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Technical note

ON THE FRACTOGRAPHY AND SOME STRENGTH PROPERTIES OF FE-BASED SINTERED MATERIALS WITH MULTICOMPONENT OXIDE MICROADDITIVES

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In the present paper, the effect of alumina and zirconia microadditives on the compressive strength and flexural strength of sintered Fe-based powder materials is shown. It was found that intercrystalline fractures, both plastic and brittle, are observed when bending. During compression, fractures are observed too, as well as flaking of thin near-surface layers. The intensity of such flaking depends on the composition of the sintered material. Strength parameters of the materials studied also depend on additives composition and quantity. The lowest parameters are observed for a material that contains *1*% alumina particulates. The compressive strength of a material containing zirconia particulates increases 3 times and the flexural strength 2 times.

Key words: Fe-based sintered materials, oxide additives, fracture analyze, flexural strength, compressive strength.

1. Introduction

Currently, materials obtained by powder metallurgy methods are widely used in various fields of engineering because of their specific features. First of all, it is the ability to manage the composition and properties of materials produced by various powder metallurgy technologies, the high precision of manufacturing parts of the required shape, almost complete elimination of finish machining and a number of others. The most widely used are materials based on iron, aluminum, copper, titanium and many other powders. Additionally, various kinds of additives on the basis of both high-hardness compounds and solid lubricants such as graphite, molybdenum disulphide or tungsten disulphide and so on are added to the metal matrix.

Studies show that such additives can to change radically the basic material properties, such as the structure, mechanical characteristics, tribological characteristics. However, both positive and negative effects are possible. In particular, in [1] significantly lower fatigue strength was recorded compared with the base material when testing Al-based MMCs with additives of *10*% SiC of two different sizes. In [2], it

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is shown that the presence of reinforcing particles and their dimensions significantly affect the fatigue limit. The presence and dimensions of the SiC particles had an effect on the damping capacity of the AlSi composite, its density and hardness [3]. Positive changes in the compressive strength were observed when carbon nanotubes were added in MMCs [4]. With simultaneous addition of SiC and WC particles to the hot-pressed ZrB_2 ceramics, the average strength of the composite increased, and this increase depended on the sintering temperature [5]. The combined effect of the purity of ceramic particles and the conditions of their bonding had an effect on the yield strength, the ultimate tensile strength and the ductility of a copper-based composite compared to pure copper [6]. The presence of Cr particles affected the aging process and the mechanical properties of the 7075Al + SiC_p composites [7]. It was shown in [8] that the presence of WC particlulates in the MMC substantially increases the microhardness and strength of the material, but significantly reduces its plasticity. It was shown in [9] that the type of reinforcing, dimensions and the content of particulates exert a significant influence on the MMC strength and density. According to [10], the introduction of oxides in FeAl-based alloys increased the compressive strength and equivalent strain of composites.

The aim of this study was to analyze the influence of oxides and graphite microadditives on the strength and destruction character of sintered materials based on iron.

2. Experimental procedure

Ready-made Fe, Gr, Al_2O_3, and ZrO_2 powders were used to prepare sintered materials. The particulates of the base atomized iron powder were of the size less than *200* microns. Graphite particulates were used as carbon additive and had the average size of *3* microns. Particulates of ZrO_2 were less than *1–3* microns and particulates of Al_2O_3 were less than *0.5–1.5* microns. Particulates of ZrO_2 were less than *0,5–1* microns and particulates of Al_2O_3 were less than *0.1–0.5* microns. They can form conglomerates *3–10* and 4–17 microns in size, respectively

An iron powder and *1* wt % graphite were used as base components to form the FeGr1 base material. The following chemical compositions for investigated materials were used: FeGr2 (FeGr1+1 % Gr); FeGr1+1 wt.% Al_2O_3; FeGr1+1 wt.% ZrO_2; FeGr1+1/3 wt.% Gr+1/3 wt.% Al_2O_3+1/3 wt.% ZrO_2. Such compositions made it possible to evaluate both the effect of individual additives and the synergistic effect of their balanced mixtures on the fracture characteristics and strength of sintered composite materials.

