BOLETÍN DE LA SOCIEDAD ESPAÑOLA DE CERÁMICA Y VIDRIO 55 (2016) 136–142

BOLETIN DE LA SOCIEDAD ESPAÑOLA DE
Cerámica y Vidrio
www.elsevier.es/bsecv

Micro-scale mechanical characterization of Inconel cermet coatings deposited by laser cladding

Chao Chang[a], *Davide Verdi*[b], *Miguel Angel Garrido*[b], *Jesus Ruiz-Hervias*[a,*]

[a] *Departamento de Ciencia de Materiales, UPM, E.T.S.I. Caminos, Canales y Puertos, c/ Profesor Aranguren, 5, E-28040 Madrid, Spain*
[b] *Departamento de Tecnología Química y Ambiental, Tecnología Química y Energética y Tecnología Mecánica, Escuela Superior de Ciencias Experimentales y Tecnología, Universidad Rey Juan Carlos, c/ Tulipán s/n Móstoles, Madrid, Spain*

ARTICLE INFO

Article history:
Received 1 December 2015
Accepted 5 January 2016
Available online 23 January 2016

Keywords:
Cermet
Inconel coating
Elastic-plastic properties
Depth sensing indentations

ABSTRACT

In this study, an Inconel 625-Cr_3C_2 cermet coating was deposited on a steel alloy by laser cladding. The elastic and plastic mechanical properties of the cermet matrix were studied by the depth sensing indentation (DSI) in the micro scale. These results were compared with those obtained from an Inconel 600 bulk specimen. The values of Young's modulus and hardness of cermet matrix were higher than those of an Inconel 600 bulk specimen. Meanwhile, the indentation stress–strain curve of the cermet matrix showed a strain hardening value which was more than twice the one obtained for the Inconel 600 bulk. Additionally, the mechanical properties of unmelted Cr_3C_2 ceramic particles, embedded in the cermet matrix were also evaluated by DSI using a spherical indenter.

Caracterización mecánica a escala microscópica de recubrimientos *cermet* de Inconel depositados mediante plaqueado láser

Palabras clave:
Cermet
Recubrimiento Inconel
Propiedades elasto-plásticas
Nanoindentación

RESUMEN

En este estudio, se han depositado recubrimientos *cermet* de Inconel 625-Cr_3C_2 sobre acero mediante plaqueado láser. Las propiedades mecánicas elasto-plásticas de la matriz de *cermet* fueron estudiadas mediante el proceso de nanoindentación (DSI) a escala microscópica. Los resultados obtenidos se han comparado con los correspondientes a una muestra masiva de Inconel 600. Los valores del módulo de Young y la dureza de la matriz de cermet son considerablemente mayores que los de la muestra masiva de Inconel 600. La curva de tensión-deformación de la matriz de *cermet* presenta un valour de endurecimiento por deformación que es más del doble del obtenido para el Inconel 600 en masa. Además, se determinaron las propiedades mecánicas de las partículas cerámicas de Cr_3C_2 sin fundir en la matriz de *cermet* mediante nanoindentación usando un indentador esférico.

* *Corresponding author.*
E-mail address: jesus.ruiz@upm.es (J. Ruiz-Hervias).

http://dx.doi.org/10.1016/j.bsecv.2016.01.001

Introduction

Cermet coatings were developed to protect the metallic substrate in high-temperature applications. The idea is to combine the hardness, oxidation resistance and high melting temperature of ceramic particles with the ductility, toughness and high thermal conductivity of metals. Different combinations of metal alloys and ceramics were blended and deposited to obtain cermet coatings [1,2].

Nickel-based superalloys are characterized by high-temperature oxidation and corrosion resistance. The commercial name Inconel is used to identify a group of Ni-based superalloys mainly composed by Ni and Cr. These alloys were demonstrated to be suitable to be deposited as a coating by laser cladding to protect substrate materials, like steel [3–5]. One way to improve the tribological properties of metallic coatings applied by laser cladding is to introduce ceramic particles in the filler material [6]. It has been shown that Inconel 625 and Cr_3C_2 particles could be used for this purpose [7]. The microstructure, the wear behaviour, and the mechanical properties of Inconel coatings have been studied in the literature [4,7–16]. Additionally, a recent study on the fracture and failure mechanisms of Ni-base laser cladding coatings was performed using in situ tensile tests [17]. However, few researches about the local mechanical behaviour in a micro-scale of Inconel cermet coatings have been carried out.

