# Application of Magnesium Sheets and Strips in Vehicle Construction

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## Abstract

Magnesium alloys have great potential in the area of lightweight production especially in the automotive industry due to their favorable combination of mechanical properties and low density.
The Institute of Metal Forming (IMF) at the TU Bergakademie Freiberg (TUBAF) and MgF Magnesium Flachprodukte GmbH have developed an energy efficient and therefore eco-friendly technology for the production of magnesium sheets to enhance their availability. For this purpose, a pilot plant has been constructed in Freiberg.
The final properties of rolled and annealed sheets and strips, respectively, and furthermore examples from the automotive and electronic industry are shown in this paper.

## 1. Introduction

Increasing demands in terms of material and energy efficiency as well as growing environmental awareness enhance the development of the production and processing of lightweight materials in many industrial sectors. As the lightest metallic construction material, magnesium and its alloys offer high potential for applications with regard to weight savings. Especially the automotive industry, the goal of which is to reduce $CO_2$ emissions over the next few years, requires approaches to achieve significant weight reductions of the vehicles [1]. In recent years, magnesium alloys were established for industrial applications but predominantly as cast products. Rising interest of magnesium sheets and strips was accompanied by the development of a new production technology due to the high costs of the conventional thin sheet production [2, 3]. Thus in 2002, a twin-roll casting (TRC) pilot plant was built up in Freiberg. TRC persuades in comparison to the conventional sheet production as an economic and energy-efficient process. Extending the existing equipment with a reversing rolling mill enables the production of magnesium thin sheet up to 0.8 mm thickness.

Application potentials for magnesium strips produced by twin-roll casting and strip rolling in the automotive industry were elaborated and presented in comparison to other lightweight materials.

## 2. Technology of twin-roll casting and strip rolling in Freiberg

The IMF is equipped with a prototype twin-roll caster (**figure 1**), a coil reheating 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**.

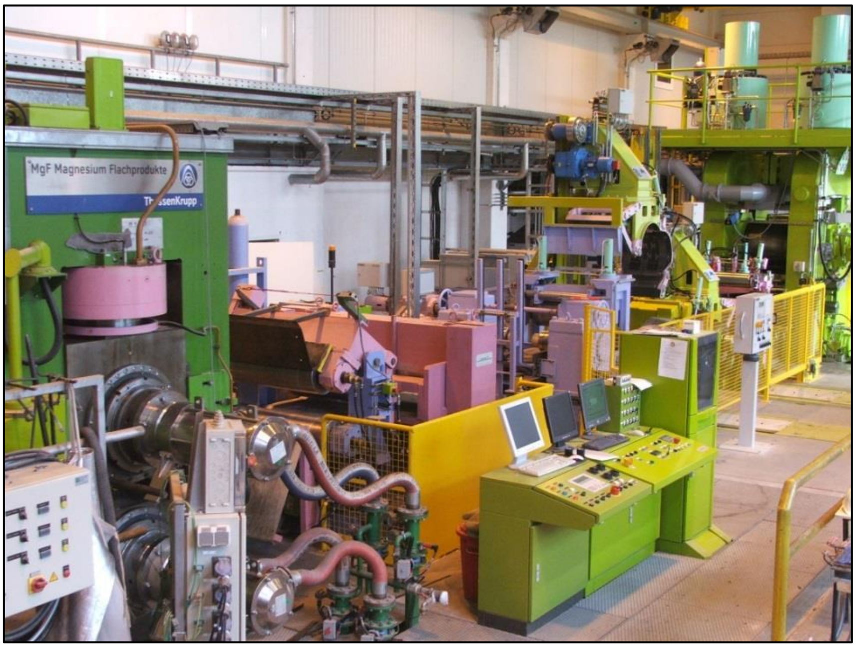



**Fig. 1:** Photograph of the twin-roll caster (in the front) and the four high quarto reversing mill (in the back) at the Institute of Metal Forming, TU Bergakademie Freiberg

**Fig. 2:** Photograph of the four high quarto reversing mill

**Fig. 3:** Photograph of the twin-roll cast and hot rolled Mg coils

**Tab. 1:** Technical data of the twin-roll caster and the four high reversing mill for production of Mg strip 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 | ≥ 0.8 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 in industrial scale. As can be seen in **table 1**, sheets with 3−8 mm thickness can be produced via twin-roll casting. According to the state of the art, the heat-treated TRC strips are rolled at temperatures between 250 °C and 400 °C on a quarto reversing mill in several roll passes with a roll pass reduction of 15−40 % (**figure 3**). Therefore, the strain rates of an individual roll pass vary between 10 $s^{-1}$ and 100 $s^{-1}$.

