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Performance Evaluation of High Velocity Flame Sprayed Ni-Al_2O_3 Coating under Different Slurry Environments

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Abstract

Slurry erosion testing results of a nickel based coating (Ni-20Al_2O_3) deposited by HVFS technique, are reported in the present work. The tests were carried out using an indigenously fabricated slurry erosion test rig. Some of the influencing parameters, such as rotational speed, average particle size of erodent and erodent concentration were selected to analyze the behavior of the test coating under various slurry environments. The experimental runs were designed using the Taguchi L4 methodology to obtain the erosion results in a controlled manner. Results obtained from the testing revealed a proportional relationship between specific mass loss and influential parameters.

Keywords : HVFS, Slurry Erosion, Nickel-Alumina, Erosion Tester, Specific Mass Loss

INTRODUCTION

Material degradation due to slurry erosion process is a serious problem related to the flow of erodent–liquid mixtures [1]. Slurry erosion is a ubiquitous form of surface degradation phenomenon finds mainly in the solid-liquid mixture handling systems and is responsible for major failures of various parts of hydraulic machineries [2]. The millions of dollars in a year are spent on the hydro-power stations located in the

Himalayan regions of India, for the repairing, maintenance and forced outages of the components affected by slurry erosion [3-5]. The impeller, buckets, spear and nozzle are the main components that are highly vulnerable to slurry erosion in case of impulse turbine, whereas guide vanes, runner blades and labyrinth seal are the main components of reaction turbine that are highly affected by slurry erosion [6]. Slurry erosion is a complex phenomenon, influenced by a number of factors, including impact velocity, mass of erodent, concentration of the erodent particles, average particle size of erodent, impact angle, exposure time and material properties.

The findings of theoretical studies and experimental works in the past have contributed significantly to the present knowledge of the slurry erosion phenomenon [7–10]. It has been learnt from the literature that there exist a severe interaction between the operating parameters and material characteristics. The involvement of these interactions limits further the understanding of the slurry erosion phenomenon, which emphasizes the need of an adequate theoretical framework for more precise predictions. Hence, many attempts are required to explore the real picture of the slurry erosion process. Further, it is found extremely both important and necessary to understand the fundamental knowledge of the erosion behavior in order to mitigate the effects of slurry erosion.

In the present work, slurry erosion performance of a nickel based coating, Ni-20Al_2O_3 (Ni-A) , has been investigated under various slurry test conditions. Keeping in view, the economic aspect, versatility and in-situ application possibilities, the HVFS process has been chosen for the deposition of coating powders on the selected test material. The results, as-obtained from the extensive investigation shell provide useful information regarding the slurry erosion behavior of the test coating under the effect of influential parameters.

EXPERIMENTAL PROGRAM

Materials:

Martensitic stainless steel, CA6NM was used as substrate material in the present study. M/s. Mithila Malleable Pvt. Ltd., Sirhind, Punjab, India provided the ingot of this material. The dimension of the specimens were kept as 12 mm outer diameter, 6 mm inner diameter and 10 mm height for the slurry testing purpose. Table 1 listed the chemical composition (nominal) of the substrate material. The physical properties of powders used for preparing the applied coating are listed in Table 2. The coating material was deposited onto the given substrate material employing high velocity flame spray (HVFS) process. The steel specimens were grit blasted with alumina powder before the deposition process, in order to activate their surfaces. The blasting helps in improving the adhesion of deposits to the steel surface. For the slurry testing, sample of sand was collected from river Sutlej (India), near the head works of Naptha Jhakri Hydro Power Project, which is one of largest capacity power plants (6 x 250 MW) in India and is severely affected by slurry erosion [11].

Table 1: Nominal chemical composition of CA6NM material.

Element	C	Si	Mn	P	Cr	S	Ni	Mo	Fe
Wt.% (max.)	0.0583	0.664	0.493	0.0263	11.56	0.0171	3.62	0.4929	Balance

Table 2: Physical characteristics of powders used in present investigation.

Powder	**Physical characteristic**	
	Morphology	**Particle shape**
Nickel	Water atomized	Spherical
Alumina	Fused and crushed	Irregular

Prior to the sieve analysis, the collected sand was firstly dried in an oven for 24 h and then sieving procedure is opted to obtain different sizes of sand particles. After the sieve analysis, the different grain size sand particles were mixed in predetermined ratios to obtain the required sample sizes of sand (300 and 500 µm). A suitable amount of distilled water was then added to the sand samples to obtain the slurry of required concentration.

Experimental Facility:

For performing the slurry erosion testing, a high speed slurry erosion tester of rotary type was fabricated in the present study. The complete detail regarding the components of fabricated test rig and their functioning can be found in Kumar et al. [12].

