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Comparative study of wear performance of ceramic/iron composite coatings under two different wear modes

Wenqin Wang [a], De Wang [b], Tomiko Yamaguchi [c], Kazumasa Nishio [d], Ming Yan [e], Yulong Li [a,f,*]

[a] School of Mechanical and Electrical Engineering, Nanchang university, Nanchang 330031, China
[b] Institute of Applied Physics, Jiangxi Academy of Sciences, Nanchang 330029, China
[c] Faculty of Engineering, Kyushu Institute of Technology, Tobata, Fukuoka 804-0015, Japan
[d] Nishinippon Institute of Technology, Kokura, Fukuoka 803-0812, Japan
[e] The Department of Materials Science and Engineering, South University of Science and Technology of China, Shenzhen 518055, China
[f] Key Laboratory for Robot & Welding Automation of Jiangxi Province, Nanchang University, Nanchang 330031, China

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ABSTRACT

WC-SHA coatings (SHA: high carbon iron alloy) with varying WC contents were successfully fabricated on Al-Mg-Si alloy substrates by resistance seam welding. The microstructures and phase compositions were investigated. Wear performance of the coatings was evaluated by both rubber wheel test and ball-on-disc test. The results showed that dense and thick WC-SHA coatings, consisting of WC reinforcement, SHA binder, A6061 and $FeAl_3$, were fabricated on A6061 alloy using different powders. With increasing the contents of WC particles, the surface wear resistance and hardness increases. Moreover, the WC particles behaved significantly different during different wear tests, resulting in different wear mechanisms of the coating. In rubber wheel test, the WC particles relieved the abrasive wear on A6061 and SHA components from abrasive particles. While in ball-on-disc test, the WC particles supported the pressure from counterpart and protected other components until the WC particles were peeled off, leading to three body abrasive wear.

1. Introduction

The growing demand for energy-saving and low exhaust gas emission in transportation applications is prompting extensive application of lightweight structural materials [1]. Aluminum alloys, having low density, high specific strength, and good corrosion resistance, attracted extremely attentions in automotive and aerospace [2]. However, the poor wear resistance of these materials significantly limits their further application [3].

Wear resistant coating has been widely used in tribological applications to protect aluminum alloy from wear [4]. Some surface modification technologies, such as physical vapor deposition (PVD) [5] and chemical vapor deposition (CVD) [6,7] were proved to be suitable for coating on thin aluminum plate. However, it is very difficult and costly to obtain thick coatings through PVD and CVD to provide a long-term wear resistance under high loads. Hence, surface cladding methods such as thermal spraying [8–12] and laser surface alloying [13–15], which are capable of coating a thick layer in short operating time, have attracted increasing attentions. Many wear resistant coating such as WC-n%Co [16–18], WC [19,20], Al_2O_3 [21,22] and SiC [23], were well performed on the aluminum alloy. However, owing to the high density heat input, a wide heat affected zone and resultant mechanical properties degradation could happen on the substrates. It is therefore still challenging to produce a high quality wear resistant coating on the thin aluminum alloy.

Resistance seam welding (RSEW) is a high productivity joining method for thin metal sheets. The electrodes apply pressure and electric current as they rotate along the overlapped area [24]. In RSEW, the joule heating is the sole heat source, and a low heat generates on aluminum alloy substrate due to its low electrical resistivity and high thermal conductivity. So it could be expected that a thick cladding layer can be effectively fabricated on thin aluminum alloy by RSEW. To date, very few works have been performed in this field [25,26].

A large number of works on wear performance have been done on different wear resistant coatings, which was found to be closely related to the wear test modes [27,28]. Since the coating could suffer several kinds of wear form simultaneously or sequentially, different wear test modes, such as ball-on-disc sliding test (BDST) and rubber wheel abrasive test (RWAT), were commonly used to characterize the wear performance. RWAT is the most commonly employed for three-body abrasion wear, in which the abrasion particles move across the surface and free to rotate. BDST has been frequently used to determine the tribological behavior of a mating system and to aid in understanding the mechanisms of wear and friction in a practical sliding system [29–31]. However, very limited work has been carried out on RSEWed coatings, the authors' previous works have evaluated the wear resistance of the iron-based

* Corresponding author at: School of Mechanical and Electrical Engineering, Nanchang University, Nanchang 330031, China.
E-mail address: liyulong@ncu.edu.cn (Y. Li).

