Effect of impact angle and impact velocity on the slurry erosion behavior of high density polyethylene (HDPE)

Ahmed Mostafa[1], **Tarek Mohamed Abd El-badia**[2], **Raafat Mahmoud Gad El-Rab**[3]

[1] Mechanical design department, El-Mataria faculty of engineering, Helwan University, Cairo, Egypt

[2] MTC, Cairo, Egypt

[3] EAE & AT Affiliated to ministry of military production

Abstract. High density polyethylene is widely used in many applications which deal with slurry because of its high erosion resistance characteristics. Slurry erosion is a type of erosive wear which takes place when a stream of liquid hits a solid body and results erosion in this body surface. Slurry erosion is affected by some parameters as material hardness, impact velocity, impact angle, slurry content, ambient temperature, particle hardness, particle size and particle shape. The changing of these parameters individually will result in useful analysis for the changing in slurry erosion rate with respect to the changed parameter. This experimental work aims to investigate the slurry erosion behavior of high density polyethylene under the effect of different impact velocities. A slurry impingement test rig will be used to make the wear test and wear rate of HDPE is investigated as a function of impact velocity and impact angle. Results showed that the maximum wear rate is at the lowest impact angle and maximum impact velocity. Weight loss is the indication of wear rate of the HDPE specimens after experiment and wear rate is defined as weight loss during the test time in [mg/h] unit

Keywords: slurry erosion, wear rate.

1. Introduction

In the last few years, non-metallic materials were widely used in many industrial and slurry transportation applications because of their erosive resistance, mechanical properties, and low cost. HDPE is one of the polymeric materials used in many applications like slurry transportation pipelines [l]. To improve the performance of machinery parts and pipes made of HDPE and to increase the service life of these parts, the slurry erosion behavior of HDPE must be studied well to investigate the effect of different parameters on these parts. Slurry erosion is a type of erosive wear which remarkably affects the service life of machine parts or pipes that deals with a stream of liquids containing solid particles. This type of erosion happens when a stream of liquid carrying solid particles hits a surface of a solid body. Many parameters affect the behavior of erosion such as the impact characteristics, erodent particle characteristics, surface of the solid body characteristics, and liquid characteristics. Impact characteristics are the properties of the impact process such as impact velocity and impact angle. Erodent particle characteristics are the shape, size, hardness, and density of the solid particles. The surface of the solid body characteristics includes hardness, ductility, toughness, and yield strength. Liquid characteristics include the viscosity and density of the liquid. All these parameters significantly affect the erosion rate. Erosion is known as the weight loss of the material sample after experiments [2]. Fact characteristics have a significant effect on the slurry erosion behavior. The experiments carried out to study the impact of various parameters on erosion rate are in the laboratory using different kinds of test rigs such as slurry pot tester as shown in Fig.1, and jet impingement tester as shown in Fig.2 [3].

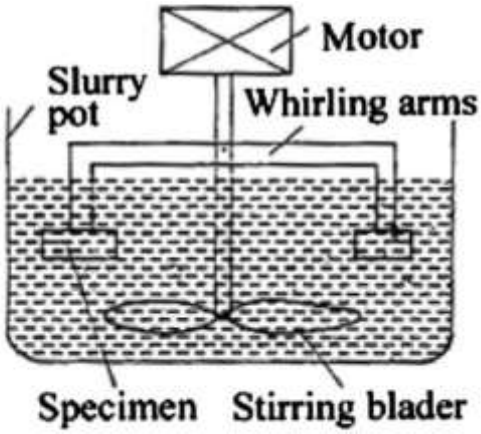

Fig.1 Schematic diagram of slurry pot [3]

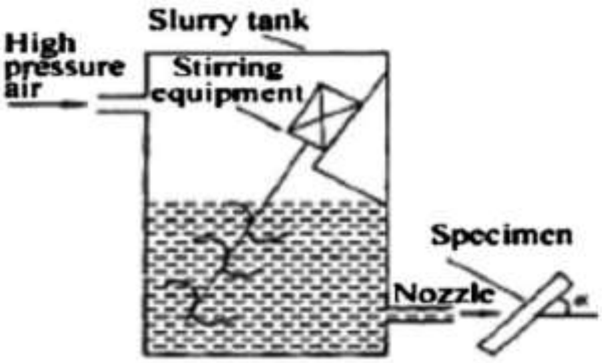

Fig. 2 Schematic diagram of jet impingement tester [3]

1.1. Effect of Impact angle on erosion rate

The impact angle is defined as the angle between target surface and the direction of the striking flow. It is known that the erosion rate is related to the impact angle. The effect of impact angle is different in the cases of brittle and ductile material. For ductile material, the maximum erosion rate takes place at lower impact angles (from 20 to 30 °) but for brittle material the maximum erosion rate occurs at highest impact angle (90 °) as shown in Fig.3 [4,5].

