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INFLUENCE OF COPPER ADDITIVE ON PRESSING AND BENDING STRENGTH OF IRON BASED HIGHLY POROUS POWDER MATERIALS

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ABSTRACT

The influence of copper content on the enhancement of the bending strength of the iron based highly porous sintered powder materials was studied. The porous samples were manufactured by replica technique using the ammonium bicarbonate powder as a space holder. The amount of the ammonium bicarbonate in a starting powder mixture was 50% volumetric. The amount of the copper additive was 0.10% and 20% by weight, respectively. The influence of the copper additive on the compaction behavior of the powder mixtures has been discussed. The microstructure of the sintered highly porous samples is presented.

Keywords: Highly porous sintered materials, space holder, copper additive, compaction, bending strength, microstructure

1. INTRODUCTION

An essential disadvantage of the porous permeable materials produced from the metallic powders is a low mechanical strength. The mechanical strength depends on the properties of the starting powders, the compaction pressure, the sintering conditions and the resulting porosity. The mechanical strength of the porous permeable materials can be enhanced using finer initial powders, increasing the compaction pressure and decreasing the final porosity [1-2]. Another way to enhance the mechanical strength of the highly porous materials supposes the usage of some additives ensuring the appearance of a liquid phase during the sintering process. The potential impact of this technique on the mechanical strength of the porous materials was highlighted elsewhere [3-4].

In the present work, the influence of the copper content on the bending strength of iron based sintered porous materials was experimentally investigated. Besides this, the influence of the copper additive on compaction behavior of the powder mixtures and the ejection of the resulting compacts was studied. Finally, the peculiarities of the microstructure of the highly porous samples are discussed. The obtained results can be used for the production of filters, heat exchangers, shock absorbers, vibration damping elements and other porous parts.

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2. EXPERIMENTAL TECHNIQUE

In the present work, a replica technique was used for manufacturing highly porous materials [5]. As basic materials, water atomized iron powder and electrolytic copper powder have been used. The ammonium bicarbonate (NH_4HCO_3) powder was used as a space holder. The ammonium bicarbonate dimension of 125–250 μm and a volumetric content of 50% were used in all experiments.

The copper content in the basic powder mixture was chosen as 0%, 10% and 20% by weight, respectively. The larger amount of the copper percentage in the iron based powder materials leads to decrease in their strength [6]. Moreover, an increase in the copper content leads to the rise of the final product price.

Table 1. Mixture compositions and samples codification

Sample code	**Components of mixture, %**		
	Iron, (weigth)	**Copper, (weight)**	**NH_4HCO_3, (vol)**
Fe	**80**	**20**	**50**
Fe-Cu 90/10	**90**	**10**	**50**
Fe-Cu 90/20	**100**	**0**	**50**

The mixing was manually performed in two stages. Initially, the iron and copper powders were mixed together during 15 minutes. A small amount of gasoline was also added (1% by weight) to avoid powder segregation. Thereafter, the ammonium bicarbonate powder was added in the mixture. The duration of the second mixing stage was 5 minutes.

The pressing behavior of the powder mixtures has been investigated by their uniaxial pressing in a cylindrical die with a diameter of 16.8 mm. The compaction pressure varying from 100 to 800 MPa with the step of 100 MPa, was used. The force needed for ejecting the samples from the die was recorded. The corresponding ejection stress was calculated according to the equation:

$$p_{ej} = \frac{P_{ej}}{\pi \cdot d \cdot h} \qquad (1)$$

where: P_{ej} – ejection force; d, h – diameter and height of the sample.
The relative densities of obtained compact ρ_{rel} were calculated using relation:

$$\rho_{rel} = \frac{m}{0.785 \cdot d^2 \cdot h \cdot \rho_{mix}} \qquad (2)$$

here: m – the weight of sample, ρ_{mix} – the theoretical density of powder mixture, determined by the equation:

