Impact and Slurry Erosion Resistance of Composite Materials

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***Abstract* - Surface erosion of materials by impact of solid particle present in the liquid is a major problem in many types of industrial equipment involving multiphase flow. Erosion causes pitting resulting in holes leads to functional failure, though the remainder of the equipment is relatively undamaged. It is therefore propose to identify suitable material with reinforced and working parameters to minimize erosion rate i.e. increase the impact slurry erosion resistance of material. So as to optimize the material properties, improvement in the efficiency of fluid flow is observed.**

Erosion phenomenon had studied for conventional material but very less work is available in case of polymer matrix composite. In current work the erosive wear of Polytetrafluoroethylene (PTFE) and PTFE matrix glass fiber reinforced composite in pure water has been studied.

Keywords: - Polytetrafluorethylene, Glass fiber (GF), Factorial design, erosion, composite.

I. INTRODUCTION

Surface erosion of materials by impact of solid particle present in the liquid is a major problem in many types of industrial equipment involving multiphase flow. Erosion causes pitting and/or holes leads to functional failure, though the remainder of the equipment is relatively undamaged [1, 2]. This may be achieved by altering the flow geometry, impact direction, suitable impinging velocity within the equipment such that the fluid flows, and in turn the particle impact dynamics are changed. As the erosion rate is considered as function of the local particle impact rate, velocity and impact angle these parameters are studied for different materials [3, 4]. Slurry erosion is common phenomenon occurring in various places such as impeller of pump, blades of water turbine, pipes carrying mud, sewerage pipes etc. Generally a suspended solid particle present in liquid makes impact on surface of target material to give rise to removing material from surface resulting in erosion. In recent years number of articles dealing in erosion of polymer and metal matrix composites are available but exhaustive study on vital aspect is hardly found [5,6].Polymer material is in the form of polytetrafluorethylene is used because of its excellent properties such as toughness, wear resistant and sustains comparatively at high temperature [7]. The metal reinforcement is also selected in the form of wear resistant properties at various configurations.

Polytetrafluoroethylene (PTFE) matrix composite has been proved useful in variety of engineering application. PTFE is used as a non-stick coating for pans and other cookware. It is often used in containers and pipe work for reactive and corrosive chemicals. PTFE reduces friction, wear, and energy consumption of machinery [7].

In the present work, polymer matrix and metal reinforced composite material is selected. Various compositions of these materials are produced. Polymer material is in the form of polytetrafluorethylene is used as it is tough, wear resistant and sustains comparatively at high temperature. Reinforcement in the form of metals is used. The metal reinforcement is also selected in the form of wear resistant properties at various configurations and their impact and erosion resistance is checked in slurry erosion apparatus.

Polytetrafluoroethylene (PTFE) matrix composite have been proved useful in variety of engineering application. PTFE is used as a non-stick coating for pans and other cookware. It is often used in containers and pipe work for reactive and corrosive chemicals. PTFE reduces friction, wear, and energy consumption of machinery. Though limited studies have been carried out in this direction wherein the effect of different factors like rate of impact of local particle, velocity and impact angle for different composite material. Composite material has found their potential as substitute metal where corrosion/erosion is major problem/condition. This kind of approach is already being adopted in areas like process metallurgy, mineral processing, etc. however such an approach does not adopted so far as the influence of various factors on the wear response of material is concerned. An attempt has been made to

develop a linear regression equation for a calculation of erosive-corrosive wear rate of PTFE with GF particulates taking into consideration factors like rate of impact of local particle, velocity and impact angle for different composite material and their effect on wear properties of material. Theoretically calculate a value of wear rate has checked through experimentally observed ones.

II. LITERATURE REVIEW

Barkoula N.M.andKarger-Kocsis J.[1] studied erosive wear behavior of glass fibre (GF) reinforced thermoplastic polypropylene (PP) composites in a modified sandblasting apparatus as a function of 1) impact angle , 2)relative fibre-orientation (parallel Pa and perpendicular Pe) 3) fibre length (discontinuous, continuous) and 4) fibre content. The results showed the erosive wear is strongly depends on the relative fibre-orientation at low impact angles (30◦), but hardly any difference for 60 and 90◦ impact angles. In contrast, the fibre length did not affect the erosive wear behavior especially at high impact angles. The wear process in thermoplastic matrix composites (GF/PP) presents a maximum ER at 30◦ impact angle. The fibre content seems to influence strongly the ER; the experimental results showed a linear variation of the ER with a fibre content up to 60wt. %.

