Slurry erosion behaviour of Ni-Hard under various impact angle and speed

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Abstract. To Study wear analysis of slurry pump with an experimental condition is an economically costly and lengthy process. Therefore, wear study can be done on various laboratory tests such as Slurry pot tester, Coriolis wear tester, Whirling arm wear test device, particle impact jet test. To analyze of erosion wear rate of slurry pump material in different operating conditions is performed on slurry pot tester. In the latest pump the Ni-Hard is widely used material in the slurry transportation. The one of the major application of slurry pump made from Ni-Hard is in Thermal power plant for ash slurry transportation. In this paper an experimental work has been carried out to find the effect of impact angle and particle impact speed at 20% w/w slurry concentration of sand on the wear rate of the Ni-Hard material. From the experimental results it is found that as particle velocity increases erosion wear rate of the material is increases. It was also found that the erosion of the material increases with impact angle till 30° then the erosion of material decreases gradually.

1. Introduction
Slurry transport is essential in many industries such as mining, thermal power plant, chemical, petroleum. Solid particles to be transported in the slurry form for small to medium distances. Various industries have a large number of applications for slurry pumping. The slurry pump is the most important component of the slurry transport system. The life of the slurry pump varies with the range of a few weeks to a few years depending upon particle size distribution, slurry concentration, abracity of the particle, specific density of particle etc. The main problem regarding slurry transport is low life expectancy and degradation of pump performance due to erosion. Hence increasing the downtime and reducing productivity. Erosion wear is important very important part for design and selection of the slurry pump Satish R More et al. [1]. S. Bree et al. [2] observed that with increase in particle kinetic energy erosion wear also increases.

To calculate and study the erosion occurred in the slurry handling materials a high speed slurry pot tester was developed by Ojala et al.[3]. The test sample is attached to whirling arm of the driven by the rotating shaft. The maximum particle size of 10mm can be used in this setup. Experiment on high speed erosion was done by Singh et al.[4] where they studied the erosion characteristic of 75 μm of particle size fly ash on the cast iron impeller. Desale et al.[6] developed a slurry pot tester for determining effect on erosion by various characteristic of slurry. Where they determined with the increase in particle concentration erosion wear also increases. The slurry pot tester developed by Desale et al. [5] can be used for various particles sizes, concentration, and impact angle. Desale et al.[6] studied the effect the slurry concentration on the erosion wear where they found that erosion increases as concentration increase. Ni-Hard is mostly used in slurry pumping applications, cylinder
liners, pistons, bearings, glands. Here in this study effect of the impact angle and impact speed on the erosion of Ni-Hard material at constant concentration and particle sized is observed.

2. Experimental Setup

A pot tester of 7 liters capacity developed by More et al.[1] is used in the present study. Figure 1 shows the schematic diagram of the slurry pot tester is shown. This Slurry pot has a capacity of containing 7 liters of water for slurry erosion test. To mitigate the vortex motion generated by the rotation of arm of the slurry pot and bottom propeller four baffles are provided. One drain hole in the bottom of the slurry pot and one hole on the acrylic lid to fill the slurry so no air remain in the slurry pot to interfere in the erosion. The simple design is useful for conducting the experiments as factors involving the slurry erosion can be set as per the requirement.

2.1 Preparation of Test Fixtures and Samples

The erosion wear test in the slurry pot testing machine requires the preparation of test specimens with proper dimension to fix in to the test fixtures. The preparation and mounting of the test sample in to the test fixture and attachment of the test fixture to motor through upper shaft is shown in Figure 1.

2.1.1 Test Fixture

Special test fixtures were fabricated to mount flat wear specimens. The erosion wear of the fixture is negligible which can impact on the performance or the accuracy of the test for the amount of time test is running. That is why same fixture can be used for the several test runs. A dimension of the sample is 30 mm x 5 mm x 2 mm, rounded at two ends was provided at the test fixture to fix a wear specimen inside it. Experiments on different angles to study the effect of impact angle is provided at every 15° from 0° to 90°. The slotted angular plate is welded to the holding arm being fitted with the brass sleeve. The brass sleeve is fixed to the upper shaft in such a way that the centre of the wear specimen could be placed equidistance from the top cover and the propeller (approximately 65 mm from each one). The test fixture, one on each holding arm, is hanged opposite by a 4 mm screw. Two fixtures were fitted at 180° apart to balance the dynamic forces, if any, with minimum wake interference-effect. It is expected that this arrangement will help in orienting the wear specimens at the angle of the tilt of the fixture for impact with the suspended solid particles. The test fixtures are rotated at a 71 mm radius in a direction opposite to the propeller rotation to minimize the rotational motion effect. Since the volume swept by the wear specimens and the holding arms is very small it can be said the condition are ideal during the set period of time.

