STUDY OF THE EFFECT OF SUB ZERO TREATMENT ON SLURRY EROSION BEHAVIOR ON DUPLEX STAINLESS STEEL

Dissertation-II

Submitted in partial fulfillment of the requirement for the award of degree

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By

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2	Project Feasibility: Project can be timely carried out in-house with low-cost and available resources in the University by the students.	5.00
3	Project Academic Inputs: Project topic is relevant and makes extensive use of academic inputs in UG program and serves as a culminating effort for core study area of the degree program.	7.00
4	Project Supervision: Project supervisor's is technically competent to guide students, resolve any issues, and impart necessary skills.	7.00
5	Social Applicability: Project work intends to solve a practical problem.	7.00
6	Future Scope: Project has potential to become basis of future research work, publication or patent.	6.00

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Final Topic Approved by PAC: **Study of the effect of Sub Zero Treatment on Slurry Erosion Behavior on Duplex Stainless steel.**

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ABSTRACT

In present study, the effect of sub zero treatment on the slurry erosion behavior of duplex stainless steel grade 2205 has been determined. The sub zero treatment is performed at a low temperature of -193 ^{o}C. The slurry erosion test rig has been used for the experimentation purpose. The impact of various erosion parameters such as impact velocity, slurry concentration and impingement angle on the material has been determined. A fixed stand off distance is used for the experimentation purpose. The design of experiments (DOE) has been used to determine the experimental conditions for slurry erosion testing. It has been observed that the erosion wear of sub zero treated samples of duplex stainless steel is less than the erosion wear of untreated samples of duplex stainless steel.

ACKNOWLEDGEMENT

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Finally, my head bows with reverence before the Almighty God and parents who have given me strength, wisdom and will to complete the work.

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CERTIFICATE

I hereby certify that the work being presented in the dissertation entitled "**Study of the Effect of Sub Zero Treatment on Slurry Erosion Behavior on Duplex Stainless Steel**" in partial fulfillment of the requirement of the award of the Degree of master of technology and submitted to the Department of Mechanical Engineering of Lovely Professional University, Phagwara, is an authentic record of my own work carried out under the supervision of **Mr. Rajeev Kumar,** Assistant professor, Department of Mechanical Engineering, Lovely Professional University. The matter embodied in this dissertation has not been submitted in part or full to any other University or Institute for the award of any degree.

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This is to certify that the above statement made by the candidate is correct to the best of my knowledge.

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The external viva-voce examination of the student was held on successfully ________________

Signature of Examiner

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Chapter-1

INTRODUCTION

1.1 IMPELLER

An impeller is a rotating device used to enhance the flow of a liquid. It is the most important component of the centrifugal pump. It changes the energy produced by a prime motor which helps in driving the pump to the liquid which is being pumped. The impeller is made from the various materials such as brass, aluminium and stainless steel. The impeller has been widely used in various devices such as air pumps, washing machines and water jets.

1.1.1 Working of Impeller

The impeller is a prime component of centrifugal pump. The centrifugal pump is based upon the principle of the centrifugal force. The impeller is placed inside the centrifugal pump in a casing. The liquid flows through the inlet of centrifugal pump into the impeller. As the impeller rotates, it creates a centrifugal force. The centrifugal force is acted upon the liquid which pushes the liquid away from the impeller towards the extreme ends of impeller blades. The liquid at the impeller blades is forced to move out through the discharge of the centrifugal pump.

Figure 1: Impeller

1.1.2 Materials Used for Making Impeller Blades

The various materials used for making impeller blades are cast iron, austenitic stainless steels, duplex stainless steels and bronze. Various austenitic stainless steel grades used for making impeller blades are 316L and 904L. Various duplex stainless steel grades used for making impeller blades are LDX 2507 and LDX 2205.

The austenitic stainless steels have low erosion resistance, low corrosion resistance and low mechanical strength while the duplex stainless steels have high erosion resistance, high corrosion resistance and high mechanical strength. The erosion wear of impeller blades made up of austenitic stainless steels is high. Due to this reason, the duplex stainless steels have been used to make impeller blades.

1.2 WEAR

It occurs when two solid surfaces are in sliding or rolling contact with each other which causes material to remove from one or both surfaces. In other words, wear results in loss of material due to physical contact between two surfaces.

1.2.1 Stages of wear: There are three stages of wear under usual mechanical and practical measures:

Primary stage: In this stage, surfaces adjust to each other and wear rate varies between high and low.

Secondary stage: In this stage, ageing occurs at a steady rate. This stage is comprised of the components operational life.

Tertiary stage: In this stage, components are prone to rapid failure due to high ageing rate.

1.3 TYPES OF WEAR

1.3.1 Adhesive wear: It occurs when two metal surfaces are in sliding contact with each other. It results in breaking the material from one surface and that material gets attached to the other surface which results in damaging the surfaces. Various Parts subjected to adhesive wear are impeller shafts, rings, engine bearings etc.

1.3.2 Abrasive wear: It occurs when hard surface moves along a soft surface under the influence of load which results in surface damage. The abrasive media results in the removal of surface material by chipping, cutting or fatigue cracking. Parts subjected to abrasive wear include piston rods, couplings, drill bits etc.

