ARCHIVES
of
FOUNDRY ENGINEERING

Published quarterly as the organ of the Foundry Commission of the Polish Academy of Sciences

ISSN (1897-3310)
Volume 12
Special Issue
2/2012

33 – 36

6/2

Tribological properties of Cu based composite materials strengthened with Al_2O_3 particles

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Received 27.07.2012; accepted in revised form 05.09.2012

Abstract

In the present work copper was strenghtened with 20 and 30 vol. % of alumina particles characterized by diameter of 3-6μm. The copper based composite materials were manufactured by the squeeze casting method. Preheated preforms made from Al_2O_3 particles were placed in the desired place in the heated cast die and the squeeze casting process with liquid copper was performed applying the infiltration pressure of 90MPa and pressure was kept for 10-15s until solidification was complete. The microstructure and physical properties: Brinell hardness (HBW) and density were characterized. Metallografic examinations showed that alumina particles were uniformly distributed in the copper matrix. Hardness of 208 HBW for composite materials containing 30 vol.% of particles was achieved. Wear investigations were performed applying the tribological pin-on-disc tester. Friction forces between copper based composite materials containing 20 and 30 vol. % of Al_2O_3 particles and cast iron were registered and wear was determined on the base of the specimen mass loss after 1.0, 3.5 and 8.5 km friction distance.

Keywords: Metal matrix composite, Copper, Aluminium oxide particles, Tribological properties, Wear resistance, Pin-on-disc tester, Friction coefficient

1. Introduction

Copper is characterized by high electrical and thermal conductivities and good corrosion resistance but has low strength at room and elevated temperature. Improvement of mechanical properties is possible by introduction of ceramic strengthening ceramic particles realized through special manufacturing processes (squeeze or stir casting, spray forming or powder metallurgy techniques). Currently the most common production method of composite materials is pressure infiltration of porous preforms made of ceramic particles or fibres with molten light alloys [1]. For this reason metal matrix composite materials based on copper and copper alloys are developed for wide range of applications like resistant welding electrodes, heat exchangers, electrical connectors and contacts [2].

Due to good corrosion resistance, good electrical and thermal conductivity copper alloys have been recently examined as a matrix for the ceramic particles reinforced composite materials. Aluminum oxide particles (Al_2O_3) are used as the reinforcement in composite materials due to its high hardness and resistance to wear. The combination of copper and aluminum oxide opens up wide possibilities for applications where good wear resistance, good electrical and thermal conductivities are required.

2. Experimental procedure

2.1. Materials

Copper based composite materials were manufactured by squeeze casting with copper Cu – ETP (99,9% purity) of porous preforms made of Al_2O_3 particles and characterized by the open porosity of 80 and 70%. Porous preforms were produced from a mixture of ceramic particles, aqueous binder solution (water glass) and a porous agent and the porous preforms were fired at a temperature 1000 ºC. The ceramic preforms were pressure infiltrated with liquid copper superheated to 1200 °C applying the infiltration pressure of 90 MPa. Microstructure of pressure infiltrated porous preform shown at the Fig. 1 indicates that the produced preforms were characterized by local concentration of the reinforcing particles and areas filled with copper matrix.

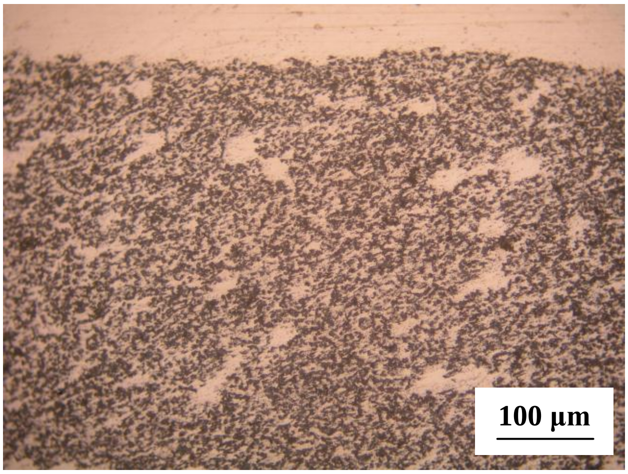

Fig. 1. Microstructure of the composite material Cu-ETP with20 vol.% of Al_2O_3 particles

Density of composite materials was characterized by Archimedes law and the results are shown at the Table 1.The alumina particles effect on the decrease of density.

