International Journal of Multidisciplinary Research and Development
Online ISSN: 2349-4182 Print ISSN: 2349-5979
www.allsubjectjournal.com
Volume 2; Issue 11; November 2015; Page No. 193-199

Development and slurry erosion analysis of Ni +SiC composite coating on turbine steel

[1] Gagandeep Singh, [2] Pushpinder Sharma, [3] Rohit Sharma

[1, 2, 3] Industrial and Production Engineering Department, Geeta Engineering College, Haryana, India.

Abstract
Development of hard coating on the soft surfaces increases the service life of components and reduces the service and maintenance costs. Surface engineering has proved to be one of the key areas for developing materials which are highly efficient. It led to the increased service life of components. Various manufacturing and processing methods are used for development of coatings however, detonation gun spray method for development of coatings proved to be cost effective and efficient. In present work metal-ceramic composite coatings using EWAC (Nickel based) and ceramic (10%wt Silicon Carbide) powders were developed using D-Gun spray method. Characterizations were carried out in terms of microstructures, mechanical and analysis of erosion wear in terms of mass loss. Results revealed that development of coatings proved to be highly efficient and reduces the erosion wear. The developed coating showed Vickers microhardness of 492.8±25HV which was 40.8% higher than the base substrate. Results of erosion wear revealed that maximum cumulative mass loss of all the samples occurred at lower angles of impingement i.e. 30°. On increasing the impingement angles mass loss decreases and this is due to the lower cutting and shearing forces. The effect of increase in rotational speed revealed that on increasing the rotational speeds the mass loss of samples increases linearly. This is due to the increase in kinetic energy of particles which increases the impact strength of particles and enhances the erosion phenomenon.

Keywords: Coating, Detonation Gun, Composite, Microhardness, Microstructure, Erosion

Introduction

The demand of renewable energy resources allowed hydro electric power plants as the major renewable power generating sources worldwide [1-3]. About 19% of the world electricity is produced by hydropower plants. Global scenario shows that India ranks 5th in terms of exploiting hydro energy for meeting the demands. India is blessed with huge amount of hydroelectric energy potential and only 17% of total potential is being effectively used till now. Lot of attention is needed in the development of hydropower potential for sustainable energy development [4, 5]. The main limitation in the path for hydro electric power plants is the initial cost required for building dams and then maintaining it. The main components of any power plant are water turbines, which converts the kinetic energy of running water into mechanical energy which in turn gets converted into electricity by generators. Maintenance costs associated with water turbines are higher and this cost further increases manifold if turbine blades have to be replaced. The hydropower plants located in northern region of Himalayas suffer from silt erosion of underwater parts mainly turbine blades [6-8]. This erosion occurs particularly in the monsoon season, when 90% of the silt particle of sizes more than 0.1mm, containing quartz with hardness of 7-8 Moh's are suspended and strikes the underwater parts. The various parts of the plant are subjected to an environment that contains silt having particles of MgO, CaO, SiO_2, clays, volcanic ash etc. These particles are further accelerated by water and results become worst due to higher impingement speeds. These sediments are formed by the fragmentation of rocks, land erosion and landslides due to heavy rain in monsoon season. It is not cost effective to construct any arrangement for the removal of various sizes of silt particles from the running water. The problem of erosion of underwater parts of the hydropower plant requires highest attention and measures to minimize such damages has been constantly engaging the researchers, engineers and manufacturers of equipment towards this situation. It is not possible that silt erosion of turbine blades requires replacement as it will add to the huge maintenance costs and this will be directly borne by the common people. The alternative to this problem is surface modification of turbine blades which will increase the erosion resistance of the material under water.

