SURFACE BEHAVIOUR OF Cu-Al AND Cu INTERMETALLIC COATING PRODUCED BY ARC SPRAYED

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Abstract

The wire electrical arc spraying process is widely used for surface treatment. Electric arc spraying is an advantageous method in many applications due to its high deposition rate and economical operation. The fast development of cored wires as a feedstock material over the past few decades has made it possible to extend the metallurgical choice of sprayed coatings significantly. New coatings with low porosity and small grains were obtained by arc-spraying. Alloys including Cu-Al intermetallic coatings are new candidates for use in tribologic and corrosion environments because of the combination of low cost and a remarkable resistance to abrasion under different working conditions. In the present work, the results concerning the development of arc-sprayed Cu-Al and Cu based coatings for applications are presented. The initial phase contents of coatings were studied by X-ray diffractometry. The optical micrograph was SEM analyses were applied to cross-section of samples.

Keywords: Wire arc, intermetallic coatings

1. INTRODUCTION

Nowadays, metallic and intermetallic coatings are being intensively verified as oxidation and corrosion protecting materials in the hotter parts of power plants and engines [1,2]. However, a number of factors determining the microstructure formation and thus influencing properties of such coatings remain unknown, namely, - an influence of the content of alloying elements (Al and B) in cored wire on the microstructure, residual stresses and hot-gas abrasive resistance of the coatings; - an evolution of phase composition and mechanical properties under a long-term exposition at elevated temperatures; - an influence of inner and outer oxidation, composition and morphology of the oxide films on the exploitation behaviour of the coatings, etc. [2-5].

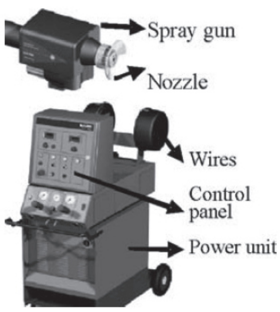
Copper (Cu) is widely used reactive metal in electrical and electronic devices. It is rapidly replacing aluminum as the interconnect material of choice in integrated circuits, particularly microprocessors, because of its low resistivity and its improved electromigration performance. Despite the fact that copper is noble, it readily corrodes in a variety of environments. The common properties of these intermetallics are their high hardness, low toughness, relatively low electrical resistivity and complex crystal structure.

Wire arc spraying is an economical coating process; therefore it has been used widely to coat engineering structures to protect them against corrosion and wear. The attractions are the low cost and the operational simplicity. The material to be deposited is introduced into the arc in the form of two wires serving as consumable arc electrodes. These intermetallic compounds have been actively researched for application in industry as a promising advanced material; their application to various engineering components has been widely studied.

2. EXPERIMENTAL PROCEDURE

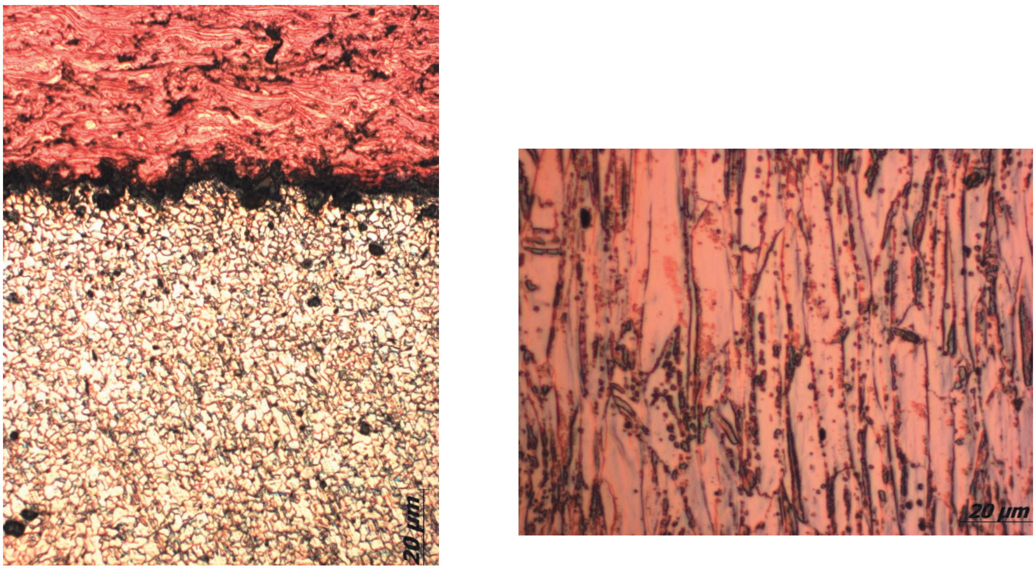
The Sulzer Metco smart arc spray system we used consists of a power supply, a control unit and a robot-controlled arc spray gun. AISI 1020 low-carbon steel and AlSi alloys with a thickness of 3 mm were used in this study, and all the specimens to be coated were pretreated by grit blasting. Aluminum and copper wires with a diameter of 1.6 mm were sprayed with air used as an atomizing gas (**Table 1**).

