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Investigation of the interaction between the CuZn38Pb2 matrix and the Fe reinforcement phase during the production of the complex relief MMCs

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Abstract

The present paper is relevant to the investigation of the interaction between the copper alloy metal matrix (CuZn38Pb2) and the reinforcement phase (Fe) during the production of "hybrid" complex relief MMCs. An innovative production method is used for the creation of composites that have been brought to the application of different space vacuum schemes for composite synthesis of vacuuming the space by using the notion of "capillary forming". In this method, the metal matrix (copper alloy melt) was forcedly infiltrated in the space between the reinforcement phase (Fe) particles as opposed to the classical method to obtain MMCs, uses a mechanism of insertion of the reinforcement phase into the ready for use melt, followed by homogenization of the composite structure. In this paper is presented a cost-effective production processes for metal-matrix composites by using single blanks implementing conventional methods for mould production (in expendable cement mould).

Studies were also carried out metallographic and X-ray diffraction phase analysis to clarify the phase composition and the ongoing diffusion processes due to the high temperature process of production of complex relief MMC. Microhardness of the composite phase was also measured.

Keywords: MMCs, copper alloy CuZn38Pb2, Fe reinforcement particles

1. Introduction

Composite materials are preferred solutions for manufacturers, designers and engineers to produce high quality products with unique properties that have not been achieved yet. The production of metal-based reinforcing composites using casting methods is a step towards wider industrial application for the production for more functional details with higher technical and economic performance [1]. The technologies used aim at improving the complex properties, mechanical and physical characteristics of the metal alloy matrix. The physicochemical interactions of the matrix and the reinforcement components in these composites take place due to diffusion and chemical reactions [2]. This determines the research of universal technologies, the great variety of these materials and the need of technological procedure optimization of composites production [3,4].

Mainly MMCs are classified according to the reinforcement phase condition: "in vitro", "in situ" and "hybrid". The metal composites which have been obtained in the research conducted can provisory be attributed to "hybrid" composites – the reinforcement phase is obtained as a result of a more complex interaction, with elements from "in vitro" and "in situ" type [1,5].

The present paper presents an innovative method for the production of complex relief MMCs. The preparation is accomplished in expendable mould by forced mixing of the reinforcement phase and metal matrix, which is essentially a new method in the production of MMCs. The methodology of MMCs production is based on a concept of new molding method – the "capillary forming" method protected by patent [6].

Given the prolonged process of heating while obtaining MMC's and the uniformity of the materials of the matrix and the reinforcement phase, interaction between them was expected, and microstructural and X-ray diffraction analysis was conducted [7,8].

2. Exposition

The purpose of the experiments conducted was to investigate the interaction between the metal matrix CuZn38Pb2 and the Fe reinforcement phase while obtaining complex relief MMCs. In this case, a “hybrid” type complex relief composite having a controllable geometry of the reinforcement phase and the metal matrix was obtained using the “capillary forming” capabilities.

The advantage of this method is that cost-effective single blanks are obtained with easy to be prepared equipment implementing the conventional methods for mould production (in expendable cement mould). There isn’t a special need for the moulds to be metallic as opposed to the classical method for obtaining MMCs [3,4].

The principle scheme of the laboratory device where the MMCs are obtained is shown in Figure 1. A number of experiments have been conducted on the production of MMCs with a different metal matrix and reinforced phase agent. The experiments have been carried out using this laboratory device. The main element of this scheme is the production chamber developed, where the chamber vacuum takes place in three directions. This effect is achieved by perforating the main flask. Thus, the pressure in the mould becomes equal along the side surfaces and the lower surface which acts as extra thickening of both the smelt and the constituents of the composite [4,9].

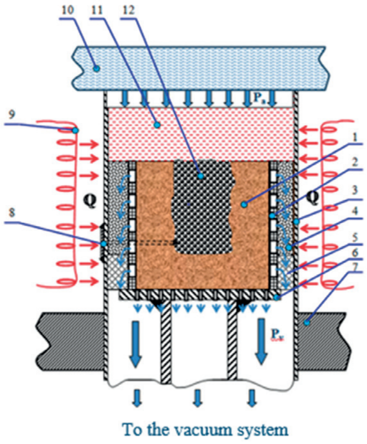


Fig. 1. A general view of a production chamber where the MMCs are obtained

1 – a mould; 2 – a perforated flask; 3 – a steel shell; 4 – a thermo-insulation seal; 5 – a fireproof insert; 6 – a fireproof stand; 7 – a fireproof plate; 8 – a thermocouples; 9 – a heaters; 10 – a fireproof insert; 11 – melt; 12 – melt (matrix) and reinforcement phase particles

The production of the composite is implemented in advance of the reinforcement phase (64% Fe particles) and 10% particles of metal matrix material (CuZn38Pb2) are mixed in the mould cavity. The mould is put in the MMCs production chamber and is heated up to 1100°C, then the copper alloy particles are melt and wet in the reinforcement phase. After, they are heated up to 1100°C while a molten copper alloy is added.

