JEGADEESWARAN N
RAJU B S
MANJUNATH L H
SOMASUNDARAM B
and
RAJU B T

Characterization of Stellite-6 high velocity oxy-fuel coating on titanium alloy

In the present investigation, cobalt based coating powder namely Stellite-6 was sprayed on titanium alloy (Ti-31) when used in gas turbines by high velocity oxy-fuel method. The microstructure and mechanical properties of the coatings were characterized like coating thickness, density, porosity, surface roughness and micro hardness. The advanced characterization of using advanced microscopy of X-ray diffraction (XRD) and Scanning Electron Microscopy (SEM/EDX). Followed by fracture toughness of the coating was measured by Palmqvist method. The very good bonding strength between coating and substrate material were identified.

Keywords: Fracture toughness, Stellite-6, Ti-31, HVOF, characterization etc.

1.0 Introduction

Today, gas turbines are used extensively to produce power for satisfying the demands of electricity, chemical, pharmaceuticals, fertilizer sectors, etc. An important developing area in the gas turbines is the use of modern materials to improve efficiencies and to reduce emissions (Wright and Gibbons, 2007). There are additional demands from the customer on to the power sector. Some of them are requirements to operate the power on part load, run with frequent starts and flexibility to run on different fuels.

Though various alternatives exist for the fuel material, coal is still a predominant fuel material for the power suppliers. This means that turbine components will be exposed to an environment consisting of abrasion, erosion, corrosion and oxidation phenomenon under hostile chemical conditions (Sidhu et al. 2005, Sidhu et al. 2007, Oskarsson, 2007, Wright and Gibbons 2007 and Kosel, 1992). Surface engineering of these components helps in protecting the components against above said environments. Thermal spray coatings are especially interesting for their cost/performance ratio. Unique alloys and microstructures can be obtained by thermal spraying which are not possible with a wrought material. This includes continuously graded composites and corrosion resistant amorphous phases on the component surface. Thermal spray coatings, additionally offer the possibility of on-site applications and repair of components, if sufficient accessibility for the sprayer and his equipment is available. Thermal spray coatings are being increasingly and successfully used for a broad variety of high temperature corrosion applications (Heath et al. 1997). High-velocity oxy-fuel (HVOF) spraying is a new type of thermal spray coating and rapidly developing technology in combating high-temperature corrosion and is now challenging the vacuum plasma spraying technique (VPS), which is very expensive. HVOF coatings have very low porosity, high hardness, high abrasion resistance, and good wear resistance with a strong ability to resist high-temperature corrosion, oxidation and erosion (Sidhu et al. 2006).

2.0 Experimental set up

Titanium alloy (Ti-31) is the substrate materials used in this study of candidate material for turbine blades and are procured from Mishra Dhatu Nigam Limited, Hyderabad, India. The stated composition of the substrate materials is given in the Table 1. Materials were brought in sheet form and coupons of size 25 mm × 25 mm × 5 mm were cut and used for HVOF spraying.

3.0 Results and discussion

3.1 Microstructure of Substrate Materials

Standard metallographic polishing technique is used to obtain the microstructure of the substrate material. The etchant used for various substrate materials are given in Table 2. The optical microstructures of the substrate materials are shown in Fig.1. The microstructure of Ti-31 (Fig.1) shows fine beta phase distributed in a matrix of alpha phase.

3.2 Morphology of Coating Powders

The morphology of the coating powder was investigated using the scanning electron microscopy (SEM). Fig.2 shows morphology of Stellite-6 powders. They are spherical in shape with particle size in the range of –45 to +15 µm. The particle size distribution of the powder as determined by the image analyzer is found to be consistent with the nominal size distribution, provided by the manufacturer.

Dr. Jegadeeswaran N, Messrs. Raju B S, Manjunath L H, and Somasundaram B, School of Mechanical Engineering, REVA University and Raju B T, School of Applied Science, REVA University, Bangalore 560064, Karnataka, India. Email: njagadeeswaran@reva.edu.in

TABLE 1: SUBSTRATE MATERIAL AND COATED POWDER COMPOSITION

Substrate Material	Titanium alloy (Ti-31)	ASTM B338 Grade 5	Ti-6Al-4V	Pressure vessels, gas turbine blades, gas and chemical pumps, marine components
Coating	Stellite-6	58.6Co–28.8Cr–2.64Ni–4.51W –2.48Fe–1.15C–1.31Si–0.3Mn –0.02P–0.009S–0.04Mo Shanghai Zhong Zhou special alloy materials Co Ltd, China.	Spherical	–45 to +15 μm

