

# Erosion Wear Behaviour of Chromium Coated Steel 304 and Grey Cast Iron

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**Abstract:** The phenomena of erosion wear due to the cutting action of ash particles in ash- liquid (slurry mixture) on steel 304 and grey cast iron has been studied in a slurry pot tester. A fixture was used to hold the work piece in a slurry pot tester to ensure that the erosion wear of work piece is due to the flow of the slurry. Experiment performed at different concentrations, at different speeds and at various time to determine the effect of these particles on the work piece. It seems that a kinetic energy of particle may exist which result in change in wear rate.

**Key words:** Erosion wear, steel 304, grey cast iron , scanning electron microscopy.

## I. INTRODUCTION

In the modern industrial world, engineering components are being subjected to increasingly demanding environments. This has made the components prone to more rapid degradation due to mechanisms such as wear, corrosion, oxidation or failure under high heat load. To full fill numerous industrial applications, an effort to achieve enhanced performance in terms of productivity and efficiency, surface treatment technologies have been attracting a great deal of attention as they present a cost-effective way to combat degradation modes such as the above without sacrificing the bulk properties of the component material. Among the entire surface phenomenon, the problem of wear is of high concern in most of the industrial components. Several forms of wear such as adhesive, abrasive, dry and wet erosion do exist. However, wet erosion also termed as slurry erosions of significant importance in determining the service life of the major components handling slurries containing hard abrasives in several chemical handling equipments, exposed parts in marine environments and in turbine blades of hydro electric power plants. Slurry erosion can be defined as a type of wear or loss of material experienced by a component, when exposed to high velocity stream of slurry mixture of solid particles in a liquid, usually water. It is a serious problem in many engineering applications. When the components are entrained in such environments, the design life of the component is greatly reduced, resulting in huge economic losses. The areas in which components suffering from this problem include, mining machinery components, hydraulic transport of solids in pipelines, marine, oil gas and power generation industries. Erosive wear of the solid bodies is caused by the action of sliding or impact of solids, liquids, gases or a combination of this. Erosion normally takes place due to two complementary mechanisms, namely cutting and deformation. Studies reported on erosion wear have concluded that the phenomenon of cutting wear is associated with particle velocity parallel to the wear surface where as deformation wear is associated with particle velocity normal to the wear surface. A large number of data on the wear has been generated using different bench scale test rigs but it is still difficult to derive a universal correlation for prediction, mainly due to different simulated test conditions and lack of control over variation of different parameters. It is well examined that the erosion rates are affected by various factors. These factors can be broadly classified into three types: impingement variables describing the particle flow, particle variables and material variables. The primary impingement variables are particle velocity, angle of incidence, flux (particle concentration) and target temperature. Particle variables include particle shape, size, hardness and friability (ease of fracture). Material variables include all the material properties, such as hardness, work hardening behaviour and microstructure. The extent of erosion wear in slurry pipe line and pumps plays a decisive role in the design of a slurry transportation system. Hence it is essential to understand the complete erosion wear mechanism. Gupta et al. [1] has developed a correlation for calculating the erosion wear of mild steel and brass:

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(An ISO 3297: 2007 Certified Organization)

**Vol. 2, Issue 9, September 2013**

$$E_{w \text{ brass}} = 0.178V^{2.4882}d^{0.291}C_w^{0.516}$$

$$E_{w \text{ mild steel}} = 0.223V^{2.148}d^{0.344}C_w^{0.556}$$

(1)

Where V is the velocity, d is the diameter of the material; C<sub>w</sub> is the concentration by weight.

To understand the complexities of erosion wear, many researchers started looking for ways and means for generating extensive experimental data on erosion wear at an accelerated rate with minimum cost. This led to the development of pot tester. Gandhi et al. [2] has developed a methodology to determine the erosion wear of grey cast iron.

erosion rate  $\propto$  (particle size)<sup>n</sup>

(2)

The exponent 'n' has been reported to vary in the range of 0.3–1.2. Gandhi et al. [3] from their experimental data in a similar pot tester, have also derived correlations for the prediction of wear rate and the general form of their correlation is given by:

$$E_w = K V^\alpha d^\beta C_w^\alpha$$

(3)

