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COMPOSITES THEORY AND PRACTICE

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APPLYING STIR CASTING METHOD FOR Mg ALLOY-SHORT CARBON FIBER COMPOSITE PROCESSING

The effects of applying the stir casting method to fabricate composites with an Mg-Zn-Zr-RE magnesium alloy matrix reinforced with short carbon fibers are presented in the article. The experimental procedure carried out in industrial conditions was described. Carbon material in the form of short staple fiber granules obtained from chopped/cut carbon roving was used. The procedure of suspension fabrication and casting in ceramic and steel moulds was described. The possibility of obtaining casts of different size and shape which can be a semi-product for die casting technology has been shown. Additionally, the microstructure and mechanical properties of the obtained material were characterized.

Keywords: magnesium matrix composite, carbon fibers, stir casting

ZASTOSOWANIE METODY STIR CASTING DO OTRZYMYWANIA KOMPOZYTU STOP Mg-WŁÓKNA WĘGLOWE KRÓTKIE

W pracy przedstawiono efekty zastosowania metody mechanicznego mieszania komponentów i odlewania suspensji (stir casting) do otrzymywania kompozytów z osnową ze stopu magnezu Mg-Zn-Zr-RE umacnianych włóknami węglowymi krótkimi. Scharakteryzowano procedury procesu technologicznego prowadzonego w warunkach przemysłowych. Użyto materiału węglowego w postaci granul włókien krótkich ciętych otrzymanych z pociętego rovingu węglowego. Scharakteryzowano procedurę przygotowania suspensji i przebieg procesu jej odlewania do form ceramicznych i stalowych. Wykazano możliwość otrzymania wlewków kompozytowych o różnym kształcie i wielkości przeznaczonych do przetopu wtórnego i odlewania ciśnieniowego. Scharakteryzowano mikrostrukturę otrzymanego materiału i określono jego właściwości mechaniczne.

Słowa kluczowe: kompozyty z osnową magnezową, włókna węglowe, odlewanie suspensji kompozytowej

INTRODUCTION

The infiltration of carbon fabrics by liquid magnesium alloys is commonly proposed in literature as the method of fabricating magnesium matrix composites with carbon fibres [1, 2]. That technological procedure ensures very good mechanical and tribological properties of the composite but limits the shape and size of the composite products. The application of cut carbon fibers, mixing them with a liquid alloy, and finally casting the suspension (stir casting process), similar to the well-known procedure for particle reinforced composites, seems to be an alternative and perspective technique for magnesium-carbon fiber consolidation. That solution should ensure obtaining products of more complex shapes and a material with an isotropic microstructure and properties. However, inferior mechanical properties compared with an infiltrated composite can be expected because of the limited maximal fiber volume fraction in a suspension of sufficiently good casting parameters. However, an advantage of composite casts obtained by stirring and gravity casting is the possibility of applying them as a semi-product for pressure die casting as well as metal forming.

In the paper, the processing of magnesium alloy-short carbon fiber casts by the stir casting method in industrial conditions is presented. It is focused on the fiber and suspension preparation, casting procedure, final product properties and microstructure.

EXPERIMENTAL PROCEDURE AND DISCUSSION

Fiber preparation

Commercial carbon fiber roving, STS 5631 1600 tex, was mechanically cut and then 3D granules of a dimension of approximately 5mm, consisting of separated single fibers with a length of less than 400 μm were prepared (Fig. 1). That form of fiber configuration was applied to ensure their proper infiltration with the liquid alloy during the stir mixing procedure. A very thin organic layer called sizing is deposited on commercial carbon fibers used with a polymer matrix and that is a disadvantage in metals technologies, therefore sizing removal is necessary. After several tests, heat treatment at 400°C and 2 h in a furnace without protective atmosphere was chosen as an effective solution. In Figure 1, the 3D granules after heat treatment and before consolidation with the liquid alloy are presented. The microstructure of a single granule consisting of separated short carbon fibers is shown in Figure 2.