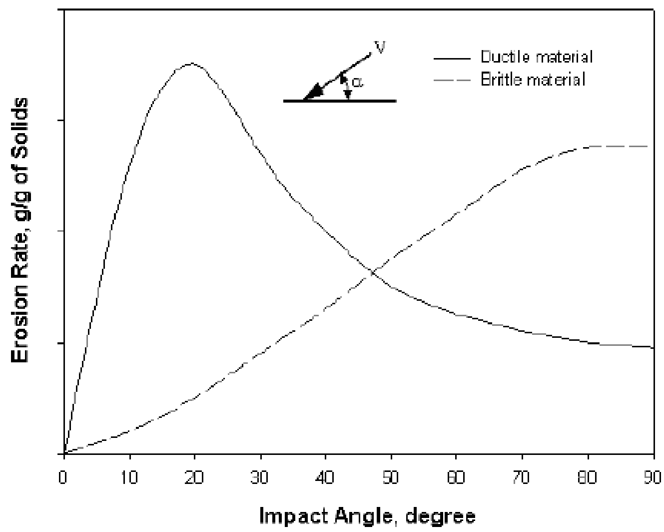

Fig.3 Variation of erosion rate according to impact angle for ductile and brittle materials [4]

Many erosion studies were previously made on plastic material such as PE [1, 6-8], polyether ether ketone (PEEK) [8-10], polyethylenimine (PEI) [8, 11-14], polyimide (PI) [15], polypropylene (PP) [6, 16], polyphenylene sulfide PPS [8, 17, 18]. In this research slurry jet erosion test was carried out on HDPE samples under the effect of different impact angles. The results showed the erosion behavior of tested samples.

1.2. Effect of Impact velocity on erosion rate

Impact velocity is defined as the exit velocity of the jet from the ejector in jet impingement test rig. Ductile and brittle material erosion rate is directly proportional to the impact velocity which means that the erosion rate of any material increases with impact velocity increasing. The main difference between ductile and brittle material erosion rate is the material removal mechanism. Fig.4 shows the relation between erosion rate and impact velocity of a polymeric paint-films using slurry erosion whirling-arm rig and it is clear that erosion rate increases with impact velocity increasing [3].

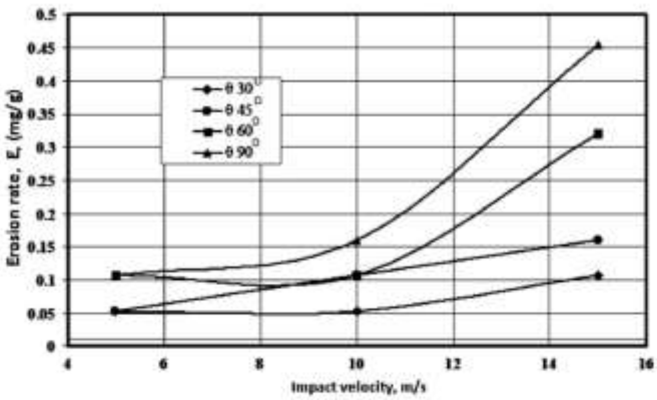

Fig.4 Relation between erosion rate and impact velocity of a polymeric paint-films [3]

In this research HDPE samples are tested using slurry impingement erosion test. The erosion rate is evaluated at different impact velocities and impact angles.

2. Experimental work

In order to investigate the slurry erosion behavior of HDPE, a laboratory test must be performed on this material changing number of parameters and the erosion behavior of HDPE can be accurately discussed using the analysis of results. In this study, high density polyethylene samples with dimensions 40x40x3 [mm] were subjected to a slurry jet with a range of impact angles. SEM examination used to insure the study and to confirm the results. An analysis of the erosion rate results (defined as the weight loss during the test time) and SEM examination to evaluate the erosion behavior of HDPE. Details of the experimental work listed in main points such as test apparatus (slurry impingement test rig), erodent particles, target material, erosion test parameters and erosion rate calculation method.

2.1. Slurry impingement test rig:

The slurry jet impingement test rig was designed and constructed to achieve control on various parameters which affect the erosion rate (impact angle, impact velocity, erodent particles size, slurry mixture type, slurry content and different target materials). This type of test rigs has been used in many earlier works [19, 20]. The test rig used in this study is formed of many components (acrylic tank, water pump, piping system, flow meter, electrical control panel, ejector and specimen holder) as shown in Fig.5.