Where K,  $\alpha$ ,  $\beta$  and  $\alpha$  are constants whose values depend on the properties of the material of solid particles as well as wear surface. They used these correlations to predict the local wear rate along the circumference of a slurry pipeline. Clark [4] had fixed 4.76mm diameter cylindrical specimens at 51mm radius and rotated them at 1750 and 3500 rpm in a pot to keep the solids (specific gravity = 2.42) suspended up to 13% concentration (by weight). On the other hand, Tsai et al. [5] observed that the shedding of vortices from 3.18mm diameter cylinders rotating at more than 1600 rpm affects the weight loss of the specimens fixed at 52mm radius. Thus they recommended using the pot tester for lower velocities Gandhi et al. [6] with propeller attached at the end of the shaft used for rotating the wear specimens in the pot. They have also reported that the orientation angle of the wear specimens can be taken as the impact angle of solid particles.

Sugiyama et al. [2008] have developed a correlation to calculate the influence of impact angle of solid particles on pure aluminium, pure copper, cast martensitic stainless steel, austenitic stainless steel.

$$W = CE = C \frac{1}{2}mv^2$$

(4)

C is a constant, m is the mass of the particle and V is the particle velocity upon impact.

In the present study flat wear test specimens with or without hard chromium coated electroplated are rotated in the cylinder at different speeds opposite to the rotational direction of the propeller while keeping the angle of rotation constant to minimize its effect on suspension of solids in the pot. Experiments on erosion of steel 304 and grey cast iron in bottom ash–water mixture has been carried out for wear evaluation.

## II. EXPERIMENTAL DETAILS

Chromium powder was chosen as coating material coated by electroplating technique. Stainless steel 304 and grey cast iron was selected as substrate considering its numerous applications in various industrial sectors. Steel 304 possesses the unique combinations of superior mechanical properties and toughness. However, poor wear and erosion resistance of steel 304 and grey cast iron causes serious limitations as regards its engineering applications.

Micro hardness of the above mentioned specimen was evaluated using Vickers hardness tester. A load of 100 g for 10 s was adopted for both specimen. The tests were carried out in such a way that the possibility of micro defects must not be shown during in the indenters mark. The hardness of both the specimens wear found out to be 107 VHN of steel 304 and 111 VHN of grey cast iron.

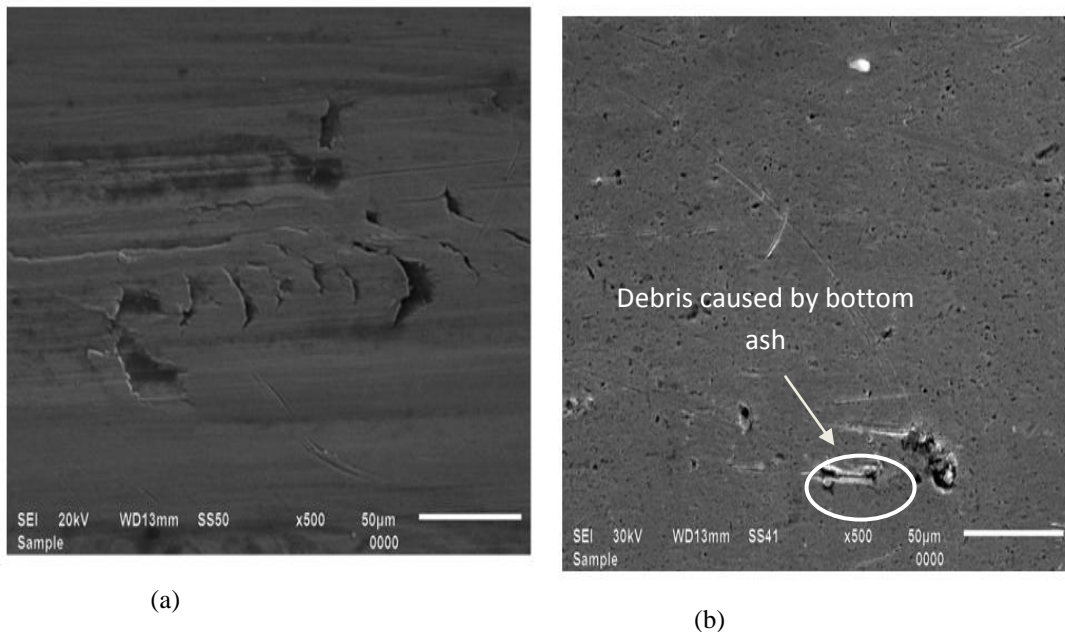
Slurry erosion test was carried on both coated and uncoated samples using a slurry erosive wear tester as shown in Fig.1. The test apparatus consists of spindle connected to an electronic motor with the maximum speed of 1500 rpm using a belt drive. All the samples were dipped into slurry pot made of stainless steel. Slurry was prepared by mixing bottom ash with distilled water. The studies were carried out at different sand concentration (20, 40 and 60%), varying rotational speed (700, 1000, 1400 rpm), and varying test duration (60, 90, 120 and 150 min.).



