Materials Science and Engineering A 490 (2008) 208–220

MATERIALS SCIENCE & ENGINEERING A

www.elsevier.com/locate/msea

Microstructure and mechanical performance of pulsed current gas tungsten arc surface engineered composite coatings on Mg alloy reinforced by SiCp

Shuyan Zhang [a], Fusong Jiang [a,*], Wenbin Ding [b]

[a] *Key Laboratory for Ultrafine Materials of Ministry of Education, School of Materials Science and Engineering, East China University of Science and Technology, 130 Meilong Road, Shanghai 200237, PR China*

[b] *China Offshore Oil Engineering Co. Ltd., 1078 Danjiang Road, Tianjin 300451, PR China*

Received 20 July 2007; received in revised form 4 January 2008; accepted 7 January 2008

Abstract

A new pulsed current GTA surface-modified process was used to fabricate composite layer on the surface of Mg alloy AZ31. Current pulsing enhances fluid flow, reduces temperature gradients and causes a continual change in the weld pool size and shape, so that it is responsible for refining the solidification structure in the composite layer. The observed grain refinement was shown to result in an appreciable increase in composite layer bend strength. Composite layers with lower scan speed have higher bend strengths and they also seem to have "good" metallurgical bond with the substrate thus showing better mechanical behavior than the other higher scan speeds used in this present study. The wear rate of the composite layer decreases linearly with increase in SiCp volume fraction and the wear resistance of composite layer varies inversely with square of the reinforcement size. Composite layers with higher *H*/*E* have smaller accumulative strain, smaller accumulative strain energy, and thus better wear resistance. The wear mechanism was oxidation at low-applied load levels and adhesion/delamination at high-applied load levels.

Keywords: Mechanical properties; Gas tungsten arc; Surface coatings; Magnesium alloy; Silicon carbide particles

1. Introduction

Magnesium alloys are gaining increasing importance as structural materials for applications where weight reduction is critical owing to their low densities (1.75–1.85 g/cm^3) and high stiffness-to-weight ratio, and these applications include automotive, industrial, materials handling, and aerospace equipment where there is an obvious need for lightweight materials [1,2]. However, magnesium alloys have not been used for high-performance applications due to their poor mechanical performance in engineering applications. Therefore, magnesium matrix composites are expected in high-performance applications due to their low density and enhanced mechanical performance [3–7]. But the actual applications of magnesium matrix composites have been limited because of their high production cost and complex process [8], and in some instances, it is unnecessary for the whole components being made by magnesium matrix composites. So it is important to produce the partial and selective reinforcement on the surface of magnesium alloy components, e.g. improving the mechanical properties of magnesium alloy by means of surface engineering which without causing significant adverse effects on the properties of the base metal. At present, wide variety of coating techniques (e.g. CVD, PVD, laser beam composite surfacing, electron beam surface modification, magnetron sputtering and plasma spraying) have been used to deposit metal or ceramic on different substrates [9–11]. However, each of the coating techniques are limited by several main factors, such as weak interfaces between coating and substrate, need for vacuum chamber, extremely slow deposition, inconvenient operating and costly manufacturing procedure.

Pulsed current gas tungsten arc (PC-GTA) surface engineering is suitable technique for improving the mechanical, tribological and chemical properties of metal surfaces. In the PC-GTA process, the arc interacts primarily with the substrate and the ceramic particles are simultaneously injected into the melt pool produced by the absorbed heat of arc. It is indicated that short processing time, flexibility in operation, economy

* Corresponding author at: Key Laboratory for Ultrafine Materials of Ministry of Education, School of Materials Science and Engineering, East China University of Science and Technology, P.O. Box 258, 130 Meilong Road, Shanghai 200237, PR China. Tel.: +86 21 64252022; fax: +86 21 64250624.

E-mail address: fsjiang@ecust.edu.cn (F. Jiang).

0921-5093/$ – see front matter
doi:10.1016/j.msea.2008.01.033

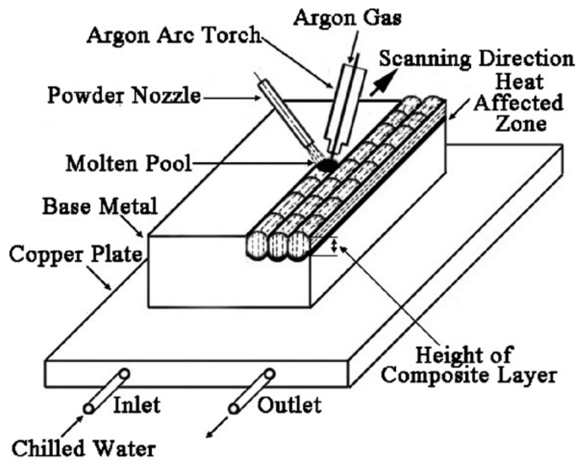

Fig. 1. Schematic illustration of the PC-GTA preparation process (reinforced with SiCp).

in time, low energy and material consumption and processing precision are the important advantages of PC-GTA surface engineering over the conventional processes. Metal matrix composite (MMC) surface layers with interesting properties and "very good" connection to the metal substrate may be prepared by a selection of suitable combination of metallic substrate and ceramic particles [12–14]. Performances of these surface-modified composite coatings depend on their ability to withstand load and stress variations acting upon them when they are put into service.

