THERMAL STABILITY AND EROSION-OXIDATION BEHAVIOR OF NANOSTRUCTURED Cr_3C_2-Ni20Cr COATINGS

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ABSTRACT

As-received (AR) and high energy milled (50-70 nm) Cr_3C_2-25(Ni20Cr) powders were used to deposit 200 µm thick coatings on AISI 310 specimens. The erosion-oxidation (E-O) resistance of the AR and nanostructured (NS) coatings was determined as wastage at 500 °C for 5h with erodent impact velocity of 20 m/s. Thermal stability of the coatings was determined from hardness measurements and microstructure examinations after annealing the coated specimens for 2 hours at 700, 800, 900 and 1000 °C. The E-O resistance of the NS coating at 500 °C was 50% higher than that of the coating prepared with the AR powders. The hardness across the coatings as a function of annealing temperature increased to a maximum and then decreased. The maximum hardness of the coating with AR powders was at 700 °C, while that of the NS coating, at 800 °C, indicating higher microstructure stability of the latter.

Keywords: Chromium carbide, nanostructured coating, thermal spraying, thermal stability, erosion-oxidation.

INTRODUCTION

Increase in demand for materials with enhanced physical properties has been steady in a number of engineering fields. Coatings have met many of these demands. Also, components of complex systems exposed to severe environments often require coatings that are wear, erosion and/or oxidation resistant. Coatings of chromium carbide particles distributed in a nickel-chromium alloy matrix, (also referred to as Cr_3C_2-NiCr system) have been used for corrosion and wear resistant applications. These coatings have been used in a variety of environments at temperatures up to 900 ºC, much higher than that at which the harder WC-Co coatings can be used. However, one of the shortcomings of Cr_3C_2-NiCr coatings was its lower hardness, and consequent lower wear resistance, compared to WC-Co coatings. This was addressed by using nanocrystalline feed stock in thermal spraying to obtain nanostructured coatings with higher hardness, strength and corrosion resistance[1-3]. Aware that grain growth of metallic materials affects mechanical

properties and that it depends on time at temperature, the high temperature thermal stability of a HVOF (High velocity oxygen fuel) sprayed nanostructured Cr_3C_2-NiCr coating was studied. Further, since a number of industrial components are exposed to environments where solid particles collide on surfaces at high velocities causing erosion, the high temperature erosion-oxidation of this coating was also studied. This paper presents the thermal stability and the erosion-oxidation resistance of HVOF sprayed coatings of as-received (AR) and nanocrystalline (Cr_3C_2-X(Ni20Cr).

MATERIALS AND METHODS

As-received (AR) powders of Cr_3C_2-X(Ni20Cr) were milled in a high energy mill for 8 hours at 400 rpm and a 10:1 ball to powder ratio to obtain nanocrystalline powders. Powder particle and crystallite sizes were determined using a particle size analyzer and by x-ray diffraction analysis, respectively. The mean crystallite size was determined using the Scherrer equation and details of the procedure can be found elsewhere [4-6].

AISI 310 stainless steel specimens (50x20x2mm) were HVOF thermal spray coated using Cr_3C_2-X(Ni20Cr) powders (X= 0, 20 and 25 wt%) in the “as received” (AR) and “nanostructured” (NS) (high energy milled) condition. The mean particle size of the powders used was about 20μm and the mean crystallite size of the milled powders was 60nm. The coating thickness varied from 50-200 μm. A scanning electron microscope coupled to an energy dispersive spectrometer was used to examine the morphology/microstructure and to determine the composition of the different phases. The Vickers hardness of the coatings was also determined with loads of 500 and 1000g, depending on the coating thickness.