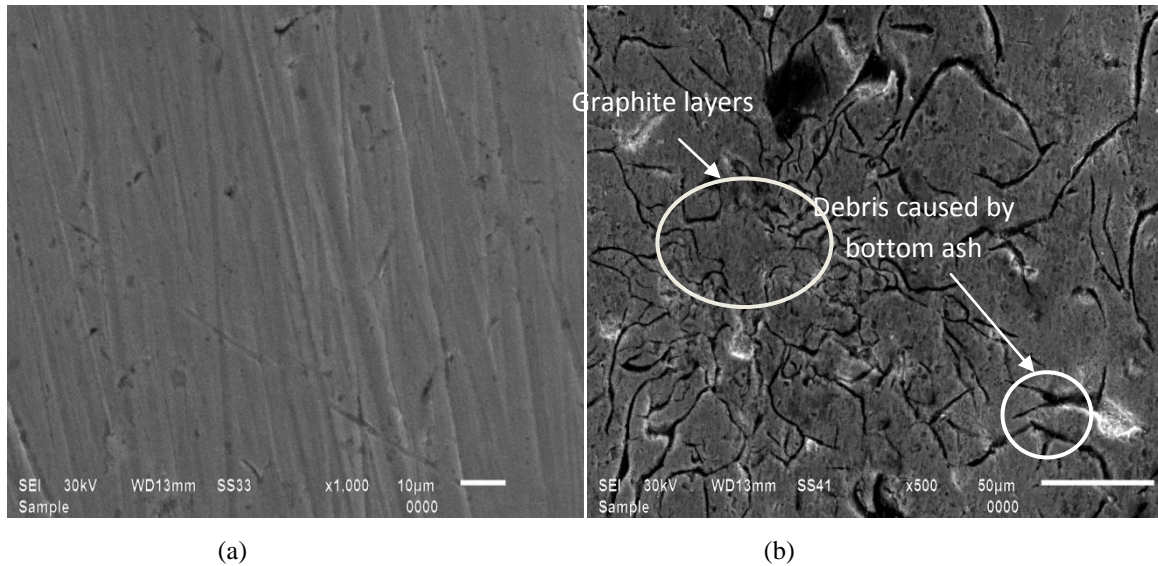
**Figure 1 slurry pot tester arrangement**

### III. SLURRY EROSION TEST

Slurry erosive wear behaviour of uncoated steel 304 and grey cast iron before and after erosion wear is shown in Fig2 and 3. It was observed that uncoated steel304 exhibits higher slurry erosive wear resistance when compared with uncoated grey cast iron. Steel 304 has high yield strength as compared to the grey cast iron, so it shows better erosion resistance as compared to the grey cast iron. Slurry erosive wear resistance increases with increase in coating thickness on base metal, as chromium is a good erosion resistance. A maximum of 50.01% mass loss is noticed in electroplated material when compared with uncoated steel 304. Similarly 61.7% mass loss is noticed in electroplated material when compared with uncoated grey cast iron.



