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A Novel Insight into Slurry Erosion Performance of Some Nickel, Alumina, and Titania Based Thermal Spray Coatings: A Review

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Abstract—

An ideal coating system is generally considered as an appropriate combination of significant hardness and toughness. In the past investigations, the potential of various hard phases, as well as tougher candidates have been already explored. Some of these works related to slurry erosion, using nickel, alumina and titania as a coating candidate has been reviewed in the present study. The study is aiming towards investigating the effect of these coating candidates on the slurry erosion performance of a coating system. The review revealed a significant improvement in the coating properties (mechanical and microstructural) as well as coating performance with the application of the investigated coating materials.

Keywords— Slurry erosion, Coating, Nickel, Alumina, Titania

I. INTRODUCTION

Slurry erosion, a wear mode, is a complex phenomenon characterized by degradation of the exposed material and is caused by the continuous interaction of solid particles entertained in the liquid media. Erosion encountered at impingement velocities higher than 6-9 m/s is termed as high-velocity erosion, whereas the erosion that occurs at relatively low impingement velocities, is known as low-velocity erosion [1].The slurry erosion problem is a serious issue related to the reliability, performance, and operational life of the systems used in many industrial applications such as: hydroelectric power stations, coal liquefaction plants, oil field mechanical equipment, solid-liquid hydro- transportation systems, and industrial boilers where coal is carried directly as a fuel in water or oil [2-4]. One possible solution to mitigate and control the effects of slurry erosion is the surface modification of the target material using thermally sprayed wear-resistant coatings. Thermal spraying process generally includes the insertion of feedstock material, in the form of powder, wire or rod, into the high-temperature flame produced by a spray gun in order to obtain melted droplets. These droplets were then allowed to accelerate towards the substrate material over which they gets solidified and deposited [5].As far as the composition and the combination of feedstock material is concerned, a wide range of materials has been investigated in the past to examine their behavior under slurry erosion environments. The literature search showed that the mechanical, as well as microstructural properties of the deposits significantly influenced the slurry erosion performance of a coating system. Moreover, an ideal coating system is generally considered to have the optimum combination of hardness and toughness. WC, Al_2O_3, TiO_2, SiC, Cr_2O_3 are various candidates of hard phases, whereas the metals such as Ni, Al, Cr, Fe, Co etc. are considered to be frequent used tougher phases. During the selection of a particular coating combination, the two aspects, namely, required slurry erosion resistance and cost effectiveness are generally considered [6].Comparatively lower cost, higher hardness, higher chemical stability and higher melting point temperature are some of the important features associated with the use of the Al_2O_3 material. However, the use of Al_2O_3 coating is generally restricted in many industrial applications such as wear resistance, especially under harsh conditions due to its high brittle nature [7]. It has been learned from the literature that the addition of TiO_2 plays an important role in enhancing the mechanical as well as microstructural properties of the Al_2O_3 coating, which may further improve the coating performance. Moreover, the coating combination, Al_2O_3-TiO_2 is well known for their excellent properties such as low thermal expansion and high toughness, those make it suitable for the slurry erosion applications [8]. Amongst tougher phases, the metal Ni is generally preferred over others as a matrix phase, due to its higher fracture toughness than Al and lower cost in comparison to Cr and Co.

With reference to these manifolds, the work of various researchers in the field of mitigating the effects of slurry erosion by the application of thermal sprayed coatings, mainly nickel, alumina and titania based, has been reviewed in the present study. This body of study seeks to understand the behavior of various coating combinations against the slurry erosion.