TABLE 2: ETCHANT USED FOR VARIOUS SUBSTRATE MATERIAL (ASTM E407)

Substrate materials	Etchant used
Ti-31	1.5ml HF-4ml HNO_3–94.5ml water

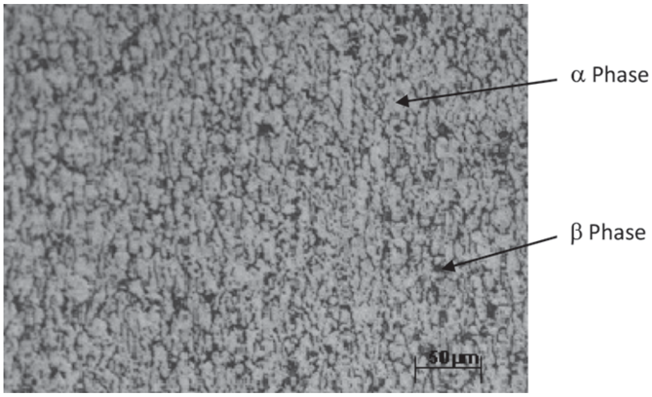

Fig.1: Optical photo micrograph of substrate materials Ti-31

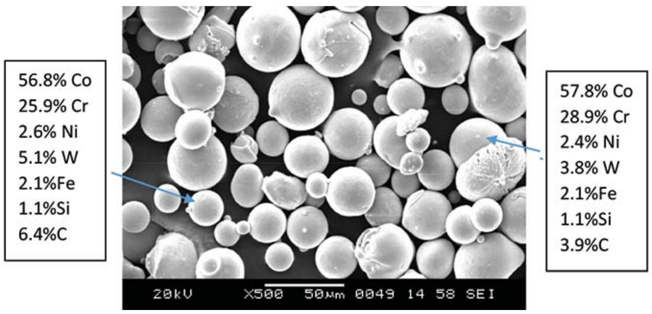

Fig.2: SEM/EDX of Stellite-6 powder

3.3 MEASUREMENT OF COATING THICKNESS, DENSITY AND POROSITY

Coating thickness was measured using the back scattered image (BSE) obtained along the cross-section of the coated specimens (Fig.3). The measured values of the coating thickness are tabulated in Table 3. The thickness of as-sprayed coatings is in the range of 250 to 325 μm. The density values of the coatings are calculated based on ASTM C135-96 (2003) standard water immersion testing method. The measured density of the coatings is reported in Table 3. The coatings surface porosity was measured according to ASTM B276, using porosity measurement device (Biovismaterials Plus V4.56, make serial 7482). The porosity values are reported in Table 3.

TABLE 3: THICKNESS, POROSITY, SURFACE ROUGHNESS AND DENSITY OF SPRAYED COATINGS

Coating type	Average thickness (μm)	Porosity %	Surface roughness (Ra)	Density (g/cm^3)
Stellite-6	325	1.08	10.1	8.33

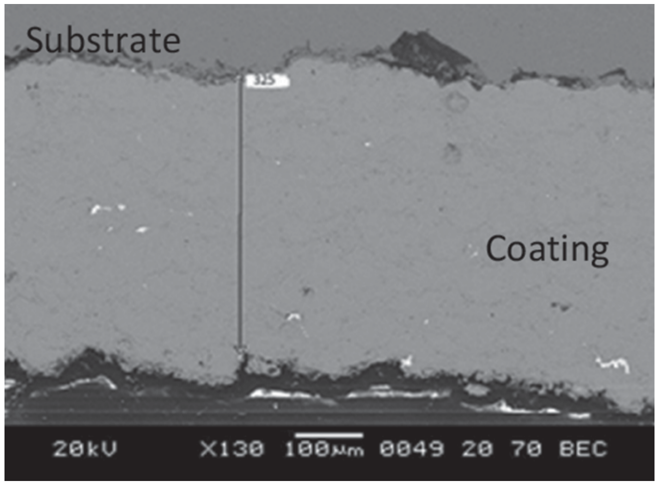

Fig.3: SEM micrograph of coating cross sections indicating coating thickness Stellite-6 coating

3.4 XRD ANALYSIS

The X-ray diffraction patterns for the substrate materials, surfaces of the HVOF sprayed Stellite-6 coatings and powders are shown in Figs.4 and 5 respectively. The alloy Ti-31 consists of b-Ti, Al and TiO_2 phases. The XRD patterns for Stellite-6 shows cobalt rich phase as principal phase. In all the coatings, the presence of weak intensity peaks, indexed to Cr_2O_3, indicate that a small amount of oxidation has occurred during spraying.