**Fig. 2. Erosion behaviour of uncoated steel 304 (a) before and (b) after erosion wear at 700 rpm with 60 wt. % bottom ash.**



**Fig. 3. Erosion behaviour of uncoated grey cast iron(a)before and(b)after erosion wear at 700rpm bottom ash with 60% bottom ash.**

**a) Effect of slurry concentration:**

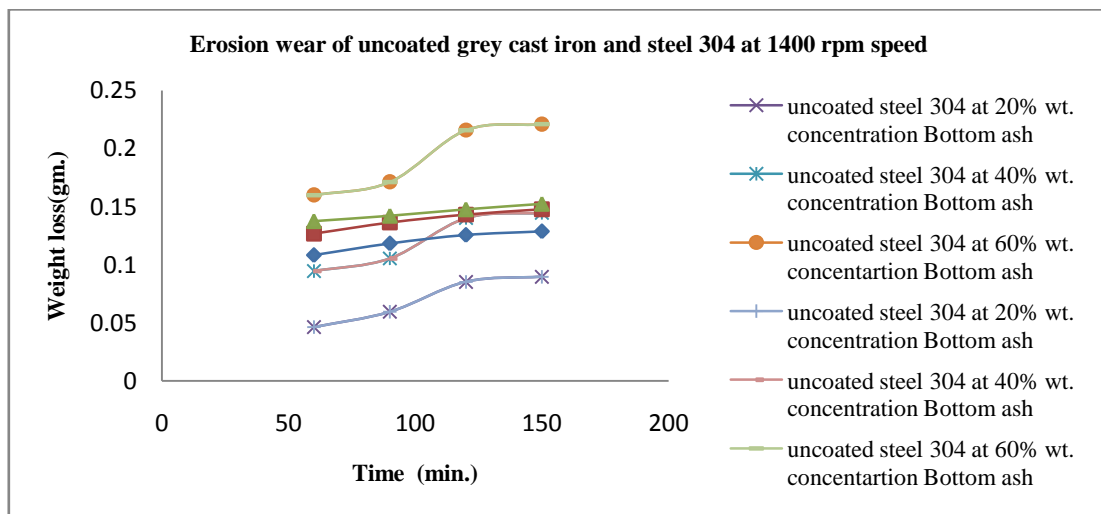
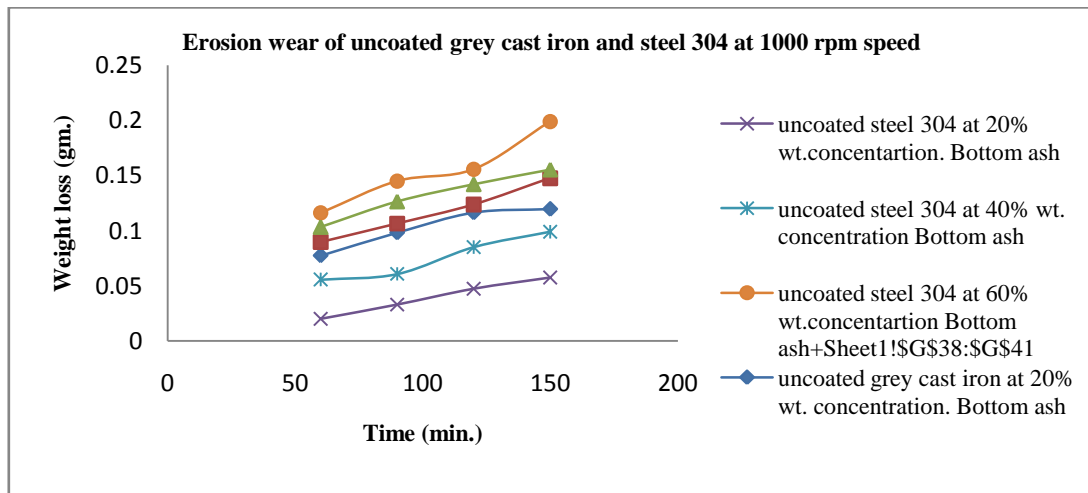
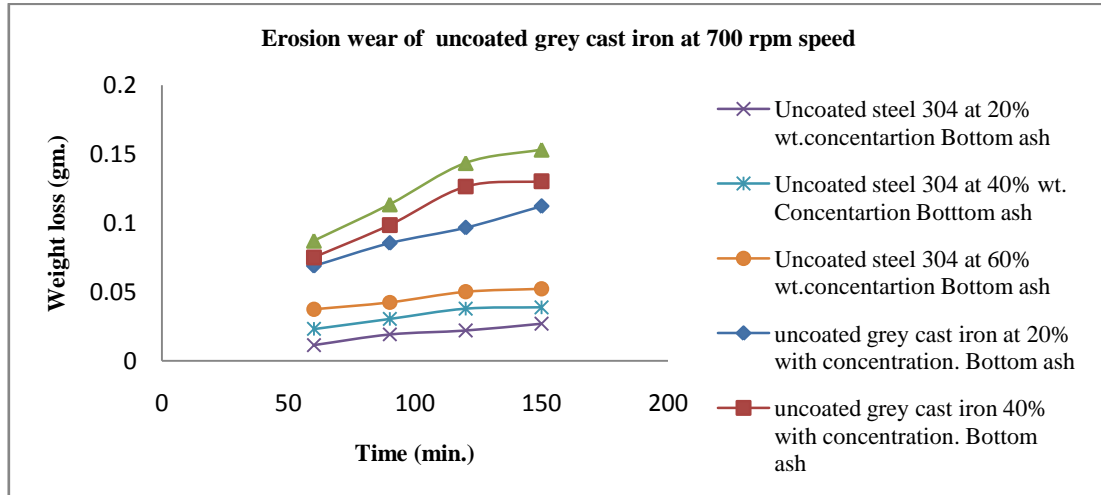
It was observed that the mass loss of uncoated steel 304 and grey cast iron increases steeply with increase in slurry concentration. However, a marginal increase in mass loss is observed in case of the developed coating. This extensive material removal observed in case uncoated grey cast iron samples at all the slurry concentration studied can be attributed mainly to its poor wear and erosion resistance. Further, increased coating thickness results in reduced slurry erosive wear loss for all the slurry concentration studied. The increased mass loss with increase in slurry concentration can be attributed to fact that, increased abrasive particle concentration in the slurry enhances the probability of more impingements on the surfaces leading to increased deterioration of material from its surfaces.

