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INFLUENCE OF CLOSED-DIE HOT COMPACTION PARAMETERS ON SELECTED PROPERTIES OF PM AL-SI-FE-CU MATERIALS

1. INTRODUCTION

The forming processes based on powder metallurgy make it possible to obtain materials showing properties which are difficult to achieve by casting. Powders or powder mixtures used as initial material allow to easily modify the chemical composition. The possibility to obtain microstructure of small grain size is also an advantage, especially in case of materials produced from pulverized powders, which is an effect of short particle solidification time [1]. In case of materials destined for constructional elements it is necessary to obtain suitably high relative density, which depends on material grade, working conditions of an element and loading scheme. In case of some powders it is possible to achieve high relative density of PM products by means of applying compaction and sintering processes. Powders produced from low-ductile, hard or fine-grained materials can be processed with application of plastic working or closed-die hot compaction [2]. During forming of products by means of plastic working and compaction, the material flow occurs. As a result of hot compaction, the decrease of initial material's volume and increase of its density is observed, along with the consolidation of powder particles. The parameters determining the properties of obtained products include: temperature, punch unit pressure and pressure duration [3]. Closed-die hot compaction can be applied instead of compaction and sintering, when the chemical composition or powder morphology makes it impossible to obtain the stable compact at room temperature, regardless of pressure level. As an example of hard-cold-deformable materials, Al-based alloys can be given, with silicon as basic alloying component. These alloys show some interesting properties, such as low specific gravity, high strength, good thermal conduction and wear resistance. They can be modified as needed, by introducing reinforcing phase or additional alloying components [4, 5, 6]. Their applications include constructional elements working in elevated or variable temperatures, mainly in automotive industry.

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2. EXPERIMENT

Objective and scope of research. The research aimed at the determination of the influence of forming parameters on selected properties of products obtained in closed-die hot compaction of Al-Si-Fe-Cu type alloy powder. The scope of research included the preparation of samples in closed-die hot compaction process, with the parameters set for the experiment, determination of selected properties of obtained products and the analysis of microstructure.

Material. The initial material used in the experiment was pulverized Al17Si5Fe3Cu1.1Mg0.6Zr alloy powder, with particles of spherical shape and size smaller than 40 μm.

Preparation of samples. The parameters of heating and forming processes, set for the experiment, are given in Table 1. The powder was loosely poured into the die of 35 mm diameter heated to the temperature resulting from testing procedure, and then kept there for a sufficient time, for the given amount of powder, until thermal stabilization of a system was reached. Subsequently, the specified pressure was applied by means of a punch, for a specified time period. After removing the load, the samples were pushed out from the die and air-cooled. The selected samples are shown in Fig. 1. The occurrence of cracks was found on the surface of samples formed at the temperature of 400 ^{o}C, under the pressure of 50 MPa, which can be seen in Fig. 1a and b. In case of materials formed at the temperature of 450 ^{o}C or higher, under the pressure of 100 MPa or 150 MPa, the surface of samples was free from visible defects (Fig. 1c).

Table 1. Parameters of hot compaction of Al17Si5Fe3Cu1.1Mg0.6Zr powder

weight of powder g	heating time min	temperature ^{o}C	unit pressure MPa	pressure duration min	cooling conditions
100	15	400	150	5	air
		450			
		485			
		500	50, 100, 150		
		515	150		

Fig. 1. Shape of samples obtained in closed-die hot compaction of Al17Si5Fe3Cu1.1Mg0.6Zr powder: a) temperature 500 ^{o}C, punch unit pressure 50 MPa; b) 400 ^{o}C, 150 MPa; c) 450 ^{o}C; 150 MPa

The effect of the applied forming parameters on density, selected mechanical properties and microstructure of products was investigated.

3. RESULTS OF INVESTIGATIONS

Relative density. Density testing was performed according to Archimedes method, and the obtained results are presented in Figure 2. It was found that compaction of powder, realized with the parameters set for the experiment, results in obtaining products of high relative density. After compaction at the temperature of 450 ^{o}C and higher (Fig. 2a), under the pressure of 100 MPa and 150 MPa (Fig. 2b), the obtained materials showed the density close to that of a solid material.

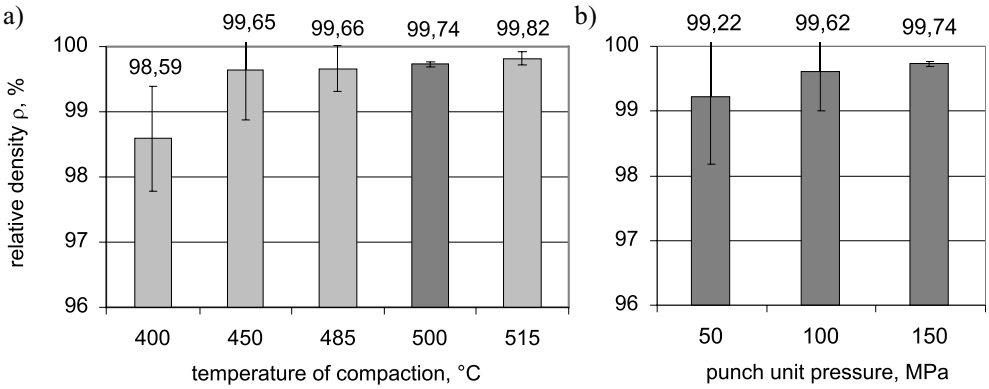

Fig. 2. *Influence of parameters of closed-die hot compaction of Al17Si5Fe3Cu1.1Mg0.6Zr powder on relative density: a) effect of temperature, at punch unit pressure 150 MPa; b) effect of punch unit pressure, at temperature 500 ^{o}C*

