METABK 54(4) 711-714 (2015)
UDC – UDK 669.721:621.41:621.74.04:621.771:620.17=111

DEVELOPMENT OF A ROLLING TECHNOLOGY FOR TWIN-ROLL CAST MAGNESIUM STRIPS

Received – Primljeno: 2014-12-05
Accepted – Prihvaćeno: 2015-03-20
Review Paper – Pregledni rad

With the best lightweight potential of all metallic construction materials, magnesium primarily helps to increase energy efficiency over the lifecycle of automotive and non-automotive industrial products. Yet to assess overall energy efficiency, the production process must also be taken into account. This paper provides an insight into the energy-efficient production of magnesium strips up to 0,8 mm in thickness based on twin-roll casting and strip rolling on an industrial scale, as developed at the Institute of Metal Forming at the Technical University Bergakademie Freiberg (Germany) in cooperation with MgF Magnesium Flachprodukte GmbH (Germany). The technology of twin-roll casting and strip rolling on a four-high reversing mill is described.

Key words: magnesium strips, AZ31, twin-roll casting, strip rolling, mechanical properties

INTRODUCTION

Metal forming enables the rational and energy efficient production of high-quality products with a focus on costs and sustainability. As a result of the forming and heat-treatment process, the mechanical properties of the material can be adjusted specifically. In particular, innovative lightweight solutions can be realized with metal forming processes due to the combination of specific constructions with defined properties.

Magnesium is the lightest metallic construction material, and has great potential for lightweight applications in the automotive, electronic, and aerospace industries. Research into and development of new semi-finished magnesium products has been increasing for more than fifteen years. In recent years, the use of magnesium components has exhibited double-digit rates of growth in the automotive industry, with a focus on cast parts. A considerable expansion of further applications depends strongly on the availability of semi-finished products, especially of sheets.

Linking continuous casting with efficient forming processes of close-contoured material enables the production of magnesium alloys that satisfy current and prospective requirements of demand.

Twin-roll casting (TRC) combines the casting and rolling processes involved in magnesium alloy production in one procedure. Therefore, several process steps can be eliminated, resulting in economic and energy-efficient production.

M. Ullmann, F. Berge, K. Neh, R. Kawalla, Institute of Metal Forming, University of Mining and Technology, Freiberg, Germany

POTENTIAL PRODUCTION ROUTES FOR MAGNESIUM SHEETS

Thin magnesium sheets have been manufactured in a complex process from slabs produced by continuous casting by companies such as Elektron, Dow, and Alcoa since the last decades of the 20th century. This conventional method is still being used by companies like Magnesium Elektron or M&B MAG Toronto.

The technology of twin-roll casting, which was developed at the beginning of the 21st century, reduces the production costs by a substantial amount and is gaining importance worldwide. Currently, research teams in Australia [1], Canada [2], China [3], Germany [4,5], Japan [6], South Korea [7,8] and Turkey [9] are exploring the potential of the process.

Major advantages are the use of cheaper input materials, such that no heating is required during subsequent rolling processes. Therefore, fewer rolling passes are needed to reach the final dimensions of the sheets. Another characteristic is the rapid solidification (10-times faster than in the continuous casting of slabs). This leads to a finer-grained microstructure and the reduction of cavities, pores, segregations, and brittle precipitations, resulting in better formability and higher quality of the final product.

In Figure 1, the conventional method for the production of thin magnesium sheets is schematically compared to twin-roll casting.

This conventional method is a highly productive but complex production installation with continuous casting, separate rough rolling and finishing lines, decoiler equipment, and a coil box.

The new twin-roll casting technology for producing strips with dimensions closer to the final product results

