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Characterization of Tool Steel M2 Friction Surfaced Desposits

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Abstract:

Friction surfacing is an advanced solid state technology, and which is capable of producing wear resisting coatings on engineering components. This process is most suitable for getting desired special properties for the surfaced deposit. This process is easily controllable, repeatable, reliable, and is a simple machine tool technology which is having similar benefits like other solid phase welding processes.

This paper is concerned with coating of AISI M2 tool steel on low carbon steel by using 2^3 factorial designs with 3 factors at two levels each of total eight treatment. Evaluated their characterization, physical and mechanical properties. The process parameters are optimized using corresponding regression equations are determined using 2^3 factorial design approach. The results obtained from the experiments are anticipated to find more industrial applications such as repair of turbine blades, hard facing of agricultural implements, bucket teeth of earth moving equipments and cutting edges on knifes of different categories, punches, dies and blades required for food processing, chemical and medical industries.

Keywords: Friction surfacing, characterization of tool steel deposit, mechanical properties, regression equations.

INTRODUCTION

Friction surfacing is one of the emerging surface engineering techniques, which is capable of depositing similar and dissimilar metals over the other more effectively. This technique is increasingly being adopted to extend the life of the components in manufacturing industries. Friction surfacing is a solid state process for producing wear and corrosion resistant coatings on different metallic surfaces [1-3]. In this process, a cylindrical consumable rod is fed against metallic substrate with certain axial load; frictional heat is generated due to rubbing action between substrate and consumable rod. After certain time, the rubbing end of consumable rod becomes plasticized. Consequently, the substrate is traversed across the face of the consumable rod, a plasticized metal at the rubbing end of the consumable rod gets deposited over the substrate. The coating materials such as tool steel, aluminum, and stainless steel, inconel and aluminum metal matrix composites were deposited over mild steel and aluminum substrates. The friction surfacing process is absence of spatter and fumes and have clean environment. The parameters such as substrate traverse speed, rotational speed of the consumable rod and axial force exerted on the consumable rod is strongly influencing quality of the coating deposit.

Friction surfacing can also performed on radial drilling machine, vertical milling machine and lathe machine with special attachments. This process is repeatable and reliable, applicable for different combinations of substrates and consumables. The obtained deposit is absence of cracks, porosity, dilution or slag inclusions normally encountered in traditional fusion welding processes.

The parameters such as torque-time are important for the quantity of heat generated at the interface of the materials. The parameters such as friction force (kN), rotational speed of consumable rod (rpm) are important for heat generation in friction surfacing. The quality of the deposit also depends on transverse speed of substrate material (mm/s). Hence they are called generally process parameters since they are influencing physical and mechanical properties, and bond quality [4]. The figure. 1 shows the schematic diagram of process and parameters involved in friction surfacing.

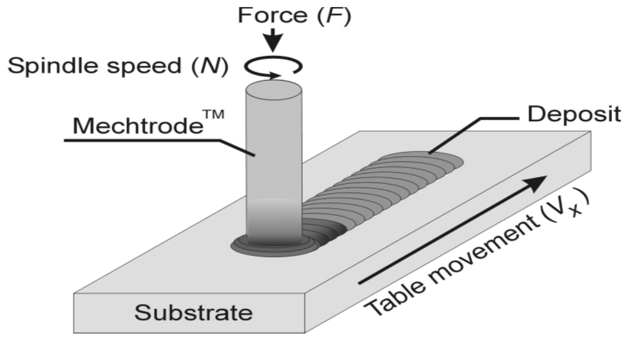

Figure 1: Principle involved in friction surfacing

Multilayer friction surfacing also possible for cladding applications [5-6]. For reconditioning of worn out shafts, restoring hard faces on cutting edges, in-situ reclamation of worn out railway points and good anti-corrosion overlay of slide valve plates, friction surfacing is most suitable. Lathe, Radial drilling and Milling machine with special attachments can be used performing friction surfacing. This process will take little time and heat effected zone is also less and hence further heat treatment process is not required which is generally done on conventional welding processes. It also is performed in under water or open air or in the presence of inert gas which will not affect quality of the deposit [5].

