MANUFACTURING OF HIGH PERFORMANCE CARBON FIBRE-REINFORCED METAL SANDWICH MATERIALS AND THEIR FORMING BEHAVIOUR

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Abstract
A new hybrid material which was developed within the research project LEIKA in collaboration with thyssenkrupp consists of cover sheets made of steel or magnesium and a core of carbon fibre-reinforced plastic in order to produce a sandwich laminate. Compared to monolithic metal sheets not only the bending stiffness, like in traditional sandwich laminates, but also the extensional stiffness is increased. As a result those carbon fibre-reinforced laminates are additionally suitable for components with plane stress such as shear panels as well as for many structural parts of the body in white. An overview will be given of the manufacturing of the hybrid sheet material, its metal cover sheets made of steel or magnesium, the core made of carbon fibre-reinforced laminates and how these components are merged to form the new high performance material with enhanced mechanical properties. In addition, tests are presented which were performed to analyse the forming behaviour of the new hybrid sheet material under industrial conditions. Stamping try-outs were conducted at the Kirchhoff group's workshop in order to investigate the forming behaviour of the new material by applying a forming sheet metal process at elevated temperatures.

1. Introduction

Lightweight design plays a key role in the development of fuel efficient vehicles [1]. An adequate performance, compliance with environmental requirements and ultimately an attractive pricing of these vehicles are challenges to be met in this context. This is especially true for electrically powered vehicles. Today's batteries exhibit a rather poor ratio of stored energy vs. mass which therefore is now a popular research topic in almost every industrial nation. In addition, mass reduction of the body in white offers a promising alternative to overcome the above mentioned dilemma.

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The application of sandwich materials and in particular of fibre metal laminates has shown the advantages for aerospace applications concerning damage tolerance and its potential for lightweight design [2, 3]. The excellent properties of steel hybrid composites are also known from investigations with automotive structures [4]. For the application in the automotive industry, short production times are of important relevance. For this reason, thermoplastic matrix composites are used for the new high performance material which is presented in this paper.

2. Manufacturing of carbon fibre-reinforced metal sandwich materials

Cover sheets made of steel or magnesium are bonded to a core of carbon fibre-reinforced plastic in order to produce a sandwich laminate. As established processes are used for the production of steel sheets, the production of magnesium sheets is still a topic of research. Therefore, the manufacturing of the magnesium cover sheets and subsequently of the carbon fibre-reinforced metal sandwich is introduced.

2.1. Manufacturing of the magnesium cover sheets

Concerning the requirements of modern lightweight design, magnesium (Mg) alloys provide significant advantages over conventional construction materials [5]. Compared to aluminium (Al) and steel, magnesium alloys have the highest specific strength [6]. Due to their low density and the related light weight, Mg alloys have already been used for a long time as casting materials, but wrought magnesium products are rare to find. A low formability and a distinctive crystallographic texture are responsible for a relatively high price [7, 8]. By Twin Roll Casting (TRC), magnesium strips can be manufactured economically and ecologically efficient [9]. During TRC, the used magnesium alloy, is being melted in protective gas and is transferred into a casting channel. A casting nozzle is located at the end of this channel. Through the nozzle, the melt is fed into the roll gap. Between rotating and cooled rolls, the melt solidifies very quickly and is deformed simultaneously. Therefore, we have both processes, casting as well as rolling, in one step. Furthermore, a material with a finer microstructure, better homogeneity, reduced segregations and less texture can be produced, which is highly suitable for further processing into thin sheets. In the 2000s the TU Bergakademie Freiberg set up a pilot-twin-roll casting plant in cooperation with the MgF Magnesium Flachprodukte GmbH. This facility was completed in 2009 by the addition of an efficient hot rolling mill. Figure 1 shows the production line located at the TU Bergakademie Freiberg.