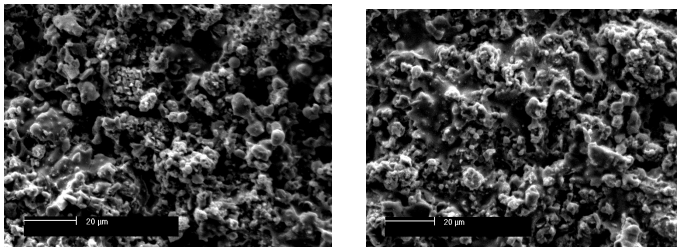
The erosion-oxidation (E-O) behavior of the coatings was evaluated in a test rig in which a specimen assembly was rotated through a fluidized bed of erodent particles. Alumina powder in the size range 212-150 μm was used as the erodent. The fluidized bed of particles was obtained by pumping pre-heated air through a porous plate supporting a bed of erodent particles. Fluidization of the erodent particles was done within a furnace and the particle impact velocity on the test specimens was controlled by a motor that rotated the specimen assembly. The E-O

behavior of the specimens was tested at 500 ºC for 5h with erodent impact velocity of 20 m/s. Wastage of the specimens was determined as weight loss after the test.

The thermal stability of the different coated specimens was determined by measuring the hardness after heat treatments. The heat treatments consisted of heating the specimens to 700 ºC, 800 ºC, 900 ºC and 1000 ºC for 2 hours, and cooling.

RESULTS AND DISCUSSION

The morphology of Cr_3C_2-25(Ni20Cr) powder in the AR condition was homogeneous and spherical, whereas the milled powder was irregular with faceted particles. EDS analyses of the milled powders revealed besides the Cr_3C_2 and Ni-Cr phases, regions with Cr_3C_2 - Ni-Cr composites.



(a) (b)

Fig. 1: Micrographs of coating surfaces prepared with Cr_3C_2-25(Ni20Cr) powders:

(a) AR, (b) NS.

The micrographs in Fig. 1 show the coating surfaces prepared with AR and NS Cr_3C_2-25(Ni20Cr) powders. No significant morphological differences could be observed.

Tab. 1 shows the Vickers microhardness of Cr_3C_2-25(Ni20Cr) coatings. The microhardness of NS coatings is higher than that of the coatings prepared with AR powders. The table also shows that hardness increased with increase in coating thickness. This could be attributed to thermal effects produced as a result of the spraying technique. The top layer cooling is affected by heat dissipation from the previous layer. Further proof of this was observed when the effect of heat treatment on coating hardness was studied.

Table 1: Vickers microhardness of coatings produced with Cr_3C_2-25(Ni20Cr) powders in the AR and NS condition.

	Vickers hardness of Cr_3C_2-25(Ni20Cr) (GPa)					
	AR			NS		
Coating thickness (μm)	56	190	234	73	175	214
Load-500 g	6.66	7.94	9.40	9.58	10.06	11.03
Load-1000 g	4.17	7.80	6.56	8.12	6.83	10.42

The erosion-oxidation (E-O) experiments were performed with only the Cr_3C_2-25(Ni20Cr) coatings. Wastage of the coated specimens was determined after 5 hours at 500ºC. The surface roughness of the samples was measured before and after the experiments. The results of these studies, shown in Tab. 2, indicate a significant increase in E-O resistance of the samples coated with NS powders. The surface roughness of the samples decreased regardless of the condition of the powder (AR or nanocrystalline) used to prepare the coating.

Table 2. Erosion-oxidation wastage of Cr_3C_2-25(Ni20Cr) coatings.

Coating		Wastage	Surface Roughness (Ra) (μm)	
Type	Condition	10^{-3} g cm^{-2}	Initial	Final
Cr_3C_2-25Ni20Cr	AR	9.20	6.58	3.95
Cr_3C_2-25Ni20Cr	NS	6.00	4.38	3.36

The thermal stability of the coatings was determined in terms of hardness variation as a function of heat treatment temperature. The microhardness measurements were made on cross sections of the specimens. Fig.2 shows the variation in hardness of the Cr_3C_2-20(Ni20Cr) coatings as a function of temperature.

