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Determination of hardness of plasma-sprayed FeCrBSi coating on steel substrate by nanoindentation

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ABSTRACT

In this paper, we develop a method for determining the hardness of FeCrBSi coating on a 1045 steel substrate. The nano-indents of the FeCrBSi coating exhibit obvious pile-up. The proposed method models the projected contact area as an equilateral triangle bounded by arcs to correct for the effect of pile-up on the contact area. The new method is described in detail and leads to improvement in obtaining coating hardness compared with the widely adopted Oliver–Pharr method.

1. Introduction

Nanoindentation testing, as a convenient method, has widely been used to characterize the hardness of materials [1–7]. The Oliver–Pharr method for determining the hardness using a calibrated indenter tip area function is widely adopted [8,9]. Its attractiveness stems largely from the fact that mechanical properties can be obtained directly from indentation load-displacement measurements without the need to image the hardness impression. The basic assumption of the method is that the contact periphery sinks in, which limits the applicability of the method because it does not account for the pile-up of material.

Bolshakov et al. have examined the influence of pile-up on the contact area by using the finite element method [10,11]. When the pile-up is small, the contact areas given by the Oliver–Pharr method match very well with the true contact areas obtained from the finite element analyses. When pile-up is significant, the Oliver–Pharr method underestimates the contact area by as much as 50%. Therefore, it is important to develop a new method to extract the contact area accurately.

In the present paper, nanoindentation experiments were used to determine the hardness of FeCrBSi coating with significant pile-up. A new corrected method was proposed to calculate the real contact area, which leads to improvement in obtaining coating hardness compared with the Oliver–Pharr method.

2. Experimental

2.1. Deposition

The 1045 steel sample of 25 mm × 15 mm × 8 mm was coated with FeCrBSi alloy powder with an average diameter of approximately 40 μm, as shown in Fig. 1. The chemical composition of the FeCrBSi alloy powder is shown in Table 1. The 1045 steel was grit blasted using Al_2O_3 particles prior to air plasma spraying (APS). In order to improve the bonding strength between coating and substrate, Ni/Al alloy powder was coated as undercoat before the FeCrBSi coating was sprayed. The parameters used in the plasma spraying process are listed in Table 2. A 300 μm thick FeCrBSi coating was prepared.

2.2. Characterization

The phase constituents of the FeCrBSi coating were identified by X-ray diffraction (XRD). The melting characteristic of the coating was observed by scanning electron microscopy (SEM). The microstructures were also examined from cross-section morphology of the coating by SEM.

2.3. Nanoindentation tests

Prior to indentation, the FeCrBSi coating was mechanically ground and polished with 1.5 μm diamond polishing paste. Sharp indentation experiments were performed using a TriboIndenter® (Hysitron Corporation, USA) equipped with a diamond Berkovich

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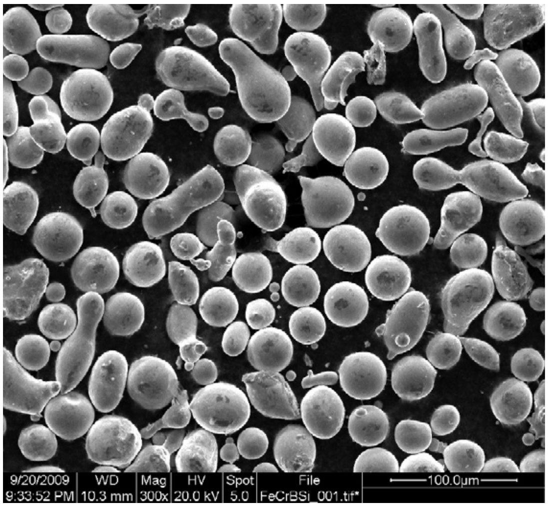

Fig. 1. Morphology of FeCrBSi alloy powder.

Table 1
Chemical composition of the FeCrBSi alloy powder.

Elements	Cr	B	Si	C	Fe
wt.%	13.6	1.6	1.1	0.16	Bal.

indenter which was also used as an AFM tip and the indented surface was imaged after indentation. All images were collected with a resolution of 256 × 256 pixels, and taken in a 5 µm × 5 µm scan area with a scan rate of 0.5 Hz. The following loading sequence was applied: (1) loading to maximum load; (2) hold for 5 s at maximum load; (3) complete unloading. The maximum load of 3 mN, 4.5 mN, 6 mN and 9 mN were applied, respectively and a 3 × 3 array indents were performed at each maximum load. The hardness of the FeCrBSi coating at each maximum load was averaged over the nine measurements.