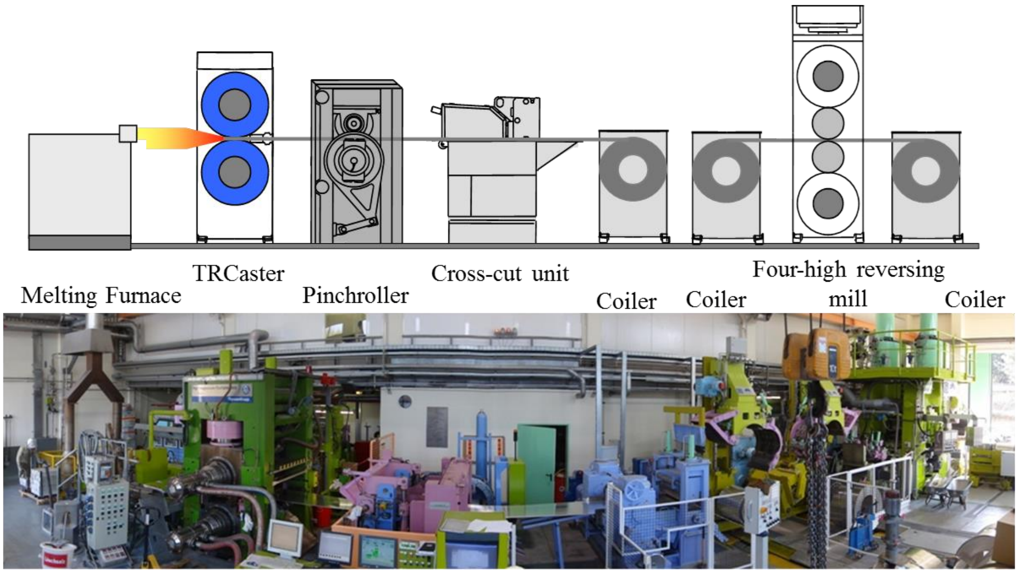

Figure 1. Twin-roll casting plant and an efficient hot rolling mill at the TU Bergakademie Freiberg.

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The Twin roll caster produces semi-finished coil material with a thickness of approximately 5.3 mm. Subsequently, the four-high reversing mill is used to roll the material down to a minimal thickness of 1.0 mm (Fig. 2). Today, the research focusses mainly on the magnesium alloy AZ31. For this alloy, an efficient and stable production process was established. The produced sheet material exhibits extraordinary good mechanical properties (Table 1). To accomplish this, a sophisticated rolling method was developed which includes a defined set of rolling steps with their respective deformation degrees as well as an adapted heat treatment after each rolling step. The heat treatment is aimed at both softening and homogenization of the material.

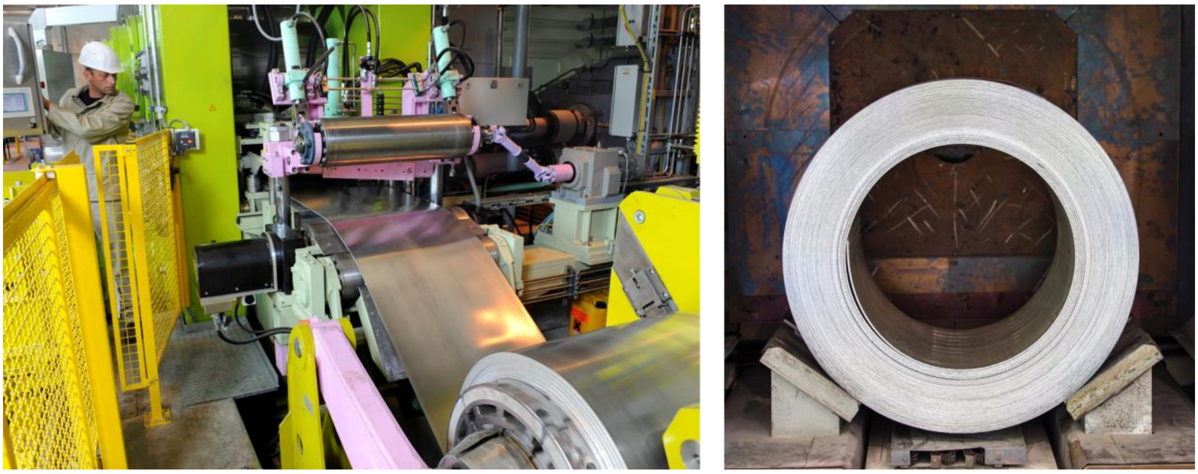

Figure 2. Four High Reversing mill at the TU Bergakademie Freiberg.