Fig. 1. View of 3D granules of short carbon fibers after heat treatment

Rys. 1. Widok granul 3D z włókien krótkich po obróbce cieplnej

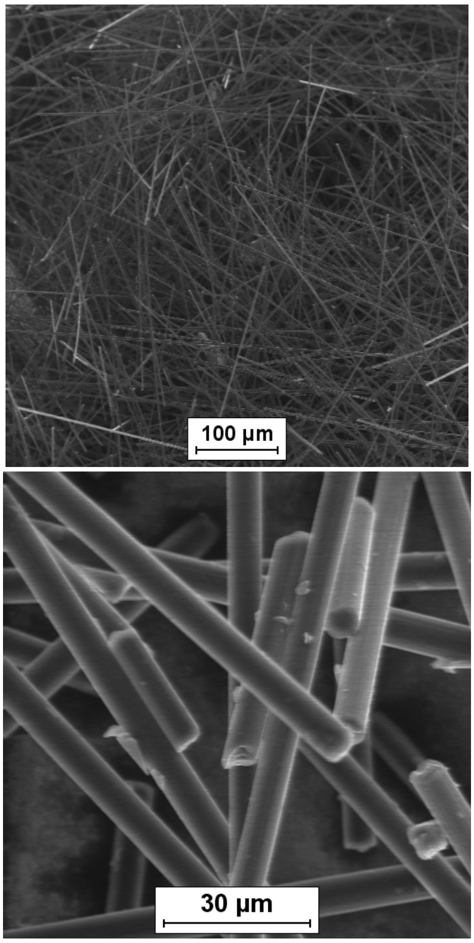

Fig. 2. Micrographs of single 3D short carbon fiber granule, SEM

Rys. 2. Mikrofotografie granul 3D z włókien węglowych krótkich, SEM

Mg alloy – Cf suspension fabrication procedure

The Mg-Cf suspension was prepared in an industrial electric furnace (Fig. 3), complete with a steel crucible and a system of protective gases (mixture of CO_2 and SF_6) according to the conditions described in [3]. At first, a basic melted magnesium alloy with Zn 2.4 wt.%, Zr 0.63 wt.% and 0.63 RE wt.% and mass of 35 kg was prepared and mixed at a velocity of 300 rpm. Then the 3D Cf granules (1.7 kg) were slowly added to the continuously mixed alloy at a temperature below 700°C during 30 minutes. An increase in the Cf amount in the suspension was not possible in the applied conditions because the mixing system seized up. After the process of Mg alloy-Cf consolidation, the suspension was continuously mixed for approximately 10 minutes. When introducing the fibers into the mixed metal, some of them burnt despite the protective atmosphere in the crucible. It was a result of the presence of some amount of air between the single short fibers that could not be removed effectively before direct contact of the fibers with the liquid metal.

Fig. 3. Electric furnace with mixing system applied for suspension fabrication

Rys. 3. Piec elektryczny z systemem mieszającym użyty do wytworzenia suspensji

Casting procedure

After the end of suspension fabrication, the mixing system was removed from the steel crucible and the crucible with the suspension and system of protective gases were transported to a special thermos. Two procedures were employed for suspension casting - directly pouring from the thermos into ceramic moulds (Fig. 4a) and pouring from a hand shank into open steel moulds (Fig. 5a). Composite casts of different shape and size were obtained (Figs. 4b and 5b).

Fig. 4. Pouring suspension from thermos into ceramic moulds (a), obtained composite casts after fettling (b)
Rys. 4. Zalewanie suspensji do form ceramicznych z termosu (a), otrzymane odlewy kompozytowe po oczyszczeniu (b)

Fig. 5. Pouring suspension from hand shank into open steel moulds (a), suspension during crystallization in steel moulds (b)
Rys. 5. Zalewanie suspensji z łyżki (a), suspensja podczas krystalizacji w formach stalowych (b)

The surface of the ingots cast in the ceramic moulds was smooth and it means that only abrasive machining of their surface will be necessary for further application of the ingots as a semi-product in pressure die casting or metal forming technologies. In the case of the casts crystallized in the open steel moulds (Fig. 5b), the casting procedure is cheaper and easier but the suspension has a tendency to self-ignite, similar to all magnesium alloys. Therefore, to ensure proper process security, the surface of the crystallizing suspension must be covered with a special casting powder. That generates a very hard ceramic layer formation on the open surface of the casts and the necessity of mechanically cutting it off.

Microstructure and properties

Investigations of a cross-sectioned and unetched composite sample and a fractured sample after a tensile strength test were performed with a scanning electron microscope, FE-SEM Hitachi 4200S. It was visible (Fig. 6) that the short Cf were properly surrounded by the matrix and their distribution was similar to a cellular network structure, which suggests that the processes occurring during matrix crystallization have a very strong influence on the final fiber arrangement. At the interface between the fibers and matrix (Fig. 6b), a zone of interaction products was formed but that effect is similar to a MgZnZrRe-GCp composite fabricated by hot pressing and was described in detail in [4]. Additionally, in the obtained material, a tendency of zirconium accumulation in the matrix near the fibers was visible. On the surface of the fractured sample (Fig. 7), phenomena such as the decohesion of fibers perpendicular to their main axis, pulling out of fibers, fiber delamination, and incidentally decohesion of fibers parallel to their main axis were observed.

The results of the tensile test of the cast composite samples and hardness measurements are presented in Table 1, and they show that the mechanical properties of the obtained material are at the level of commercial magnesium alloys. It may be a consequence of the presence of pores in the gravity cast semi-product and the relatively low volume fraction of Cf.

