



# A novel approach of in-situ synthesis of WC particulate-reinforced Fe-30Ni ceramic metal coating

Youlu Yuan <sup>a,\*</sup>, Zhuguo Li <sup>b,\*</sup>

<sup>a</sup> Hubei Key Laboratory of Hydroelectric Machinery Design & Maintenance, College of Mechanical and Power Engineering, China Three Gorges University, Yichang 443002, PR China

<sup>b</sup> Shanghai key Laboratory of Materials Laser Processing and Modification, School of Materials Science and Engineering, Shanghai Jiaotong University, Shanghai 200240, PR China

## ARTICLE INFO

### Article history:

Received 25 June 2017

Revised 20 August 2017

Accepted in revised form 21 August 2017

Available online 31 August 2017

### Keywords:

In-situ synthesis

Tungsten carbide

Ceramic metal coating

Plasma transferred arc metallurgical reaction

Hardness and toughness

Wear resistance

## ABSTRACT

In-situ synthesis of WC/Fe-30Ni ceramic metal coating (CMC) by plasma transferred arc metallurgical reaction (PTAMR) with raw materials W, C and Fe-30 wt% Ni were investigated. The in-situ metallurgical reaction was investigated by thermodynamic calculation and X-ray diffractometry (XRD). The in-situ WC grain size, grain growth characteristic and microstructures were analyzed by scanning electron microscopy (SEM) equipped with energy-dispersive spectroscopy (EDS). The mechanical properties such as hardness, toughness and wear resistance were tested. Results show that the morphology of in-situ WC grain is triangular prism which is a multi-layered crystal structure with high hardness, good toughness and high wear resistance. The excellent mechanical behaviors of in-situ WC are decided by its growth mechanism. Increasing the contents of in-situ WC will directly increase the wear resistance of WC/Fe-30Ni coating.

© 2017 Elsevier B.V. All rights reserved.

## 1. Introduction

Wolfram Carbide (WC) is well known for its attractive physical properties, such as high hardness, well abrasion resistance, good toughness and a certain amount of plasticity [1,2]. Thus WC-based hard alloys are widely used in cutting tools, mining tools, rock drill tips and moulds [3]. Usually, the hard alloys are fabricated by powder metallurgy methods. For example, the hot-pressed sintering [4], spark plasma sintering [5], vacuum sintering [6], and high-frequency induction-heating sintering [7]. Because the sintering processes are high temperature solid phase reaction, heating at high temperature is too long, causing the energy consumption high and the productions expensive [8].

In addition, prior to the sintering process, WC and binder metals, such as cobalt (Co) [9], nickel (Ni) [10], and iron (Fe) [11] were prepared separately, thus sintering are also called ex-situ method. For this method, several typical disadvantages are still unsettled. For example, the wettability of WC becomes worse due to the surface pollution, the interface reaction between WC and metal matrix prone to damaging [12]; WC particles tend to dissolve in the liquid metal [13]; ex-situ WC particles are easily sunk to the coating bottom [14]; cracks were easily formed due to the big difference of thermal expansion coefficient between WC and metal matrix [15]. Moreover, binding force between WC and metal matrix easily decrease with the WC content, thus under

rolling wear conditions, ex-situ WC particles easily peel off the matrix [16].

To overcome these inherent disadvantages, recently, in-situ WC as a new method has been developed, where WC particles are synthesized in liquid metallic matrix by chemical reaction [17–19]. Compared with the ex-situ method, the in-situ method has proved many significant advantages: the interface between WC and metal is generally cleaner and more compatible; the in-situ WC are thermodynamically stable and less degradation in high-temperature applications; the interfacial bonding force between WC and metal is strong [1].

