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ScienceDirect
Trans. Nonferrous Met. Soc. China 25(2015) 2608−2616
Transactions of Nonferrous Metals Society of China
www.tnmsc.cn

Influence of processing parameters on laser metal deposited copper and titanium alloy composites

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Received 17 October 2014; accepted 9 May 2015

Abstract: The laser metal deposition (LMD) was conducted on copper by varying the processing parameters in order to achieve the best possible settings. Two sets of experiments were conducted. The deposited composites were characterized through the evolving microstructure, microhardness profiling and mechanical properties. It was found that the evolving microstructures of the deposited composites were characterized with primary, secondary and tertiary arms dendrites, acicular microstructure as well as the alpha and beta eutectic structures. From the two sets of experiments performed, it was found that Sample E produced at a laser power of 1200 W and a scanning speed of 1.2 m/min has the highest hardness of HV (190±42) but exhibits some lateral cracks due to its brittle nature, while Sample B produced at laser power of 1200 W and a scanning speed of 0.3 m/min shows no crack and a good microstructure with an increase in dendrites. The strain hardening coefficient of the deposited copper composite obtained in this experiment is 3.35.

Key words: copper composites; laser metal deposition; mechanical properties; strain hardening

1 Introduction

Laser metal deposition (LMD) is an offshoot of additive manufacturing and an important process in the field of engineering for industrial development. In modern age, LMD has been greatly invested on due to its effectiveness and high efficiency in the repair of complex parts through cladding. The complexity of damaged parts has been taken care of with the application of powder metallurgy in additive manufacturing processes. Precision of repaired component is made easily which reduces or eliminates machining to some extent.

Copper (Cu) is very attractive due to good corrosion resistance, excellent workability, attractive colour, good mechanical properties and the best electrical and thermal conductivity compared with other commercial metals [1]; its corrosion resistance and antimicrobial effect makes it ideal for brewing vessels [2], and an increase in the current density of Cu changes its morphology [3]. Cu is a strong β-stabilizing element and its atomic migration into titanium lattice results in the formation of β-Ti [4].

Several researches have been done in which different powders have been deposited on titanium alloy (grade 5, Ti6Al4V) substrate with varying laser process parameters to understand the laser−material interactions [5−8]; however, there is a paucity of published literatures on LMD and characterization of Cu composites on titanium alloy (grade 5) substrate. DAO et al [9] presented a computational analysis on the ultrafine crystalline pure Cu with nanoscale growth twins using the pulsed electrodeposition technique at room temperature and laid emphasis on the tensile yield strength from the crystal plasticity model through computational simulations. The deformation characteristics within the grain orientation and the misalignment between the adjacent grains and strain rate sensitivity were studied and characterized. Their results revealed that a decrease in the grain size and the twin spacing leads to an increase in the strength and the ductility of the samples produced [9]. SPASOEVIĆ et al [10] deposited copper on steel from a solution of Cu (II) complex and the coating quality was dependent on the potential difference between the Cu electrode and the steel electrode. A smooth and homogeneous Cu coating was made with good or poor adhesion which

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DOI: 10.1016/S1003-6326(15)63882-1

depended on the rate of cementation [10]. FLOEGEL-DELOR [11] also fabricated a Cu stabilizer on a coated conductor, which led to an improvement in the technical and practical performance of the samples during electroplating pulse laser deposition [11]. KHALID et al [12] investigated the microstructural effect of H13 steel powder on high strength Cu substrate via LMD process. They reported that the adhesion between Cu and the steel in the first layer of deposit was more pronounced in the melt pool. The particle size was reduced with an increase in thickness distribution as a result of the process parameters employed and the layer clad. KRISHNA et al [13] predicted the strength of Cu alloy with their derived formula in the study conducted in predicting the strength from the hardness of Cu. The measurement was made in various categories of working heat treatment conditions such as hot working and cold working. They concluded that the accuracy of the strength can be analyzed and estimated using correlations for alloys with low and medium strain-hardening potentials. DASGUPTA et al [14] reported the structural characteristics of titanium coatings produced on Cu substrates. Ti films were deposited on three different substrates which included Cu, glass and silicon substrates at 473 K for 3 h each and these were done in order to optimize the deposition parameters. The thicknesses of the coatings between the interface of the titanium film and the substrate and the intermixing of the elements at the interface were investigated and found to be free from voids.

The motivation for this study is to augmentatively improve and enhance the strain hardening coefficient of Cu, as well as the yield strength and the ultimate tensile strength through LMD process.

In this work, the influence of selected process parameters on the laser metal deposited Cu and Ti6Al4V alloy composites was studied. In the two sets of experiments conducted, the process parameters used included the laser power, scanning speed, powder flow rate and the gas flow rate. The hardness analysis and profiling, yield strength and ultimate tensile strength and the evolving microstructures were investigated.

2 Experimental

The experiment was conducted on the ytterbium laser system equipment (YLS−2000−TR) at the National Laser Centre of Council of Scientific Industrial Research (NLC-CSIR), Pretoria, South Africa. The maximum inbuilt power of the laser was 2 kW. The laser equipment was supported with Kuka robot. A three-way nozzle jet was attached to the Kuka robotic arm end. The laser beam radiation passed through the centre of the nozzle while the powder flowed through the three ways jet. Figure 1 shows a schematic view of the LMD process.

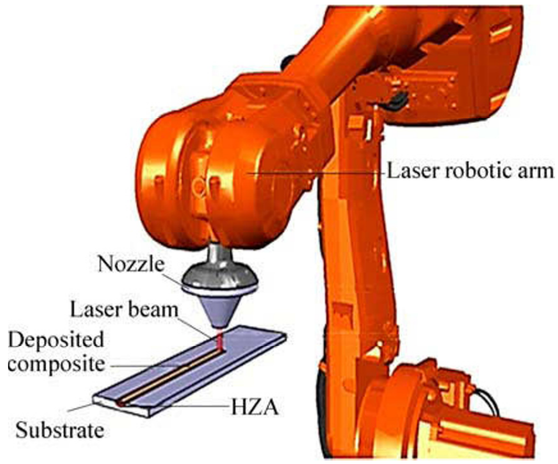

Fig. 1 Robotic laser showing schematic view of LMD process

From the schematic view shown in Fig. 1, a nozzle was connected to a laser robotic arm. Both the powder and the laser beam were ejected at the end of the nozzle and laser deposit on the substrate to form the solid deposited composite. The heat affected zone (HAZ) and the deposited composite were shown on the substrate as an indication of the deposition process.

2.1 Materials and methods

Pure Cu powder and Ti6Al4V substrate were used for the laser experiments. The Cu powder was supplied by Industrial Analytical (Pty) Limited, South Africa. The composition of the Cu powder is shown in Table 1.

Table 1 Composition and property of Cu powder

Mass fraction/%	Hydrogen loss/%	Apparent density/(g·cm^{-3})
99.83	0.31	5.1

The powder was fed via a hopper, a powder feeder capillary which was connected to the nozzle via a long hose. The particle sizes of the pure Cu powder were between 100 and 200 μm. The powder flowed through the round groove at the base of the hopper assisted by the argon carrier gas. Argon gas was supplied at 10 L/min to provide a shield for the deposited composite during the operation so as to prevent oxygen contamination.

A square plate with dimensions of 102 mm × 102 mm × 7.54 mm containing 99.6% Ti6Al4V alloy was used for the substrate. The substrate was sand blasted prior to deposition process in a cubicle to create rough surface for metallographic bonding between the composite and the substrate. Surface cleaning was achieved with acetone and dried off. As shown in Table 1, almost 100% of the Cu powder was present in the