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Original Research Article

Application of interlayers in the soldering process of graphite composite to aluminium alloy 6060

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ABSTRACT

The paper presents a problem of joining graphite-copper composite to aluminium alloy 6060 by soldering method. This type of joints is used in electricity transmitting devices, e.g. in current receivers of rail vehicles. Therefore, the joints should show good electrical conductivity. Soldering process of graphite to aluminium directly is impossible and requires application of metallic interlayers. The problem was solved by using interlayers deposited by electroplating and low pressure cold spraying (LPCS) prior to soldering process. Various methods of substrate preparation were used. The results of shear strength and metallographic analysis were described. The highest shear strength of 17.6 MPa showed sample prepared by grit blasting and cold plasma, simultaneously.

1. Introduction

Welding of graphite or composite materials with graphite matrix directly to other material is impossible. Graphite, ceramics and selected metals, e.g. aluminium and titanium, have relatively high stability of ceramic surfaces and thus are not wetted by molten metals [1,2]. Application of process dedicated for joining dissimilar materials, e.g. soldering or brazing, is difficult also. The main problem is lack of wettability of graphite surface by solders. Graphite can by joined to other materials using a high-temperature vacuum brazing, where diffusion phenomena are working [3]. Direct active soldering with the filler metal containing an active element, e.g. Ti, Zr, Hf, Ta, V or Cr) can be used also [4]. Nevertheless, joining of graphite to metals, and especially to aluminium and its alloys, makes a huge technological problem. Recently, glueing is being highly developed. However, glued joint cannot provide of appropriate electrical conductivity, even using composite glues with metal powder fillers or copper mesh [3]. The application of graphite and aluminium alloy joint include mainly electricity transmitting devices, e.g. in current receivers of rail vehicles, and therefore should show good electrical conductivity and mechanical strength. In the case of glues, there would be high loss of power, what eliminate this method. Good electrical conductivity can ensure other joining methods, e.g. brazing or soldering [5]. However, the former method is limited to high melting point materials and the process would change microstructure of annealed 6060 aluminium alloy. On the

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other hand, the latter method disable materials diffusion. Therefore, it is necessary to apply interlayers onto the surface of graphite and 6060 aluminium alloy while joining both materials to provide higher mechanical and electrical properties.

Intermediate layers became more and more popular in joining dissimilar materials. In soldering process interlayers were successively applied to join: (i) copper to austenitic steel with the use of copper-phosphorus binder [6] or (ii) copper to aluminium with the use of zinc solder [7]. There is a lot of various methods of metal interlayers deposition. One of the most popular is electroplating. The phenomenon responsible for bonding metal coating to other material, e.g. graphite, is mechanical adhesion. In electrical conductivity application a coating with mechanical adhesion to the substrate is fully suitable. Nevertheless, when higher mechanical strength of the coating is required, the graphite surface should be activated.

There are other methods of interlayers deposition, e.g. silver paint or thermal spraying. Silver paint is applied in automotive industry. The silver paint is burned out on the car window and afterwards works as interlayer in brazing process of connector to the car window. However, in the case of graphite, this solution can be insufficient because of low bond strength of the coating.

Thermal spraying methods can be applied to various materials. In conventional spraying processes material is melted and accelerated in the stream of pressurized gas. However, metal coatings deposited with most popular flame spraying, arc spraying or plasma spraying in the atmosphere of air have low quality. According to Wielage et al. [8] coatings are characterized by defects, such as: inclusions, high oxidation and porosity, what significantly decrease surface wettability in soldering process. Nevertheless, there is one method that can be applied to spray metal interlayers prior to soldering processes, e.g. cold spraying. In cold spraying compressed gas (helium, nitrogen or air) is heated to the temperature of 20–1100 °C and accelerated to supersonic velocity while passing through de Laval nozzle [9,10]. Therefore, powder particles introduced to the nozzle gain supersonic velocity. When particles impact the substrate, kinetic energy is transferred into plastic strain [11]. As a result, particles join with the substrate by mechanical interlocking [12]. Temperature in the spraying process is significantly lower than the melting point of sprayed material and thus the coating is deposited in solid state. The coatings are characterized by lower oxidation compared to basic thermal sprayed methods [13]. What is more, the coatings show good mechanical properties [12,14], good electrical conductivity [15] and solderability. The application of cold spraying process in soldering is known [16].

However, selecting appropriate method for interlayers deposition prior to soldering process of graphite-copper composite to 6060 aluminium alloy is difficult. A good bonding of the coating to graphite substrate should be ensured. The soldered joint while service conditions is endangered to surface pressure and compressive stresses. An example of application of these two materials is current collector in pantograph slipper of the train (Fig. 1). In this research, two methods of coatings deposition were selected and compared: (i) electroplating and (ii) cold spraying.

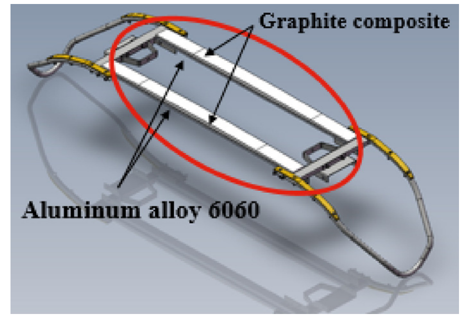

Fig. 1 – Construction of the pantograph slipper applied in trains.

2. Materials and test methodology

2.1. *Materials*

The graphite-copper composite used in the research is based on pitch coke with addition of graphite, that works as a lubricant, and 40 wt.% of copper powder (Table 1). Prepared in this way die stamping was filled with epoxy resin. Prior to the filling process the epoxy resin was burned to glassy carbon. The graphite-copper composite is characterized by good bending strength (about 60 MPa) and tribological properties (wear rate about 2×10^{-7} mm^3/Nm), lack of absorbability, low porosity (about 1%), high hardness (about 100 HV) and high electrical conductivity. Therefore this material is used as a contact to electrical traction conductor.

Aluminium alloy 6060 is generally applied to slipper frames [17]. Its tensile strength is about 130 MPa. However, it is characterized by high stamping flexibility to perform profiles of complicated shapes.

2.2. *Test methodology*

Prior to soldering process, surfaces of joined parts were coated with electroplating and cold spraying method. The samples dimensions of composite and metal used in the research are presented in Fig. 2. In the electroplating process, the coating was deposited onto graphite-copper composite surface only. In the plating process cyanide free copper bath SUR-TEC 864 was used. This bath is based on pyrophosphates. It is worth stressing, that the parts were inserted into the plating bath under current flow, to prevent an electroless and amorphous copper deposition [18,19]. The bath was heated up to 60 °C. The deposition time was 60 min with the current density of 3 A/dm^2.

In electroplating processes substrate preparation is very important. Therefore, the graphite-copper composite surface was modified by: (i) abrasive paper (180 grade), (ii) abrasive

Table 1 – The chemical composition of the graphite-copper composite.

Cu/carbon [wt.%]	Pitch coke/graphite [wt.%]
40/60	70/30