3.5 EVALUATION OF FRACTURE TOUGHNESS

The fracture toughness or critical stress intensity factor (K_{1C}) is an important mechanical property required for the improved mechanical performance of structural materials (Thomas Wasik, 2005 and George Dieter, 1988). In this investigation indentation hardness method is used for estimating K_{1C} (Niihara, 1983). The method uses Vickers microhardness test facility. A normal load of 2 kgf is used. The length of the crack generated during indentation is measured using SEM micrographs. A schematic diagram of crack generated during indentation is shown Fig.5, is called as radial

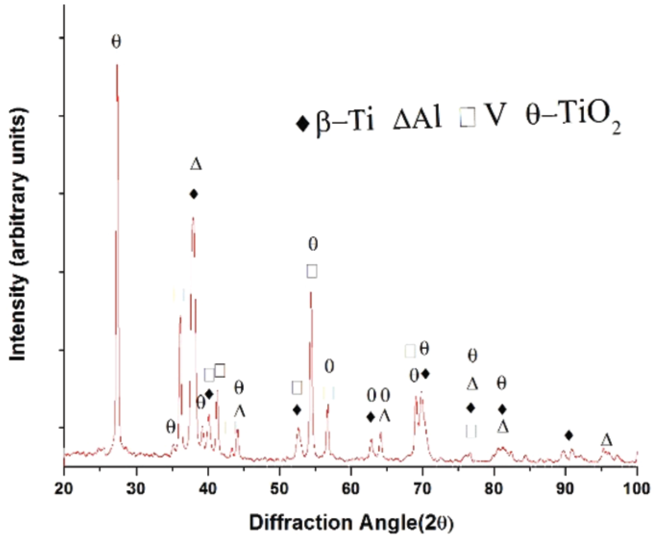

Fig.4: X-ray diffraction patterns for substrate material of Ti-31

crack length, d is half diagonal length and c is crack radius measured from the center of the indentation. Based on the relative values of c/d, two types of cracks are observed during the indentation.

When c/d £ 2.5 the crack is called as Palmqvist crack and c/d³ 2.5 the crack is called as half penny crack. The fracture toughness is calculated using the following equations (Mingxiang et al. 2013).

K_{IC}= 0.0193(Hvd) $(E/Hv)^{2/5}$ $(a)^{-1/2}$ (c/d£ 2.5) Palmqvist cracks

K_{IC}= 0.0711($Hvd^{1/2}$) $(E/Hv)^{2/5}$ $(c/d)^{-3/2}$ (c/d³ 2.5) Half penny cracks

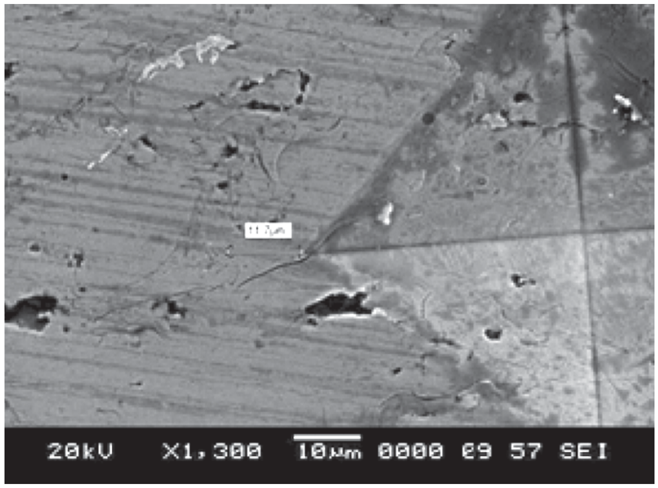

Fig.6: Back scattered electron image of indentation on the as-sprayed coating Stellite-6

TABLE 4: VICKERS MICROHARDNESS, YOUNG'S MODULUS AND FRACTURE TOUGHNESS OF SPRAYED COATINGS. (YOUNG'S MODULUS IS TAKEN FROM WWW.MATWEB.COM)

Coating type	Vickers micro hardness(Hv)	Young's modulus (GPa)	Fracture toughness K_{IC}(MPa $m^{1/2}$)
Stellite-6	980	207	10.54

Where Hv is the Vickers hardness, E is the Young's modulus, Fig.6 shows the typical indentations on transverse section with in-plane cracks for three coatings, Stellite-6 in sequence from top to bottom. Table 4 shows the estimated fracture toughness values for above coating on Ti-31 substrate.