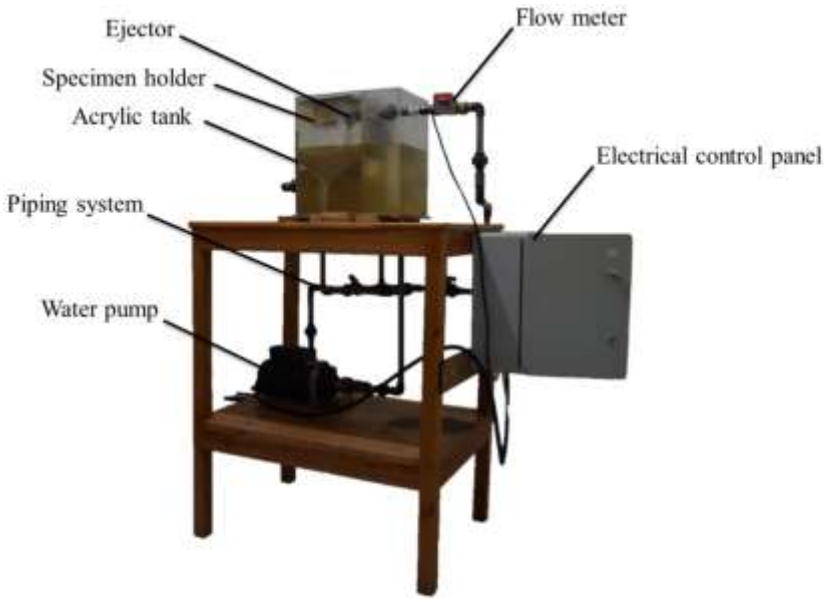

Fig.5 Slurry impingement test rig

2.1.1. Acrylic tank:

Acrylic tank is made of transparent acrylic 10 mm thickness and made of two main sections slurry section and water section. Slurry section contains the required amount of silica solid particles and the water section contains water which used to make a jet. The inner wall which separates slurry and water sections has a rectangular opening with stainless steel filter with size 200 μm to allow water to return from the slurry section to the water section and preventing solid particles from entering into the water section. Fig.6 shows the acrylic tank sections.

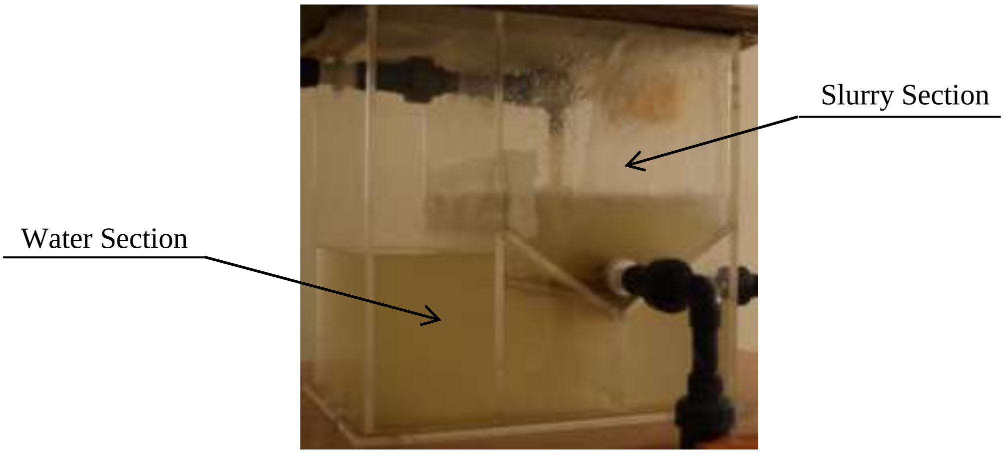

Fig.6 Acrylic tank

2.1.2. Water pump:

The pump with 0.5 HP 3 phase electrical motor used for water pumping into piping system.

2.1.3. Piping system:

Piping system is made of 0.5 inch PVC pipes, joints and stop valves to control the flow in the test rig.

2.1.4. Flow meter:

Digital flow meter assembled in the pipe line to monitor the actual flow rate and be able to calculate the actual impact velocity.

2.1.5. Electrical control panel:

Control panel consists of main circuit breaker to provide the panel components with the required electrical 220 VAC power, 5 VDC power supply provides electrical power to the flow meter and frequency converter to control speed of pump to control the impact velocity.

2.1.6. *Ejector:*

Teflon ejector is designed according to venture theory and used for mixing the slurry jet (silica – water) and direct the slurry jet towards the target material, Fig.7 shows half section of the ejector.

