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LAMINAR COPPER-INTERMETALLICS COMPOSITE - GENERATION AND PROPERTIES

Copper-intermetallic compound layered composites with different ratio of thickness of copper layers to intermetallics layers have been fabricated from elemental copper band and titanium foil. This article is devoted to examination of the composite structure and its properties. Using X-ray microprobe analysis the intermetallic compounds: Cu_4Ti, Cu_2Ti, CuTi (Fig. 4) were identified in the composite. The predominant part of the phases layer is Cu_4Ti, the richest compound in copper in Cu-Ti binary phase diagram (Figs. 5 and 6). Results show that the hardness of the intermetallics layers in composite is about seven time higher than hardness of the copper layers. Tribological tests showed that wear resistance of the composites increases with increase of thickness of intermetallics layers and is similar to that of CuSn8 bronze (Fig. 7).

Keywords: **metals, alloys, composites, surface properties**

KOMPOZYT WARSTWOWY MIEDŹ-FAZY MIĘDZYMETALICZNE - WYTWARZANIE I WŁASNOŚCI

Podjęto próbę uzyskania materiału łączącego wysoką przewodność elektryczną z podwyższoną odpornością na ścieranie. Uzyskanie takiego materiału jest zadaniem trudnym, gdyż stopy cechuje obniżona przewodność elektryczna, a czyste metale nie są odporne na zużycie ścierne. Kompozyt warstwowy miedź-fazy międzymetaliczne miedziowo-tytanowe o zróżnicowanym stosunku grubości warstwy miedzi do grubości warstwy faz międzymetalicznych uzyskano metodą syntezy faz międzymetalicznych z blachy miedzianej i folii tytanowej podczas reakcji przebiegających w temp. 890°C (przy czym nastąpiło całkowite wyczerpanie metalicznego tytanu). Warstwy miedzi miały zapewnić dobrą przewodność elektryczną, a twarde warstwy zbudowane z faz międzymetalicznych odpowiednią odporność na ścieranie. W badaniach skupiono się głównie na strukturze i własnościach powstałego kompozytu. Przy wykorzystaniu mikroanalizatora rentgenowskiego zidentyfikowano w kompozycie następujące fazy międzymetaliczne: Cu_4Ti, Cu_2Ti, CuTi (rys. 4) oraz mieszaninę składającą się z fazy Cu_4Ti i roztworu stałego tytanu w miedzi. Dominującą fazą jest jednak Cu_4Ti - faza najbogatsza w miedź ze wszystkich występujących w układzie Cu-Ti (rys. rys. 5 i 6). Stwierdzono, że mikrotwardość warstwy kompozytu zbudowanej z faz międzymetalicznych jest około siedem razy większa niż mikrotwardość warstw miedzi i wynosi 510÷550 μHV_{65} (twardość miedzi - 72 μHV_{65}). Odporność kompozytu na zużycie przez tarcie suche jest tym większa, im większy jest stosunek grubości warstw faz międzymetalicznych do grubości warstw miedzi. Dla każdego z badanych kompozytów jest ona jednak znacznie bliższa odporności na ścieranie brązu B8 (CuSn8) niż odporności na ścieranie miedzi M1E (rys. 7).

Słowa kluczowe: **kompozyt warstwowy, fazy międzymetaliczne, synteza faz**

INTRODUCTION

Copper is commonly used as a very good electrical conductor, but its conductivity is conditioned by retaining high purity. Unfortunately, pure copper has a very low abrasion resistance. On the other hand, the copper-based alloys have high level of hardness and wear resistance, but their electrical conductivity is much lower in comparison with copper. For example, thin bronze, silicon bronze and manganese bronze have an electrical conductivity lower than 10 $m/\Omega \cdot mm^2$ while pure copper has 59.7 $m/\Omega \cdot mm^2$ [1].

Metal-intermetallic composites are unique structures, as they offer an attractive combination of properties from both component phases. It appears that a composite consisting of layers - copper partitioned by hard intermetallic phases - could meet the opposed requirements. Certainly, the maintenance of high purity copper in the layered composite is necessary to obtain its high electrical conductivity.