Table 1.
Density of composite materials Cu-alumina particles

Materials	g/cm^3
Cu Matrix	8,94
Composite with 20 vol. % Al_2O_3 particles	7,93
Composite with 30 vol. % Al_2O_3 particles	7,43

Hardness of composite materials was measured applying the Brinell Hardness Tester with the ball of 2.5 mm and load of 625N and results are shown at the Table 2.

Hardness of the composite materials strengthened with Al_2O_3 particles is about three times higher than hardness of the unreinforced copper matrix and is the average of five measurements.

Table 2.
Hardness HBW of composite materials Cu- alumina particles

Materials	HB
Matrix	65
Composite with 20% Al_2O_3 particles	195
Composite with 30% Al_2O_3 particles	208

2.2. Wear examinations

The wear examinations were performed applying the tribological "pin-on-disk" tester T-01. The specimens (with diameter of 7.1 mm) were made from copper based composite materials and for comparative reasons from non-reinforced copper. The abrasion resistance process was performed under the pressure of 1 MPa against the counterspeciman from cast iron brake disk (hardness of 180HBW) and rotating 318rpm (linear velocity of 1m/s). Measurements of mass loss were performed after friction distances of 1.0, 3.5 and 8.5 km and friction force during the tests was controlled in order to calculate the friction coefficient μ. The steady-state coefficients of friction is summarized at Table 3. Generally coefficient of friction decrease with sliding time and is almost 1/3 smaller for composite materials in comparison to the unreinforced Cu matrix.

Table 3.
The mean friction coefficient after different wear distances

μ Materials	μ (after distance)		
	1km	3.5km	8.5km
Cu (cast)	0.854	0.795	0.744
Cu +20 vol.% Al_2O_3 p	0.619	0.578	0.554
Cu +30 vol.% Al_2O_3 p.	0.579	0.549	0.544

2.3. Roughness analysis

Roughness surfaces were analyzed by profilometer Form Talysurf 120L Rank Taylor Hobson Limited Company. The measurements were performed at the cast iron specimens (in three places) used in tribological tests against copper based composite materials and pure copper and are shown at Fig.2. The roughness parameters Ra are shown at the Table 3.

Table 4.
The mean of the roughness profiles from the mean line (Ra)

Materials	Ra [µm]
Cu (cast)	3.9401
Cu +20 vol.% Al_2O_3 p	8.5210
Cu +30 vol.% Al_2O_3 p.	2.5818

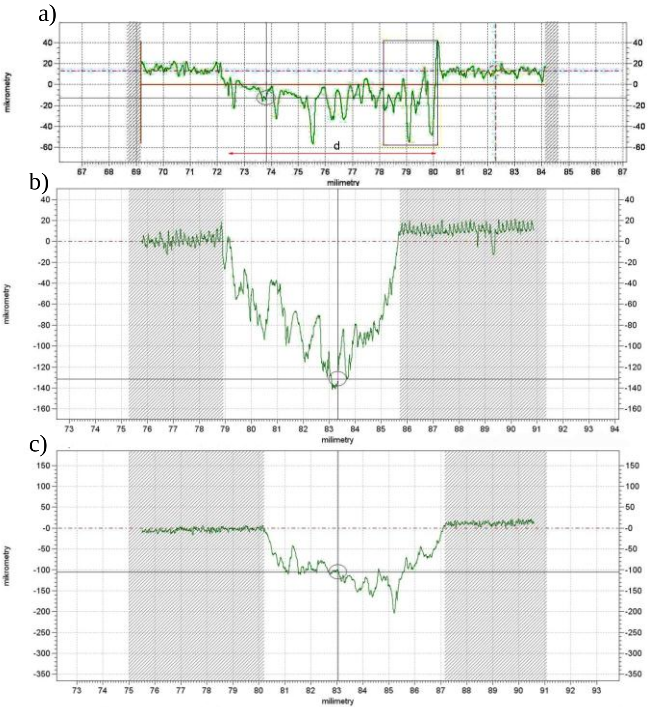

Fig. 2. Surface profiles of the counterspecimen after abrasion resistance test against: a) Cu-matrix; b) Cu+20 vol.% of Al_2O_3 particles c) 30 vol.% of Al_2O_3 particles