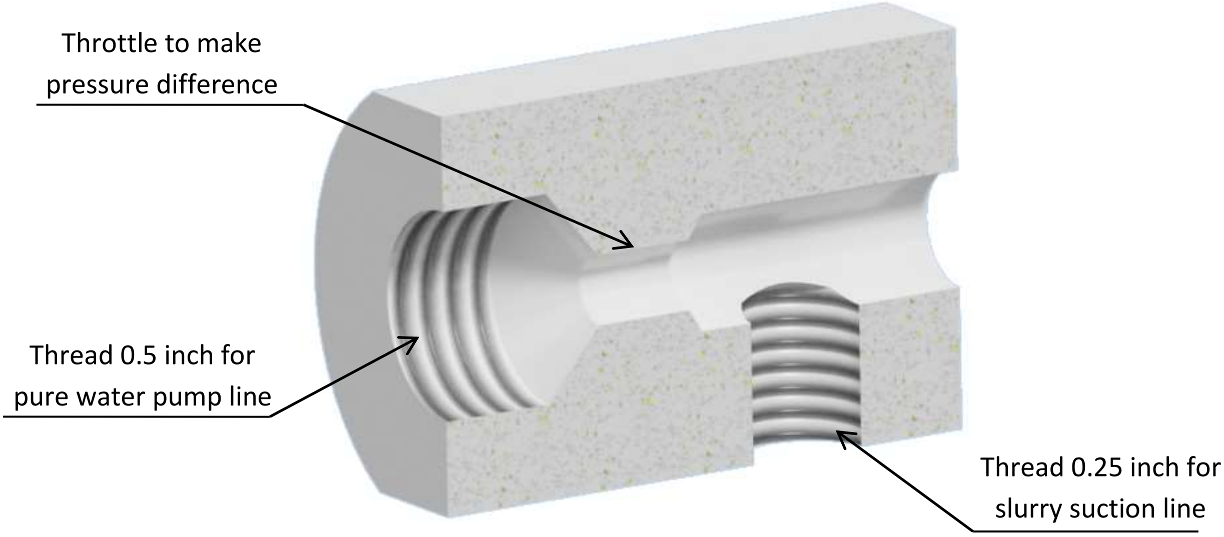

Fig.7 Half section of the Teflon ejector

2.1.7. *Specimen holder:*

Holder was constructed of fixed part and rotating part. The fixed part is fixed to the acrylic tank in front of the ejector and rotating part is used for specimen fixing and changing impact angle by rotating it. The specimen holder can achieve 30°, 45°, 60° and 90° impact angles. Fig.8 shows the specimen holder.

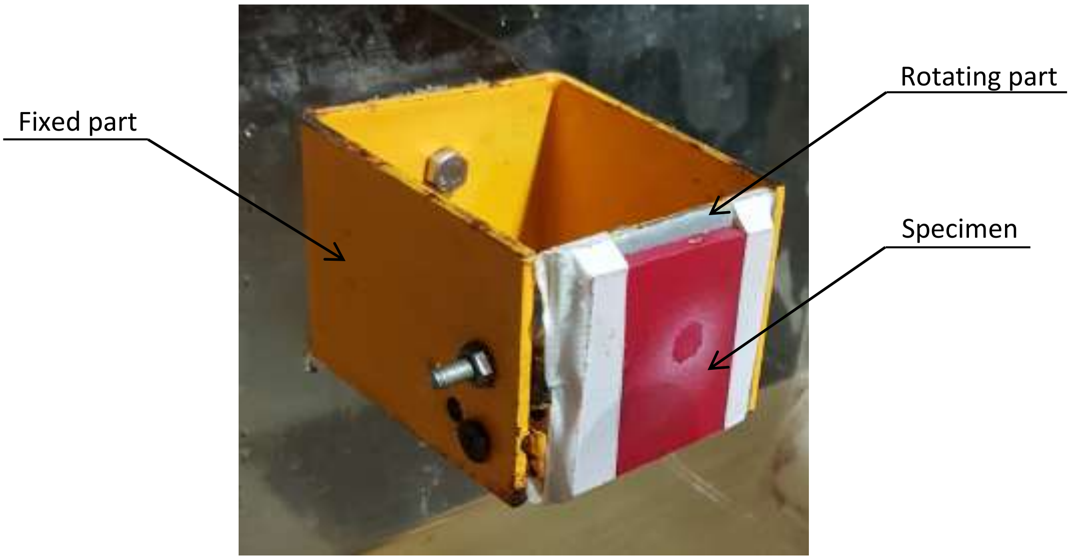

Fig.8 Specimen holder

2.2. Erodent particles:

The solid erodent particles were silica sand with size range 600 – 710 μm mixed with water. Sand particles were prepared using two stainless steel sieves with sizes 710 and 600 μm. Therefore the average size of solid particles was 655 μm as shown in Fig.9.

Fig.9 Solid particles, 710 μm and 600 μm sieves

2.3. Target material:

Material subjected to erosion test was HDPE samples with dimensions 40x40x4 [mm]. The mechanical properties of HDPE are listed in table 1.

Table 1. Technical data of HDPE used in tests

Mechanical	Nominal value (SI)	Test method
Tensile strength		
Yield	31.0 MPa	ASTM D638[1], ISO 527
Break	17.9 MPa	
Tensile Elongation		
Yield	6.0 %	ASTM D638[1], ISO 527
Break	350 %	
Flexural modulus – 2% Secant	1410 MPa	ASTM D790B[1], ISO 178
Impact	Nominal value (SI)	Test method
Tensile impact strength	168 KJ/m^2	ASTM D1822[1,2], ISO 8256
Hardness	Nominal value (SI)	Test method
Durometer hardness (shore D)	61	ASTM D2240[1], ISO/IEC 17025:1999

2.4. Erosion test conditions and parameters:

Tests were conducted with some fixed parameters slurry concentration 4 wt. %, the slurry content tested practically during preparation of test rig, a digital flow meter used in calculating the jet velocity. Experiments done by subjecting each sample to slurry jet with previous parameters for 30 minutes, impact angles 90, 60, 45 and 30 degrees were adjusted to study the effect of impact angle on the slurry erosion rate, impact velocities 4, 5, 6 m/s.

