Surface modification of mild steel: investigation of basic mechanical properties

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Abstract: The study reveals surface modification of mild steel carried out using friction surfacing process. Friction surfacing is a solid state coating process which enhances the properties of the substrate. The process involves deposition of aluminium-cadmium alloy on the surface of mild steel substrate. The aluminium-cadmium alloy was used in three different proportions namely sample 1 (Al-75%,Cd-25%), sample 2 (Al-80%,Cd-20%) and sample 3 (Al-85%,Cd-15%). Lathe machine was modified to enable the process parameters of friction surfacing. Hardness test, wear test, corrosion test, flexural strength and temperature profile measurement was carried out on the surface coating. There was considerable increase in hardness as the coating showed excellent resistance to corrosion, wear and flexural strength. The temperature profile was noted for all coated samples indicating the re-crystallisation temperature.

Keywords: friction surfacing; hardness; wear; corrosion; flexural strength; temperature profile.
1 Introduction

Friction based solid state processes have played major role in the field of welding and joining in recent years, due to great flexibility in terms of materials. Research in this process has provided superior results and various fields have been benefited (Vitanov et al., 2001). A spectrum of topics that represent the diverse nature in the field of surface engineering includes various methods such as plating, deposition and spraying, which have been attempted and commercialised to surface modify materials. Each of these methods, however, involves complex procedures and requires numerous processes. The friction surfacing is a potential surface modification method, the principle of which is relatively simple, with which coating would be enabled after rebuilt of friction welding machines (Nakama et al., 2008; Tokiwue et al., 2004). Friction surfacing is a coating technique where materials of dissimilar combinations can be coated with reduced loss of material properties and distortion of the substrate (Voutchkov et al., 2001). In case of high contact pressure, strong bonding is achieved. It has proved to be advancement in
manufacturing process, successfully developed and commercialised over the past decade. Research so far has revealed that in friction surfacing the mechtrode force, mechtrode rotation speed and substrate traverse speed are of critical importance for the final quality of the coating and bond. According to research on some aluminium alloys used for friction welding, a similar technique to friction surfacing based on the effective use of frictional heat (Shinoda et al., 1998; Gandra et al., 2012). Surfacing can be done at low temperatures because surface modification takes place in the solid phase; therefore, minimal thermal effects on the materials can be anticipated. A viscoplasticised solid state region is generated and processed with improved metallurgical properties in all friction based manufacturing technologies (Janakiraman and Udayabhat, 2012; Yamashita and Fujira, 2001). One of the most added advantages of this process is that less heat affected zone is formed in this process. It would appear at first glance that increasing the diameter of the coating material would increase the surface area of the deposit; however, it actually results in an increase in frictional force during surfacing process, which is detrimental to the equipment employed (Chandrasekaran et al., 1997). The friction surfacing of aluminium presents an inherent problem due to the high thermal conductivity of the metal. However, with aluminium heat quickly escapes upwards through the rod material. Effectively the cooling rate of the substrate is increased, thus achieving thermal balance between the rod and the substrate to retain more heat in the metal transfer zone. However, there are currently no reports on this type of surfacing technique. This is an innovative technique of using alloy as a coating material in three different proportions so as to check the various possible experimental results. Till date there has been no previous research of using Aluminium Cadmium alloy. The present investigation gives a detailed explanation coating of Aluminium Cadmium alloy on mild steel substrate.

