Experimental investigation of Solid Particle Erosion of Brass, Stainless Steel 304, And Aluminium 6063

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Abstract - *In the present work, the erosion behaviour of ductile metals namely aluminium, brass, and stainless steel is investigated. Experiments using a jet impingement tester (JIT) are conducted to obtain the material loss of the target surface due to solid particle impact. The experiments are conducted at different impact velocities (40 –70 m/s) and the particle's impact angles (30° to 90°). The results show that the increase in particle impact velocity increases the erosion rate of the materials. The power law exponent of the velocity for brass, steel, and aluminium is obtained as 1.94,1.7, and 1.67 respectively. Further, the material's erosion rate varies with the change in the particle impact angle. The maximum erosion for all the materials is obtained at an impact angle of 60° degree in the present test conditions. The present work provides useful experimental data for calibrating the available semi-empirical erosion wear models for Computational Fluid Dynamics (CFD) based erosive wear analysis of the industrial systems.*

Key Words: Erosion, Impact Angle, Impact Velocity, Jet Impingement Tester, Solid Particle Impact

1. INTRODUCTION

Erosion caused by solid particles striking metal surfaces affects the operational economy of several industries, including aerospace, oil & gas, power production, chemical, mining, pneumatic, and hydraulics. It is undeniably a tough process to investigate and comprehend due to its reliance on multiple aspects, making it a complex phenomenon. It has taken a lot of effort to develop a fundamental knowledge of this intricate manner of failure and to provide models and mechanisms that would explain the observed erosion rates. It is widely accepted that factors such as the mass, shape, and hardness of the particles, the speed at which they move, and the angle at which they contact the surfaces are crucial in terms of material degradation when erosive wear is caused by impacts of solid particles [1].

The material's removal mechanism must be understood to increase engineered materials' erosion resistance. However, analyses often employed scratches formed by solid particles on the target surface to determine how materials behave when subjected to erosion. Cutting, ploughing, extrusion and forging, and subsurface deformation and cracking are the categories for the widely acknowledged erosion mechanisms [2]. According to the literature, surfaces of ductile materials undergo considerable plastic deformation while brittle materials fracture at impact angles [3]. The mechanism utilized for ploughing is related to the material removal that creates plough markings on the desired surface. The substance is extruded (by plastic deformation) ahead of a solid particle to provide a raised lip when ploughing. These lips stay attached to the target surface but are vulnerable to further blows [4]. Bench scale testing, in-situ measurement, pilot plant testing and laboratory tests were carried out for experimental inquiry connected to erosion wear.

Impact velocity and angle have been found to substantially impact wear rates and surface degradation in tribo-systems that experience erosion. In order to get more clear-cut and understandable results, many researchers have run erosion experiments related to velocity and angles. The correlative investigation of steel, copper, cast iron, and carbon steel at speeds between 50 and 150 m/s utilizing a sandblast-type erosion tester was covered by Oka et al. [5] along with the erosion study's predictive models. Harsha and Bhaskar [6] looked at the erosion behaviour of ferrous and non-ferrous materials as well as Hutchings' erosion model for normal and oblique impact angles. Materials tested were cast iron, brass, copper, mild steel, aluminium, and stainless steel at impact angles between 30°to 90° with speeds between 24 to 52 m/s. Islam and Farhat's [7] paper described the erosion of APIX42 Stainless material at various velocities(36,47,56,81 m/s) and impact angles. AISI 304, 316, and 420 stainless steel solid particle erosion of J.R. Laguna-Camacho et al.[8] have taken a velocity of 24 m/s along with a high feed rate of 150 g/min. Saarivirta et al.[9] discussed boiler steel using sand and ash particles at a velocity range of 10 and 20 m/s and impact angles of 30°,45° and 90. Arabnejad et al. [10] used Particle Image Velocimetry (PIV) to determine the velocity range for the test (9,18,28 m/s) at impact angles of (15,30,45,60,75, and 90) degrees. Mayank et al.[11] conducted a room temperature investigation of SS 304 at impact angles of 30° and 90° with an impact velocity of 40 m/s to determine the erosion rate. In their experimental work, Hong et al.[12] used SS 304 and L245 carbon steel at impact velocities of (26.20, 28.82, 31.43, and 36.67 m/s) while maintaining consistent impact angles. Lopez et al. [13] discussed the effects of velocity and came to the conclusion that the erosion rate rises as velocity rises. The empirical power law relationship for erosion rate is $E = kV^n$, where E is the erosion rate, V is the velocity, k is a constant, and n is the velocity exponent [14]. The value of n generally varies between 2-3 for metallic materials. The velocity exponent may decrease if the hardness of the target material converges to that of the particle. A value of n smaller than 2 has not yet been discovered in solid particle erosion, however, erosion-corrosion studies have discovered values as low as 0.8 [15].

