A Comparative Study on the Erosive Wear Characteristics of HDPE/Tantalum Iron Using Titanium/Rutile Sludge as Abrasive

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Abstract. This paper aimed to study the erosive wear characteristics of high density polyethylene (HDPE) and Tantalum iron using Titanium/Rutile sludge as an abrasive material. The sludge is obtained from Travancore Titanium Products Ltd(TTPL) which is a waste material with 6 to 6.5 hardness on mohs scale. An inhouse built erosive wear test rig will be used to simulate the erosive wear characteristics of HDPE/ Tantalum iron using Titanium/Rutile as abrasive. The process parameters, including specimen velocity, slurry concentration, impact angle, and time are varied within fixed ranges. From the studies it reached to the conclusion that erosive wear is more on Tantalum iron when compared to HDPE and time has more contribution to erosive wear loss.

Keywords: HDPE; Tantalum iron; sludge; erosive wear; abrasive.

1 Introduction

For mechanical systems that handle erosive-liquid mixtures, slurry erosion wear is regarded as the most unfavorable problem. Practically all fluid equipment, fluid transfer, and fluid control lines, slurry erosion is a well-known cause of material degradation [1]. Erosion difficulties are especially problematic for the mining, agricultural, service, and petroleum industries. The features of the slurry, including the form, size, density, and chemical makeup of the particles, all have a big impact on how quickly erosion wears away material. In slurry transportation systems, the material of the various hydraulic components breaks down because of the continual passage of slurry particles over them. The wearing process involves the loss of material from the pipeline surfaces due to mechanical action during the operation of a system under situations like impact, and sliding motion. As a result, the system as a whole has become more expensive due to the shorter lifespan of the various components. Daniel C. Ribu et al.2021[2], studied the influence of rotational speed, concentration of slurry, impact angle and time on erosion performance of 35CrMo steel. They found that rotational speed has most influencing effect on erosive wear of steel followed by impact angle, slurry concentration, and time. They have also developed empirical relationships between process parameters and responses using Response Surface Methodology. Kaushal et al.2020[3], have studied about slurry erosion behavior of brass and established the effect of Rotational speed, Concentration of slurry and Time duration on erosion wear of brass. Material loss increases with Rotational speed, Concentration of slurry and Time duration. Majid Jahangir et al.2020[4], have conducted experiment on Stainless steel SS-404 pump impeller to determine erosive wear response using fly ash as abrasive. They have observed the contributing percentage of Time, Speed and Concentration. They have found that velocity has the highest influence while time contributes least. They have used Taguchi approach for the analysis of erosion wear rate using MINITAB 17. In view of the above, the present project aims to study the erosive wear of HDPE and Tantalum iron utilizing the derivatives of ilmenite/rutile produced during the processing of ilmenite to TiO2 sludge received from M/s Travancore Titanium Products Limited (TTPL) as an industrial abrasive. Both ilmenite and rutile are known for their high specific gravity and hardness (5- 6.5 in Mohs scale). In this work, the design and fabrication of an experimental setup that could perform erosion experiments on High Density Polyethylene and Tantalum iron are envisaged. The process parameters of the erosive wear setup, that are considered are velocity of rotation of the specimen, slurry concentration, impact angle, and time, were to be investigated [5,6]. A pilot experimentation and optimization study were carried out to fix the ranges of the above-mentioned process parameters, involved in the erosion process.

2 Experimental details

2.1 Materials

High Density Polyethylene (HDPE)- In this work, experiments are conducted using the material HDPE (High Density Polyethylene). It is a polymer of ethylene. In TTPL, HDPE pipelines are used for carrying sludge, and it is also the impeller material used for pumping the sludge. HDPE is highly corrosion resistant and therefore it is widely used in industries for transporting corrosive substances. In TTPL, the sludge is acidic in nature, and therefore HDPE pipelines are used for its transportation. Also HDPE pipelines are flexible, durable, chemical-resistant, lightweight, and economical. All these features make it a better option for applications such as water supply, gas distribution, sewerage and drainage systems, mining, chemical transportation, etc.

Tantalum iron- The tantalum iron was also used in the present experiments. A transition metal that is blue-gray in color, tantalum iron is extremely hard, ductile, glossy, and highly corrosion-resistant. In the past, sludge was transported using tantalum pipelines, and the sludge was pumped using an impeller made of tantalum iron.