H.M. Hawthorne et al. [2] analyzed theCoriolis test is used for evaluating the slurry erosion behavior of materials. Experiment is carried out with a model single glass bead-in-water “slurry” has revealed the nature of, and extent of damage at, all contact sites along a soft copper specimen surface. The results confirm previous theoretical predictions that in this test erodent particles interact with the specimen in a series of low angle impacts of decreasing angle, normal velocity component and rebound height along the specimen. The theoretical model reasonably predicts the slurry particle dynamics in this Coriolis erosion test. Without knowing the precise value of the coefficient of restitution, however, accurate calculation is not possible.

Miyazaki N. andHamao T. [3] used experimental analysis by erosion test apparatus for the effect of Interfacial Strength between a matrix material and fibre on the solid particle Erosion Behavior of FRPs. The results of the erosion tests show that the FRPs with treated fibers have higher erosion resistance than the FRPs with untreated fibers due to higher interfacial strength between a matrix material and fibers. - The interfacial strength of the PRPs with the treated fibers is nearly 1.6 times as large as that of the FRPs with untreated fibers. The FRPs with high interfacial strength between a matrix material and fibres show small erosion rate or high erosion resistance.

Pool K. V. [4] - studied erosive wear behavior of selected polymer matrix composite materials using erosion wear tester. To characterize the eroded surfacescanning electron micros- copy was used. The results show that the erosive wear rates in studied materials are at least an order of magnitude greater than that of low carbon steel. - The erosion rates in the composites tested are greater than those of steel by at least an order of magnitude. The well-bonded ductile fibers in a thermoplastic matrix should exhibit the lowest erosion rates.

DasS. [5] has done work on Erosion–behavior of a SiC particle reinforced Al–Si alloy in two different environments, Saline andAcidic to simulate sea water and mining atmospheres, respectively. These studies were performed at different sand concentrations (20–40 wt %) and varying rotational speeds (700–900 rpm). the wear rate of the alloy approached to a peak value and then decreased to a stable value. The wear rates of the composites decreased monotonically with distance traversed and attained constant value at long testing times. Rotational speed also affects the wear behavior by intensifying the erosive attack. Composite exhibited better wear resistance than the alloy in marine and acidic atmospheres irrespective of speed and sand content. Wear rates increased with increasing sand content and speed irrespective of material due to increase in the severity of erosive attacks. However, at the higherspeeds the wear rates decreased (e.g., 1100 rpm) due to increased reboundingandintercollisions and also the decrease in the mobility of the erodent particles. From this it is clear that the erosion is the dominant mode of material removal in these two media.

WangY.Q. [6] By using air-borne particle erosion equipment the experimentally analyzed erosive wear behavior of ultrahigh molecular weight polyethylene (UHMWPE) was tested. The effects of impact angle, velocity and the particle hardness on the erosive wear of UHMWPE were demonstrated. By scanning electronic microscopy (SEM) the worm surface morphology was analyzed. The erosion rate is chiefly controlled by three aspects of factors: 1- impact velocity, the angle of incidence under the same testing temperature. 2- The properties of the impingement particles such as shape, size, hardness and fragility. 3- The properties of the materials. When the hard particles (silicon dioxide) act as the impingement particles, the erosion mechanisms of UHMWPE are microcuttingandmicroploughing at lower angles, while the mechanism is plastic deformation at higher angles.

Amar Patnaika et al. [8] studied various predictions and models proposed to describe the erosion rate were listed and their suitability was mentioned. Implementation of statistical techniques anddesign of experiments in analyzing the erosion behavior of composites was discussed. Studies carried out worldwide on erosion behavior of composites have largely been experimental and use of statistical techniques to analyzing wear characteristics is rare. It appears that the effect of fiber reinforcement and ceramic particulate filling on erosion characteristics of polyester composites has still remained a less studied area.