Investigating laboratory-based erosion tests on steel, brass, and aluminium materials is the goal of the current effort. To gather the necessary information for empirical and semi-mechanistic erosion model prediction, a number of parameters relating to impact velocity, impact angle, erosion rate, and discharge were carried out.

2. Experimental Details

2.1 Experimental Setup

The experiments are performed using the Air Jet Erosion Tester (ASTM G76) (Make: Ducom) [16] available at the Tribology laboratory, Shri G.S. Institute of Technology and Science Indore (India). A tester schematic is shown in Figure 1.

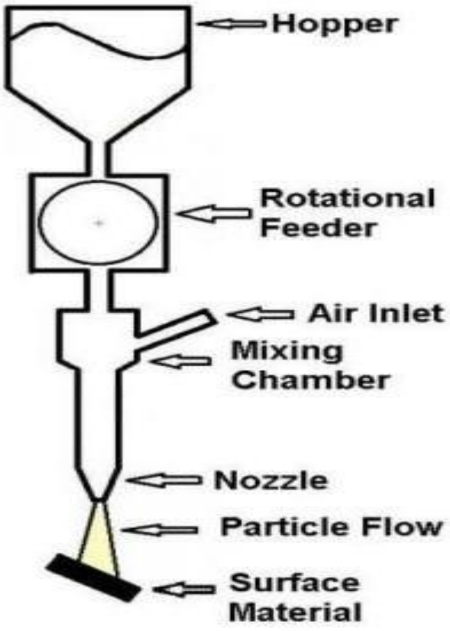


Figure 1. Schematic Image of Air Jet Erosion Test

All experiments were conducted at room temperature. The main components of the device are the double disc assembly, rotatable feeder, mixing chamber, acceleration tube, nozzle, testing chamber, and hopper. The device receives pressurized air from an external source called a compressor.

2.2 Target Materials Properties

Three ductile materials were chosen for testing: aluminium, brass, and stainless steel. These type of material is commonly used in industries and household tasks. The specimens had a square shape with dimensions of (50 x 50 x 5) mm. . The mechanical and physical properties of the materials are shown in Table 1. The hardness of the material is determined using a Rockwell hardness tester. The chemical composition of the material is shown in Table 2.

Table 1. Mechanical and Physical Properties of Testing Materials [6]

Physical Properties	Aluminium	Brass	Steel
Density	2710 Kg/m3	8470 Kg/m3	8000 kg/m3
Modulus of Elasticity	68.85 GPa	97 GPa	195 GPa
Ultimate Tensile Strength	89.6 MPa	315MPa	506 MPa
Yield Tensile Strength	48.3 MPa	97MPa	214MPa
Rockwell Hardness	66	58	92

Table 2. Chemical Composition of Test Specimen Material

Material	Chemical Composition
Aluminium 6063	0.2-0.6 Si , 0.35 Fe , 0.9 Mg
Brass	0.05 Fe , 0.15 Pb , 31.3-36 Zn , 65 Cu
Stainless Steel 304	0.08 C , 2.0 Mn , 0.74 Si , 0.044 P , 18-20 Cr , 8-10 Ni

2.3 Erodent Properties

Alumina oxide (Al2O3) 50 microns mean particles were used as an abrasive. These semi-rounded particles have a specific gravity of 3.9 and a density of 3.95 g/cm2, which were determined using sieve analysis.