TiO_2 Sludge-The sludge collected from TTPL is the abrasive used in this work. The sludge is mixed in water at the appropriate mass quantity to prepare the required concentration of slurry. The sludge is basically rutilized ilmenite, with 60% ilmenite and 40% rutile. The sludge is acidic in nature, with a pH around 2.5. The mean particle diameter of rutilized sludge is 312 nm.[7,8]

2.2 Erosive Wear Setup

The experiments are conducted using an in-house designed and developed slurry pot erosive wear test rig (ASTM G73 standard). The vessel is filled with required amount of slurry and the specimen is immersed inside the slurry to conduct the experiments[9]. The specimen is rotated and erosion mainly occurs due to the impingement of abrasive particles on the specimen. The schematic diagram of the slurry poter erosion test setup is shown in Figure 1.The specimen is held by the specimen holder which is attached on a shaft coupled with the motor. The closing lid is made up of transparent acrylic sheet. There is an agitator at the bottom of the vessel to keep the sludge particles in suspension. This would prevent the settling down of particles at the bottom. A Variable Frequency Drive is installed to regulate the RPM of the motor. This would allow to conduct the experiments at different velocities. The installation of a protective shield inside the slurry poter would prevent the sludge from entering the gap between the bearing of the closing lid and the rotating shaft. The process parameters taken in the experiment are concentration of sludge (10% and 20%), velocity of impingement (1m/s and 2m/s), angle of impingement (0^0 and 60^0) and time duration(1hour and 2 hour)

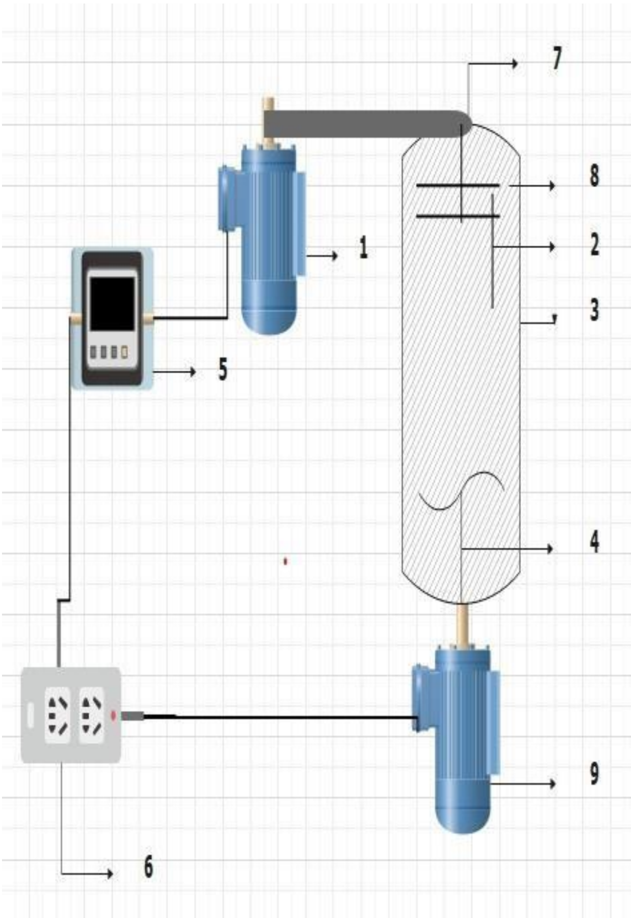

Fig. 1: Schematic Diagram of Slurry Pot Erosion Experimental Setup

1: Motor which drives the pulley 2, 3ø1HP Induction Motor having rated RPM 1440, 1.7Amp, 420V
2: Specimen used in erosive wear experiment.
3: Vessel of capacity 5.5L.
4: Agitator is connected to Motor 2.
5: VFD, 3ø-2 HP 415V
6: Power Supply,3ø 415 V
7: Belt, which is connected to motor 1 shaft, and it transmit power to V- belt drive of B-type.
8: Shield, to prevent sludge from leakage
9: Motor, which drives the blade inside the vessel.

2.3 Experimental Plan Based on $2^{(4-1)}$ Factorial Design

Table 1 shows the ranges of process parameters taken in the experiment. Here parameters are taken in $2^{(4-1)}$ Factorial Design method. Therefore 8 experiments are done in both HDPE and Tantalum iron. Here the erosive wear loss of both HDPE and Tantalum iron are shown.

