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Microstructural evaluation and corrosion properties of aluminium matrix surface composite adding Al-based amorphous fabricated by friction stir processing

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ABSTRACT

A novel aluminium matrix surface composite adding $Al_{84.2}Ni_{10}La_{2.1}$ amorphous, which the layer depth was 5 mm, was fabricated by friction stir processing. The surface composite region shows obvious sandwich structure. The average hardness of the surface composite is about HV97, higher than the base metal is about HV80. The maximum tensile strength of the processed aluminium plate with the surface composite is 410 MPa. The surface composite was mainly composed of phases α-Al, Mg_2Al_3, $MnAl_6$ and La_3Al_{11}. The surface composite added the amorphous strip had the lower *i*corr, corrosion current density, and the higher passivation current than the surface composite not added amorphous strip. And there is obvious passivation zone for the surface composite. However, a large number of ultrafine grained which was composed of the α-Al and α-Al amorphous structures can be observed in the surface composite. And the grain size range of them is 90–400 nm. It is conceivable that the existence of these ultrafine grained structures and change of crystal plane would contribute greatly to improve the mechanical properties and corrosion resistance of the aluminium matrix surface composite.

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1. Introduction

Friction stir processing (FSP), FSP, which is based on the basic principles of friction stir welding (FSW) [1,2], has attracted a lot of attention as a new solid-state processing technique for microstructural modification and preparation of composites. During FSP, the material undergoes severe plastic deformation (SPD) and mixing, and thermal exposure takes place in the material resulting in significant microstructural change. The microstructure of aluminium alloys is improved owing to the intense plastic deformation by FSP [3,4]. Moreover, FSP has been also successfully used to obtain the metal matrix composites (MMCs) and the surface composite [5–7]. A main method to improve the performance of the surface composite is to obtain the ultrafine grained structure (UFG). Interestingly, FSP is an effective technique to refine grain for most aluminium alloys [8]. Ma and Mishra [9] reported Al–4Mg–1Zr aluminium alloy achieved the ultrafine grained (UFG) microstructures with minimal grains sized 0.7 μm by FSP. A maximum superplastic elongation of 240% was obtained. Recently, the studies of Liu and Ma [10] suggested that 7075 aluminium alloy also obtained an obvious UFG microstructure by FSP with water cooling. Previously, Su et al. [11] produced an UFG 7075 aluminium alloy of 100–200 nm by FSP with an active cooling using a mixture of water. The minimal grain size was 0.8 μm. And a low-temperature superplasticity of 350–540% was achieved at 200–350 °C. In short, these above studies suggest that FSP can cause UFG structure produced in aluminium alloys, similar to equal channel angular pressing (ECAP) [12], accumulative roll bonding (ARB) [13] and high-pressure torsion (HPT) [14]. In addition, some reports about surface nanocomposites fabricated by adding some particles such as nano Al_2O_3, nano SiO_2 and nano ZrO_2, can also decrease the grain size of base metal [15,16]. However, the above methods are still limited to refine grain. In this paper, a novel aluminium matrix surface composite adding Al-based amorphous was produced by FSP, at an air cooling. And a low rotational speed of tool is used.

In experiment, the amorphous alloy, $Al_{84.2}Ni_{10}La_{2.1}$ [17], is chosen as an auxiliary material because it has received increased attention as high strength, lightweight material, lower crystallization temperature and super-elasticity under a high temperature. In this study, the microstructure characterizations, mechanical and corrosion properties of the aluminium matrix surface composite are conducted and analyzed. And the fine microstructure and phase constituents of the surface composite can be performed by X-ray diffraction (XRD) and transmission electron microscope (TEM). This study may contribute to have a clear understanding

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for the influence of surface composite layer on the whole aluminium matrix composite.

2. Experimental

The test materials are 5A06 aluminium alloys and $Al_{84.2}Ni_{10}La_{2.1}$ amorphous with a crystalline characteristic. The 5A06 aluminium alloys in this test is mainly used as the auxiliary structure in the aircraft. The thin Al–Ni–La amorphous strip is used as an auxiliary material. The dimension of test plate is 120 mm × 60 mm. The thickness of the test plate is 15 mm. The thickness of the Al–Ni–La amorphous strip is 65 μm. Chemical composition and mechanical properties of 5A06 aluminium alloys are listed in Table 1. The XRD results of the Al–Ni–La amorphous strip are shown in Fig. 1a. The Schematic of friction stir processing is described in Fig. 1b.

