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Erosive Wear Behaviour of Ni-WC Coatings Developed by Flame Spraying

Rambabu Arji[1], and D. K. Dwivedi[2]*

Abstract—This paper describes the erosive wear behaviour of Ni-WC coating deposited on mild steel by flame spraying process. A slurry pot tester with a provision for holding flat plate specimen (12X12X35 mm^3) was used to evaluate the erosive wear behaviour of the coating and mild steel. The wear test was conducted using two slurry concentrations (20% & 40% silica sand and water mixture) at three rotational speeds i.e. 600, 800 and 1000rpm. It was observed that the rotational speed affects the wear behaviour of coating and mild steel at both slurry concentrations. The increase in rotational speed showed continuous increase in the wear rate of the coatings for both 20 % and 40% sand slurry. The wear behaviour of coating has been explained in light of microstructure and microhardness. SEM study of wear surface showed that the wear of coating takes place by fragmentation, crater formation and abrasion.

Keywords---Flame spraying, Ni-WC coating, erosion, microstructure

I. Introduction

WEAR of the materials exposed to a high velocity stream of slurry is known as slurry erosion. Slurry pot tester is one of the many important methods used to evaluate slurry erosive wear behaviour of materials [1]-[4]. Surface modification and use of hard coatings for preventing the failure of components in oil industry and hydro electric power plants is continuously increasing. Recently [3]-[5] few attempts have been made to investigate the solid particles, slurry erosive and adhesive wear of Ni and Co base alloy coating deposited by HVOF process, laser cladding, plasma spraying and flame spraying. Hawthorne et al. [6] investigated the wear behaviour of high velocity oxy-fuel (HVOF) sprayed Co and Ni coatings under dry particle and slurry erosion (alumina) conditions and found that dry erosion rates three orders of magnitude greater than slurry erosion rates. Karimi et al. [7] investigated sand slurry erosion wear behaviour of tungsten carbide-metal cermets coatings deposited using high velocity oxyfuel spraying, using sand slurry having abrasive sand concentration 0.3 wt.% in tap water and found that during thermal spraying a substantial fraction of WC was melted and reacted with metal matrix to form ternary carbides or mixed W-C-M compounds (M is Co, Co, Cr, and Ni). Ni base alloy flame sprayed coatings have been investigated earlier mainly for their adhesive and abrasive wear behaviour.

[1]Rambabu Arji, Department of Mechanical and Industrial Engineering, IIT Roorkee, Roorkee-247667, India
[2*]D. K. Dwivedi, Department of Mechanical and Industrial Engineering, IIT Roorkee, Roorkee-247667, India

Relatively less attention has been paid to investigate the slurry erosive wear behaviour of flame sprayed coating. Aim of present work is to investigate the effect of slurry concentration and rotational speed on the wear behaviour of Ni-WC coatings deposited by flame spraying process. The erosion results are discussed with respect to the microstructure and microhardness of coating.

II. Experimental Procedure

Chemical composition of coating material and mild steel substrate used in this investigation is shown in Table I. Thermal spraying was carried out on the mild steel plate of size 50 x 30 x 12 mm^3. Details of the procedure used to develop the coating are shown in Table II. Transverse section of the coating was polished using standard metallographic procedure. Microhardness tests (HV) of base metal and coating were conducted at constant load of 100g. Macro-hardness (VHN) of the coating was evaluated at constant load of 5kg. The test equipment essentially comprised of a steel container for holding the slurry of silica sand (average particle size of 452 µm) and water within which specimens were rotated as shown in Fig. 1. Specimens were fitted to a mild steel bar at a radial distance of 97mm. The samples were thoroughly ultrasonically cleaned and weighed prior to and after the erosion tests. Weight loss was used as measure of wear. Electronic balance of 0.1mg accuracy was used to measure the weight of specimen. Wear test was conducted by traversing the coated specimen for one hour in slurry (20% and 40% sand) at three rotational speeds (600, 800 and 1000 rpm). Characteristics of the coating are shown in Table III.

TABLE I
CHEMICAL COMPOSITION OF COATING AND SUBSTRATE

Element	Ni-WC coating	Substrate
C	4.5-6.0	0.2-0.22
Cr	6.5-7.3	-
Ni	Balance	-
W	30-35	-
Si	2.5-4.3	0.4-0.6
Fe	-	Balance
Mn	0.6-0.72	0.4-0.8

TABLE II
THERMAL SPRAY CONDITIONS AND OTHER DETAILS

Parameters	Quantity
Cleaning of substrate using acetone	-
The pressure of the oxygen	3kg/cm^2
The pressure of acetylene	1.2kg/cm^2
Torch angle with respect to plate	90^0
Distance of torch tip from the substrate	20 mm
Torch speed.	10 cm/min
Preheat temperature	300^{0}C
Powder particle size range	45-100µm
Initial roughness (Ra) of substrate before spraying	6.5µm
Initial roughness (Ra) of coating before test	0.5 µm

