with mechanical stirring of the melt installed directly above the roll gap. The melt supply into the space between rotating rolls occurs by means of intermediate ceramic tundish as well as nozzle with flat channel. The main parameters of twin-roll casting were: melting temperature 655 °C, casting rate 2.75 m/min, setback length 80 mm and cooling water flow rate 115 l/min. Light optical microscope (LOM) Olympus GX51 and scanning electron microscope (SEM) FEI Quanta 200 FX FEG with EDAX energy dispersive spectrometry (EDS) and EDAX electron backscatter diffraction (EBSD) camera were used for basic observations. X-ray computed tomography (XCT) measurements were carried out using a Nanotom 180NF desktop device from General Electric with a 2316 × 2316 Hamamatsu flat panel detector and a 180 keV nano-focus X-ray tube with a transmission target. 80 kV, 240 mA and 7.5 μm^3 Voxel size were used as scan parameters for XCT.

Table 1 Chemical composition of Al-Mg-Sc-Zr alloy (wt.%)

Al	Mg	Zr	Sc	Mn	Si	Cu	Fe	Zn
Balance	3.24	0.14	0.19	0.16	0.11	0.024	0.21	<0.002

2. RESULTS AND DISCUSSION

The microstructure of the as-cast strip exhibits significant inhomogeneity through the thickness. Smaller and flat grains were observed near both surfaces of the strip followed by coarser grains in their vicinity. The grains gradually start to transform into finer equiaxed ones at the distance of about 1.3 mm from the strip surfaces (see **Figure 1a**). Similarly, the distribution of primary phases in **Figure 1b** shows rather non-uniform distribution with a remarkable central segregation (TD, ND and RD stay for transversal, normal and rolling directions, respectively).

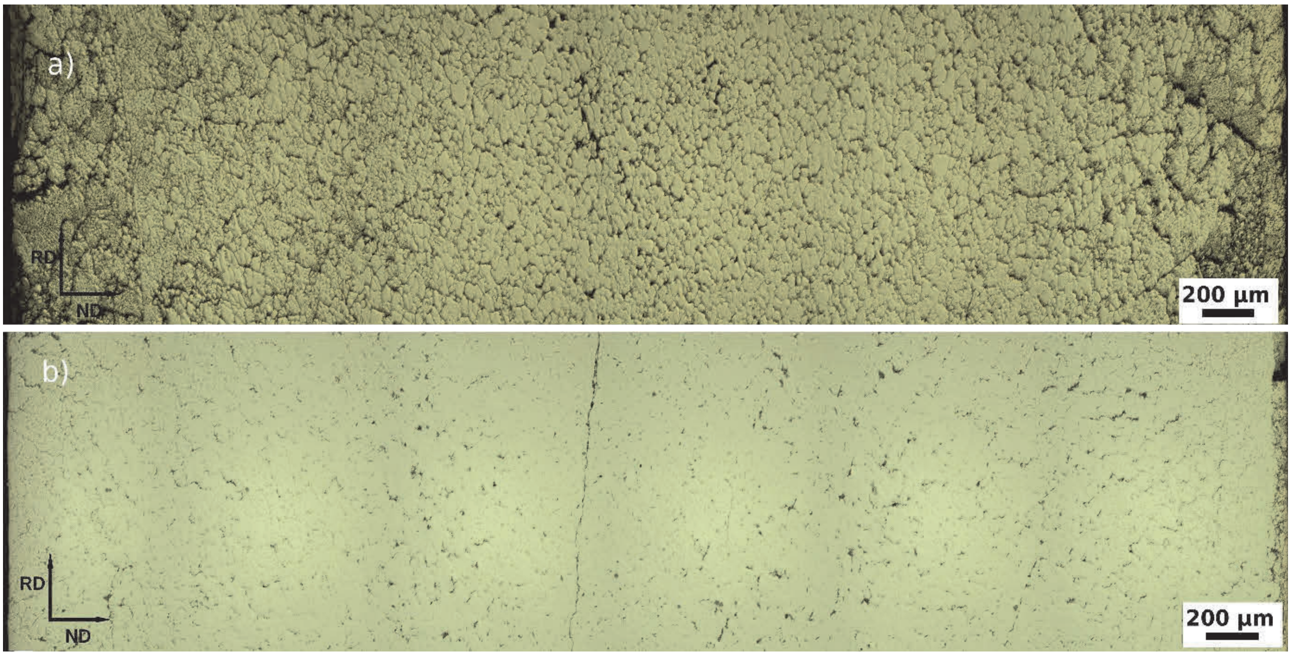

Figure 1 LOM of the as cast strip showing the distribution of grains (a) and primary phase particles (b)

Detailed analysis of primary particles performed by SEM and EDS investigations shows that several phases are present in the observed clusters with an irregular size, number density and shape. They are mainly Fe-rich particles known from TRC technical low-alloyed alloys with Fe and Si as impurities of the type Al_6Fe and α-$Al_{12}Fe_3Si$ (cubic or hexagonal) [10, 11]. Moreover, Mg-rich phases known from Al-Mg and Al-Mg-Si systems are also present. They are equilibrium β-Mg_2Si phase in the Si-containing alloys and β-Al_3Mg_2 phase in alloys with a low Si concentration [12, 13] (see **Figure 2**). No signs of Sc- or Zr-containing particles were revealed by electron microscopy confirming that these elements are fully dissolved in the solid solution.

