UDK 621.793:539.231
Professional article/Strokovni članek

ISSN 1580-2949
MTAEC9, 46(2)181(2012)

WEAR-RESISTANT INTERMETALLIC ARC SPRAY COATINGS

OBRABNA OBSTOJNOST INTERMETALNIH PREVLEK, NAPRŠENIH V ELEKTRIČNEM OBLOKU

Ekrem Altuncu[1-3], Sedat Iriç[2], Fatih Ustel[3]

[1]Kocaeli University, Machine-Metal Tech., Kocaeli, Turkey,
[2]Sakarya University, Machine Eng. Dept., Sakarya, Turkey
[3]Sakarya University, Metall.-Materials Eng. Dept., Thermal Spray Center, Sakarya, Turkey
altuncu@kocaeli.edu.tr

Prejem rokopisa – received: 2011-10-20; sprejem za objavo – accepted for publication: 2011-12-08

The twin-wire electrical arc spraying (TWAS) process is widely used for worn-out surface restoration and the corrosion protection of metallic constructions. The industrial benefit of arc spray coatings is the possibility of cost-effective coating solutions to minimize corrosion problems. However, the wear resistance of metallic (such as Al, Cu and its alloys) arc sprayed coatings is inadequate. Alloys including Cu-Al intermetallic coatings are new candidates for use in tribological environments because of the combination of low cost and a remarkable resistance to abrasion under different working conditions. In this study the tribological properties of Al-Cu twin-wire arc-spray coatings are investigated in dry sliding test conditions depending on the load and the sliding distance.

Keywords: TWAS, intermetallic coatings, wear resistance

Elekrično naprševanje z dvojno žico (TWAS) se široko uporablja za popravilo obrabljenih površin in protikorozijsko zaščito kovinskih konstrukcij. Industrijska prednost postopka je priprava poceni prevlek za zmanjšanje korozijskih težav. Vendar obrabna obstojnost kovinskih (Al, Cu in zlitine) napršenih prevlek ni primerna. Intermetalne zlitine so nove kandidatke za uporabo v triboloških okoljih, ker združujejo nizko ceno in pomembno odpornost proti abrazivni obrabi. V tem delu so opisane tribološke lastnosti prevlek, napršenih z dvojno žico AlCu pri drsnem preizkusu v odvisnosti od obremenitve in drsne razdalje.

Ključne besede: TWAS, intermetalne prevleke, obrabna odpornost

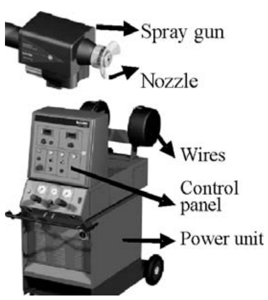
1 INTRODUCTION

Wear-resistant coatings are used to reduce the damage caused by abrasion, erosion, cavitation, and fretting, also potentially associated with corrosion, and in some cases to reduce friction[1–3]. The optimal wear protection of light metallic substrates can be provided by a cost-effective thermal spray coating process and composition, depending on the operating environment and working conditions[4–9]. Intermetallic coatings, alloy coatings or metal-ceramic composite coatings can be obtained by wire arc spraying with cored wires or pre-alloyed wires. Cu-Al intermetallic systems were actively researched for applications in the aviation, automobile, naval, construction and defense sectors. The Cu-Al alloy system has long been used for wheel bearings for airplanes and screws for ships because of its resistance to abrasion, corrosion, and heat[7]. The purpose of this work is to develop an economical and effective deposition method for copper-aluminum intermetallic coatings to improve the wear resistance of light alloys. The sliding wear resistance of Al-Cu intermetallic arc spray coatings was investigated depending on load and sliding distance. The crystal structure and composition of the alloys were studied by x-ray diffraction.

2 EXPERIMENTAL DETAILS

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**). The sliding wear test (ASTM G133) conditions were as follows: sliding stroke, 20 mm; sliding frequency, 5 Hz; and normal

Table 1: Arc Spray Process Parameters
Tabela 1: Parametri naprševanja v električnem obloku



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

loads, 10 N to 30 N. The resulting sliding distances were 200 m to 1 600 m. The thickness loss and weight loss were measured on all the specimens under dry conditions. The weight loss of the specimen after the test was measured by an electronic analytical balance with a minimum reading of 0.01 mg. The friction coefficients of the coatings were measured using a ball-on-disc test in a CSM tribotester.

3 RESULTS AND DISCUSSION

3.1 Microstructure of the coatings

Surface and cross-sectional SEM micrographs of the arc-sprayed Cu-Al intermetallic coatings are shown in **Figure 1**. It is clear that the coating is a mixture of white and gray regions, which were identified as Cu and Al, respectively, by EDS analysis. The microhardness of the gray regions was found to be higher than that of the white regions.

