Mansoura University
Faculty of Engineering
Mansoura Engineering Journal

Effect of Material Type, Impact Angle and Specimen Shape on Erosion Process

تأثيرنوع المادة وزاوية التصادم والشكل الهندسى للعينة على عملية التآكل

Tawfik Tawfik El-Midany, *Abdou Abdel Fattah Abdel Samad*, *Ahmed Mohamed Galal Abdel Moneim* and Yaser Sood Abdel-Aziz Saleh

KEYWORDS:
Slurry pot erosion tester, Impact angle, Stainless Steel 304, coated Steel 37 and Erosion resistance

الملخص العربي:- **تم دراسة تأثير الشكل الهندسى على عملية التآكل وكذلك زاوية التصادم للصلب 304 المقاوم للصدأ وصلب 37 المطلي بطبقة نيكل كروم سمكها 38 ميكرون مقاومة للتآكل، وذلك بأستخدام جهاز يقوم بدوران العينات داخل خزان أسطوانى شفاف يحتوى على مياة وبها حبيبات رمل معلقة وبذلك تكون هناك سرعة نسبية بين العينات والحبيبات المعلقة بالسائل. تم إجراء اختبارات التآكل عندما كان تركيز الحبيبات الصلبة 40% وسرعة التصادم بين العينات والسائل المحمل بالحبيبات الصلبة 2.3 م/ث. حجم الحبيبات المستخدمة فى الأختبارات أقل من 550 ميكرون .**

تم إختبار شكلين من العينات الأولى مسطحة وتم تثبيتها بزوايا مختلفة و الثانية أسطوانية الشكل. تم قياس معدل التآكل فى العينات عن طريق ميزان الكترونى ذو حساسية 0.0001 جرام وتم دراسة وفحص عدد من مواقع الصدم وطرق تشكيلها على سطح العينات المختلفة بإستخدام مجهر الماسح الإلكترونى ثم تحليل الصور المجهرية.

أوضحت النتائج أن شكل المعدن يوثر مباشرة فى زاوية إصطدام الحبيبات بالمعدن. وأن زاوية إصطدام الحبيبات تؤثر مباشرة على معدل تأكل المعدن و شكل التآكل ويتضح ذلك من تغير التآكل على السطح الأسطوانى مما يدل على أن الشكل المقابل للسائل المحمل بالحبيبات الصلبة يؤثر تأثيرا كبيرا على معدل التآكل ويمكن مراعاة ذلك فى التصميم.كما أن زيادة مدة الأختبار الزمنية توثر على زيادة معدل التآكل وكذلك شكل معدل التآكل وكذلك طلاء المعدن بطبقة مقاومة للتآكل تقلل من معدل التآكل.

Abstract— **The present work is a study of the effect of specimen shape for different specimen types and test duration times on the erosion process. Erosion changes the surface geometry of the parts, components of machines that will affect the performance and efficiency of the parts to be lower than design and may cause failure. Experimental test was carried out using a specially designed test-rig to investigate the effect of specimen shape for Stainless steel 304, and steel 37 coated with Ni-Cr thin film (38 μm) in material erosion. The test-rig is based on Specimens rotate in slurry pot, sand in water, with a controlled speed to simulate a required relative velocity between slurry and specimens. Sand particles concentration with water was of 40 wt. %. The sand particle maximum size was 550 μm.**

Results were investigated using weighting with sensitivity up to 0.0001gm and SEM examination. Results showed that there are different erosions on the cylindrical surface according to the impact direction. Also the impact angle has a great effect on the weight loss, for stainless steel 304, the maximum weight loss around 47o impact angle. Coating steel 37 showed a maximum wear in coating for the cylindrical shape at positions with angles between 40 o and 60o with the velocity direction.

Received: 10 February, 2016 – accepted: 4 April, 2016

Prof. Dr. Tawfik Tawfik El-Midany, Prof. at Department of Production Engineering and Mechanical Design.

Prof. Dr. Abdou Abdel Fattah Abdel Samad, Prof. at Department of Production Engineering and Mechanical Design.

Assoc. Prof. Dr. Ahmed Mohamed Galal Abdel Moneim, Assoc. Prof.at Department of Production Engineering and Mechanical Design.

Eng. Yaser Sood Abdel-Aziz Saleh, B.Sc. (Eng.), M.Sc. at Department of Production Engineering and Mechanical Design.

I. INTRODUCTION

Wear may occur due to corrosion, which is caused by chemical reactions. Other three major categories of wear in which most situations can be abrasive, adhesive, and erosive. [1]

Erosion is a type of wear which is defined as the progressive volume loss of material from a target surface. Thus erosion can be a serious deteriorating effect in many engineering systems, including hydraulic machines, hydraulic systems, pipelines and valve handling gases, aerospace components, and liquid impellers. The damage occurs at individual microscopic strikes, where many repeated strikes may cause material loss. [2]

Slurry erosion is the progressive damage created on solid surfaces by the impact of solid particles carried by a liquid stream. Slurry erosion is a serious problem for the industries, which deals with the liquids having solid particles entrained in them. When such a mixture of liquid and solid particles termed as slurry come in contact with the machine element, the removal of material takes place from the surface making the component redundant from the surface. [3, 4, 5, and 6]

Cavitation erosion usually involves an attack on the surface by gas or vapor bubbles, creating a sudden collapse due to a change in pressure near the surface.