1.3.3 Erosive wear: It occurs when particles of solid or liquid impacts against a surface which results in removing the material from surface. Piping systems are usually prone to erosive wear. Slurry erosion results in the erosive wear. The rate of erosion depends upon various parameters such as impact velocity, impingement angle, slurry concentration, shape and size of particles. Slurry erosion is one of the main problem responsible for the deterioration in fluid machineries. Hydroturbines are mostly affected by the slurry erosion. The hydropower plants working in highly concentrated sandy water also faces the problem of slurry erosion. The blades of impeller are damaged due to the erosion wear. The Various Parts of hydroturbines subjected to erosive wear include impellers, nozzles, guide vanes, etc.

Figure 2: Erosion Wear of Impellers.

1.3.4 Corrosion and Oxidation wear: It takes place both in lubricated and unlubricated contacts. It occurs mostly due to chemical reaction between the worn material and corroding medium. It is also defined as a combination of corrosion and wear.

1.3.5 Fretting wear: This kind of wear takes place between two surfaces in contact due to the repeated cyclical rubbing. The material will be removed from the surfaces in contact after duration of time. Bearings are very much prone to this wear, even though bearings are provided with hard surface in order to oppose this problem. Fretting fatigue can takes place in which cracks are created in either surface. It can also cause catastrophic failure of the bearing which makes it most dangerous out of the two phenomenons.

1.4 CRYOGENIC TREATMENT

Steels are subjected to low temperatures i.e. below -190 ^oC in atmosphere of liquid nitrogen with a purpose to develop wear resistance and reduce residual stresses. This treatment is known as cryogenic treatment. Cryogenic treatment enhances performance by relieving residual stresses, increasing wear resistance and transforming the microstructure.

The process has found its use in various fields like aerospace, defence, automotives, mechanical industry etc. Cryogenic treatment provides several advantages which include improved thermal properties, less coefficient of friction, easier machining, and improved electrical properties.

1.5 TYPES OF CRYOGENIC TREATMENT

Cryogenic treatment is classified into two types:

1.5.1 Shallow Cryogenic Treatment (SCT): In this process, material is subjected to a low temperature range which is in between -100 ^oC to -60 ^oC. It results in reducing the retained austenite which results in enhancing the wear resistance of steel. Soaking time is around 6 hours.

1.5.2 Sub Zero Treatment: In this process, material is subjected to a very low temperature i.e. around -190 ^oC in order to improve its metallurgical properties. It causes martensite structure to reduce to a high extent. Soaking time is around 24 hours. In sub zero treatment, the temperature is decreased from room temperature to a low temperature around -190 ^oC. Then, soaking is done at low temperature of -190 ^oC for around 24 hours. Atlast, the temperature is increased from -190 ^oC to the room temperature.

Various benefits of sub zero treatment are:

It causes an improvement in the wear resistance property of the material.

It results in enhancing the impact resistance and fatigue limit of the material.

The sub zero treated material can resist higher temperatures.

It also causes an enhancement in the corrosion resistant property of the material.

1.6 PROCESSES

1.6.1 Cryogenic Hardening: In this process, liquid nitrogen is used to perform cooling of material to the temperature around -185^{o}C. The mechanical properties of some steels are deeply affected by this process but certain austenite is retained at room temperature on the basis of their composition and past heat treatment. It improves strength and hardness of the crystal structure of steel by enhancing the martensite amount in crystal structure. Excellent wear resistance is obtained when high chromium and high carbon steels are subjected to it. This process is applicable to various parts like brake motors, transmissions, clutches, brake parts, cutting tools, forming tools etc.

1.6.2 Cryogenic Machining: In this process, liquid nitrogen (LN_2) or pre-compressed carbon dioxide (CO_2) either is used to replace the conventional cooling liquid which contains a mixture of oil and water in order to carry the machining. It improves tool life when used in rough machining operations. It is used in finish machining operations in order to retain the quality and integrity of the machined surfaces. Machining with LN_2 or CO_2 reduces cutting temperature, cutting forces and tool flank wear.

1.6.3 Cryogenic Deflashing: In this process, flash removal from moulded work pieces is performed at low temperatures. It results in making the flash stiffer which helps in easily breaking it. It is used to remove excess material from oddly shaped, custom moulded products. Various moulded materials which can utilize cryogenic deflashing are silicones, plastics, rubber, liquid crystal polymer etc.

1.6.4 Cryogenic Deburring: In this process, burrs and flash are removed from the die casted work pieces at low temperatures. Work pieces are tumbled and abrasively blasted at low temperatures. In order to achieve the low temperature at around -195 ^{o}C, Liquid nitrogen or liquid carbon dioxide is used.

Chapter-2

REVIEW OF LITERATURE

M. Gholami et al.[1][2015] In present study, the impact of annealing temperature on the corrosion resistance of ferritic-austenitic stainless steel grade 2205 had been investigated. It was observed that the corrosion resistance of material got reduced by increasing the temperature. It was also revealed that after fast cooling from high temperatures, precipitates had been found in the microstructure. It resulted in reducing the corrosion resistance of material.

Gulovleen Singh et al.[2][2015] In present study, the erosion wear resistance of stainless steel grade 316L had been examined. The procedure involved comparing weight loss of samples after a fixed time. The erosion wear rate of material was determined on the basis of mass losses. It was observed that the erosion of material in standard load had occurred due to Wear mechanism. It was also found that the erosion wear rate had not been affected by the nozzle dimensions. Increasing the concentration would increase the erosion rate in uniform manner.