The work of Gandhi et al [9]. found that both 304 and 316 stainless steels have the same rate of wear when impinged with an air jet containing SiC particles that were 160 microns in diameter and angular shapes. In both metals have wear rate fastest when the impingement angle was at 30° and it was the slowest at 90°.This information is very useful when designing a test because it indicates where attention must be directed to evaluate the maximum wear locations. Ramesh et al [10]. studied the behavior of Inconel-718 powder on mild steel. The powder was thermal sprayed on mild steel substrate utilizing APS (air plasma spray) thermal spraying facility. The surface hardness of developed coatings were higher than that of the substrate and increases with increase in coating thickness. It was reported that slurry erosive wear resistance of developed coatings was superior than that of uncoated mild steel substrate. Mishra et al [11]. studied all the parameters affecting the erosion wear using jet erosion tester on fly ash-quartz coating. By varying different parameters they evaluated that impact angle is the most significant factor influencing the erosion wear of fly ash-quartz coating. They also evaluated that maximum erosion takes place at impact angle of 90°. Work carried by Santa et al [12]. compared the erosion wear of coated and uncoated stainless steel used for hydraulic machinery. The slurry was composed of distilled water and quartz sand particles with an average diameter between 212 and 300 µm and the solids content was 10 wt% in all the tests. . It has been observed that the coated surfaces showed higher erosion resistance than the uncoated stainless steels. Authors [13-15] reported that detonation gun spray coatings proved to highly efficient and is cost effective.

2. Materials and method

This section provides details on the materials selected for the present research work on D-Gun sprayed coatings and various details of the experimental work involved in the work.

2.1 Materials

Nickel based composites are extensively used in many anti wear, anti corrosion and hard facing thermal resistant components [16-18] for many industrial purposes. In present work nickel based powder (EWAC EN 1004) is used as matrix material which is reinforced with 10% SiC ceramic powder. Table 1 shows the elemental percentage composition of nickel based powder and Fig 1 (a-b) shows the scanning electron microscope (SEM) images of powder particles.

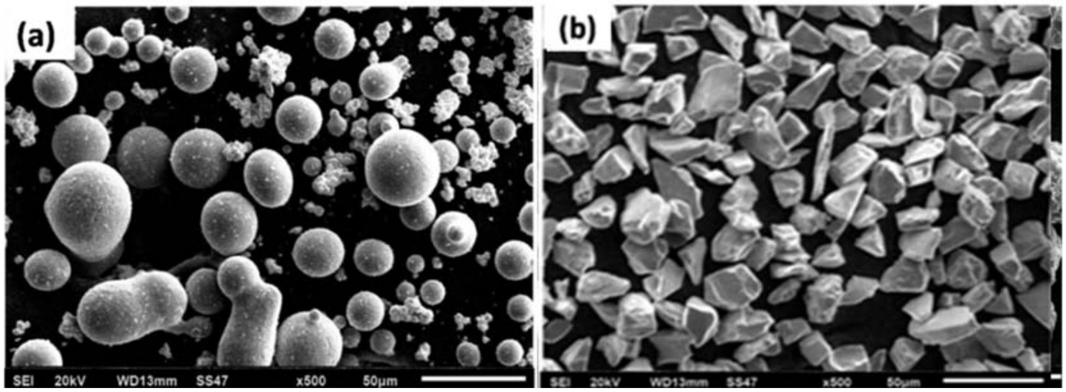

Fig. 1: Typical SEM images showing morphology of (a) EWAC powder and (b) SiC powder particles

Steel based materials are widely used in pumps, turbines and pipelines for various industrial applications. These parts are used to carry various solids, liquid and gaseous material and this can cause erosion wear. Erosion wear is also a serious problem for turbine blades which encounters silt particles impinging at higher velocities. In present work turbine steel also known as 13Cr-4Ni steel is used as base material. This material is currently being used for fabrication of turbine blades, pumps for different applications and under water parts in hydroelectric projects because its nickel content, associated with low carbon ensures better erosion resistance, weldability, ductility, impact resistance and fatigue resistance properties. The chemical composition of substrate material was determined by using spectrometer and is shown in Table 1.

Table 1: Percentage elemental composition of EWAC powder

Element	Cr	C	Si	Ni
Weight (%)	0.14-0.17	0.2	2.5-3.0	Bal.

2.2 Development of coating

The detonation gun (D-gun) process was the first type of HVOF process used in which kinetic energy of particles is more important than temperature. These processes use high-impact energy through accelerating the coating particles with carrier gases which acts as fuels, to produce dense coatings at relatively low temperatures. The fuel gases can be hydrogen, oxygen, methane, propane, liquid fuels such as kerosene and mixture of these gases can be used. The coatings developed by this process further depends upon many factors such as stand-off distance, pressure of carrier gases, types of coating powder and material to be coated i.e. substrate. The schematic arrangement for development of coating is shown in Fig 2.