A marine pump impeller made from stainless steel 304 has been reported failure at root cause after 2-year service in high-velocity sand containing seawater. The failure was identified as erosion–corrosion for this case is defined as acceleration or increase in the rate of materials deterioration caused by the combined actions of electrochemical corrosion and mechanical wear processes [7]

In general wear may cause significant surface damage which is usually thought as gradual deterioration. The main feature in wear failure are:

(a) Removal of material and reduction of dimension as a mechanical action

(b) Wear takes place as a result of plastic deformation and detachment of materials over a period of time. [8]

Parameters affecting Erosion Wear are the angle of impingement and the other listed parameters illustrated schematically in Figure (1). These are the parameters which can control the erosive wear. [9].

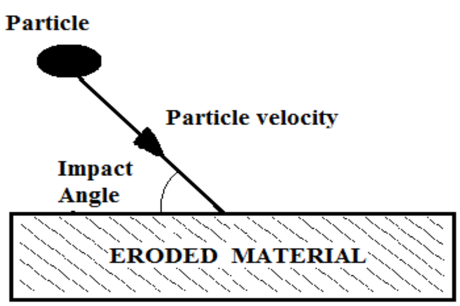


Figure (1) Physical and material parameters for controlling erosive wear.

These quantities are largely determined by the flow conditions and many practical examples may be found where a change in flow conditions has greatly increased or decreased erosion. Where the wear is due to abrasion and/or erosion, it can only be minimized by controlling the affecting parameters.

Finally, parameters affecting erosion wear can be divided into three groups, properties of target material, erodent properties, and Test parameters

a) Properties of target material; Chemical composition, Microstructure, Surface Mechanical properties, Surface roughness

b) Erodent properties, Shape, Size, Hardness, Type of erodent and Particle flux

c) Test parameters; Angle of impingement, Particle velocity, Temperature, Particle flux (mass per time), Erosion media (air or water), Time duration.

Clearly, the site of impact is subjected to extremely high stress, strain, and strain rates, and there is now evidence that local heating can be generated by the impact energy. Oxidation can therefore be induced; the erosion of a surface by abrasive particles in an inert fluid should depend on the number of particles striking the surface, their velocity and their direction relative to the surface. [9, 10, and 11]

In Erosion process there is a transfer of kinetic energy to the surface. With the increase in kinetic energy of the particles impacting at the target surface, it leads to increase in the material loss due to erosion. It depends on the predominant impact angle of particle impingement with the material surface and it will vary from 0 to 90 degrees. Impact angle depend on both fluid particle and particle –particle interaction. This type of wear can be practically found in slurry pumps, angled pipe bends, turbines, pipes and pipefitting, nozzles, burners etc. The material loss due to erosion increases with the increase in kinetic energy of the particles impacting at the target surface. [3].

Imrek et al. [12] studied the effects of erodent impact angles on erosive wear at different external tensile load. The study shows that increase the applied tensile loads on the specimen, erosive wear increases. Due to the stress increase in the cross section of the specimen causes changes in the atomic lattice and this increased erosive wear. Results show that the impact angle affecting the erosion rate, the maximum erosive wear rate lies between 20o and 30o. and the maximum erosion rate was obtained at 30o impinging angle. However; as the angle increases the erosion rate was seen to decrease.

Pramod et al (2015) [3] investigate the mean particle size of 655 μm was collected as the material retained between the two sieves of 600 μm and 710 μm sizes. The target material is Aluminum alloy 6063 and the solid particles are Quartz (IS Sand), particle size is 655 μm, solid concentration is 10% by weight in water fluid. The test time is 60 min. It was found that the test taken for different angular positions it is observe that the maximum weight loss is occur at 300 angle of impact and it decreases as angle is decreases respectively that is due to the target material (AA6063) is ductile material.

Abd-Elrhman et al. (2013) [13] investigated the influence of carburizing on the slurry erosion behavior of AISI 5117 steel. They utilized a whirling-arm rig. They investigated the microstructure and hardness profile of the surface layer. Scanning electron microscope (SEM) images at different locations were used to characterize the slurry damage process. The study also focused on studying the erosion wear resistance properties of AISI 5117 steel after carburizing. The tests were carried out with particle concentration of 1 wt. %, and the impact velocity of slurry stream was 15 m/s. Silica sand had a nominal size range of 250 – 355 µm. The results showed that, carburizing process of steel increased the erosion resistance and hardness compared with untreated material for all impact angles. The erosion resistance of AISI 5117 steel increases by 75%, 61%, 33%, 10% at an impact angle of 30 deg, 45 deg, 60 deg, and 90 deg, respectively. Treated and untreated specimens behaved as ductile material, and the maximum mass loss appeared at impact angle of 45 deg. They concluded that chipping of the former impact sites by subsequent impact particles plays an important role in developing erosion.