The four impact angles are adjusted at each impact velocity, three samples are used for each impact angle. The average erosion rate is taken. The total number of tested samples in this study is 36.

2.5. Erosion rate calculation method

Erosion rate is defined as the mass loss of target material per time of the test, all samples were weighed before tests using digital scale with accuracy 10^{-4} g and weighed again after tests to calculate the mass loss and erosion rate. Results can be compared with SEM of the tested samples.

3. Results and discussion:

Experimental investigation of the slurry erosion rate and weight loss of HDPE has been carried out in the conditions listed in paragraph 2.4. Results are recorded in the table 2. Fig.10 shows that the erosion rate is directly proportional to the impact angle till the impact angle is about 48° and then it is inversely proportional to the impact angle. The maximum erosion rate takes place between impact angles 40° and 50°. Fig.11 shows the slurry erosion rate under the effect of different impact angles and different velocities. It is clear that the erosion rate increases with the impact velocity increasing. The erosion rate at impact velocity 4 m/s increases with impact velocity increasing till the impact angle reaches about 45° and then starts decreasing with the impact angle increasing. At impact velocity 5 m/s the erosion rate is directly proportional to the impact angle till the value about 56° and then it inversely proportional to the impact angle. The erosion rate at impact velocity 6 m/s increases with the increasing of impact angle till it reaches about 48° and then starts in decreasing with the increasing of impact angle. Fig.12 shows the slurry erosion rate at impact angle 45° and it is clear that the erosion rate is directly proportional to the impact velocity. The results follow the slurry erosion of ductile materials and it is agreed with the mechanical properties of the HDPE which have been listed in the technical datasheet.

Table 2. Erosion rate tests results

Test parameters	Erosion rate [mg/h]
Impact velocity 4 [m/s]	
Impact angle 30°	1.66
Impact angle 45°	6
Impact angle 60°	3.26
Impact angle 90°	1.47
Impact velocity 5 [m/s]	
Impact angle 30°	4.14
Impact angle 45°	9.4
Impact angle 60°	11
Impact angle 90°	4
Impact velocity 6 [m/s]	
Impact angle 30°	4.6
Impact angle 45°	13.94
Impact angle 60°	11.9
Impact angle 90°	5.26

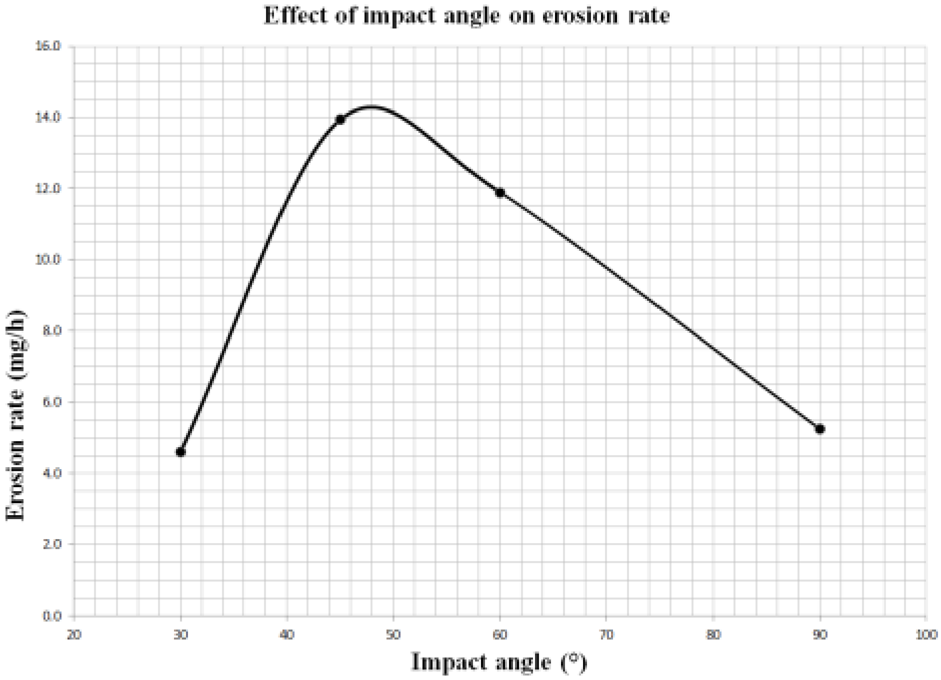

Fig.10 Slurry erosion rate of HDPE for different impact angles, at impact velocity 6 [m/s].