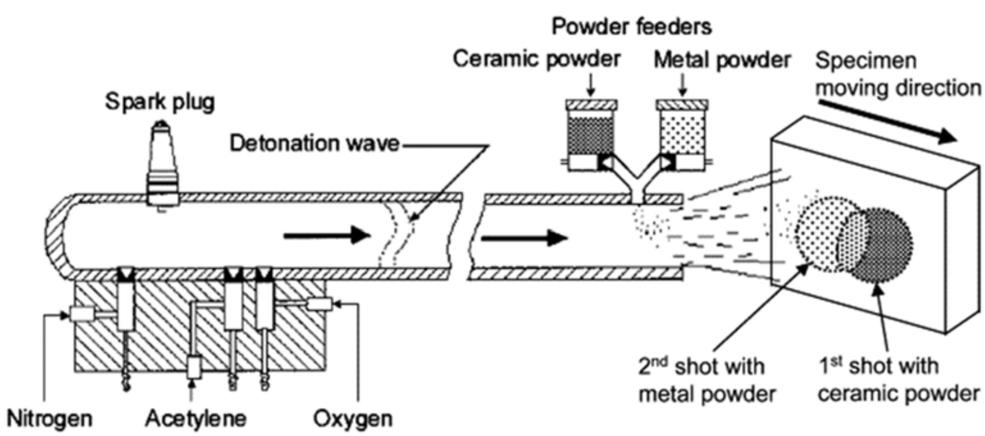

Fig 2: Schematic representation of D-Gun spray coating technique [19]

2.3 Characterization of developed coating

The developed nickel based composite coatings were characterized by relevant available techniques using Scanning Electron Microscopy (SEM), Energy Dispersive Spectroscopy (EDS), Vickers micro hardness and erosion wear analysis. The parameters used for studying the slurry erosion behavior are presented in Table 2.

Table 2: Experimental tests parameters for studying erosion wear

Dimensions of Specimen	**40 mm × 40 mm × 5 mm**
Flow Rate	Fixed 3.0 lit/sec
Impinging Angle	30°,60° and 90°
Slurry Concentration	10% and 20%
Rotational Speed	1000, 2000, 3000 RPM
Silica sand particle size	100 microns fixed
Time	Fixed 2 hours for each sample
Nozzle Diameter	8 mm
Stand Off Distance	45 mm

3. Results and discussion

The following sections provides the detailed results of various characterizations carried on the EWAC+10% SiC composite coating developed by D-Gun spray method. The detailed results are presented below in the terms of microstructural characterizations, followed by mechanical and lastly for the erosion wear behavior.

3.1 Microstructure study

The performances of any developed composite coatings depend upon the microstructures and dispersion of reinforcements in the matrix, which relates to the property-structure relations. The developed coatings of metal-ceramic powders on turbine steel are visually inspected and it was observed that coatings of less thickness with dense layers were formed on the surface. No sign of cracks and porosity was observed by naked eyes. Color of coating was similar to the base steel material and this may be due to the presence of nickel. Coated samples were placed under Carl Zeiss optical microscope and were observed at 50X magnification. It was observed that some porosity was presence in the top surface of coatings. The optical micrograph of developed coating is shown in Fig 3 (a). The developed microstructure of EWAC+10%SiC is shown in Fig 3 (b-c), which shows typical D-Gun sprayed coating of average thickness of 280µm.