Via tensile tests at room temperature, the mechanical properties in the finish-rolled 1.0 mm heat-treated AZ31 TRC sheets was proved. Tensile-testing specimens were milled from the strips parallel (0°) and perpendicular (90°) to the direction of TRC and rolling. Quasi static uniaxial tensile tests were carried out at room temperature. In Table 1, the elongation to failure (A_{80}), the yield strength ($R_{p0.2}$) and the tensile strength (R_m) of the tested tensile specimen series are listed. It is becoming clear that the 1.0 mm sheets having exceptional fine and macroscopic isotopic mechanical properties.

Table 1. Elongation to failure (A_{80}), yield strength ($R_{p0.2}$) and the tensile strength (R_m) of the tested 1.0 mm finish-rolled sheets.

		90°	*0°*
A_{80}	[%]	23.4 ± 0.8	24.4 ±1,4
$R_{p0.2}$	[MPa]	180.0 ± 1.7	181.6 ± 1.9
R_m	[MPa]	261.4 ± 2.2	249.8 ± 1.6

2.2. Merging of the individual components to a new high performance material

The metal sandwich materials were produced by the thyssenkrupp TechCenter Carbon composites at Kesselsdorf. The manufacturing took place on production-ready machinery lines. For the project LEIKA a fully automated production of the metal sandwich material was realized. Figure 3 shows the process layout for the sandwich production. Hereby, the steps 3 to 10 were implemented fully automated.

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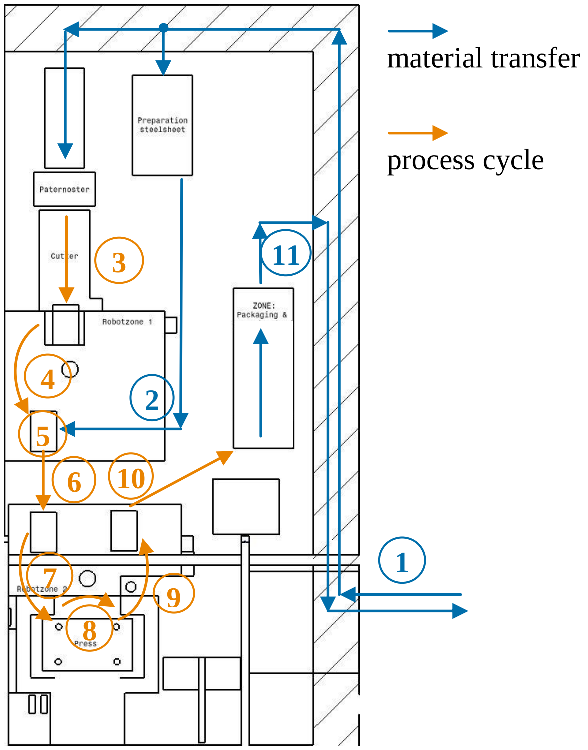

no.	process step
1	material delivery zone
2	metal sheet transport
3	textile cutting
4	textile handling and stacking
5	stack and metal sheets placement
6	automated transfer in the second robot zone
7	mould transfer
8	press cycle and changing between hot and cold zone
9	automated extraction
10	transfer to packing station
11	distribution

Figure 3. Material transfer and process cycle at the metal sandwich fabrication

The results from the part simulation showed an appropriate structure for seat cross-member consisting of 1mm magnesium cover plates and a 0.7mm CFRP-core with unidirectional reinforcement. The used magnesium plates were coated on one side with a bonding agent. For the core material a special textile laminated with polyamide 6 foils was used. The textile material consists of a 160g/m² unidirectional woven fabric. For the realization of the 0.7mm core thickness 3 layers of laminated woven fabrics were necessary. By differences in properties of magnesium in the rolling direction and transverse to the rolling direction of the defined alignment from the simulation must be observed (Fig. 4).

