Effect of process parameters on the width of friction surfaced tool steel M2 deposit over low carbon steel

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ABSTRACT:
Friction surfacing is a well established technology for depositing corrosion and wear resistant coatings. It is an energy efficient process and low environmental impact when compared with other alternative technologies. This process opens up a new area especially in the field of repair and reclamation of worn and damaged components. This process is capable of producing coatings with zero dilution and good metallurgical bonding. This paper is concerned with coating of AISI M2 tool steel on low carbon steel by using $2^3$ factorial designs with three factors at two levels each of total eight treatment combinations. The present work focus on effect of process parameters on the width of tool steel M2 deposit on low carbon steel produced by friction surfacing process to suit the specific industrial applications. The process parameters are strongly influencing the coating characteristics and integrity. The selection of optimum level of process parameters causes obtained good quality of coating. The regression equation is calculated based on the $2^3$ factorial designs and ANOVA table is constructed to test the significance of process parameters such as friction pressure, rotational speed and welding speed. The results shows that the width of the deposit is directly proportional to friction pressure and inversely proportional to rotational speed, combined effect of friction pressure and rotational speed, combined effect of friction pressure and welding speed and combined effect of friction pressure, rotational speed and welding speed.

Keywords: Friction surfacing, process parameters, Tool steel deposit, solid state welding.
1. INTRODUCTION

Surface engineering is the sub-discipline of material science, which involves altering surface phase properties in order to decrease depreciation over the period of time. Friction surfacing is derivative of friction welding process and which retains all the advantages of solid state fusion welding like excellent metallurgical bond and forged microstructure. Fusion welding based techniques are produce coarse microstructure with high levels of dilution and also these processes often suffers with porosity, oxidation and hot cracking. But friction surfacing process is an advanced technique, which produce clean, dense and fine microstructure and joining dissimilar metal combinations. The process has already been successfully used in industry for edge retention of industrial knifes [1].

The friction surfacing was first patented as a metal-coating process by Klopstock in 1941 [2]. Friction surfacing is reliable and repeatable process for many combinations of metals deposit on different varieties of substrates. Cylindrical consumable rod which is rotating is fed against a substrate by applying axial force continuously on the consumable rod. Due to this heat is generated, which softens the rubbing end of rotating consumable rod. Once the plasticized metal stage reached at tip of the rod, alternately, substrate is traversed with respect to vertical consumable rod in horizontal position. Consequently, plasticized metal deposited over the substrate. This process has been used for producing various different metal coatings such as tool steel coatings on mild steel or stainless steel on mild steel [3]. The range of materials in research work so far studied in friction surfacing is mostly limited to ferrous alloys, e.g., chromium alloys [4,5], but some focus on deposition of non-ferrous corrosion resistance materials such as inconel and stellite[6] and aluminum alloy [7]. The selection of critical process parameters for variety of different substrate geometries and for new coating material involves lengthy experimental research work. Friction surfacing has become a potential green manufacturing technology because of its advantages such as clean, good quality and high efficiency. In order to speed up parameter selection process, V.I.Vitanov, I.I. Voutchkov, et.al. [8, 9, 10] developed a neurofuzzy model based Decision support system. Batchelor, A.W et.al. attempted the feasibility of different materials (brass, aluminum, stainless steel) on substrate in different environment. For industrial applications, friction surfacing has mainly focus on in the manufacturing of long-life cutting tools with a strong resistance to delamination, prominent uses in hardfacing, damage repair or corrosion resistance [11]. This process is also used to repair oil pipes and marine under water[12]. Multilayer friction surfacing is another important techniques for cladding applications[13]. The critical areas of applications include depositing hardfacing metals on knife cutting edges of different categories such as dies, tools, punches and blades required for chemical, medical, food processing and agricultural industries[14]. This process can be carried out in open air [15], in under water without sealing [16] and inert gas atmosphere [17]. Friction surfacing of different metal substrates with different coating combinations, comprising of hard coatings on soft substrates and soft coatings on hard substrates [18, 19].
2. EXPERIMENTAL WORK

2.1 Materials

Tool Steel M2 is the rotating consumable rod is termed as mechtrode of diameter 10.5 mm and length of 290 mm and low carbon steel is the substrate of 330 mm x 220 mm x 11 mm dimensions were selected as per experimental design matrix [20]. The tool steel M2 and Low carbon steel are used in annealed condition. The mechanical and chemical composition tests were performed for mechtrode and substrate materials as per the ARE: 773129 part 1 and IS 1608 respectively. The results are tabulated in table 1.

Table 1: Chemical composition of Low carbon steel and Tool steel M2 (% in weight)

<table>
<thead>
<tr>
<th>Material</th>
<th>C</th>
<th>Mn</th>
<th>P</th>
<th>S</th>
<th>Cr</th>
<th>Mo</th>
<th>Ni</th>
<th>V</th>
<th>Si</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low carbon steel</td>
<td>0.21</td>
<td>0.655</td>
<td>0.026</td>
<td>0.019</td>
<td>0.022</td>
<td>0.012</td>
<td>0.017</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Tool steel M2</td>
<td>0.791</td>
<td>0.16</td>
<td>--</td>
<td>--</td>
<td>3.83</td>
<td>5.3</td>
<td>--</td>
<td>1.82</td>
<td>0.34</td>
</tr>
</tbody>
</table>