Abd-Elrhman et al. (2014) [14] described erosion technique to investigate the influence of impact angle on the erosion process of AISI 5117 steel. They investigated the number of impact sites and their morphologies at different impact angles. Scanning electron microscope (SEM) examination and image analysis were performed. The tests were carried out with concentration of 1 wt. %, and the impact velocity of slurry was 15 m/s. Silica sand with nominal size range of 250–355 µm, was used as an erodent, using whirling-arm test rig. The results showed that the number of craters, increases with the increase in the mass of erodent for all impact angles. The effect of impact angle based on the impact crater shape was divided into two regions; the first region for $\theta \leq 60$ deg and the second region for $\theta \geq 75$ deg. The shape of the craters was related to the dominant erosion mechanisms of plowing and micro-cutting in the first region and indentation and lip extrusion in the second region. In the first region, the length of the tracks decreased with the increase of impact angle. The calculated size ranges were from few micrometers to 100 µm for the first region and to 50 µm in the second region. Chipping of the former impact sites by subsequent impact particles played an important role in developing erosion.

Amarendra et al (2012) [15] modified a slurry pot tester for cavitation and slurry erosion. A test setup and tests were conducted in a conventional slurry pot having a circular section of diameter 282 mm and height of 286 mm, with four baffle plates Specimen holder fastened to spindle of the tester through a connecting rod. The spindle was driven by a 3 kW motor through stepped cone pulley capable of delivering 500, 900 and 1400 rpm speeds. They concluded that cavitation inducer is adapted in the conventional slurry pot tester to induce cavitation damage along with the slurry erosion. With present test setup, 240% more erosion for brass is observed as compared to slurry erosion alone. It is observed that testing with the cavitation inducers together with the slurry resulted in synergistic wear. This laboratory test method is ideal for the study of combined effects of particle and cavitation erosion.

Bazanini et al. (2008) [16] studied cavitation erosion wear of metallic specimens using the new compact rotating disk device The device consists of a water chamber in which a metallic disk rotates. On the disk surface are located the cavity inducers, that may be holes or protruding pins, and the specimens as well. The disk is fixed on the shaft and may be detached to switch the specimens. A glass cover is mounted on the chamber to visualize the flow and the bubble formation inside.

The purpose of the device is to create the bubbles that will be responsible for the erosion of the specimens fixed on the disk surface and close to the inducers. To prevent vibration problems, the holes and the specimens are situated on opposite radial positions of their reciprocals.

Murugan et al. (2015) [17] investigated the effect of impingement angle and standoff distance using water jet on Naval brass, they concluded that Naval brass eroded high at an angle of impingement of 30-450. It shows that naval brass erosion takes place in a ductile mode. Lower angle impingement produces rough surfaces whereas high angle impingement produces craters and surface cracks. While changing the standoff distance no improvement was observed in naval brass erosion.

II. Test-Rig Description

The test rig is a mechanical stirrer with accurate rotation control which has been designed and constructed to be used as slurry erosion tester or cavitation erosion for some sections. Figure (2) gives a schematic drawing for the test rig showing its main components.

Figure (3) shows actual test rig photo. It is mainly comprised of seven units; namely driving unit (1), power transmission element (2), Jaws unit (3), rotating unit for holding specimens (4), cylindrical tank (5), base frame (6).

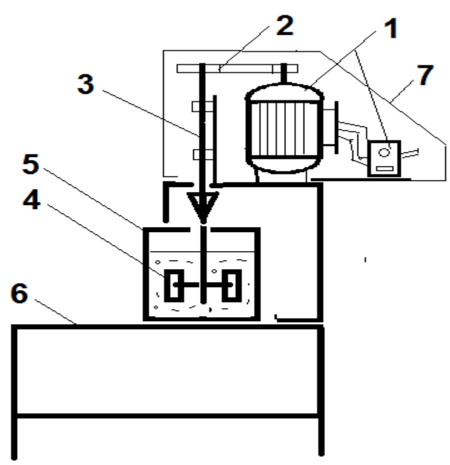


Figure (2) Test Rig schematic drawing showing its main components.

1) Driving unit
2) Power transmission elements
3) Jaws unit
4) Rotating unit for holding specimens
5) Cylindrical tank
6) Base frame
7) Protection cover

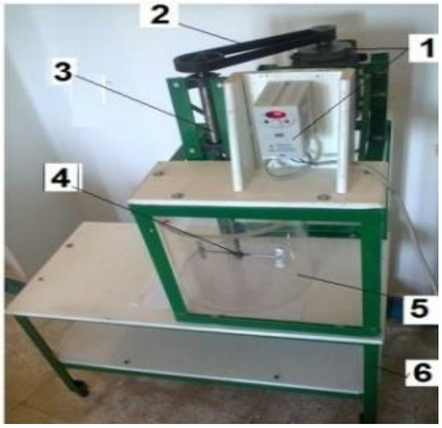


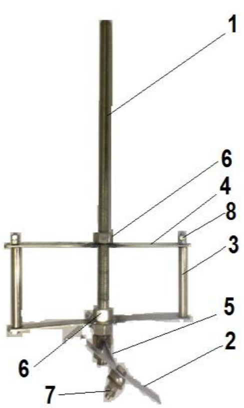
Figure (3) Photo of the actual test rig

The driving unit (1), as shown in Figures (2, 3) is consists of a 3-phase induction motor (1hp.,1400rev./min.), which controlled by inverter with type LSIS (SV-iC5). The inverter is control the output motor speed to be changing from zero r.p.m to 1800 r.pm.