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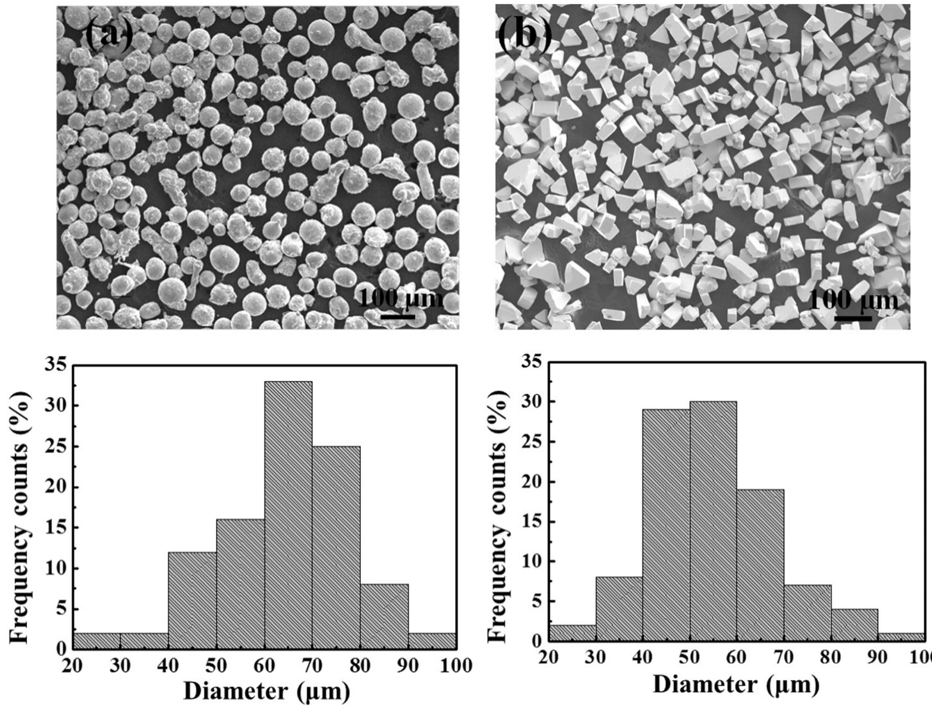

Fig. 1. SEM images and size distributions of the SHA and WC powders. (a) SHA; (b) WC.

Table 1
Chemical composition of SHA powders (wt.%).

Elements	Fe	Cr	C	Mo	Ni	Si
SHA	Bal.	9.84	4.99	4.92	4.83	0.99

coating using BDST, while the cermet/iron coating using RWAT [25,26]. However, the influence of different wear test modes on each coating has not been uncovered. It is therefore that a comparative study on the coating wear performance is very necessary in different wear test modes.

In this study, ceramic-iron composite coatings with different WC cermet contents were fabricated on the A6061 aluminum alloy sheets using RSEW. And then, the wear performance of ceramic/iron coatings was conducted using both BDST and RWAT methods. The evolution of wear behaviors and wear mechanisms were studied, as well as the influence of the WC ceramic content on the wear performance.

2. Material and methods

2.1. Material

The Al-Si-Mg alloy (A6061-T6) plate of 2 × 30 × 150 mm was selected as the substrate. The high carbon iron (SHA) powders with WC ceramic volume contents of 0%, 30%, 50% and 70%, were used as the coating materials. Fig. 1 shows the SEM images and size distributions of SHA and WC powders. The average particle diameter of SHA and WC are 60 μm and 55 μm, respectively. The chemical composition of SHA powders is shown in Table 1.

2.2. Resistance seam welding process

Before welding, the mixed WC-SHA powders were pre-placed on the surface of A6061 alloy substrate with dimensions of 0.8 × 5 × 50 mm using organic binder and dried for 4 h at room temperature as shown in Fig. 2(a). Fig. 2(b) shows the process of resistance seam welding. The electrodes had dimensions of 65 mm in diameter and 5 mm in width. An SUS304 foil with the thickness of 100 μm was placed on the powder layer to protect the electrodes. The welding conditions are listed in Table 2.

2.3. Experimental methods

The microstructure and the worn surfaces of the coatings were characterized using two stereoscopic scanning electron microscope (SEM, EMR-8800, Elionix, Japan) combined with energy dispersive X-ray analysis (EDX) operating at a vacuum mode of 3.0– 5.0 × 10^{-4} Pa and an accelerating voltage of 15 kV. Moreover, the 3D surface topographies of

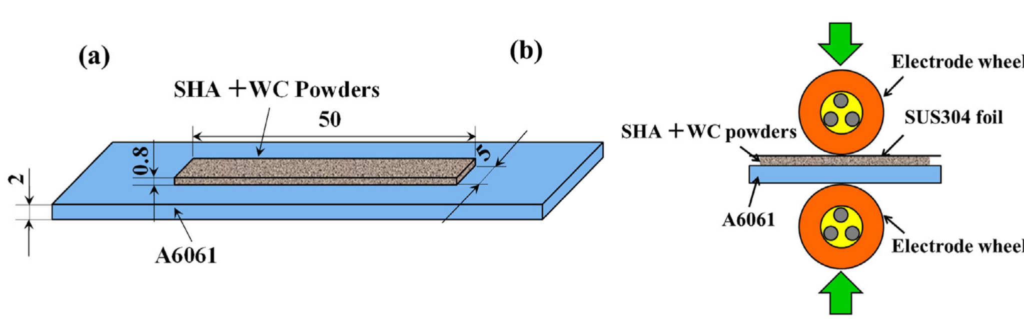

Fig. 2. Schematic diagram of (a) sample; (b) resistance seam welding method.