$$\rho_{mix} = 0.5 \cdot \rho_{Fe-Cu} + 0.5 \cdot \rho_{pf} \qquad (3)$$

where: $\rho_{pf} = 1.586$ g/cm^3 – the theoretical density of ammonium bicarbonate, $\rho_{Fe\text{-}Cu}$ – the theoretical density of the iron and copper mixture, calculated according to the equation:

$$\rho_{Fe-Cu} = \frac{1}{\frac{X_{Fe}}{\rho_{Fe}} + \frac{X_{Cu}}{\rho_{Cu}}} \qquad (4)$$

where: X_{Fe} is the iron content (by weight); X_{Cu} is the copper content (by weight); $\rho_{Fe} = 7.874$ g/cm^3 is the theoretical density of iron; $\rho_{Cu} = 8.93$ g/cm^3 is the theoretical density of copper.

The samples for strength testing were compacted by uniaxial pressing in a rectangular die with the cavity size of 55.2 × 10.2 mm^2 in plane. The compaction pressure varying from 100 MPa to 600 MPa was used. These samples were sintered at the temperature of 1150°C during 1 hour in reducing atmosphere of CO. This temperature was chosen to provide the presence of the liquid phase during sintering [7]. The heating rate was maintained at 7°C/min. The intermediate dwell was carried out at the temperature of 850°C during 30 minutes. Thereat, the ammonium bicarbonate particles have been decomposed to ammoniac, carbon dioxide and water, leaving large pores. After the end of sintering, the samples were cooled in the furnace to 300°C and then in plain air up to the room temperature. The sintered rectangular specimens were tested in three points bending test, according to ISO 3325 standard [8]. The transverse rupture strength was calculated using the relation:

$$\sigma_b = \frac{3P \cdot L}{2 \cdot b \cdot h^2} \qquad (5)$$

where: P – the rupture force, L = 25 mm – the distance between supports, b – the sample width, h – the sample height.

3. RESULTS AND DISCUSSION

The densification curves for the investigated mixtures are shown in Fig. 1.

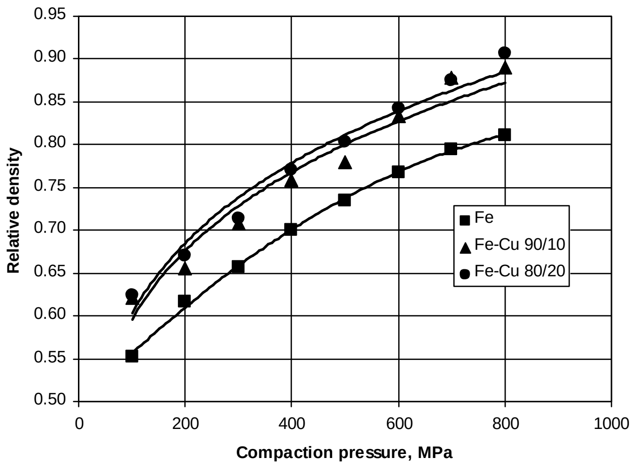

Fig. 1. Densification curves of the powder mixtures

The presence of the copper in the mixture leads to a rise in the density of the powder compacts. This observation is related to the lower strength of copper particles comparing with iron ones. It is worthy of noting that an increase of the copper content from 10% to 20% does not sufficiently influence the resulting density of the compacted samples.

The variation of the ejection stresses with the compaction pressure is shown in Fig. 2. At a given compaction pressure, the ejection stress diminishes with the rise of the copper amount especially at higher pressures. This is the result of a decline in friction between the powder and the die wall due to the decrease of the compaction pressure and, correspondingly, the lateral pressure increase of the copper content and smaller shear stress of the copper particles as compared to the iron ones. Therefore, copper acts as a kind of solid lubricant in the powder mixture.

The variation of bending strength of sintered samples with compaction pressure is shown in Fig. 3.