Figure 1: Schematic diagram of Slurry pot tester. [All dimensions are in mm] [Desale et al. 2005]
2.1.2 Test Specimens
Ni-Hard (Chemical Name- Nickel Chromium Martensitic white iron NiCr 30/550) being a cast iron used widely in ash slurry pump has been chosen as the wear test piece material for the present study. The size of the wear piece used was (30 mm x 5 mm), rounded at both ends with a thickness of 2 mm (surface area 144.64 mm²) to fit in the slot of the fixture. The wear pieces were polished using #110, #220, # 600 & # 1000 number emery papers and cloth before conducting the experiment to ensure identical initial conditions for each set of data. Then the test samples were cleaned with water and acetone for a clean surface.

2.2 Properties of Material Used
In the present investigation Indian Standard Sand is used as erodent material and Ni Hard (Type 1B) as target material.

2.2.1 Particle Size Distribution
It is well known that particle size of the particle in the slurry have considerable impact on the erosion wear of the slurry handling equipment. Therefore it is essential to know determine the particle size distribution of the erodent material for establishing the relation between different parameters. Particle sieve analysis is used to determine particle size distribution for coarser particles. This distribution has been obtained by the dry sieve analysis method. Here the sand of different sizes is passed through the number of sieves to categorise as per the size requirement. Here care is taken to keep the sand dry before mixing it with water. The sample retained on each sieve is collected, and its percentage is calculated following the standard procedure.

The particles of IS sand grade III are selected as erodent material for the investigation, and the physical properties are shown in Table 1. Collecting identical sand size is not possible because of fine size and amount of the material being used. The particles are, therefore, sieved using successive sieves sizes, and the mean sieve size designates the particles collected between two successive sieves. To collect quartz particles, Grade III of Indian standard (IS 650:1991) sand was used. From Grade III, the mean particle size of 655 µm was collected as the material retained between the two sieves of 710 µm and 600 µm sizes.

| Table 1 Erodent Properties |
|----------------------------|
| Solid particle | Chemical formula | Colour | Sp. Gravity (Kg/m³) | Hardness VHN | Particle Shape |
| Quartz (IS Sand) | SiO2 | Whitish | 2652 | 1100 | Sub Angular |
2.2.2 Properties of Target Material
The material was acquired from the Thermal Power Plant. The Ni-Hard has different types of material in various percentages depending on the composition of Iron, Nickel, Chromium, Silicon, Manganese etc. Here in this study Ni-Hard (Type 1B) is used and its elemental composition is given in Table 2. The hardness of the material was tested on Mututoyo Rockwell Hardness Testing Machine and found 62.5 HRC hardness of the material. Ni-Hard generally used for abrasion resistance and erosion resistance. This type of material used for the different types of slurry pump. Mainly it is used in ash handling plant of thermal power station to transport ash slurry. This material is used in the form as available i.e. machinable and no heat treatment is carried out. The table motioned below shows the typical range of the Ni-Hard (Type 1B) composition. Toughness and resistance to repeated shock increase as carbon content decreases.

Table 2 –Target material properties

| Target Material | Elemental composition (wt. %) |
|-----------------|-------------------------------|
|                 | C   | Mn | P   | S   | Si  |
| Ni Hard (Type 1B) | 2.8-3.3 | 0.3-0.6 | 0.3 | 0.015 Max | 1.5-2.2 |
|                 | Cr  | Ni | Mo  | N   | Cr  |
|                 | 8.0-10.0 | 4.0-6.0 | 0.5 Max | 0.10 | 8.0 – 10.0 |

2.3 Range of Parameters
The experiments have been carried out using sand slurry of IS sand of 655 μm mean particle size. The mixture was prepared by mixing the sand and tap water in the slurry pot. Slurry erosion of material depends on the many parameters such as particle size, concentration of slurry, impact velocity, impact angle, particle shape etc. Here in this study concentration has been taken 20% by weight and Mean particle size of 655 μm of sand has been taken as constant. Slurry erosion of with two impact velocity (8 and 10 m/s) with different impact angles (15, 30, 45, 60, 75, 90) has been taken as to study the effect of the impact angle and impact velocity.