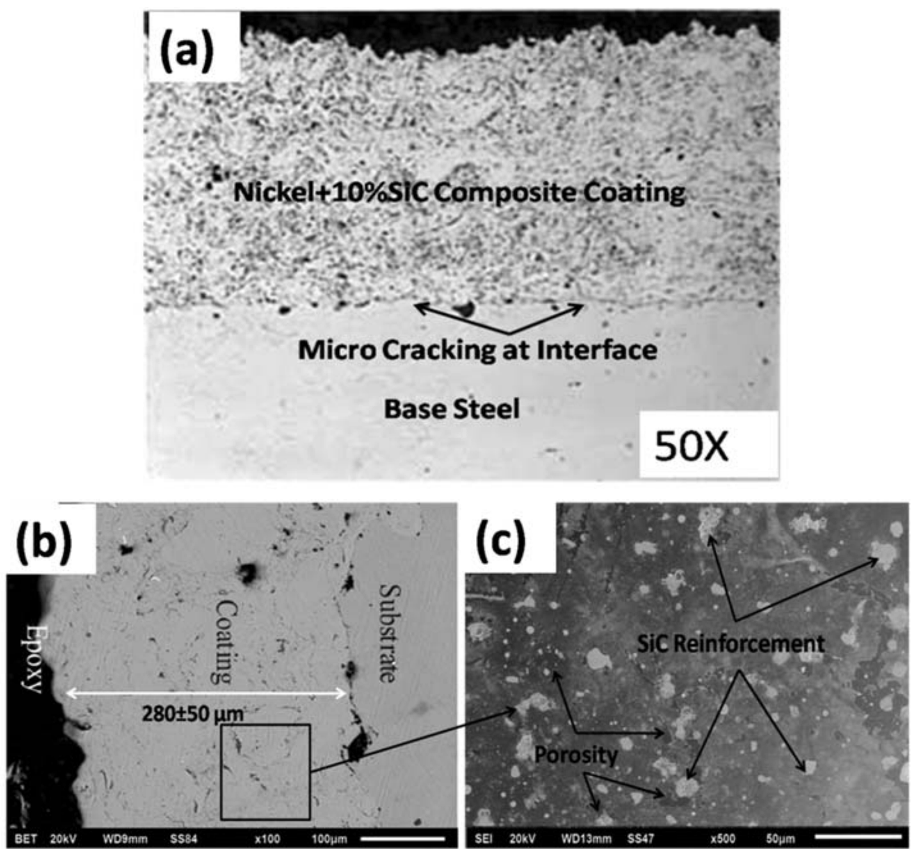

Fig 3: (a) Optical micrograph of EWAC+10% SiC coating, (b) SEM image of D-Gun sprayed coating and (c) Distribution of SiC reinforcement in nickel based matrix coating

The enlarged view of microstructure shows the distributions of SiC particles in nickel matrix. Microstructure reveals that due to difference in melting points of matrix and reinforcements, interfacial cracking and micro cracking is present. Insufficient bonding caused interfacial cracking, however, uniform distributions of reinforcement are observed.

Elemental analysis of developed coatings is carried out by using EDS analysis which is equipped with SEM. The results of elemental analysis of EWAC+10% SiC coatings developed by detonation gun are shown in Fig 4. Results revealed that nickel element is present in highest quantities at various locations of both the coatings. Presence of carbon and chromium can be seen in the analyses which are present in lower percentages. These elements are due to the EWAC powder composition.

