THERMAL STABILITY OF Cu-Al_2O_3 AND CuCr MATERIALS

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Abstract

The aim of this work was the comparison of the thermal stability of dispersion strengthened (DS) Cu - 5 vol. % Al_2O_3 system with the CuCr electrode material. The DS material is characterized by high hardness, high strength and excellent thermal stability of the structure due to the highly stable γ Al_2O_3 dispersoid. The CuCr material has comparable hardness and strength, however the thermal stability is limited by the thermal stability of the precipitate.

Keywords: Cu-based composites, dispersion strengthening, precipitation strengthening, thermal stability

INTRODUCTION

Electrodes are subjected during resistance spot welding (RWS) to extreme temperature change and mechanical loading, which results in wear of the electrodes. It includes abrasion and contamination, and possibly mushrooming of the tip, what leads to a decrease of the quality of the welding seams and durability of the electrodes [1]. Well-known electrodes used for RWS are of CuCr [2]. Comparison of electrodes' durability suggested that those prepared by unconventional methods are more suitable than conventional electrodes [3]. Especially materials prepared by powder metallurgy (PM) methods may represent a better way of preparation. This would enable an increase in the quality of welding seams, decrease material loss, increase the durability of electrodes and shorten the welding process [4]. The goal of this work was the comparison of progressive DS Cu material developed for electrical applications with the standard electrode CuCr material, considering thermal stability, strength properties and, in consequence, structure.

EXPERIMENTAL MATERIALS AND METHODS

The DS material was prepared by PM technology, by a process described in the patent [5]. Powder pressing at 150 MPa was at 400°C in a protective atmosphere, sintering in H_2 at 850°C for 1 h, forging and extrusion at 950°C with a 95% cross section area reduction. CuCr material was obtained from an electrode used for automated welding of automotive body sheets.

The structure of the materials was investigated by X-ray diffraction (XRD) using an X'Pert Pro diffractometer with CuKα radiation and with a high temperature chamber. The average crystallite size of the Cu matrix and the dislocations density were determined using the Williamson-Hall equations [6]. The thermal stability of structure was studied by in situ measurement up to the temperature 773 K, and after the regressive cooling, by ex situ measurements after annealing at 773 K and 1073 K for 1 hour in air. The microhardness HVM (Leco equipment), hardness HB and strength properties (INSTRON) were analyzed in both materials.

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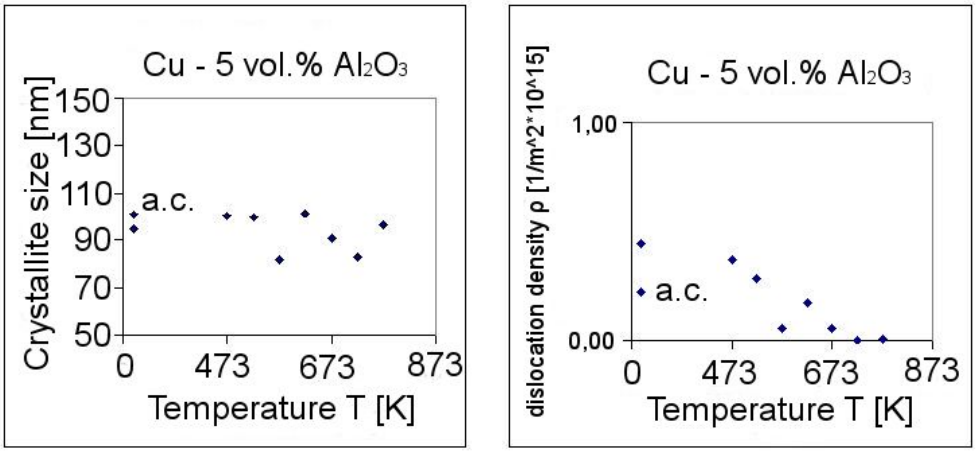
RESULTS AND DISCUSSION

Microstructure and properties of Cu-Al_2O_3 material

The average crystallite size of Cu matrix is 76 nm. The almost unchanged crystallite size of Cu matrix at selected temperatures (in situ) and after regressive cooling implies good thermal stability of the structure, Fig.1a. The average crystallite size is retained in nano-metric scale after annealing the material at 1073 K/1 h (ex situ). This confirms the excellent thermal stability of the structure due to the nanosized thermodynamically stable particles of the γAl_2O_3 dispersoid, [7] that restrict dislocation movement and stabilize grain boundaries up to the temperature 1073 K.