Table 1 Arc Spray Process Parameters and Smart ArcSpray (Sulzer)

	Smart ArcSpray (Sulzer)	
	Current (Ampere)	205–210
	Voltage (Volt)	26–28
	Spray Distance (mm)	120–150
	Gas Pressure (bar)	4

For the production of binary Cu-Al solid solution and intermetallics on the copper-rich side of Cu-Al binary system stainless-steel were used as substrates. The duration of total processing time was varied, keeping the depositing and bombarding voltages as well as rotation intervals of the substrate constant.

3. RESULTS AND DISCUSSION



(a) (b)

Fig. 1 The optic micrographs a) the cross-section of Cu coating, b) Cu-Al coating

The optic micrograph of Cu and coating were shown in **Figs. 1 (a) and (b)**. All arc-sprayed coatings have a characteristic lamella structure. The high cooling rates of the droplets on the steel surface promote the formation of supersaturated solid solutions and amorphous structures in the coating. The micrographs of the coatings reveal that there were a few unmelted or partially melted copper particles, which can be seen as circular shape rather than thin, pancake-like shape of splats. The porosity of the coatings increased with increasing amount of aluminium added. When a copper splat solidifies next to an aluminium splat, the less wettability between copper and aluminium (compared to copper and copper) results in a gap between the splats which then turns to a pore [5,6].

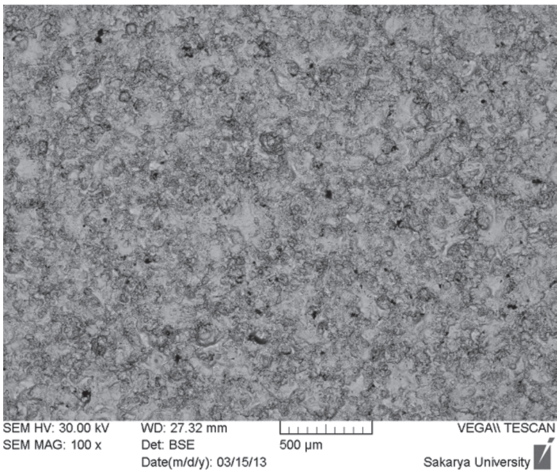


Fig. 2 The SEM micrograph of Cu coating

The hard particles can cause the formation of microcracks perpendicular to the lamella. Some typical porosity is also observed. A particular feature of the coatings sprayed from cored wires is the rather inhomogeneous chemical composition in comparison with that sprayed from the solid wires, which can strongly influence the properties and exploitation behaviour of the sprayed coatings [7,8].

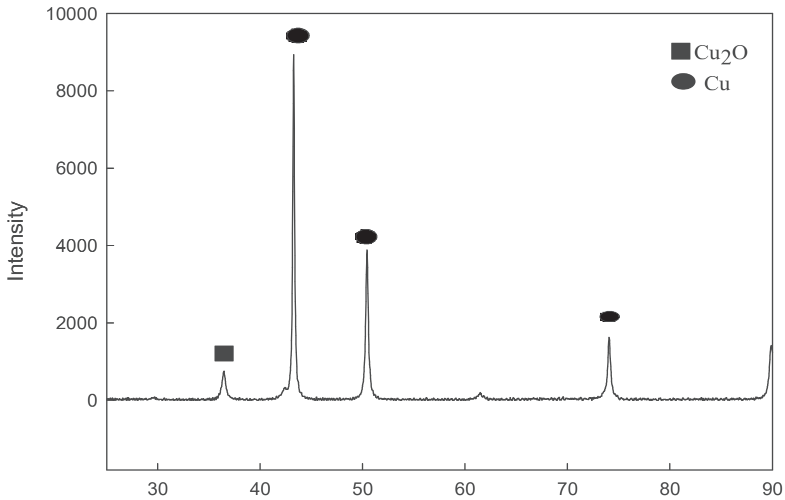


Fig. 3 The results of XRD analyses of Cu coating

The morphology of the as-received Cu powders was dendritic (**Fig.1b**).

Surface and cross-sectional SEM micrographs of the arc-sprayed Cu, Cu-Al intermetallic coatings are shown in **Figs. 2 (a) and (b)**. There were some porosity in bonding layer and coating bulk (**Fig. 2a**). It is clear that the coating is a mixture of white and gray regions, which were identified as Cu and Al, respectively (**Fig. 3b**) The microhardness of the gray regions has higher than that of the white regions [5-7].