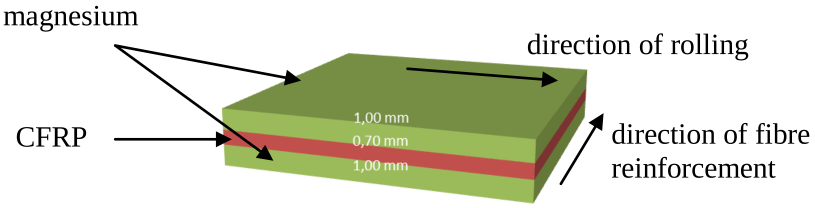

Figure 4. Structure of magnesium sandwich materials for the seat cross-member

The manufacturing of the metal sandwich materials takes place in a 2 zone sheet tool in two subsequent steps. In the first step the stack, made of metal cover sheets and textile layer, would be mould in the so called hot zone. The polyamide 6 flows into dry textile during this press step. Figure 5 shows this process in the area of the hot zone by a decrease of force. After that the stack is transported through a robot from the hot into the cold zone. Through the second process step into the cold zone the stack is pressed to final thickness and consolidated, as well as cooled down to 80°C. Exemplary, the relevant process parameters force and temperature are shown in Figure 5 against time for a total process step. The maximum size of the investigated material that was produced with this equipment is 2000mm x 1100mm.

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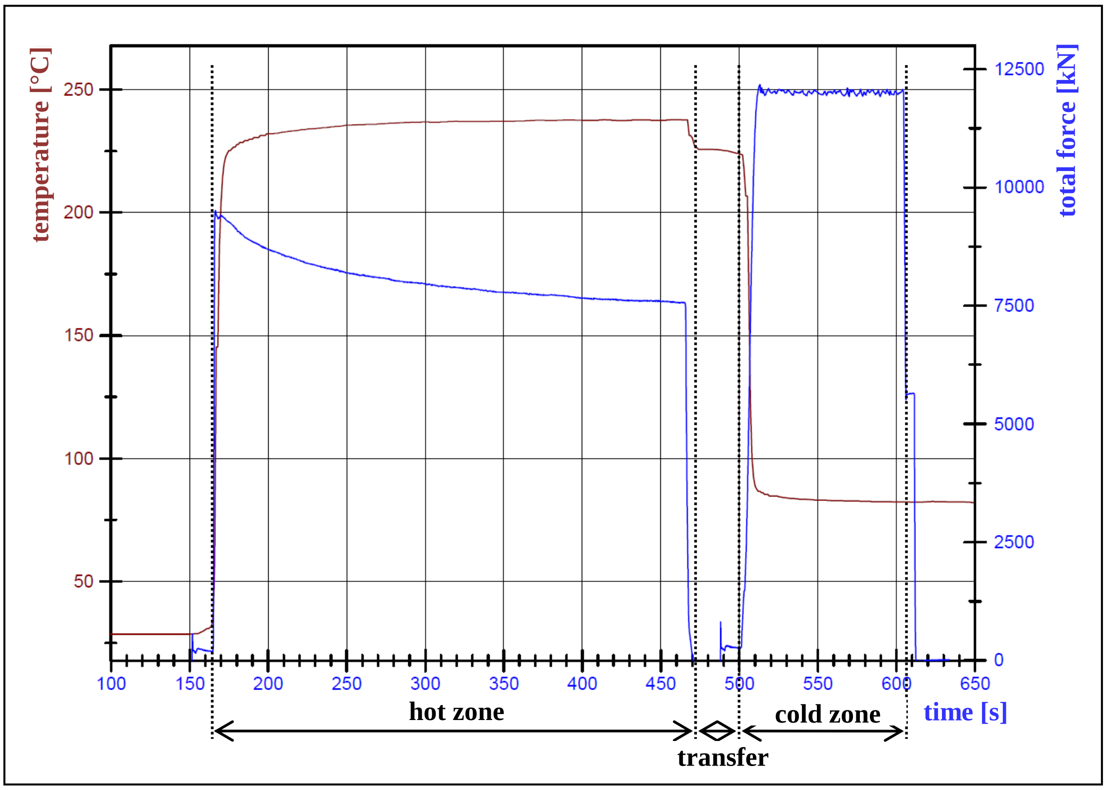

Figure 5. Temperature and force profile during the metal sandwich production process

The relevant quality parameters for this metal sandwich material are a constant sandwich thickness and a good impregnation of fibres with a low number of bubbles. The maximum thickness deviation is tolerated with +/- 0.05mm. To evaluate the impregnation quality an ultrasonic inspect technique, HFUS 2400 with air-coupling, is used. The investigations allow a good evaluation of a complete impregnation of the fibres with the matrix of the manufactured sandwich materials.

