Jet slurry erosion performance of composite clad and its characterization

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Abstract
In the present work, development of composite cladding consists of Cr₂₃C₆ (chromium carbide) as reinforcement particles 20 wt. % in Ni-based matrix 80 wt. % on austenitic stainless steel through exposure of microwave radiation has been carried out. The jet slurry erosion test was performed on microwave composite clad. The functional performance of composite clad has been evaluated for different parametric conditions like varying impingement velocity and impact angle. The increasing weight loss trend was observed with time for the first 30 min. after that the individual trend decreased; at high impingement velocity and maximum impact angle. SEM micrographs of eroded clad samples at various impact angle and impingement velocity were discussed. The maximum weight loss occurred at 90° angle and velocity of 60 m/s, and minimum at 30° angle and velocity of 20 m/s.

Key words: Ni-based- Cr₂₃C₆; Composite Clad; Microwave Cladding; Jet Slurry Erosion.

1. Introduction
Loss of material due to erosive wear is a critical problem associated with flow of slurry (solid-liquid mixture). Erosion problem is observed in several industrial applications such as slurry pumps, hydraulic turbines and valves [1, 2]. To improve the service life of the component/equipment one can either change the design of component or change in material selection or improve the surface properties. The surface modification technique is a preferred alternative to improve erosion resistance properties. Coating/cladding of suitable material is required for modification of the functional surface in order to resist erosive wear. There are several techniques to improve the surface properties are thermal spraying, high velocity oxy-fuel, carburizing, nitriding and coating/cladding [3, 4]. The furtherance in erosive wear resistance of the functional surfaces through cladding with suitable overlaying material would be one of the most straightforward and economical solutions for above problem[5]. Laser cladding is also one of the prominent surfacing technique among the widely practiced methods to provide anti-wear solutions for industrial applications. The laser processing has some limitations including high distortion, development of porosity and interface cracking apart from associated high setup and running cost [6, 7]. From last two decades, the researchers were mainly focused on processing of materials through microwave irradiation. Recent research activities indicate possible to process metals in the form of sintering under certain conditions. Microwave energy has been effectively utilised in processing of ceramics and ceramic composites and very few studies have been reported on heating of metallic materials through microwave radiation. The most recent application of microwave has been in the field of processing metallic materials for brazing/joining and melting (Agrawal, 2006 [8]). Recently a group of researchers (Gupta and Sharma, 2011[9]) have developed WC10Co2Ni and EWAC cladding on austenitic stainless steel SS-316 through microwave energy by using a multimode microwave oven.
The clad sliding wear performance of WC10Co2Ni has been evaluated and results higher sliding wears resistance against substrate austenitic stainless steel SS-316 [7]. Gupta et al. reported the procedure for developing composite clad over SS-316 using microwave irradiation [10]. Recently Srinath et al developed Ni based cladding on austenitic steel SS-304 through microwave energy [11,12]. Microwave cladding with hard-facing powders is relatively new technology and a suitable cermet powder has been selected to produce a hardface in order to improve erosion resistance behavior.

2. Experimental Procedure

In the present work development of composite clad consists of Nickel based matrix and Cr$_{23}$C$_6$ (Chromium carbide) reinforcement particles, is recommended for hard-facing on austenitic stainless steel to resist wear by microwave cladding. The jet slurry erosion test rig is used to evaluate erosion resistance performance of developed microwave composite clad for different operating conditions.

2.1 Microwave Cladding

Composite cladding has been developed in order to enhance surface properties and increase life of the component. In the present work the erosion resistant cladding is developed on austenitic stainless steel as metallic substrate through microwave energy used as a heating source. The figure 1 shows the schematic representation of microwave heating by microwave radiation.

![Figure 1. Schematic representation of Microwave heating](image)

The absorption of microwave energy dependent on powder particle size, properly mixed powder particles cannot directly interact with microwave radiation at room temperature, will tend to reflect microwaves [6]. In order to overcome the problem of microwave being reflected by Ni-based and Cr$_{23}$C$_6$ powder (80%wt. and 20% wt.), claddings were developed by microwave heating technique using suitable susceptor operated at 900 W of power and 2.45GHz frequency. The experiment was carried out 360s of the duration. The susceptor material, which absorbs microwave energy and then transfers heat
source to powder particles on to the substrate. In order to avoid possible contamination of cladding by susceptor powder used, a pure graphite sheet was used as a separator between the susceptor and powder as shown in the Figure 1. The developed composite clad was well metallurgical bonded with substrate.

