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Study of Slurry Abrasion Behaviour of mild steel and weld deposited alloy steel

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Abstract
Slurry abrasion wear is a potential problem in engineering components subjected to particulate flow. Hardfacing by welding is one of the economic methods to improve wear life of engineering components. The present work deals with the slurry abrasion behavior of the mild steel and weld deposited alloy steel. The experiments were performed using silica sand slurry with different slurry concentration, load, total revolution & particle size for both mild steel & weld deposited martensitic steel. The results of the investigation suggest that slurry concentration had relatively stronger effect on wear than the normal load for both steels and the weld deposited alloy steel exhibits better slurry abrasion wear resistance than mild steel. The morphological studies of the worn surfaces revealed characteristic differences in the wear pattern under different test conditions and the operating mechanisms of material removal involved ploughing and cutting.

Keywords: Slurry Abrasion, Load, Slurry Concentration, Ploughing, Cutting, Volume loss

1. Introduction
Wear is not only responsible for material removal but also leads to the premature failure of engineering components. Wear causes huge monetary loss in industries as it includes cost in replacement and downtime cost. In industrial applications, abrasive wear is the most common mode of failure near which constitutes about 50% of the total failure. In most cases wear is detrimental which leads to increased in clearances between the moving components, often vibration which increases mechanical loading and yet more rapid wear and sometimes fatigue failure. Wear by slurry abrasion mainly occurs in slurry pumps, extruders and pipes carrying slurry of minerals and ores in mineral processing industries [1, 3].
The objective of present work is to study slurry abrasion behavior of weld deposited alloy steel. The result of present work shall useful in development of alloys for slurry abrasion applications. The slurry abrasion experiments were performed as silica sand abrasive particles and the effect of test parameters such as slurry concentration, normal load and particle size of silica sand on slurry abrasion volume loss was investigated. The investigation suggests that the slurry concentration had relatively stronger effect to that of normal load and the slurry abrasion volume wear loss is more for mild steel as compared to martensitic steel. SEM studies revealed different morphology of the worn surfaces.

2. Experimental
2.1 Material
The slurry abrasion experiments were carried out on the mild steel and martensitic steel. The chemical composition of mild steel by wt. % was C- 0.118, Si-0.229, Mn-0.806, Cr-0.040, Ni-0.009, P-0.029 and Fe-bal and for weld deposited alloy steel by wt. % was C- 0.052, Si-0.586, Mn-2.54, Cr-6.25, Ni-3.64, P-0.033 and Fe- bal. The bulk hardness of mild steel was 27HRC and weld deposited alloy steel was 55HRC at 150kgf load.

