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Evaluation of deformation methods of Cu-Al_2O_3 systems with quality factor

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Abstract. Quality of Cu-Al_2O_3 composite materials, prepared vith powder metallurgy, is assessed on the basis of the analysis of the deformation processes. Powder mixture was prepared by grinding Cu and Al_2O_3 particles. After the compaction, the materials were deformed by extrusion, forging, and isostacic pressing. Their microstructure and mechanical properties were qualitatively evaluated. By comparison of these three deformation technologies we found isotropic microstructure in the materials forged and isostatically pressed. The materials, deformed by hot isostatic pressing, which possessed a low residual porosity ($<1\%$), showed optimum properties (the ultimate tensile strength and reduction of the area).

Key words: Cu-Al_2O_3 composites, powder metallurgy, deformation process, mechanical properties, microstructure, quality factor.

1. INTRODUCTION

Materials with high thermal conductivity and sufficient strength at elevated temperatures are in growing demand in industry. Due to excellent thermal and electrical conductivity, Cu-based alloys are convenient for these applications. Development of Cu alloys with high strength at elevated temperatures is difficult because age-hardened alloys incline to precipitation coarsening and dissolution. Thermodynamically stable dispersoids, without these negative features, can have excellent mechanical properties at high temperatures. Provided that dispersoids are fine and their mean interparticle distances are relatively small, it is possible to achieve high strength at low volume fraction of dispersoids with powder metallurgy methods. This is very important because the lower the fraction of dispersoids, the higher is the conductivity of the Cu alloy. Such materials are used for point-welding electrodes, efficient electrical switches, electric motors, and heat exchangers as well as for cooling parts of gas turbines and generators.

Most of the papers deal with the study of strengthening of Cu by Al_2O_3 phase in the case of a monocomponent or polycomponent matrix. Some production technologies of these systems, like mechanical homogenization, oxidation and reduction, reaction milling, mechanical alloying and others [1] have been applied. From the published papers it follows that high-energy milling of powder mixtures with following hot compacting is the best method to incorporate nanodispersoids into the Cu matrix. The grain growth during the heat treatment is strongly hindered and that is why the structure of the alloys is microcrystalline. A problem is the creep strength of fine-grain alloys, but it is overcome in dispersion-strengthened Cu alloys [2].

Properties of dispersion-strengthened materials depend on the matrix parameters (size, shape, grain or subgrain disorientation, dislocation substructure, and grain boundaries) as well as on the parameters of the dispersoids (volume fraction, size, shape, spatial distribution, and interparticles distance).

Porosity of sintered dispersion-strengthened materials is too high. The aim of forming is to minimize the porosity and to modify optimal dislocation substructure of the system as well as mechanical properties and to increase their stability, especially at higher temperatures. Deformation by forming leads simultaneously to changes in spatial arrangement of the dispersion particles and in their morphology. From the forming technologies as extrusion pressing, forging, rolling, and isostatic pressing, the first one is the most commonly used. Isostatic pressing is used for more precise applications due to the nearly unporous microstructure [1]. Experiments with rolling of composites have also been carried out. It is to be noted that highly refractory dispersion-strengthened materials can be obtained by additional deformation and heat treatment with the aim to create a dense dislocation net. Influence of preparation technologies on material properties has been evaluated in [3]. On the basis of statistical analysis of an extensive set of values of Al-Al_4C_3 materials, the quality factor (QF) was determined as:

$$QF = (R_\mathrm{m} + 500)\, A_{10}^{0.2} \big/ 1420,$$

where R_m and A_{10} are the ultimate tensile strength and the elongation at room temperature, respectively. The quality factor evaluates the final material quality as a function of the starting powders and preparation technologies of the compacts. It is meant for materials prepared with powder metallurgy.

The aim of this work is to compare mechanical properties, evaluated by the QF, for differently deformed Cu-Al_2O_3 materials.

2. EXPERIMENTS

Dispersion-strengthened Cu-Al_2O_3 materials were prepared by the method of mechanical homogenization of metal and ceramic powders: electrolytic copper of 99.7% purity and Al_2O_3 (α) of size <0.1 μm, used as starting powders, were homogenized in attritor Netch PEO 75 in benzyl alcohol during 5 h. The dry mixture was reduction-annealed at 400 °C for 3 h. The compacts were sintered at 850 °C for 3 h in cracked ammonia. Materials with 2 to 10 vol% of Al_2O_3 were prepared.

Experimental materials were compacted as follows.

Material A: pressed and sintered to approximatelly 25% porosity, then extrusion pressed by 94% reduction at temperature 850 °C.

Material B: extrusion-pressed materials, hot forged at 900 °C.