PROCESS PARAMETERS

The amount of heat produced in friction surfacing is the most important for feasible and strong bond between the materials being used for getting desired properties. The amount of power consumed depends on force and rotation speed, and torque-time characteristics. But the level of friction pressure is depends on forging pressure of materials to be joined.. When sufficient heat is obtained, the substrate is moved with desired linear speed to get the uniform thickness and surface finish of the deposit for particular diameter of the consumable rod. The selection of parameters such as friction pressure (Mpa), rotational speed of consumable rod (Rpm) and transverse speed of substrate material (mm/s) are depend on quality of the deposit, and hence these parameters are called controlled parameters.

The selection of above process parameters depend on the following factors. i) forging strength of the consumable rod and the substrate. ii) coefficient of friction between consumable rod and substrate. iii) diameter of the consumable and thickness of the substrate and iv) physical and mechanical properties of consumable rod and substrate. Welding speed of the substrate also affects the thickness and quality of the deposit. Hence it is necessary to determine the process parameters for any size of the consumable rod which affects the quality of the final deposit.

Dwell time of 5-10 seconds is usually required, but it depends on the thermal conductivity and forging temperature of the materials to be joined.

From the literature it is observed that for the tool steel consumable and Low carbon steel substrate combination, nearly 1.2 % of the tool steel which is heated to plastic state initially, will be deposited over the low carbon steel substrate. In friction surfacing the width of the deposit is nearly 0.5 times diameter of the consumable rod. Hence the thickness of the deposit can be estimated by selecting welding speed of the substrate or table speed on which substrate is fixed.

From it is concluded that the friction forces lie within the range of 6-12 KN, rotational speed 120-310 rpm and welding speed 42-65 mm/min. These main process parameters with 2^3 factorial designs are adopted for doing experimental work[7-8]

EXPERIMENTAL WORK

Annealed tool steel AISI M2 is the mechtrode and it is rotating consumable rod of 10.25 mm diameter and length of 290 mm and annealed low carbon steel is the substrate having dimensions of 450 mm x 150 mm x 11 mm in this experimental work. The mechanical and metallurgical tests are done for substrate and mechtrode materials according to IS 1608 and standard ARE: 773129 respectively. The chemical composition and test results are tabulated in Table 1 and Table 2.

Table 1: Chemical composition of materials used for friction surfacing processes (% in weight)

Material used	C	Mn	P	S	Cr	Mo	Ni	V	Si
Low carbon steel (Consumable)	0.21	0.64	0.02	0.02	0.02	0.01	0.02	--	--
Tool steel M2	0.78	0.17	--	--	3.85	5.2	--	1.85	0.33

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

Material	Yield strength (N/mm^2)	Tensile strength (N/mm^2)	% of elongation	Hardness HV
Low carbon steel	319	514	28.74	176
Tool steel M2	452	831	16.79	745

Mechtrode is prepared by machining 12 mm diameter tool steel M2 rod into 295 mm length and it is shown in figure 1. After machining to get desired dimensions, low carbon steel plate is cleaned with acetone, which to remove all impurities dust, oil and grease etc.

Figure 2: Mechtrode before friction surfacing

Friction surfacing experimental trails are conducted by using indigenously developed friction surfacing machine which is capable of rotates spindle speed up to 2500 rpm and applying axial load up to 50 KN with motor capacity of 30 KW The three main process parameters such as spindle speed (rpm), friction pressure (MPa) and table feed (mm/min) are controlled by CNC technology which is inbuilt within the machine.

Experimental Procedure

Statistical design of experimental approach [5] is selected to minimize the number of trials required to optimize welding conditions. The three important parameters such as friction force (kN), rotational speed of the mechtrode (rpm) and transverse speed of the substrate (mm/sec) are selected for the experimental work with 2^3 designs for the deposition of tool steel over low carbon steel. Experimental design matrix indicating the eight treatment combinations are given in table 1.

Figure 3: Friction surfacing machine used for conducting experiments.

Using these eight trials tool steel is deposited with surfacing machine shown in figure 2, and made for investigation.

Table 3: Tool steel M2 deposits onto low carbon steel for eight treatment combinations.

TC	Process Parameters			Tool Steel M2 deposits onto low carbon steel for eight treatment combinations
	Friction Force (kN), X_1	Mechtrode rotational speed (rpm) X_2	Welding speed (mm/min) X_3	
1	6	120	42	
2	12	120	42	
3	6	310	42	
4	12	3010	42	
5	6	120	65	
6	12	120	605	
7	6	310	65	
8	12	310	65	

Testing of Deposits:

Primary tests: These tests are conducted in the shop floor after each of the trial completed to now the bond strength. Visual examination also conducted to know the deposits free from voids, pores and surface cracks. Adhesion tests such as lifting by chisel, hammer test and grinding wheel tests are performed to check the bond strength quantitatively.