Table 1: Data Collected as Per Experiment plan.

Run	Factor 1	Factor 2	Factor 3	Factor 4	Response 1(HDPE)	Response 2(Ta)
	weight	m/s	degree	hour	mg	mg
1	10	2	60	1	1.1	10
2	20	1	0	2	2.5	28
3	10	2	0	2	2	25
4	10	1	0	1	1.4	15
5	20	1	60	1	1.1	10
6	20	2	0	1	1.9	17
7	20	2	60	2	2.1	26
8	10	1	60	2	1.5	16

3 Results and Discussions

3.1 Statistical Analysis of HDPE and Tantalum iron

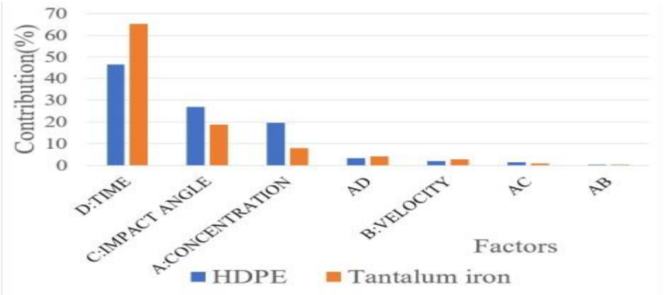

Fig. 2: Percentage Contributions of Process Parameters on the Erosive Wear Characteristics of HDPE and Tantalum iron

The chart above shows the contributions of each factor on mass loss of both materials (Fig.2). The ranking of these factors is same for both materials. Time has the maximum contribution to the wear loss of both materials. It is also notable that the effect of interaction AD (between concentration and time) is higher than that for the individual parameter velocity. While the order ranking of contribution is same, the degree of effect each parameter has on erosive wear loss is different. It is most visible in the case of time. The contribution of time on wear loss of Tantalum iron is comparatively higher than that on HDPE.

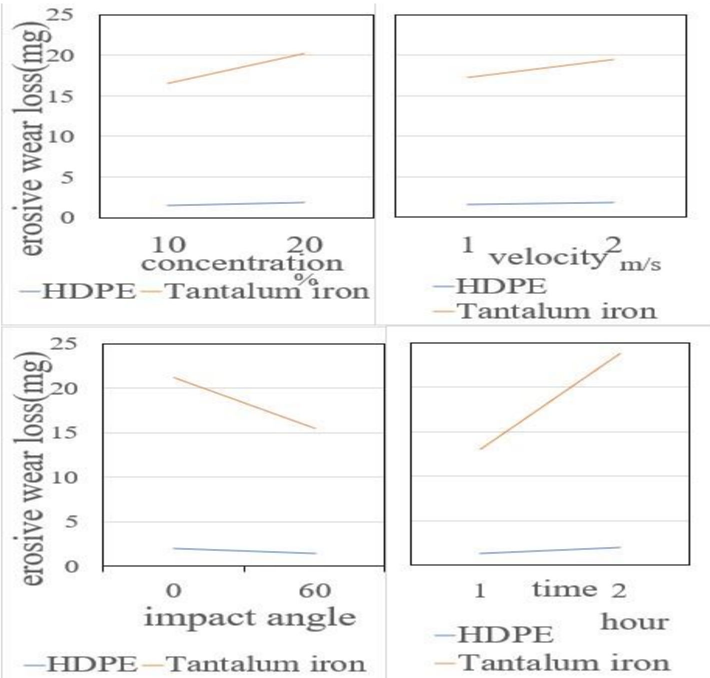

Fig. 3: Process Parameters v/s Erosive Wear Loss of HDPE and Tantalum iron

From fig.3, it is evident that the effect of process parameters are almost same in both Tantalum iron and HDPE. The relationship between erosive wear loss and each parameter is the same for both materials. The relationships are also as expected after conducting the pilot experiments. Out of the four parameters only impact angle shows an inverse relation with erosive wear loss (satisfies Islam,A.M.,Farhat,Z.N.,2014 and partially agrees Gandhi,B.K and et al)[10][11],while in the case other three ero- sive wear loss increases with their respective values.[12]