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 maximum five roll passes without additional heat-treatment steps. Therefore, the rolling mill is equipped with industrial working features like a flatness measuring system, minimum quantity lubrication and a coiling system for the application of strip tension (usually 20−50 kN).

Besides the rolling in one heat, pass schedules with reheating of the coils are developed in order to get specific sheet properties.

With the current technical development, the aim is to develop a rolling technology for the production of magnesium strips with a minimal final thickness of 0.8 mm and improved properties under stable process conditions. Currently, both process stages, twin-roll casting and strip rolling, have been investigated for the magnesium alloys AZ21, AZ31, AM20, AM40, AM50, ZE10, ME21 and WE43.

## 3. Final properties of the rolled magnesium strips

The magnesium alloy AZ31 is a standard alloy in the research field. Most material data are available with regard to other manufacturing and processing technologies.

Through the selection of the process and heat-treatment parameters during TRC and strip rolling, defined property combinations can be set in semi-finished magnesium products. Finished AZ31 strips with a thickness below 1 mm offer the following mechanical values at room temperature deformation: yield strength $R_{p0.2}$ > 180 MPa, tensile strength $R_m$ > 250 MPa and minimal elongation to failure $A_{80}$ > 22 %.

Additionally, investigations on TRC and hot rolling as well as on the property development of the alloy AM50 were conducted which could be established as a second standard TRC alloy besides AZ31. In general, the initial state of AM50 TRC strips is comparable to the AZ31, which shows a characteristic TRC microstructure (described in [12]). However, stronger developed centerline segregation and a greater number of dispersed segregations are noticeable in the AM50 alloy. This is due to the increased Al content which enhances for example the formation of lamellar $Mg_{17}Al_{12}$ precipitations. The rolled AZ31 and AM50 strips with 1.5 mm final thickness have a similar range of properties in the rolled and annealed state. A comparison of the mechanical properties of AM50 and AZ31 is displayed in **figure 4**.

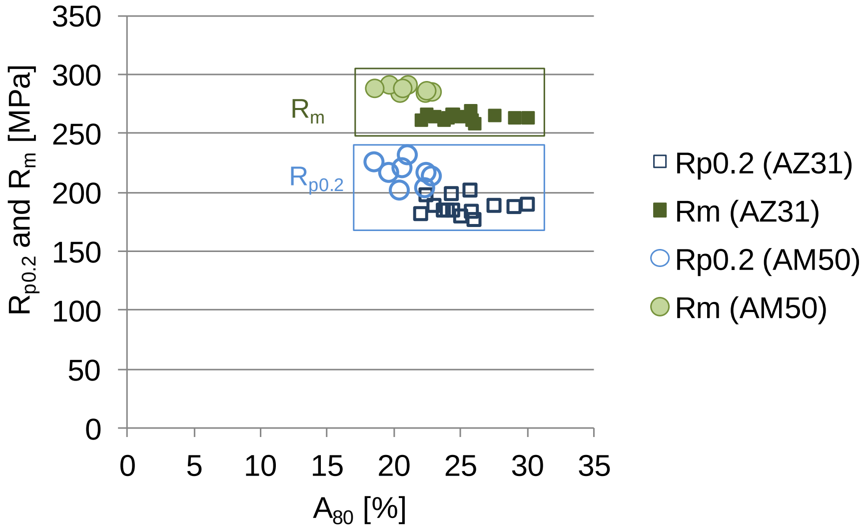



**Fig. 4:** Mechanical properties of the final rolled and annealed strips with a thickness of 1.5 mm at room temperature (longitudinal direction)

Only a slight tendency towards higher yield strength and tensile strength values at lower elongations could be observed for AM50 strips compared to the AZ31 strips (see **figure 4**) due to different microstructures (e. g. precipitations and solid solution) of the both alloys.