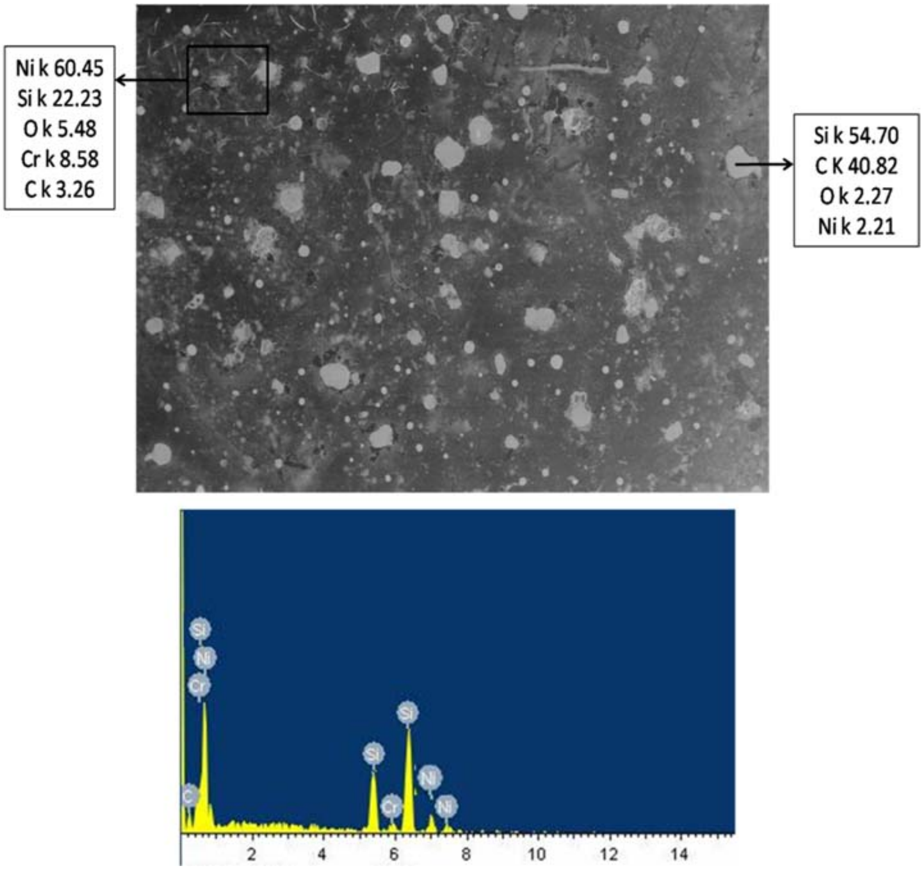

Fig 4: Results of EDS analysis carried out at various locations of EWAC+10% SiC

3.2 Microhardness study

The usefulness of developing coating on mild steel is evaluated by carrying out microhardness tests on the developed coatings. Microhardness contributes to the overall wear and erosion resistance of coatings. The result of Vickers microhardness of develop coatings were evaluated at load of 300 grams with dwell period of 25 seconds. Results revealed that base substrate exhibits Vickers microhardness of 350±18HV whereas developed coating showed 1.4 times higher microhardness i.e. 492.8±15HV. This increased microhardness will certainly affect the erosion wear of coating in comparison to base material.

3.3 Erosion wear study

Erosion wear is an important term related to machinery working under bulk material transportation or under silt conditions such as turbine blades. Experiments for erosion wear were carried out on the developed coatings and substrate material at varying levels of parameters. Cumulative mass loss (in milligrams) was recorded for all the samples and effect of various parameters on erosion wear was studied. The block representation of jet erosion tester is shown in Fig 5, which is used for erosion wear study.

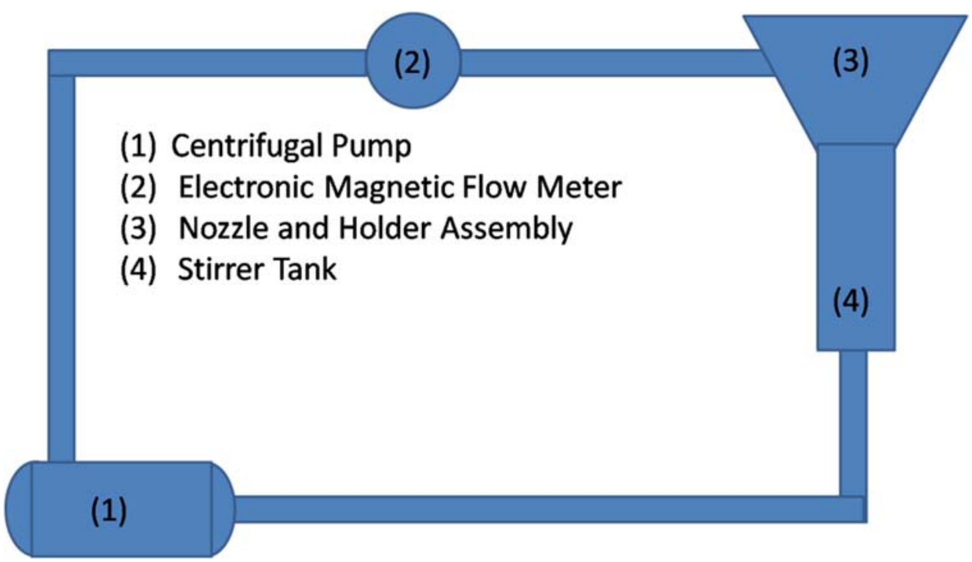

Fig 5: Block diagram showing the jet erosion tester

To study the effect of rotational speeds of pump on erosion wear at varying impingement angles, samples of substrate and developed coatings were placed in the holder. After placing of sample, angle is set and at particular RPM with slurry concentration (10% and 20% of silica sand mixed in water), flow rate and varying erodent size, tests were performed. Further, as per requirements the parameters were changed and results are reported in Table 3 and Table 4. Results are represented in the Fig 6-7.