The power transmission elements consist of drive timing pulley with 20 teeth is fixed on the motor shaft and drive another driven pulley with 40 teeth with a timing belt. Then the specimens can rotate at any required speed from 0.0 up to 900 r.p.m.

Jaws unit consists of three jaws adjusting to hold or leave the rotating specimens shaft with maximum diameter of 16 mm.

Specimen holding arrangement was designed and fabricated to hold flat specimen by taking suitable dimensions according to experimental needs by using this slurry erosion tester. Maximum length for holder arm is 150 mm, the maximum rotating diameter is 320 mm. Experiments can be carried out for investigating the wear characteristics of various materials which are subjected to slurry erosion. To be sure the slurry concentration in the fluid is the same, the end of the rotating rod must contain a blower or the specimen itself works as a blower, as the present work. Figure (4) shows specimens which were hold with arms and rotating shaft.



1- Rotating shaft
2- Plate specimen
3-Cylindrical Specimen
4-Cylindrical Support arm
5- Plate support arm
6- Locking nut M 16
7- Bolt with nuts
8- Bolt with nuts

Figure (4) Specimens holding are with arms and rotating shaft.

III. Preparation for Test

Investigate particles sizes and particles shapes as shown in Figure (5) using a scanning electronic microscope (SEM) which used to investigate the slurry erosive surface.

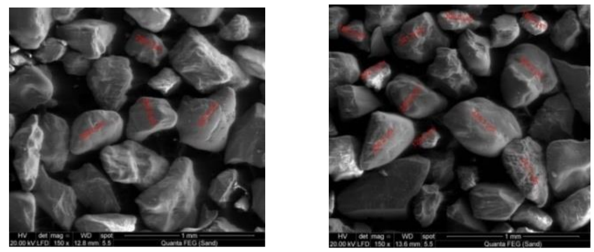


Figure (5) photographic for the particles shapes and sizes

Weight the particles and fluid using balance with sensitivity 1 gm to prepare the slurry concentration in water.

The test specimens were Stainless steel 304 and thin coated steel 37. The specimens shape were two types; plate and cylindrical

a) Plate Specimen dimensions (Stainless steel 304), 0.7 ± 0.1 mm thicknesses, 20 ± 1 mm width, and 100 ± 2 mm Long.
b) Cylinder specimen (Stainless steel 304), 12.5 ± 0.1 mm outer diameter ,840 ± 2 mm Length and 1.8 ± 0.1 mm thickness.
c) Cylinder specimen (steel 37 chromium coated), 12.5 ± 0.1 mm outer, diameter, 840 ± 2 mm Length, and 1.8 ± 0.1 mm thickness.

Each specimen is identified and measured its weight by using accurate balance with sensitivity of (0.0001 g).

The test conditions were;

a) Test temperature: 25 Co.
b) Slurry (sand) medium: water
c) Slurry concentration: 40 wt%.
d) Slurry (sand) particle size: between 120 μmm and 550 μ mm,

The test procedure to be followed to calculate the erosion wear of different specimen materials for the present test rig were as follow:

1) Cutting each specimen at the required dimensions without affecting the microscopic structure or surface finish of it.
2) Specimens were cleaned.
3) Identify and weight each specimen.
4) Holding the specimens on the rotating shaft.
5) Mixing the required particles and water as required concentration of slurry.
6) Put the rotating shaft with specimens in slurry and cover the cylindrical tank.
7) Fixed the rotating shaft in the jaw unit very well.
8) Start the motor to rotates at low speed until the slurry to be homogenous with liquid.

9) Adjust the motor speed to obtain desired test speed.
10) Running the test for required duration test time.
11) Stop the test and removing the specimen from the specimen holder.
12) Cleaning and drying the specimen very well.
13) Weighing the specimen after test to measure the weight loss with the same balance and record the new specimen weight after test.
14) Microstructure test for the specimens using SEM and photographic the surface

IV. Test Results

A) The First Test Group Results

First test was carried out for different Impact angles, stainless steel 304 plate specimens.

The specimens rotate with speeds 200 r.p.m (corresponding impact velocities 2.3 m/s). Test duration time was 3 hours; the maximum test time was 18 hours.