3. Results and discussion

3.1. Characterization

Fig. 2 shows the surface morphology of the FeCrBSi coating. It can be seen that the coating was well-molten. The cross-section morphology of the coating is shown in Fig. 3. The coating with some micro-pores shows obvious lamellar and dense microstructure. Fig. 4 shows the XRD pattern of the FeCrBSi coating. It is found that the diffraction peaks of the coating are mainly α-Fe. The coating shows high crystallinity.

3.2. Hardness

The widely known Oliver and Pharr hardness denoted H_{op}, which uses a calibrated indenter tip area function, is accurate only for indentations that do not exhibit significant pile-up or sink-in. The Oliver and Pharr method will overestimate or underestimate the hardness when pile-up or sink-in occurs.

Fig. 5 shows a typical AFM image and of cross-section profile nanoindent for the FeCrBSi coating at a fixed load of 9 mN. The light

Table 2
Plasma spray parameters.

Parameters	Ni/Al	FeCrBSi
Primary gas, Ar (m^3/h)	3.6	3.6
Secondary gas, H_2 (m^3/h)	0.22	0.25
Powder feed rate (g/min)	35	40
Spraying current (A)	340	380
Spraying voltage (V)	140	135
Spraying distance (mm)	140	120

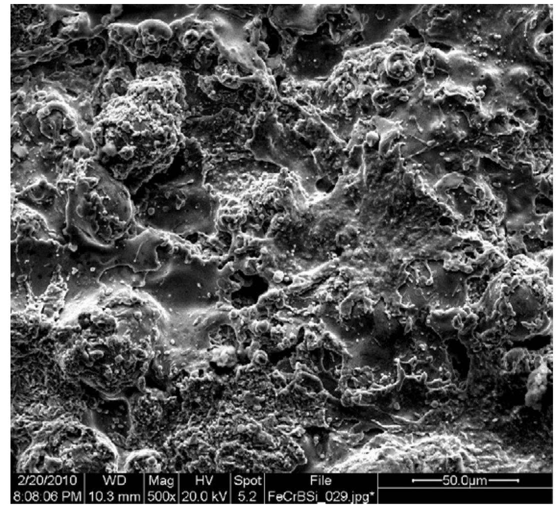

Fig. 2. The surface morphology of the FeCrBSi coating.

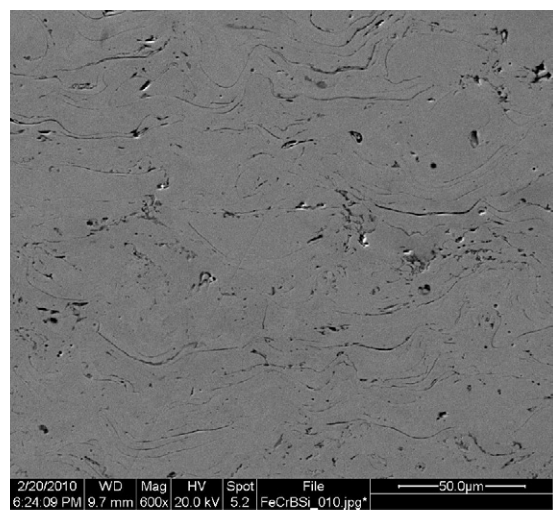

Fig. 3. The cross-section morphology of the FeCrBSi coating.

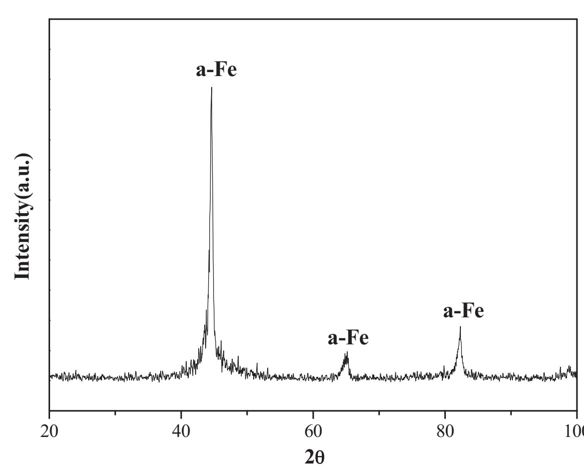

Fig. 4. The XRD pattern of the FeCrBSi coating.