TABLE III
CHARACTERISTICS OF COATING

Sr. No.	Characteristics	Value
1	Coating thickness (µm)	200
2	Porosity (%)	5%
3	Adhesion strength (MPa)	38

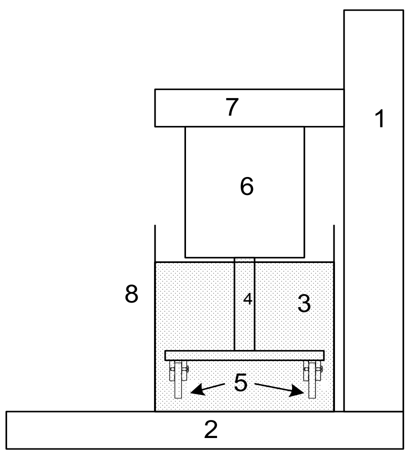
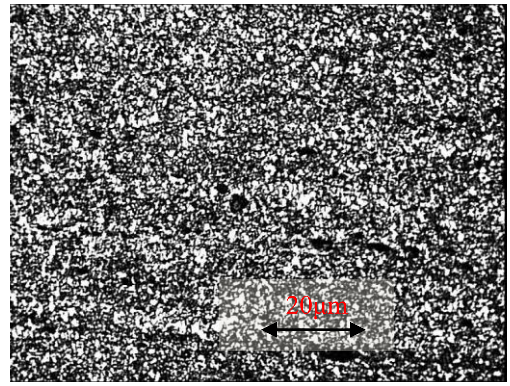


Fig. 1 Schematic diagram of the Slurry Pot Tester, 1 Column, 2 Machine base, 3 Slurry, 4 Spindle, 5 Sample, 6 Motor, 7 Motor Base and 8 Slurry Tank.

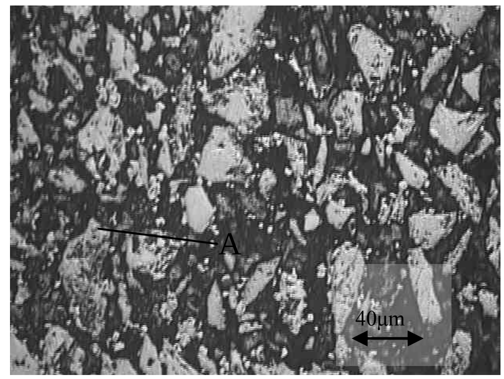
III. RESULTS & DISCUSSION

A. Microstructure

Optical micrographs of coatings and substrates are shown in Fig. 2 (a, b). Microstructure of steel substrate is shown in Fig. 2(a). Microstructure of Ni-WC coating is shown in Fig. 2(b). These micrographs were taken from a central region of the coating. Ni-WC coating primarily exhibits two micro-constituents namely primary WC carbides of polyhedral shape (light etched) and eutectic-carbides (dark etched). The cuboid shape primary carbide particles are present in the matrix of eutectic.



(a)



(b)

Fig. 2 Optical micrographs of (a) mild steel substrate, and (b) Ni-WC coating

B. Microhardness

Microhardness of WC carbide particle in Ni-WC coating was found in range of 3528-6130HV whereas that of eutectic was in range of 913 to 1465HV. Average hardness of carbide particles and eutectic was 5035 and 1210HV respectively. Macro-hardness of Ni-WC coating and mild steel was 1348.47 and 148.25VHN respectively.

C. Erosive Wear

The erosive wear behaviour of the substrate and coating as a function of rotational speed is shown in Fig. 3. It is observed that the weight loss of both coating and substrate increases with the increase in the rotational speed and sand concentration in the slurry. In 20% sand slurry, the weight loss increased with the increase in the rotation speed while in case of 40% sand slurry the weight loss increases with increase in the speed but in different way for substrate and coating. Weight loss of the substrate becomes too high in 40% sand slurry if rotational speed is high while coating is subjected to comparatively lower rates. Wear ratio indicates the improvement in wear resistance owing to development of the coating (Fig. 4).

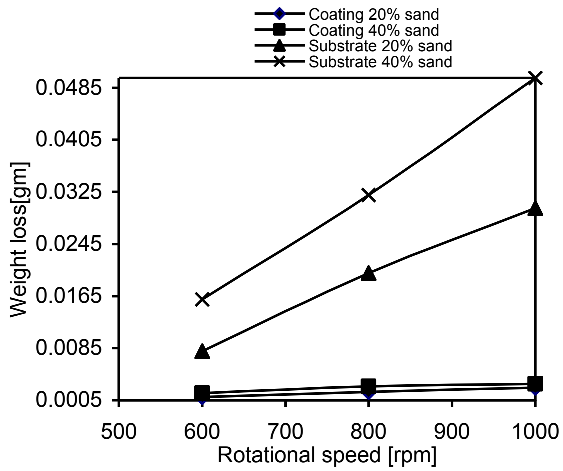


Fig. 3 Weight loss vs. rotational speed relationship for substrate and coating in 20% and 40% silica sand slurry.