3. Forming behaviour of carbon fibre-reinforced metal sandwich materials

To analyse the formability, a seat cross-member of an automotive structure was selected as reference geometry. For the forming process a tooling concept with two manufacturing steps was developed (Fig. 6).
In the first stage the 2D water cutted sandwich sheets were heated up in a contact heating from 240°C to 280°C for approximately 40 seconds. The contact heating was chosen, because the heating rate is ten times faster compared to the heating rate in a furnace.
In the second stage the forming process of the heated sheet at a Servo-Excenter press with 1000 metric tons was done. Within this investigation the press force and the closing time were varied to check the influence of the part and to find the best forming parameters. The handling system was fully automatic by a handling robot system.
After the forming of the near net shape profile, the profile was measured by a 3D GOM measuring system. Furthermore macrosections were made at the Institute of Lightweight Engineering and Polymer Technology (ILK) in Dresden in order to check the delamination between the layers of the fibre metal material after forming process. In the macrosection neither air inclusions in the core material nor cracks in the surrounding metal sheet layers could be observed.

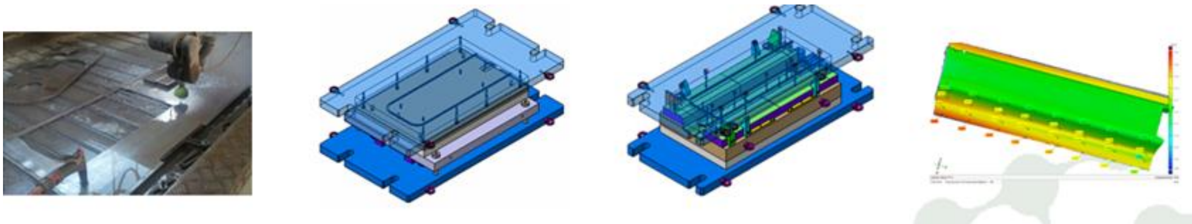

Figure 6. Process chain for the forming of LEIKA sandwich sheets.

During the whole process chain the temperature was measured with a thermocouple in the core material, as shown in Figure 7. Based on the temperature measurement the heating time and the forming time in the process could be improved.

