Microstructure and experimental design analysis of nickel based clad developed through microwave energy

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Summary In the present investigation microwave processing method was explored for the enhancement of surface properties of austenitic stainless steel (SS-304). The nickel based clads were developed through microwave energy. Taguchi’s L9 orthogonal array was successfully adapted to study the slurry erosive wear rate. The obtained result indicated that erosion rate of the developed clad varied between 0.0336 g to 0.03570 g as an increase in slurry parameters like slurry velocity and impingement angle respectively. It is confirmed by the response table for means of DOE that the wear rate of the developed clad was more influenced by the rotational slurry speed and impingement angle; finally the possible mechanisms of the worn surface of the tested samples were observed through SEM.

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Introduction

Hydraulic turbines, gas turbines, pumps, boilers and fluid transport systems are dealing with particle — laden fluids, which leads extensive erosive wear of various machine components (Mann, 2000; Duan and Karelín, 2002). At present situation of high speed machines working environment is detrimental to the component material. Austenitic SS-304 has excellent corrosion resistant and has great utility in engineering material for various applications (Sun and Bell, 2002; Sharma and Gupta, 2010). The components which are in contact with each other undergo loss of energy and reducing the life of the component due to corrosion, wear and tear. The surface coating method has acquired the attention of tribologists of the entire world for improving surface resistance to wear and corrosion by surface modification. Commercially, many surface modification techniques like tungsten inert gas (TIG) surfacing, thermal spraying and laser cladding are in use over the years. Now-a-days, thermal spraying is a most widely used surface enhancement technique, due to its cost

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effectiveness and exceptional wear resistance. TIG surfacing based welding technique provides a good metallurgical bond with the substrate, but excess dilution can lead to severe deformation of the substrate. Laser cladding process is used to deposit wear resistant and hard alloy layer, with minimum dilution on a soft substrate. This technique is attractive in industrial applications due to the benefits of high power density and low heat input and also has good metallurgical bonding with substrate. It has some limitations like residual stresses, presence of porosity and development of high thermal stresses due to high thermal gradient. Recently, microwave cladding has emerged as a new processing technique for surface modification to resolve the limitations of laser cladding. The microstructure of the microwave clad transverse section revealed good metallurgical bond with the substrate by partial mutual diffusion of constituent elements with less thermal distortion and uniform structure attributed to volumetric heating. The clad developed through the conventional process has less bonding strength than microwave cladding (Sharma and Krishnamurthy, 2002; Oghbai and Mirzaee, 2010). The present work deals with erosion studies of nickel based microwave cladding on SS-304.

**Experimentation**

**Microwave processing**

Present investigation deals with nickel based clad powder and SS-304 stainless steel substrate as clad material. The substrate (SS-304) was machined to a size 65 mm × 25mm × 6 mm. The powder was placed manually on the substrate SS-304 by maintaining an approximately uniform thickness. The experimental trials were conducted in a domestic microwave oven with the help of Al₂O₃ shield (specimen enclosures) to confine the flame generated due to microwaves contact with metals and for maximum utilization of microwave energy. Initially to raise the temperature of powder particles, a highly microwave absorbing material as a susceptor was used to absorb microwaves. Finally the preplaced powder was melted by microwave hybrid heating. The Clads were developed through microwave radiation at a frequency of 2.45 GHz with exposure time of about 20–25 min in a domestic microwave oven. The oven has great popularity for less temperature applications and especially for heating food items. The numerous experimental trials were carried out in a domestic microwave oven to achieve the desired clad thickness. The detailed information about development of nickel based clad is explained by Hebbale and Srinath (2015).

**Slurry erosion studies**

The erosion test was carried out through wear testing experimental set up [Make: Ducom Instrument Pvt. Ltd. Model: TR-40] was successfully utilized to find out the slurry erosive wear rate of the developed clad. The test setup consists of the six spindles connected to an electric motor through a belt drive with a maximum speed of 1500 rpm. The developed clad samples were attached to each spindle and completely dipped in the slurry pot, which consists of 1:1 ratio of distilled water with silica sand particles. Finally the slurry erosive wear studies were carried out as per the Taguchi L9 orthogonal array for a constant duration of three hours followed by every set.

**Experimental design**

In the present work Taguchi technique, method was used to optimize the design parameters. This technique helps to advance the quality of product through engineering concepts and statistical applications. The most essential requirement of any design objectives is to full fill with a limited number of tests. The standard L9 orthogonal array was successfully used to conduct the slurry erosive wear studies and the obtained results as shown in Table 1. Speed, particles size and impingement angle are the selected parameters of the optimization technique. The smaller is the better condition was adopted to determine the mean response of the slurry erosive wear studies.