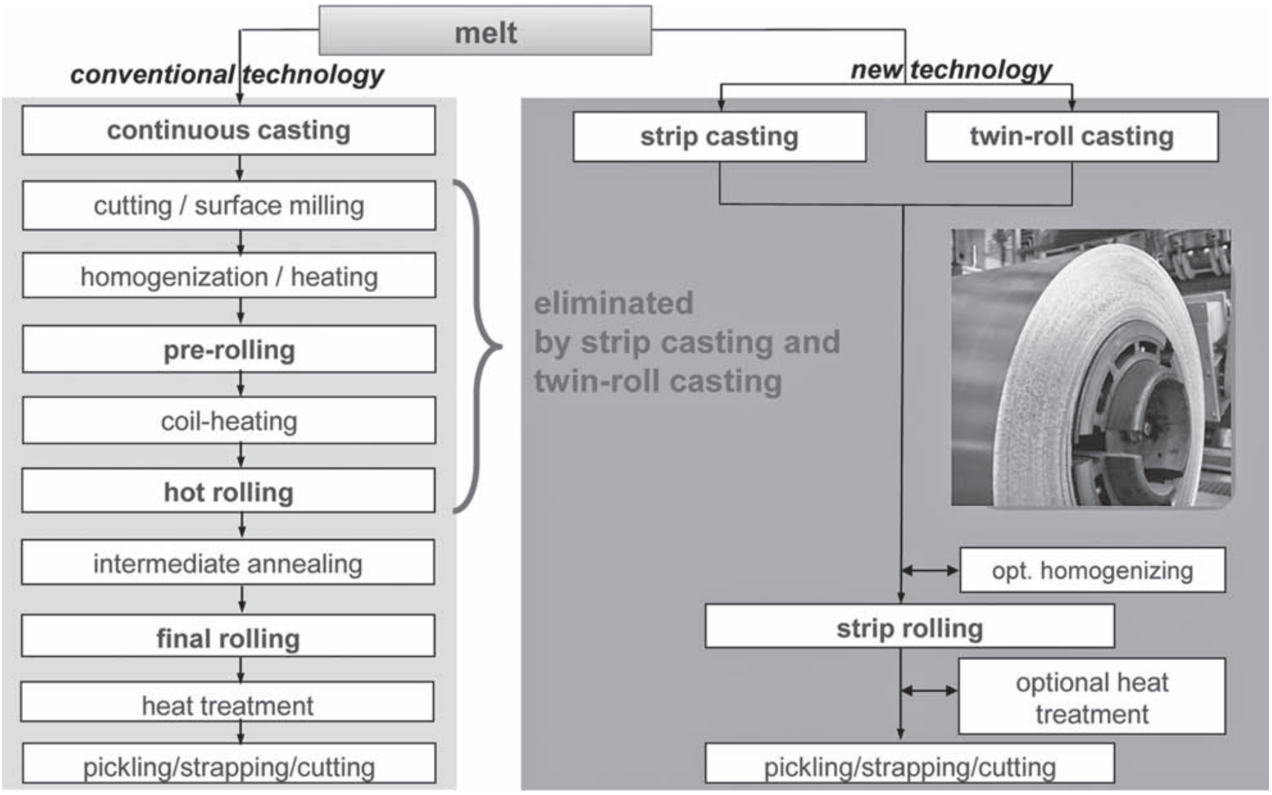

Figure 1 Production technologies for the manufacture of thin magnesium sheets: a) Conventional technology, b) Twin-roll casting