Hardness. Hardness measurements were performed according to Brinell method, and the results are given in Figure 3, for individual process parameters. HB hardness of investigated materials decreases with increasing temperature of compaction (Fig. 3a). HB values observed for materials obtained in compaction at the temperature of 500 ^{o}C, under various unit pressures (Fig. 3b), were found comparable.

Flexural strength. Three-point flexural test was performed at room temperature. The velocity of 0.017 mm/s was applied and the length of support span was set to 26 mm. The effect of forming process parameters on flexural strength of products is presented in Figure 4.

The highest average flexural strength, amounting to 733 MPa, was found for the material obtained through compaction at the temperature of 485 ^{o}C, under punch unit pressure of 150 MPa. For samples compacted at temperatures of 400 ^{o}C and 450 ^{o}C, under unit pressure of 150 MPa, the largest scatter of flexural strength results was observed (Fig. 4a). In case of

materials compacted at temperatures of 500 °C and 515 °C, under unit pressure of 150 MPa, lower average values of flexural strength were found (Fig. 4a), and the scatter of results was insignificant.

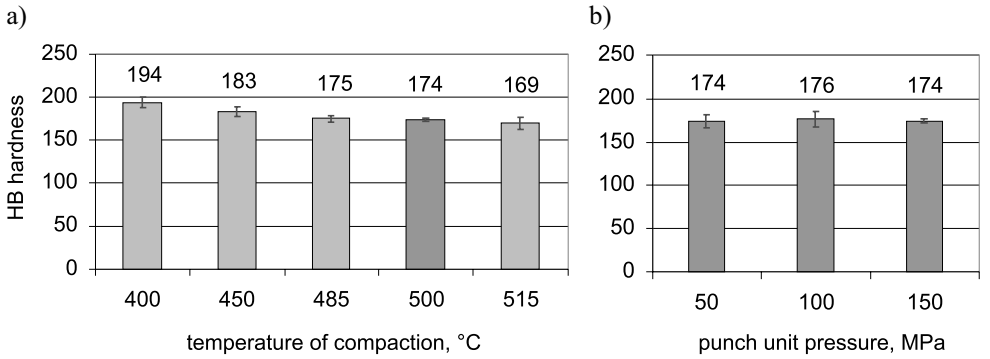

Fig. 3. *Influence of parameters of closed-die hot compaction of Al17Si5Fe3Cu1.1Mg0.6Zr powder on HB hardness: a) effect of temperature, at punch unit pressure 150 MPa; b) effect of punch unit pressure, at temperature 500 °C*

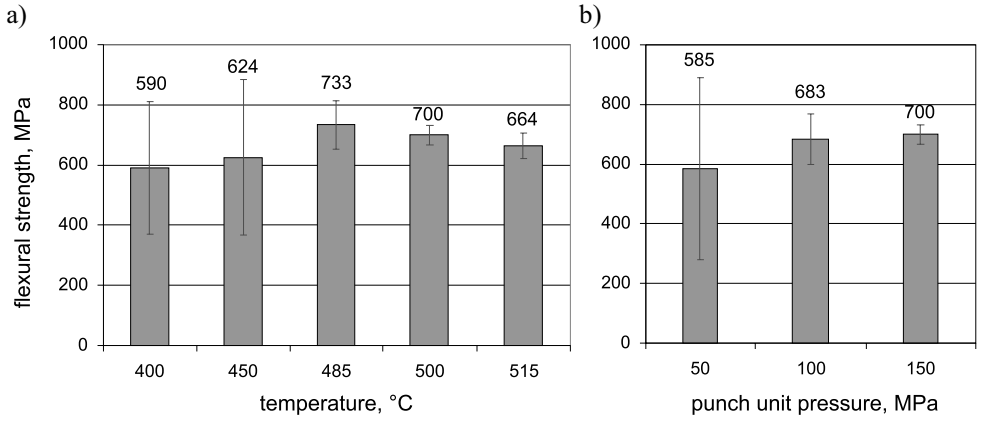

Fig. 4. *Influence of parameters of closed-die hot compaction of Al17Si5Fe3Cu1.1Mg0.6Zr powder on flexural strength: a) effect of temperature, at punch unit pressure 150 MPa; b) effect of punch unit pressure, at temperature 500 °C*

Metallographic examination. Light microscopy was applied to the observation of microstructure. Selected microstructures are presented in Figure 5.