Experimental Strategy and Testing Procedure:

Under the present work, the effects of three parameters, namely rotational speed (RS), average particle sizes (APS) of erodent and erodent concentration (EC) were investigated. In order to obtain the erosion results in a controlled manner, Taguchi's L4 methodology was employed in the present investigation. The number of experimental runs and testing conditions are given in Table 3.

Table 3: Taguchi's L4 experimental plan

Various runs	**Investigated parameters and their values**		
	RS (RPM)	**APS (µm)**	**EC (PPM)**
1	1000	300	10,000
2	1000	500	30,000
3	3000	500	10,000
4	3000	300	30,000

The duration of each test was fixed for 6 h; however, the tests were interrupted regularly after 1 h in order to make mass loss measurements. The short-interval measurements help in identifying the actual erosion trend for the tested surfaces. A digital highly précised micro-balancer (least count of 0.0001 g) was utilized for the mass loss measurements. The test surfaces were gently cleaned with distilled water followed by rinsing in acetone and then dried under the hot air blower, to reduce the chances of error in mass measurements.

RESULTS AND DISCUSSION

Comparison of Specific Mass Loss at Various Runs:

The plots as shown in Figure 1, clearly indicates that the specific mass loss for run 1 is least and most for run 4 among all the experimental runs for HVFS coated Ni-A specimens. The marginal variation in the values of rotational speed and erodent concentration during these runs might be one of the possible reasons for such behavior. The plot also illustrated that the coated specimens show almost similar specific mass loss behavior during the test runs 1 and 3 and these trends are quite distinguished in comparison to the specific mass loss trends, as obtained during the test runs 2 and 4. These results highlighted the fact that the test parameters play a decisive role during the slurry testing.

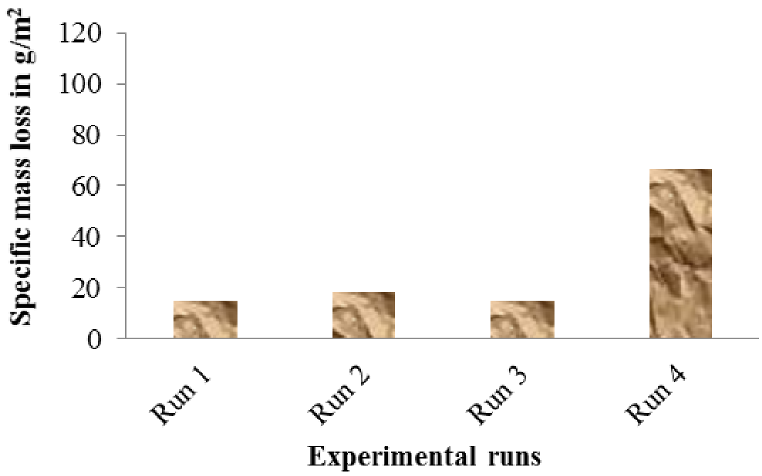

Figure 1: Specific mass loss results at various runs.

Comparison of Specific Mass Loss Rate at Various Runs:

Figure 2 depicts the trends of specific mass loss rate (in g/m^2h) recorded for various experimental runs (Table 3). Irrespective to the test conditions, the specific mass loss rate is found to be increased during the initial hour (1 h) of testing and then gradually reduced with increasing exposure duration. The work hardening on the exposed surfaces due to repeated impacts of erodent particles might be responsible for such behavior. As the coated surfaces are considered to be highly ductile in nature (due to the high percentage of Ni), the longer the exposure time, the harder the exposed surface becomes and thus resulting in less removal of material. However, after a certain duration of the testing period, the specific mass loss rate becomes almost constant. This stage is called as steady state, beyond which no further increase in the specific mass loss rate takes place. In the present investigation, irrespective of the test conditions, the coated surfaces attained a steady state after the 4th hour of testing duration.

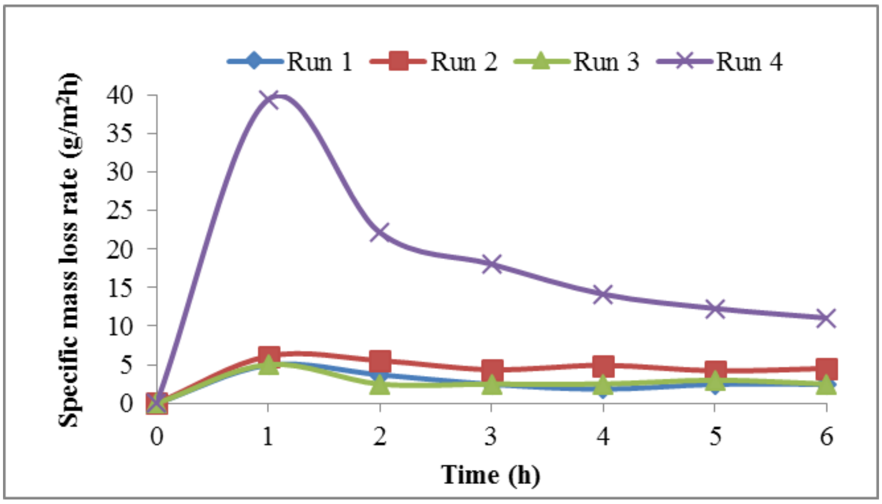

Figure 2: Specific mass loss rate at various runs.