The process of forming intermetallic compounds from reaction between elemental powders has been widely used to produce intermetallic and ceramic powders and *in situ* two-phase composites [2-6]. Recently, it was shown that metal-intermetallic phases layered composites can be processed in the way of self-propagating high temperature synthesis of intermetallic compounds at the interface between Ni and Al, Al and Fe and also Al and Ti foils [7-9].

The intermetallic phases were formed by high temperature reactions between copper and titanium in solid and liquid state. The primary purpose of this study was

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to form the composite containing layers of copper metallurgically bonded with alternately located layers of an intermetallic. To do it, a microscopical examination of the reaction zone was performed to identify the intermetallic phases. Finally, mechanical and tribological properties together with electrical conductivity measu-rements of the layered composite were performed.

EXPERIMENTAL PROCEDURE

Materials used in this experiment were M1E copper (containing 99.9%Cu) and WT-0 titanium containing impurities: oxygen 530 ppm, nitrogen 100 ppm, carbon 200 ppm, aluminium 2700 ppm and iron 900 ppm. The 50 x 10 mm specimens were cut from 0.7 mm thick copper sheets and 0.07, 0.10 and 0.12 mm thick titanium foil. The joining surfaces were polished on 600 grade abrasive paper just before bonding and a sample (multilayered Cu-Ti ”sandwich”) was placed in a vacuum furnace. Pressure of 5 MPa that was used to ensure good bonding was released at a temperature of 850°C. Afterwards the sample was held at a temperature of 890°C for 10 minutes and then the furnace was cooled down to room temperature. The specimens were mechanically polished. The chemical composition of the phases was determined by an electron microprobe analysis using ISIS 300 Oxford Instruments. Vickers ($HV_{0.065}$) measurements were performed by Hanemann microhardness tester mounted on Neophot 2 microscope. The impact resistance was determined using Charpy pendulum machine. Tribological tests were performed by T-05 tribological tester.

RESULTS AND DISCUSSION

Figure 1 shows a schematic representation of the process used to form the composite.

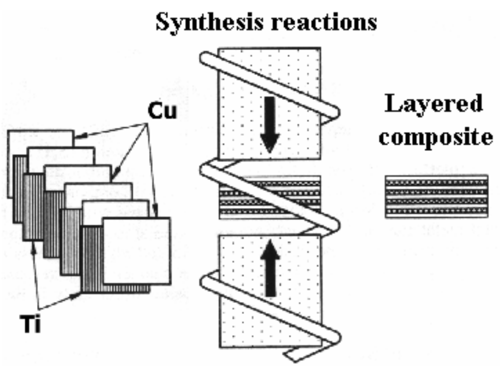

Fig. 1. Schematic representation of the process used to form composite

Rys. 1. Schemat procesu zastosowanego do formowania kompozytu miedź--fazy międzymetaliczne

Figure 2 shows the composite formed from Cu and Ti foils after holding of the packet of foils for 10 minutes at a temperature of 890°C.

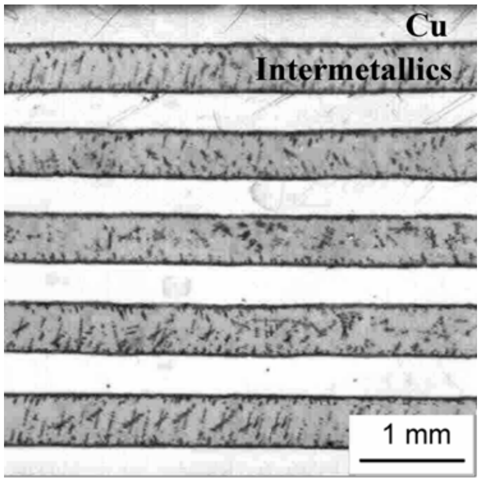

Fig. 2. Macrostructure of copper-intermetallic composite formed at 890°C

Rys. 2. Makrostruktura kompozytu miedź-fazy międzymetaliczne

Structural transformations at the Cu-Ti interface during synthesis of copper-intermetallics layered composite were investigated earlier [10]. A structural analysis of the composite was performed by a scanning electron microscope equipped with a system for microprobe analysis. The main aim of these examinations was identification of the chemical composition of phases synthesised at the reaction zone. The dendritic structure of the layers indicates that this stage of the Cu-Ti reaction proceeds in the liquid phase. A study of the above structures was based on the Cu-Ti binary phase diagram presented in Figure 3.