Figure 1  Schematic diagram of friction surfacing

2 Literature survey

Sugandhi and Ravishankar (2012) investigated the Friction surfacing of aluminium on a mild steel substrate. The study focuses on the coating width and coating thickness of friction surfaced materials with help of empirical relationship. It was noted that input parameters play a vital role in coating and their relationship was constructed by multiple regression analysis. Design-expert software was used to optimise the model and study the coating width and thickness. The results obtained show that the developed empirical relationship can be applied to estimate the effectiveness of process parameters for a given
coating width and thickness (Rafi et al., 2010). Puli and Ram (2012a) work deals with corrosion performance of AISI 316L friction surfaced over Mild steel. Friction surfacing machine was used for coating purpose. AISI 316L stainless steel annealed for 1 hour and then coated over Mild steel which resulted in better resistance to pitting corrosion. Corrosion test, X-ray diffraction, travelling electron microscope test were conducted on coating. Absence of δ-ferrite in coating is reason for superior corrosion as 1mm thick friction surfaced coating resulted in better corrosion resistance than 6mm thick manual metal arc welding (Puli and Ram, 2012a). Janakiraman and Udayabhat (2012) demonstrated that it was possible to achieve coating with excellent inter-tracking bond consisting of multiple overlapping tracks. It was also found that friction surfacing was very useful process for producing wear resistance coating in difficult to fusion deposit materials such as martensitic stainless steel AISI 440C which is one of the strongest and hardest of martensitic class of stainless steel (Puli and Ram, 2012b). Barnabas et al. (2014) investigated the friction surfacing of stainless steel over ductile iron. Microstructure revealed good bonding between stainless steel and ductile iron with dense, clear and fine microstructure. The bend test and corrosion test results proved it would be beneficial for applications in petrochemical vessels and pumps for chemicals (Barnabas et al., 2014).

3 Experimental details

3.1 Machine used and process parameters

A lathe machine was modified to enable the process parameters of friction surfacing machine in order to carry out the current work. The parameters considered for the experiment are:

1. rotational speed (RPM) of consumable rod
2. traverse speed (mm/s) of the substrate traverses horizontally
3. axial force (KN) applied along the axis of the consumable rod.

The parameters were automatically set for operation. In present work the axial force was kept constant at 2KN, rotational speed at 1,300 RPM and traverse speed at 3mm/s.

Figure 2 Modified lathe machine and coated samples (see online version for colours)
3.2 **Materials used**

Aluminium cadmium alloy was used as the coating metal. Aluminium 6063 alloy and cadmium were taken in three samples in the proportion of 75:25, 80:20 and 85:15. The aluminium cadmium alloy rod was of 200mm length and 22mm diameter. Mild steel was used as substrate. The dimensions of the substrate were 100mm×30mm×5mm.

3.3 **Testing equipment**

3.3.1 **Hardness test**

Hardness test determines the indentation hardness of the material. Hardness test was conducted using Rockwell hardness test with diamond intender load of 150 KN. Rockwell hardness number is calculated from the depth of permanent deformation of indenter on to the sample. Hardness test was conducted as per ASTM E18 standards.

3.3.2 **Wear test**

Wear can be defined as the removal of surface material as a result of mechanical abrasion. Pin-on-disc wear testing is a method of characterising the coefficient of friction, frictional force and rate of wear between two materials. During this tribological test, a stationary disc articulates against a rotating pin while under a constant applied load. The weight loss due to the abrasion is measured in a particular interval of time (1 min) using Pin-on-disc wear testing machine. The test was carried out as per ASTM G99 standards.

3.3.3 **Bend test**

Bend test determines the ductility or the strength of material by bending the material over a given radius. Bend test with a three point or four point bend fixture can be carried out. A universal testing machine used to perform three point bend test as per ASTM D790 standard.

3.3.4 **Corrosion test**

Corrosion is deterioration of metal as a result of chemical reaction between it and the surrounding environment. Corrosion resistance can be increased in components using friction surfacing process. The samples were tested using applied corrosion monitoring instruments. Corrosion test was conducted as per ASTM standards.

4 **Results and discussion**

4.1 **Hardness test**

Hardness test was conducted using Rockwell hardness test with diamond intender load of 150 KN.
Hardness test was conducted as per ASTM standards and the values were tabulated in Table 1. The graphical representation of result comparison is shown in Figure 4. The graph clearly states the hardness of the friction surfaced materials was increased considerably.