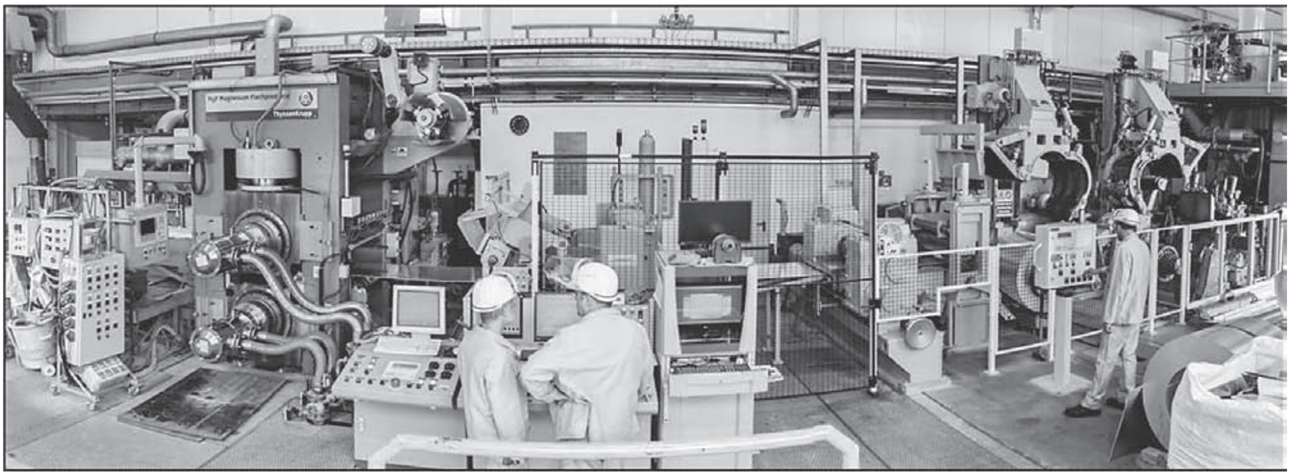

Figure 2 Photograph of the twin-roll caster at the Institute of Metal Forming, Technical University Bergakademie Freiberg

in a reduction of the number of process steps. This is mainly due to not having to use the costly roughing process, including the mechanical treatment of slabs.

Until now, rolling of magnesium strips has only been done on an industrial scale by the companies Magnesium Elektron and POSCO. Successful research has been conducted since 2009 at the Institute of Metal Forming (IMF) in Freiberg into developing a strip-rolling technology with twin-roll casting, producing Mg strips to standard industrial levels.

MAGNESIUM STRIP-ROLLING TECHNOLOGY IN FREIBERG

The IMF is equipped with a prototype twin-roll caster, a coil heating and annealing furnace, and a four-high quarto reversing mill (Figure 2). A summary of the technical data for both prototype plants is given in Table 1.

Table 1 **Technical data of the twin-roll caster and the four-high reversing mill for production of Mg strips at the Institute of Metal Forming**

	Twin-roll caster	Four-high reversing mill
Max. roll force	7 MN	12 MN
Max. roll torque	200 kNm	130 kNm
Max. strip speed	3 m/min	225 m/min
Max. strip width	780 mm	720 mm
Final strip thickness	3–7 mm	≥ 1,0 mm
Work roll diameter	840 mm	400 mm

These two pilot plants are designed for the investigation and development of TRC and strip-rolling technology for magnesium alloys on an industrial scale. Therefore, the melting furnace is also utilised for recy-cling material and the rolling mill is equipped with industrial operating features such as a flatness measuring system, minimum quantity lubrication, and a coiling system for the application of strip tension (usually 20 − 50 kN). In addition, the TRC plant can be complemented by a smaller prototype TRC system with a melt capacity of 250 kg for the production of smaller strips of approx. 300 mm in width for development of a TRC technology for new or enhanced magnesium alloys.

These two pilot plants are designed for the investigation and development of TRC and strip-rolling technology for magnesium alloys on an industrial scale. Therefore, the melting furnace is also utilised for recy-cling material and the rolling mill is equipped with industrial operating features such as a flatness measuring system, minimum quantity lubrication, and a coiling system for the application of strip tension (usually 20 − 50 kN). In addition, the TRC plant can be complemented by a smaller prototype TRC system with a melt capacity of 250 kg for the production of smaller strips of approx. 300 mm in width for development of a TRC technology for new or enhanced magnesium alloys.

As can be seen in Table 1, sheets of 3 − 8 mm in thickness can be produced via twin-roll casting. The AZ31 TRC sheet has already been the subject of several investigations [4, 10]. It has an inhomogeneous microstructure due to the combination of solidification and rolling processes in the TRC mill. The formation of the microstructure strongly depends on the process parameters. In addition to heat transfer and flow processes, several parameters play an important role, such as forces, torques, effective strains, TRC speed, and TRC sheet geometry. The resulting areas in the sheet thickness direction can be divided into three different zones: the rapid solidification edge zone at the sheet surface, the globular inner zone, and the intermediate columnar zone (Figure 3). Along with the hdp magnesium solid solution (α), additional metastable particles of the rhombohedral high-temperature η phase Al_8Mn_5 and the cubic body-centred γ phase $Mg_{17}Al_{12}$ are present in the TRC material.

For further technology development and processing, attention must focus on the specific and homogeneous microstructure because an inhomogeneous TRC sheet may not be formed safely even at high temperatures. On the basis of several heat-treatment tests, the optimum parameters could be identified (430 °C, 6 h). Due to diffusion processes during the heat treatment, the concentration differences of the elements are reduced as a result of the segregation distribution. Above 200 °C, the γ phase dissolves while the Al-Mn particles remain stable. Static recrystallization and grain growth occur due to the small amount of hardening during the TRC process. The EBSD image in Figure 4 shows that the heat-treated TRC sheet has random orientation distribution and an average grain size of 17 μm.