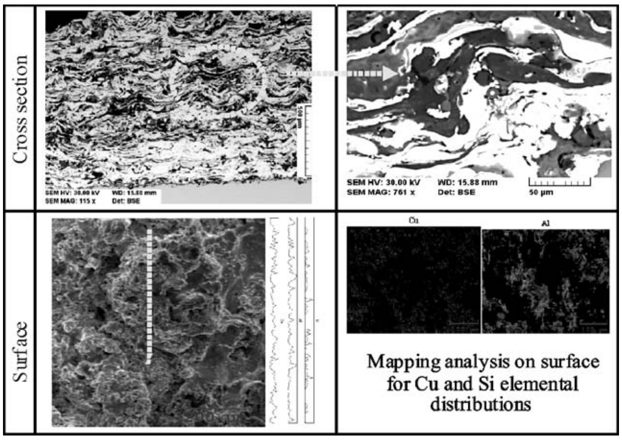


Figure1: Surface and cross-sectional SEM micrographs of the arc-sprayed Cu-Al intermetallic coatings
Slika 1: SEM-posnetki površine in prereza interemetalnih prevlek Cu-Al, napršenih v električnem obloku

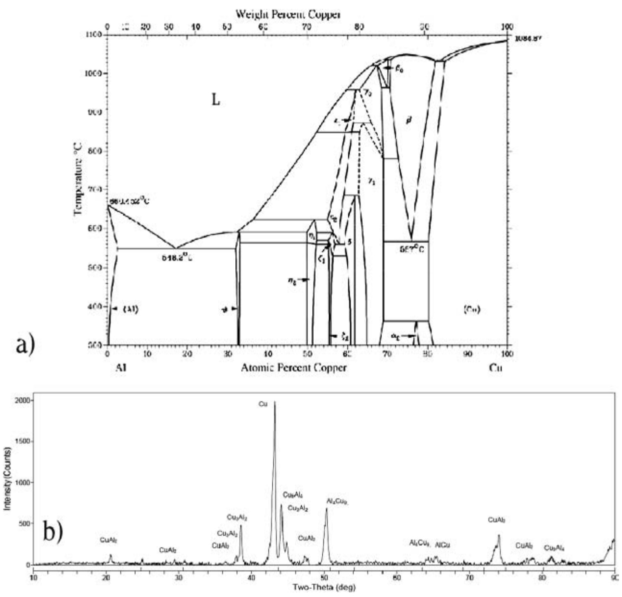


Figure 2: a) Phase diagram of Al-Cu binary system[8], b) XRD pattern of the coating
Slika 2: a) Binarni fazni diagram Al-Cu[8] in b) XRD-spekter prevlek

3.2 Cu-Al intermetallic phases

In the equilibrium phase diagram of Cu and Al (**Figure 2a**) there are five stable intermetallic phases, i.e., Cu_9Al_4, Cu_3Al_2, Cu_4Al_3, CuAl, and $CuAl_2$, with two terminal solid solutions of Cu(Al), which are often designated as αCu and Al(Cu)[8]. In this study different intermetallic phases were identified from XRD patterns. These phases are: 00-025-0012; $CuAl_2$, 00-024-000; Cu_9Al_4, 00-050-1477; Cu_3Al_2, 00-002-1254; Al_4Cu_9 (JCPDS numbers). The main phase content of Cu_9Al_4 and Cu_3Al_2 intermetallics affected the wear resistance of the coating. After a heat treatment at 400 °C for 3 h these phase ratios were increased.

3.3 Comparative wear resistance

The effects of porosity, flattening ratio, oxide content, and splat-to-splat bonding strength play an important role in the coating's antiwear performance. Low cohesion and high porosity generally cause a large piece of the coating to wear away and result in a decrease of the wear resistance

The thickness loss of the specimens was determined by measuring the cross-sectional thickness of the sound material after testing using an optical micrometer to observe accurately a cross-section through the central