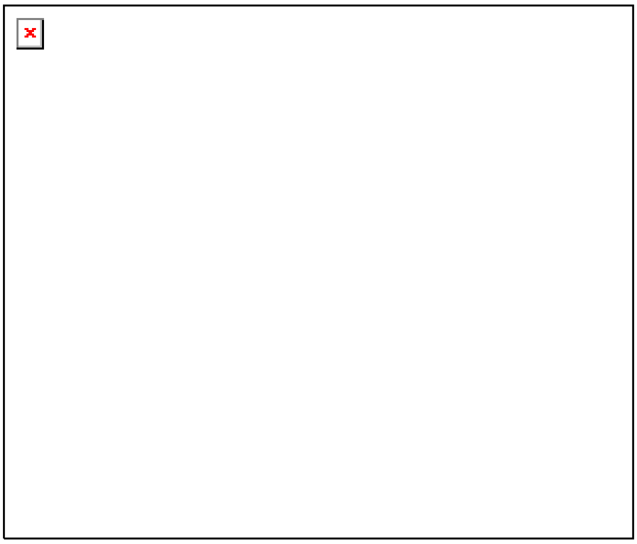

Fig. 3. Cu-Ti binary phase diagram [11]

Rys. 3. Układ równowagi fazowej Cu-Ti [11]

The elemental analysis performed by the X-ray spectroscope was made for areas marked A, B, C, D in the micrographs shown in Figure 4. An example of X-ray diffraction spectrum for a single phase of the D-area of the specimen is given in Figure 5. The Cu:Ti ratio, about 4:1, suggests a Cu_4Ti intermetallic compound. Using X-ray microanalysis, it was found that for also single phase areas marked A and C, A is CuTi and C is Cu_2Ti.

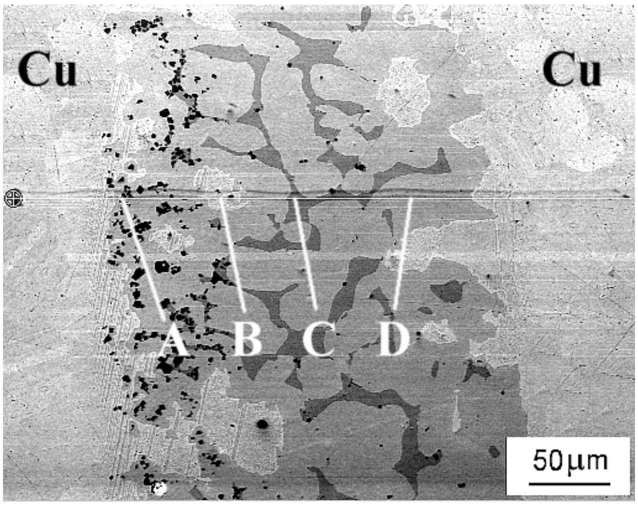

Fig. 4. Microstructure of reaction zone after holding at 890°C for 10 minutes

Rys. 4. Mikrostruktura strefy reakcji po wygrzewaniu w temperaturze 890°C przez 10 minut

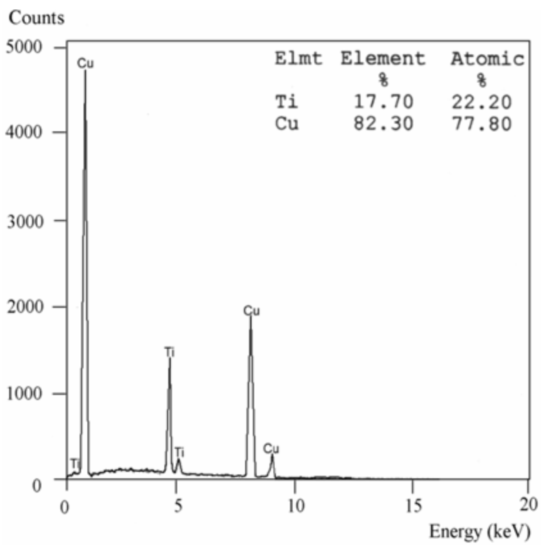

Fig. 5. X-ray spectrum for D-marked area of structure depicted in Figure 4

Rys. 5. Wynik mikroanalizy rentgenowskiej dla obszaru D zaznaczonego na rysunku 4

The chemical composition of the zone marked B was 90.26 at. % Cu and 9.74 at. % Ti. It should be mentioned that in the case of B area X radiation was simultaneously emitted by two phases of the structure. This result indicates, according to the phase diagram of Cu-Ti system (Fig. 3), a mixture of Cu_4Ti and solid solution titanium in copper.