The melt pressurizes the system and then is infiltrated forcefully in the capillary space among the reinforcement phase particles with pressure $\Delta p = p_a - p_{\text{в}}$. There is atmospheric pressure above the melt whereas (100 kPa), under the melt the pressure is lower (−96 kPa) since the space in this area is connected with the vacuum system. Obtained by this method and studied in the present paper complex relief composite, is shown in Figure 2.

Fig. 2. Picture of the obtained complex relief MMC with copper alloy (CuZn38Pb2) matrix and Fe reinforcing phase

3. Results and analysing

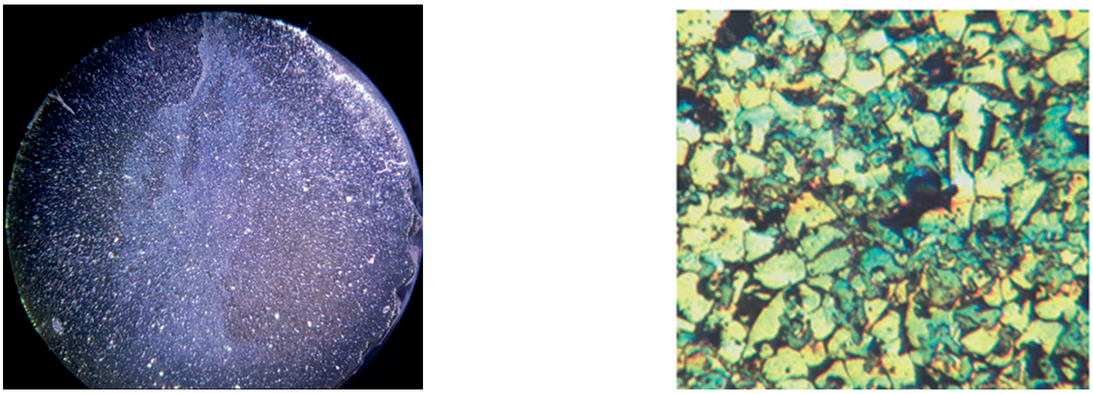
The experimental sample obtained is used to prepare some samples for a macrostructural and microstructural analyses. As can be seen in the macrostructure shown in Figure 3a, the reinforcement phase (iron particles) are evenly distributed throughout the casting volume. It can be seen from the microstructure shown in Figure 3b too, which shows a low magnification.

In Figures 3a and 4 it can be seen that the composite has a dense structure and a very good infiltration of the melt in the capillary cavities formed among the reinforcement phase particles (Fe).

3.1. Results of microhardness analyze

The microhardness of the reinforcement phase is average 150 HV, which is 100 units more than that of pure iron (Fig. 4). In the area of the molten and crystallized copper alloy (the matrix) microhardness with an average 120 HV was measured, which is 40−50 units more (CuZn38Pb2 has 70−80 HV). The increase of hardness proves ongoing diffusion processes between the metal matrix and the reinforcement phase exist.

Correctly analysed microstructure of the obtained composites of the X-ray diffraction phase analysis was conducted.


a)

b)

Fig. 3. Macrostructure of the obtained MMC (a) and microstructure after etching ×100 (b)

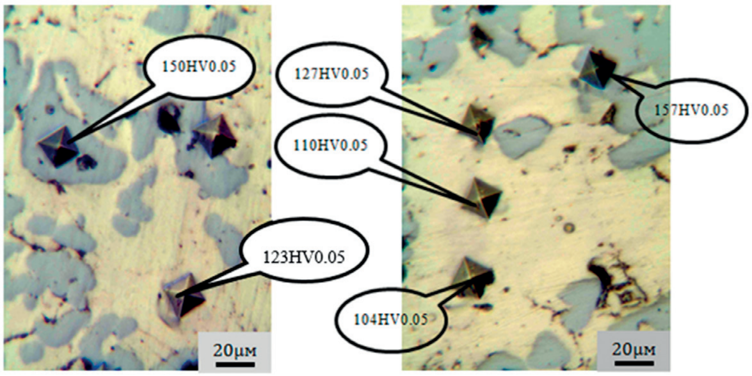


Fig. 4. Microstructure ×500 before etching of the obtained MMC, by measured Vickers microhardness in the area of the matrix and a reinforcement phase

3.2. Results of the X-ray diffraction phase analysis

The purpose of the X-ray diffraction phase analysis to determine the phases obtained on the basis of ongoing diffusion processes during the production of the complex relief MMC with metal matrix CuZn38Pb2 and Fe reinforcement phase.

X-ray diffraction analyses were performed using chromium tube radiation. The alloy constituting the matrix is copper alloy (CuZn38Pb2) with a zinc content of 38%. In this composition, the expected phases are a solid solution of α-Cu (FCC lattice) and an intermetallic compound CuZn-β (BCC lattice) (Fig. 5). The main phase is the intermetallic compound β (CuZn) with a BCC Lattice. In the 830−500°C temperature range, the intermetallic compound has a high degree of homogeneity and α-Cu is released. Below this temperature, a $\beta \rightarrow \beta'$ transformation and shift of the β' phase to higher Zn concentrations is observed.