M. Lindgren et al.[3][2015] In present study, erosion wear resistance of three ferritic-austenitic stainless steel grades LDX 2101, LDX 2205, LDX 2507 and two austenitic stainless steel grades, 316L and 904L had been determined. It was observed that the improved erosion wear resistance had been shown by ferritic-austenitic grades LDX 2101 and LDX 2507 while the lesser erosion wear resistance had been shown by austenitic grades 316L, 904L and duplex grades 2205. It was also found that suction side samples had superior mass losses in comparison to pressure side samples.

Q.B. Nguyen et al.[4][2014] In present study, the slurry erosion behavior of the stainless steel-304 had been investigated with the help of a new advanced erosion test rig. It was revealed that initially the material had a high erosion wear rate but after some time it got reduced. Moreover, it was observed that a rise in velocity would enhance the erosion wear rate. Similarly, a rise in impact velocity would enhance the surface roughness of the material.

M. Lindgren et al.[5][2014] In present study, experimental work was done to investigate the erosion wear resistance of numerous austenitic and ferritic-austenitic stainless steel grades.

It was observed that austenitic grades had lower erosion resistance in comparison to ferritic-austenitic stainless grades. It was found that greater erosion wear resistance had been achieved by 316L amongst austenitic grades. Moreover, the lowest erosion wear resistance had been achieved by 2205 amongst ferritic-austenitic grades.

A. Idayan et al.[6][2014] In present study, the shallow and sub zero treatment had been performed on the AISI 440C bearing steel and its influence on the metallurgical attributes of the material was studied. It was observed that the shallow treated sample had more percentage amount of austenite which was reserved. Moreover, sub zero treated sample had more hardness as compared to the shallow treated sample. Scanning Electron Microscopy (SEM) was used to perform microstructural characterization of material.

Susanne Cordes et al.[7][2014] The present study described a new milling idea, Walter Cryo tec. With this idea, the internal multi-channel supply of cryogenic media as well as other media e.g. cold air, MQL or cutting emulsion was supported by means of a special machine tool spindle and an adapted cutting tool. Cutting tests were carried out with different cooling and lubrication strategies. The effects of these strategies were compared.

H.S. Grewal et al.[8][2013] In present study, the slurry erosion behavior of CA6NM steel had been investigated. The slurry erosion test rig had been used for the experimentation purpose. The effect of various erosion parameters on the material was analysed. The impingement angle and impact velocity had a significant effect on the erosion behavior of material. The erosion behavior of material remained unaffected by several parameters such as slurry concentration.

H.S. Grewal et al.[9][2013] In command to determine the means of erosion wear in materials, a factor named ''erosion mechanism identifier,'' ξ, had been recommended. It was found that the factor helped in judging the means of erosion wear in both elastic and breakable materials. Moreover, the factor had been proved helpful in enhancing the various attributes of material prone to the wear.

B. Dilip Jerold et al.[10][2012] In present study, the consequences of perfoming low temperature cooling during the machining of AISI 1045 steel material had been investigated. Liquid nitrogen had been used to attain low temperature cooling. It was observed that the low temperature cooling had resulted a significant decrease in the cutting temperature. It had impacted in decreasing the tool wear.

S. Ravi et al.[11][2011] In present study, the consequences of performing low temperature cooling during the milling process of hardened steel material had been examined. Low temperature cooling had been preferred over conservative cutting fluids. It was observed that the low temperature cooling had resulted in decreasing the tool flank wear and cutting temperature during the process.

Paolo Baldisesera et al.[12][2010] In present study, the sub zero treatment had been carried out on the stainless steel AISI 302 and its influence on fatigue and corrosion resistance of the material was examined. It was observed that sub zero treatment could provide advancement in the fatigue behavior of the material. In addition, the sub zero treatment had not caused much deviation in the corrosion resistance of the material.

Paolo Baldisesera et al.[13][2010] In present study, the sub zero treatment had been performed on the stainless steel AISI 302 and its influence on the metallurgical attributes of the material was investigated. Different metallurgical attributes such as hardness and toughness were determined. Moreover, the consequences of soaking-time and lowest temperature on different attributes of material was observed. It was found that sub zero treatment had resulted in advancing the metallurgical attributes of material.

Muammer Nalbant et al.[14][2010] In present study, the outcomes of low temperature cooling on various cutting parameters during the milling process of stainless steel AISI 304 had been investigated. Liquid nitrogen had been used with a purpose to attain low temperature cooling. It was found that the low temperature cooling had resulted in increasing the cutting forces and torque.

Mahdi Koneshlou et al.[15][2010] In present study, the sub zero treatment had been carried out on a hot worked tool steel and its influence on the microstructure and metallurgical attributes of the material was studied. By performing sub zero treatment, it had been observed that the retained austenite got changed into martensite. It was found that the change in microstructure had caused a chief enhancement in the metallurgical attributes of the material.

Girish R. Desale et al.[16][2009] In present study, the influence of particle size on the erosion wear mechanism of aluminium alloy had been investigated. A slurry pot tester was used for the experimentation purpose. It was observed that as the mean particle size had increased, the erosion wear had also increased. It happened due to the occurrence of a threshold kinetic energy of the striking particles.