The powder compositions were mixed in a mixer of “drunken barrel” type for *3* h. Then the samples were pressed using a hydraulic press with the pressure *500* MPa and sintered in an endothermic gas atmosphere at *1100* °C for *1 h*.

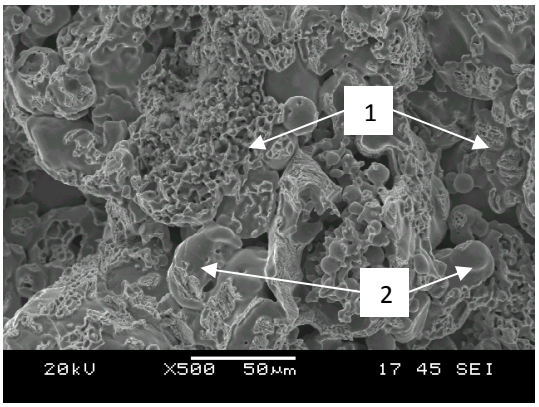
The fractographic tests were performed using the “JEOL JSM-5600LV” Scanning Electron Microscope.

The compressive strength was determined using cylindrical specimens with a diameter of *10 mm* and a height of *16 mm*. The flexural strength was determined using samples of *5×10×55 mm* with a three-point flexure. The studies were performed on a universal test machine "Tinius Olsen H150K-U" with a loading rate of *2 mm/min*.

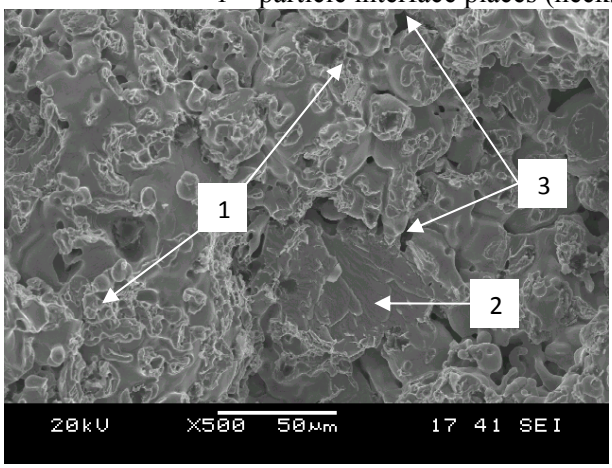
3. Results of research

3.1. Fractographic analysis of fractures after flexure

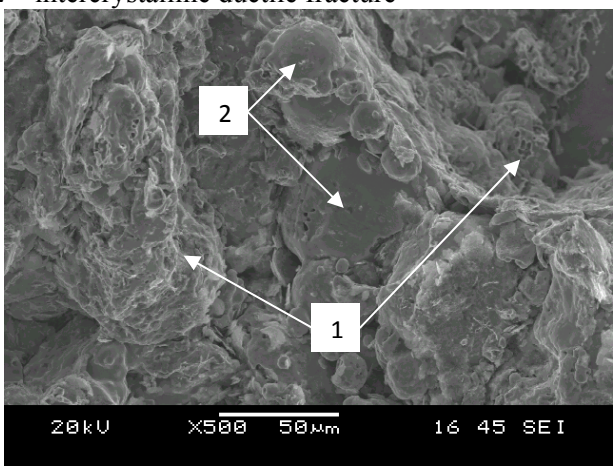
The fracture surfaces of the tested materials after the bending tests are shown in Fig.1. The following conclusions can be made.