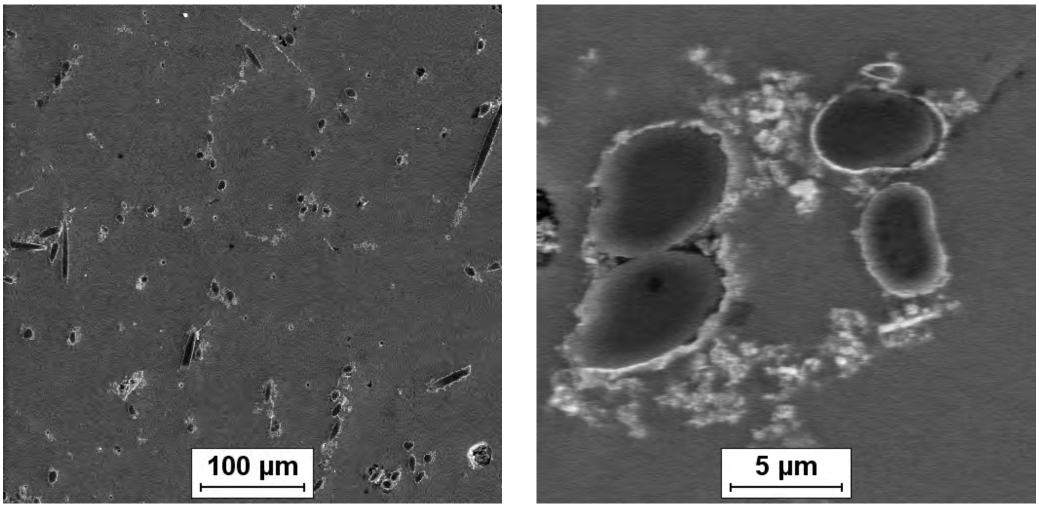

Fig. 6. Micrographs of Mg-Cf composite, polished unetched cross-section, SEM
Rys. 6. Mikrofotografie Mg-Cf, zgład nietrawiony, SEM

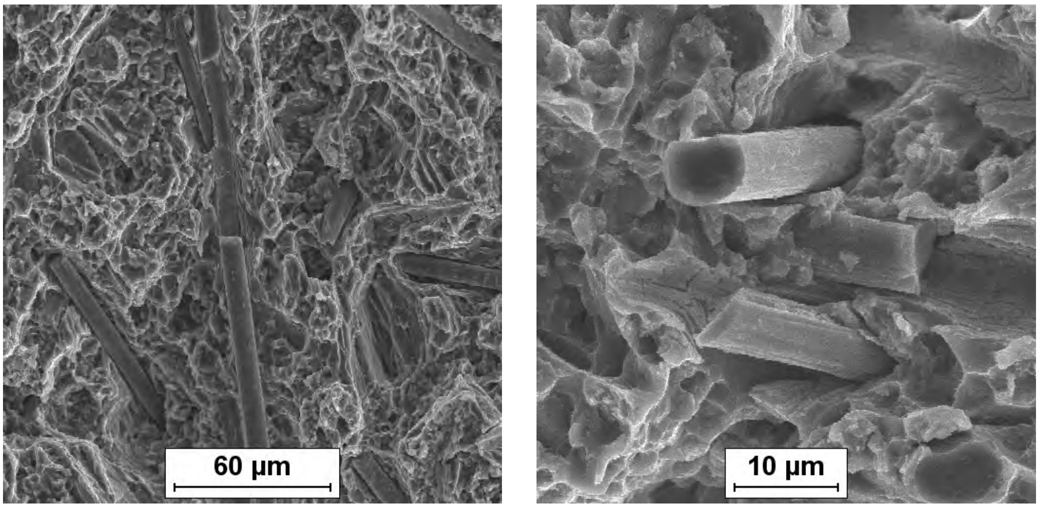

Fig. 7. Micrographs of Mg-Cf composite fracture after tensile test, SEM
Rys. 7. Mikrofotografie przełomu kompozytu Mg-Cf powstałego podczas próby rozciągania

TABLE 1. **Mechanical properties of Mg-Cp stir cast composite**
TABELA 1. **Właściwości mechaniczne odlewanego kompozytu Mg-Cp**

E [MPa]	Rp, 0.2 [MPa]	Rm [MPa]	A5 [%]	HB
10566	66	190	9	51

Further experiments with that composite such as remelting and die casting will show the real potential of short Cf as a reinforcing phase of magnesium alloys. However, the mere presence of carbon fibers in the obtained material guarantees improvement of the sliding wear parameters and that aspect of future application should be taken into account.

CONCLUSIONS

Our research on stir casting technology with Mg alloy-short fibers performed in industrial conditions can be concluded as follows:

1. The preparation of short carbon fibers in the form of 3D granules consisting of separated single fibers allows us to obtain a magnesium-based suspension with properly wetted and distributed fibers. A conventional industrial furnace with an atmosphere of protective gases completed with a proper stirring system can be used for fabricating a magnesium alloy-short carbon fiber suspension.
2. For the correct rotation speed and geometry of the stirrer, the amount of fibers in the suspension was limited by the power of the stirring system and that aspect must be taken into account when designing a technological apparatus.
3. Composite ingots of different shape and size gravity cast in ceramic and metal moulds can be obtained from the Mg alloy-Cf composite suspension. The risk of suspension self-ignition occurred during its stirring, casting as well as crystallization, and proper security of the technological procedure must be ensured.

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