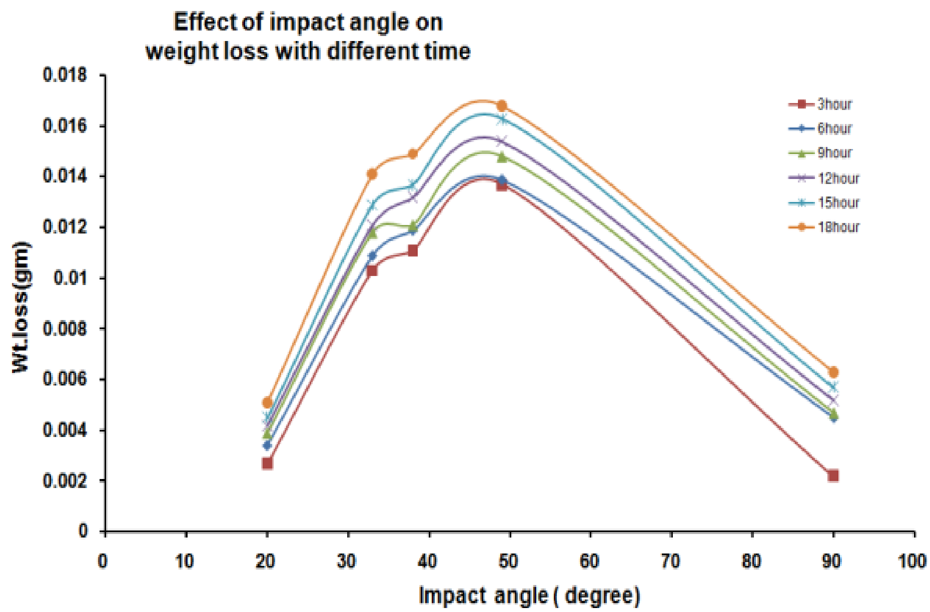


Figure (6): The weight loss in sand 40 wt. % with different impact angles and time where the impact velocity is 2.3 m/s

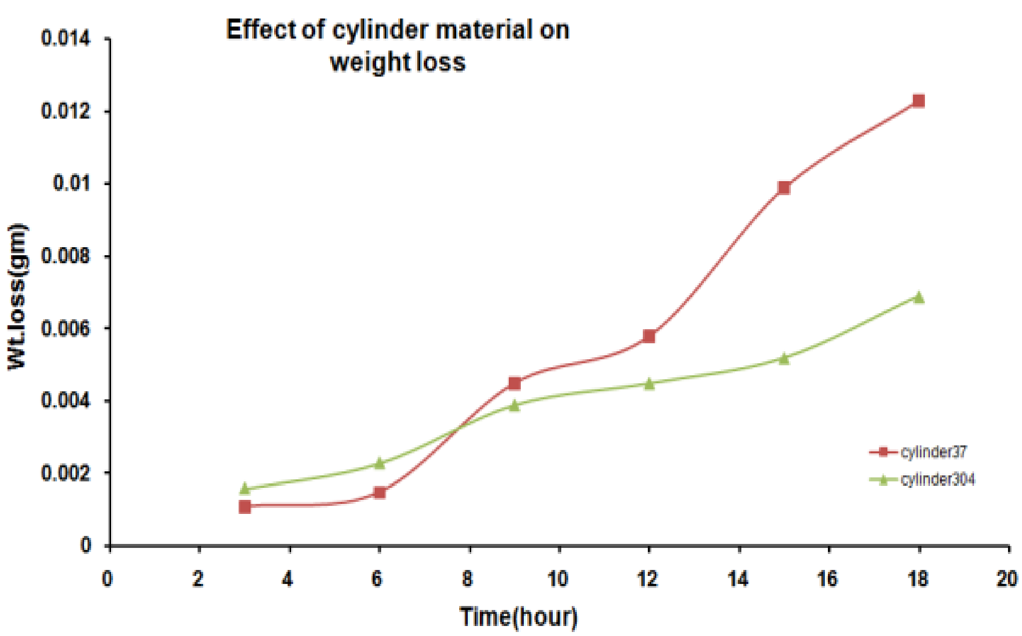


Figure (7): The weight loss in sand 40 wt. % with different material types (Stainless steel 304, and coated steel 37).

The weight loss is measured using an electronic balance with sensitivity 0.0001 gm and their morphologies at different impact angles were investigated using scanning electron microscope (SEM) examination

Figure (6) illustrates the variation of weight loss against impact angles at different test duration time. As shown, for different test duration time, the weight losses increasing with increase the impact angle up to 42o, and the weight loss decrease with impact angle between 50o and 90o.

B) The Second Test Group Results

Second test were carried out with two types of cylinder, one made from Stainless steel 304, another made from steel 37 with a thin coated layer. The test for both types is the same sand concentration 40 wt. % and the test speeds wear 200 r.p.m (corresponding impact velocities 2.3 m/s). Test duration time was 3 hours; the maximum test time was 18 hours.

The specimen weight is measured using an electronic balance with sensitivity 0.0001 gm and their morphologies at different impact angles were investigated using scanning electron microscope (SEM) examination.

Figure (7) illustrates the variation of weight loss against test duration time for two different material specimens; coated Steel 37 Specimens, and stainless steel 304 specimens. As shown the first the weight loss from Steel 37 Specimens stage are small compare with stainless steel 304 specimens, up to 8 hours, but after that weight losses increase for steel 37 much more than stainless steel 304. Also the weight losses are three stages in both samples.