Higher temperatures tend to an enhanced deformation behavior. An increase of the temperature from 20 °C to 200 °C leads to an improvement of the ductility because of the activation of additional slip systems within the hexagonal crystal besides the thermal activation of dislocation motion [4]. Therefore, elongations to failure $A_{80}$ up to 60 % can be achieved for both Mg alloys. As a result of the temperature rise, the formability increases significantly (**figure 5**). As can be seen, both alloys lie nearly on the same formability level at 200 °C.

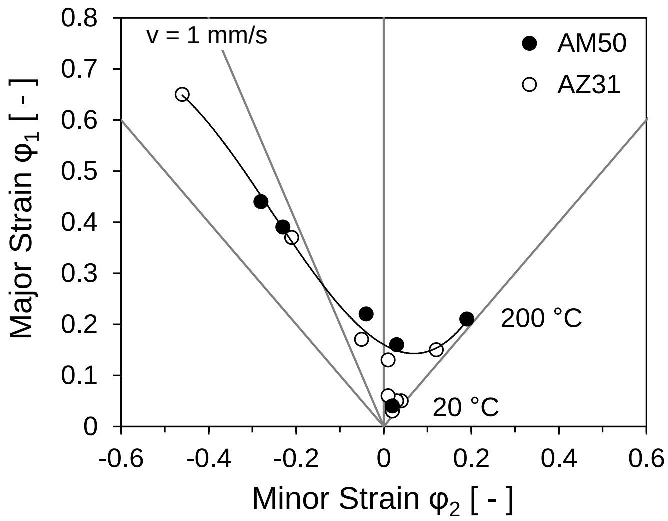



**Fig. 5:** Forming limit diagram of AZ31 and AM50 at different temperatures

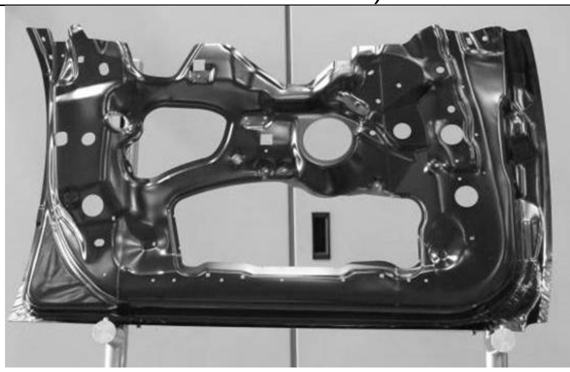
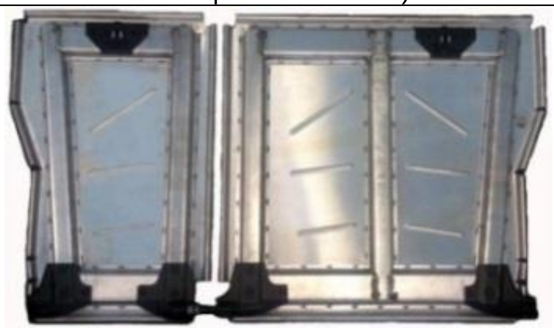
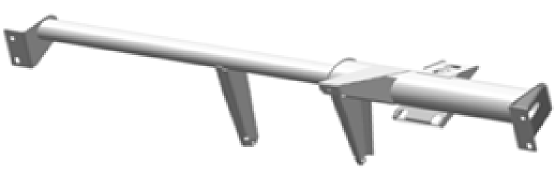
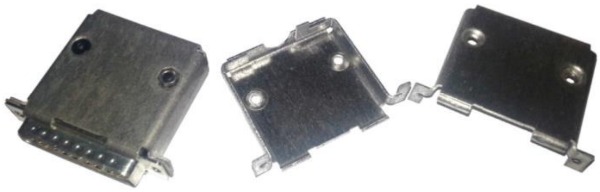
# 4. Application of the magnesium strips for automotive lightweight construction

Prototyping examples show the perspectives of magnesium flat products for a variety of different application areas. Referring to the automotive sector, magnesium sheets offer new opportunities for lightweight constructions, primarily in the car body, but also in chassis, interior, and motor component. The following **table 2** visualizes a list of possible components for an automotive application which can reasonably be made of magnesium sheets. **Table 3** represents some prototypes out of magnesium alloy AZ31.