2.2 Microstrures of Material

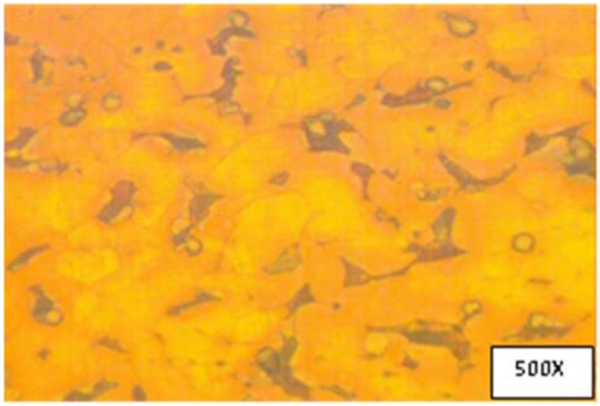

Fig 1: Optical microstructure of mild steel at 500X

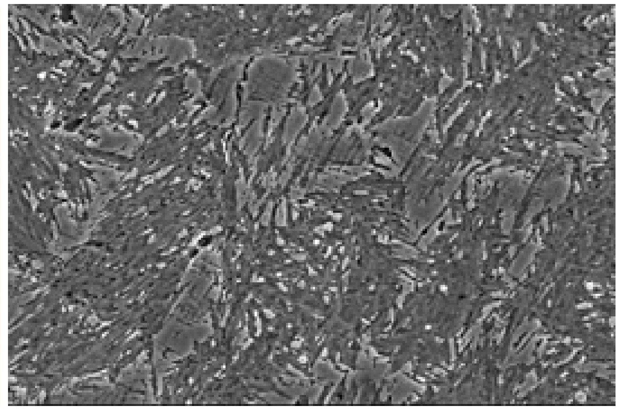

Fig 2: SEM microstructure of martensitic steel at 1500X

2.3 Silica sand abrasive paricle

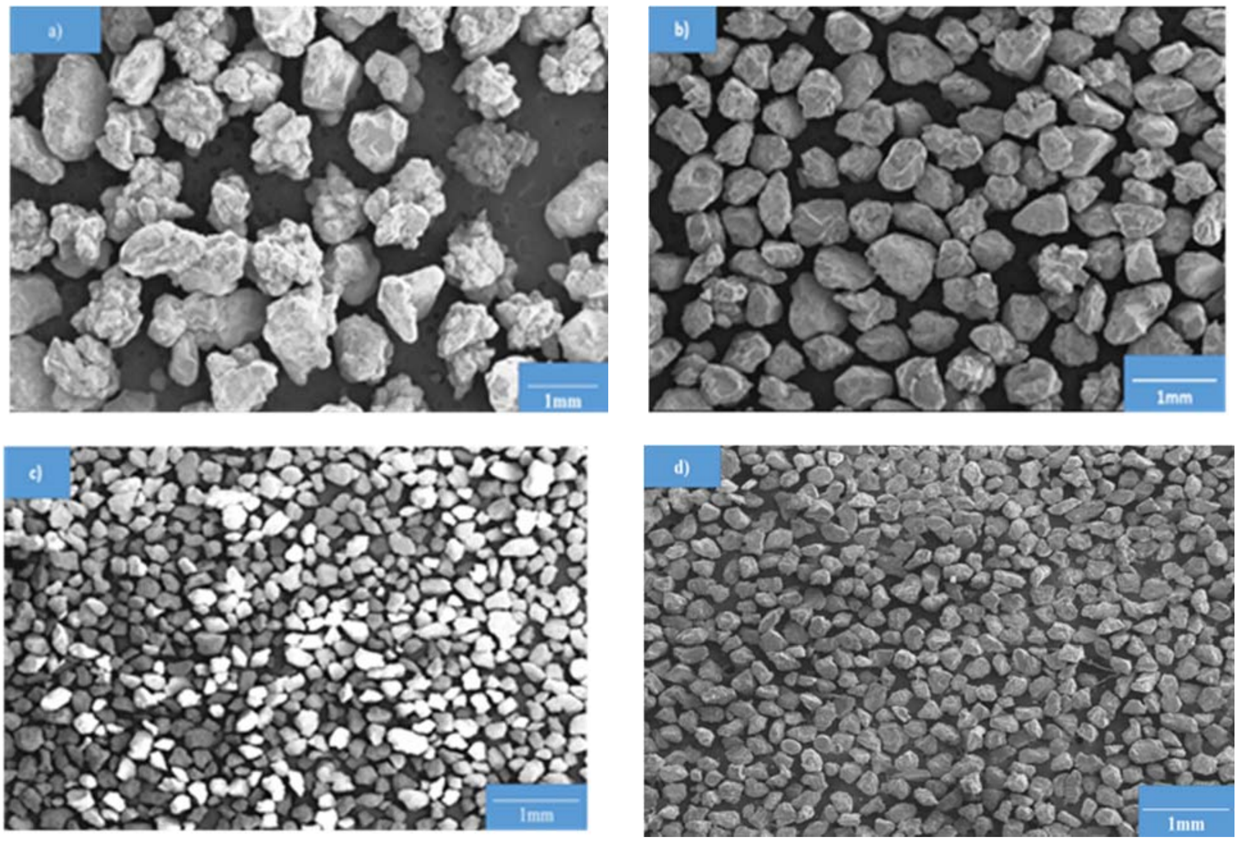

Fig 3. (a–d) SEM photographs of silica sand particles used for slurry abrasion testing: (a) 425-600μm, (b) 300-425μm, (c) 250 300μm and (d) 150-250μm.