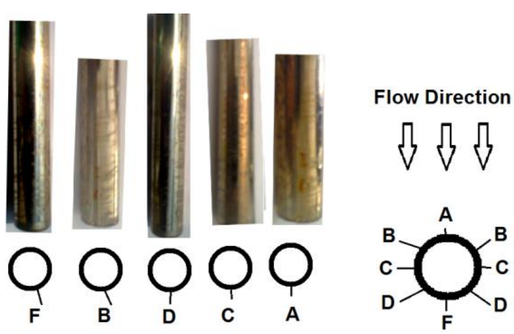


Figure (8): Visual inspection of coated steel 37 shown the sight direction and flow direction, the velocity is 2.3 m/s

Figure (8) shows a visual inspection of coated steel 37 shown the sight direction and flow direction, the velocity is 2.3 m/s.

C) *The Specimens Scanning Electron Microscope photographs*

All specimens are tested at velocity of 2.3 m/s, sand particle in water with concentration 40 wt. %. The next figures are for The Scanning Electron Microscope for plate specimens and cylinders using SEM Model Quanta 250 FEG (Field Emission Gun).

1) Plate Specimens after 9 Hours

The next Figures (9), (10) are SEM photographs for plates specimens were tested up to 9 hours, the impact angles were 33o, and 90o respectively. The Figures shows that wear for impact angle 33o is higher slurry erosive wear rate than impact angle 90o. But for impact angle 90o the photographs show much more plastic deformation on material surface.

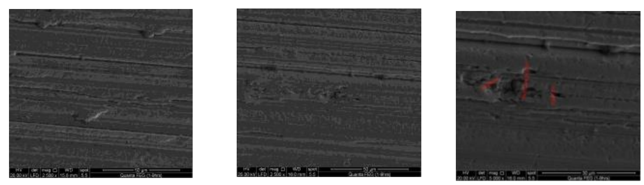


Figure (9), SEM for plate specimen, 9 hours, Impact angle 33o

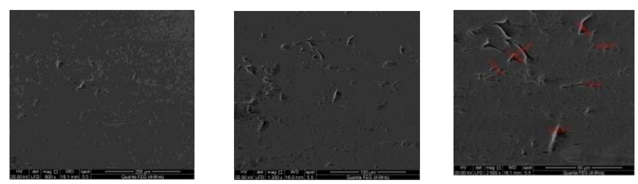


Figure (10), SEM for plate specimen, 9 hours, Impact angle 90o

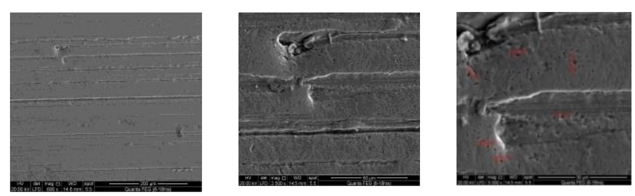


Figure (11), SEM for plate specimen, 18 hours, Impact angle 49o

2. *Plate Specimens after 18 Hours*

The next Figures (11), (12) are SEM photographs for plates specimens were tested up to 18 hours, the impact angles were 49o, and 90o respectively. The Figures shows that wear for impact angle 49o is higher slurry erosive wear rate than impact angle 90o.

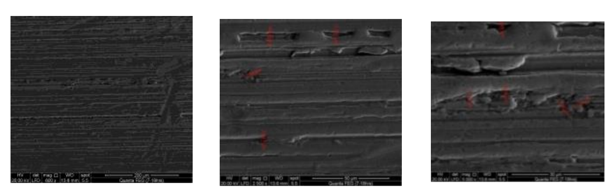


Figure (12), SEM for plate specimen, 18 hours, Impact angle 90o

3. *Cylinder Specimens Coated Steel After 9 Hours and 18 Hours*

The next Figures (13), (14) are SEM photographs for coated steel 37 cylindrical specimens who were tested up to 9 hours, and 18 hours respectively.

The Figures shows that wear is increase with increase test time.

4. *Cylinder Specimens, st. 304 after 9 Hours and 18 Hours*

The next Figures (15), (16) are SEM photographs for which stainless steel 304 cylindrical specimens were tested up to 9 hours, and 18 hours respectively. The Figures shows that wear is increase with increase test time.

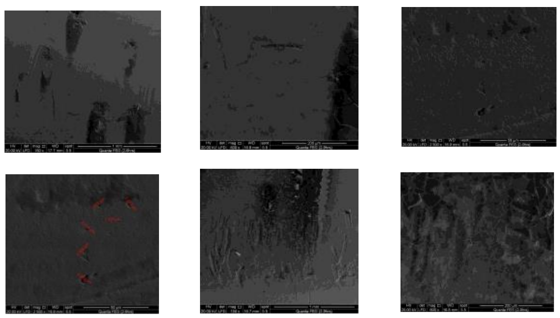


Figure (13), SEM for cylindrical specimen, coated St. 37, 9 hrs

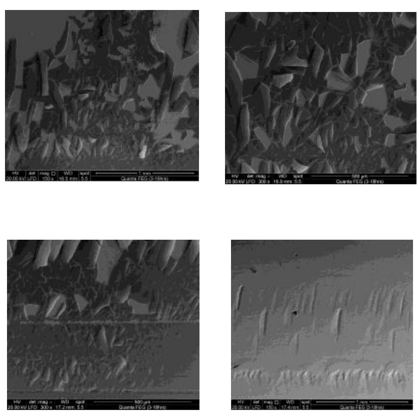


Figure (14), SEM for cylindrical specimen, coated St. 37, 18 hrs.

