JMEPEG (1999) 8:716-718

Erosion-Resistance of Plasma Sprayed Coatings

Z. Xia, X. Zhang, and J. Song

(Submitted 22 January 1999; in revised form 19 July 1999)

Cr_3C_2/NiCr, ZrO_2/NiCr, $WTiC_2$/NiCr, and X40 were plasma sprayed on the substrate 1Cr18Ni9Ti in order to solve the erosion wear at high temperature encountered in the oil-refining industry. A series of properties of the coatings, including their microstructure, hardness, and erosion-behavior, have been tested. The test results show that the properties of the coatings have a significant effect on their erosion-resistant performance. Good erosion-resistant materials need to be hard and tough. Both Cr_3C_2/NiCr and X40 have good erosion resistance at elevated temperature.

Keywords coatings, erosion resistance, hardness, plasma spraying, toughness, tribology

1. Introduction

Erosion, one of the types of wear, accounts for about 8% of all the wear characteristics. Erosion is a very complex phenomenon. Using systematic analysis, a great number of tests and theoretical analysis have been done mainly on the wear mechanism and on the influence of the wear parameters, including erodent, target (eroded material), erosion-process parameter, and some environmental media. There are many factors playing roles in the erosion-resistance of the target, such as hardness, toughness, thermoconductivity, elastic modulus, and so forth. There are two equations:

$$1/W = \alpha \cdot K_{Ic}^{2} \cdot H^{3/2} \quad \text{(Eq 1)}$$

$$1/W = \alpha \cdot K_{Ic}^{3/4} \cdot H^{1/2} \quad \text{(Eq 2)}$$

where, $1/W$ is erosion resistance (W is the mass loss of the target) and K_{Ic} and H are fracture toughness and hardness of the target, respectively. These two equations imply that the wear resistance of the target is proportional to $K_{Ic}^{\alpha} \cdot H^{\beta}$ ($\alpha, \beta > 0$).

This article studies the erosion wear of the refining device at elevated temperature in the oil-refining industry. In order to improve the erosion resistance of the substrate, four kinds of powder were used in a plasma spraying method. After testing the mechanical properties of the coatings, an erosion-wear test was done. By analyzing the experimental result, the authors investigated the erosion-wear mechanism of the coating materials at high temperature.

Z. Xia, X. Zhang, and **J. Song,** School of Materials Science & Engineering, Beijing Polytechnic University, Beijing 100022, People's Republic of China. Contact e-mail: shusen@2911.net.

2. Experiment

2.1 Materials

Austenitic stainless steel 1Cr18Ni9Ti was used as the substrate (composition is shown in Table 1). Considering the severe environment encountered in actual practice, four kinds of powder (Cr_3C_2/NiCr, ZrO_2/NiCr, $WTiC_2$/NiCr, and X40) were chosen as the working coating, while NiCr powder was used as the transit layer to improve the bonding strength between the substrate and the service coatings.

2.2 Procedure

The surfaces of the stainless steel were all sand blasted before spraying. All specimens were plasma sprayed with a thin layer of NiCr first. Then the four kinds of powder were sprayed onto the pretreated specimens.

2.3 Test Description

Monochrome and color metallography were used to evaluate the performance of the coatings. Thickness, defect rate, and hardness were also measured. Bond strength was also tested according to the Deloro Stellite standard (Ref 1).

The erosion-wear test was carried out at room temperature, 400, and 700 °C at impact angles of 30 and 90° at a given gas fluid velocity using a high-temperature erosion-wear tester. The erosion rate was calculated by dividing the mass loss of the target (which was measured by optoelectronic scales) by erodent mass. A relative erosion rate equal to the erosion rate of the target divided by that of the substrate was used to evaluate the erosion resistance of the materials.

Table 1 Composition of substrate 1Cr18Ni9Ti

Composition, wt%							
C	Cr	Ni	Si	Mn	Ti	S, P	Fe
≤0.12	17 to 19	8 to 11	≤1.00	≤2.00	5(C%-0.02) to 0.80	≤0.03	bal

3. Experimental Results

3.1 Coating Structure

The coatings have a lamella structure. Their thickness and defect rates are listed in Table 2. Here, the thickness of the coatings includes the thickness of the transit and the service layers. It is shown that coatings A, B, and C are all less than 0.2 mm thick, and coating D is more than 0.4 mm thick. The reason is that coating D has good spraying process performance, and coatings A, B, and C do poorly. If coatings A, B, and C were more than 0.2 mm, the structure would crack. Cavitation and inclusions are the main defects. The defect rates of all coatings are within 2 to 5%.