The density of dislocations measured in situ decreased stepwise with increasing temperature, Fig.1b. This decrease is caused by reordering and annihilation of dislocations due to the thermal activation of dislocations. After reverse cooling from 773 K, as well as after annealing at 1073 K for 1 h, the dislocations density increased to the value near to the initial state. The dislocations density increase is induced by thermal stresses during cooling, due to thermal expansion coefficient difference between the Cu matrix($\alpha = 16.5 \times 10^{-6}\ K^{-1}$) and the Al_2O_3 ($\alpha = 8 \times 10^{-6}\ K^{-1}$) particles.



a) b)

Fig.1. Results of in situ X-ray diffraction measurements on the Cu – Al_2O_3 material (a.c. - after cooling): a) crystallite size vs. annealing temperature, b) dislocation density vs. annealing temperature.

The DS Cu material is characterized by high HVM and HB, Fig.2 and high strength, Fig.3. The strength of the material is regulated predominantly by two strengthening mechanisms: grain size and dispersion strengthening [8]. The hardness and the strength of the material remain unchanged after temperature exposure at 773 K for 1 h and 1073 K for 1 h, Figs.2 and 3. This excellent thermal stability of material properties is provided by the thermal stability of structure.

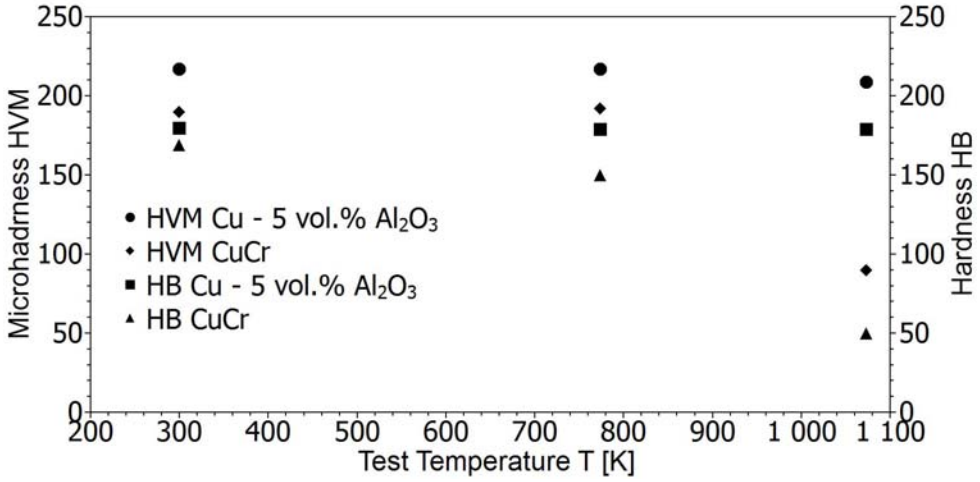


Fig.2. Microhardness HVM and hardness HB of the as-received Cu – Al_2O_3 material and materials annealed at 773 K and 1073 K in comparison with the CuCr material.

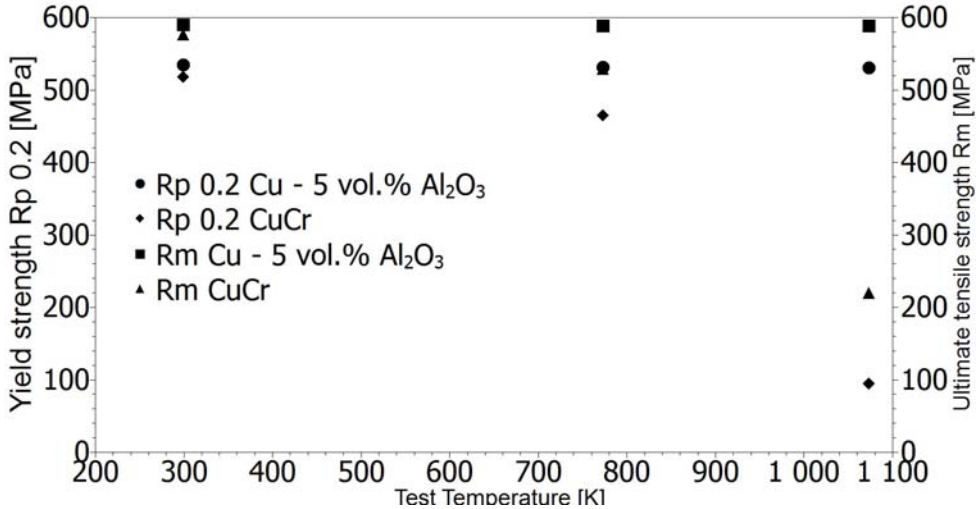
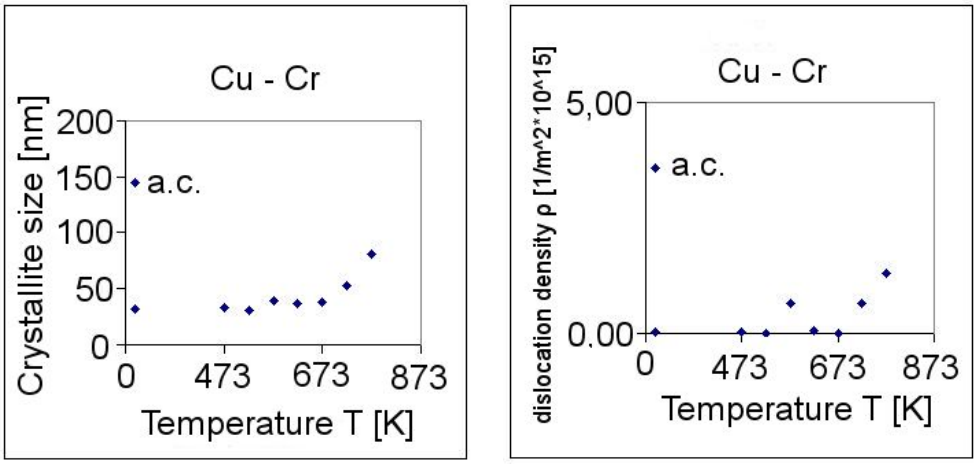