Table 3: Effect of various parameters on erosion wear of substrate material

Exp. No.	Impingement Angle (Degree)	Rotational Speed	Erosion Wear (Cumulative mass loss in mg)	
			Slurry Concentration (Silica sand)	
			10%	20%
1	30	1000	35.8	51.6
2	45	1000	32.4	45.5
3	60	1000	28.6	32.2
4	30	2000	42.6	58.9
5	45	2000	36.4	46.8
6	60	2000	32.2	38.6
7	30	3000	51.8	72.6
8	45	3000	47.8	66.8
9	60	3000	37.3	52.9

Table 4: Effect of various parameters on erosion wear of EWAC+10% SiC coating

Exp. No.	Impingement Angle (Degree)	Rotational Speed	Erosion Wear (Cumulative mass loss in mg)	
			Slurry Concentration (Silica sand)	
			10%	20%
1	30	1000	22.2	32.7
2	45	1000	18.7	26.3
3	60	1000	16.5	19.8
4	30	2000	37.8	45.8
5	45	2000	33.5	38.2
6	60	2000	27.6	29.6
7	30	3000	42.2	54.9
8	45	3000	39.8	48.3
9	60	3000	29.8	41.5

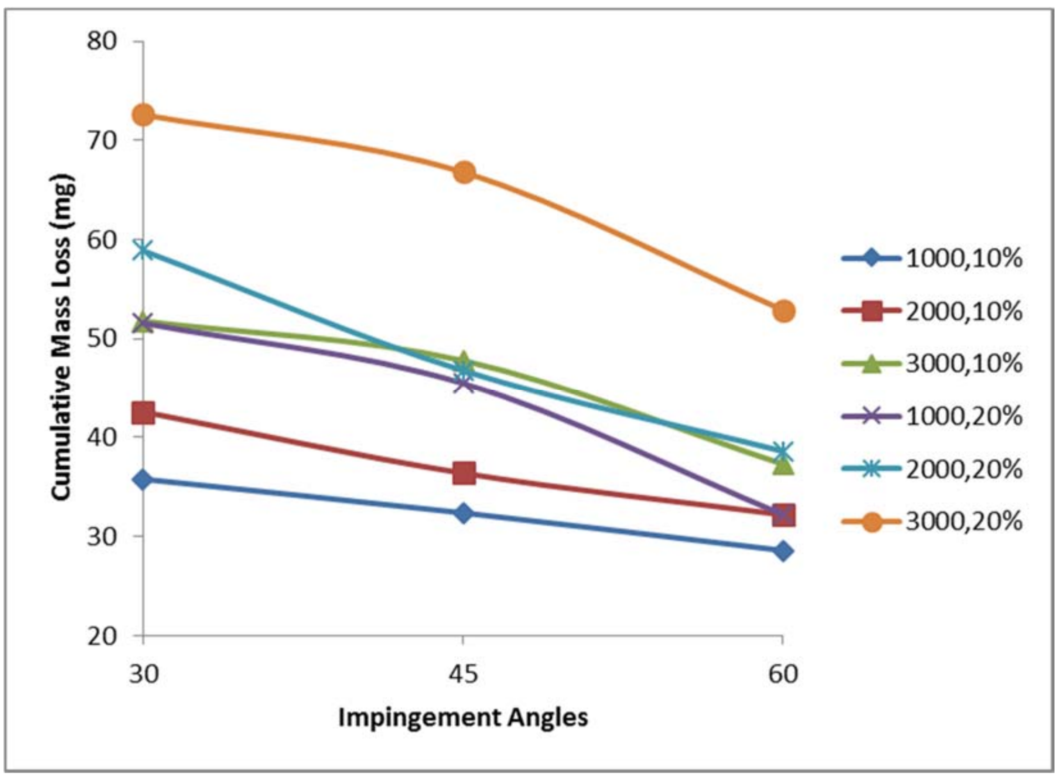

Fig 6: Erosion wear results of substrate material at varying parameters

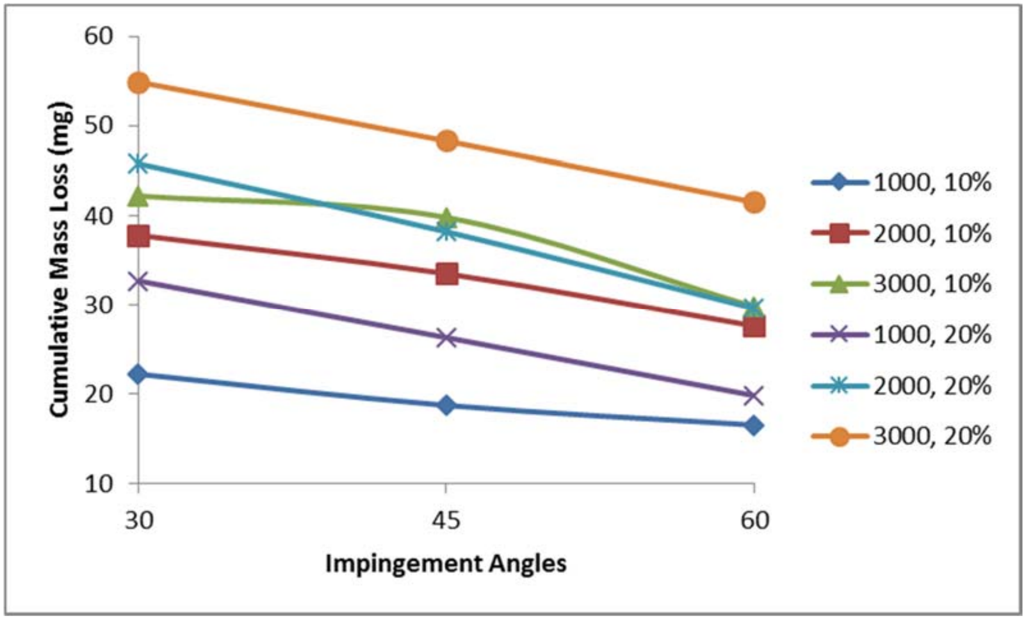

Fig 7: Erosion wear results of EWAC+10% SiC at varying parameters

Results revealed that maximum loss of material occurs for uncoated steel and at lower angles of impingement. As angles are increased, lower erosion wear occurs and this can be attributed due to the lower shearing force components at higher angles. It can be clearly seen that erosion wear of material decreases with increase in microhardness of materials. Lowest wear (16.6 mg) was reported for EWAC+10% SiC coating at 60° impingement angle, due to higher Vickers microhardness; whereas erosion wear was highest for substrate material (28.6 mg) at 1000 RPM and 10% concentration. Results again show that with further increase in rotational speed the mass loss increases significantly. This increase in mass loss is due to the increased momentum of particles striking the surface. Also the trend for impingement angles, the trend remains same i.e. decreasing mass loss with increase in angles. Coating of 10% SiC reinforced EWAC shows 22.2 mg of mass loss at 30°, which further reduces to 16.5 mg at 60° impingement angle. In comparison to substrate at an angle of 30°, 10% SiC reinforced composite shows 37.15% lower erosion wear at 10% slurry concentration.