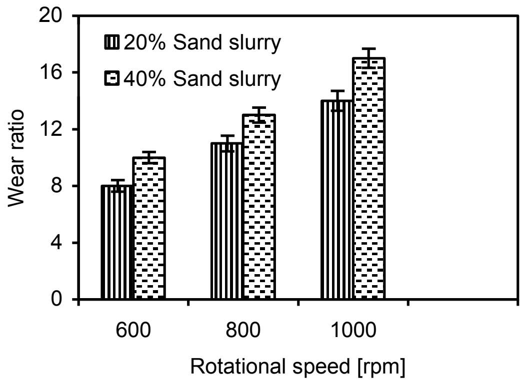


Fig. 4 Wear ratio as a function of rotational speed in 20% and 40% silica sand slurry.

D. SEM Study

SEM images of as sprayed and wear surface of mild steel and Ni-WC coating are shown in Fig. (5-6). SEM image of wear surface of mild steel is shown in Fig. 5. It can be seen that wear surface of mild steel exhibits indentations and elongated scratching marks. Some of the sand particles sitting on the surface are also visible. SEM images of as sprayed surface of Ni-WC coating are shown in Fig. 6(a). It can be seen that surface is uneven and has WC particle imbedded in nickel dominated eutectic matrix. Size of craters, scratches and indentations on the mild steel surface are found significantly larger than Ni-WC coating surface tested under similar conditions. Wear surface of Ni-WC coating shows primarily fine indentation on the surface as shown in Fig. 6(b). It can be observed that both WC particles and nickel dominated eutectic matrix have been indented. Indentation seems to be more in eutectic matrix than carbide particles.

Erosion by pitting and indentation is promoted by a) soft wear surface so that it is easily indented by hard particles, b) low relative speed of solid particles with respect to target surface so that abrasives get enough time to indent the target surface and c) low concentration of solid particles. Scratching of the wear surface is encouraged by a) hard wear surface so that it is not indented but gets only scratched by hard particles, b) high relative speed of solid particles with respect to target surface so that abrasives brush past the target surface and c) high concentration of solid particles [1, 15].

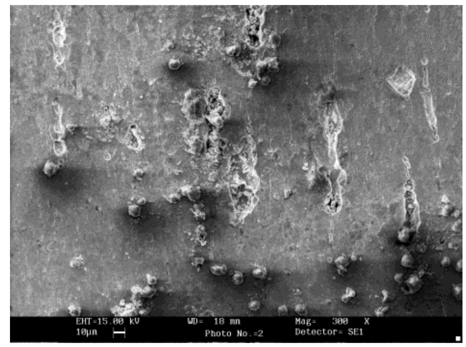
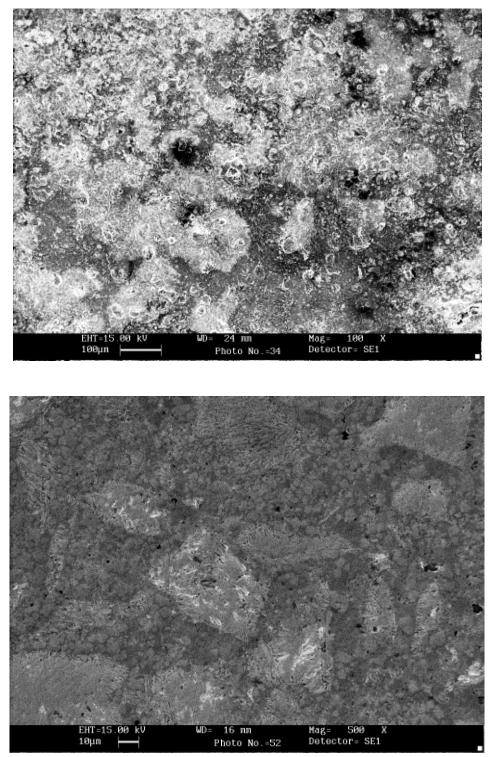


Fig. 5 SEM images of wear surface mild steel substrate 20% sand slurry and 600 rpm rotational speed.



(a)

(b)

Fig. 6 SEM images (a) as sprayed un-worn surface of coating (b) wear surface coating tested in 20% sand slurry at 600rpm rotational speed.

IV. Conclusions

1. Slurry erosive wear of the Ni-WC coating showed that with the increase in the rotational speed weight loss increases in both 20 and 40% silica sand slurry concentration. Moreover, weight loss was found in case of 40% sand slurry compared to 20% sand slurry.
2. The Ni-WC coating on mild steel improved wear resistance by 8-16 folds. Increase in wear resistance was quantified in terms of wear ratio (weight loss of mild steel and that of coating under identical erosion test

conditions). Wear ratio for Ni-WC coating was found in range of 8-16 under different test conditions.

3. Wear of Ni-WC coating was found to take place by pitting, crater formation and scratching. Soft nickel dominated eutectic matrix wear out by indentation and pitting while scratches and indentation are formed on the surface of WC particles.

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