Pores and boundaries of primary powder particles can be seen in the microstructures of materials formed at temperatures not exceeding 450 °C and under punch unit pressure of 50 MPa (Fig. 5a and b). They gradually fade away with increasing temperature and pressure. As a result of forming at temperatures of 500 °C or higher, under pressure of 150 MPa, the materials obtained showed regular and fine-grained structure, and the surface was free from pores (Fig. 5c and d).

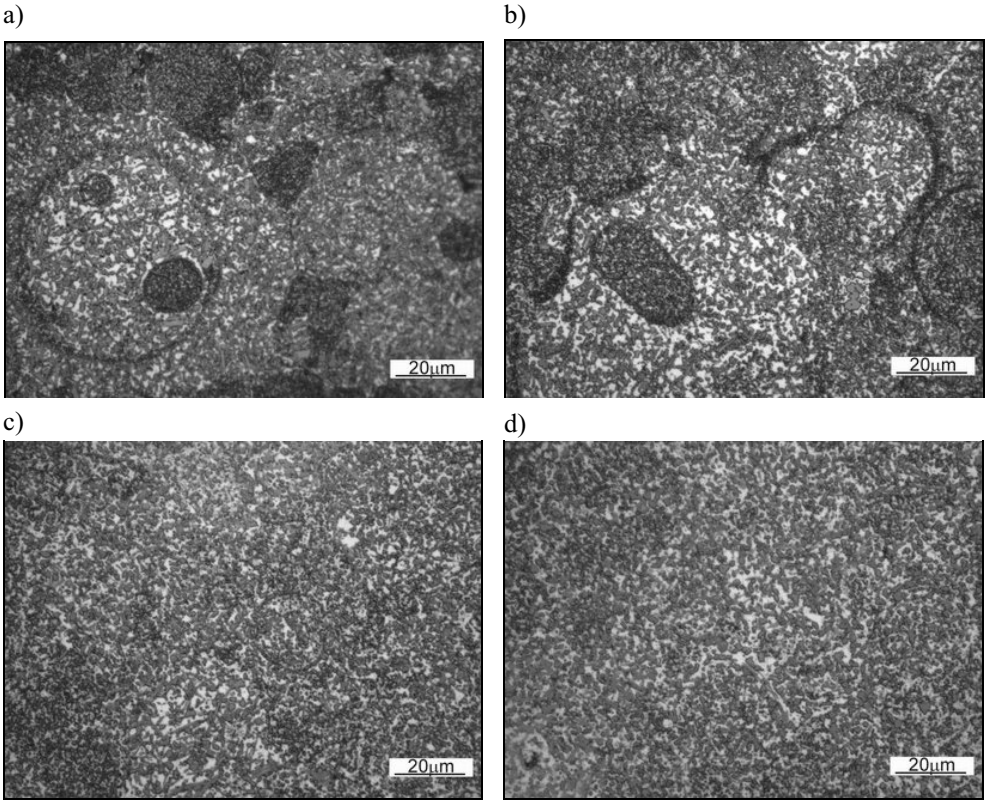

Fig. 5. *Microstructures of materials obtained in closed-die hot compaction of Al17Si5Fe3Cu1.1Mg0.6Zr powder. Transverse sections, after etching: a) temperature 400 ^{o}C, punch unit pressure 50 MPa; b) 450 ^{o}C, 150 MPa; c) 485 ^{o}C, 150 MPa; d) 500 ^{o}C, 150 MPa*

4. CONCLUSIONS

Basing on the results of investigations of the influence of forming parameters on selected properties of materials produced by isothermal closed-die hot compaction of Al17Si5Fe3Cu1.1Mg0.6Zr alloy powder, it can be concluded as follows:

1. Surface of samples produced at the temperature of 400 ^{o}C, under the pressure of 50 MPa, reveals the occurrence of cracks. In case of materials formed at higher temperatures, under the pressure of 100 or 150 MPa, no such defects were observed.
2. Closed-die hot compaction of powder, realized at the temperature of 450 ^{o}C or higher, under the pressure of 100 MPa and 150 MPa, makes it possible to obtain products showing the relative density close to that of a solid material.
3. The decrease of HB hardness of investigated materials was observed with increasing temperature of compaction. The level of unit pressure, at the temperature of 500 ^{o}C, had no effect on hardness.

4. The highest flexural strength was obtained for the material compacted at the temperature of 485 ^{o}C, under punch pressure of 150 MPa. For samples compacted under the same pressure at lower temperatures, large scatter of results was found. At the temperatures of 500 ^{o}C and 515 ^{o}C the decrease of flexural strength was observed.
5. The observation of microstructure of materials formed at temperatures not exceeding 450 ^{o}C, under punch unit pressure of 50 MPa, revealed the occurrence of pores and boundaries of primary powder particles. As a result of powder compaction at the temperature of 485 ^{o}C or higher, under pressure of 150 MPa, the materials obtained showed regular and fine-grained structure, and the surface was free from pores.
6. Basing on the results of investigations and observations of microstructure, considering the established conditions of the experiment and scope of research, it can be concluded that the proper process parameters are: the temperature within the range 485–500 ^{o}C and the punch unit pressure of 150 MPa.

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