B.C. Patel et al. [9] has completed work as the effect of stacking sequence on erosive wear behavior of untreated woven jute and glass fabric reinforced epoxy hybrid composites experimentally by using erosion test rig apparatus. By studying parameters such as: 1. different impingement angles 2. different particle speed 3. erodent used is silica with different size range and irregular shapes. The author concluded that composite material showed semi ductile behaviour with maximum erosion at 45^0 impingement angle. By incorporating glass in jute fiber composite enhances the erosive properties of resulting hybrid composite. Layering sequence (altering the position of glass piles) significantly affects the erosive strength. It is clear from this study that erosive strength of natural fiber (Jute) can be increased by hybridization with synthetic fiber.

C R Mahesha et al. [10] in his work, total experiments carried out to study the effects of Impingement angle, Particle velocityand Filler materials on the solid particle erosive wear behavior of composite. The author examined morphology of the eroded surfaces was by using Scanning electron microscopy (SEM). The resultof this study shows that semi-ductile behavior with maximum erosion rate at 60° impingement angle. It also shows that the wear rate increases with increasing particle velocity and decreases with increases of filler percentage. Due to addition of Nano clay in B-E composite shows minimum erosion rate as it restricts the fiber–matrix deboning. Influence of the impingement angle on erosive wear of all composites under consideration exhibits semi-ductile behavior with maximum erosion at 60° impingement angle.

Mohammed Ismail et al. [11] has studied solid particle erosion characteristics of the CSP filled C-E composites and the experimental results were compared with that of unfilled C-E composites. To do this, an air jet type erosion test rig and Taguchi orthogonal arrays were used. The result of these results indicates that the rate of erosion by impact of solid erodent was greatly influenced by various control factors. The tensile modulus and flexural modulus of cenospheres filled C-E composites shows good improvement compared with that of the unfilled C-E composites. This study also indicates that the CSP filled C-E composites exhibit better erosive wear performance than that of the unfilled C-E composites. Various factors like filler content, impact velocity, impingement angle, erodent time and erodent size are found to be the significant control factors affecting the erosion rate. Another conclusion of this is that the erosion time is identified as the least significant parameter as far as the wear of such composites is concerned.

U.S. Tewari et al. [12] studied solid particle erosion behavior of unidirectional carbon and glass fibre reinforced epoxy composites has been characterized by using erosion rig apparatus. The author analyzed the erosive wear of these composites at different impingement angles (15-90°) and for different fibre orientations (0, 45, and 90°). The particles (erodent) used for this purpose of erosion measurements were steel balls with diameter of 300-500 mm and impact velocity of 45 m/s. The author concluded that unidirectional carbon and glass fibre reinforced epoxy composites shows semi ductile erosion behavior, with maximum erosion rate at 60° impingement angle. And the fibre orientations had a significant influence on erosion. It also concludes that the erosion is higher when the steel balls impact on fibres normally than when they impact the composite in a direction parallel to the fibres. The degree of fibre breakage appears to vary with fibre orientation. It also shows that erosive wear of GF/EP composite is higher than that of CF/EP composite.

PatilParmeshwar S. and Dr. Kivade S. B. [13] had done work on solid particle erosion behavior of polymer matrix composites. The experimental analysis of erosion of PMCs and theoretical models proposed to describe the erosion rate were studied. Implementation of Design of Experiments (DOE) and Finite Element Analysis (FEA) techniques in analyzing the erosion characteristics of PMCs were also explained. It shows that there is inadequate data available about erosion wear behavior of polymers with addition of filler materials and still it remains a less studied area. Studies almost carried out on erosion behavior of composites are largely been experimental and theoretical.

From above literature review it is clear that the good fiber/matrix adhesion improved the resistance to erosive wear. As compare with untreated FRPs,the treated FRPs give the best erosion resistance. Also without any filler the sample shows highest erosion rate due to weak bonding strength and has adequate potential for tribological applications. For further study to improve the erosion resistance of various polymers composite

we use the fiber and ceramic as an reinforcement materials for manufacturing of new composite

Objective of the experiment are to study the effect of different angle, velocities on test specimen. To study the erosion rate with its erosion characteristics of composite materials, compare it with pure metals and to check the feasibility of material.