Figure (15), SEM for cylindrical specimen, St. St. 304, 9 hrs.

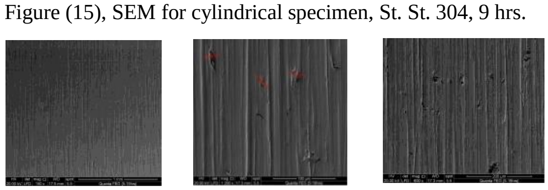


Figure (16), SEM for cylindrical specimen, St. St. 304, 18 hrs.

V. DISCUSSION OF RESULTS

A) The Effect of Impact Angle

The impact angle is the angle between the eroded material surface and the direction of the particle immediately before impact. The effect of impact angle on erosion rate of stainless steel 304 is studied, and results are shown in Figure (6). It is evident from the figures that impact angle has significant influence on erosion; it can be divided into three different regions. The first region from 20o up to 44o, it shows that increasing the impact angle result in increasing the weight loss. The second region shows that the maximum erosion is occurring at an impact angle between 45o and 49 o. The third region, it is clear that the weight loss with increasing the impact angle from 50o up to 90o. So it is concluded that this is "ductile mode of erosion wear".

Also it is clear from SEM photograph the effect of different impact angles on the surface of specimens. Figures (9), (10) are SEM photographs for plates specimens were tested up to 9 hours, the relative velocity was 2.3 m/s, using sand particles maximum size 550 µm with water 40 wt.%. And the impact angles were 33o, and 90o respectively. The Figures shows that wear for impact angle 33o is higher slurry erosive wear rate than impact angle 90o. That is due to impact angle 33o get good angle for cutting and separate small parts from surface, but for impact angle 90o the photographs show much more plastic deformation on material surface due to particles impact perpendicular to surface without weight loss.

Figures (11), (12) are SEM photographs for plates specimens which were tested up to 18 hours, the impact angles were 49o, and 90o respectively. The Figures shows that wear for impact angle 49o is higher slurry erosive wear rate than impact angle 90o. That is due to impact angle 49o get very good angle for cutting and separate small parts from this material surface than angle 33o, but for impact angle 90o the photographs show much more plastic deformation on material surface and small wear in the surface more than 9 hours' test.

However, control impact angle can reduce the slurry erosive wear rate when understanding the material behavior with the slurry properties.

B) Effect of Specimen Geometry Cylinder on Erosion.

Figure (8) shows a visual inspection of coated steel 37 showing the sight direction and flow direction, the velocity is 2.3 m/s. The test duration time was 18 hours with sand particles with concentration of 40 wt. %in water. The figure shows the position in cylinder cross section and the direction of impact particles in slurry pot, it is clear that position A, C, and B are simulating impact angles 90o,0o, and angle between 90o and 0o. The specimen is for coated steel 37 is selected with light coated layer in order to show the erosion in coated material with different position by visional inspection. Also it is clear that there is a color difference between positions D, and F, that position F has start cavitation erosion due to pressure drop at this position.

Figures (13), (14) are SEM photographs for coated steel 37 cylindrical specimens were tested up to 9 hours, and 18 hours respectively. Figure (7) shows that wear is increase with increase test duration time. At this case the wear is from coated surface and cylinder material.

C)The Effect of Material

The test was carried out with two types of cylinder, one made from Stainless steel 304, and the other made from steel 37 with a thin coated layer. The test for both types is the same sand concentration 40 wt. % and the test speeds wear 200 r.p.m (corresponding impact velocities 2.3 m/s). Test duration time was 3 hours; the maximum test time was 18 hours. Figure (7) illustrates the variation of weight loss against test duration time for two different material specimens; coated Steel 37 Specimens, and stainless steel 304 specimens. As shown first the weight loss from Steel 37 Specimens stage are small compare with stainless steel 304 specimens, up to 8 hours, that is due to plastic deformation and cracks in the coated surface. After that the weight losses increase for steel 37 much more than stainless steel 304 due to wear in both coated and steel 37. Also the weight loss for both types of materials are the same, first less weight loss but plastic deformation and cracks on surface, next stage weight the wear is increase with time, next wear is increased slightly due to the increase in surface hardening as a result of particle impact energy.

Also Figures (6) and (7) show in general that the increasing in duration time result in increased weight loss. The effect of duration time is mean lifetime of actual parts, which suffer from erosion that is mean according to the required lifetime and maintenance cost.

VI. CONCLUSION

The previous experimental results investigate the effect of the test duration time, the impact angle, and shape of material type on erosion.

For the same testing conditions, it is concluded that: -

1) Impact angle has a great effect on erosion, control impact angle can reduce the slurry erosive wear rate when understand the material behavior with the slurry properties.
2) There is different erosion on the cylindrical surface according to the impact direction on the surface.
3) Both, the material properties or the coated layer can reduce the weight loss according to their hardness.
4) For slurry pipe elbow it is preferred to design the elbow angle to avoid maximum wear rate according to the ductile or brittle elbow materials and flow conditions.
5) The test time affecting the erosion rate, it can design a part for erosion resistance according to the required lifetime for it with easy and fast replace.

