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Microstructure and adhesion of 100Cr6 steel coatings thermally sprayed on a 35CrMo4 steel substrate

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Abstract

Thermally sprayed of 100Cr6 steel coatings are widely used to combat degradation of components and structures due to mechanical wear. In this paper, the microstructure and adhesion energy of 100Cr6 steel coatings thermally sprayed on a 35CrMo4 steel substrate are investigated. The microstructure characteristics of the deposits are studied using the combined techniques of X-ray diffraction (XRD), optical microscopy, scanning electron microscopy (SEM) including energy-dispersive spectroscopy (EDS). The practical work of adhesion of flame-sprayed 100Cr6 on steel substrate is determined using a four-point *delamination* bending test. The influence of a molybdenum bond coat on the adhesion is also studied. Microstructure suggests that the coating is mainly constructed by splats of γ-phase (fcc) and FeO. Phase analysis also confirms that during spraying process, a stable α-phase (bcc) was transformed into a new γ-phase (fcc). The highest values of the fracture energy are obtained for the 35CrMo4 substrate/100Cr6 steel deposit type samples. On the contrary, when a molybdenum bond coat is introduced (composite system 35CrMo4 substrate/Mo bond coat/100Cr6 steel deposit), the fracture energy decreases in a ratio of approximately three. So, the presence of a Mo bond coat as a barrier between the coating and the substrate has a negative role on the adhesion.

Keywords: Thermal spraying; Microstructure; Phase; Bond coat; Coatings; Adhesion

1. Introduction

Thermal spray coating represents an important and cost-effective technique for tailoring the surface properties of engineering components with a view to enhance their durability and performance under a variety of operating conditions [1,2]. It is also used to repair and refurbish worn or otherwise degraded parts, to restore a part to its original dimensions and improve its surface properties. Adhesion is one of the most important characteristics used to determine the quality of the coating [3–6]. Coating quality was characterized using a number of different tests [7,8]: one of them is the four-point "delamination" bending test [9]. In the present work, the role of the molybdenum bond coat on the practical work of adhesion of the100Cr6 steel deposit is investigated. In this goal, two types of composite system, A and B, have been prepared: (A) (35CrMo4 substrate/Mo bond coat/100Cr6 coating) and (B) (34CrMo4 substrate/100Cr6 coating). First, the aim of this work is to explore the results of the microstructure and morphology of coating using a flame spray technique. Produced coatings are characterized by X-ray diffraction (XRD) analysis and scanning electron microscopy (SEM) with energy-dispersive X-ray spectrometry (EDS). Second, the adhesion of flame-sprayed 100Cr6 on 35CrMo4 steel substrate is determined using a four-point bending test. The influence of a molybdenum bond coat on the adhesion is considered.

2. Experimental procedures

2.1. Material and spray conditions

The common substrate used is a 35CrMo4 steel with the dimensions of $60\times10\times4$ mm^3. Two types of sample are realized: (A) 35CrMo4 steel substrate/Mo bond coat/100Cr6 steel coating. To point out the specific effect of the molybdenum

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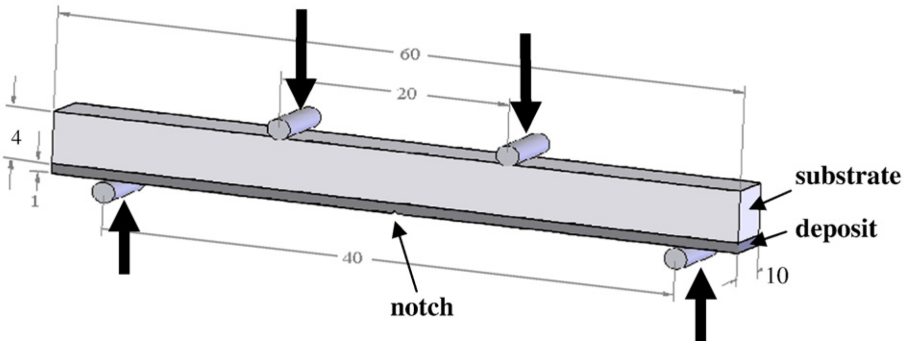

Fig. 1. Adhesion testing; experimental set-up for the four-point *delamination* bending test.

bond coat, the second sample is covered by a 100Cr6 steel deposit directly on the substrate, (B) 34CrMo4 substrate/100Cr6 coating. Prior to deposition, the samples are cleaned, degreased and grit blasted according to usual procedures [10]. The metal deposits are performed by means of a gun with a standard flame-wire “Mark 60” with a thickness of 1 mm. For the molybdenum deposit, the bond coat is 0.1 mm thick.