3. Results and discussion

Microscopic analysis of the composite materials and non-reinforced Cu after wear tests were performed applying the optical microscope (specimens were cut perpendicular to to the abrasion plane) and the scanning electron microscope (observations of friction surface). Figure 3 shows typical adhesive nature of wear of unreinforced copper seen applying the SEM. Areas of relatively plastic copper adjacent to the wear surface are plastically deformed what consequently led to forming of the characteristic build-up edge (Fig. 4.). It should be noted that the specimens were weighed together with the strongly adhered build-up edge and the visible decrease of wear in the later stages of the friction distance is probably caused by the graphite from the cast iron effecting on the significant lowering of friction coefficient (Fig. 7).

At the wear surfaces of the copper based composite materials are observed embedded or adhering products of abrasive wear from both materials: from the copper based specimen and the cast-iron counterspecimen, (Fig. 5 and 6). Characteristic plastic deformation and forming of build-up edge like in the case of pure copper has not been observed. Friction surface of the composite materials containing 30 vol. % of alumina particles is not smooth and has numerous deep craters caused by tearing-out from the surface extensive pieces of the material containing ceramic particles. Loosing of the alumina reinforcing particles from the copper matrix probably incompletely infiltrated is the reason of a large depth of wear of cast iron counterspecimens by copper based composite materials strengthened with 20 vol.% and 30 vol.% of alumina particles (Fig.2 b, c).

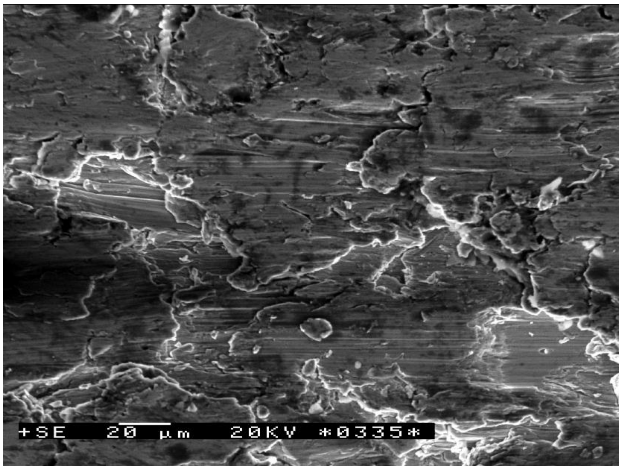

Fig. 3. SEM of friction surface of the Cu-CTP

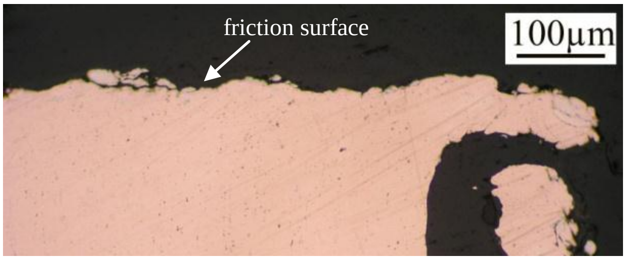

Fig. 4. Friction surface of the Cu-CTP

Roughness analysis of the cast iron counterspecimens after wear tests with application of the specimen from the composite materials (Cu with alumina particles) revealed the local loss of material much deeper comparing with results obtained for the specimen made of the not strengthened copper. The wear depth applying the Cu specimens is about 25µm, while for the composite materials about 100 µm and 150µm (for Cu +20 vol.% Al_2O_3 particles and for Cu +30 vol.% Al_2O_3 particles respectively). Parameters Ra for Cu +20 vol.% alumina particles is quite high (8,5 µm) which is caused by tearing-out from the surface larger extensive ceramic pieces. Ra for Cu+30 vol.% alumina particles is about 2,6µm, causing in this case a smoother surface than the sample of pure copper (Table 4).

Wear of the examined copper based composite materials decreases with increasing volume fraction of ceramic reinforcing particles and is about 3 times smaller comparing with the wear of pure copper which is shown at Fig.7. Wear of matrix initially increases and after distance 3,5km decreases which is probably due to the lubrication effect of graphite from the wear surface of cast iron. The wear of the described friction pair is very large and in further investigations the new friction material based on the new friction pair should be determined.