2.4 Slurry abrasion wear testing

Slurry abrasion test was performed on rectangular specimen of 57.2 mm (length) ×25.4 mm (width) × 9 mm (thickness) and then specimens preparation is done by polishing using emery papers of 1/0, 2/0, 3/0 and 4/0 and after that specimens were subjected to wheel polishing using alumina slurry to obtain excellent surface finish. The well-polished specimen of mild steel & martensitic steel were etched with nital and kalling etching reagent respectively to reveal the microstructure. Then the specimens were cleaned with alcohol and dried with compressed air and then weighed using a digital electronic balance to the accuracy of 0.1 mg. Then specimens were placed in the holder assembly of Ducom TR 44 ASTM G105 testing apparatus such that flat test specimen is pressed radially against a rubber wheel with a known force. After the test was over the specimens were removed from the slurry chamber, cleaned with alcohol and weighed. The loss in mass (gm) was calculated as the difference of initial and final weight of the specimen. This testing machine allows users to test under a variety of load and types of abrasive media.

Fig 4: Slurry Abrasion Test Rig – 44 (Ducom Made)

Table 1

Parameters	Unit	Normal value	Remarks
Specimen size	mm	57.2× 25.4× 9	Length×Width× Thickness
Rubber wheel size	mm	178× 12.7	Diameter× Thickness
Hardness	Shore A	50±2, 60±2, 70±2	3 wheels of neoprene rubber rim
Test load	N	222.4 ± 3.6	Range is 100 N to 300 N, Dead weight loading
Test Speed	RPM	245±5	1 HP geared motor

2.5 Test summary of the present work
The effect of slurry concentration (0.4g/cc, 0.8g/cc,1.2g/cc,1.5g/cc), effect of load (30N, 60N, 90N, 120N) on slurry abrasion volume wear loss of mild steel and weld deposited alloy steel was studied. The effect of silica sand particle size(425-600µm, 300-425µm, 250-300µm, 150-250µm) on weld deposited steel and the effect of sliding distance on mild steel was studied.

3. Results

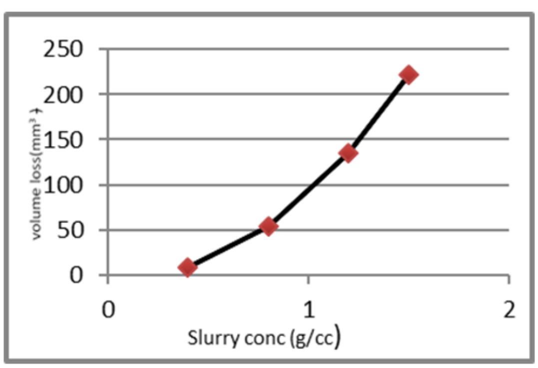

Fig 5: Graph Showing Volume Loss vs. Slurry Conc. at 120 N load, 425-600µm for mild steel

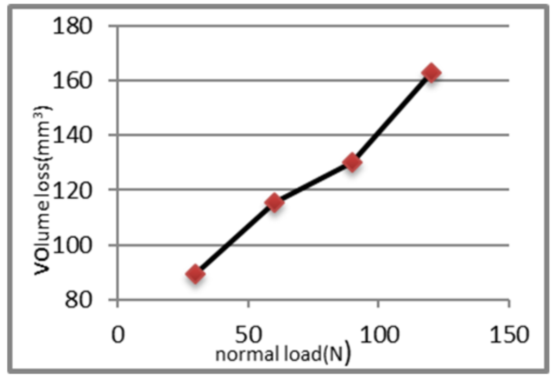

Fig 6: Graph Showing Volume Loss vs. Normal Load at 2000rev, 300-425µm for mild steel

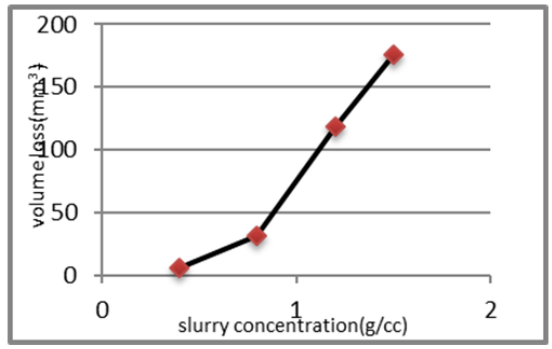

Fig 7: Graph Showing Volume Loss vs. Slurry Conc. at 120 N load, 2000rev for martensitic