Shaohong li et al.[17][2009] In present study, the sub zero treatment had been performed on a cold worked die steel and its influence on the metallurgical attributes of the material was examined. By application of sub zero treatment on the material, the hardness of material improves at the expense of its toughness. The retained austenite had not been entirely changed to martensite.

A Akhbarizadeh et al.[18][2009] In present study, the sub zero treatment had been performed on D6 tool steel material and its influence on metallurgical and microstructural attributes of the material was examined. The SEM and XRD techniques were used to determine the microstructural features. It was observed that the austenite which was reserved had been entirely altered to martensite throughout the sub zero treatment.

J.F. Santa et al.[19][2007] In present study, the two layers developed by oxy-fuel powder (OFP) and wire arc spraying (WAS) processes onto the stainless steel AISI 304 had been examined to determine the slurry erosion behavior. Modified centrifugal pump was used to carry out slurry erosion tests. The composition of slurry includes quartz sand particles, distilled water and amount of solid content. It was observed that uncoated surfaces showed lower erosion resistance in comparison to coated surfaces.

E.A.M. Hussain et al.[20][2006] In present study, the duplex stainless steel 2205 was tested to determine the erosion-corrosion. The impact of particles had damaged the passive film which caused anodic current density to increase. The particle kinetic energy and hydrodynamic conditions were responsible for controlling the erosion-corrosion of the material. The stagnation region in which particles of sand had impacted normal to the surface was the location of maximum erosion-corrosion.

M. Scherge et al.[21][2003] In present study, the friction had been discussed. When surfaces interact during comparative motion between each other, it was observed that maximum impact occurred at various locations of roughness. Every location of roughness had an initiated energy which was sufficient to relocate the material into a fluid state. Occurrence of roughness had resulted in internal mixing of surfaces of materials. It had affected the surface properties of the materials in contact.

Shane Y. Hong et al.[22][2000] In present study, the liquid nitrogen had been used in cryogenic machining which impacted the various parameters during machining of AISI 304 austenitic stainless steel. In comparison to conservative machining using environmentally polluting cutting oils, cryogenic machining served as a clean choice. Hence, better results could be obtained by employing a cryogenic cooling approach.

Fuyan Lin et al.[23][1991] In present study, the impact of impingement angle on the slurry erosion behavior of metallic and non- metallic materials had been investigated. It had been observed that the erosion rate for ductile materials increased with an increase in impingement angle whereas the erosion rate for brittle materials decreased with an increase in impingement angle. It was also observed that the erosion rate had a linear relation with respect to abrasive grit size.

M. Fiset et al.[24][1990] In present study, the impact of sand concentration on the slurry erosion behavior of material had been investigated. An erosion machine with a slurry jet was used for the experimentation purpose. It had been observed that erosion rate showed reduction. It was also observed that the erosion profile had been more dependent on the flowing property of abrasive particles.

S. Turenne et al.[25][1990] In present study, the experimental work was performed on different abrasive size ranges of alumina-particle-reinforced aluminium alloy in order to investigate the slurry erosion behavior. In shallow-impingement-angle conditions, the surrounding matrix was sheltered by the reinforcement. The fine particles powerfully deviate near the surface for large impact angles.

Chapter-3

SCOPE OF THE STUDY

The stainless steel grades are widely used to make different parts of hydroturbines. The blades of impeller are made from different austenitic stainless steel grades such as 316L and 904L. The various properties of austenitic stainless steels include higher ductility, higher strength etc. The material of impeller blades suffer from the problem of erosion wear due to continuous exposure to slurry. The slurry erosion is one of the main problems associated with the hydroturbines.

So, we need to select a material for making impeller blades which has better erosion resistance. Therefore, austenitic-ferritic or duplex stainless steel grades such as LDX 2205 and LDX 2507 are employed to make blades of impeller. Duplex stainless steels have greater strength as compared to austenitic grades. They have better erosion resistance than austenitic grades. Other advantages of duplex stainless steels over austenitic stainless steels include less weight and low cost. Further we can perform the sub zero treatment on duplex stainless steel and compare the erosion wear of sub zero treated and non-treated duplex stainless steel. The impact of various erosion parameters such as impact velocity, impingement angle and concentration can also be studied.

Chapter-4

OBJECTIVES OF THE STUDY

Some of the proposed objectives of the study are discussed as:

1. To study the effect of sub zero treatment on the slurry erosion behavior on duplex stainless steel grade 2205.

2. To compare and study the erosion wear property of sub zero treated duplex stainless steel and non-treated duplex stainless steel.

3. To compare and study the effect of various erosion parameters such as impact velocity, impingement angle and slurry concentration on sub zero treated duplex stainless steel and non-treated duplex stainless steel.

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Chapter-5

MATERIAL AND RESEARCH METHODOLOGY

5.1 MATERIAL

The material used for the research work is duplex stainless steel grade LDX 2205.
The material has been purchased from Bharat Aerospace Metals, Mumbai, Maharashtra.
The spectroscopy analysis of the material has been performed at the Institute for Auto Parts and Hand Tools Technology, Ludhiana, Punjab to ensure the chemical composition of the material.
The general chemical composition (% by wt.) of material includes:

Elements	**Chemical Composition (% by wt.)**
Carbon	0.03
Chromium	22.33
Nickel	5.33
Molybdenum	3.00

Table 1: Chemical Composition of Material

Each sample of the duplex stainless steel grade 2205 has dimensions of 30×20×5 mm.
Before testing, samples are polished with emery papers of 1200 grit size. This has been followed by polishing with the help of diamond paste on the disc polishing machine.