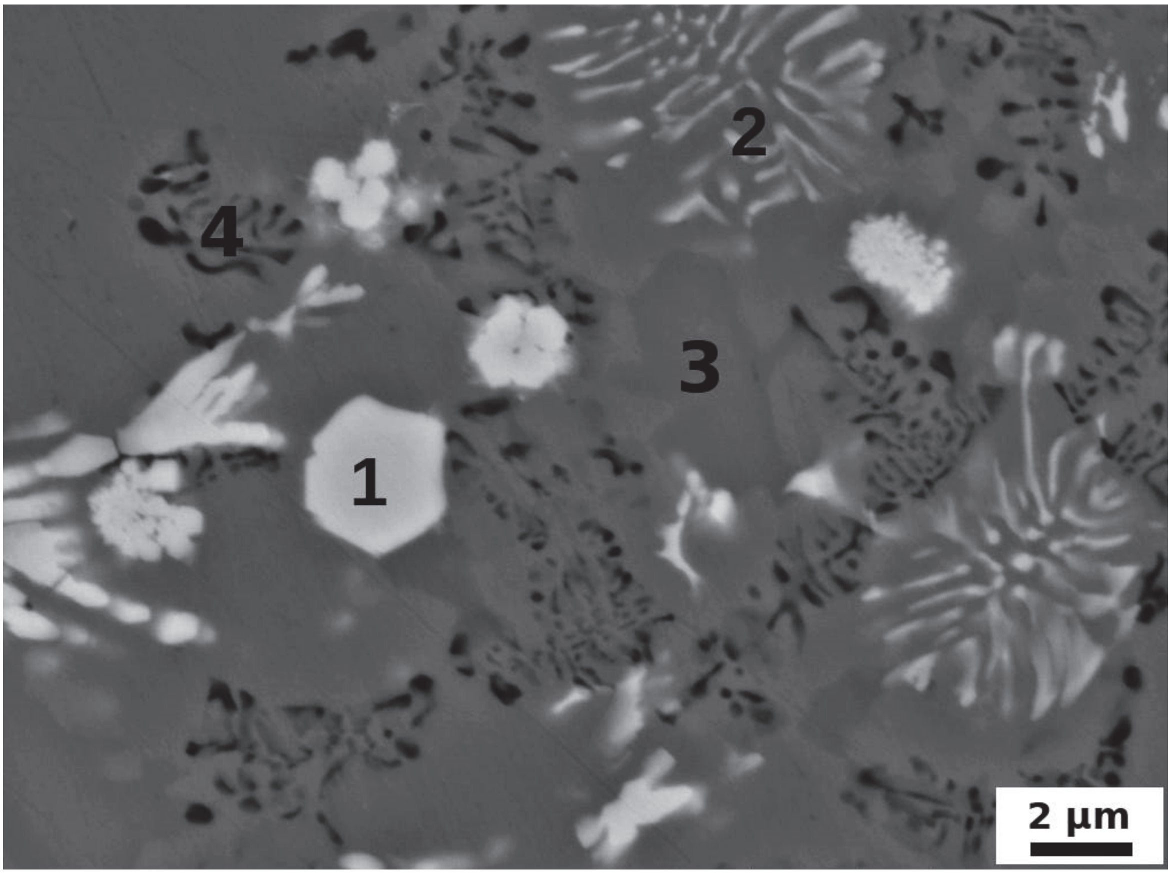

Figure 2 Back scattered electron image of a cluster of primary phases:
1 - most probably Al_6Fe, 2 - α-$Al_{12}Fe_3Si$, 3 - β-Al_3Mg_2 and 4 - β-Mg_2Si