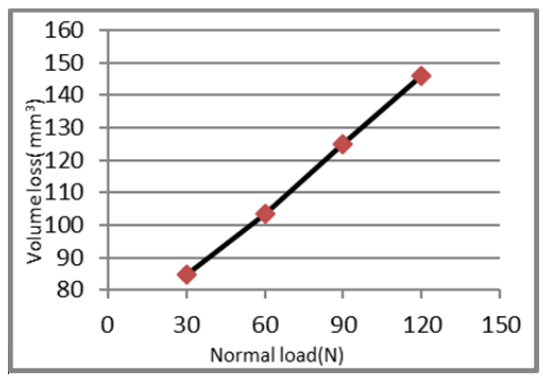

Fig 8: Graph Showing Volume Loss vs. Normal Load at 2000rev, 300-425µm for martensitic steel

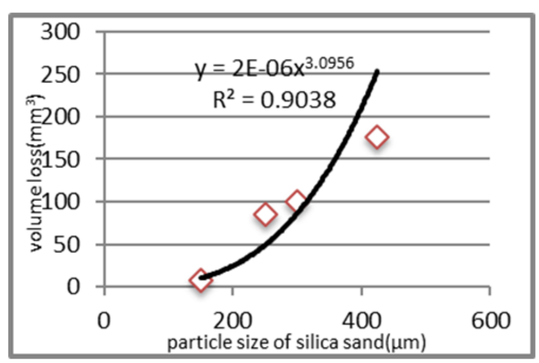

Fig 9: Graph Showing Volume Loss vs. Particle Size at 120 N load & 1.5g/cc for martensitic steel

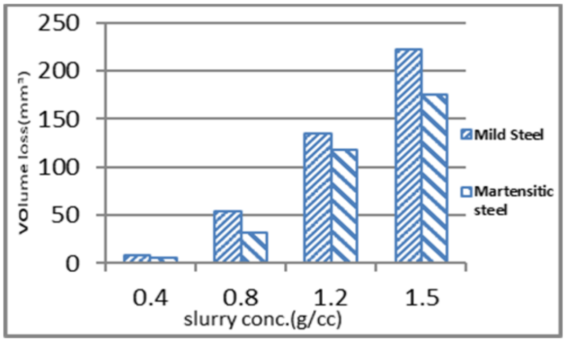

Fig 10:- Bar Chart Showing Volume Loss vs. Slurry Conc. For Mild Steel & Martensitic Steel

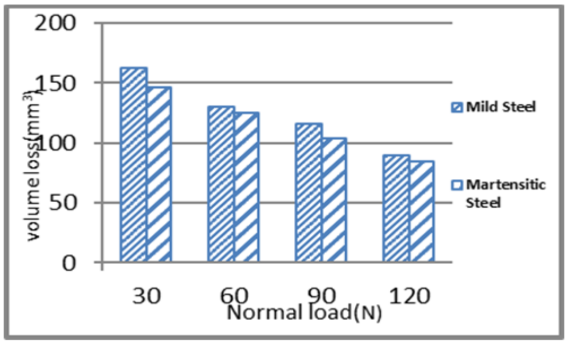

Fig 11: Bar Chart Showing Volume Loss vs. Normal Load for Mild Steel & Martensitic

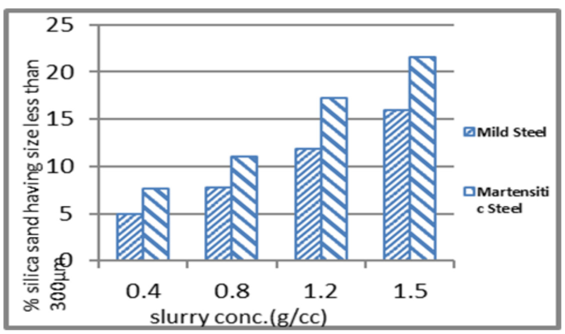

Fig 12: Bar Chart showing % of silica sand below 180µm vs. Normal load for martensitic steel