The aim of this work is to study the mechanical properties in the micro-scale of Inconel 625-Cr_3C_2 cermet coatings deposited by laser cladding. The elastic-plastic properties of the cermet matrix obtained by depth-sensing indentation (DSI) were compared with those of an Inconel 600 bulk specimen. In addition, for a more in situ analysis of the coatings, the properties of unmelted Cr_3C_2 ceramic particles, embedded in the in the cermet matrix, were also evaluated by DSI.

Materials and experimental procedures

Materials

Inconel 625-Cr_3C_2 cermet coating was deposited by laser cladding onto Gr22 ferritic steel (ASTM A387). Inconel 625 and Cr_3C_2 powders were supplied by Sulzer-Metco (MetcoClad 625 and Metco 70C-NS, respectively). The composition of Inconel 625 powder and the Inconel 600 bulk are presented in Table 1. The Inconel 625 powders were mechanically mixed with the 20 wt% of Cr_3C_2 before processing the cermet coatings.

Experimental procedure

A Rofin-Dilas High-Power Diode Laser (HPDL) with a wavelength of 940 nm and a maximum output power of 1300 W was used. Argon was applied as a protective and powder carrier gas. In order to deposit the cermet coatings, the laser beam power was fixed at 900 W, the scanning speed at 15 mm/s, the powder feeding rate at 16.5 g/min, and the flux of Ar between 14 and 15 l/min. The substrates were coated by 10 single clad tracks with a 40% overlap between two adjacent tracks [7].

Metallographic samples were prepared in plain-view section. The coated specimens were grounded with SiC paper up to 1200 grit to remove the superficial roughness of the coatings. Successively, they were polished in a diamond slurry of up to 1 μm nominal size. Finally, the polished surfaces were cleaned in deionised water and then by ultrasound in acetone and propanol. The same procedure was followed to obtain a polished surface of the Inconel 600 bulk sample.

Depth sensing indentations tests (DSI) were performed with a Nanoindenter XP (MTS systems Co.), on the polished surfaces of the samples, by using the continuous stiffness measurement methodology (CSM) [18]. Continuous loading and unloading cycles were conducted during the loading branch by imposing a small dynamic oscillation of 2 nm and 45 Hz on the displacement signal and measuring the amplitude and phase of the corresponding force. Consequently, the contact stiffness was continuously measured as a function of the penetration depth during the experiment. Two different batches of indentation tests were carried out on Inconel bulk and cermet samples. For each batch, an indentation matrix of 10 × 10 indentations, spaced 50 microns between them, was performed in displacement control. The first batch of indentation tests was carried out using a Berkovich diamond indenter with a tip radius of 50 nm. A maximum penetration depth of 1000 nm was selected to perform the DSI tests with the Berkovich tip. The aim of these tests was to obtain values of Young's modulus (E) and hardness (H) of the studied materials. Both properties were obtained by following the Oliver–Pharr methodology [19]. The other batch of indentation tests was conducted using a spherical diamond indenter with a tip radius of 10 μm. The aim of these tests was to study the local plastic properties and to obtain the indentation stress–strain curve of both samples. A maximum penetration depth of 1500 nm was selected to perform the DSI tests with the spherical tip. Prior to making the Berkovich indentations, a tip calibration procedure was carried out using the bulk Inconel 600 alloy as the reference material, according to the CSM methodology [3,19,20]. The nominal elastic modulus was set to 214 GPa and the real contact area of the indenter was iteratively obtained through the following equation.

$$A_c = c_0 h_c^2 + c_1 h_c + c_2 h_c^{1/2} + c_3 h_c^{1/4} + \cdots \quad (1)$$

where c_i are constants determined by curve fitting procedure. The first term was set to 24.5 for an ideal Berkovich indenter.

In addition, Vicker microhardness indentation tests were carried out on the polished surfaces of the studied materials, with a maximum load of 300 gf and a dwell time of 12 s.

Results and discussion

DSI tests with Berkovich indenter tip

In a previous work [7], the microstructure of the cermet matrix was analyzed by scanning electron microscopy (SEM) and transmission electron microscopy (TEM). Unmelted Cr_3C_2 ceramic particles were randomly distributed in the Inconel matrix. Additionally, Cr-rich carbides of stoichiometry M_7C_3,