Comments on process of duplex coatings on aluminum alloys

Samir H. A., QIAN Han-cheng(钱翰城), XIA Bo-cai(夏伯才), WU Shi-ming(吴仕明)
(School of Mechanical Engineering, Chongqing University, Chongqing 400044, China)

Abstract: Despite the great achievements made in improvement of wear resistance properties of aluminum alloys, their applications in heavy surface load-bearing are limited. Single coating is insufficient to produce the desired combination of surface properties. These problems can be solved through the duplex coatings. The aim of the present study is to overview the research advances on processes of duplex coatings on aluminum alloys combined with micro plasma oxidation process and with other modern processes such as physical vapour deposition and plasma assisted chemical vapour deposition and also to evaluate the performance of micro plasma oxidation coatings in improving the load-bearing, friction and wear resistance properties of aluminum alloys in comparison with other coatings. Wherein, a more detailed presentation of the processes and their performances and disadvantages are given as well.

Key words: aluminum alloy; duplex coating; micro plasma oxidation; physical vapour deposition; plasma assisted chemical vapour deposition; tribological property

CLC number: TG178 Document code: A

1 INTRODUCTION

Mass saving materials such as aluminum and its alloys have become increasingly important and have attracted increasing attention in the recent decades, specially in the automotive, aerospace, chemical industries, and electrical devices because of their high strength-to-mass ratio, high electrical and thermal conductivities, good abilities for recycling and processing and good resistance to degradation in some corrosive environments[1-3]. In the automotive industry, there is desire to apply aluminum alloys more widely and extensively in order to achieve better energy efficiency and economical profit, and more durable and recyclable goods, i.e., the aluminum alloys are used for many engine parts in toady's cars such as pistons for small automotive and internal combustion engines and parts working at high temperatures and stresses[3,4]. Unfortunately, the light metals mentioned above have poor wear resistance. Specially, the poor surface hardness of aluminum and its alloys and their relatively low yield strength compared to steel and other materials give these materials poor wear resistance in contact situations, and thus reduce life time and their applications in heavy surface load-bearing conditions[5-7]. The micro plasma oxidation (MPO) has recently been studied as a novel and effective technique to provide thick and ultra-hard ceramic coatings with excellent properties, such as load support, corrosion, electrical and thermal properties on light alloy materials, particularly on aluminum alloys[8]. It is unconventional plasma chemical-electrochemical method of forming ceramic coatings on aluminum alloys. In MPO, the aluminum material is immersed as an anode in an aqueous solution containing modifying elements, and voltage greater than high voltage of the original oxide film (400 - 600 V) is applied between the anode and the cathode. During oxidation, many visible sparks or microarc spots move rapidly on the metal surface[9,10]. The excellent properties of these coatings are of particular interest to the components of textile machine, aerospace and engineering equipments, biomedical devices and machine building[11]. This study introduces research advances on processes of duplex coatings on aluminum alloys combined with micro plasma oxidation process, and with other modern processes such as physical vapour deposition (PVD) and plasma assisted chemical vapour deposition (PACVD). Also this study evaluates the performance of micro plasma oxidation coatings in comparison to other coatings.

2 DUPLEX SURFACE ENGINEERING

Although great developments have been made in the surface-engineering technologies, the traditional coating technologies are expected to continue to dominate the market. One reason lies in the relatively high cost of the advanced processes. The other reason lies in the usual unsuitability of advanced surface engineering for cheap substrate such as mild steel and aluminum alloy[12-14]. There are materials and several conditions existing in industrial applications in which single treatment is insuf-
cient to produce the desired combination of surface properties, or their market penetration is limited despite their excellent performances in improving surface properties. These challenges can be overcome by duplex surface engineering. It is recently developed that surface modification method can improve the tribological performance and the load capacity of industrial parts and forming tools\[15\]. It has shown some beneficial effects on adhesion of coating to substrate and the performance of some cutting tools. The first attempt to apply the duplex surface treatment was carried out in 1980\[16\]. Duplex coating can be defined as the sequential applications of two or more established surface technologies to produce a surface composite with combined properties which cannot be achieved through any individual surface technology\[2a2\]. Two general groups are identified. In the first group, two individual processes complement each other and the combined effects result from both processes. In the second group, one process supplements and reinforces the other, acting as a pre- or post-treatment, and the resultant properties are related to one process. Some examples of duplex surface engineering are listed in Table 1.

Table 1 Examples of typical duplex surface engineering technologies\[12\]

<table>
<thead>
<tr>
<th>Group 1</th>
<th>Group 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>PVD coating of pre-nitrided steel</td>
<td>Energy beam melting of overlay coatings</td>
</tr>
<tr>
<td>Plasma nitriding of energy beam alloyed Ti</td>
<td>Nitriding of pre-laser-alloyed steels</td>
</tr>
<tr>
<td>PVD coating of Ni/Cu diffusion treated substrates</td>
<td>Nitriding of pre-laser hardened steels</td>
</tr>
<tr>
<td>Nitriding of pre-carburised steels</td>
<td>Sprayed MoS$_2$ on electroless Ni coatings</td>
</tr>
<tr>
<td>PVD coating of electroplated deposits</td>
<td>SIC intermediate layer for diamond-like carbon (DLC) coatings</td>
</tr>
</tbody>
</table>

3 TECHNIQUES OF DUPLEX COATINGS ON ALUMINUM ALLOYS

In accordance with the above classification, the main research advances on the processes of duplex coatings on aluminum alloys combined with micro plasma oxidation and vapour deposition (PVD and PECVD) processes were presented.

3.1 PVD coating on energy beam alloyed metallic coating

Energy beam melting and alloying treatments such as plasma nitriding, are shown to be suitable pre-treatment techniques\[17,18\]. In this duplex surface engineering, prior to PVD ion plating, LM13 aluminum piston alloys were locally melted over a small area of a few hundred square millimeters by two-stages alloying method using an oscillating beam of 3 kW power. During such procedures, various elements (Ni, Si) were alloyed into the surface. By PVD ion plating, thin layers of 5 μm thick of copper, nickel and chromium were deposited on the nickel-alloyed materials. Pin-on-disc wear tests and hardness test show the expected improvements in wear performance in nickel and silicon alloyed materials over the aged LM13 substrates due to the higher hardness (1400, 800 and 140 HV, respectively) achieved by refining the structure of the substrates during surface melting. Also, the higher peak surface hardness recorded throughout the range of applied loads in the duplex coating proves the load bearing ability of the subsequent PVD metallic layers. Wear test results show that the duplex coatings have a significant impact on improving the wear rate of Al-based materials as shown in Fig. 1\[17\]. However, these techniques require relatively high substrate temperature to provide adequate coating. Whereas, an oscillating beam was used to create a wider track, and the optimum results were achieved by two-stages alloying. Furthermore, melting to obtain good adherence between the alloying elements and the substrate was carried out prior to the second treatment, necessary to obtain good homogeneity to an appropriate depth with useful surface finish. Other issues are the relatively high costs and the process technology is required for the existing surface treatment processes.

![Fig. 1 Wear test results for Al alloy LM13 with PVD coated and duplex treated materials at load of 1 N\[17\]](image-url)

3.2 Plasma nitriding on PVD coating

This technique was modified by Musil et al as a "converse method" in duplex coating techniques\[18,19\]. It differs in the order of individual steps from the duplex coating combining with plasma nitriding of the substrate prior to the