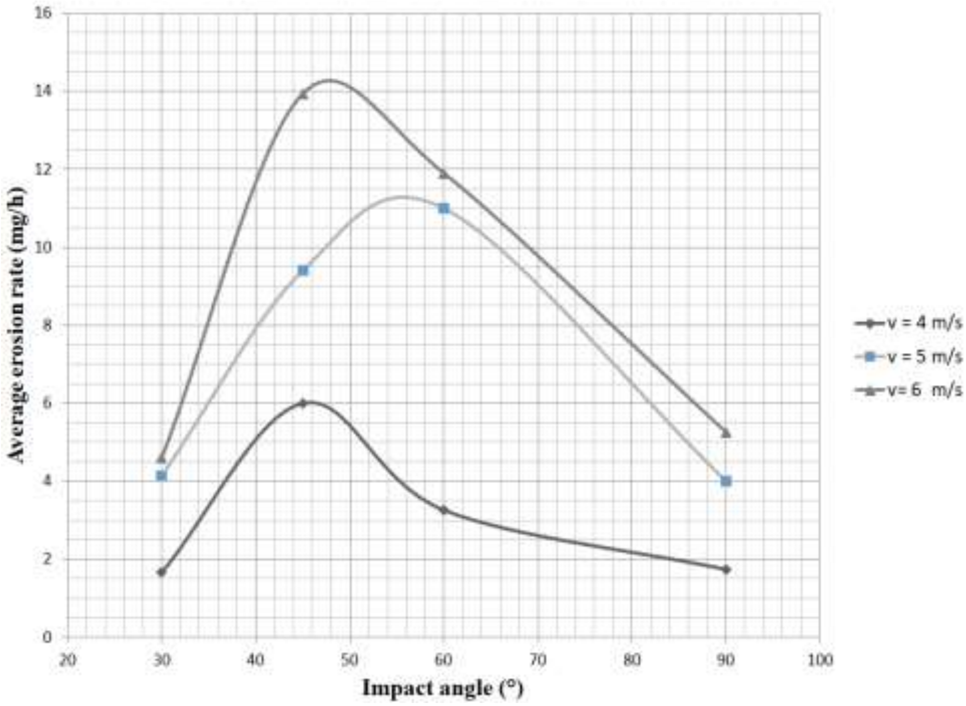

Fig.11 Slurry erosion rate of HDPE for different impact velocity and impact angles

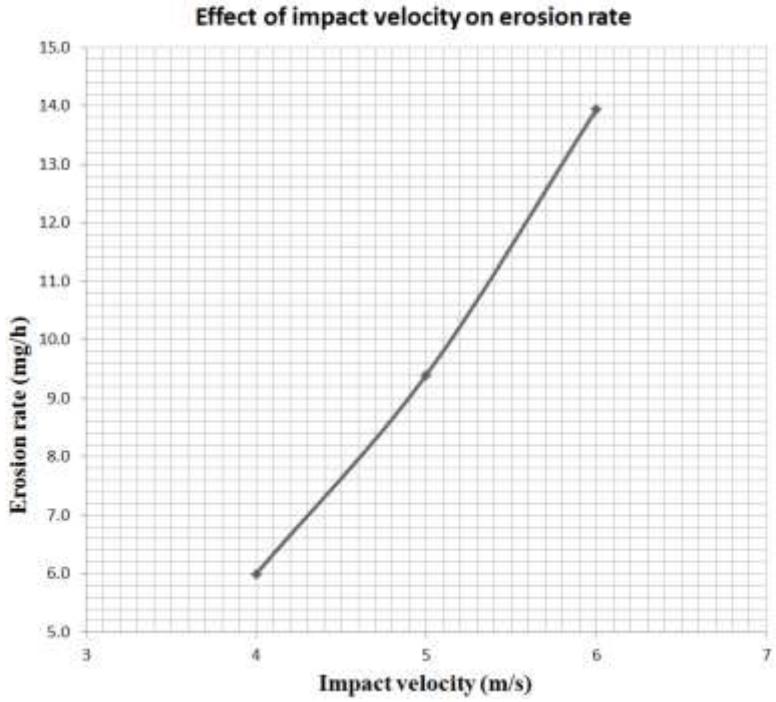

Fig.12 Slurry erosion rate of HDPE for different impact velocity at 45° impact angle

4. SEM Examination:

The eroded specimens have been examined using scanning electron microscope (SEM). Fig.13 shows the mechanism of material removal in case of 90° impact angle and impact velocity 5 [m/s]. In case of ductile material like HDPE (the tested material) the removal mechanism of material occurs in following sequence: crack formation, crack propagation and bulk material loss marked with the circle marks in Fig.13 and it is matching with the material removal mechanism of ductile materials.