II. LITERATURE REVIEW

Lathabai et al.[9] compared the slurry erosion resistance of two oxide coatings, viz. Al_2O_3 and Cr_2O_3, deposited by flame sprayed method. The erosion resistance of both the coatings was found to be significantly higher than the AISI 316 and mild steel substrate materials. However, amongst the investigated coatings, Al_2O_3 coating showed higher erosion rate than Cr_2O_3 coating. Hawthorne et al. [10] carried out slurry erosion testing on a range of cermet coatings and ranked them accordingly. The coatings were six WC cermets with Co- or Ni-based matrices, a Cr_3C_2–NiCr composite and three metallic alloys. HVOF process of spraying was utilized for the deposition of coatings. The slurry having 9 wt% alumina was used as impingement media. The SEM results revealed the ductile behavior of coatings characterized by mainly plastic deformation and platelet formation. An increment in carbide content within the cermet coatings was suggested by the authors to enhance the wear resistance of deposits. Sharma et al. [11] employed different thermal spray coating processes for the application of different deposits viz. Al_2O_3, Ni-Cr-B-Si, H.T., Al_2O_3 -13TiO_2 and TiC-CrC-82Co. The various deposits were then evaluated for their performances against slit erosion. The Al_2O_3 -13TiO_2 coatings deposited by D-Gun spray method showed the best results of erosion resistance among all other investigated coatings, whereas the sample coated with Al_2O_3 coating using plasma spray process has shown poorest results. Arji et al. [12] aimed towards evaluating the slurry erosion response of Ni-based coatings fabricated on mild steel substrates by the flame spray method under different slurry test conditions. A test rig of pot type was used to perform the various slurry tests onto the coated specimens using 20 and 40% silica sand slurry as erodent media. The tests were conducted for three levels of rotational speeds, viz. 600, 800 and 1,000 rpm. An increment in weight loss was observed for 20% silica sand slurry during the rotational speeds of 600 to 1,000 rpm, whereas in case of 40% silica sand slurry, the weight loss was found to be firstly increased with increase in rotational speed from 600 to 800 rpm and then decreased for the 800-1000 rpm range of rotational speed. It has been observed that Ni-Cr-Si-B coating showed significant resistance to the slurry erosion process. Moreover, pitting, plowing and indentation were found to be the main mechanisms responsible for material removal in case of wear of Ni-Cr-Si-B coating. Santa et al. [13] had investigated experimentally the slurry and cavitation erosion behavior of six thermal spray coatings. CA6NM was utilized as a substrate material for the present investigation. The OFP spraying process was employed for deposition of Ni, Cr_2O_3, and WC based coatings, whereas Cr and WC coatings were applied using the HVOF process. The slurry tests were conducted on the modified centrifugal pump tester and a vibratory apparatus was utilized for the testing of cavitation erosion. The results revealed that the application of thermal spray coatings can enhance significantly (up to 16 times) the slurry erosion performance of the given steel. On the contrary side, each coated specimen showed lower resistance to cavitation erosion than uncoated specimens. Moreover, micro-cutting and micro-ploughing were observed as the main material removal mechanism responsible during slurry erosion. In the case of cavitation erosion, the material removal mechanisms such as micro-cracking and brittle fracture were observed for OFP coatings, and the nickel-based coatings showed ductile behavior. For the HVOF coatings, the brittle fracture was observed as main wear mechanism for CrC coatings, while the detachment of small particles was seen in the case of WC/Co coatings. Bhandari et al. [14] evaluated the behavior of two ceramic coatings viz. Al_2O_3 and Al_2O_3-13TiO_2 under the effect of the slurry action. The coatings were deposited onto the CF8M steel substrates using detonation gun spray method of spraying. Three parameters, viz. concentration, the average size of erodent particles and rotational speed were selected for determining the behavior of coatings under various slurry environments. The results showed the better slurry erosion performance of Al_2O_3-13TiO_2 coatings as compared to Al_2O_3 coatings due to the higher toughness of Al_2O_3-13TiO_2 coatings than Al_2O_3 coatings. However, both the deposits showed similar material removal mechanism (brittle fracture) during the slurry erosion. Further, in the case of Al_2O_3 coatings, erodent concentration and average particle size were observed to be comparatively more dominant factors in comparison to rotational speed, while rotational speed is found to be more dominant than other factors in the case of Al_2O_3-13TiO_2 coatings. Goyal et al. [15] attempted to evaluate the performance of two different HVOF deposited coatings, viz. WC–10Co–4Cr and Al_2O_3+13TiO_2 under the effect of variation in various slurry test parameters. A high-speed erosion tester was employed for slurry testing and three parameters namely average particle size (µm), slurry concentration (ppm) and speed (rpm) were selected to evaluate the behavior of test coatings. The mixed behavior (mainly ductile) of material removal was observed for WC–10Co–4Cr coating, whereas Al_2O_3+13TiO_2 coating showed brittle signatures of erosion. The wear resistance of WC–10Co–4Cr coating was found to be higher than Al_2O_3+13TiO_2 coating. This may be attributed to the higher hardness of WC–10Co–4Cr coating as compared to Al_2O_3+13TiO_2 coating. In the case of Al_2O_3+13TiO_2 coating, the variation in average particle size of erodent was found to be contributed dominantly to the erosion process amongst all the other investigated parameters. Grewal et al. [16] attempted to investigate the effect of alumina content on the erosion performance of Ni–Al_2O_3 based composite coating. Commonly used hydro-turbine steel, CA6NM, was used as a substrate material in the present investigation. Erosion results were correlated with the different mechanical and microstructural properties of the coatings. A significant variation in the slurry erosion resistance has been observed with the proportions of alumina. Moreover, the coating having 40wt% alumina showed better results of slurry erosion performance in comparison with its other investigation counterparts. The mechanical property, namely, fracture toughness was found to one of the most significant parameters for controlling the erosion wear. Cracking, fracture of reinforced particles and removal of splats were observed to be the main mechanisms responsible for erosion wear during the slurry action. Yang et al. [17] utilized the plasma spray method for the fabrication of alumina (Al_2O_3) and alumina-based composite coating (Al_2O_3–Cr_2O_3) with the aim to compare their slurry erosion resistances. The slurry tests were conducted on a new type of solid particle impact test (slurry jet). The prepared slurry was allowed to mix with compressed air in the impinging nozzle and then eventually impacted upon the coated surface at high kinetic energy. The study concluded that the addition of chromium oxide leads to enhance the mechanical as well as microstructural properties of Al_2O_3 coating, which might be the responsible reason for relatively higher erosion resistance of Al_2O_3–Cr_2O_3 composite coating than Al_2O_3 coated surfaces.

III. CONCLUSION REMARKS

Slurry erosion of the components cannot be avoided completely but can be minimized to an economically acceptable level. Many investigators have attempted to mitigate and control the slurry erosion process, using various surface modification techniques, especially thermal spray coatings. The present study explored the potential of some of the nickel, alumina and titania based coatings, those are frequently used against the slurry erosion protection. The literature search showed a significant improvement in slurry erosion resistance of materials by the application of these coatings. However, it has been observed from the existing literature that a less attention has been given in the past to analyze the slurry erosion behavior of Ni-Al_2O_3 and Ni-TiO_2 coatings. Moreover, no attempts have been made in the past to investigate the synergistic effect of Al_2O_3 and TiO_2 on the slurry erosion performance of nickel-based coatings.

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