2.2 Jet Slurry Erosion Testing

The schematic representation of experimental setup as shown in Figure 2 consists of a centrifugal pump, conical tank, nozzle, specimen holder, valves and flow meter. Centrifugal pump driven by 7.5 hp, 1440 r.p.m electric motor has a capacity of maximum pressure 13.5 bar at a discharge of 240 l/min. Slurry available in a conical tank as can be seen in figure 2 is sucked through a 51.2 mm G.I. pipe with the help of pump and delivered to the nozzle through 25.6 mm pipe having control valves and electromagnetic flow meter located upstream [13]. Slurry is re-circulated during the test. The flow rate of the slurry is controlled with the help of main valve and bypass regulator valve between delivery side and nozzle. Slurry flowing through the pump at high pressure is converted into high velocity stream while passing through the converging section of the nozzle which is 125 mm long and have 8 mm diameter.

![Figure 2. Schematic representation of jet slurry erosion test](image)

The Electromagnetic flow meter (Elmag-200M) arranged as shown, in between control valve and nozzle is equipped with digital display which shows the slurry discharge. In the present erosion study the concentration of 10000 ppm and erodent (silica particles) of the average size of 400 µm used throughout the experimentation.

2.2.1 Impingement Velocity

The monitor of the flow measurement system is set to display the flow in terms of litres per seconds. Velocity of the jet is calculated considering the 8 mm nozzle diameter. To compensate the reduction in the velocity of jet due to erosion of the nozzle the diameter of the nozzle was measured and the value of the discharge was thus adjusted to obtain required velocity 20, 40 and 60 m/s were selected for the study.
2.2.2 Impact Angle
The angle of jet can be changed in between 30° to 90°. This angle of impact influences the effect of particle impact on specimen. The specimen holder can be rotated with respect to jet axis and fixed with the help of set screws. The angle can also be verified with help of template. Three levels of angle selected for investigation were 30°, 60° and 90°.

3. Results and Discussion

3.1 Erosion performance of microwave clad
The developed composite clad performance on erosion is the effect of time on the weight loss while varying the other parameters is presented along with the effect of each parameter. It can be seen that amount of material loss increases with time. It is interesting to note that the slopes at initial level are less steep as compared later stages.

Table 1. Effect of velocity on impact angle for Ni based -Cr₂₃C₆ composite clad

| Time interval (min.) | 30° Impingement velocity (m/s) | 60° Impingement velocity (m/s) | 90° Impingement velocity (m/s) |
|---------------------|---------------------------------|---------------------------------|---------------------------------|
|                     | 20 40 60                        | 20 40 60                        | 20 40 60                        |
| 30                  | 28 33 34 27 35 37               | 38 40 65                        |
| 60                  | 21 22 24 25 20 23               | 25 28 32                        |
| 90                  | 13 15 20 20 17 16               | 14 20 16                        |
| 120                 | 10 13 13 16 11 14              | 3 10 12                         |

It shows the amount of erosion is less at initial stage, but with the advancement of time, the mass loss increases. The velocity effect on impact angle was the weight loss of the material as shown in the Table 1. Fig 3. Show the graphical trend of weight loss versus Impingement velocity as shown. The change in material loss with increase in velocity is almost linear. It is clear that the main effects shown in the table 1. that an increase the velocity from 20 to 40 m/s (80 mg) and thereafter to 60 m/s (91 mg) the increase in material weight loss at an impact angle of 30° as shown in the graph. Similarly the increasing trend of weight loss of the material is observed at an impact angle of 60° and 90° as shown in the Table 1.

Table 2. Effect of impact angle and velocity on composite clad (Ni based-Cr₂₃C₆) in terms of weight loss (mg) with time

| Impingement velocity (m/s) | 30° Material weight loss (mg) | 60° Material weight loss (mg) | 90° Material weight loss (mg) |
|---------------------------|-----------------------------|-----------------------------|-----------------------------|
| 20                        | 72                          | 78                          | 80                          |
| 40                        | 80                          | 83                          | 98                          |
| 60                        | 91                          | 94                          | 125                         |
Table 2 represents the weight loss with time for variables like velocity and impact angle on jet slurry erosion testing, data was recorded for the weight loss with different conditions. It was observed that the maximum weight loss at velocity 60 m/s and an impact angle of 90°.

![Graph](image)

**Figure 3.** Effect of impingement velocity and impact angle for Ni based -Cr$_2$C$_6$ composite clad erosion shows in (a), (b) and (c) in terms of weight loss with time.