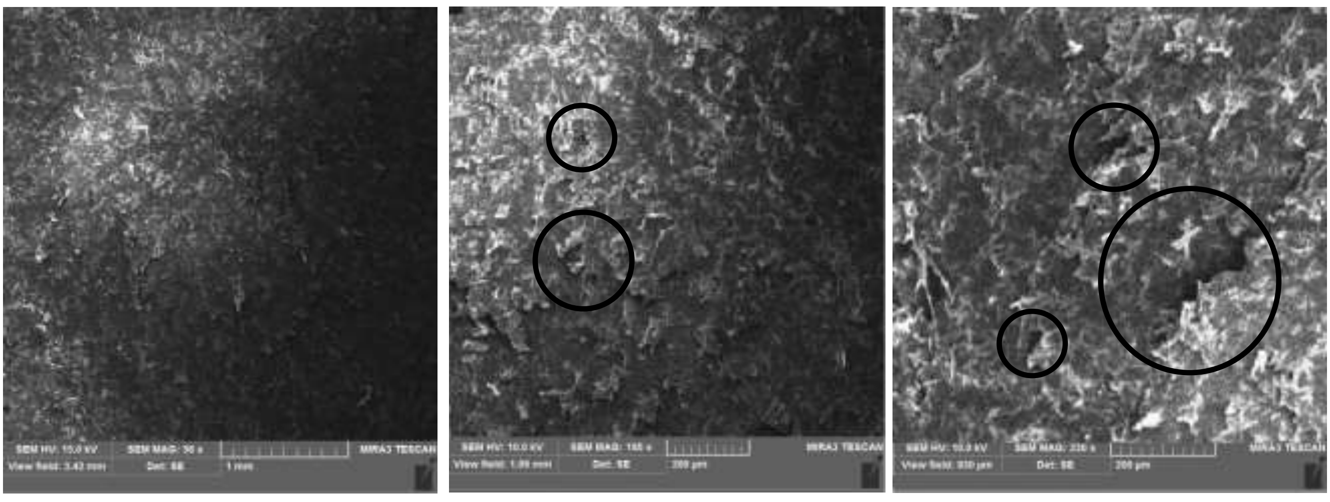

Fig.13 SEM examination image for HDPE sample tested at 90° impact angle and 5 [m/s] impact velocity

Fig.14 shows the material removal mechanism of tested sample at 30° impact angle and impact velocity 6 [m/s]. For ductile material the removal mechanism takes place by cutting wear as shown. The oval marks in the same figure refer to longitudinal cutting wear and the square marks refer to the removed materials in the direction of the slurry flow.

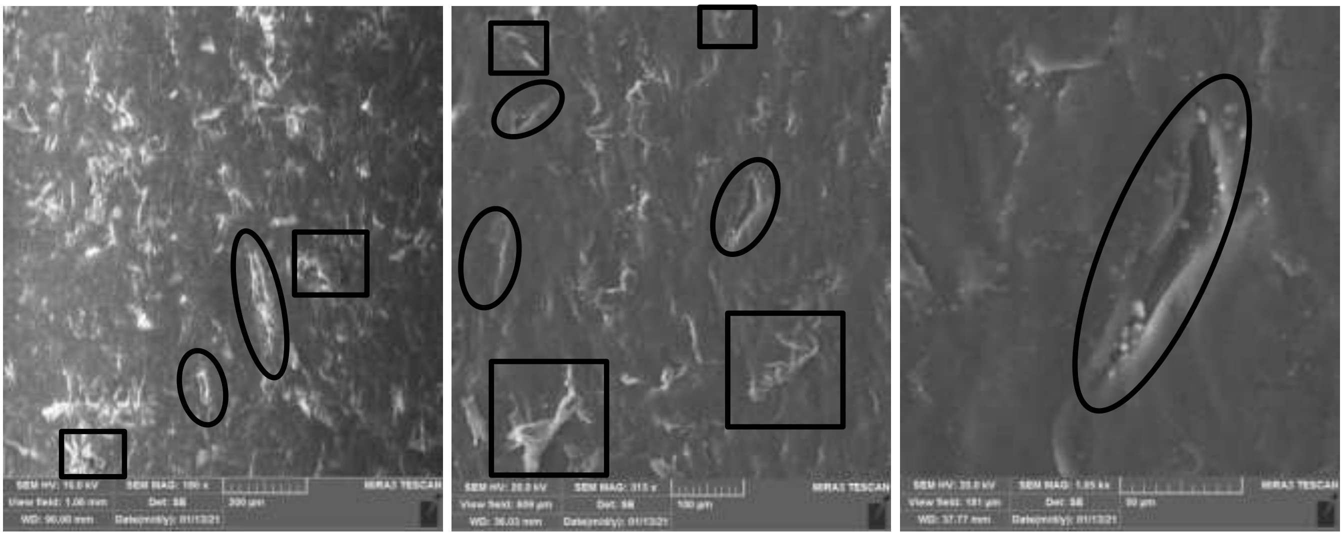

Fig.14 SEM examination image for HDPE sample tested at 30° impact angle and impact velocity 6 [m/s]