5.2 RESEARCH METHODOLOGY

The sub zero treatment of the material has been performed at Cryonet, Surat, Gujarat. The sub zero treatment of the material has been performed at a temperature of -193 ^{o}C.
For the purpose of testing, jet type erosion test rig has been used which is available at the Indian Institute of Technology, Roopnagar, Punjab.

Figure 3: Slurry Erosion Test Rig.

Testing has been done using slurry composed of sand mixed in tap water. For the experimentation purpose, three of the operating parameters namely impact velocity, impingement angle and slurry concentration are varied using the full factorial approach. The Design of Experiments ((DOE) has been prepared using the full factorial approach in the minitab software.

The fixed stand-off distance of 30 mm has been utilised for the testing purpose. The testing has been done on each sample for a cycle of 1 minute and after each cycle, weight loss is measured. The weight loss has been measured using a precision weighing balance having an accuracy of 0.01 mg. Before weight measurements, samples are washed with acetone and dried in air to remove any dirt on moisture content. The full factorial design using three parameters shows that eight samples are to be prepared. As the sub zero treatment is also done, therefore eight samples of sub zero treated duplex stainless steel and eight samples of untreated duplex stainless steel are to be prepared. It means that 16 samples of duplex stainless steel are prepared. The weight loss measured provides the erosion wear.

In the full factorial approach, the impact velocity is varied from 4 m/s to 12 m/s, the impingement angle varies from 30 degrees to 90 degrees and the concentration varies from 0.1 wt% to 0.3 wt%.

Chapter-6

RESULTS AND DISCUSSION

6.1 THE EROSION WEAR ANALYSIS OF UNTREATED SAMPLES

The experimental conditions have been prepared using the full factorial approach. The impact velocity is varied from 4 to 12 m/s, the impingement angle varies from 30 degrees to 90 degrees and the concentration varies from 0.1 wt% to 0.3wt%. As three factors are varied using the full factorial approach, therefore eight experimental conditions are prepared.

Run	Impact Velocity (m/s)	Impingement Angle (Degrees)	Concentration (wt%)	Erosion Wear (Grams)
1.	12	90	0.3	0.00043
2.	12	90	0.1	0.00050
3.	4	90	0.3	0.00027
4.	12	30	0.1	0.00026
5.	4	30	0.3	0.00046
6.	4	90	0.1	0.00023
7.	12	30	0.3	0.00112
8.	4	30	0.1	0.00032

Table 2: Erosion Wear of Untreated Duplex Stainless Steel Samples.

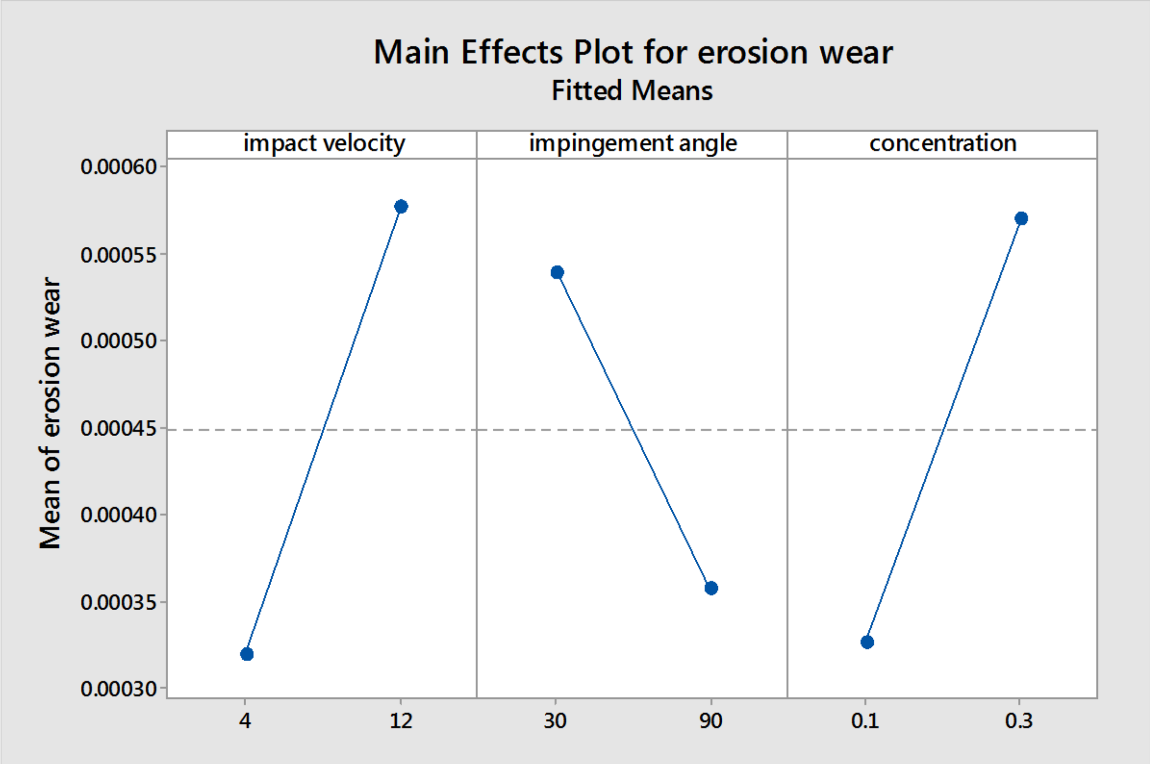

Figure 4: Main Effects Plot for Erosion Wear of Untreated Duplex Stainless Steel.