Wear resistance= (wt. loss of M.S.) ÷ (wt. loss of Martensitic sample)

Abrasive wear resistance of M.S. =1

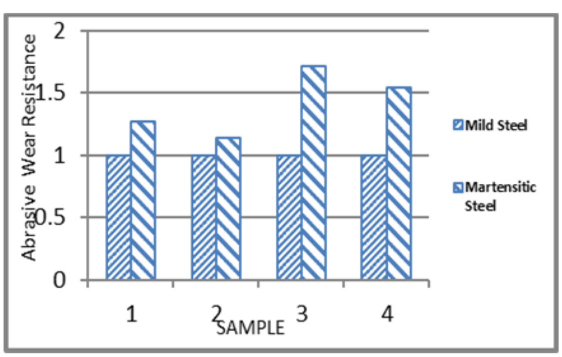

Fig 13: Bar Chart Showing Abrasive Wear Resistance for martensitic steel

4. Discussion

The present investigation reports wear behavior of mild steel and hard-faced martensitic steel under different experimental conditions. The slurry abrasion volume wear loss exhibited increasing trend with slurry concentration, normal load and the sliding distance for both mild and martensitic steel. However the magnitude was different for both mild as well as martensitic steel.

Fig. 5, 7 shows that, when slurry concentration increases then more number of particles will come in contact with the surface of component and hence increases the wear rate for both mild as well as martensitic steel [1, 3].

For mild steel and martensitic steel specimen slurry abrasive wear tests were performed at 2000 revolution, 120 N & particle size 425-600µm and at slurry concentration 0.4g/cc the slurry abrasion volume wear loss for mild steel was 8.083mm^{3}and 5.235mm^3 for martensitic steel which is 1.6 times less than of mild steel, at 0.8g/cc for mild steel was 53.98mm^3 and 31.56mm^3 for martensitic steel and at 1.2g/cc, for mild steel was 134.503mm^3 and 118.34mm^3 for martensitic steel and for slurry conc. 1.5g/cc the slurry for mild steel was 222.081mm^3 and 175.510 mm^3 for martensitic steel which is 1.26times less than volume wear loss of mild steel. Fig 10 shows that for martensitic steel slurry abrasion volume wear loss is less than mild steel when slurry concentration is varying.

Fig 6, 8 shows that with increase in normal load, slurry abrasion volume loss increased for both steels as it results in greater depth of cut by silica sand abrasive particles leading to more amount of material removal [1, 3].

For mild steel and martensitic steel specimens, abrasion wear tests were performed at 2000 revolution, 1.5g/cc slurry concentration & particle size 300-425µm, at normal load 30N, the slurry abrasion wear loss for mild steel was 89.364mm^3 & for martensitic steel was 84.885mm^3 which is 1.05times of mild steel. At normal load 60N, it was 115.527mm^3 for mild steel & was 103.54mm^3 for martensitic steel. At normal load 90N, it was 130.358mm^3 for mild steel & 125.05mm^3 for martensitic steel and at further increase in normal load to 120N, it increase to 162.961mm^3 for mild steel & to 146.0178mm^3 for martensitic steel, which is 1.11times less than slurry abrasion volume wear loss of mild steel as shown in fig 11.

The slurry abrasion volume loss exhibited power law dependence on abrasive particle size [3] as shown in Fig 9, which is expressed as,

$$V=k\times d^n$$

Where,

V=slurry abrasion volume loss (mm^3)

k= constant

d= silica sand particle size (µm)

n= particle size exponent

The value of $k=2\times10^{-6}$, $n=3.0956$ and the regression coefficient $R^2=0.9038$

Fig 11 shows that the percentage of silica sand having size less than 300µm when 425-600µm particle size is used for varying slurry concentration is less for mild steel as compared to martensitic and it is observed that sand particle fracture more with martensitic steel as it is a hard-faced alloy.

Abrasive wear resistance for martensitic steel was 1.5 times of abrasive wear resistance for mild steel at 0.4g/cc, 1.7 times at 0.8g/cc, 1.13 times at 1.2g/cc & 1.26 times at 1.5g/cc as shown in fig 13. It is observed that martensitic steel is less prone to wear than mild steel because it resist wear more as compared to mild steel due to presence of carbide forming agents like Cr in martensitic steel [10].