**Figure 3** Rockwell hardness tester (see online version for colours)

![Rockwell hardness tester](image)

**Table 1** Hardness test results

<table>
<thead>
<tr>
<th>Trial no</th>
<th>Mild steel [HRC]</th>
<th>Sample 1 (75:25) [HRC]</th>
<th>Sample 2 (80:20) [HRC]</th>
<th>Sample 3 (85:15) [HRC]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>39.6</td>
<td>48.5</td>
<td>45.8</td>
<td>42.5</td>
</tr>
<tr>
<td>2</td>
<td>39.6</td>
<td>47.8</td>
<td>46.2</td>
<td>43.3</td>
</tr>
<tr>
<td>3</td>
<td>39.6</td>
<td>48.7</td>
<td>44.9</td>
<td>42.4</td>
</tr>
<tr>
<td>4</td>
<td>39.6</td>
<td>49.1</td>
<td>46.4</td>
<td>43.7</td>
</tr>
<tr>
<td>5</td>
<td>39.6</td>
<td>47.3</td>
<td>44.7</td>
<td>41.8</td>
</tr>
<tr>
<td><strong>Average [HRC]</strong></td>
<td><strong>48.28</strong></td>
<td><strong>45.6</strong></td>
<td><strong>42.74</strong></td>
<td></td>
</tr>
</tbody>
</table>

**Figure 4** Comparison of hardness test (see online version for colours)

![Comparison of hardness test](image)
4.2 Wear test

Wear is a process of gradual removal of material from surface of solids. The result of wear test taken on the coated substrate is shown in Table 2. The coefficient of friction is compared with base metal in Figure 6. The result shows surface coated mild steel having better wear resistance than mild steel substrate.

Figure 5 Pin-on-disc wear apparatus (see online version for colours)

Table 2 Change in coefficient of friction corresponding to time

<table>
<thead>
<tr>
<th>Time (sec)</th>
<th>MS plate (change in coefficient of friction)</th>
<th>Aluminium cadmium alloy coating (change in coefficient of friction)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Sample 1 (75:25)</td>
<td>Sample 2 (80:20)</td>
</tr>
<tr>
<td>50</td>
<td>17</td>
<td>11.2</td>
</tr>
<tr>
<td>100</td>
<td>17.5</td>
<td>11.6</td>
</tr>
<tr>
<td>150</td>
<td>17.8</td>
<td>12.4</td>
</tr>
<tr>
<td>200</td>
<td>17.9</td>
<td>12.7</td>
</tr>
<tr>
<td>250</td>
<td>18.4</td>
<td>12.8</td>
</tr>
<tr>
<td>300</td>
<td>18.7</td>
<td>12.9</td>
</tr>
<tr>
<td>350</td>
<td>19</td>
<td>13.2</td>
</tr>
<tr>
<td>Average</td>
<td>18.04</td>
<td>12.4</td>
</tr>
</tbody>
</table>

Figure 6 Changing coefficient of friction corresponding to time (see online version for colours)

4.3 Bend test

Bend testing provides insight into bending strength of the material. Test was conducted as per the ASTM standards and resulting bending load was tabulated in Table 3 and the
Surface modification of mild steel

A graphical representation is shown in Figure 8. We can declare from the graph that coated substrate had better result.

**Figure 7** Three-point bend tester (see online version for colours)

![Three-point bend tester](image)

**Table 3** Bending loads before and after coating of mild steel

<table>
<thead>
<tr>
<th>Material</th>
<th>Bending load (kN)</th>
<th>Needle movement (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mild steel</td>
<td>12.5</td>
<td>15</td>
</tr>
<tr>
<td>Aluminium cadmium coating</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sample 1 (75:25)</td>
<td>13.9</td>
<td>15</td>
</tr>
<tr>
<td>Sample 2 (80:20)</td>
<td>13.5</td>
<td>15</td>
</tr>
<tr>
<td>Sample 3 (85:15)</td>
<td>12.8</td>
<td>15</td>
</tr>
</tbody>
</table>

**Figure 8** Bend test comparison (see online version for colours)

![Bend test comparison](image)

4.4 Corrosion test

Corrosion test was conducted using ACM instrument.