The erosion wear versus impact velocity plot shows that as the impact velocity increases, the erosion wear also increases in a similar manner. It occurs due to the pit density which is defined as the number of pits produced per unit area due to particles impact. At low impact velocity, the pit density was less while at high impact velocity, the pit density was high. Therefore, as the pit density increases, the erosion wear also increases.

The erosion wear versus impingement angle plot shows that as the impingement angle increases, the erosion wear decreases. At 90 degrees impingement angle, the platelet mechanism occurs which is a slow process while at 30 degrees impingement angle, the ploughing occurs along with mixed cutting ploughing mechanism which is more effective for material loss. Therefore, erosion wear is high at 30 degrees angle while low at 90 degrees angle.

The erosion wear versus concentration plot shows that as the concentration increases, the erosion wear also increases in a similar manner. At a concentration of 0.1 wt%, the number of particles impacting the surface are less while at a concentration of 0.3 wt%, the number of particles impacting the surface are more. Therefore, erosion wear is lesser at low concentration while erosion wear is more at high concentration.

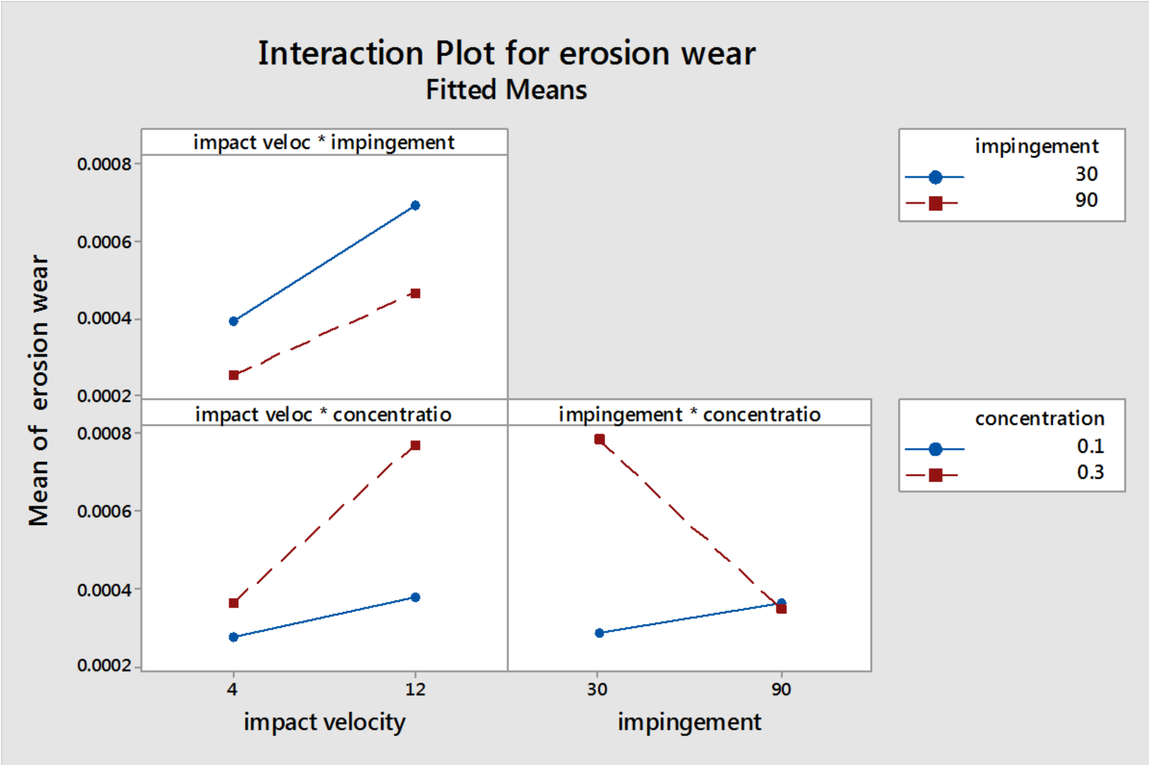

Figure 5: Interaction Plot for Erosion Wear of Untreated Duplex Stainless Steel.

The erosion wear versus impact velocity and impingement angle plot shows that as the impact velocity increases at 90 degrees impingement angle, the erosion wear also increases. Similarly, as the impact velocity increases at 30 degrees impingement angle, the erosion wear also shows increase. It is also observed that erosion wear at 30 degrees impingement angle is greater than erosion wear at 90 degrees impingement angle.