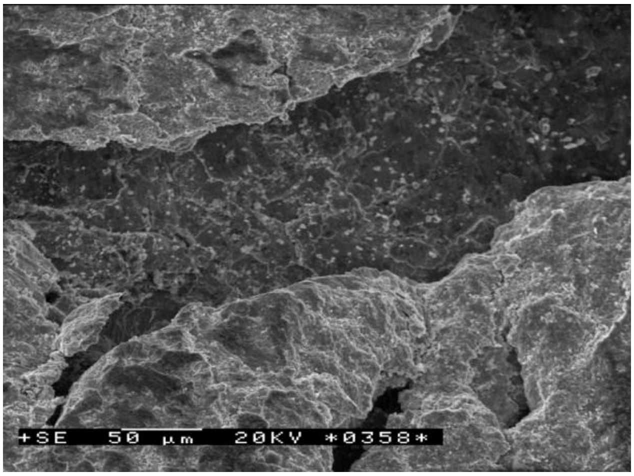

Fig. 5. SEM of friction surface of the copper based composite materials with 20 vol.% of Al_2O_3 particles

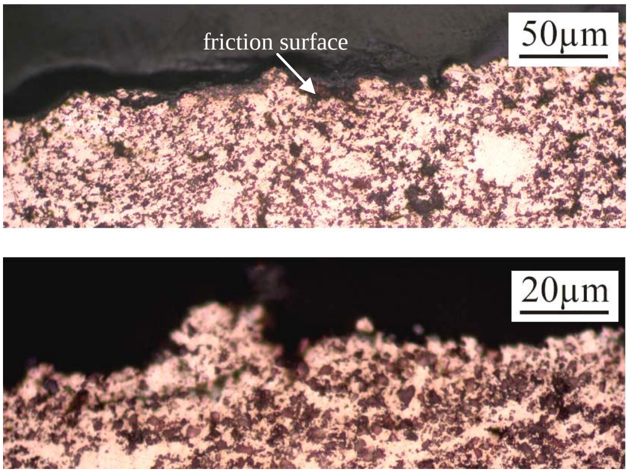

Fig. 6. Friction surfaces of the copper based composite materials with 30 vol.% of Al_2O_3 particles

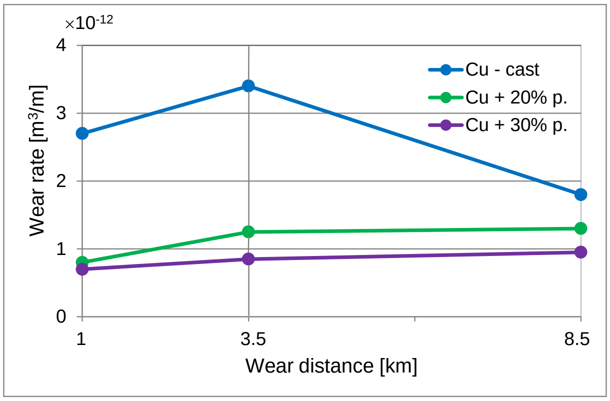

Fig. 7. Wear of composite materials and Cu-ETP on the distances of 1.0 km, 3.5 km and 8.5 km

4. Summary

1. Composite materials with Cu-ETP matrix strengthened with alumina particles can be manufactured by squeeze casting method and arecharacterized by large hardness (three times larger than pure copper).
2. Materials containing ceramic particles are characterized by three times better wear resistance comparing to unreinforced copper matrix. The coefficients of friction decrease with increasing particles content of the copper based composite material.
3. Higher volume fraction of Al_2O_3 particles in the composite materials results in more intensive groves forming of the counterspecimen material made of cast iron.

Acknowledgment

The results presented in this paper have been obtained within the project "KomCerMet" Ceramic Metal Composites and Nanocomposites for the Aerospace and Car Industry, (contract No. POIG.01.03.01-00-013/08 with the Polish Ministry of Science and Higher Education, Warsaw) in the framework of the Innovative Economy Operational Programme (POIG) 2007-2013.

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