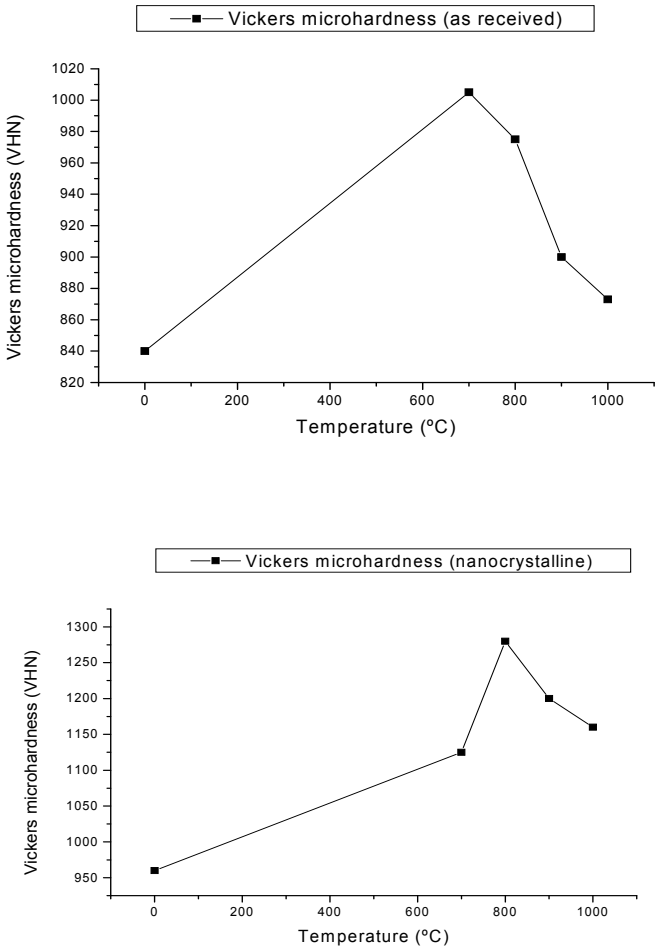


Fig. 6: Vickers microhardness variation of Cr_3C_2-20(Ni20Cr) coating as a function of heat treatment temperature: Top - AR, bottom – NS.

The hardness of all the coatings heat treated at 700 ºC was always higher than that prior to heat treatment. As a general rule, as the temperature increased, the hardness of all the coatings increased up to a maximum and then decreased. This maximum hardness value and the temperature at which it happened varied with the type of coating. In the case of the Cr_3C_2 coating, the hardness was much higher than that of the coating with the metallic phase Ni-Cr. The temperature at which the maximum hardness was obtained for the Cr_3C_2 coating was higher for that prepared with AR powder. In the case of the Cr_3C_2 with a metallic phase Ni20Cr, the maximum Vickers hardness for the coating in the AR condition (1000 kgf/mm^2) was achieved at 700ºC, while for the same coating but NS, the maximum (1250 kgf/mm^2) was obtained at 800ºC. This indicated that the maximum hardness value for NS coatings

was not only higher, but was achieved at higher temperatures, suggesting improved microstructure stability of the NS coating. Similar observations were made with the coating with 25wt % of the metallic phase, i.e., Cr_3C_2-25(Ni20Cr) powder.

The hardness indents were examined and several cracks were observed. All the indents on the AR and NS Cr_3C_2 coatings revealed cracks independent of the heat treatment temperature, indicating the brittle nature and the low fracture toughness of this coating. On the other hand, in the Cr_3C_2-20(Ni20Cr) coatings prepared with AR powder, the indents revealed cracks only at hardness values higher than 850 kgf/mm^2, while coatings produced with nanocrystalline powder revealed cracks only at hardness values above 1000 kgf/mm^2. Similarly, the coatings produced with NS Cr_3C_2-25(Ni20Cr) powder revealed cracks only at hardness values higher than 1200 kgf/mm^2. These observations indicate that the NS coatings have higher resistance to crack formation, compared to coatings prepared with AR powders. The increase in metallic phase content in NS coatings prepared from Cr_3C_2-X(Ni20Cr) increased the fracture toughness.

CONCLUSIONS

1. The erosion-oxidation resistance of the nanostructured Cr_3C_2-25(Ni20Cr) coating was 50% higher than that of the coating prepared with as-received powders.
2. Thermal stability of the coatings, determined as microhardness revealed that the hardness of NS coatings was not only higher, but was achieved at higher temperatures, suggesting improved microstructure stability.
3. Study of cracks emanating from hardness indents revealed that NS coatings have higher resistance to crack formation, compared to coatings prepared with AR powders.

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