REFERENCES

[1] A. BALL "The mechanisms of wear, and the performance of engineering materials" J. S. Afr. Inst. Min. Metal/., vol. 86, no. 1. Jan. 1986. pp. 1-13.

[2] D.M. Kennedy, M.S.J. Hashmi, "Methods of Wear Testing for Advanced Surface Coatings and Bulk Materials" Journal of Materials Processing Technology 77 (1998) 246–253.

[3] Pramod A. Thakur, Hitesh S. Khairnar, E.R. Deore, S.R. More, "Development of Slurry Jet Erosion Tester to Simulate the Erosion Wear due to Solid-Liquid Mixture" International Journal of Novel Research in Engineering and Science Vol. 2, Issue 1, pp: (14-20), Month: March 2015 - August 2015.

[4] J. Mccann, J.S. Ellis "Abrasion, Erosion and Wear Resistant Steels for Improved Reliability and Performance of Plant and Equipment" Report Commission of the European Communities, technical steel research Science, Research and Development 1986 EUR 10143 EN

[5] Mousab Hadad, Reinhard Hitzek, Johann. Michler, Jacky Lesage3 "Tribological Behavior of Sandwich Structured WC-CO-CR Thermally Sprayed Coatings" EMPA20090392 ECOTRIB 2009- 2end European Conference on Tribology, June 7-10, Pisa, Ialy

[6] Niko Ojala1, Kati Valtonen1, Paivi Kivikyto-Reponen, Petri Vuorinen, and Veli-Tapani Kuokkala1 "High Speed Slurry-Pot Erosion Wear Testing With Large Abrasive Particles" Tribologia - Finnish Journal of Tribology 1 vol 33/2015

[7] Y. Wang , Y.G. Zheng , W. Ke , W.H. Sun , W.L. Hou , X.C. Chang , J.Q. Wang "Slurry erosion–corrosion behaviour of high-velocity oxy-fuel (HVOF) sprayed Fe-based amorphous metallic coatings for marine pump in sand-containing NaCl solutions" Corrosion Science 53 (2011) 3177–3185

[8] M. A. Maleque and M. S. Salit," Mechanical Failure of Materials" Materials Selection and Design, Springer Briefs in Materials, DOI: 10.1007/978-981-4560- 8-2_2, The Author(s) 2013

[9] Hari Prasad Neopane "Sediment Erosion in Hydro Turbines" PhD thesis, Faculty of Engineering Science and Technology, Norwegian University of Science and Technology (NTNU), Trondheim, Norway March 2010

[10] Lalit Upadhayay, Satish Kumar "Numerical Investigation of Silicon Carbide Particle Suspension Behavior for Enhancing Uniform Suspension in Erosion Wear Test Rig" International Journal of Advanced Research in Engineering and Applied Sciences Vol. 4 | No. 6 | June 2015.

[11] A.P. Harsha, U.S. Tewari, B. Venkatraman "Solid particle erosion behaviour of various polyaryletherketone composites" an Industrial Tribology Machine Dynamics and Maintenance Engineering Centre, Indian Institute of Technology,HauzKhas, New Delhi 110016, India Defense Metallurgical Research Laboratory, Kanchanbagh, Hyderabad 500058, India Received 30 July 2002; accepted 5 February 2003.

[12] H. Imrek, M. Bagci, O.M. Khalfan "Experimental investigation of effects of external loads on erosive wear" JAMME Journal of Achievements in Materials and Manufacturing Engineering Volume 32 Issue 1 January 2009.

[13] Y. M. Abd-Elrhman, A. Abouel-Kasem, K. M. Emara and S. M. Ahmed, "Effect of Impact Angle on Slurry Erosion Behavior and Mechanisms of Carburized AISI 5117 Steel", Journal of Tribology, Vol.136, Part 1, 2013

[14] Y. M. Abd-Elrhman, A. Abouel-Kasem1, S. M. Ahmed and K. M. Emara "Stepwise Erosion as a Method for Investigating the Wear Mechanisms at Different Impact Angles in Slurry Erosion ".Journal of Tribology, Vol. 136, Part 2, 2014, (9 pages)

[15] H.J. Amarendra, G.P. Chaudhari, S.K. Nath, "Synergy of cavitation and slurry erosion in the slurry pot tester" Wear290–291(2012)25–31Accepted 30May2012

[16] Mehdi Azimian and Hans-Jörg Barta "CFD simulation and experimental analysis of erosion in a slurry tank test rig" EPJ Web of Conferences 45, 01009 (2013) DOI: 10.1051/ epjconf/ 20134501009 published by EDP Sciences, 2013

[17] Murugan K, Ragupathy A, Balasubramanian V and Sridhar K "Evaluating Effects of Water Jet Erosion Parameters on Erosion Behaviour of Naval Brass Alloy" Journal of Manufacturing Engineering, March 201 5, Vol. 10, Issue. 1, pp 43-48.