**Tab. 2:** List of possible Mg components for automotive application

| component | component weight of Mg [kg] |
|---|---|
| roof cross member (b-pillar) | ~ 2.0 |
| roof cross member (a- and c-pillar) | ~ 0.6 |
| instrument cross-member | ~ 3.0 |
| seat shell | ~ 1.0 |
| cover parcel shelf | ~ 1.2 |
| door inner part | ~ 2.5 |
| front wall | ~ 2.0 |
| back wall | ~ 4.0 |
| bottom plate loading space | ~ 1.0 |
| window management | ~ 0.4 |
| bay gain | ~ 0.5 |
| decorative components such as hide | ~ 0.5 |
| tailgate (inside / outside) | ~ 3.5 / ~ 2.0 |
| hood (exterior / interior) | ~ 4.5 / ~ 3.0 |
| roof outside | ~ 7.0 |
| roof cover for rht | ~ 5.0 |

**Tab. 3:** Examples of automotive components

| | |
|---|---|
|  |  |
| a) car brake lever tray (source: IRE) | b) part of crossmember (producer: AWEBA Werkzeugbau GmbH and Karosseriewerke Dresden GmbH) |
|  |  |
| c) radio housing (source: MgF Magnesium Flachprodukte GmbH) | d) door inner reinforcement (producer: FhG, IWU Chemnitz) |
|  |  |
| e) automobile rear panel (source: BMW) | f) car roof (source: MgF Magnesium Flachprodukte GmbH) |
|  |  |
| g) cockpit mount (source: MgF Magnesium Flachprodukte GmbH) | h) shell type handle (producer: Altran GmbH & Co. KG, AWEBA Werkzeugbau GmbH and Karosseriewerke Dresden GmbH) |

Compared to other construction materials used for applications of the automotive industry, the magnesium alloy AZ31 offers good mechanical properties. The specific strength of AZ31 achieves three times higher values than cold or hot rolled steels. In comparison to the aluminum alloy EN-AW-5182-0, which is used as body sheet in vehicle constructions, AZ31 strip exhibits 20 % higher strength in relation to the density. Maximum values of the specific strength are provided by carbon fiber reinforced plastics (CFRP). These materials are investigated for the application of roofs or bonnets, but they are currently only used in the sports car sector. Although CFRP reveals high potential of weight savings and therefore resource conservation during utilization phase, the energy expenditure for their production compared to steel or aluminum as well as insufficient technologies and processes of recycling lead to high costs, which hinder their introduction to the market [6]. For magnesium, these gaps were bridged due to intensive research over the last years. The development of economic production technologies is associated with cost reduction for the procurement of magnesium strips. Substantial advantages of magnesium are established recycling procedures (especially over CFRP) and virtually unlimited availability. Moreover, hot rolled strips of the magnesium alloy AZ31 exhibit excellent elongation comparable with the values of hot or cold rolled steels and the aluminum alloy EN-AW-5182-0 (**figure 6**). CFRP offers an elongation of 1 % and consequently exhibits deviant behavior of material failure compared to metallic materials. Further research in the field of magnesium alloys focuses on the improvement of corrosion resistance to overcome the main disadvantage of these materials. For automotive application, several studies of prototyping using magnesium strips have been carried out:

- General Motors: Trunk lid inner panel [7]
- Porsche 911 Cabrio: Roof construction [8]
- BMW M: Rear seat back (project: TeMaKplus)