5. Sem photographs of worn surfaces

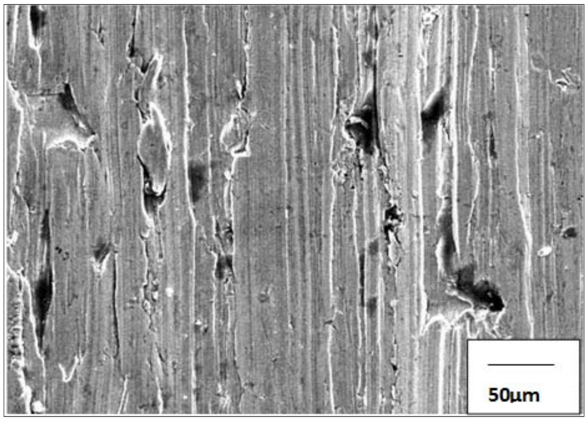

Fig 14: SEM image after slurry abrasion test at 1.5g/cc slurry conc. at 500X for mild steel

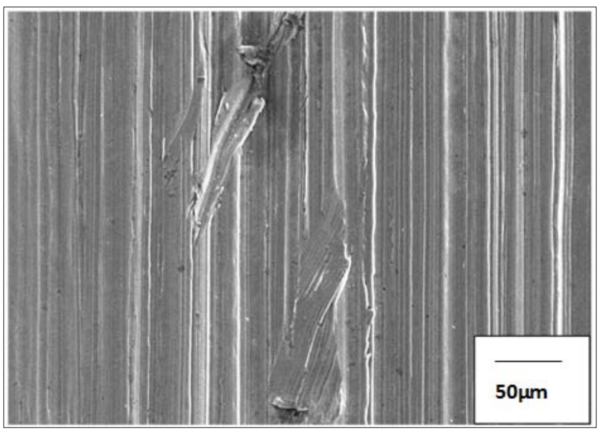

Fig 15: SEM image after slurry abrasion test at 1.5g/cc slurry conc. at 500X for martensitic steel

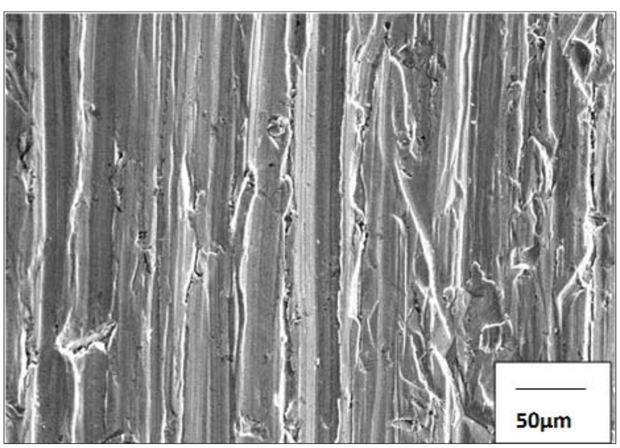

Fig 16: SEM image after slurry abrasion test at 120N normal at load at 500X for mild steel

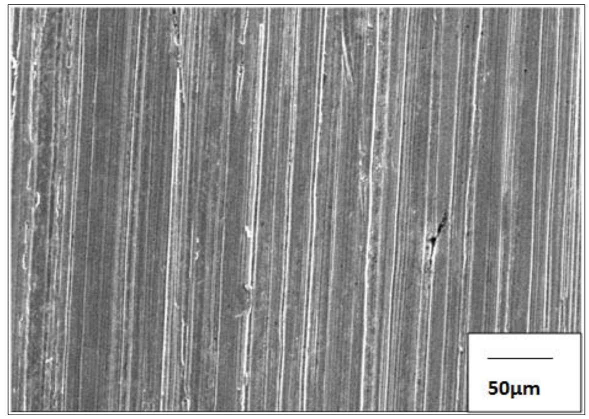

Fig 17: SEM image after slurry abrasion test at 120N normal load 500X for martensitic steel