2.4 Experimental Procedure and Data Analysis
The every test specimens for each experiment are polished with #110, #220, #600 and #1000 emery paper for mirror finish and cleaned with water and acetone respectively. Mass loss of the wear specimen is measured by an electronic balance having least count of 0.1 mg. Each experiment is done with 90 min time. The average mass loss of two wear specimens is used to evaluate the erosion rate according to the relationship proposed by Bree et al.

\[
E_W = \frac{W_L}{\rho_S \times A_{SP} \times C_V \times V_{SP} \times T} \tag{1}
\]

\[
C_V = \frac{C_W}{\rho_S - (\rho_S - 1) \times C_W} \tag{2}
\]

Where,
\(\rho_S\) - Mass density of the solid particle material, (kg/m³)
\(A_{SP}\) - Surface area of the wear specimen subjected to erosion, (m²)
\(C_V\) - Solid concentration by volume, fraction;
\(C_W\) - Solid concentration by weight, fraction;
\(E_W\) - Total erosion rate, (g/g)
\(T\) - Time over which mass loss has been measured, (sec)
\(V_{SP}\) - Peripheral velocity of wear specimen, (m/s)
Preparation of the sample and slurry are key factors for the slurry pot testing. That is why test is done as a standard procedure by first mixing the slurry where predetermined amount of known mean particle size particles and water is mixed in the slurry pot. Sample is prepared by cleaning and polishing to the mirror finish without an external layer of oil or dirt. After closing the acrylic lid and first to ensure particles are uniformly distributed in the slurry bottom propeller is given and have to run at a desired speed after that main shaft should run to at a desired experimental requirement.

3. Results and Discussion
The impact angle of the particles is one of the critical parameters affecting the erosion rate of the target material. It gives an idea about the location of maximum erosion in slurry handling equipment. Hence initially, the erosion wear of the materials was evaluated at different impact angles in the pot tester at 6 m/s velocity, and 20% weight concentration for 655µm mean particle sizes. The wear specimens were positioned at different orientation angles varying from 15 to 90 deg with respect to the flow direction using the slotted angular plate. The results then compared to existing published results of SS304 at 10% concentration, 4m/s particle velocity and 655 µm as mean particle size. By comparing the results with SS304 material at different material we can observe that Ni-Hard also follows the ductile erosion behaviour.

| Speed (m/s) | Impact angle (Degree) | Mass Loss (gram) | Erosion Rate (g/g*10^-7) |
|------------|-----------------------|------------------|--------------------------|
| 6 m/s      | 15                    | 0.0184           | 1.7219                   |
|            | 30                    | 0.0428           | 4.00548                  |
|            | 45                    | 0.0398           | 3.72472                  |
|            | 60                    | 0.0375           | 3.50947                  |
|            | 75                    | 0.0348           | 3.25679                  |
|            | 90                    | 0.0266           | 2.48939                  |
| 8 m/s      | 15                    | 0.0316           | 2.2179                   |
|            | 30                    | 0.0468           | 4.88502                  |
|            | 45                    | 0.0559           | 3.9234                   |
|            | 60                    | 0.0543           | 3.811                    |
|            | 75                    | 0.0498           | 3.49544                  |
|            | 90                    | 0.0376           | 2.63903                  |

Effect of Impact Angle on Erosion Rate
- The variation of the erosion rate of the Ni-Hard at different orientation angles is presented in the table and figure 3.
- It has been observed from the figure that the erosion rate of the material Ni-hard white cast iron increases with the peaked at 30 deg and then decreases with the further increase in impact angle till 90 deg for both the particle sizes.
- It is evident from the figure 3 by comparing SS304 erosion wear behavior due to maximum wear on 30 deg and then gradually decreasing it can be said that Ni-Hard shows the ductile behavior of erosion.

Effect of Impact Velocity on Erosion Rate
- To investigate the effect of velocity on the slurry erosion of target material, experiments were conducted in the velocity of 6 and 8 m/s.
- First, the measurements were performed at different impact angles and velocities to determine the effect of velocity on the erosion wear dependence of target materials with impact angle.
• The measured erosion rate of the Ni hard at different orientation angles and velocities is presented graphically. It is seen that the increase in velocity increases the erosion rate of the materials.

• The variation in erosion rate of the material shows a similar trend with impact angle at all the velocities. The 30 degree impact angle at which the maximum erosion of the target material occurred is the same for both the velocities.

![Figure 3: Change of Erosion rate with impact angle](image)

**Conclusion**

- Erosion wear of Ni hard using slurry erosion pot tester is investigated with parameters such as particle velocity, impact angle.
- Based on the preliminary experiments, it can be said that Ni Hard has ductile type slurry erosion.
- The effect of particle size and slurry concentration is required to study as they are major parameters affecting slurry erosion.
- The experiments show the relationship of particle velocity and impact angle but further understanding of the parameters and its effects is required to study the dependence on each parameter.
- The erosion of the material increases with impact angle till 30° then the erosion of material decreases gradually.
- The erosion increases as the velocity of the particle impact increases. Further full scale study required to study velocity variation with respect to other parameters.

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