For the projection of molybdenum, an oxyacetylene flame is used. The fuel is acetylene under a pressure of 1.2 bars and the combustive gas is oxygen used under a pressure of 4 bars. An oxypropane flame is prepared for the projection of 100Cr6 steel by using a pressure of 3 bars for the propane gas. The projection pressure of the molten metal is 4.5 bars for steel and 3.8 bars for molybdenum. The projection parameters used to form the composite systems A and B are the following: projection distance 140 mm, wire speed 0.015 m/s. These projection parameters are those indicated in the technical chart of the SNC ATRA Company [11].

2.2. Characterization techniques

2.2.1. Coating characterization. As-received coatings are cross-sectioned, ground using SiC papers with grit sizes down to 2400 and finally polished with 1 μm alumina. Microstructure of the coatings is observed using optical microscopy and scanning electron microscopy (PHILIPS XL 30 SEM). Chemical composition is analyzed using an energy-dispersive spectroscopy (EDX–SEM) and phase analysis using an X-ray diffraction (XRD). The XRD spectra brought back in this work are recorded by using a chromium anticathode, starting from a polished side cut of the sample. The X-ray beam passing through a collimator of 0.8 mm in diameter can be applied to the desired zone, which makes it possible to separate the contribution of the substrate from that of the deposit. Identification of the crystalline phases is made by comparison of the observed lines with those of the suitable phases contained in the data base PDF2.

2.2.2. Adhesion testing. From the microscopic point of view, adhesion is due to reversible interactions (Van Der Waals, covalent, ionic) which can be established at the coating–substrate interface [12,13] and corresponds to the work of adhesion, a thermodynamic parameter. From the mechanical point of view, the practical work of adhesion corresponds to interfacial fracture energy. It is of a macroscopic nature and includes all energies (mechanical, electrical, thermal) that are dissipated in the different materials (layer, bond coat, substrate) during the delamination. In this study, the fracture energy of the deposited material on the substrate is measured using a four-point ‘delamination’ bending test [14–16] in agreement with the European standards.

This test consists of a notch flexural beam. The specimen is a bi (or more) material beam with a central notch (Fig. 1). In our case, the coating is stiff enough so that we do not have to glue a stiffener to enhance the delamination: this allows to suppress energy dissipation in an adhesive. Moreover, due to the brittle behaviour of the coating, only a short notch is necessary to initiate fracture. The sample is placed in a bending set-up where the distances between inner load lines is 20 mm and between outer load lines is 40 mm (Fig. 1). Tests are conducted with a constant displacement rate of 0.5 mm min^{-1}. Hence, a CCD camera allows to record beam cross-section all along its deformation.

During the load, a crack initiates at the notch, first in the coating and then propagates symmetrically in the coating–substrate interface. This crack is subject to constant moment conditions and propagates in steady state conditions. The strain energy release rate G_{IF} can be evaluated analytically using Euler–Bernoulli beam theory as following (Eq. (1)) [8,16]:

$$G_{IF} = \frac{p_c^2 l^2 (1-\nu_s^2)}{E_s e^3 b^2} \times \frac{3}{2}\left\{\frac{1}{(e_s/e)^3} - \frac{\lambda}{(e_d/e)^3+\lambda(e_s/e)^3+3\lambda(e_d e_s/e^2)(e_d/e+\lambda(e_s/e))^{-1}}\right\} \quad (1)$$

where

$$\lambda = \frac{E_s\left(1-\nu_d^2\right)}{E_d\left(1-\nu_s^2\right)} \quad (2)$$

and p_c is delamination strength (Newton); E_s is substrate Young’s modulus (210 GPa for 35CrMo4 steel); E_d is deposit Young’s modulus (210 GPa for 100Cr6 steel); ν_s is substrate Poisson’s ratio (0.3 for 35CrMo4 steel); ν_d is deposit Poisson’s ratio (0.3 for 100Cr6 steel); e_s is substrate thickness = 4 mm e_d is deposit thickness = 1 mm; $e = e_s + e_d = 5$ mm; b is sample widths = 10 mm; and l is distance between internal and external alumina blocks = 10 mm. The fracture (or delamination) strength p_c is determined from the load–displacement curve obtained during the test. It generally corresponds to a plateau, but in some case only an inflexion on the curve is observed.