In Figure 6 is shown an X-ray diffraction analysis pattern of complex relief MMC with copper alloy matrix CuZn38Pb2 and Fe reinforcing phase. If the α-Cu lines are traced, the presence of a significant quantity of dissolved zinc in the examined solid solution can be detected, as shown by the significant displacement of the α-Cu (220) line to the smaller angles (2θ, 128.3 → 2θ, 125.3). The low degree of homogeneity at lower temperatures of the β' phase does not significantly change the diffraction angles of the captured pattern. Interesting is the reading of the intermetallic compound Γ_1-Fe_3Zn_{10} with the BCC Lattice (Fig. 6, Fig. 7b). It is formed along the iron particles border due to the diffusion processes in the temperature range of 762 to 450°C (Fig. 5b and Fig. 6). Thus, a chemical compound is formed between the reinforcement particles Fe and the Zn saturated α-Cu solid solution.

As well as the microstructure analysis there can be seen an interaction among the liquid phase and the solid phase, as a result of the high temperature process and prolonged obtained time of the MMC, conducted to ongoing diffusion processes. This fact is confirmed by the conducted X-ray diffraction phase analysis and measured Vickers microhardness in the area of the metal matrix and the reinforcement phase. Phases determined by X-ray analysis are visible on the microstructure in Figure 7.

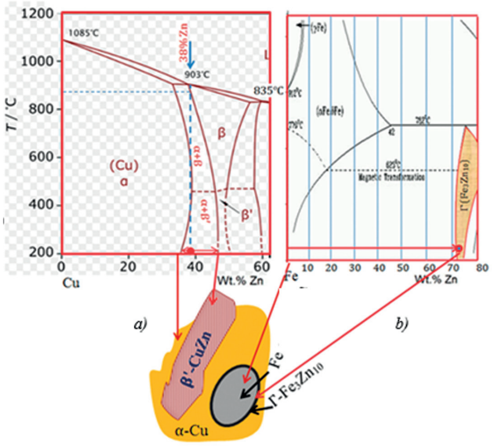


Fig. 5. Phase diagram of Cu-Zn (a) and phase diagram Fe-Zn (b)

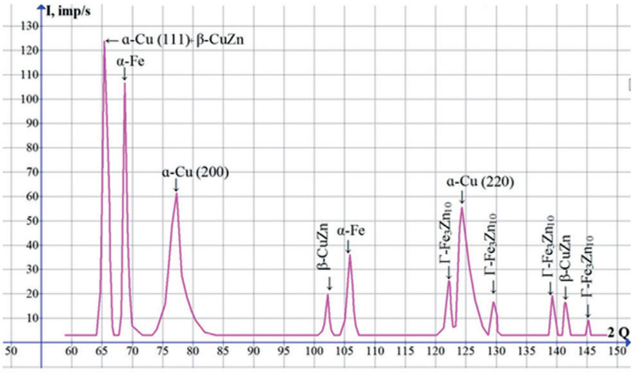


Fig. 6. X-ray diffraction pattern of the complex relief MMC with metal matrix CuZn38Pb2 and Fe reinforcement phase

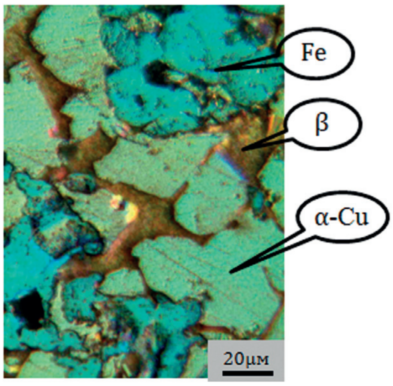


Fig. 7. Microstructure of the obtained MMC with metal matrix CuZn38Pb2 and Fe reinforcement phase – a) after etching ×500, b) after etching ×1000

4. Conclusion

After the conducted investigation, based on the results obtained, the following more important conclusions can be drawn:

1. The methodology developed for the preparation of complex-relief MMCs provides good results in relation to the infiltration of the melt (CuZn38Pb2) in the capillary cavities formed among the reinforcement phase particles (Fe), and as a result the areas with volume defects (pores, draws) are not observed and the composite has a dense structure.
2. The cost-efficient production processes for obtaining complex relief MMCs is developed, using single

blanks implementing conventional methods for mold production (in expendable cement mould).

3. The microhardness measured has revealed an increase in the hardness of the phases in the composite obtained in comparison with the initial components, which proves ongoing diffusion processes between the metal matrix and the reinforcement phase exist. The hardness of metal matrix CuZn38 increases with 40−50 Vickers units and the hardness of the Fe reinforcement phase increases with 100 Vickers units.

4. The X-ray diffraction phase analysis conducted of complex relief MMC proved the presence of diffusion processes that lead to the formation of the intermetallic compound Γ_1-Fe_3Zn_{10} located at the border of the metal particles as well as iron diffusion in cuprum.

Acknowledgments

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