**b) Effect of speed of slurry rotation:**

Figure 4 shows the effect of speed rotation on the erosion behaviour of uncoated steel 304 and grey cast iron. It was observed that increased speed of slurry rotation results in marginal increased mass loss for both uncoated and chromium coated ductile material. However the developed coatings exhibited a significantly reduced mass loss when compared with Un-coated material. It was reported that an increase in slurry rotation results in increase mass loss .Maximum material loss is encountered at a very high speed of 1400 rpm. This can be attributed to the fact that, increased speed of slurry rotation will increase the kinetic energy of abrasive particle. This increased kinetic energy will lead to more localized attacks at several spots on the target material and can cause severe plastic deformation leading to increased material loss in both coated and uncoated specimens.

**c) Effect of test duration:**

It was observed that increased test duration results in increased mass loss continuously for both uncoated and chromium coated steel304 and grey cast iron. This may be due to fact that, continuous and repeated impinging action of ash particles in the slurry on the target materials results in increased mass loss. Under identical test conditions, chromium coated mild steel exhibits a maximum reduction in mass loss for a test duration of 120and 150 minutes respectively when compared with the uncoated substrate. It was observed that the mass loss was exponentially high with increased test duration.

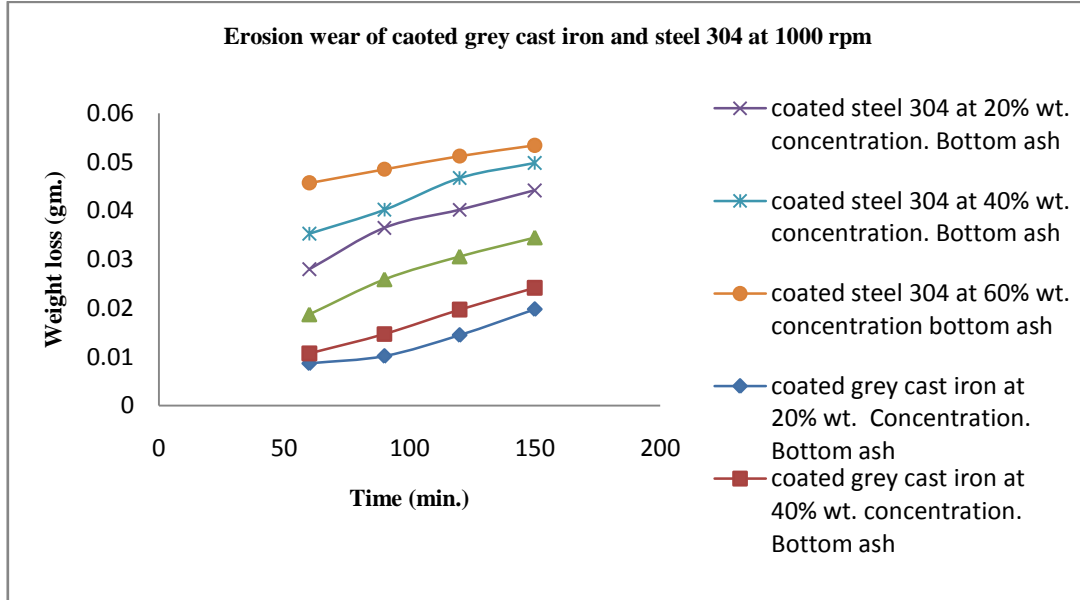
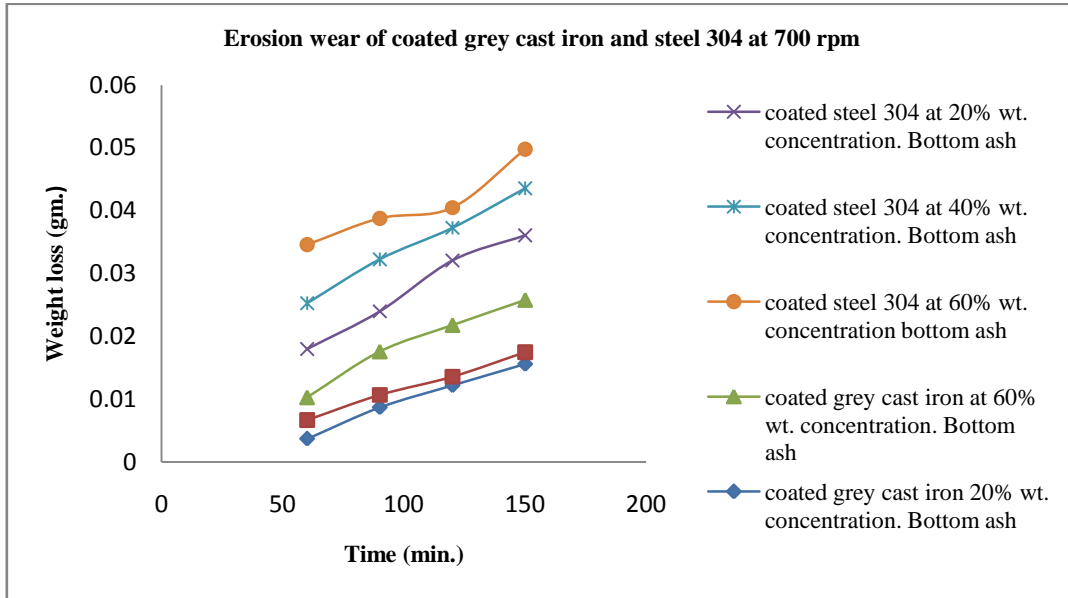