However, neither SEM nor LOM could fully describe the distribution of clusters of particles within the volume of the specimen. In general, during the solidification of the strip the two solidification fronts approaches each other from the surface, and in the case of eutectic reactions (Fe, Si, Mn and Mg in Al) the unsolidified part is enriched in alloying elements. When the two solidification fronts meet, solute rich segregations of primary particles forms. As can be seen on XCT projections of slubs of several millimetres thick the central segregations appear as channels partially preferentially oriented in the rolling direction (**Figure 3a**). They are of irregular shapes and strong differences in their intensities confirmed the SEM observations about the non-uniform distribution of primary particles in the channels. Similar channels were observed in several TRC aluminum alloy [3,14,15]. However, the main features of segregations observed in the present alloy slightly differ from the ones described in the above mentioned literature. First of all, the orientations of channels are more random, and in addition to centreline segregation strong surface and near-surface microsegregations appear (**Figures 3b, c**). They are the local areas of solidified interdendritic liquid that is enriched in alloying elements. The surface segregations are located directly on the surface of the strip, while the near-surface microsegregations appear on the grain boundaries in the form of bands up to 0.1 mm thick, oriented towards the strip surface. Nevertheless, similar behavior was observed in highly alloyed aluminum alloys and is strongly influenced by a roll separating force [16,17].

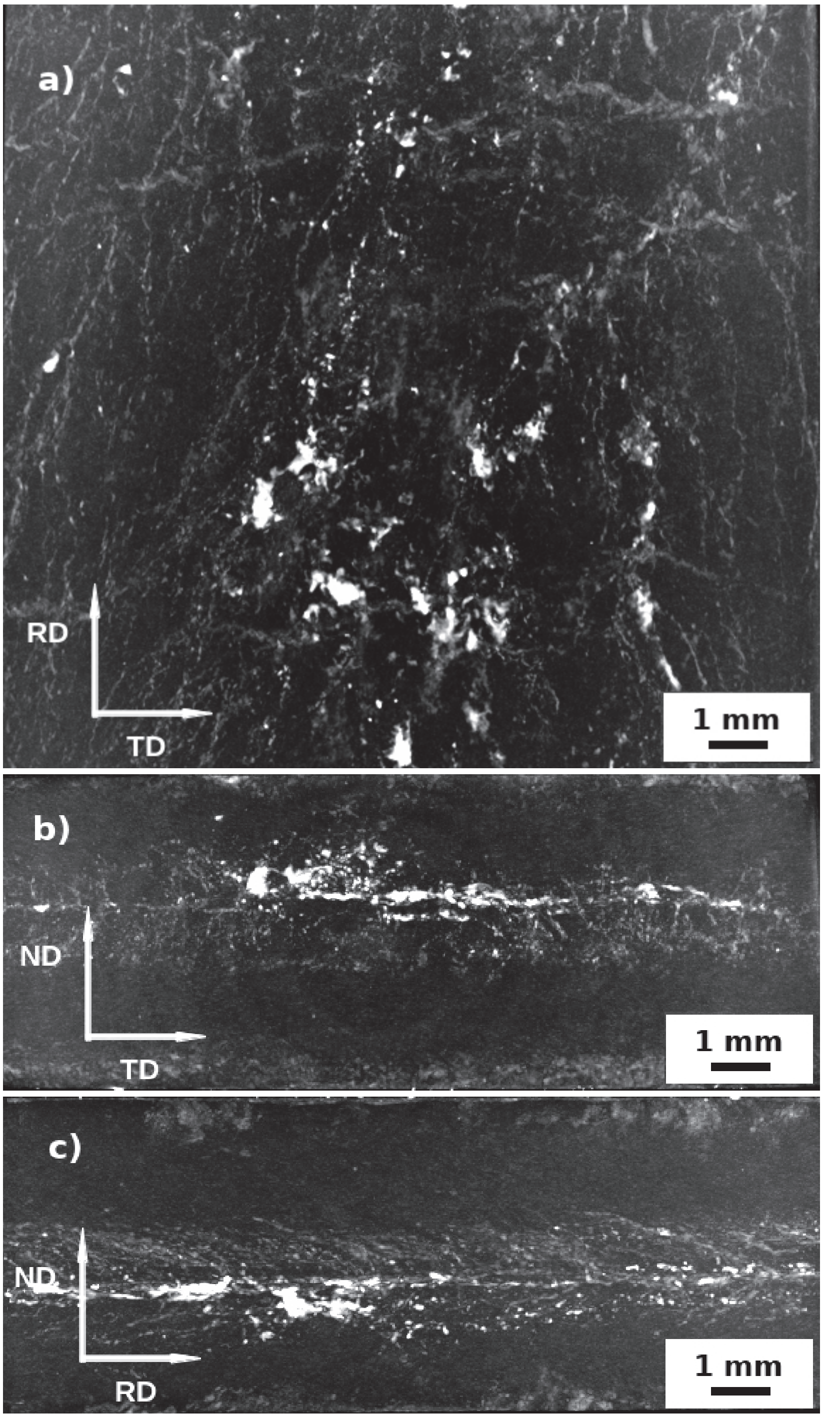

Figure 3 XCT projections of several mm thick slabs in three principal directions: a) ND, b) RD and c) TD

3. SUMMARY

Twin-roll casting of Al-Mg alloy with small additions of Sc and Zr generates central, surface and near-surface segregations. Information received from SEM and XCT could provide complementary data about the spatial distribution of these macrosegregating objects and also about the composition and shape of main constituent phases. The segregations consist of coarse intermetallic particles and eutectic phases of alloying elements with aluminium They have a form of discontinuous channels partially oriented in the rolling direction in the case of central segregations, while bands inclined towards the strip surface are the basic characteristic of near-surface ones.