III. COMPOSITE MATERIAL

A composite material is a material mode from two or more constituents materials with significantly different physical or chemical properties that, when combined produce a material with characteristics different from the individual components.

Most composites have two constituent materials: A binder or matrix and B reinforcement or filler.

Erosion wear involves several wear mechanisms which are widely controlled by various parameter such as the angle of impingement / impact, impact velocity and erodent type and size.

VI. ANGLE OF IMPINGEMENT

The angle of impingement is the angle between the end surface and the trajectory of the particle immediately before impact.

V. SLIDING / IMPACT VELOCITY

The speed of erosive particle has a very strong effect on the wear process. If the speed is very low, then stresses at impact and insufficient for plastic deformation to occur and wear processed by surface fatigue. When the speed increase, it is possible for the eroded material to deform plastically on particle impact.

VI. EFFECT OF ERODENT PARTICLE CHARACTERISTICS ON EROSION RATE

materials.

In case of erodent the erosion rate is depends on erodent type, erodent shape and erodent size of the erodent particle. There is various types of erodent particles is available in various fluid flowing applications. Most commonly addressed erodent types is alumina and silica. It was determined that particle size effect was different for spherical and angular particles.

VII. EROSION TESTING APPARATUS

Erosion test is carried out by rotating sample test method and discussed at length. Fig.1 shows schematic view of test apparatus. The standard testing parameters of the testing apparatus is as shown in table no. 1. The medium used for testing the sample is pure water. The specimen having size 25 mm X 25 mm surface area & 4-8 mm thickness were used for study. The linear velocity of rotation of sample in slurry is given in table. The experimental parameters whose effects on wear behavior of sample were studied including velocity, impact angle, reinforcement with respect to direction of rotation in pure water.

Fig. 1 - Water jet erosion tester [14]

Table: 1. Specifications of Water jet erosion tester [14]

Parameter	Unit	Value	Remarks
Jet velocity	m/s	10 - 50	Variable
Jet diameter	mm	4	Fixed
Erodent size	mm	1	Maximum
Erodent flux	cc/min	30 - 1500	Variable
Impingement angle	degree	15 – 90	In steps of 15^0
Standard sample size	mm	25 × 25 × 4 - 8	Other sizes on order
Space for sample	mm	150 × 150 × 150	For customized sample
Standoff distance	mm	50	Nozzle to sample
Tank capacity	liters	1200	
Erodent capacity	liters	60	

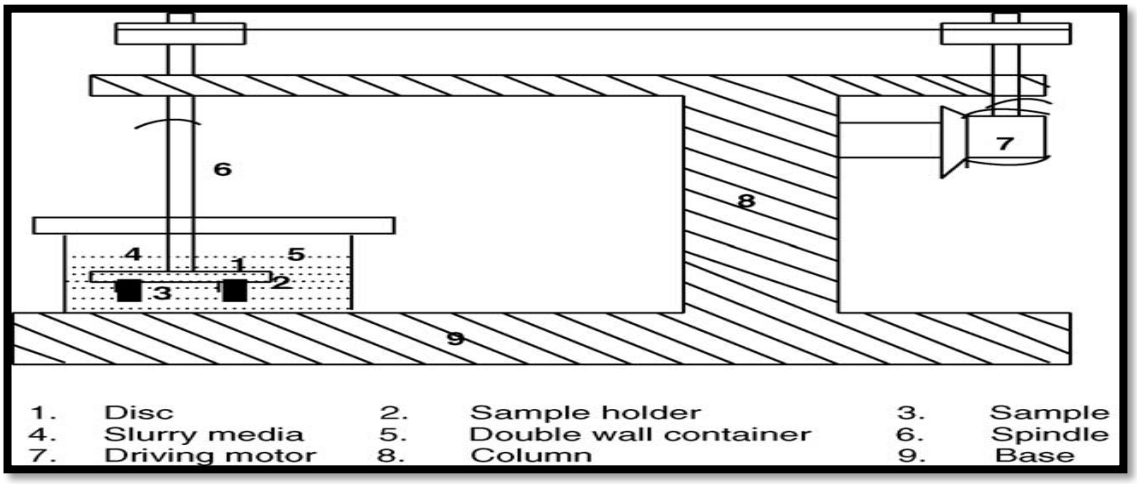

Fig. 2 –Schematic view of the erosion testing mechanism [5]

VIII. EXPERIMENTAL WORK

Slurry Erosion test rig is developed to study the erosive wear characteristics of composite materials as well as metals. The testing mechanism of test rig is as shown in fig. 2. A slurry erosion apparatus is developed to check the effect of impact angle and velocity on target material. In present work effect of pure water particles is studied in order to find the erosion of composite material in pure water. It has been found that due to rotation of target material in pure water erosion happens. It may be due to water particles or very small size particles present in the water.