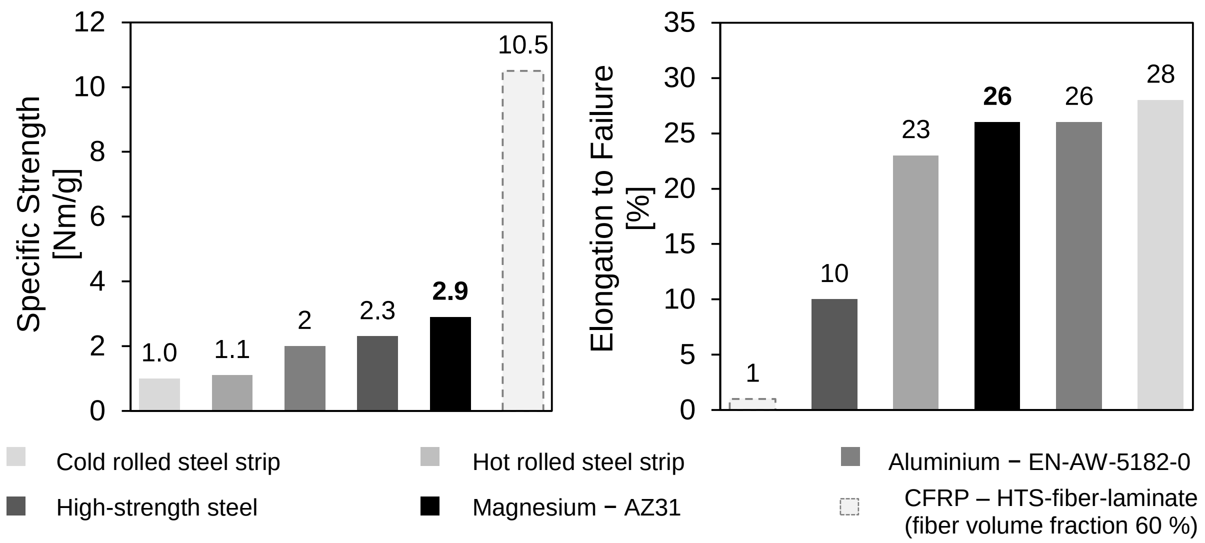



**Fig. 6:** Comparison of specific strength ($R_m/\rho$) and elongation of several lightweight materials used preferentially in the automotive industry [5, 9-11]

The potential of magnesium alloys as lightweight material is illustrated using the example of a cockpit mount. The investigations include the comparison of steel MHZ 340, an Al-Cu-Mg-alloy and the magnesium alloy AZ31. Basically, the cockpit mount consists of several components: console crossmembers, steering mount and column, crossmember to firewall and dashboard as well as tunnel strut. Dimensioning of the misuse load case and a model analysis for the determination of the self-resonant frequency were conducted. This allows statements about the dynamic behavior of the cockpit mount. Two characteristic loading conditions (vertical and horizontal movement of the steering column) were performed. In both cases, the misuse load case and the dynamic behavior, AZ31 exhibits identical material behavior compared to steel and aluminium. For AZ31, the stresses of the misuse load case achieve 95 MPa, which corresponds to 44 % of the yield strength. Weight comparison of the cockpit mounts made of steel (5.8 kg), aluminium (3.1 kg) and magnesium (2.4 kg) shows the potential of magnesium as lightweight material. However, lightweight construction is generally associated with additional costs. Referring to steel (1), costs increase by a factor of 1.6 for aluminium and 2.2 for magnesium.

## 5. Conclusions

Magnesium twin-roll casting is going to emerge as the future producing method for magnesium strips as a result of its economic and material-specific advantages.

The rolling tests with twin-roll cast AZ31 coils have shown that favorable combinations of properties can be adjusted in reversing strip rolling process. Finished AZ31 strips with a thickness below 1 mm offer the following mechanical values at room temperature deformation: yield strength $R_{p0.2}$ > 180 MPa, tensile strength $R_m$ > 250 MPa and minimal elongation to failure $A_{80}$ > 22 %. Only a slight tendency towards higher yield strength and tensile strength values at lower elongations could be observed for AM50 strips compared to the AZ31 strips.

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Prototyping examples show the perspectives of magnesium flat products for a variety of different application areas. Referring to the automotive sector, magnesium sheets offer new opportunities for lightweight constructions, primarily in the car body, but also in chassis, interior, and motor components.

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