2.4 Experimental Procedure

For each experiment, new samples was used. Specimens were cleaned using 1200 grit emery paper, followed by acetone cleaning and drying before testing. After cooling, preheated erodent is retained in the Air Jet Erosion Tester hooper. To obtain the appropriate parameters, which were stated in Table 3, operating knobs were slowly turned. The test nozzle is cleaned and put back in place prior to operation. The data for velocity and discharge has already been predetermined as frequencies and pressures. Angles of

(30°, 45°, 60°, and 90°) are maintained at a distance of 10 mm below the nozzle tip in order to obtain the necessary impact angle research. The test is conducted at the following speeds: (40, 50, 60, and 70) m/s with a 10 g/min discharge rate. Using weighing equipment with a 0.1 mg precision, the first and final readings of the specimen were taken. Repeated tests were conducted at intervals of 10 minutes to produce steady-state erosion and get the desired test results. Additionally, the test findings were contrasted and analyzed in relation to the behaviour of steady-state erosion. The erosion rate was then determined by dividing this weight loss by the weight of the eroding particles responsible for the loss (i.e., testing duration divided by particle feed rate).

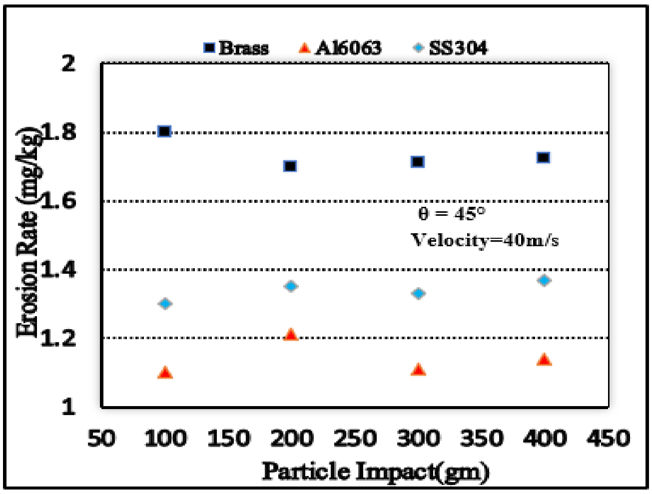
Table 3. Erosion Test Parameters

Parameters	Particulars
Erosion Size	50 Microns
Erodent Shape	Semi Rounded
Impingement Angle (degree)	30°,45°,60°,90°
Impact Velocity (m/s)	40±2,50±2,60±2,70±2
Erodent Feed Rate (g/min)	10 g/min
Test Temperature	Room temperature

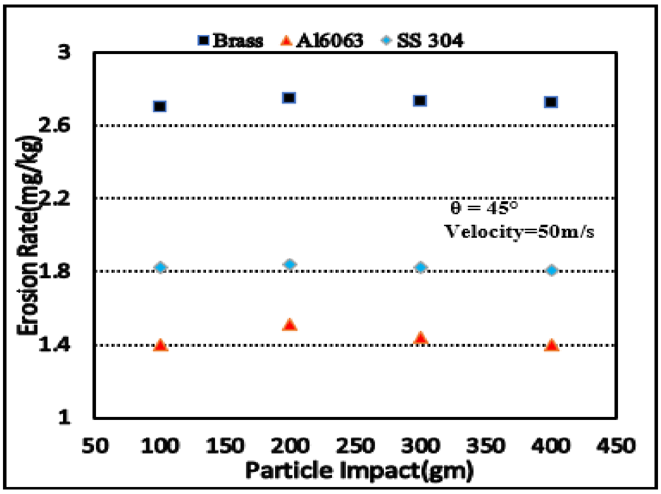
3. Results and Discussions

Based on the size of the nozzle diameter, small shape abrasive alumina particles (50 microns) were utilized to ensure that the experiment went smoothly at test velocities of (40, 50, 60, and 70) m/s, respectively. It can be seen from the presented figure 2 that erosion time has little to no effect on the rate of erosion.