Compared with present in-situ methods, such as centrifugal casting [18], selective laser melting [1], and laser cladding [17,20], the plasma transferred arc (PTA) offers a unique heat source along with enormous potentials, such as low cost, high heat input and high efficiency, thus it has been widely used in coatings fabrication [13,21] and films synthesis [22,23]. However, few researches have been reported about the fabrication of in-situ WC CMC using PTA. Partly because here are two main specific problems remain unsettled. Firstly, C powders are too light to be blown steadily in the powder feeding pipe, thus how to provide enough C for the in-situ reaction is a key problem. Secondly, W is a weak carbide-forming element, hence how to prolong the liquid-phase reaction between W and C to get enough time for the in-situ metallurgical kinetics reaction is another important issue. In this study, the afore-problems were settled and a novel approach of in-situ synthesis WC particulate-reinforced Fe-30Ni ceramic metal coating was reported. Furthermore, the microstructures and mechanical properties of the in-situ WC particles were tested.

\* Corresponding authors.

E-mail addresses: [yyulu@ctgu.edu.cn](mailto:yyulu@ctgu.edu.cn) (Y. Yuan), [lizg@sjtu.edu.cn](mailto:lizg@sjtu.edu.cn) (Z. Li).

**Table 1**

Weight percent of raw materials of in-situ WC/Fe-30Ni ceramic-metal composite (CMC) coatings.

| WC/Fe-30Ni CMC coatings | Composition (wt%) |            |            |
|-------------------------|-------------------|------------|------------|
|                         | Fe-30Ni           | W particle | C particle |
| WC-1                    | 67.90             | 30.00      | 2.10       |
| WC-2                    | 51.85             | 45.00      | 3.15       |
| WC-3                    | 35.80             | 60.00      | 4.20       |

**Table 2**

Chemical composition of reacted powders (mass, wt%).

| Powders | C      | Cr   | Ni    | W     | S    | P    | Fe   |
|---------|--------|------|-------|-------|------|------|------|
| Fe-30Ni | 0.02   | 0.05 | 30.00 | –     | 0.03 | 0.06 | Bal. |
| W       | –      | –    | –     | ≥99.8 | –    | –    | –    |
| C       | ≥99.85 | –    | –     | –     | –    | –    | –    |

## 2. Experimental procedure

### 2.1. Specimen preparation

Raw materials for PTAMR are W, C (graphite) and Fe-30Ni alloy powders with three mass ratios were listed in Table 1. In addition, the chemical compositions of W, C and Fe-30Ni are given in Table 2. Based on the equation  $W + C = WC$ , where W to C atomic ratio is 1:1, so the mass ratio is 15.3:1. The morphology and size of Fe-30Ni and W were shown in Fig. 1. It can be seen that the powders size and shape are irregular and unequal, hence will be unstable as sending in the powder feeding pipe. Further, powder C is too light to be blown steadily in the powder feeding pipe. As shown in Fig. 2a [24], the above problems were solved by precoat technology, that is before coating fabrication, all weighed powders were firstly mixed and then precoat onto the substrate, an AISI A36 low carbon steel plate, the size is  $150 \times 50 \times 10 \text{ mm}^3$ .

And then, as shown in Fig. 2b, the precoat powders were heated by PTA-200 (Wuhan Research Institute of Materials Protection, China) with parameters such as the PTA current 75A, voltage 40 V, travel speed  $300 \text{ mm} \cdot \text{min}^{-1}$ , plasma gas (Ar)  $3 \text{ L} \cdot \text{min}^{-1}$  and shielding gas (Ar)  $6 \text{ L} \cdot \text{min}^{-1}$ . More importantly, as shown in Fig. 2c, in order to prolong the metallurgical reaction between W and C to make the in-situ WC grain grow fully in the molten pool, insulation materials such as  $\text{Al}_2\text{SiO}_5$  ceramic fiber and  $\text{Al}_2\text{O}_3$  ceramic plate were used to keep heat from escaping through the coating top and side direction, so that the heat can only conduct from the bottom substrate.