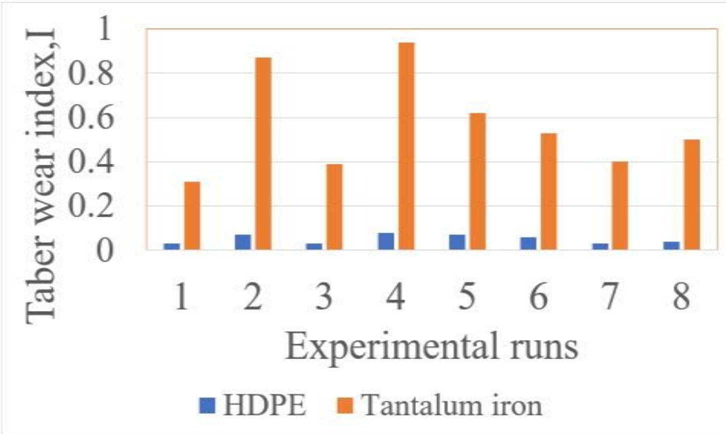

Fig. 4: Wear Index Graph v/s Experimental Runs

From fig.4, it is evident that wear index of HDPE is less compared to Tantalum iron.ie per 1000 cycle of erosive wear loss in milligram for HDPE is more and it can resist the erosion more than 10 times compared to Tantalum iron. This rate of erosion is calculated in terms of Taber wear index, I as follows.

$$I = [(A - B) * 1000]/C \quad (1)$$

where,

A: mass of specimen before erosion(mg)
B: mass of specimen after erosion(mg)
C: number of test cycles(mg)

3.2 Interactions of Process Parameters on Erosive Wear Loss of HDPE and Tantalum iron

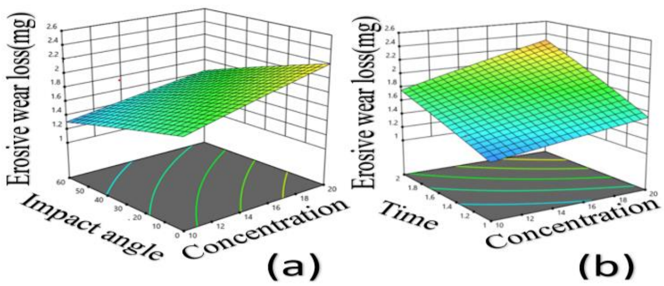

Fig. 5: Combined Effect of (a) Angle of impingement and Concentration of TiO_2 Sludge and (b) Time and Concentration of TiO_2 Sludge on the Erosive Wear Characteristics of HDPE

In Fig 5, there is a cross over interaction between concentration and impact angle. Erosive wear loss increases with the increase in concentration while it is reverse in the case of impact angle, wear loss decreases with increase in impact angle. Here maximum wear loss is noted for the maximum value of concentration [13]. And the least wear loss is noted at zero-degree impact angle. The interaction is exponential in the case of concentration and time. Erosive wear loss increases with the increase in both concentration and time. We can see on the graph that the minimum and maximum values of erosive wear loss occur on maximum and minimum values of the both concentration and time respectively.

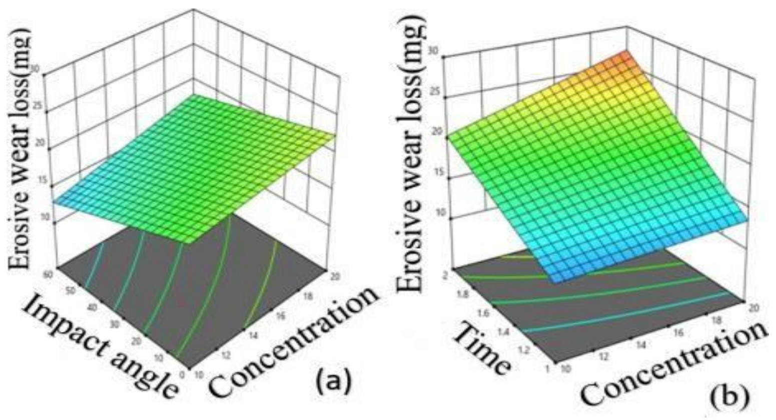

Fig. 6: Combined Effect of (a) Angle of impingement and Concentration of TiO_2 Sludge and (b) Time and Concentration of TiO_2 Sludge on the Erosive Wear Characteristics of Tantalum iron.