Due to micro-cutting and material removal, erosion rates initially increase [6], but as the test progresses, they stabilize and reach a steady state. The mass flow rate has a negligible impact on the erosion rate at a particular velocity. From the given figure 2 it seen the difference in the erosion rate of different materials at different velocities and their erosion behaviour. But from the erosion data available it is impossible to predict the material condition at which it will achieve a steady state. It is evident that regardless of the impact's angle and velocity, Brass erodes more quickly than aluminium. This is due to aluminium's ductile nature, which causes it to become harder quickly after being worked, whereas ductile materials that are more ductile than aluminium do not exhibit this behaviour. Based on this finding, this can be concluded that single target material property cannot be the only factor used to predict erosion rate Even in the second scenario, aluminium showed a higher rate of degradation while having a lower hardness than stainless steel. Various studies related to ductile materials are discussed in the past literature [17-19].



(a)



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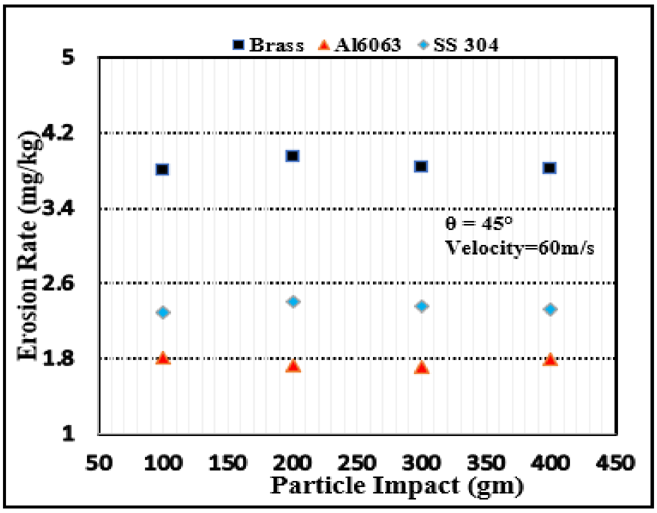

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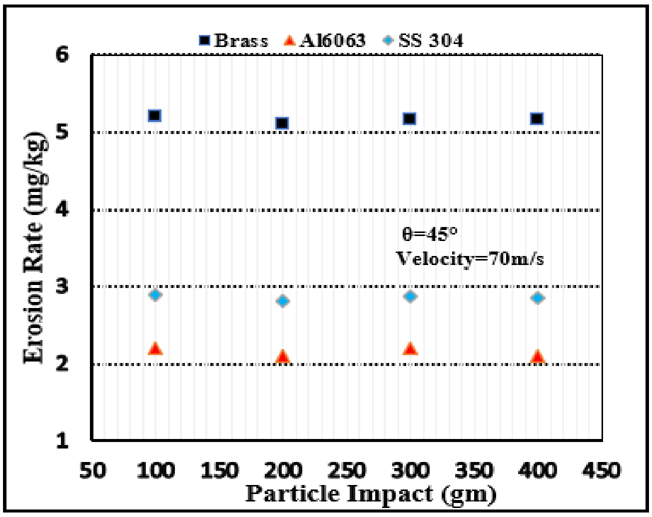

(d)

Figure 2 (a-d) Showing Variation in Erosion Rate with respect to impact velocities

3.1 Effect of Impact Angle

This is a crucial factor impacting the rate at which the test material erodes. The angles chosen for test observation in our work linked to the impact angle shown in Figure are (30°,45°,60°, and 90°) at a constant velocity of 50 m/s and discharge rate of 10 g/min. Based on test trials, in the given Figure the rate of erosion in aluminium material is largest at 30° and minimum at 90°, demonstrating the material's ductile behaviour that has already been covered in past literature [20-21]. Maximum erosion in stainless steel and brass occurs at both 30° and 60°, which may be related to the higher impact velocity of 50 m/s on these two materials, as described by Harsha and Bhaskar [6].

Grooves and lip development occur at lower impact angles. Lips, edges, and grooves were swapped out for erosion pits for angles greater than 30°. Maximum wear at swallow angles is shown by the change in erosion rate with respect to the erosion angle of ductile material [22]. This is due to the ploughing action of ductile materials. Material removal occurs by scoops, whereas at higher impact angles, kinetic energy is wasted, resulting in material deformation [23]. At low cutting angles, the projected area of the eroded surface has a fairly elliptical form, whereas, at higher degrees, it tends to be circular.