### 2.2. Characterization

After coating fabrication, samples were sectioned by wire-cutting and polished by SiC papers from P240 to P1200 grades, finally using diamond abrasive of  $2 \mu\text{m}$ . Phase identification was performed by X-ray diffractometer (XRD, DX-2700) with the Cu-K $\alpha$  radiation at 35 kV and 25 mA scanning from  $20^\circ$  to  $90^\circ$  with a step size of  $0.02^\circ \cdot \text{s}^{-1}$ . Microstructures were observed by scanning electron microscope (SEM, JEOL JSM 6510A). The grain size and content of in-situ WC were analyzed by the ImageJ software using watershed algorithm [25]. To view the three-dimensional (3D) microstructures of in-situ WC grains, the matrix were etched deeply with HCl etchant for about 48 h. Micro-hardness was tested by Vickers hardness tester (MH-5) under load 4.9 N for 15 s. Fracture toughness was calculated by the following equation [26,27]:

$$K_C = \delta \left( \frac{E}{H} \right)^{2/5} \cdot \frac{P}{bl^{1/2}} \quad (1)$$

where,

$\delta$  is the shape constant of 0.0089 for standard Vickers indenter.

$E$  is the elastic modulus of the WC (GPa).

$H$  is the micro-hardness of the WC (GPa).

$P$  is the normal load (N).

$b$  is the half-diagonal of indentation impression (m).

$l$  is the crack length (m).

The dry sliding wear test was carried out by using a block-on-wheel tester (M2000) with normal load 300 N, sliding speed 0.836 m/s and sliding distance 500 m. Before wear tests, all coating samples were cut in block with dimensions of  $15 \times 7 \times 5 \text{ mm}^3$  then polished by using the diamond polishing paste of  $1.5 \mu\text{m}$ . The rotating counter wheel, a cylinder of 10 mm high and 40 mm diameter, is AISI W1–1.0C hard alloy with hardness of  $\text{HRC } 61 \pm 3$  and roughness of  $R_a = 0.15 \pm 0.03 \mu\text{m}$ . The wear rate was calculated with formula [21]:

$$K_s = \frac{\Delta M}{\rho L F_n} \quad (\text{mm}^3/\text{Nm}) \quad (2)$$

where,

$\Delta M$  is the mass loss.

$\rho$  is the coating's density ( $\text{g}/\text{cm}^3$ ).

$F_n$  is the normal load (N).

$L$  is the sliding distance (m).

The mass loss before and after each test were measured by using AG204 digital balance with accuracy 0.1 mg for three times to calculate the  $\Delta M$ . Worn surfaces were observed by SEM.

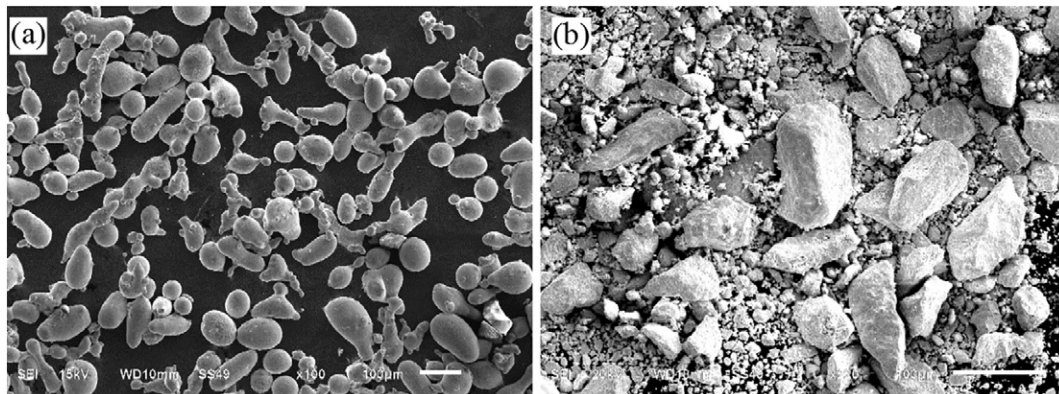


Fig. 1. SEM images of powder Fe-30Ni (a) and W (b).

Download English Version:

<https://daneshyari.com/en/article/5464468>

Download Persian Version:

<https://daneshyari.com/article/5464468>

[Daneshyari.com](https://daneshyari.com)