(a) Weight loss with time at 30°  
(b) Weight loss with time at 60°  
(c) Weight loss with time at 90°

**Figure 4.** Ni based-Cr$_2$C$_6$ composite clad erosion shows in (a), (b) and (c) in terms of weight loss with time.
The above graphs almost linear trend shows in the weight loss which is increased in the initial stage after 30 min. and for 60,90,120 min. of time interval the individual trend decreased because of the erodent loses its geometry due to frequent impacting on the surface of the clad sample and also when the particles starts to strike the surface it is usually that metals gets work hardening owing to their ductility, which reduces the initial loss of material, but with the further impacts, fatigue is introduced due to fluctuating stresses in this hardened layer which causes its removal.

3.2 Fractography of Eroded Composite Clad
The surface morphology of eroded sample of Ni based -Cr$_{23}$C$_{6}$ composite clad studied through FE-SEM which is shown in figure 5. All the samples were subjected to 30°, 60° and 90° impact angle, corresponding to 20, 40 and 60 m/s impingement velocity and eroded at 10000 ppm. concentration. The erodent (silica particles) was used in the concentration with average size of 400 µm. To study the characteristic features of eroded surfaces the slurry eroded samples were analysed under FE-SEM in order and to understand the slurry erosive operative mechanisms.

![Figure 5 (a). Impact angle 90° and velocity 60 m/s](image)

![Figure 5 (b). Impact angle 90° and velocity 40 m/s](image)

![Figure 5 (c). Impact angle 90° and velocity 20 m/s](image)

![Figure 5 (d). Impact angle 60° and velocity 60 m/s](image)
Figure 5. SEM Micrographs of Eroded Ni based -Cr$_2$C$_6$ composite clad at various conditions

(e) Impact angle 60° and velocity 40 m/s

(f) Impact angle 60° and velocity 20 m/s

(g) Impact angle 30° and velocity 60 m/s

(h) Impact angle 30° and velocity 40 m/s

(i) Impact angle 30° and velocity 20 m/s
The FE-SEM feature of the surfaces of the Ni based - Cr$_2$C$_6$ composite clad eroded samples are shown in figure 5 (a), (b), (c), (d), (e), (f), (g), (h) and (i). The results of fractography exhibited fatigue formation, followed by the fracturing of chips (figure 5 (a)), further deep ploughing marks at the leading edge are responsible for the maximum erosive wear is observed at 90°. The minimum erosive wear occurred at 30° and the corresponding eroded surface showed crater lip formation (figure 5 (g)) and the subsequent removal as platelets and shallow discontinuous ploughing marks along with plough lips similar to wedge formation of erosive wear (figure 5 (i)).

The FE-SEM images of the eroded surfaces (minimum rate of erosion observed at 30°) displayed fracture of hard phase and less carbide pullout from the impact region (figure 5 (h)). There was no effect on carbides at the regions away from the impact; only ploughing marks were observed (figure 5. (i)). When Ni based - Cr$_2$C$_6$ composite clad is impacted with particles of 400 µm, there occurred more carbide fracture, and less carbide pullout, thus more carbides remained intact (figure 5 (a) and (b)) at eroded surfaces that correspond to a maximum erosive wear at 90°. Surfaces that had minimum erosion, showed only carbide fracture and carbide intact at both the regions of impact, away-from impact regions (figure 5 (h) and (i)). Figure 5 (a) and (b) show failure mechanisms at high angles of impact. Here, the lip formation is followed by crater from the impact of the first few erodent particles. The so formed lips further elongate along the surface by the subsequent impingement of erodent, leading to a further widening of the crater and removal of the elongated lips as platelets. These types of failure mechanisms are observed in Ni based -Cr$_2$C$_6$ composite clads as observed in figures 5 (a) and (b), the erodent particles impacting at low angles initially strike the surface, creating shallow craters. The successive erodent particles would tend to fracture the secondary hard phases within the coating without removing it. As observed, the maximum and minimum erosion rates are related to the impact angle and impingement velocity with particular erosion mechanisms.

4. Conclusions

i. The developed clad shows well metallurgical bonded with substrate by partial mutual diffusion of elements, which exhibits the erosion resistant property when the clad subjected to jet slurry erosion testing.

ii. The cumulative weight loss during slurry jet erosion of composite clads were found least at 30° Impact angle and a velocity 20 m/s had 72 mg.

iii. The cumulative weight loss during slurry jet erosion of composite clads were found maximum at 90° impact angle and a velocity 60m/s had 125 mg.

iv. The micrographs of eroded samples show fatigue formation and fracture lead to subsequent fracturing of chips, deep ploughing marks at 90° Impact angle and a velocity 60m/s in clad leads to maximum weight loss.

v. The micrographs of eroded samples show micro-cutting and crater lip formation at 30° Impact angle and a velocity 20 m/s in clad leads to minimum amount of weight loss.

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