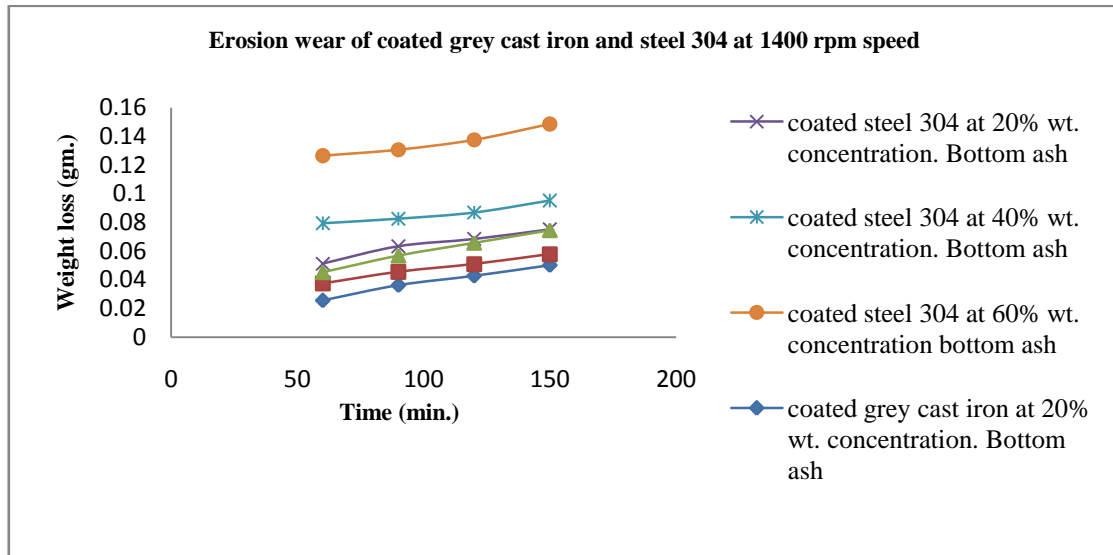
**Figure 4 Effect of speed rotation on erosion behaviour of uncoated steel 304 and grey C.I**

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(An ISO 3297: 2007 Certified Organization)

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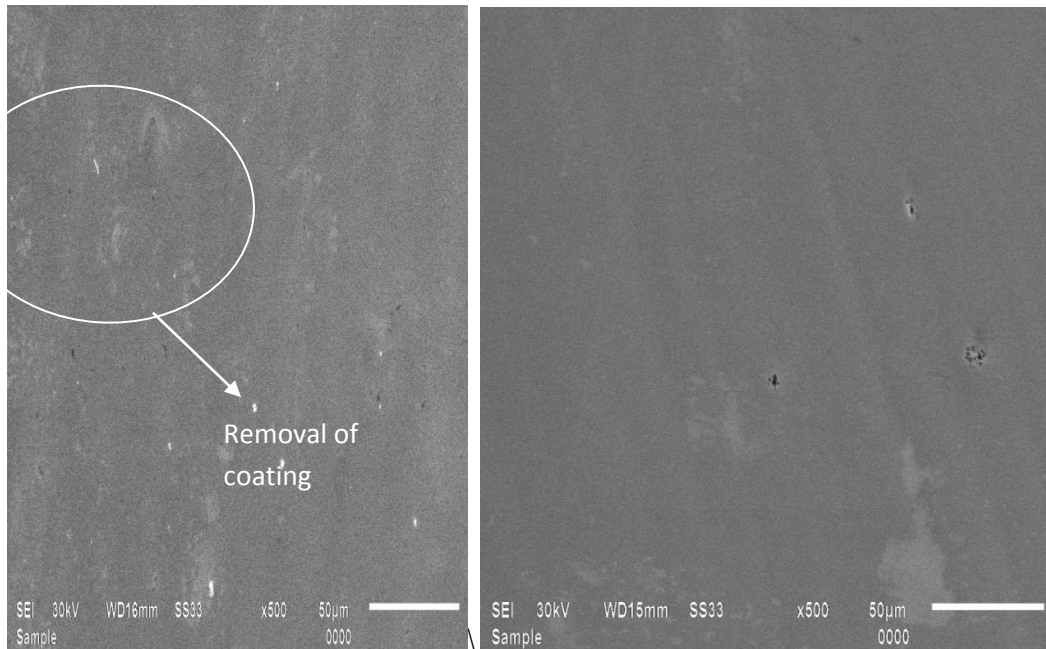