In Tantalum iron is similar to the case of HDPE, the interaction is cross over between the factors: concentration and impact angle (Fig 6). The combined effect of impact angle and concentration is same for both Tantalum iron and HDPE. Erosive wear loss increases with increase in concentration and decreases with increase in impact angle. Maximum wear loss is obtained at maximum concentration and minimum impact angle. Interaction is exponential for time and concentration. Erosive wear loss increases with increase in both time and concentration. Maximum erosive wear loss is obtained at maximum values of time and concentration while minimum wear loss obtained in minimum values of time and concentration.

3.3 ANOVA Analysis on the Erosive Wear Characteristics of Tantalum iron and HDPE

In table 2, we can identify that all the factors are significant in HDPE (ie, p-value< 0.05). The Equation (2) for erosive wear loss of HDPE is as follows(L):

$$L^{(1.5)} = 0.441981 + 0.001742A + 0.261031B - 0.005111C + 0.243664D - 0.000734(AC) + 0.068401(AD) \pm \epsilon \qquad (2)$$

where,

A: Concentration
B: Velocity
C: Impact Angle

D: Time
ϵ: Error
The given equation can be used to predict the erosive wear loss of the HDPE.

Table 2: ANOVA Analysis of HDPE

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	6.92	6	1.15	2047.20	0.0169	significant
A-concentration of TiO_2 sludge	1.36	1	1.36	2406.65	0.0130	
B-velocity of impingement	0.1363	1	0.1363	241.96	0.0409	
C-angle of impingement	1.87	1	1.87	3322.39	0.0110	
D-time duration	3.22	1	3.22	5724.66	0.0084	
AC	0.0970	1	0.0970	172.19	0.0484	
AD	0.2339	1	0.2339	415.36	0.0312	
Residual	0.0006	1	0.0006			
Cor Total	6.92	7				

The given equation can be used to predict the erosive wear loss of the HDPE specimen at the investigated range of parameters. The equation comprises of only those factors which have significant contribution on the erosive wear loss of the material.

Table 3: ANOVA Analysis of Tantalum iron

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	353.75	6	58.96	471.67	0.0352	significant
A-concentration of TiO_2 sludge	28.12	1	28.12	225.00	0.0424	
B-velocity of impingement	10.12	1	10.12	81.00	0.0704	
C-angle of impingement	66.13	1	66.13	529.00	0.0277	
D-time duration	231.13	1	231.13	1849.00	0.0148	
AC	3.12	1	3.12	25.00	0.1257	
AD	15.13	1	15.13	121.00	0.0577	
Residual	0.1250	1	0.1250			
Cor Total	353.88	7				

In table 3, we can identify that only concentration of sludge and angle of impingement are significant in case of Tantalum iron. The equation (3) for erosive wear loss of Tantalum iron is as follows(L):

$$L= 10.375 - 0.575A + 2.250B - 0.158333C + 2.500D + 0.00416(AC) \pm \epsilon \quad (3)$$

where,
A: Concentration
B: Velocity
C: Impact Angle
D: Time
ϵ: Error
The given equation can predict the erosive wear loss for the Tantalum iron specimen at the estimated range of parametric values.

4 Conclusion

All process parameters selected (concentration, velocity, impact angle and time) are found significant in the erosive wear loss of HDPE while in the case of Tantalum iron, only three are found significant. The erosive wear loss is found to increase with the increase in time, velocity, and concentration. Other than the four parameters, two interactions (between concentration and time and concentration and impact angle) are also found significant for HDPE. For Tantalum iron, the interactions are not significant. Among the significant parameters velocity has the least contribution to the erosive wear loss. When the angle of orientation of the blade surface with respect to slurry impact angle increases then the erosion rates decreases with constant speed. It may be due to the low range of velocity. From the contribution chart we can depict that time is the most contributing factor that causes erosive wear loss (46.6% in HDPE and 65.3% in Tantalum iron). The erosive wear loss of Tantalum iron is nearly 10 times more than HDPE. The maximum wear loss occurred was at 0 0. HDPE has less Taber Wear index compared to Tantalum iron ie, Taber wear index of Tantalum iron is nearly 10 times more than HDPE).As we can say the lower the Taber wear index, the better the erosion resistance.

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