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NOVEL FABRICATION TECHNOLOGIES FOR CARBON FIBRE REINFORCED MAGNESIUM

Carbon fibre reinforced magnesium composites (CF-Mg) offer a considerable potential for lightweight applications especially in aerospace and automotive industry. Due to their outstanding specific stiffness and strength as well as the excellent fatigue and creep properties CF-Mg composites are predestined not only for static loads but also particularly for applications with dynamic loads and complex superimposed stress conditions. The fabrication of the CF-Mg samples as well as component structures was accomplished with the aid of a modified gas infiltration technique. Furthermore, tensile tests for the determination of stiffness and strength data were performed on samples of the fabricated CF-Mg composites for various fibre orientations.

Key words: **metal matrix composite, production technology**

NOWE TECHNOLOGIE PRODUKCJI MAGNEZU WZMOCNIONEGO WŁÓKNAMI WĘGLOWYMI

Magnez wzmocniony włóknami węglowymi (CF-Mg) oferuje bardzo duże możliwości w konstrukcjach lekkich, szczególnie w przemyśle lotniczym i samochodowym. Z powodu znakomitych parametrów sztywności i wytrzymałości oraz dobrej odporności na zmęczenie oraz pelzanie te kompozyty nadają się nie tylko do elementów obciążonych statycznie, ale także do zastosowań w komponentach obciążonych zmiennymi w czasie ze złożonym stanem naprężeń. Wytworzenie próbek i kompozytów z CF-Mg udało się osiągnąć, po licznych eksperymentach, za pomocą zmodyfikowanej metody infiltracji gazowej. Testy w celu określenia własności sztywności i wytrzymałości zostały przeprowadzone na próbkach z kompozytów CF-Mg ze zmienną orientacją włókien.

Słowa kluczowe: **kompozyty metalowe, technologia produkcji**

INTRODUCTION

The development of modern metal matrix composites is the basis for a variety of innovative lightweight products, due to they offer a technological advantage compared to the conventional monolithic materials, as their property profile can be specifically adapted to the corresponding mechanical and functional loads. Based on the lightweight potential, magnesium is particularly suitable for the load-adapted combination with carbon fibres to CF-Mg. However, only the development and optimisation of production processes adapted to the material and the ongoing research of micro-structural processes and interfacial reactions allow fibre magnesium composites to develop into an interesting alternative to conventional design materials. The advantage of fibre-reinforced magnesium, for instance, in comparison to fibre-reinforced polymers, is in particular its better temperature stability up to temperature range of 300°C. Furthermore, fibre-magnesium composites offer, due to their highly ductile matrix, a more advantageous deformation behaviour, which makes this material predestined for use in structures subjected to crash and impact loads [1, 2].

CARBON FIBRE REINFORCED MAGNESIUM

The characteristic profile of fibre-reinforced magnesium can be controlled by the selection of reinforcing fibres [3] and their interface in a controlled way by the variation of alloy compositions and process parameters during the production of the composite [4]. Since the system magnesium/carbon itself is not reactive (known magnesium carbides MgC_2 and Mg_2C_2 are regarded as endothermic compounds which are not synthesisable from the elements and which are subject to thermal decay at temperatures above 500°C, respectively 650°C) [5], this results in low adhesion between fibre and matrix. Therefore, the selective increase of interfacial surface adhesion is achieved, on the one hand, by the addition of a carbide-forming element - as a rule, aluminium - to the magnesium and on the other hand by the modification of the fibre surface, for instance, by the selection of a special type of fibre or by coating of the fibres.

Various different research projects have performed in-depth studies of the connections between the fibre/ matrix interface and the micro-mechanical failure mechanisms, such as boundary surface failure („initial debonding" and „progressive debonding"), fibre fracture and fibre pull out and have thus provided the foundation

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for the optimisation of compounds of fibre-reinforced magnesium alloys [3, 5].

MANUFACTURING OF CF-Mg BY GAS PRESSURE INFILTRATION

Due to poor wetting between magnesium and uncoated carbon fibres, extremely high infiltration pressures are required in the production of carbon fibre magnesium composites. Therefore, hot-pressing, squeeze casting and gas pressure infiltration techniques have proven to be particularly effective production processes, which allow sufficiently high infiltration pressures at the required high processing temperatures [6, 7].

The fabrication of specimen of the carbon fibre reinforced magnesium was realised with the aid of an advanced differential gas pressure infiltration (DGPI) technique, which was developed at the ILK [4]. The advantage of this technique is that, for instance, in contrast to hot pressing, the atmosphere in the fibre preform is reduced during the infiltration. The solidification takes place with a high gas pressure, so that significantly fewer pores are created during the infiltration procedure. Further to that, in gas pressure infiltration the decisive process parameters, such as temperature, pressure and infiltration as well as cooling times can be adjusted selectively, allowing optimisation of the infiltration sequence.

The hot-pressing method, which also allows defined process control, is suitable only for the production of simple plate structures, while the gas pressure infiltration also enables the production of CF-Mg prototypes or low volume serial production with complex geometry close to the final contour. The process sequence of conventional gas pressure infiltration technique, which is shown in form of a schematic diagram in Figure 1, includes essentially the process phases flushing and evacuating, melting, infiltrating and cooling.

The advantage of the novel differential gas pressure infiltration techniques comparing to conventional techniques is that very thin-walled infiltration tools can be applied, what results in a better controllable process.

A laboratory autoclave, designed for a maximum process pressure of 100 bar at temperatures up to 1200°C, was initially used for the fabrication of CF-Mg semi-finished plates. The autoclave, which is equipped with two independently controlled heating zones, offers a capacity with a diameter of 140 mm and a height of 300 mm. Larger CF-Mg structures and substructures can be processed in an autoclave especially set up at the ILK. The processing chamber of this autoclave has a height of 800 mm and a diameter of 600 mm and is provide with three heating zones, the maximum process parameters are at 850°C and 80 bar.