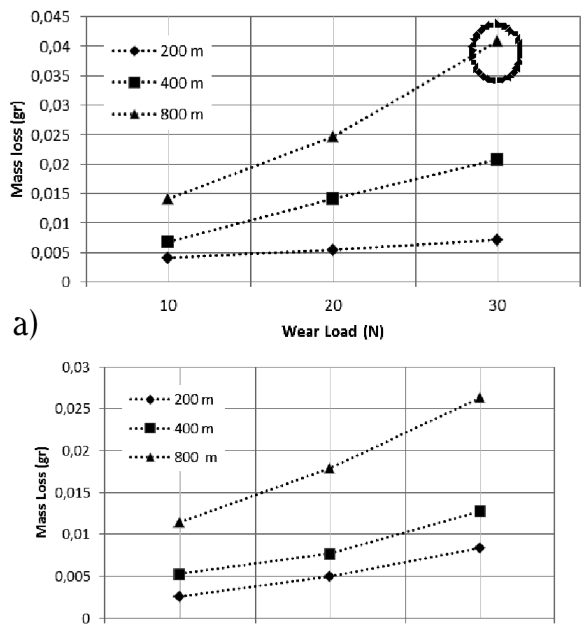


Figure 3: Mass-loss diagram as a function of wear load and sliding distance for samples: a) as-sprayed and b) heat treated
Slika 3: Izguba mase v odvisnosti od obrabne obremenitve in razdalje za vzorce: a) napršene in b) toplotno obdelane

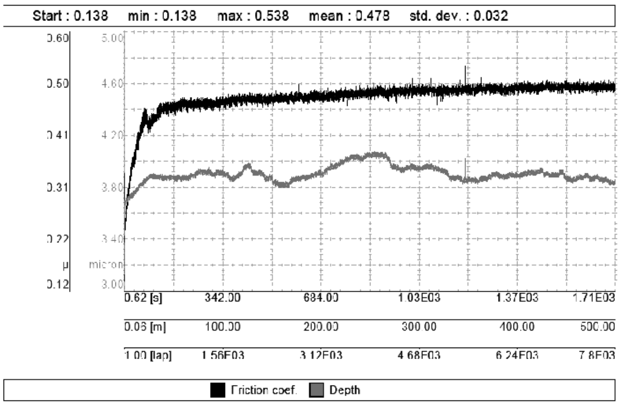


Figure 4: Cof of the coatings
Slika 4: Torni koeficient (*Cof*) prevlek

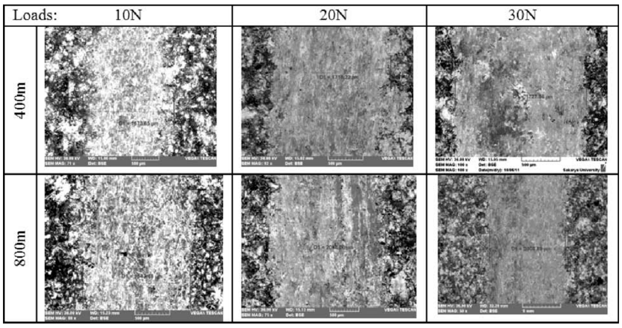


Figure 5: Wear-track profile views
Slika 5: Videz profila obrabnih poti

part of the track zone. The mass losses of the coatings are shown in **Figure 3a**. At a low load of 10 N a very small mass-loss difference was observed for sliding distances between 200 m and 800 m. When the wear load increased, the mass-loss difference increased. The highest wear mass loss on the coating and thickness was observed for 30 N at 800 m of sliding distance. The wear mass-loss change after the heat treatment of the coating is shown in **Figure 3b**. The heat-treated samples showed a lower mass loss. The microstructure and phase content of the coating have been suggested to influence the mass loss. In **Figure 4** the coefficient-of-friction (*Cof*) changes are shown for the Al-Cu coating. As can be seen the *Cof* values changed in the first stage of the test after which a steady state is observed. The *Cof* values were measured between 0.47 and 0.53. The heat-treated samples exhibited lower *Cof* values between 0.41 and 0.45.

Figure 5 shows the wear-track profiles of the coatings, both the track depth and width changed with an increase of the load. The width of the wear tracks varied between 1 650 μm and 1 730 μm at 400 m. When the sliding distance increased to 800 m the width varied between 1 747 μm and 2 015 μm. In both cases, the wear track is rougher than the initial coating surface, which indicates that particle pull-out took place during the sliding. The morphology of the wear tracks of the arc sprayed Al-Cu coatings confirmed that wear primarily arose through cracked particles. The pull-out particles then stayed in the contact area and led to three-body abrasive wear, which was the main wear type in these coatings.

4 CONCLUSION

Intermetallic coatings can be produced easily using the twin-wire arc spray process. A process optimization is required for a better coating quality. As a result of the heat treatment of the Cu-Al arc spray coatings, significant amounts of Cu_4Al_9 and Cu_3Al_2 intermetallic phases were identified by XRD analysis. These phase contents affected the wear mass loss and wear track-profile width. The comparative mass loss as a function of the wear load and sliding distance for both of the heat treated coatings and original coatings were determined. With the heat treatment we were able to improve the wear resistance of the coating by a factor of two.

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