In accordance with the state of the art of the technology, the heat-treated TRC sheet is rolled at temperatures ϑ between 250 °C and 400 °C on a quarto reversing mill in several roll passes, with a roll pass reduction of 15 − 40 %. Therefore, the forming rates of an individual roll pass vary between 10 s^{-1} and 100 s^{-1}.

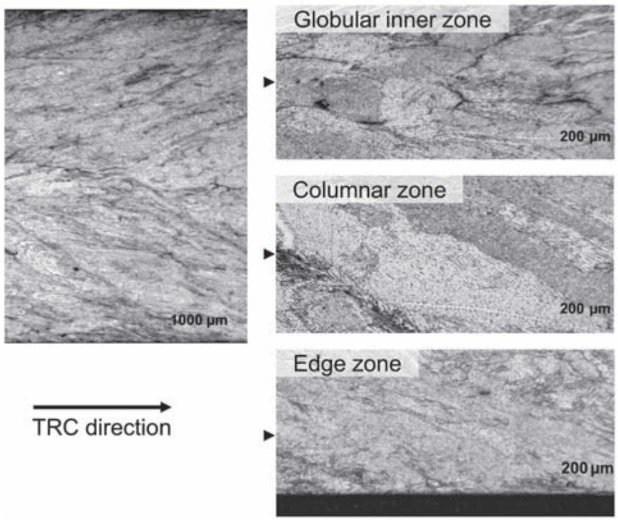

Figure 3 Microstructure of the AZ31 TRC sheet

Selecting the appropriate parameters of the pilot plant enables the hot rolling of the TRC coils to sheet thicknesses of 0,8 − 1,5 mm in a maximum of five roll passes without additional heat-treatment steps.

Using an automatic roll-gap control system, adjustment of the roll speed thus reducing heat losses within the sheet is possible. On the one hand, the initial temperature required for producing an optimal sheet surface can be reduced to a minimum. On the other hand, the final rolling temperature necessary for securing the sheet properties can be maintained. Besides rolling with one heating operation, pass schedules that include reheating of the coils are developed in order to obtain specific sheet properties. The formation of the microstructure and texture is investigated immediately after each step to enable optimization of the rolling process. The finished strips have an average grain size of 5 μm, which depends strongly on the thermomechanical treatment.

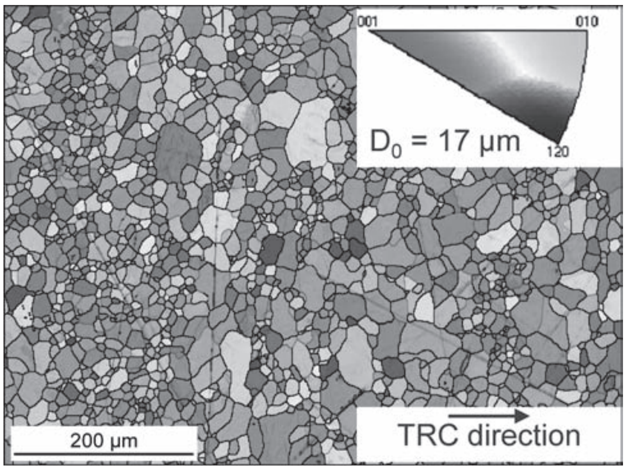

Figure 4 EBSD image showing colour-coded crystal orientation and grain boundaries of TRC and heat-treated (430 °C, 6 h) AZ31

Mechanical properties of the final strips

During the reversing rolling process, favourable combinations of mechanical properties can be set up. The strength ($R_{p0,2}$ and R_m) and elongation to failure (A_{80}) values are displayed in Figure 5 as a function of the sheet thickness. It can be seen that the elongation to failure at 3 mm thickness, which was rolled without additional heat-treatment, has lower elongation values than the thinner sheets. The reason for this is the higher degree of deformation and the additional heat-treatment involved in thin sheets. Moreover, the differences in the longitudinal (0 °) and transversal (90 °) values decrease with decreasing sheet thickness. The sheet thickness influences the yield strength slightly. For the tensile strength, no effect can be determined, which is a result of the formation of the microstructure. Through the selection of the process and the heat-treatment parameters, defined combinations of properties can be set for semi-finished magnesium products. Finished strips with a thickness below 1 mm have the following deformation values at room temperature: yield strength of $R_{p0,2} > 180$ MPa, tensile strength of $R_m > 250$ MPa, and elongation to failure of $A_{80} > 22$ %.