It is well known that the application of friction surfacing in automatic components can reduce the corrosion rate by coating Aluminium Cadmium alloy on mild steel. The Figure 10 shows the comparison between corrosion rate of mild steel and Aluminium Cadmium alloy. Among them the friction surfaced coating has the higher corrosion resistance.
Figure 9  ACM corrosion testing setup (see online version for colours)

![ACM corrosion testing setup](image)

Table 4  Corrosion test comparison

<table>
<thead>
<tr>
<th>Material</th>
<th>Mild steel</th>
<th>Aluminium cadmium alloy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample 1 (75:25)</td>
<td>0.3640</td>
<td>0.1023</td>
</tr>
<tr>
<td>Sample 2 (80:20)</td>
<td>0.2018</td>
<td>0.2942</td>
</tr>
<tr>
<td>Sample 3 (85:15)</td>
<td>0.2942</td>
<td></td>
</tr>
</tbody>
</table>

Figure 10  Comparison of corrosion test (see online version for colours)

![Comparison of corrosion test](image)

4.5  Temperature profile

Temperature variations per 5 seconds are noted using IR Thermometer for different combinations of sample 1 (75:25), sample 2 (80:20) and sample 3 (85:15). These values are plotted with time taken in X-axis and temperature in Y-axis. The dwell time for the combination 75:25 represented in the Figure 13 was 122 seconds. The recrystallisation temperature for the alloy composition was approximately 402.675°C and a steady state was achieved during the operation at 393.9°C.

Figure 11  Experimental setup – IR thermometer, rod and substrate (see online version for colours)

![Experimental setup](image)
**Figure 12** Temperature profile for sample 1 alloy composition 80:20 (see online version for colours)

**Figure 13** Temperature profile for sample 2 alloy composition 75:25 (see online version for colours)

**Figure 14** Temperature profile for sample 3 alloy composition 85:15 (see online version for colours)
The reading obtained can be divided into four stages: the first stage starts soon after there is a contact between the two metals. The friction caused in the initial period is an important factor for temperature generation during the stage 1, the heat generated during this stage is due to the coefficient of friction between the rotating consumable rod and the substrate. The rate of heat generation increases with increase in coefficient of friction.

There is gradual increase in the temperature (from the room temperature to 200°C) due to this heat generated during stage 1, the temperature increases approximately to 260°C during stage 2. Sudden increase in the torque and ‘sticking and slipping’ occurs in the interface. This phenomenon happens where the top surface asperities will get joined. In order to overcome this effect, large amount of energy is generated by the system causing severe plastic deformation at the interface. The heat generated is in much faster rate than the being heat dissipated, as this leads to adiabatic heating condition. The sudden rise in the temperature at stage 2 attributes to viscous heat dissipation caused due to plastic deformation.

The friction component of the heat gets lessen as soon as the temperature reaches to 260°C and it is gradually taken over by viscous heat dissipation (Stage 3) (between 280 to 370°C). The peak temperature of 393.6°C is attained during the process which reaches steady state value which we term as stage 4 where coating was formed. There is continuous heat generation during stage 4 till the end of process. There is no stability in the temperature as we find that there is gradual amount of increase in temperature in each point.

5 Conclusions:

From the above investigation, we derive the following:
1. lathe machine was successfully modified to enable the process parameter of friction surfacing
2. flexural strength of the deposit was slightly higher than the base metal
3. hardness of the deposit was higher than that of the mild steel base metal
4. wear resistance showed better resistance to friction than the base metal
5. friction surfaced coating had higher corrosion resistance than that of base metal
6. temperature profile indicate the re-crystallisation temperature for the alloy composition was approximately 402.675°C.

References