Effect of Operational Parameters:

Figure 3(a) presents the results of specific mass loss with respect to variation in rotational speed. The results indicated that the specific mass loss was minimal at lower values of rotational speed and significantly increases with increase in rotational speed. In other words, the erosion becomes more serious at high rotational speeds. As, it is quite obvious that the erosion wear rate is highly influenced by the movement of impacting particles, thus higher movement may results in a significant increase in material removal. This fact has already been proved by a number of investigators [3, 4, 13-14] on the basis of their experimental studies.

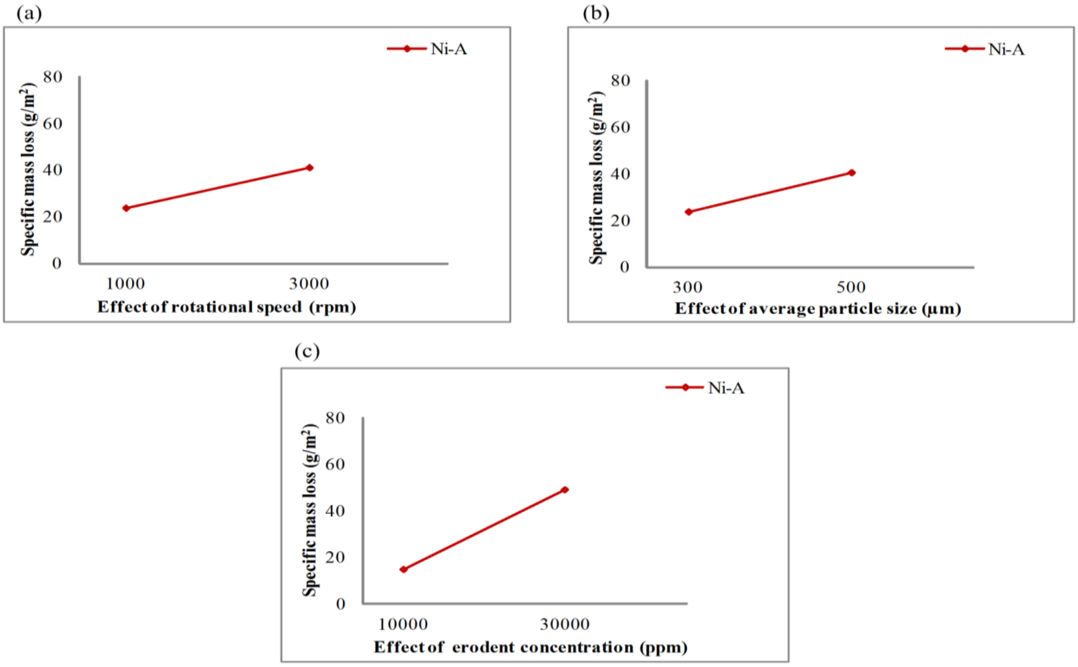

Figure 3: Effect of influential parameters (a) rotational speed, (b) average particle size, (c) erodent concentration on specific mass loss of Ni-A coating.

The variation of specific mass loss (g/m^2) with average particle size is reported in Figure 3(b). It can be observed that with the increase in average particle size of erodent from 300 to 500 µm, the specific mass loss increases. This may be due to the more impact energy apportioned to the exposed surface by large erodent particles than the finer ones [15]. In other words, it is generally considered that larger the size of erodent particle more will be impacted energy and higher will be the material removal. As the material removal for any material is a function of number of erodent particles impacting to the exposed surface. Therefore, the erosion rate of an exposed surface is generally related with the population of impacting particles. Figure 3(c) presents the obtained trend of specific mass loss of the test coating with respect to variation in erodent concentration. The increase in the specific mass loss was observed with the increase in concentration. However, the slope of obtained trend is not as proportioned as expected. The shielding effect at higher values of erodent concentration might be attributed to such behavior.

CONCLUSION REMARKS

The following conclusions have been drawn from the present investigation

- The Ni-20Al_2O_3 coating was successfully deposited onto the CA6NM material.

- The slurry environments largely influence the erosion performance of the target surface.
- Each investigating parameters found to have a proportional effect on specific mass loss of Ni-20Al_2O_3 coating.
- Amongst all the investigating parameters, erodent concentration is found to be the most significant factor.

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