Higher temperatures tend to enhance deformation behaviour. An increase in temperature from 20 °C to 230 °C leads to an improvement in ductility because of the activation of additional slip systems within the hdp crystal, along with the thermal activation of dislocation motion [11]. Therefore, elongations to failure A_{80} of over 60 % can be achieved.

In another study concerning the further processing of finished sheets, the producibility of complex applications by means of several process routes is successfully confirmed [12].

INFLUENCE OF SKIN-PASS ROLLING OF THE FINAL STRIPS

Following final rolling and annealing, the strips were skin-pass rolled at room temperature with reductions in thickness of between 0,25 % and 4,5 %.

With higher thickness-reduction levels during skin-pass rolling, focused variation of the mechanical properties (higher tensile strength) can be achieved (Figure 6). The distinctive yield point is eliminated and a defined surface roughness is set. Thus, the desired visual appearance is achieved, and the tribological properties for subsequent processes are positively influenced, for example by the formation of closed lubricant pockets.

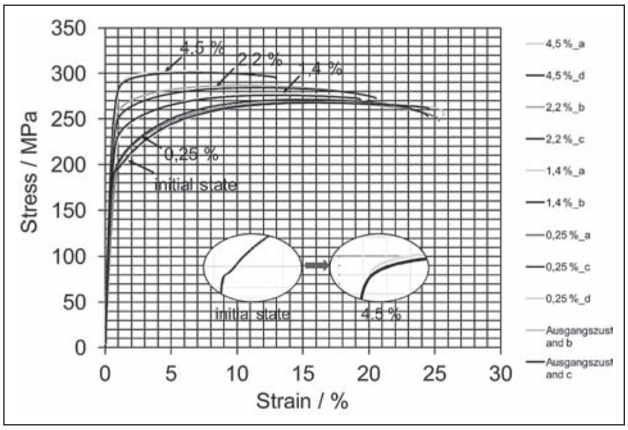

Figure 6 Influence of skin-pass rolling (0,25 – 4,5 % reduction) on the stress-strain curves of annealed AZ31 strips with a thickness of 1,9 mm

REFERENCES

[1] D. R. East, M. Kellam, M. A. Gibson, A. Seeber, D. Liang, J. F. Nie, Materials Science Forum 654-656 (2010), 1078-1081.

[2] M. Masoumi, F. Zarandi, M. Pekguleryuz, Materials Science and Engineering: A, 528 (2011), 1268–1279.

[3] X. Gong, S.-B. Kang, S. Li, J.H. Cho, Materials & Design 30 (2009), 3345-3350.

[4] R. Kawalla, M. Oswald, C. Schmidt, M. Ullmann, H.-P. Vogt, N.D. Cuong, Magnesium Technology (2008), 177-182.

[5] G. Kurz, J. Bohlen, D. Letzig, K.U. Kainer, Materials Science Forum 765 (2013), 205-209.

[6] Y. Nakaura, K. Ohori, Materials Science Forum 488-489 (2005), 419-426.

[7] G. Bae, J. Bae, D. Kang, H. Lee, N. Kim, Metals and Materials International 15 (2009), 1-5.

[8] H. Watari, K. Davey, M.T. Rasgado, T. Haga, S. Izawa, Journal of Materials Processing Technology 155-156 (2004), 1662–1667.

[9] O. Duygulu, S. Ucuncuoglu, G. Oktay, D.S. Temur, O. Yucel, A.A. Kaya, Magnesium Technology (2009), 379-384.

[10] R. Kawalla, M. Ullmann, C. Schmidt, J. Dembińska, H.-P. Vogt, Materials Science Forum 690 (2011), 21-24.

[11] M.R. Barnett, Metallurgical and Materials Transactions A, 34 (2003), 1799-1806.

[12] M. Ullmann, F. Berge, K. Neh, R. Kawalla, Archives of Civil and Mechanical Engineering, submitted (2014).

Note: The responsible for English language is Alan McDonnel, Meissen, Germany