3.2 Surface Hardness and Bond Strength

Table 3 lists the surface hardness of the coatings, the hardness of the hard phases, and the bond strength between the coating and the base metal. From Table 3 it can be seen that the surface hardness of the coatings is lower than that of the phases. Meanwhile, coatings A, B, and C have high hardness, while the substrate is soft. Coating D has a medium hardness. Coatings A, C, and D bond well with the substrate. Coating B does worst.

3.3 Erosion Rate

Figure 1 is the relative erosion rate column of the substrate and the coatings under different conditions. In Fig. 1, regard the relative erosion rate of the substrate as 1. In any case, the relative erosion rate of coating D is less than 1, which means that the erosion resistance of coating D is always higher than that of the substrate. Coating A performs better than the stainless steel substrate, except at room temperature and 90° impact angle. Coatings B and C always do worse than the substrate, especially at 700 °C, where coating C oxidizes severely, peeling off as a result. This implies that coating C is unsuitable for service at elevated temperatures.

Table 2 Defect rate and coating thickness

Code	Coating	Defect rate, %	Thickness, mm
A	Cr_3C_2/NiCr	3.6	0.090
B	ZrO_2/NiCr	5.0	0.122
C	$WTiC_2$/NiCr	2.7	0.185
D	X40	4.0	0.414

Table 3 Properties of the coating and the substrate

Code	Surface hardness, $HV_{0.1}$	Hardness of the hard phase, $HV_{0.1}$	Bond strength, MPa
A	824	1400	39.20
B	572	2000	17.64
C	885	2000 to 3000	34.30
D	420	…	44.10
SS(a)	206	…	…

(a) SS, substrate

4. Discussion

4.1 Influence of the Coating Structure on Erosion Resistance

The coating structure is characterized by low density and discontinuity in inner regions and at the surface. The lamella structure is harmful to its erosion resistance. Impacted by the erodent particles, the target either deforms plastically or cracks. The lamella structure helps the target to expand its crosswise crack, which will lead to the peeling off of the coating, while the discontinuous point is the best origin of the peeling off. Therefore, the defect rate and the bonding behavior all significantly influence erosive behavior. As the test results show (Tables 2 and 3), the defect rate of various coatings is nearly the same, but the bond strength of both coatings A and D with the substrate is high (>39.2 MPa), which implies that they are difficult to peel off. Coating C suffered much oxidation and is therefore unsuitable for working at high temperature. Coating B is very brittle and is apt to crack under the impact of the erodent. Its relative erosion rate is high at 90° impact angle at various temperatures.