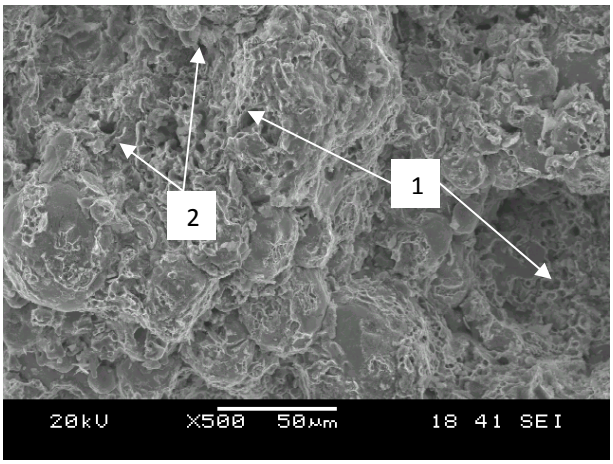
FeGr1 material (basic):
1 – particle interface places (necks), 2 – intercrystalline ductile fracture



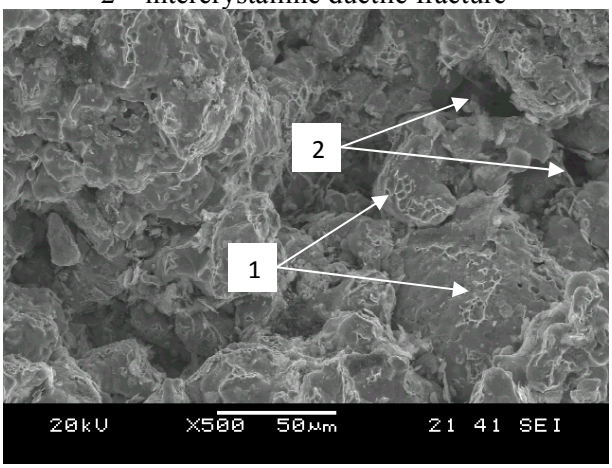
FeGr2 material: 1 – places of sintering,
2 – local intergranular brittle fracture, 3 – pores



FeGr1+1 wt.% Al_2O_3 material:
1 – particle interface places (necks),
2 – intercrystalline ductile fracture



FeGr1+1 wt.% ZrO_2 material: 1 – particle interface places (necks); 2 – pores



FeGr1+1/3 wt.% Gr+1/3 wt.% Al_2O_3+1/3 wt.% ZrO_2 material: 1 – particle interface places (necks), 2 – pores

Fig.1. Surfaces of destruction of materials investigated (bending tests).

In the FeGr1 base material, the fracture passes through the surfaces of the powder particles and the separation of the material fragments occurs in the regions of particle interface places (necks), where plastic destruction is observed. A significant area of the neck surfaces provides high strength of the material. Local microvolumes of ductile intercrystalline fracture through the initial particles of the iron powder are observed.

In the FeGr2 material with a high carbon content, the fracture surface passes between the sintered particles of the powder. The destruction of the material occurs in the areas of sintering between the powder particles and has a ductile character in these places. Local microvolumes of brittle intercrystalline fracture through the initial particles of the iron powder are also observed. The pores presence is also observed.

In the material with Al_2O_3 particulates (FeGr1 + 1 wt.% Al_2O_3), the destruction occurs as a result of intercrystalline brittle fracture. The surfaces of the fracture pass between the particles of the sintered powder. A small number of necks that connect the sintered particles and their insignificant surface is the reasons for the low strength of the material (see below).

In the material with ZrO_2 particles (FeGr1 + 1 wt.% ZrO_2), the destruction also occurs as a result of intercrystalline fracture. The destruction develops on the initial surfaces of the powder particles, in the areas of sintering (compounding of particles) and has a plastic character.

In the material containing a multicomponent additive (FeGr1 + 1/3 wt.% Gr + 1/3 wt.% Al_2O_3 + 1/3 wt.% ZrO_2), intercrystalline fracture is also observed. The destruction develops through the pores along the surfaces of the necks of the sintered powder particles. The particles separation occurs in the neck areas and has a plastic character.

3.2. Fractographic analysis of fractures after compression

The fracture surfaces of the tested materials after the compression tests are shown in Fig.2. The following conclusions can be drawn.