Fig.3. Yield strength and ultimate tensile strength of the as-received Cu – Al_2O_3 material and material annealed at 773 K and 1073 K in comparison with the CuCr material.

Microstructure and properties of CuCr material

The average crystallite size of the CuCr material is 32 nm. The calculated values of the crystallites size, measured in situ are noted in Fig.4a. The increase of the crystallite size is not noticeable up to 673 K. Moreover the average crystallite size increases slowly with increasing temperature up to 773 K. The average crystallite size after the cooling is 150 nm. It can be stated that structure of the CuCr material is thermally stable up to 673 K.

The dislocation density decreased with increasing temperature up to 673 K, Fig.4b. This decrease is a natural feature caused by moving and annihilation of dislocations. However, the increase of dislocation density above 673 K is surprising. This is in contrast to the fact that temperature activation leads to recovery of point defects and dislocations, which results in a decrease of stored strain energy in the material. After cooling, the value of dislocation density is high ~ 10^{15}. This value is of two orders of magnitude higher than for the initial material. Probably, the increase of dislocation density is a result of strains induced in the material due to the transition of fcc Cr nuclei, that are coherent with the Cu-rich matrix, to incoherent bcc Cr precipitates [9]. During cooling, the thermal stress is activated due to the high difference of thermal expansion coefficients of the Cu matrix (α = 16.5 x 10^{-6} K^{-1}) and the Cr particles (α = 4.9 x 10^{-6} K^{-1}). It can be considered very probable that the stability of the fcc precipitates decreases by thermal exposure over the temperature 673 K and precipitation of the bcc phase on fcc nuclei, due to the presence of the large amount of Cr present in fcc nuclei. The isothermal annealing caused the coarsening (non-measurable by XRD) of the structure.



a) b)

Fig.4. Results of in situ X-ray diffraction measurements on the CuCr material: a) crystallite size vs. annealing temperature, b) dislocation density vs. annealing temperature.

Hardness and strength of the CuCr material are high, Figs.2, 3. The strength of the CuCr alloys resulted from sum of strengthening by solid solution, which is directly dependent on the Cr amount, and precipitation strengthening [10]. The hardness and strength of CuCr material were dependent on the exposure temperature. After isothermal annealing at 773 K for 1 h, the values of microhardness are almost unchanged, but hardness and strength characteristics are slight decreased, Figs.2 and 3. Hardness and strength after exposure at 1073 K achieved small values, which represent the hardness and strength of pure Cu in the soft state.

CONCLUSIONS

The DS Cu – 5 vol. % Al_2O_3 material is characterized by excellent thermal stability of the structure and properties due to the DS of the Cu matrix by thermodynamically stable γAl_2O_3 particles that restrict dislocation movement and stabilize

grain boundaries up to the temperature 1073 K. Components produced from this material should work effectively at high working temperatures.

The CuCr material is characterized by high strength properties due to the precipitation strengthening by Cr particles. The thermal stability of the structure and properties is limited by the thermal stability of the precipitate. After thermal treatment at 1073 K for 1 h, the structure had recrystallized and strength properties decreased. Therefore the components produced from the precipitation hardened CuCr material have limited working temperature.

Acknowledgement

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