The erosion wear versus impact velocity and concentration plot shows that as the impact velocity increases at concentration of 0.1 wt% , the erosion wear also increases. Similarly, as the impact velocity increases at concentration of 0.3 wt% , the erosion wear also shows increase. It is also observed that erosion wear at concentration of 0.3 wt% is greater than erosion wear at concentration of 0.1 wt%.

The erosion wear versus impingement angle and concentration plot shows that as the impingement angle increases at concentration of 0.1 wt% , the erosion wear shows increase. It is also observed that as the impingement angle increases at concentration of 0.3 wt% , then the erosion wear decreases.

6.2 THE EROSION WEAR ANALYSIS OF SUB ZERO TREATED SAMPLES

The experimental conditions have been prepared using the full factorial approach. The impact velocity is varied from 4 to 12 m/s, the impingement angle varies from 30 degrees to 90 degrees and the concentration varies from 0.1 wt% to 0.3wt%. As three factors are varied using the full factorial approach, therefore eight experimental conditions are prepared.

Run	**Impact Velocity (m/s)**	**Impingement Angle (Degrees)**	**Concentration (wt%)**	**Erosion Wear (Grams)**
1.	12	90	0.3	0.00028
2.	12	90	0.1	0.00014
3.	4	90	0.3	0.00017
4.	12	30	0.1	0.00022
5.	4	30	0.3	0.00018
6.	4	90	0.1	0.00022
7.	12	30	0.3	0.00021
8.	4	30	0.1	0.00018

Table 3: Erosion Wear of Sub Zero Treated Duplex Stainless Steel Samples.

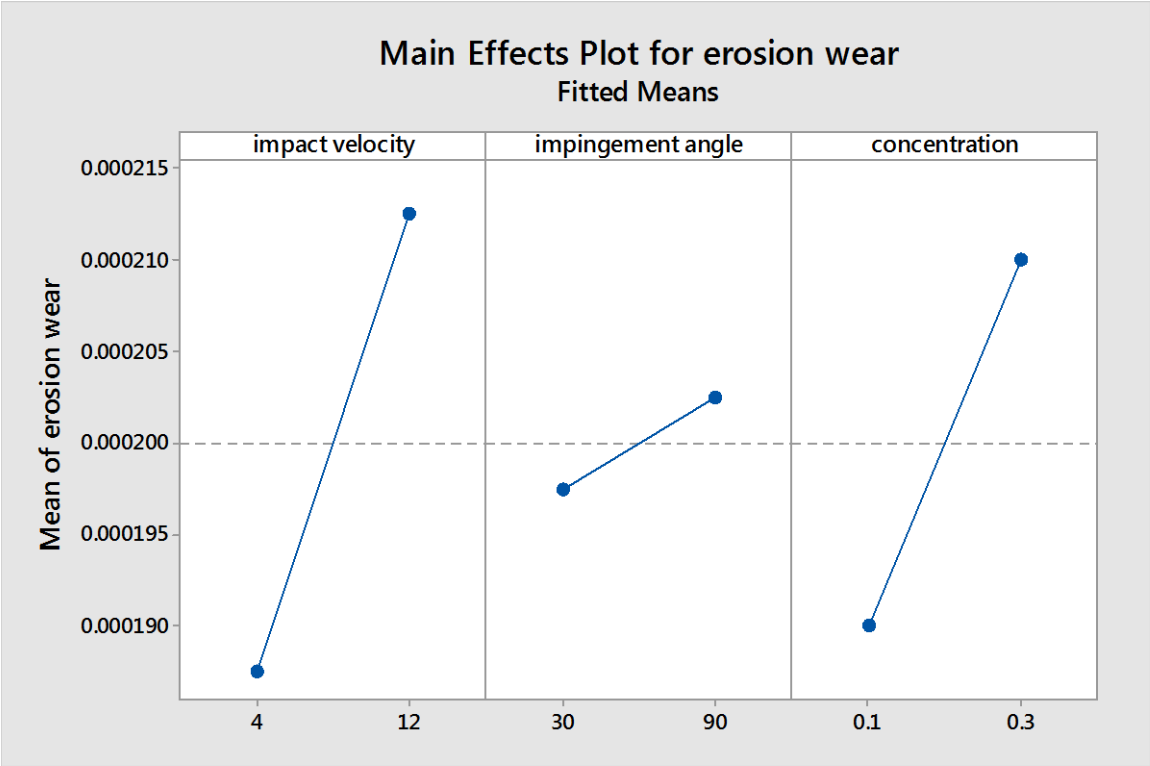

Figure 6: Main Effects Plot for Erosion Wear of Sub Zero Treated Duplex Stainless Steel.

The erosion wear versus impact velocity plot shows that as the impact velocity increases, the erosion wear increases in a similar manner. It occurs due to the pit density which is defined as the number of pits produced per unit area due to particles impact. At low impact velocity, the pit density was less while at high impact velocity, the pit density was high. Therefore, as the pit density increases, the erosion wear also increases.

The erosion wear versus impingement angle plot shows that as the impingement angle increases, the erosion wear also increases up to a smaller extent. This happens because at 90 degrees impingement angle, the platelet mechanism occurs while at 30 degrees impingement angle, ploughing occurs at a smaller extent.