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REFERENCES

[1] BAREKAR, N. S. and DHINDAW, B. K. Twin-roll casting of aluminum alloys - an overview. *Materials and Manufacturing Processes.* 2014. vol. 29, pp. 651-661.

[2] XIN, S, TAN, L. and GUANGMING, X. Composition homogenization evolution of twin-roll cast 7075 aluminum alloy using electromagnetic field. *Rare Metal Materials and Engineering.* 2015. vol. 44, pp. 581-586.

[3] ŠLAPÁKOVÁ, M., ZIMINA, M., ZAUNSCHIRM, S., KASTNER J., BAJER, J. and CIESLAR, M. 3D analysis of macrosegregation in twin-roll cast AA3003 alloy. *Materials Characterization.* 2016. vol. 118, pp. 44-49.

[4] SUN, K. M., LI, L., CHEN, S.D., XU, G.M., CHEN, G., MISRA, R.D.K. and ZHANG, G. A new approach to control centerline macrosegregation in Al-Mg-Si alloys during twin roll continuous casting. *Materials Letters.* 2017. vol. 190; pp. 205-208.

[5] MALCIOGLU, A. U. and ERTAN, S. Production of 3004 Aluminum Alloy Sheet for Structural Applications from Twin Roll Casting. *Light Metals.* 2017. pp. 173-180.

[6] GRAS, C., MEREDITH, M. and HUNT, J. D. Microstructure and texture evolution after twin roll casting and subsequent cold rolling of Al-Mg-Mn aluminium alloys. *Journal of Materials Processing Technology*. 2005. vol. 169, pp. 156-163.

[7] CHEN, G., LI, J.T., YIN, Z.K. and XU, G.M. Improvement of microstructure and properties in twin-roll casting 7075 sheet by lower casting speed and compound field. *Materials Characterization.* 2017. vol. 127, pp. 325-332.

[8] SCHMIDT, C.W., MORTENSEN, D. and KARHAUSEN, K.-F. Influence of process conditions on segregation behavior in twin-roll casting of an AlFeSi alloy. *Light Metals.* 2017. pp. 811-819.

[9] GRYDIN, O., OGINS'KYY, Y.K., DANCHENKO, V.M. and Bach, Fr.-W. Experimental twin-roll casting equipment for production of thin strips. *Metallurgical and Mining Industry*. 2010. vol. 2, pp. 348-354.

[10] BIROL, Y. Interannealing twin-roll cast Al-Fe-Si strips without homogenization. *Scripta Materialia.* 2009. vol. 61, pp. 185-188.

[11] GAO, T., HU, K., WANG, L., ZHANG, B. and LIU, X. Morphological evolution and strengthening of α-Al(Fe,Mn)Si in Al-6Si-2Fe-xMn alloys. *Results in Physics.* 2017. vol. 7, pp. 1051-1054.

[12] ZHU, H., COUPER, M.J. and DAHLE, A.K. Effect of process variables on Mg-Si particles and extrudability of 6xxx series aluminum extrusions. *JOM.* 2011. vol. 63, pp. 66-71.

[13] YI, G., ZENG, W., POPLAWSKY, J.D., WANG, Z. and FREE, M.L. Characterizing and modelling the precipitation of Mg-rich phases in Al 5xxx alloys aged at low temperatures. *Journal of Materials Science & Technology.* 2017. vol. 33, pp. 991-1003.

[14] YUN, M., LOKYER, S. and HUNT J.D. Twin roll casting of aluminium alloys. *Materials Science and Engineering A.* 2000. vol. 280, pp. 116-123.

[15] BIROL, Y. Analysis of macrosegregation in twin-roll cast aluminium strips via solidification curves. *Journal of Alloys and Compounds.* 2009, vol. 486, pp. 168-172.

[16] FORBORD, B., ANDERSSON, B., INGVALDSEN, F., AUSTEVIK, O., HORST, J.A. and SKAUVIK, I. The formation of surface segregates during twin roll casting of aluminium alloys. *Materials Science and Engineering A.* 2006. vol. 415, pp. 12-20.

[17] DAALAND, O., ESPEDAL, A.B., NEDREBERG and M.L. and ALVESTAD, I. Thin gauge twin-roll casting, process capabilities and product quality. Essential Readings in Light Metals: Cast Shop for Aluminum Production, GRANFIELD, J.F. and ESKIN D.G. eds., MMS 2013, pp. 989-996.