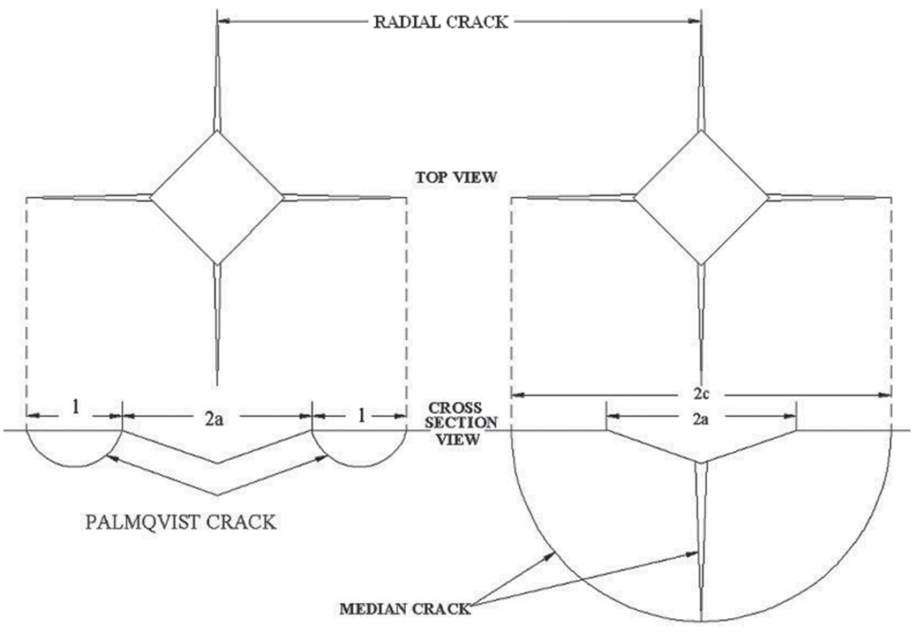

Fig.5: Comparison of geometries of Palmqvist and median cracks around Vickers indentation (Niihara, 1983)

4.0 Conclusion

HVOF sprayed Stellite-6 coating was successfully deposited on Ti-31 substrate materials. Under the given spray parameters, coatings are laminar structured, dense with porosity less than 2%. The thickness is in the range of 260-325 µm. The coating has retained the phases observed in starting powder. Stellite-6 coating shows cobalt rich phase as principal phase. The fracture toughness values show the very good bonding between substrate and Stellite-6 coating by Palmqvist method.

References

1. Sidhu, B.S., Puri, D. and Prakash, S. (2005): "Mechanical and metallurgical properties of plasma sprayed and laser remelted Ni-20Cr

and satellite-6 coatings." *Journal of Materials Processing Technology,* 159 (3), 347-355.

2. Sidhu, T.S., Malik, A., Prakash, S. and Agarwal, R.D. (2007): "Oxidation and hot corrosion resistance of HVOF WC-NiCrFeSiB coating on Ni-and Fe-based superalloys at 800ºC." *J. Thermal Spray Technol*., 16(5-6), 844-849.
3. Oskarsson, H. (2007): "Material challenges in industrial gas turbines." Proc., of Sino-Swedish Structural Materials Symposium, 11-14.
4. Wright, I.G. and Gibbons, T.B. (2007): "Recent developments in gas turbine materials and technology and their implications for syngas firing." *Int. Journal of Hydrogen Energy*, 32, 3610-3621.
5. Kosel, T.H. (1992): "Friction, lubrication and wear technology." ASM Handbook, 18, 199-205.
6. Heath, G.R., Heimgartner, P., Irons, G. and Miller. (1997): "An assessment of thermal spray coating technologies for high temperature corrosion protection." *Material Science Forum*, 251-54, 809-816.
7. Sidhu, T. S., Prakash. and Agrawal. (2006): "Hot corrosion resistance of high velocity Oxy-fuel sprayed coatings on a nickel-based superalloy in molten salt environment." *J. Thermal Spray Technol.*, 15(3), 387-399.
8. Niihara, K. (1983): "A fracture-mechanics analysis of indentation-induced palmqvist crack in ceramics." *Mater. Letters*, 2, 221-223.
9. George, E. Dieter, (1988): "Mechanical metallurgy." McGrew-Hill book company, Singapore, 11-4, 348-375.