The extraordinarily great bandwidth of variable material and process parameters in the production of carbon fibre-reinforced magnesium by means of gas pressure infiltration methods requires a systematic approach in the selection of optimal parameters [4]. In the course of these efforts, the material parameters of fibre type and textile reinforcement and magnesium matrix were varied as were the essential process parameters, such as pre-mould, mould and casting temperature as well as infiltration pressure.

As infiltration tools multi-component graphite moulds were used, which consist of chill and inner mould. Their development and modification were carried out in accordance with specified requirements on the semi-finished sample plates. The moulds enabled the production of sample plates with a length of 160 to 250 mm, a width of 65 to 150 mm and a thickness of 0.5 to 13 mm.

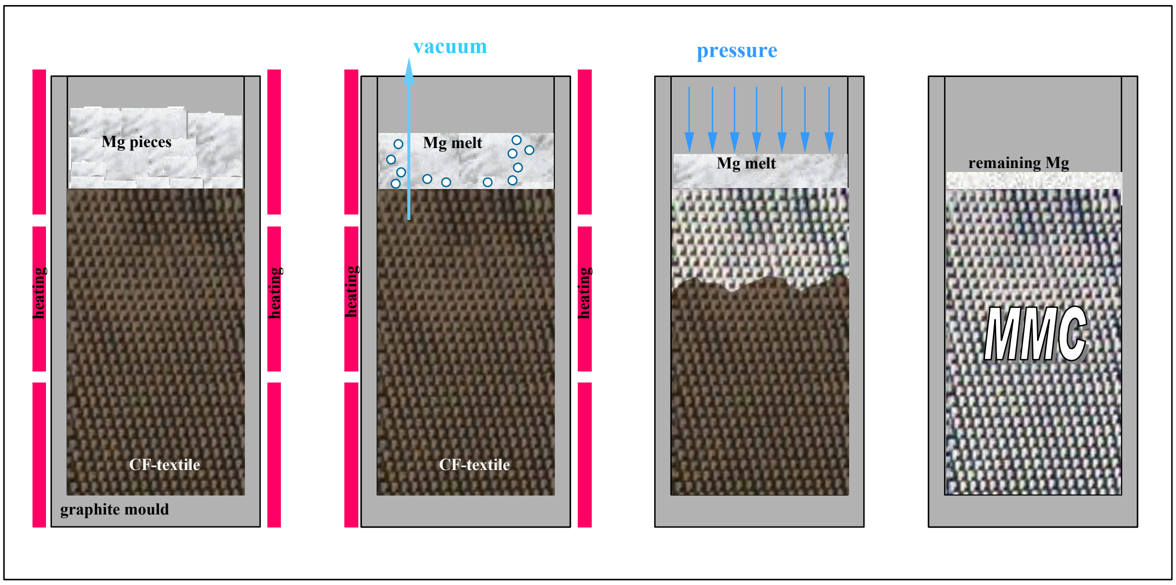

Fig. 1. Schematic diagram of the gas pressure infiltration process (ILK)

Fig. 2. High temperature autoclaves for the production of CF-Mg samples and for technology demonstrators

Fig. 3. Component graphite moulds for CF-Mg plates [4]

MATERIAL-MECHANICAL STUDIES OF FIBRE-MAGNESIUM COMPOUNDS

Tensile tests for the determination of stiffness and strength parameters were performed on samples of flat specimens for various fibre orientations. For this purpose, the tensile strength is determined by means of force sensors and the occurring elongation is determined using extension sensors as well as strain gauges. The modulus in tension of selected carbon fibre-reinforced magnesium composites with textile reinforcement determined in the tensile tests is shown in Table 1. Further to that, Figure 4 shows the directional stiffness parameters of a bidirectional, textile-reinforced magnesium in form of a polar diagram.

TABLE 1. **Modulus in tension and strength data of selected carbon fibre magnesium composites**

Fibre reinforcement of Mg-composites	E-module in tension	Strength
	E_1, GPa	R_m, MPa
T800 (50/50) *	77	500
M 40 (50/50) *	77	470
T300 (80/20) *	110	660
T300 (50/50) *	68	425

* portion of reinforcing fibres in warp and weft direction

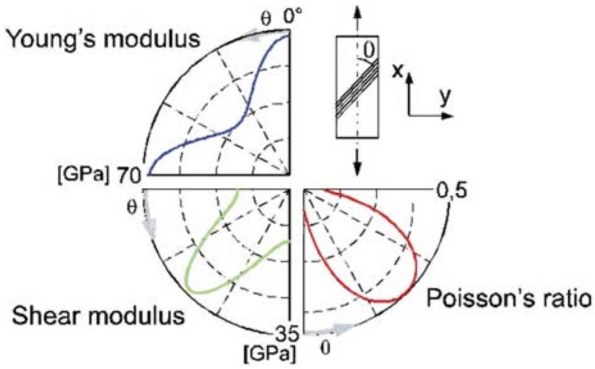

Fig. 4. Directional stiffness parameters of bidirectional reinforced magnesium (T300-Mg)

CONCLUSION

The differential gas pressure infiltration technology enables to fabricate complex carbon magnesium composites with fibre or textile reinforcement, while it is possible to vary the processing parameters in a great range. This allows to produce reinforced magnesium composite with optimal protection of the fibres and matrix materials. Furthermore, special developed divisible graphite moulds approve to manufacture samples in different sizes. The fabricated composites indicate excellent stiffness and strength properties.

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Recenzent
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