The erosion wear versus concentration plot shows that as the concentration increases, the erosion wear also increases. At a concentration of 0.1 wt%, the number of particles impacting the surface are less while at a concentration of 0.3 wt%, the number of particles impacting the surface are more. Therefore, erosion wear is lesser at low concentration while erosion wear is more at high concentration.

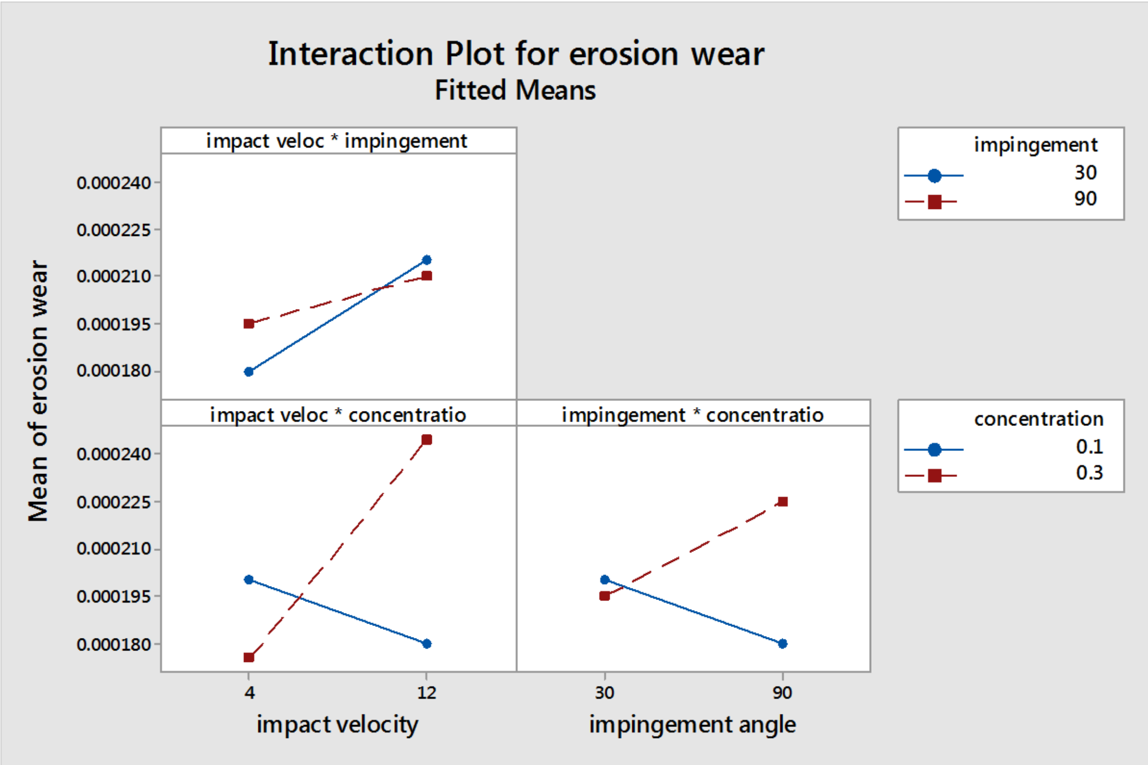

Figure 7: Interaction Plot for Erosion Wear of Sub Zero Treated Duplex Stainless Steel.

The erosion wear versus impact velocity and impingement angle plot shows that as the impact velocity increases at 30 degrees impingement angle, the erosion wear also increases. Similarly, as the impact velocity increases at 90 degrees impingement angle, the erosion wear shows a increase. It is also observed that erosion wear at 30 degrees impingement angle is greater than erosion wear at 90 degrees impingement angle.

The erosion wear versus impact velocity and concentration plot shows that as the impact velocity increases at concentration of 0.1 wt% , the erosion wear shows a decrease. It also shows that as the impact velocity increases at concentration of 0.3 wt% , the erosion wear shows a increase. It is also observed that erosion wear at concentration of 0.3 wt% is greater than the erosion wear at concentration of 0.1 wt%.

The erosion wear versus impingement angle and concentration plot shows that as the impingement angle increases at the concentration of 0.1 wt% , the erosion wear shows a decrease. It also shows that as the impingement angle increases at concentration of 0.3 wt%, the erosion wear shows a increase. It is also observed that the erosion wear at the concentration of 0.3 wt% is greater than the erosion wear at concentration of 0.1 wt %.

Chapter-7

CONCLUSION AND FUTURE SCOPE

The effect of sub zero treatment on the slurry erosion behavior on duplex stainless steel grade LDX 2205 has been investigated. The duplex stainless steel has been used as a material for making blades of impellers in hydroturbines. The erosion wear of sub zero treated and untreated samples of duplex stainless steel have been determined with the help of slurry erosion test rig. The effect of various parameters such as impact velocity, impingement angle and slurry concentration on the erosion wear of material has been determined. It has been observed that the erosion wear of sub zero treated samples of duplex stainless steel is lower than that of the untreated samples of duplex stainless steel. It has also been observed that the impact velocity and impingement angle has a significant effect on the erosion wear of material.

Further, we can compare and study the erosion wear of sub zero treated austenitic and duplex stainless steel grades. We can also compare and study the microstructural characterization of sub zero treated austenitic and duplex stainless steel grades. The impact of various erosion parameters such as stand off distance and cycle time duration can also be studied.

Chapter-8

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