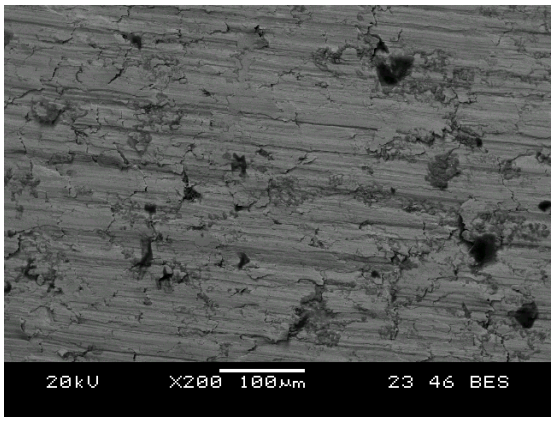
Traces of grinding, pores on the surface, as well as extremely thin microcracks that were caused, possibly by overheating of ground surfaces, are noticeable on the initial surfaces of the samples. After compression, for all materials studied, flaking of the near-surface layers was observed. Its highest intensity is observed for FeGr2 material and FeGr1 material with the multicomponent additive 1/3 wt.% Gr+1/3 wt.% Al_2O_3+ 1/3 wt.% ZrO_2. In the case of materials with additives of Al_2O_3 and ZrO_2 oxides, flaking is much less intensive, which may indicate reduced fragility of these materials.

3.3. The strength of the materials studied

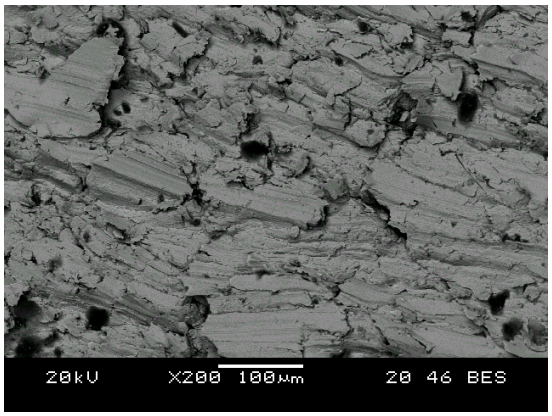
Measurements of the compressive strength and bending strength of the materials studied have shown the direct relationship between the composition of the material and its strength (Fig.3). The lowest characteristics are observed for a material containing alumina particulates. The compressive strength of a material containing zirconia particulates increases by 3 times and the bending strength by 2 times.

Conclusions

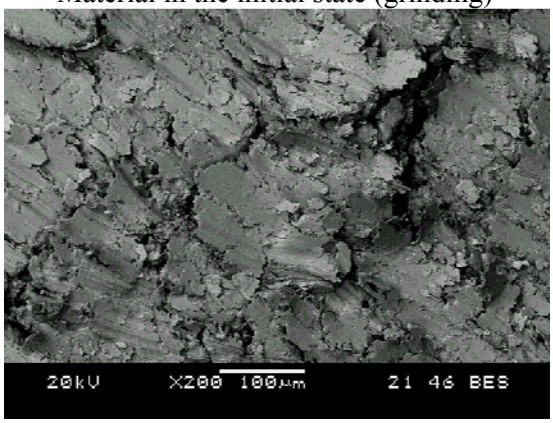
1. The effect of alumina and zirconia microadditives on the specificity of fracture and some strength characteristics of sintered Fe-based materials is shown. Based on the fractographic analysis, it is found that destruction takes place in the regions of powder particle interface places and has the character of intercrystalline fractures, both ductile and brittle. During compression, fractures are observed, as well as flaking of thin near-surface layers. The intensity of this flaking depends on the composition of the sintered material.