Material: - The erosion testing is carried on different material as sown in Table 2 to Table 5.

Table: 2. Pure PTFE

Test	Angle	Velocity	Initial Weight	Final Weight	Erosion
1	90	15	3.525	3.522	3
2	90	30	3.522	3.518	4
3	90	45	3.518	3.513	5
4	60	15	3.513	3.511	2
5	60	30	3.511	3.508	3
6	60	45	3.508	3.505	3
7	30	15	3.505	3.503	2
8	30	30	3.503	3.500	2
9	30	45	3.500	3.497	3

The erosion resistance of pure PTFE (Polytetrafluoroethylene) material with changing testing parameters like impingement angle and velocities in the water plus silica sand solution and the results shown in the above table no. 2.

Table: 3. PTFE + 15% Glass Fibre

Test	Angle	Velocity	Initial Weight	Final Weight	Erosion
1	90	15	4.083	4.082	1
2	90	30	4.082	4.080	2
3	90	45	4.080	4.078	2
4	60	15	4.078	4.077	1
5	60	30	4.077	4.076	1

6	60	45	4.076	4.074	2
7	30	15	4.074	4.074	0
8	30	30	4.074	4.073	1
9	30	45	4.073	4.071	2

The erosion resistance of PTFE (Polytetrafluoroethylene) plus 15 percent of GF (Glass Fibre) material with changing testing parameters like impingment angle and velocities in the water plus silica sand solutionand the results shown in the above table no. 3.

Table: 4. PTFE + 25% Glass Fibre

Test	Angle	Velocity	Initial Weight	Final Weight	Erosion
1	90	15	4.139	4.137	2
2	90	30	4.137	4.134	3
3	90	45	4.134	4.130	4
4	60	15	4.130	4.129	1
5	60	30	4.129	4.128	1
6	60	45	4.128	4.125	3
7	30	15	4.125	4.124	1
8	30	30	4.124	4.123	1
9	30	45	4.123	4.121	2

The erosion resistance of PTFE (Polytetrafluoroethylene) plus 25 percent of GF (Glass Fibre) material with changing testing parameters likeimpingement angle and velocities in the water plus silica sand solution and the results shown in the above table no. 4.

Table: 5. PTFE + 35% Glass Fibre

Test	Angle	Velocity	Initial Weight	Final Weight	Erosion
1	90	15	4.440	4.437	3
2	90	30	4.437	4.432	5
3	90	45	4.432	4.427	5
4	60	15	4.427	4.425	2
5	60	30	4.425	4.423	2
6	60	45	4.423	4.420	3
7	30	15	4.420	4.418	2
8	30	30	4.418	4.416	2
9	30	45	4.416	4.413	3

The erosion resistance of PTFE (Polytetrafluoroethylene) plus 35 percent of GF (Glass Fibre) material with changing testing parameters likeimpingement angle and velocities in the water plus silica sand solution and the results shown in the above table no. 5.

IX. CONCLUSIONS

1. It has been found that due to rotation of target material in pure water erosion happens. It may be due to water particles or very small size particles present in the water.
2. It is also observed that as velocity of water increases erosion also increases.

3. The process of erosion takes place after the critical value of velocity of solution.
4. It is found that this critical value is different for different materials.
5. The result indicate that erodent size, fibre loading, impingement angle, impact velocity, volume fraction, reinforcement type have the significant effect on erosion rate.
6. Increase in reinforcement percent of glass fibre in PTFE erosion decreased up to 15 percent increment of glass fibre.
7. Erosion of PTFE matrix glass reinforced composite increases after 15 percent increment in glass fibre reinforcement.

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