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Review

Characterization of high-temperature mechanical properties of plasma-cladded coatings with thermo-mechanical coupling

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ABSTRACT

High temperature mechanical properties was detected here to study the failure and strengthening mechanism of the coating-substrate (cobalt-based coatings were fabricated on FV520B substrate) integral structure with thermo-mechanical coupling effects. Microstructure, phase composition, element distribution of the coatings was characterized by optical microscopy (OM), scanning electron microscopy (SEM), transmission electron microscope (TEM), electron back scattering diffraction (EBSD), X-ray diffraction (XRD), electron probe microanalysis (EPMA) and energy dispersive X-ray analysis (EDS). Results elucidate that fracture occurs in the coating for Co50 coating-substrate structure from 300 °C to 700 °C, but failure position transfer to substrate from coating at elevated temperatures with the addition of niobium and cerium oxide. Throughout, there is no crack originated from the interface. Fracture mechanism: the dislocation pile-up causes great stress concentration in the grain boundary, which results in the nucleation of the crack, and then the crack extends along the hard brittle Fe-Cr phase until the material fails. HRTEM shows the high density dislocation and the severe lattice distortion was formed during tensile deformation. On the macro level, the fracture tends to occur in the coarse dendrites region.

1. Introduction

As an important technical means of surface engineering field, plasma cladding technology has the characteristics of high energy density, simple process and high production efficiency, which might better meet the needs of practical application [1–4]. Plasma cladding can prepare thicker and stronger coatings than the technology such as spraying and chemical treatment [5,6], and the lower cost and higher efficiency are the reasons why it defeats the laser cladding in industrial application [7]. Therefore, plasma cladding technique becomes one attractive research field that is used to produce several kinds of metal matrix coatings [8–11]. Nowadays, it is mainly used in the field of engineering machinery and mining machinery, most plasma cladding layers work under the complex and rigorous condition for a long time, such as heat and force, which even lead equipment into waster.

The whole structure of the coating-substrate is formed after the plasma cladding modification. Once the failure of any part of the overall structure occurs, it will affect the use of the entire component and the engineering application is impossible. So whether it is electronic circuit coating, decorative coating, protective coating, or industrial wear-resistant coating, enough strong bonding force is one of the important factors to ensure durability and the basic conditions that the coating plays its role [12–15]. Therefore, it has practical significance to evaluate the quality of coating-substrate overall structure. In the field of surface engineering, at present, the main research directions include phenomena and mechanisms of the corrosion, wear and oxidation of the coating in the environment [16–19]. In contrast, scholars rarely study work on the failure modes and mechanisms of remanufacturing coating system (coating-interface-substrate) under mechanical action, which mainly caused by the small size of coating and interface. In order to meet more requirements, the plasma modified coating is developing towards a wider field, not just the surface corrosion, abrasion resistance and antioxidant, etc. So, the research on different service forms of coatings needs to be comprehensive and thorough.

The paper takes large compressor rotor shaft and blade as the object to fabricate superior coating. Cobalt base coating is usually used to repair the shafts and blades due to its good corrosion resistance and excellent red hardness, and FV520B is the common materials to manufacture compressor rotor [20], so cobalt base coating and FV520B are selected as the coating material and substrate material. The actual application temperature of compressor rotor shaft and blade is near

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Table 1
Element composition of substrate material-FV520B and cladding material-Co50.

	C	Mn	Si	Cr	Ni	Mo	Nb	Fe	B	Co	W
FV520B	0.05	0.7	0.45	14	5.4	1.5	0.4	77.5	–	–	–
Co50	0.07	–	1.80	21.5	1.90	–	–	–	2.55	66.56	5.62

600 °C, and there will be a great centrifugal force in practical application. High temperature tensile test that closes to the actual situation was performed, in order to study the failure mechanism of coating-substrate overall structure with thermo-mechanical coupling effects in practical application. It is expected that the results of this study will help promoting a deeper understanding of the overall structure of metallurgical coating, and promote the development and practical application of coating materials.

2. Experimental Procedures

2.1. Materials and Plasma Cladding Processing

A PAW-160 plasma cladding system was used to prepare the coating. Cobalt-base composite powder, with an average particle diameter ranging from 70 to 150 μm, was selected as the cladding materials deposited on FV520B substrate materials (100 × 20 × 20 mm in size), and the component proportion of mixed metal powder are Co50, Co50 + 5%Nb and Co50 + 5%Nb + 1%CeO_2 (wt%). The compositions of the cladding material (Co50) and substrate material (FV520B) are listed in Table 1. Before coating preparation, the composite powders were mixed by a PMQW planetary ball mill (China) for 0.5 h and then dried for 2 h at 120 °C. The substrate surface was cleaned by mechanical grinding and subsequently washed with acetone. The parameters for the plasma cladding process were: current 100 A, powder feeding 12 g/min, scanning speed 3 mm/s, plasma gas (argon) flow 2 L/min, protective gas (argon) flow 3 L/min, powder feed gas (nitrogen) flow 5 L/min.