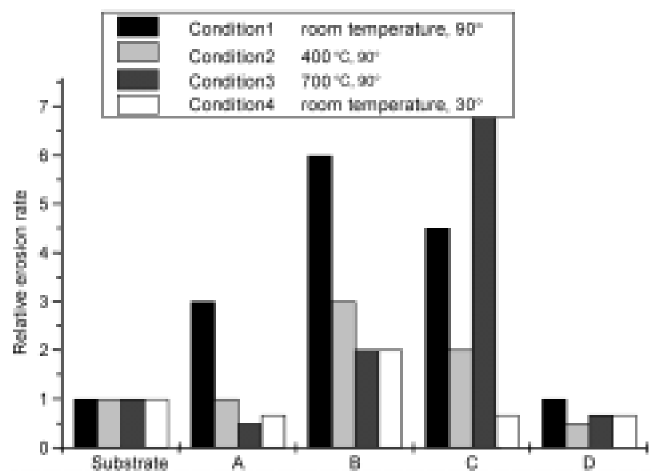

Fig. 1 Relative erosion rate column of the substrate and the coatings

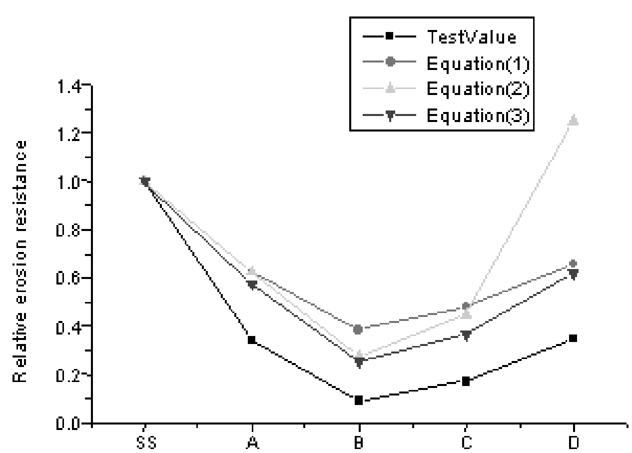

Fig. 2 Relative erosion resistance of the substrate and coatings

Table 4 Values 1/*W* from testing and Eq 1 to 3

Code	Hardness, $HV_{0.1}$	Fracture toughness (K_{Ic}), $N/mm^{3/2}$	Eq 1(a)	Eq 2(a)	Tested 1/*W*(a)	Eq 3(a)
SS	206	2212	1.000	1.000	1.000	1.000
A	824	569	0.340	0.626	0.625	0.575
B	572	379	0.090	0.385	0.275	0.252
C	885	379	0.171	0.479	0.45	0.365
D	420	942	0.347	0.656	1.25	0.617

Note: All data were measured at room temperature; K_{Ic} were extracted from Ref 2 and 3. SS, substrate. (a) Data have been divided by the value of the substrate.

4.2 Effect of Target Hardness and Toughness

The mechanical properties of the target are very important to its wear-resistant performance. Equations 1 and 2 show the relationship between them. Using tested data, one gets:

$$1/W = 2.75 \times K_{Ic}^{1.270} \times H^{0.845} \quad \text{(Eq 3)}$$

Table 4 lists the relative erosion resistance of the substrate and the coatings calculated from Eq 1 to 3. Figure 2 shows the listed data schematically. As Fig. 2 shows, values calculated from Eq 1 are far from the tested data, while values calculated from Eq 2 and 3 conform to the tested values substantially, except for X40. From this, one can see that there are some other factors that influence the erosion resistance of the target besides its hardness and toughness. These factors include the parameters of the tough materials, such as elastic modulus, thermal conductivity, and so forth, which will be studied further.

However, the effect of the fracture toughness and the hardness of the target on its erosion resistance are significant, and their relationship indices in the three equations are positive. The system in which hard particles (such as carbide) embed in the target leading to high hardness and good toughness show the most resistant behavior. Since the base metal usually is softer than the particles, which is helpful to resist wear, improving hardness of the substrate will protect it from losing its mass quickly. If the substrate has high toughness, it can be beneficial to decrease the likelihood of the hard particles peeling off. The structure with hard particles wrapped within the ductile alloys is both tough and hard in addition to having improved its procedure behavior. However, an increase in hardness always is accompanied by a decrease in toughness. So, it should be better to give attention to the two sides when choosing the optimal materials.

5. Conclusions

- Plasma sprayed coatings Cr_3C_2/NiCr and X40 improve the erosion resistance of the substrate effectively. The effect of coating ZrO_2/NiCr is indistinct, and $WTiO_2$/NiCr is unsuitable for service at high temperature due to its tendency to experience serious oxidation.
- Erosion wear is a systematic period, and every system parameter influences its behavior. Among these parameters, the hardness and toughness of the target are the most important. A good erosion-resistant target must be tough and hard. Coating Cr_3C_2/NiCr has good erosion resistance due to its high hardness and moderate toughness. Though its hardness is not high, coating X40 has good toughness and is also an ideal target.

References

1. "Properties of Delero Stellite Alloys," Delero Stellite, 1970
2. R.J. Dawson, A Guide to Weld and Thermal Spray Hardfacing in the Pulp and Paper Industry, *Mater. Perform.*, Vol 30 (No. 10), Oct 1991, p 55-58
3. T. Mclaren, Fracture Toughness as an Aid to Alloy Development, *Science of Hard Materials,* Plenum Press, 1983, p 687-707