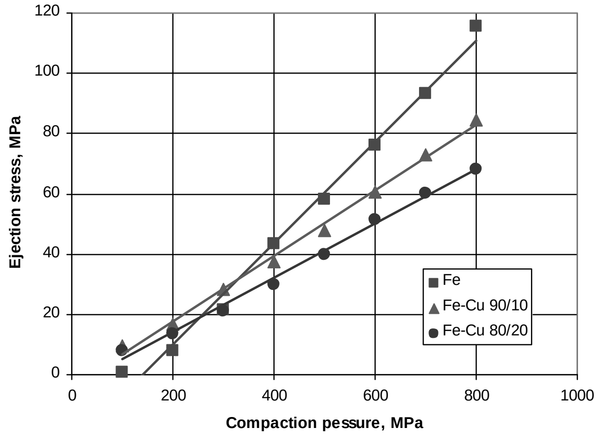

Fig. 2. Dependence of the ejection stresses on the compaction pressure for the investigated mixtures

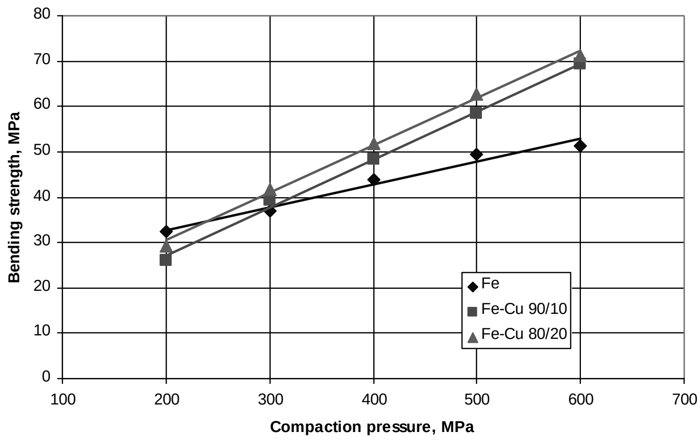

Fig. 3. Bending strength of the sintered samples vs. compaction pressure

The strength of the sintered compacts has been improved with the increase in the compaction pressure. This is a result of a closer packing density of the powder particles. The addition of copper in the iron based mixture leads to a noticeable increase in the strength of the highly porous samples. The rise of the copper content, from 10% to 20%, does not sufficiently influence the strength of the porous materials.

The microstructure of porous sintered sample manufactured from Fe-Cu 90/10 mixture is shown in Fig. 4. The structure of the samples consists of several phases. The black areas correspond to the pores. The gray areas represent the sintered iron particles. The bright areas correspond to the copper particles located along the boundaries of the iron grains. Small pores were formed between the powder particles and large pores appeared as a result of the space holder removal.

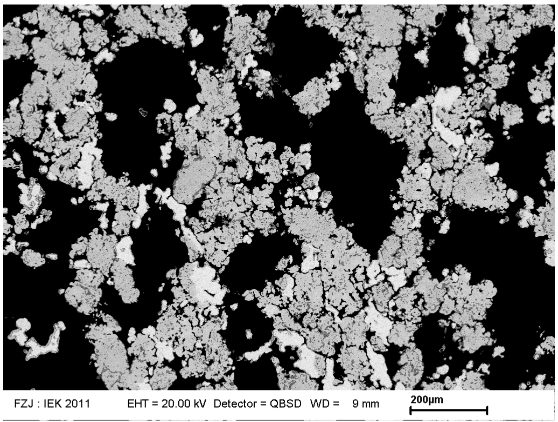

Fig. 4. Microstructure of the sample with porosity of 50% (provided by IEK-1, FZJ, Germany)

5. CONCLUSIONS

1. The addition of more than 10% of the copper powder in the iron powder based mixture leads to an increase in the densification and the decrease in the ejection stress in manufacturing the porous materials due to the lower strength of the copper particles as compared to the iron ones.

2. The bending strength of the sintered porous compacts is enhanced with an increase of the compaction pressure. This is a result of the closer packing of the powder particles at pressing.

3. The addition of 10% of copper powder in the iron based powder mixture provides an increase of the bending strength of the sintered highly porous materials, especially at higher compaction pressures.

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