Material C: powder mixture compacted by hot isostatic pressing at 850 °C, 130 MPa for 1 h in Cu covers.

3. EXPERIMENTAL RESULTS AND DISCUSSION

The used forming technologies of Cu-Al_2O_3 composites modified their microstructure and mechanical properties. Anisotropic microstructure of the material A can be seen in Fig. 1 (in parallel direction). The Al_2O_3 particles are arranged in lines due to extrusion pressing. The microstructure of the materials B and C, hot forged and hot isostatic pressed, respectively, is isotropic (Fig. 2). The Al_2O_3 particles are arranged approximately homogeneously randomly (PPP) in both directions. Dependence of the ultimate strength as well as of the area reduction

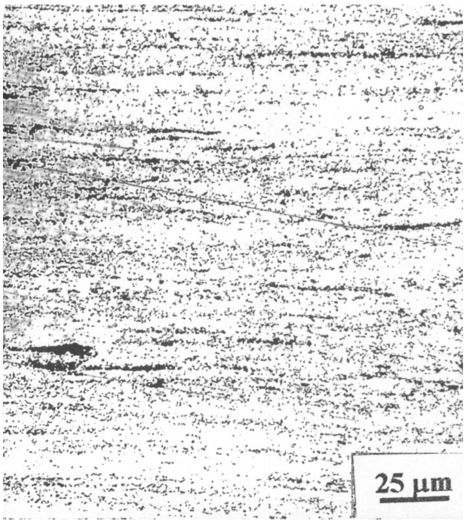

Fig. 1. Microstructure of the material A.

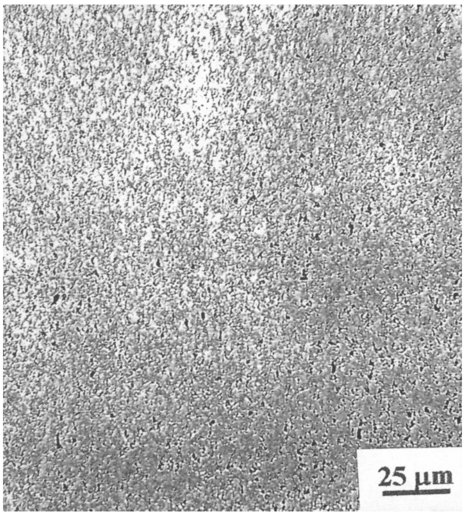

Fig. 2. Microstructure of the material C.

on volume fraction of Al_2O_3 particles are shown in Fig. 3. The ultimate strength decreases with increasing temperature. For the material A this phenomenon is described in [4]. It can be seen that the material C, formed by hot isostatic pressing, has optimal combination of both, strength and plastic properties. It is in agreement with the low residual porosity of the material (<1%) in contrast to the materials A and B with the porosity up to 3%. The microstructure of the optimally formed material C is analysed in the following. The mean size as well as the subgrain size of effective Al_2O_3 particles is determined by means of extraction of carbon replicas and thin foils. The Al_2O_3 particles on a replica in Fig. 4 are of two categories: fine particles from 60 to 80 nm and big particles from 0.2 to 0.4 μm. X-ray diffractograms of particles from the extraction carbon replica proved the presence of the Al_2O_3 phase. The FeO inclusions are also presented in the material, which get into the material from the milling environment during mechanical alloying [6]. The mean subgrain size, measured on thin foils, is about 1 μm (Fig. 5). The particles are localized on subgrain boundaries and inside the subgrains.

The trends of calculated *QF* values in the range of 0.8–1.0, which are determined from mechanical properties, are depicted in Fig. 6. From the comparison of the *QF* values for different materials it is evident that the material C, characterized by the fine-grain matrix microstructure, homogeneous distribution of the Al_2O_3 dispersoids and minimum residual porosity, has the highest *QF* value. The quality factor for Pt-Y_2O_3 systems is determined in [5]. The Cu-Al_2O_3 system, prepared by powder metallurgy methods, is in detail analysed in [6].

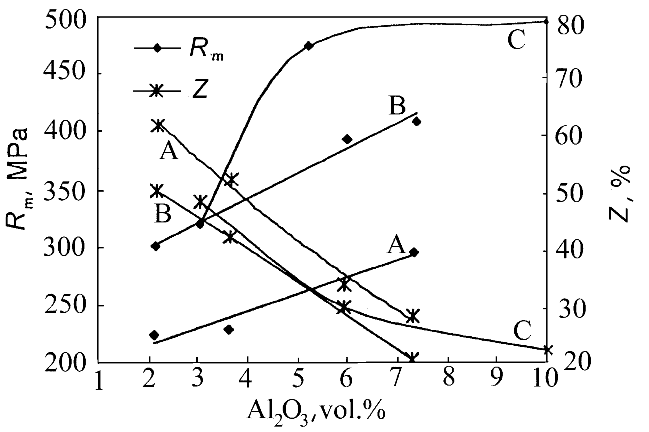

Fig. 3. Dependence of the ultimate tensile strength R_m and area reduction Z on the volume fraction of A_2O_3 particles for materials A, B, and C.