**Table 1** Experimental layout and result.

<table>
<thead>
<tr>
<th>S. no</th>
<th>Speed (rpm)</th>
<th>Particles (μm)</th>
<th>Angle (°)</th>
<th>Wear (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>01</td>
<td>1000</td>
<td>106</td>
<td>15</td>
<td>0.02560</td>
</tr>
<tr>
<td>02</td>
<td>1000</td>
<td>212</td>
<td>30</td>
<td>0.02110</td>
</tr>
<tr>
<td>03</td>
<td>1000</td>
<td>425</td>
<td>45</td>
<td>0.01910</td>
</tr>
<tr>
<td>04</td>
<td>1250</td>
<td>106</td>
<td>30</td>
<td>0.02856</td>
</tr>
<tr>
<td>05</td>
<td>1250</td>
<td>212</td>
<td>45</td>
<td>0.02723</td>
</tr>
<tr>
<td>06</td>
<td>1250</td>
<td>425</td>
<td>15</td>
<td>0.04190</td>
</tr>
<tr>
<td>07</td>
<td>1500</td>
<td>106</td>
<td>45</td>
<td>0.03123</td>
</tr>
<tr>
<td>08</td>
<td>1500</td>
<td>212</td>
<td>15</td>
<td>0.03960</td>
</tr>
<tr>
<td>09</td>
<td>1500</td>
<td>425</td>
<td>30</td>
<td>0.03006</td>
</tr>
</tbody>
</table>

**Table 2** Response table for means.

<table>
<thead>
<tr>
<th>Level</th>
<th>Speed</th>
<th>Particles</th>
<th>Angle</th>
</tr>
</thead>
<tbody>
<tr>
<td>01</td>
<td>0.02193</td>
<td>0.02846</td>
<td>0.03570</td>
</tr>
<tr>
<td>02</td>
<td>0.03256</td>
<td>0.02931</td>
<td>0.02657</td>
</tr>
<tr>
<td>03</td>
<td>0.03363</td>
<td>0.03035</td>
<td>0.02858</td>
</tr>
<tr>
<td>Delta</td>
<td>0.01170</td>
<td>0.00189</td>
<td>0.00985</td>
</tr>
<tr>
<td>Rank</td>
<td>1</td>
<td>3</td>
<td>2</td>
</tr>
</tbody>
</table>

![Figure 1](image) Main effects plot for means of clad surface.
Results and discussion

The obtained results were analyzed through MINITAB 16 software tool for mean variance study, which indicates the application of DOE. Finally the microstructure of developed clad and also worn clad surface was observed through a scanning electron microscope.

Control factor analysis

The analysis helps to examine the control factors effect on the developed surface. This mainly deals with delta statistics and delta ranks are assigned based on the average value of delta statistics. The highest delta value indicates the more influence factor on mass loss of the developed surface. The response table for means of the Taguchi analysis as shown in Table 2. The speed and impingement angle factors were played more influence for mass loss on the developed surface. The main effects plot for means as shown in Fig. 1. The parameter line which has more inclination from the horizontal line represents the more significant effect. The effect of speed was observed from the plot, as speed increases the wear rate of the developed clad was also increased in the range between 0.02193 g to 0.03363 g. It is also observed for the control factor of impingement angle, more the wear rate was noted for lesser the impingement angle. The range of wear rate was observed between 0.00985 g to 0.03570 g. It is also noted; the wear rate of the developed clad surface had less effect of the particle size control factor. The range of wear rate for this factor is between 0.02846 g to 0.03035 g.

Microstructure analysis

Microstructure analysis plays a very important role to identify the phases present, grain structure and their morphology, etc. The developed and worn clad samples were observed through a scanning electron microscope as shown in Fig. 2. The typical cross section of the developed clad structure Fig. 2(a) shows well metallurgical bond with the substrate and pore free structure. During microwave heating the sprayed powder particles observed heat and melted on the substrate (SS-304), which leads to metallurgical bond with the substrate. Volumetric heating at the molecular level whereby the entire volume of the exposed material is heated simultaneously (volume heating). This causes the rapid heating of the exposed materials to elevated temperature with less thermal gradient. There is no transition of cellular to dendrites, which is one of the major significances of the process and could be clearly observed in the microstructure. Fig. 2(b) shows the more effect for worn out the clad surface was due to the high speed of sand particles hits the developed surface and leads to cause microcracks, due to repeated action of sand particles at 15° impingement angle leads to easily remove the material in the form of small chips.

Conclusion

The nickel based clads were developed on austenitic SS-304 steel through microwave energy. The slurry erosive wear behaviour of the developed clads were studied through sandder orthogonal array L9 and the obtained results are outlined as follows.

- The developed microwave clad shows crack free structure.
- The Taguchi L9 orthogonal array was successfully utilized to optimize the design parameters.
- The slurry speed and impingement angle control factors were the most influenced factors for the mass loss.
- The maximum wear rate found is in the range 0.03363—0.03570 g of mass loss on the developed surface.

References