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Review

An empirical examination of the thickness profile formation of twin-roll-cast magnesium strips

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ABSTRACT

The recently developed technology of twin-roll-cast (TRC) magnesium strips permits an efficient production of magnesium sheets, primarily for the automotive industry. The focus of the paper is to develop a structural equation model explaining the variance of the thickness profile formation. Hence, the complex and partially unknown relationships between twin-roll casting process parameters and the thickness profile formation are analyzed using latent variables, e.g. the deformation resistance, length of contact arc, etc., which consist of several observed parameters. The fundamental process variables and their effect on the thickness profile formation during twin-roll casting are investigated and evaluated by partial least squares structural equation modeling (PLS-SEM) – a statistical method that fits networks of constructs to empirical data. The results of the predictive modeling technique allow an approximation of the existing interrelationships between thickness profiles, rolling force as well as processes in the roll gap which are typically difficult to measure directly using sensors. In this context, it was identified that the thickness profile variation is primarily caused by the forming force, which is mainly driven by the length of contact arc. Moreover, implications for the control of the thickness profile are derived.

1. Introduction

Magnesium has a high application potential due to its low density of 1.74 g/cm^3 and beneficial properties such as high specific strength [1–3]. These advantageous characteristics of magnesium as a lightweight construction material are especially in the automotive industry of interest [4,5]. Yet, most magnesium construction parts in the automotive industry are cast products, such as engine blocks. Only few components are nowadays made from semi-finished products such as strips or sheets. A main barrier to a wider-ranging use is the cost-intensive conventional forming method of magnesium strips, which consists of slab casting

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with subsequent hot rolling including several reheating steps in between.

As an alternative approach the Institute of Metal Forming (IMF) at the Technical University Bergakademie Freiberg, in collaboration with MgF Magnesium Flachprodukte GmbH, a subsidiary of the ThyssenKrupp Steel Europe AG, developed a new cost-efficient technology for magnesium strip production, based on twin-roll casting and hot strip rolling [6]. The intended industrial application of this technology requires a quality assurance ensuring reproducible production runs under the influence of unavoidable process related deviations. In an initial step to develop such a quality assurance system the processes and their interrelations need to be captured and analyzed, whereby twin-roll casting combines multi-stage forming processes and parameter settings. In addition several of the theoretical induced parameters which influence the quality of the thickness profile, like the deformation resistance and length of contact arc, are often difficult to measure directly using sensors, but can be approximated indirectly using a set of observed variables. Hence, structural equation modeling – a statistical method that fits networks of latent variables, i.e. indirectly measured parameters, to empirical data – is applied to quantify the interdependences between different process parameters and quality characteristics. The paper proposes a predictive modeling approach to approximate the interdependences of selected quality characteristics, such as the camber and wedge shape of TRC strip. Hereunto, the twin-roll casting process is analyzed regarding the causes, which lead to different characteristics of the thickness profile.

The aim of this paper is to establish a process model of the thickness profile formation of magnesium strips. The results of the PLS-SEM analysis show that variations in the thickness profile are to a large extend determined by the forming force, which in return is driven by the length of the contact arc, i.e. length of the solidification zone, as main control parameter of the deformation process. Furthermore, this paper serves as an example for quality assurance in developing innovative production technologies. The systematic procedure of preventing defects in manufactured products requires a flexible, predictive modeling technique, such as the proposed PLS-SEM approach, to analyze roughly the complex and to some extend unknown effects of various control parameter settings.

2. Magnesium strip production

The first step of the magnesium strip production is the twin-roll casting, which starts with melting magnesium alloy ingots in a furnace. Subsequently, the melted magnesium alloy is led through the casting channel to the nozzle. The melt is fed from the nozzle into the roll gap of two horizontally positioned rolls counter-rotating at the same peripheral speed. As soon as the melt gets in touch with the cooled work rolls, a meniscus-shaped solidification zone is formed. In total, two solidifying shells build up in the contact areas on both roll surfaces, which grow into each other during the process in the roll gap. They are merged together and deformed by the roll pressure [7–9]. Therefore, the deformation process already starts in the area of the heterogeneous phase (l_m) and extends to the solid phase of the material (l_s), which makes modeling and simulation of the twin-roll casting process so complex. l_s and l_m can also be summarized as length of contact arc l_{ca}.

The result of twin-roll casting is TRC strip, which can be refined in a following production step. During hot strip rolling the TRC strip is reheated and homogenized in an air circulated furnace. Afterwards magnesium strip is rolled out by a quarto-reversing mill to the required thickness and final annealed. The technology enables the production of hot rolled strips up to a thickness of 0.8 mm.

One of the most important quality criteria of TRC strips is the thickness profile for hot strip rolling. The thickness profile can be classified into symmetric and asymmetric profiles, which have different effects on the flatness of hot rolled strips. Fig. 2 shows the effects of the thickness profile on the flatness of 1.5 mm of a certain hot rolled magnesium alloy (AZ31) strip. On the left side, a symmetric thickness profile (a) is shown, whereas on the right side an asymmetric thickness profile (b) is illustrated, which causes so-called flatness errors. The flatness errors are illustrated as red areas. Local deviation of thickness in the thickness profile leads to flatness errors due to difference of local yield stresses. In case of extreme differences [7], the thickness deviation cannot be compensated by the shape control of the rolling mill. It is also not possible to eliminate these deviations completely by subsequent straightening of rolled strip.

In order to release symmetric and asymmetric profiles of TRC strips for further processing, a quality standard including tolerance limits has been established (Table 1). The camber profile, the maximum thickness difference between the neighboring measured points and the wedge shape belong to these criteria, whereby the tolerance limits depend on the subsequent rolling strategy. The tolerances are defined based on the guidelines of Pechiney SA – a major aluminum conglomerate based in France (PAE), in accordance to EN DIN 485 and individual experiences of the IMF.

3. Process model of the formation of the thickness profile

A first process model, which describes the formation of the thickness profile of TRC magnesium strips, has been

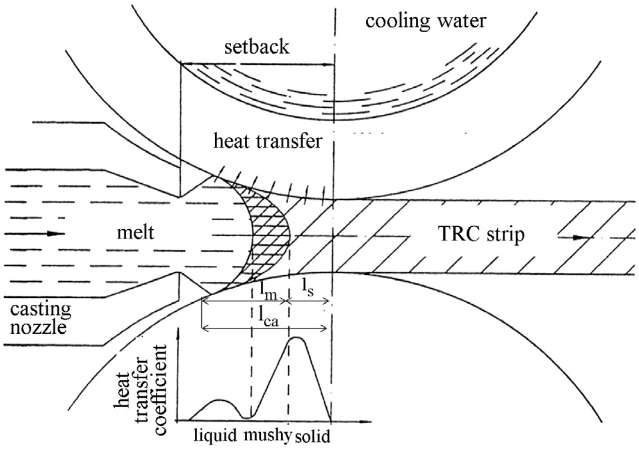

Fig. 1 – Schematic illustration of the twin-roll casting process (cf. [10,11]).