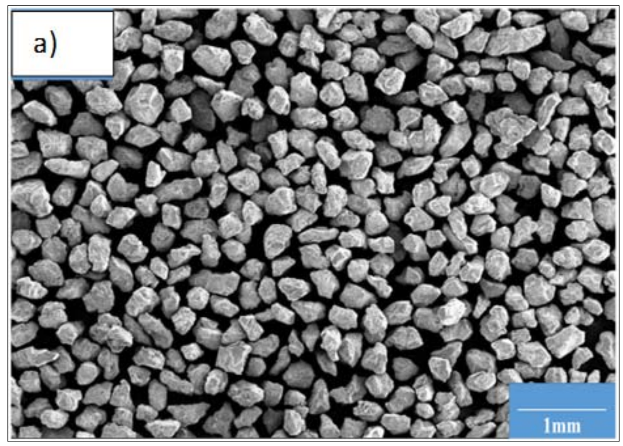

Fig 18: SEM image of fractured silica sand particle after experimentation on mild steel

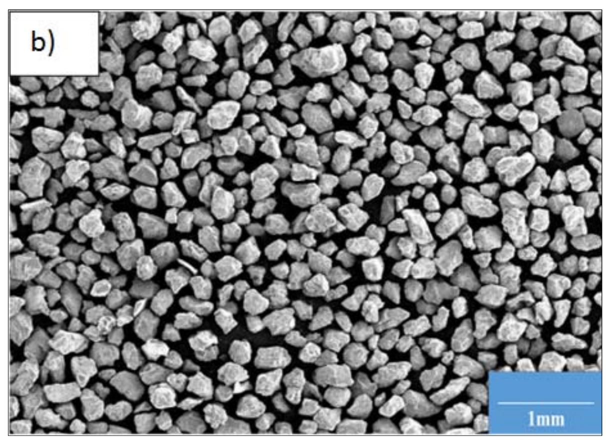

Fig 19: SEM image of fractured silica sand particle after experimentation specimen on martensitic steel specimen

SEM photographs reveals that with increasing severity of experimental conditions, the depth and width of the wear groove increased significantly resulting in increased material removal for both mild steel as well as martensitic steel, since with increasing severity of test parameter, increased load and particle size leads to greater depth of penetration into the surface [1, 3, 6, 10, 14].

At higher loads of 120N worn out surface reveals continues grooves caused by abrasive particles and the mechanism of material removal involves ploughing and cutting as shown in Fig 16, 17.

It is also expected that with increasing load silica sand particle fractures generating additional fine particles. These fractured particles tend to have more angularity which also causes additional abrasion to the surface. The above observations can explain significant increase in slurry abrasion volume loss with increase in normal load and slurry concentration [3].

For mild steel specimen, SEM reveals that there are deep grooves, cutting & ploughing is more, as mild steel is softer material so abrasive particles effect mild steel more, so more volume wear loss as compared to martensitic steel at same test conditions as shown in fig: 14, 15.

Fig: 18, 5.6b shows the fracture of silica sand particles after experimentation on mild steel and martensitic steel respectively. In both cases, sand particle fractures forming more sharp and angular edges as compared with sand before experimentation. As discussed in earlier section, that silica sand fractures more with martensitic steel as compared to mild steel, the SEM images [6, 10].

6 Conclusion

1) The slurry abrasion volume loss increased with increase in slurry concentration, normal load, total revolution and particle size for both mild steel as well as weld deposited alloy steel but the magnitude of increase was different.
2) The slurry concentration had more pronounced effect on slurry abrasion volume loss than normal load.
3) The slurry abrasion volume wear loss exhibited power law dependence on abrasive particle size.
4) The morphology of worn out surfaces was influenced by test conditions and material used.
5) The slurry abrasion volume loss is more for mild steel as compared to martensitic steel.
6) The important mechanisms of material removal were ploughing, cutting and indentation.
7) The predominant mechanisms of material removal by abrasion were influenced by severity of test conditions.
8) The tendency of particle fracture increased with load and the particle fracture is more severe for weld deposited alloy steel as compared to mild steel.
9) The abrasive wear resistance for weld deposited alloy is more than mild steel which means that these steels is less prone to wear than mild steel on same test conditions.

7. Acknowledgement

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8. References

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