The results revealed significant increase in erosion wear on increasing the slurry concentration and this is due to increased number of impacts per second per cm^2. This increase in impact increases the stress raisers which contribute to the overall mass loss. The wear of substrate was significantly affected due to lower microhardness, which leads to the higher removal of material with increased impacts.

4. Conclusions

The present work is based on the development of detonation gun sprayed coating of EWAC+ 10% SiC powders (metal-ceramic composite) on 13Cr4Ni steel. D-Gun sprayed developed coatings were characterized by analyzing the microstructures and elemental distributions. Microhardness was found out to justify the developmental purpose of coatings and further coatings were analyzed by carrying out erosion wear tests at various parameters. Following conclusions can be summarized from the work:

- In case of EWAC+SiC coatings, the microstructure revealed uniform distribution of ceramic reinforcement in the nickel based matrix.
- Results of Vickers microhardness tests revealed that average microhardness of substrate was 350 HV whereas coating of 10% SiC reinforced shows average microhardness of 492.8 HV, which was 1.4 times higher than the substrate material
- Results of erosion wear revealed that maximum cumulative mass loss of all the samples occurred at lower angles of impingement i.e. 30°. On increasing the impingement angles mass loss decreases and this is due to the lower cutting and shearing forces.
- The effect of increase in rotational speed revealed that on increasing the rotational speeds the mass loss of samples increases linearly. This is due to the increase in kinetic energy of particles which increases the impact strength of particles and enhances the erosion phenomenon.
- The results of slurry concentration revealed that on increasing the slurry concentration from 10% to 20%, a significant increase in mass loss of samples was observed.
- D-Gun spray composite coating was effective in erosion wear resistance.