5. Conclusion

- Slurry erosion test was carried out using slurry jet impingement test rig on HDPE samples for 30 minutes for each sample. Sand erodent particles with 655 μm average particle size, 4 wt. % slurry content, impact angles (30°,45°,60° and 90°) and range of impact velocity 4, 5, 6 m/s.
- Maximum measured erosion rate is 13.94 [mg/h] at 45° impact angle and 6 [m/s] impact velocity.
- The results showed that the maximum erosion rate of HDPE takes place at impact angles (40° - 50°) as shown in Fig.10.
- The SEM results showed the material removal mechanism of HDPE in case of high and low impact angles (90° and 30°) of the erosion rate as shown in Fig.13 and Fig.14.
- The erosion rate is directly proportional to the impact velocity as shown in Fig.11 and Fig.12.
- These results are acceptable compared with the behavior of erosion rate of ductile materials.
- The results of HDPE can be used in applications with impact angles from (0° to 40°) and from (50° to 90°) as petroleum transportation pipelines taking in consideration the effect of impact velocity.

References

[1] K.Koskelaa, M.Lindgrenb, Slurry erosion resistance of polyethylene under conditions relevant for mineral processing, Wear 392-393 (2017) 1-7.

[2] T.Frosell, M.Fripp , E.Gutmark, Investigation of slurry concentration effects on solid particle erosion rate for an impinging jet, Wear 342-343 (2015) 33-43.

[3] A. Abouel-Kasem, Y. M. Abd-elrhman, K. M. Emara, S. M. Ahmed, Design and Performance of Slurry Erosion Tester, Journal of tribology 132 (2010) 1-10.

[4] B.D. Nandre , G.R.Desale, Study the Effect of Impact Angle on Slurry Erosion Wear of Four Different Ductile Materials, Materials Today: Proceedings 5 (2018) 7561-7570.

[5] B.S.Chahar, Siddhartha, A.K.Pun, Erosion wear of ductile materials: a review, ELK Asia pacific journals (2018) ISBN: 978-81-930411-8-5.

[6] K. Friedrich, Erosive wear of polymer surfaces by steel ball blasting, Journal of Materials Science 21 (1986) 3317–3332.

[7] A.Yabuki, K.Sugita, M.Matsumura, M.Hirashima, M. Tsunaga, The anti-slurry erosion properties of polyethylene for sewerage pipe use, Wear 240 (2000) 52–58.

[8] S.Arjula, A.P.Harsha, M.K.Ghosh, Solid-particle erosion behavior of high-performance thermoplastic polymers, Sci. 43 (2008) 1757–1768.

[9] S.Arjula, A.P.Harsha, M.K.Ghosh, Solid particle erosion of unidirectional fiber reinforced thermoplastic composites, Wear 267 (2009) 1516–1524.

[10] A.P.Harsha, U.S.Tewari, B.Venkatraman, Three-body abrasive wear behavior of polyaryletherketone composites, Wear 254 (2003) 680–692.

[11] S.Arjula, A.P.Harsha, M.K.Ghosh, Erosive wear of unidirectional carbon fiber reinforced polyetherimide composite, Lett. 62 (2008) 3246–3249.

[12] A.P.Harsha, A.A.Thakre, Investigation on solid particle erosion behavior of polyetherimide and its composites, Wear 262 (2007) 807–818.

[13] R.Rattan, J.Bijwe, Influence of impingement angle on solid particle erosion of carbon fabric reinforced polyetherimide composite, Wear 262 (2007) 568–574.

[14] N.Sarı, T.Sınmazçelik, Erosive wear behavior of carbon fiber/polyetherimide composites under low particle speed, Materials and design 28 (2007) 351–355.

[15] M.Ivosevic, R.Knight, S.R.Kalidindi, G.R.Palmese, J.K.Sutter, Solid particle erosion resistance of thermally sprayed functionally graded coatings for polymer matrix composites, Surf. Coat. Technol. 200 (2006) 5145–5151.

[16] S.M.Walley, J.E.Field, P.Yennadhiou, Single solid particle impact erosion damage on polypropylene, Wear 100 (1984) 263–280.

[17] T.Sınmazçelik, İ.Taşkıran, Erosive wear behavior of polyphenylenesulphide (PPS) composites, Materials and design 28 (2007) 2471–2477.

[18] T.Sınmazçelik, S.Fidan, V.Günay, Residual mechanical properties of carbon / polyphenylenesulphide composites after solid particle erosion, Materials and design 29(2008) 1419–1426.

[19] M.M.Stack , T.M.Abd El Badia, Mapping erosion–corrosion of WC/Co–Cr based composite coatings:Particle velocity and applied potential effects, Surface & Coatings Technology 201 (2006) 1335-1347.

[20] M.M.Stack , T.M.Abd El Badia, On the construction of erosion–corrosion maps for WC/Co–Cr-based coatings in aqueous conditions, Wear 261 (2006) 1181-1190.