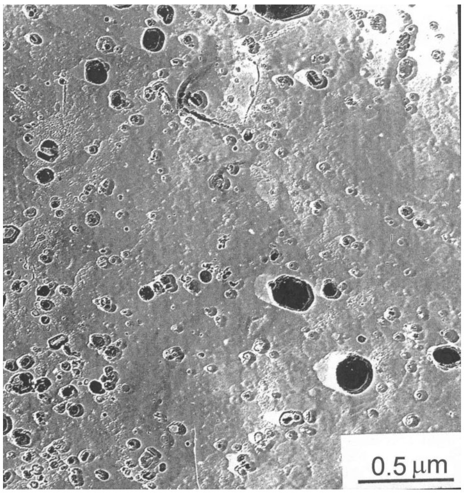

Fig. 4. Micrograph of an extraction carbon replica removed from the material C with Al_2O_3 particles.

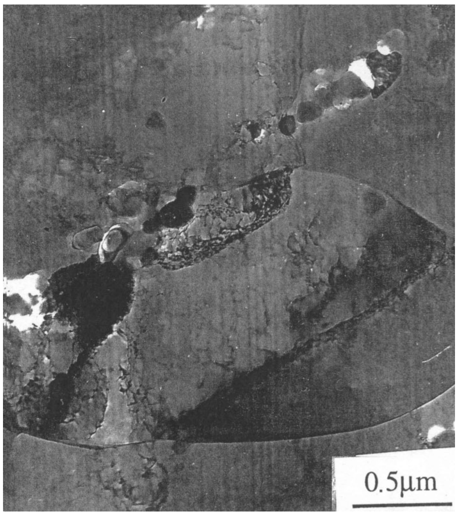

Fig. 5. TEM micrograph of a thin foil from the material C with matrix subgrains.

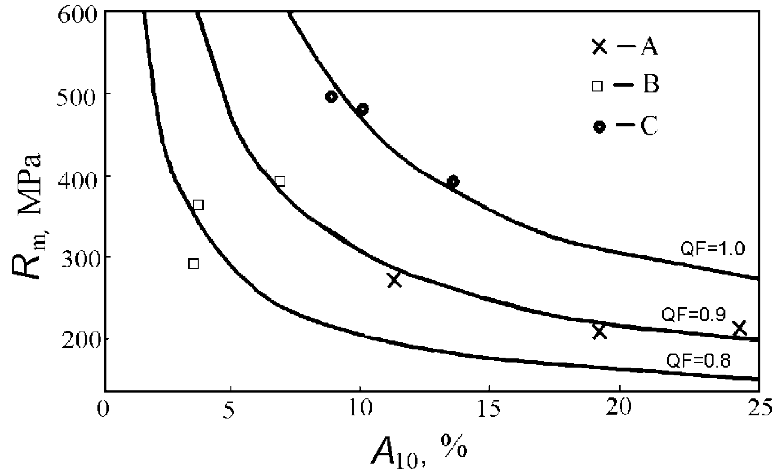

Fig. 6. *QF* values for the materials A, B, and C.

4. CONCLUSIONS

From the results obtained the following conclusions can be drawn.

1. Isotropic distribution of Al_2O_3 particles in the Cu-Al_2O_3 system is attained by application of forging and isostatic pressing.

2. Optimal combination of mechanical properties ($QF = 1$) is obtained with application of compacting by hot isostatic pressing.

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Cu-Al_2O_3 süsteemide deformatsioonimeetodite hindamine kvaliteediteguri põhjal

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On vaadeldud pulbermetallurgia meetodil valmistatud Cu-Al_2O_3 komposiitmaterjalide kvaliteediga seotud küsimusi deformatsiooniprotsesside analüüsil. Cu ja Al_2O_3 pulbrist valmistati materjalid ekstrusiooni, sepistamise ja isostaatilise pressimise teel. Kvalitatiivselt hinnati materjali mikrostruktuuri ja mehaanilisi omadusi. Kolmest vaadeldavast deformeerimise viisist tagasid isotroopse mikrostruktuuri sepistamine ja isostaatiline pressimine. Kuumisostaatiline pressimine võimaldab saada minimaalse jääkpoorsuse (<1%) ja optimaalsete omadustega (tõmbetugevus, katkeahenemine) materjali.