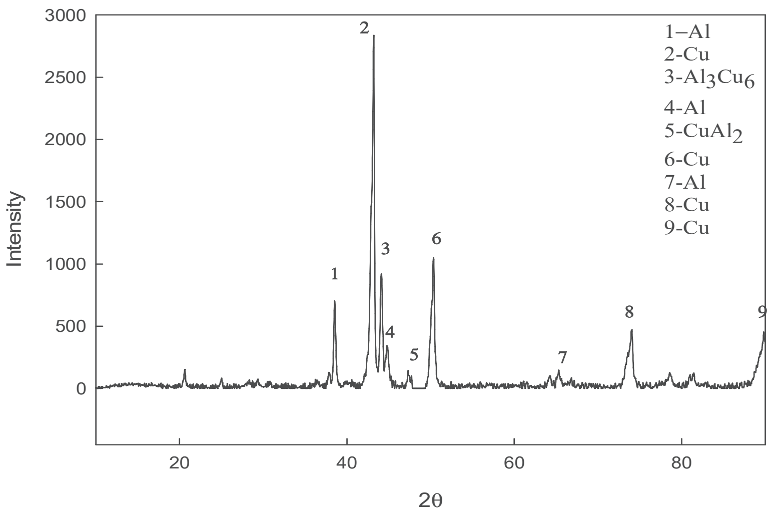


Fig. 4 The results of XRD analyses of Cu-Al coating

It is generally agreed that the presence of open pores within the coating structure is a main drawback of arc spray [6,7]. Pore spaces present in coatings allow the penetration of oxygen, which results in oxidation inside the coatings. It was found that the coatings contained more oxide after than before oxidation. According to Wagner oxidation theory, the oxidation is controlled by diffusion of elements in the oxide. When all the pore spaces closed, the oxides in the coatings would act as barriers to hinder oxygen or metal elements from diffusing to avoid inner alloy oxidizing [6-9].

XRD result in **Fig. 4** shows that all coatings had $CuAl_2$. The peak between 45° and 50° in the Cu-Al sample indicates the overlap between the aluminum peak and the peak of Cu-Al intermetallic phase, which could be $CuAl_2$ [8]. XRD result does not show the presence of alumina (Al_2O_3) in the Cu/Al coatings although the oxidation of aluminum is possible (but the volume fraction of alumina is so low that XRD cannot detect) [9]. It is also interesting that aluminum oxide phase was not found in the XRD spectra, which may be relevant to ittle mass fraction of aluminum oxide in the this coating.

CONCLUSION

Intermetallic coatings can be produced easily using the wire arc spray process. A process optimization is required for a better coating quality. The Cu-Al and Cu coating structure were different. There were micropores on surface sutructure. The dendtritic and lamellar structure were formed on surface. The amount of micropores is higher than in Cu coating. The Al phases was blocked micropores structure.

REFERENCES

[1] ALTUNCU,E., IRIÇ, S., USTEL, F. Wear-Resistant Intermetallic Arc Spray Coatings. *Materiali in Tehnologije / Materials and Technology,* 2012, 46(2), 181-183.

[2] Y.ÖZBEK, Y., ALTUNCU, E., İRİÇ, S., ÜSTEL, F. Characterization of Arc-sprayed AlCu Intermetallic. *16th International Metallurgy & Materials Congress* (IMMC 2012), ISTANBUL: 13-15 September 2012.

[3] ARPAT, E., ÜRGEN, M. Production of free standing CuAl intermetallics by cathodic arc plasma treatment. *Intermetallics*, 2011, 19, 1817-1822.

[4] WATANABE, T., SATO, T., NEZU, A. Electrode phenomena investigation of wire arc spraying for preparation of Ti-Al intermetallic compounds. *Thin Solid Films,* 2002, 407, 98-103.

[5] WIELAGE,B., POKHMURSKA, H., STUDENT, M., GVOZDECKI,V., STUPNYCKYJ, T., POKHMURSKI, V. Iron-based coatings arc-sprayed with cored wires for applications at elevated temperatures. *Surface & Coatings Technology,* 2013, 220, 27-35.

[6] POKHMURSKA, H., DOVHUNYK, V., STUDENT, M., BIELANSKA, E., BELTOWSKA, E. Tribological properties of arc sprayed coatings obtained from FeCrB and FeCr-based powder wires. *Surface and Coatings Technology,* 2002, 151-152, pp. 490-494.

[7] LIMPICHAIPANIT, A., WATCHARAPASORN, A., WIROJANUPATUMP, S., JIANSIRISOMBOON, S. Fabrication and Mechanical Properties of Thermal Sprayed Copper-based Coatings. 2006, 16, 868-872.

[8] ZHONG-LI, Z., DE-YUAN, L., SHUI-YONG, W. High temperature performance of arc-sprayed aluminum bronze coatings for steel. *Transactions of Nonferrous Metals Society of China*, 2011, 4 (2), 123-126.

[9] CHEN,Y., LIANG, X., WEI, S., LIU, Y., XU, B. Heat treatment induced intermetallic phase transition of arc-sprayed coating prepared by the wires combination of aluminum-cathode and steel-anode. *Applied Surface Science*, 2009, 255, 8299-8304.