**Figure 5 Effect of speed rotation on erosion behaviour of coated steel 304 and grey C.I**

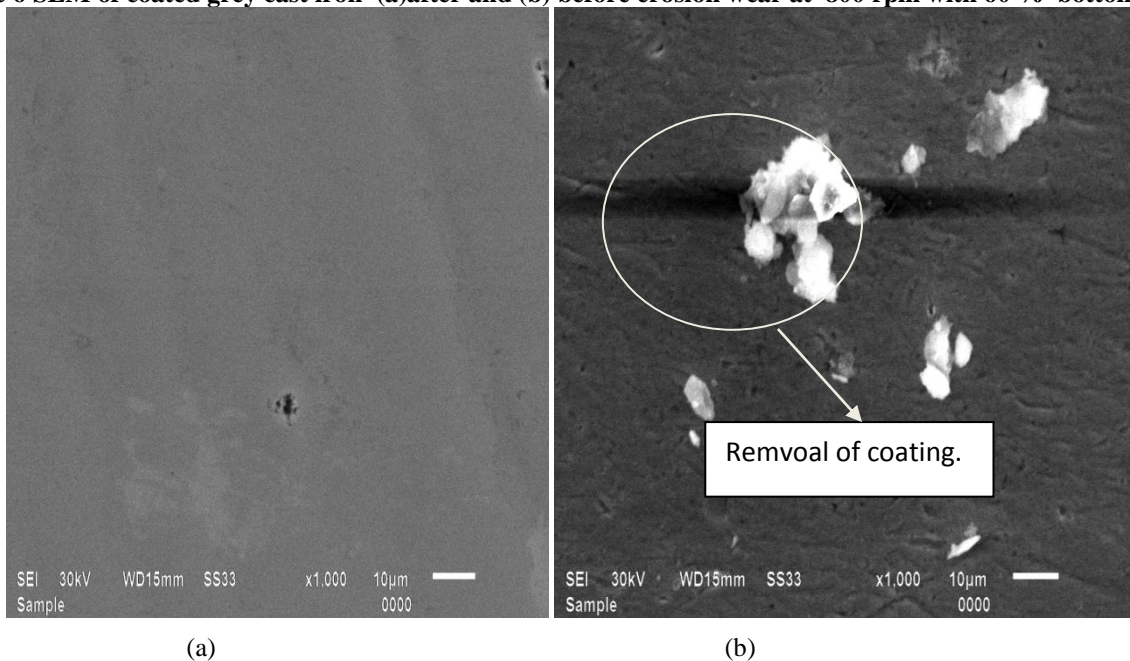
**d) Worn surface analysis:**

Fig. 6 and 7 shows the SEM photographs of slurry eroded chromium coated steel304 and grey cast iron substrates. It was observed that the extent of damage in case of coated steel 304 as compared to coated grey cast iron specimen. The increased coating thickness has reduced the surface damage as observed in all the micrographs. The clear observation of SEM micrographs shows that the major mechanism of material removal in case of uncoated specimens which may be attributed to poor erosion resistance. The continuous mechanical action of the bottom ash particles in the slurry increases the material loss by removing the reaction layer leading to exposure of fresh surface area as the corroded surface offers poor resistance to mechanical wear. The micrographs show that the material removal occurs predominantly in the corroded regions owing to its poor resistance to mechanical wear.

It is also observed from the impact of bottom ash particles near the micro porosities generates the micro cracks. The repeated impact and abrasive action of bottom ash particles causes chipping on the surface and removes the material easily in the form of small pieces. However, the micrographs show some abrasive and ploughing marks on the coated surface. Some plastically deformed craters are also observed indicating that the material removal is mainly by delaminating and micro cutting damage by abrasive action of ash particles rather than erosion. In case of chromium coated specimens, increase in coating thickness decreases the extent of the surface damages. This can be reasoned to the higher hardness value of coated specimens with increased thickness. Surface hardness of the coated specimens have played significant role in reducing the wear by mechanical action of sand particles.



**Figure 6 SEM of coated grey cast iron (a)after and (b) before erosion wear at 800 rpm with 60 % bottom ash**



**Figure 7 SEM of coated steel 304 (b) before and (a)after erosion wear at 800 rpm bottom ash with 60% bottom ash.**

#### IV) CONCLUSION



# International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 2, Issue 9, September 2013

1. Uncoated steel 304 shows better erosion resistance as compared to the uncoated grey cast iron as steel 304 has more yield strength.
2. Increased coating thickness decreases the porosity and increases the hardness significantly.
3. Under all the test conditions studied, chromium coatings exhibited improved slurry erosive wear resistance when compared with uncoated steel 304 and grey cast iron.
4. Chromium coated steel shows approximately 1.5 times better performance than uncoated steel. Similarly chromium coated grey cast iron shows approximately 2.5 times better performance than uncoated grey cast iron.

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