Table 2: Mechanical properties of low carbon steel and Tool steel M2

<table>
<thead>
<tr>
<th>S.No</th>
<th>Material</th>
<th>Yield strength (N/ mm²)</th>
<th>Tensile strength (N/ mm²)</th>
<th>% of elongation</th>
<th>Hardness HV</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Low carbon steel</td>
<td>317</td>
<td>504</td>
<td>28.84</td>
<td>185</td>
</tr>
<tr>
<td>2</td>
<td>Tool steel M2</td>
<td>453</td>
<td>827</td>
<td>16.86</td>
<td>279</td>
</tr>
</tbody>
</table>

2.2 Equipment

The friction surfacing process was carried out on an indigenously developed friction surfacing machine manufactured by ETA Technologies, Bangalore, India. The machine shown in fig. 2.
Technical specification of friction surfacing machine are i). motor capacity: 30kW, ii). Permissible spindle speed: 2500 rpm (maximum), iii). Axial load: 50 KN Max and iv) Table size: 330 x 450 mm. The process parameters such as spindle speed, table feed and axial force are controlled by using CNC technology.

2.3 Procedure of Experimental Work:
The identified process parameters such as friction pressure range: 5-10 KN, welding speed range: 40-60 mm/min and rotational speed range: 100-300 rpm are selected. The three primary process parameters selected for experimental work by using $2^3$ factorial designs with three factors at two levels each of total eight treatment combinations [21]. These eight treatment combinations used for depositing tool steel M2 on low carbon steel. The table 3 shows treatment combinations with response (width) obtained and indicating corresponding deposits.

Table 3: Selected process parameters for tool steel M2 deposit on low carbon steel and response (width) obtained [20, 21].

<table>
<thead>
<tr>
<th>T C</th>
<th>Process Parameters</th>
<th>Response (Width) (mm)</th>
<th>Deposit</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Friction pressure (Mpa) $X_1$</td>
<td>Speed of mechtrod (rpm) $X_2$</td>
<td>Welding speed (mm/min) $X_3$</td>
</tr>
<tr>
<td>1</td>
<td>5</td>
<td>100</td>
<td>40</td>
</tr>
<tr>
<td>2</td>
<td>10</td>
<td>100</td>
<td>40</td>
</tr>
<tr>
<td>3</td>
<td>5</td>
<td>300</td>
<td>40</td>
</tr>
<tr>
<td>4</td>
<td>10</td>
<td>300</td>
<td>40</td>
</tr>
<tr>
<td>5</td>
<td>5</td>
<td>100</td>
<td>60</td>
</tr>
<tr>
<td>6</td>
<td>10</td>
<td>100</td>
<td>60</td>
</tr>
<tr>
<td>7</td>
<td>5</td>
<td>300</td>
<td>60</td>
</tr>
</tbody>
</table>
3. TESTING

3.1 Width of the Deposit
The obtained widths are not uniform for all eight treatment combinations. The deposit width is noticed that maximum value at the initial stage and maintaining remains constant while continuing friction surfacing process. The effective contact coating width was obtained by machining the unbounded region of both advancing and retreating side of the width of the coating. The deposit width values are not constant for all eight treatment combinations. The width of the bead was measured by digital vernier caliper. The deposit width at six marked locations is measured along the length of the coating. The width of the bead was taken an average of six locations, similarly method was followed for the remaining deposits and the values are tabulated in table 3.

3.2 Regression Equation for the Response (Width)
ANOVA table is constructed to test the significance of process parameters. The regression equation can be written after substituting $\beta$ coefficients. Now eliminating less significant terms, the equation can be written as $y = 13.39 + 15.28X_1 - 0.83 X_2 - 0.86 X_1 X_2 - 0.38 X_1 X_3 + 0.12 X_1 X_2 X_3$

4. RESULTS AND DISCUSSIONS
The obtained widths are not constant for all eight treatment combinations. The deposit width is noticed that maximum value at initial stage and maintains remains constant while continuing friction surfacing process. The deposit width values are not constant for all eight treatment combinations and it depends on level of the process parameters used.

It is found from the regression equations, the width of the deposit is directly proportional to friction pressure and inversely proportional to rotational speed, combined effect of friction pressure and rotational speed, combined effect of friction pressure and welding speed, and combined effect of friction pressure, rotational speed and welding speed. There is a limitation in increasing the rotational speed of mechtrode and friction pressure as more torque is developed at the starting of the operation, and this may cause stalling the motor of machine or spindle bearings may damaged because of initial dry friction between tip of consumable rod and substrate and also friction pressure is applied more, it causes bends the mechtrode, when its tip gets plasticized.
5. CONCLUSIONS

- The selection of process parameter as a function of material properties is an important factor for obtaining successful coatings.
- Friction surfacing was found to be an effective method for obtaining tool steel M2 coatings.
- The width of the deposit lies between 11.48 mm to 17.47 mm and its value primarily depends on the magnitude of process parameters.
- The width of the deposit is directly proportional to friction pressure and inversely proportional to rotational speed, combined effect of friction pressure and rotational speed.
- The study on analysis of width obviously furnishes information and guidance while depositing on different geometrical shapes and sizes such as on a flat, circular and circumferential surfaces and even on to edge and central recess, precise locations and pre-formed hole spot areas for selection of process parameters and mechtrode diameter to avoid lack of bonding at the sharp corners of the deposit.

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