References

1. Ardizzon G, Cavazzini G, Pavesi G. A new generation of small hydro and pumped-hydro power plants: Advances and future challenges. Renewable and Sustainable Energy Reviews 2014; 31:746-761.
2. Khan R. Small Hydro Power in India: Is it a sustainable business? Applied Energy 2015; 152:207-216.
3. Mishra MK, Khare N, Agrawal AB. Small hydro power in India: Current status and future perspectives. Renewable and Sustainable Energy Reviews 2015; 51:101-115.
4. Martins DEC, Seiffert MEB, Dziedzic M. The importance of clean development mechanism for small hydro power plants. Renewable Energy 2013; 60:643-647.
5. Nasir BA. Design Considerations of Micro-hydro-electric Power Plant. Energy Procedia 2014; 50:19-29.

6. Yüksel I. Hydropower for sustainable water and energy development. Renewable and Sustainable Energy Reviews 2010; 14(1):462-469.
7. Khurana Varun S, Kumar A. Effect of silt particles on erosion of Turgo impulse turbine blades. International Journal of Ambient Energy 2014; 35(3):155-162.
8. Bajracharya TR, Acharya B, Joshi CB, Saini RP, Dahlhaug OG. Sand erosion of Pelton turbine nozzles and buckets: A case study of Chilime Hydropower Plant. Wear, 2008; 264(3-4):177-184.
9. Kumar L, Parashar C, Kaur S. Prediction of silt erosion in hydraulic turbine, International Journal of Engineering Science. 2013; 4:963-970.
10. Gandhi BK, Singh SN, Seshadri V. A study on the effect of surface orientation on erosion wear of flat specimens moving in a solid–liquid suspension. Wear, 2003; 254(12):1233-1238.
11. Ramesh CS, Devaraj DS, Keshavamurthy R, Sridhar BR. Slurry erosive wear behaviour of thermally sprayed Inconel-718 coatings by APS process. Wear, 2011; 271(9-10):1365-1371.
12. Mishra SC, Praharaj S, Satpathy A. Evaluation of Erosion Wear of a Ceramic Coating With Taguchi Approach. Journal of Manufacturing Engineering. 2009; 4(2):241-246.
13. Santa JF, Espitia LA, Blanco JA, Romo SA, Toro A. Slurry and cavitation erosion resistance of thermal spray coatings. Wear, 2009; 267(1-4):160-167.
14. Kaushal G, Bala N, Kaur N, Singh H, Prakash S. Comparative High-Temperature Corrosion Behavior of Ni-20Cr Coatings on T22 Boiler Steel Produced by HVOF, D-Gun, and Cold Spraying. Metallurgical and Materials Transactions A, 2014; 45(1):395-410.
15. Kaushal G, Kaur N, Singh H, Prakash S. Effect of zirconium addition in HVOF sprayed Ni–20Cr coating. Surface Engineering, 2013; 29(1):46-54.
16. Kaushal G, Singh H, Prakash S. Performance of Detonation Gun-Sprayed Ni-20Cr Coating on ASTM A213 TP347H Steel in a Boiler Environment. Journal of Thermal Spray Technology. 2012; 21(5):975-986.
17. Higuera V, Belzunce FJ, Carriles A, Poveda S. Influence of the thermal-spray procedure on the properties of a nickel-chromium coating. Journal of Materials Science. 2002; 37(3):649-654.
18. Bala N, Singh H, Karthikeyan J, Prakash S. Performance of cold sprayed Ni-20Cr and Ni-50Cr coatings on SA 516 steel in actual industrial environment of a coal fired boiler. Materials and Corrosion 2013; 64(9):783-793.
19. Kim JH, Kim MC, Park CG. Evaluation of functionally graded thermal barrier coatings fabricated by detonation gun spray technique. Surface and Coatings Technology 2003; 168(2-3):275-280.