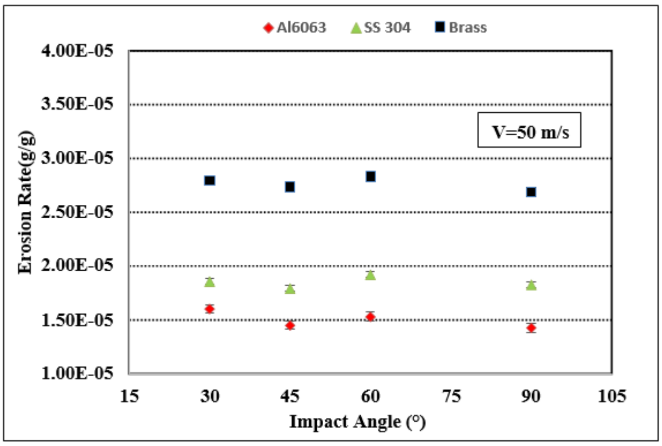

Figure 3 Effect of impact angle on erosion rate of Test Specimens.

3.2 Effect of Impact Velocity on Erosion Rate

A range of velocities (40-70 m/s) was used to study materials behaviour in terms of erosion rate. Impact angle and discharge rate are held constant at 45° and 10 g/min, respectively, to evaluate erosion at steady state behaviour. The increase in material degradation rate as the particle impact velocity rises is depicted in the figure 4. This is a result of the particle's kinetic energy when it collides with the surface of the substance.

According to the test results, aluminium exhibits good erosion resistance whereas brass exhibits the highest erosion rate. At all speeds, the variance in erosion rate exhibits a consistent pattern with impact angle. Many researchers [5,7,13,24] hypothesized the following power law relationship between erosion rate and impact velocity.

$$E = k(V)^n$$

Where,

E= Erosion rate in (mg/kg)

V= Impact Velocity in (m/s)

k=Constant based on impact angle

n= velocity exponent

For our test results, the n value lies between 1.7-2 for various metals at a 45° impingement angle. In general, the values of n lie between 2-3 for metallic materials [25]. During the test investigation of the velocity-based effect on erosion rate, a number of things were noticed. Brass, SS 304, and aluminium each had exponent values of 1.94, 1.70, and 1.67, which were primarily depending on the characteristics of the target material. Second, regardless of other conditions, erosion will continue to accelerate as the velocity rises.

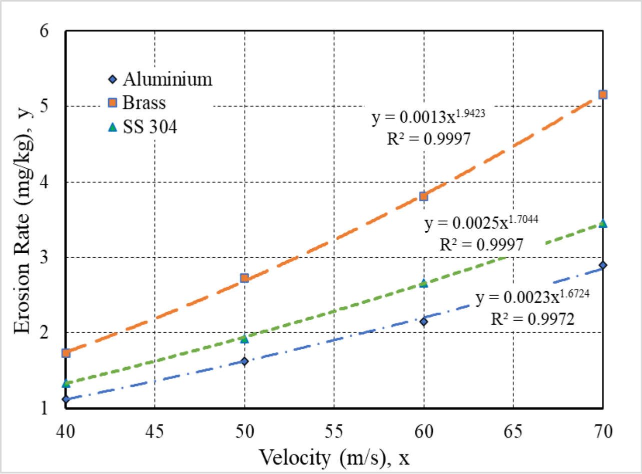

Figure 4. Shows variation in erosion rate with respect to impact velocities

3. CONCLUSIONS

- Brass and steel exhibit an angled peak at 60° at greater impact velocities (50 m/s), which may be the result of micro-cuts in the ductile material.
- The erosion rate increases with particle velocity due to an increase in kinetic energy, which follows a Power Law Relationship $E = k(V)^n$ and our exponent value is between 1.7 and 2.
- In a comparative study of aluminium, brass, and steel specimens, brass exhibits the greatest erosion, due to its lower hardness when compared to the other two materials.
- According to our test, impact velocity and particle size are independent of one another.

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