In the current study, the performance of ceramic (SiCp)-reinforced coatings on Mg alloy AZ31 was determined using the four-point bend test. Fracture strength will be calculated from the load-deflection measurements carried out during the bend test. The surface-modified composite layer was subjected to dry-sliding wear tests on a pin-on-disc test apparatus. This study also examines the effect of SiCp volume fraction and particle size on the dry-sliding wear behavior. Performance of these coatings, therefore, manufactured by PC-GTA techniques depend on the particle size, shape and distribution of the reinforcing material as well as the processing parameters such as scan current, scan speed, pulsed current frequency and powder feed rate. Hence, studies regarding the effect of these parameters on the mechanical properties and on the microstructure of the resulting surface-modified composite layer is also carried out in this present investigation. This study is aimed at optimizing the processing parameters to manufacture coatings with a desired performance.

2. Experimental procedures

A new pulsed current GTA surface-modified process was used to fabricate the various particle size and volume fraction composite layer. Fig. 1 is the PC-GTA surface-modified experimental set-up schematic diagram. In the present study, rectangular plates of magnesium alloy AZ31 (rolled condition; 200 mm long, 200 mm wide and 10 mm thick; chemical composition (wt.%,): Al, 2.9; Zn, 0.8; Mn, 0.1; Si, 0.05; Cu, 0.0005; Fe, 0.0025; balance Mg, were used as substrates in the PC-GTA processing experiments. The AZ31 plate surface was polished by abrasive paper to clear the oxide film, and using acetone to clean the organic substance on the surface. After drying, the specimens were assembled on a water-chilled copper rectangular plate. PC-GTA surface modification was carried out with an auto-pulsed square-wave alternating current inert gas tungsten arc-welding machine by melting of AZ31 substrate and simultaneous feeding of SiCp powders (the average particle size was from 20 μm, 40 μm to 60 μm, respectively; purity was >98.0 wt.% SiC and <2.0 wt.% silicon).

During the process, using Ar gas (purity was 99.999%, flow rate was maintained constantly at 10 L/min) to flow over the PC-GTA processing region in order to provide a relatively inert environment. Scanning speed was maintained at a certain value to control the substrate–GTA interaction time and the area coverage. To achieve microstructural and compositional homogeneity of the PC-GTA modified surface, a 20–30% overlap between the successive scanning beads was followed. Sufficient time was allowed for each scanning bead to reach room temperature before the subsequent PC-GTA operation was resumed to treat the adjacent scanning bead. The angle between the argon arc torch and the specimen was maintained at 60°. The electrode was 2% ThO_2 tungsten, its diameter was 2.0 mm and the nozzle diameter of the argon arc torch was 10 mm. The arc length was maintained at 2 mm and the arc voltage was at 26 V constantly. The processing parameters were PC-GTA scanning current (I), scanning speed (v), current pulsing frequencies (f) and SiCp powder feed rate. In this study, the applied scanning current was 100–200 A, the chosen scanning speed was 150–300 mm/min, current pulsing frequencies was applied 3–12 Hz and SiCp powder feed rate was maintained constant at 5, 10 and 15 mg/s, respectively.

Macrography of PC-GTA surface-modified composite layer given in Fig. 2 indicates that under the optimum processing parameters, there are no obvious welding defects such as porosities, arc craters, slag, etc, on the surface of PC-GTA surface-modified composite layer.

The characterization techniques such as SEM, hardness, bend test and sliding wear test were used to measure the properties of the PC-GTA surface-modified composite layer. The samples for metallographic studies were polished on 800–2000-grif emery paper and etched in nital (volume concentration 4%) for about 30 s to reveal the microstructure evolved during PC-GTA processing.

The specimens used in the four-point bend test consist of straight beams of rectangular cross-section (with dimensions of 60 mm long, 10 mm wide and the thickness ratio of composite layer/substrate was 1:1) cut from each block processed under different conditions. Since the thickness of the composite layer (h_c) under all the conditions is 0.9–1.5 mm, the selected dimensions of the specimen ensure that the final test sample consisted of both coating and substrate, so that it ensured enough volume of the composite layer in the material system to provide a clear signal for the load corresponding to initiation of the crack within the composite layer. The blocks were cut by means of wire-cutting in order to have better control on the dimensions. A universal material testing machine was used to perform the four-point bend test at a cross-head displacement rate of