Mechanical and tribological properties of the composites were performed. The results show that the microhardness of the dendritic layer of the composite was 510÷550 HV. Comparatively measured, the microhardness of copper was 72 HV (Fig. 6).

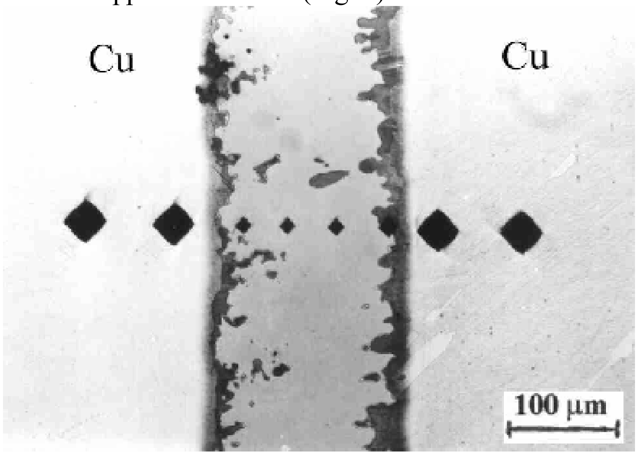

Fig. 6. Indentations of the Vickers penetrator in copper and intermetallic phases

Rys. 6. Ślady pomiarów mikrotwardości metodą Vickersa pozostawione w warstwach miedzi i warstwie faz międzymetalicznych

Tribological tests were performed on the T-05 tester, where a rectangular specimen mates with a cylindrical hardened (64 HRC) anti-specimen. Abrasive wear tests were made on five different specimens: one made of Cu, three made of composites with different ratios Cu to phases (1.6:1, 2.5:1 and 4.9:1), one made of Cu-Ti alloy (consisting only intermetallic phases) and one made of CuSn8 bronze (for comparison). Tribological tests showed that wear resistance of the composites increases with increase of the thickness of the intermetallics layers and is similar to behaviour of CuSn8 bronze (Fig. 7).

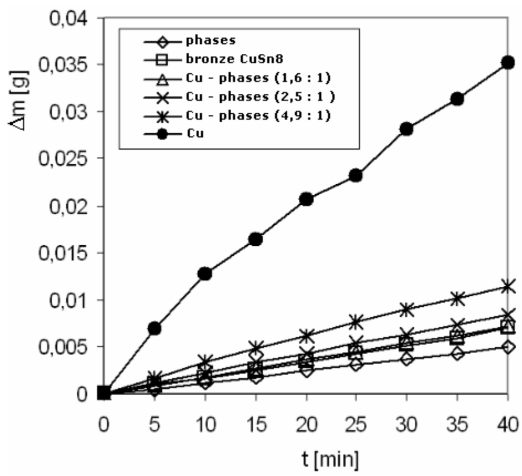

Fig. 7. Abrasive wear made by dry friction - the mass decrement in time

Rys. 7. Zużycie próbek przez tarcie suche wyrażone jako ubytek masy w funkcji czasu

CONCLUSIONS

The principal results of this study can be summarised as follows:

1. In a consequence of a reaction occurring between copper and titanium at a temperature of 890°C, a layered composite Cu-intermetallic phases is formed. It was found using microprobe analysis that the reaction zone contains intermetallic compounds: Cu_4Ti, Cu_2Ti, CuTi and a solid solution of titanium in copper.
2. The predominant part of the structure formed in the reaction zone consists of the Cu_4Ti intermetallic phase.
3. The hardness of the intermetallics layers in composite is about seven time higher than the hardness of the copper layers.
4. Wear resistance of the composites increases with increase of the thickness of the intermetallics layers and is similar to that of CuSn8 bronze.

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