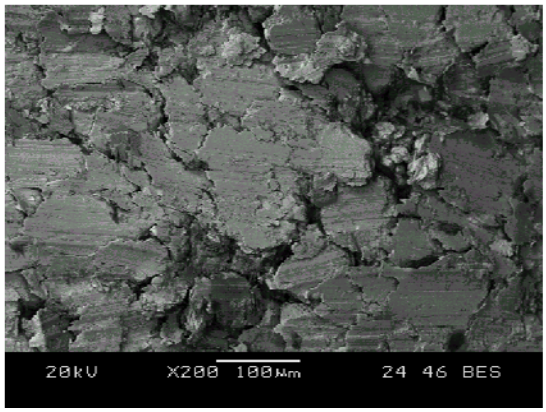
Material in the initial state (grinding)



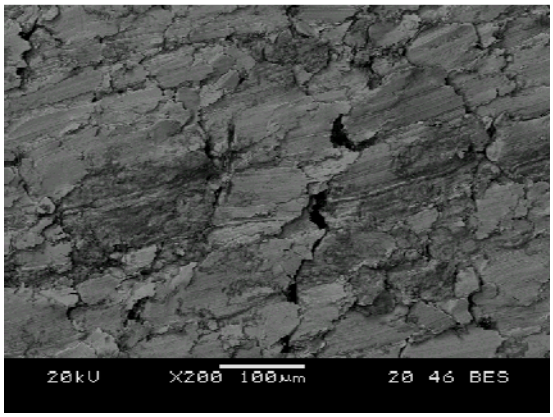
FeGr1 material (basic)



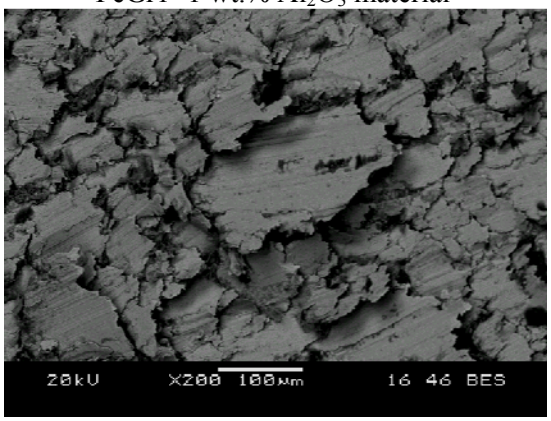
FeGr2 material



FeGr1+1 wt.% Al_2O_3 material



FeGr1+1 wt.% ZrO_2 material



FeGr1+1/3 wt.% Gr+1/3 wt.% Al_2O_3+ 1/3 wt.% ZrO_2 material

Fig.2. Surfaces of destruction of materials investigated (compression tests).

2. Strength characteristics of the materials studied depend directly on their composition. The lowest characteristics are observed for a material containing alumina particulates. The compressive strength of a material containing zirconia particulates increases 3 times and the flexural strength 2 times.

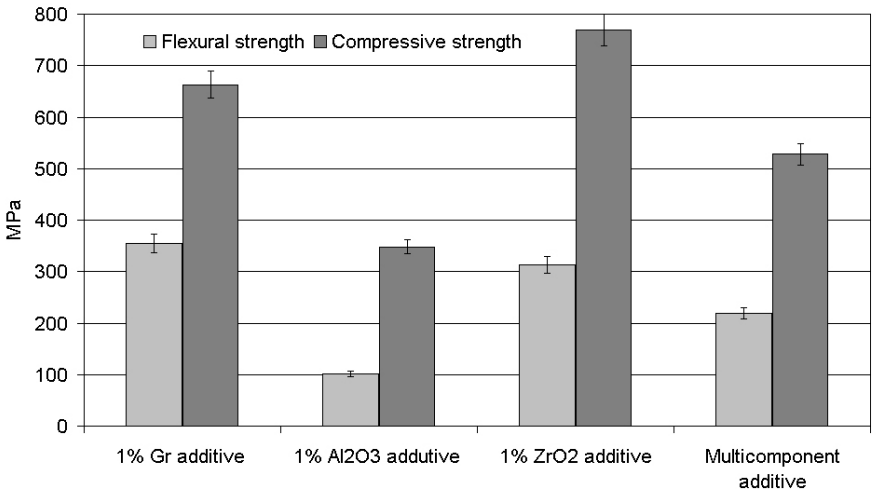


Fig.3. Strength characteristics of the materials investigated.

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