The oxide film at friction stir processed region of base metal was removed by the H_2SO_4 solution corrosion and mechanical polish before FSP. According to our previous researches [18], a groove, which is 0.5 mm width and 1.0 mm depth, was prepared at the edge of the pin in the advancing side (AS). Then, the amorphous strip with 0.5–0.8 mm width was embedded in the test plate before processing. At last, these workpieces were fixed at an operation table. At this time, a stir tool with the columnar shape shoulder (18 mm) and the screwed pin (4 mm) penetrated into the test plate until the head face of the shoulder reaches 0.5 mm under upper surface. The rotational speed of the stir tool is 500–1000 r/min, and the travel speed is 40–150 mm/min along the centre line. In addition, a tool tilt forward angle of 2.5° is used. In this study, quick water cooling that could effectively restrain the grain growth was not used. Instead, an air cooling technique is applied. After processing, a surface composite with 6 mm depth can be obtained.

Table 1
Chemical composition and mechanical properties of 5A06 aluminium alloy.

Materials	Chemical composition (wt.%)						
	Cu	Mg	Mn	Si	Cr	Ti	Other
5A06 Al	0.10	5.8–6.8	0.5–0.8	–	–	0.02–0.10	Al

Materials	Mechanical properties			
	Density/ g cm^{-3}	Tensile strength/ MPa	Elongation/ %	Hardness/ HV
5A06 Al	2.64	340	20	70~80

A series of specimens were cut from the surface composite along a longitudinal direction by lining cutting machine. These specimens were made into metallographic samples. In this study, some samples with different parameters were used. The rotational speed is 500 r/min, 750 r/min, 900 r/min and 1000 r/min, separately. And the travel speed is 40 mm/min and 70 mm/min. Then, these samples were etched using a mixed solution 1.0%HF + 1.5%HCl + 2.5%HNO_3 + 95%H_2O. The microstructure of the surface composite was observed and analyzed by means of scanning electron microscope (SEM). The tensile strength was measured using a CSS-1100 tensile test machine. In this experiment, three samples were tested for each kind parameter and base metal (the average value is used). So the result is an average value. Vickers hardness tests were conducted on the cross-sectional plane using Vickers indenter with a 25 g loading and a load time of 5 s. The chemical composition of the surface composite was measured by electron probe micro-analysis (EPMA). And phase constituents of the surface composite were analyzed by XRD. In this experiment, the X-ray diffraction instrument of Rigaku-2500 type was used. Fine microstructure characterizations of the surface composite were performed by TEM. Some thin slice samples were cut out from the surface composite and abraded into samples of thickness 50 μm, and then prepared as thin film sample by an electrolyzing corrosion. The test conditions are 150 kV voltage and 200 mA current.

The corrosion behaviors of the as-received, surface composite added the amorphous strip and no amorphous strip samples were evaluated using a dynamic potential scanning technique. The test equipment is the advanced electrochemical system of PARSTAT 2273 type. The samples were mounted in epoxy to expose only one surface for the electrochemical tests. The polarization behavior was studied in a 3.5% NaCl solution at a potential scanning speed of 3 mV/s. A saturated calomel camel electrode (SCE) was used as the reference electrode and a platinum wire was used as the counter electrode. All electrochemical tests were carried out at room temperature.

3. Results and discussions

The typical microstructure of the surface composite is shown in Fig. 2a. An obvious "sandwich structure" can be observed. The sandwich structure includes the narrow bright structure and the grey structure (see Fig. 2b). The grey structure is similar to the base metal away from this region. However, it is obvious that the bright structure is different from the base metal. It is probably a new structure. Therefore, the composition analysis of the narrow bright structure is necessary to further validate the structure transition happened during FSP. And the analysis of EPMA was used in this

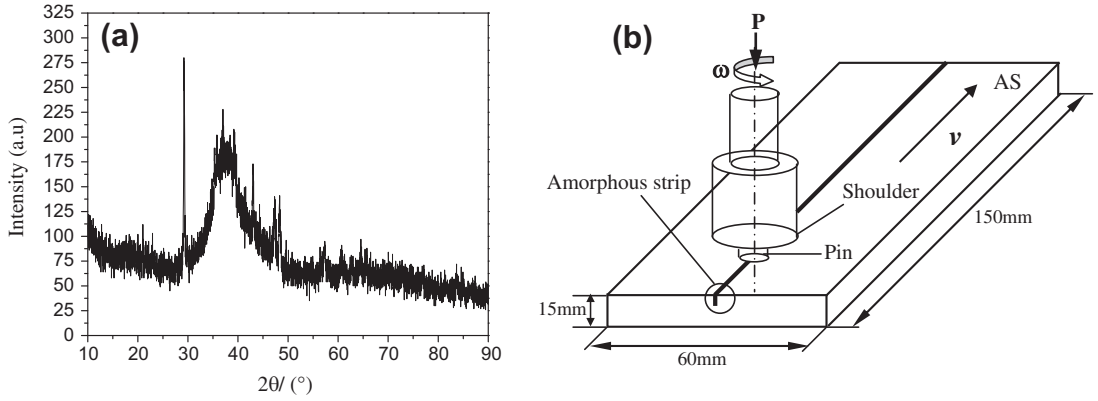

Fig. 1. XRD results of amorphous strip (a), and schematic of FSP (b).

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