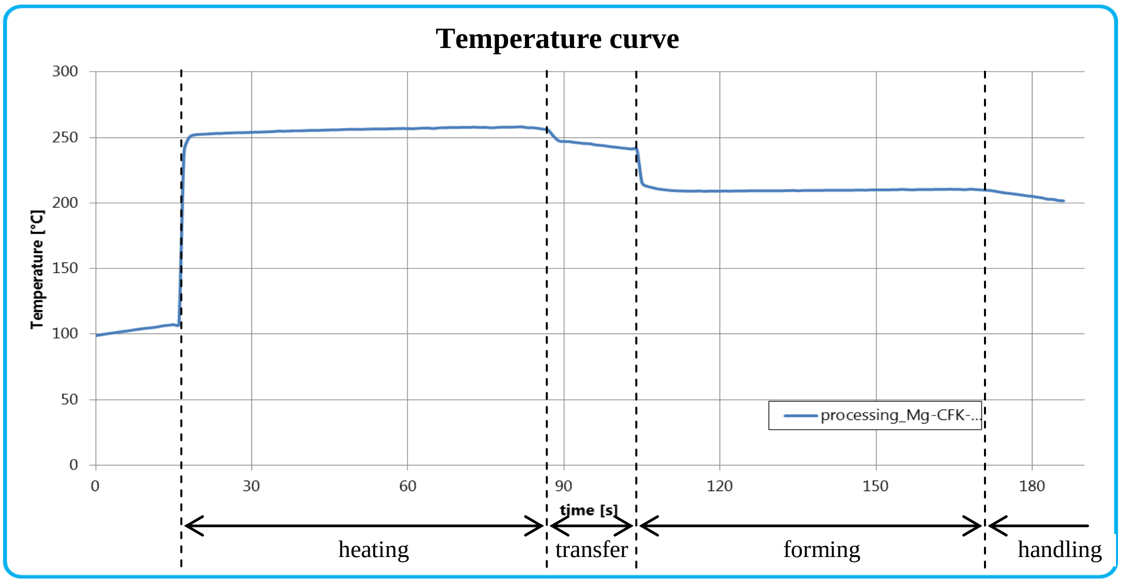

Figure 7. Temperature profile during the process.

The sandwich sheet is heated up in the heating station in less than five seconds to the forming temperature. Due to the magnesium cover sheets a forming temperature of 250°C is necesarry to enable additional gliding planes in the hexagonal elemtar cell of the AZ31-B.
After heating up the blank it is transferred to the forming station and will be formed to the final geometry. During the transfer from the heating to the forming station the temperature of the blank decreases around ten degrees.
Subsequently the profiles were measured in a 3D GOM measuring cell. Deviations, which could be observed at the first trials, could be minimized by improving the quality of the hybrid material sheets. Furthermore, an improvement of the process parameters, mainly temperature, was a possibility to decrease the deviations to a tolerable dimension. (Fig. 8)

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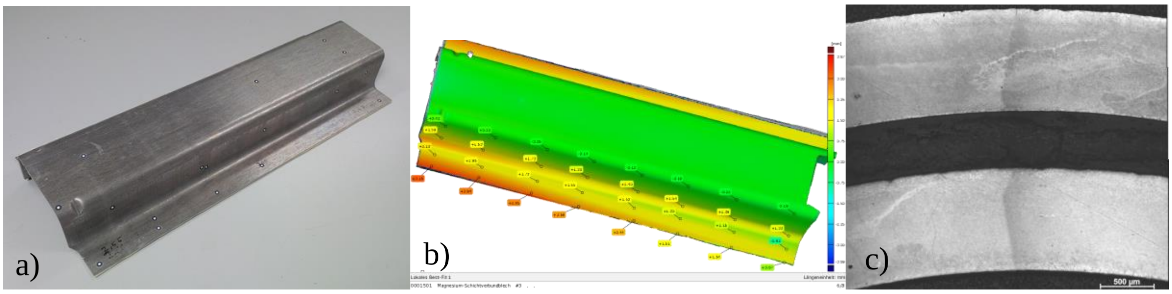

Figure 8. a) Final formed, b) measured part, c) makrosection.

As the forming process is here demonstrated on a seat cross-member, additional parts will be manufactured to build a floor assembly within the research project LEIKA. The forming process of the centre tunnel will be combined with injection moulding to add reinforcing and functional elements. Figure 9 shows the floor assembly made of the newly developed high performance sandwich materials.

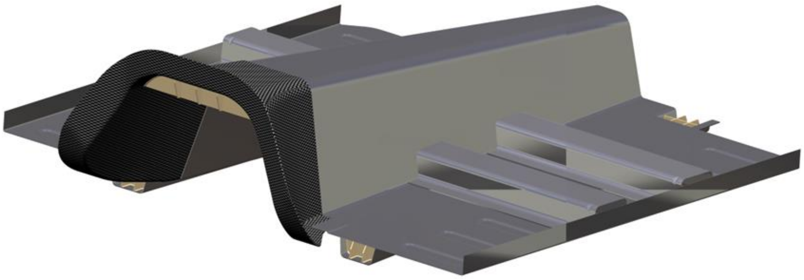

Figure 9. Floor assembly part designed of high performance sandwich materials.

4. Conclusions

The manufacturing of carbon fibre-reinforced metal sandwich materials and their forming behaviour was described in this paper. The production of the magnesium cover sheets and the merging of the individual components to a new high performance material were therefore described in detail. Furthermore, the forming behaviour was demonstrated on a seat cross-member of an automotive structure with a two-step manufacturing process.

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