2.2. Experimental Methods

The microstructures and compositions of the coatings were determined using a scanning electron microscope (SEM) equipped with an energy dispersion spectroscope (EDS) (QUANTA 200 and EDAX genesis xm-2), a JXA-8230 electron probe microanalysis and a JEM-2100 transmission electron microscope (TEM). The phase structure was determined by BRUKER-D8 X-ray diffraction (XRD), Cu Kα radiation, wave length for 0.154056 nm and a JEM-2010F transmission electron microscope (TEM). Microscopic structure characterization was conducted by BX-51(OLYMPUS) optical microscope (OM).The strength of Co50 coating material at the different temperature was calculated by JMatPro software. The EBSD measurements were performed in a ZEISS SUPRA55 field emission gun (FEG) scanning electron microscope (SEM) equipped with EBSD system.

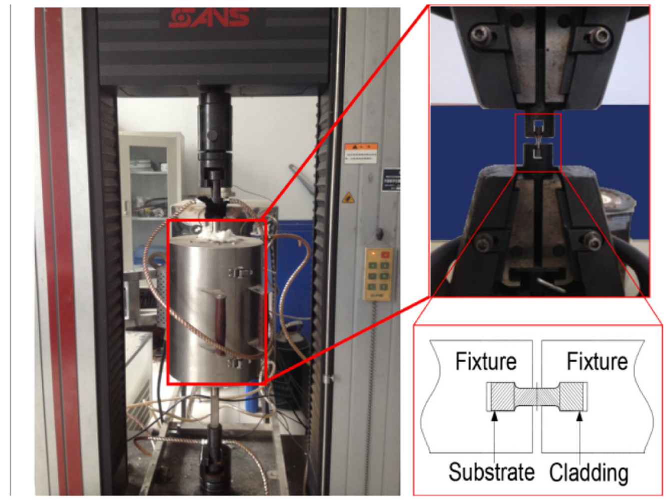

Fig. 2. Tensile test equipment and clamping mode.

2.3. High Temperature Tensile Experiment

The bonding strength was measured with the assistance of a universal testing machine (Instron5500R). Once the coating had been built up by plasma cladding equipment, the dog-bone-shaped samples were obtained by machining to achieve the appropriate size and shape, finally polished smooth with diamond paste so as to reduce the surface roughness, so that the effect of surface roughness was decreased in the test result. The sampling method of uniaxial tension experiment is shown in Fig. 1(a). The bottom part of the specimen is substrate material, while the upper part shows the plasma cladding layer. The detailed size of the sample and processing conditions is shown in Fig. 1(b). Due to the limited size of the coating, a non-standard size sample has to be chosen. Fig. 2 shows the tensile test equipment and the design of the fixture for the tensile test.

3. Results

The high temperature mechanical properties of Co50 coating-substrate material was first studied in the high temperature tensile test. All of the coating-substrate structure fractured in coating from 300 °C to 700 °C, which indicates that the coating strength is lower than that of substrate. The Fig. 3(a) shows the stress-strain curve from tensile test of Co50 materials at different temperature. The strength gap is small ((max − min)/ min = 5.56%), but the strains at the different temperature have large difference, which causes this phenomenon is that the plastic deformation ability of the material is enhanced as temperature rise. The results in Fig. 3(b), calculation result from JMatPro software, provide the proof for the small change strength value at different temperature. By comparison, the results of calculation and testing are in good agreement.

Alloy element (Nb) and rare earth oxide (CeO_2) were selected to

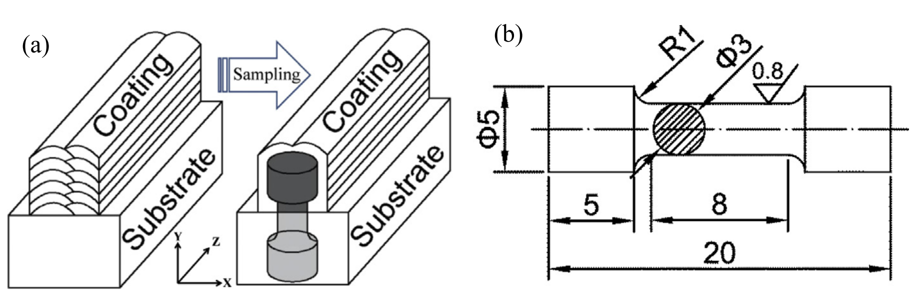

Fig. 1. (a) Design of test part after plasma cladding processing; (b) size of the tensile specimen and processing conditions.