Dye Penetration Test: Dye penetration test is conducted for the deposits, as per standard ASME Sec V SE 165. This test is performed to the entire specimens used in bend tests.

Measurement of Responses

i). Width of the deposit: Digital vernier caliper is used to measure the width of the deposit. The length of the deposit is divided in to five equal parts leaving edges and marked those positions. Width is measured at marked positions and its average of value is determined. This average value is taken as the width of deposit. The same is procedure is repeated for the remaining deposits and the values are tabulated in table 1

ii) Height of the deposit: The height of the deposit is measured with dial indicator. Height of the deposit at three positions along the width of the deposit is measured at marked positions and its average value is treated as width of the deposit. Repeated the same procedure at six marked positions and average value is determined which is known as height of the deposit. Similarly measured height of each deposit and their results are tabulated in table 3.

iii) Surface roughness of the deposit: Surface roughness is measured with surface roughness tester made by Tsusubushi Corporation, Japan. The surface roughness at eight positions along the length of the deposit is measured and the mean value is calculated. This will be the surface roughness value for that treatment combination. Repeated the same for the remaining deposits and the values are tabulated in table 3.

iv) Shear Strength Test: The samples are prepared according to the standard ASTM 264. Shear test is done by using a fixture and 40 Ton UTM machine. This procedure is repeated for each treatment combination deposit to determine shear strength and the values are tabulated in table 3 and sample used shear test are shown in figure 3.

Specimen before shear test	Specimen after shear test
	

Figure 4: Specimen before and after shear test

v) Ram Tensile Test: Ram tensile test is used to determine the tensile strength of bond ram is made with a diameter to get sliding fit in the drilled hole in the opposite side of the deposit. Figure 4 shows the specimen used for tensile strength. Ram tensile test is done by using a special designed ram with fixture and 40 Ton UTM machine. This procedure is repeated for all treatment combination to determine shear strength and the values are tabulated in table 3 and sample with the testing equipment used for determination of tensile strength test are shown in figure 4.

Specimen before ram tensile test	Specimen after ram tensile test
	

Figure 5: Specimen samples before and after tensile strength test.

Figure 6: The ram and fixture used for ram tensile test.

Table 3: Shows the values of height, surface roughness, shear strength and tensile strength for all eight treatment combinations.

TC	Responses of the dposite for eight treatment combinations (TC)				
	Width (mm)	Height (mm)	Surface roughness (microns)	Shear strength (Mpa)	Tensile strength (Mpa)
1	10.6	1.35	6.52	61.06	25.16
2	12.42	2.54	2.43	129.39	55.08
3	11.32	1.45	6.15	67.20	25.13
4	13.85	1.55	1.84	122.66	49.25
5	10.24	1.12	6.05	67.13	28.51
6	12.27	1.23	7.63	62.42	24.53
7	10.76	0.95	6.55	158.36	75.62
8	13.05	1.53	9.48	138.62	61.65
Average	12.15	1.32	5.27		435
Standard deviation	1.28	0.562	2.67	90.2	114.7

Deposit Analysis Using Regression Equations:

The responses such as physical properties and bond test results of tool steel deposit over low carbon steel using friction surfacing (responses) are analyzed using taguchi quality approach. The regression equations for the above responses are determined. ANOVA table is constructed to determine the significance of the parameters. The significance values which are nearer to the 3.59 (as per the 2^3 design principle) are considered and corresponding coefficients values (β) are substituted in the regression equation. Here X_1 refers to force applied, X_2 refers to speed of consumable (rpm), and X_3 refers to welding linear speed substrate used in friction surfacing [9-10].

i). Width of the deposit:

In the typical procedure for calculation of the regression equations for the width of the deposit, y_0= Mean of the response of the width = 13.39 mm and Standard Deviation = 2.003. Analysis of variance (ANOVA) table is constructed for width to test the significance of process parameters. Then the regression equation can be written after substitution of coefficients of significant factors. The obtained regression equation for width is y=13.39+15.28X1-0.83X2-0.21X3-0.86X1X2-0.38X1X3+0.031X2X3+0.21 X1X2X3.
After test of significance of the parameters eliminating the less important (least significant) terms, the regression equation can be rewritten as y= 13.39+ 15.28 X1-0.83 X2 - 0.86 X1X2 – 0.38 X1X3 + 0.21 X1X2X3

ii) Height of the deposit:

The normal procedure for calculating the regression equations for the height responses. y_0= Mean of the response of the height =0.961 mm and Standard Deviation (σ) = 0.276.Analysis of variance (ANOVA) table is constructed for height of the deposit is to test the significance of process parameters. Write the regression equation after substitution of coefficients of significant factors (β coefficients) y = 0.961-0.0037X1-0.2187X2 -0.023X3-0.158X1X2+ 0.00125 X1X3+0.026 X2X3 – 0.043X1X2X3 Then the significant values which are closer to the (According to the 2^3factorial design principle) are to be considered and related coefficient values (β) are substituted in the written regression equation, afterwards, eliminating the less significant(least important) terms, then the equation can be written in simplified form as y= 0.961-0.2187 X2-0.023 X3-0.158 X1X2+0.026 X2X3-0.043X1X2X3.

iii) Surface roughness of the deposit:

The evaluation of roughness or smoothness of deposit surface based on the frequency of material transfer in discrete layers. The surface roughness values are not constant for all eight treatment
combinations and it is based on the selection of the levels of the process parameter. The surface roughness is crucial factor for deciding the further surface operations are necessary or not prior to using it.

Analysis of variance (ANOVA) table is constructed for surface of the deposit is to test the significance of process parameters. Write the regression equation after substitution of coefficients of significant factors (β coefficients). The obtained regression equation for the surface roughness is y = 2.02+0.828X1+0.258X2+0.611X3-0.121 X1 X2+0.326 X1 X3-0.473 X2 X3-0.328 X1 X2 X3. Later test of significance, Eliminating the less important (least significant) terms, the regression equation can be re-written as y= 2.02+0.828X1+0.611X3+0.326 X1 X3-0.473 X2 X3-0.328 X1 X2 X3.

iv) Shear Strength Test:

Analysis of variation (ANOVA) table is constructed to test the significance of the process parameters. The regression equation for the shear strength is is obtained as y = 43.75+ 4.5X1 +9.75X2+ 4.25X3-2X1X2-9X1X3 +11.25X 2X3 – 0.5 X1X2X3.
Later test of significance, Eliminating the less important (least significant) terms, the regression equation can be re-written as y = 43.75+ 4.5X1 +9.75X2+ 4.25X3-9X1X3 +11.25X 2X3

Ram Tensile Test:

Analysis of variation (ANOVA) table is constructed to examine the significance of the process parameters The

obtained regression equation for the tensile strength is y = 103.4 + 15.125X1+ 21.875X2 + 6.875X3 – 3.875 X1X2 – 18.87 X1X3+21.875X2X3+0.125X1X2X3
Later test of significance, eliminating the less important (least significant) terms, the regression equation can be re-written as y = 103.4 + 15.125X1+ 21.875X2 + 6.875X3 – 18.87X1X3 + 21.875X2X3.

Micro Hardness Survey:
The micro hardness survey is performed across the interface of tool steel deposit onto low carbon steel based on standard procedure IS 1501-2002 with Vickers micro hardness tester. The obtained values are indicated in table.

Table 4: Micro hardness survey of the tool steel deposit over low carbon steel

Distance of the point with reference to interface layer	Hardness survey in transverse direction (HV)	Hardness survey in longitudinal direction (HV)
In the direction of TS at 1.0 mm	826	801
In the direction of TS at 0.8 mm	796	770
In the direction of TS at 0.6 mm	774	743
In the direction of TS at 0.4 mm	771	743
In the direction of TS at 0.2 mm	765	740
At the interface	372	353
In the direction ofLCS at 0.2 mm	184	145
In the direction of LCS at 0.4 mm	180	152
In the direction of LCS at 0.6 mm	176	156
In the direction of LCS at 0.8 mm	176	156
In the direction of LCS at 1.0 mm	162	151

Note: where TS: Tool Steel and LCS: Low Carbon Steel

RESULTS AND DISCUSSIONS

Experimental results show that the friction surfacing could be used as a method for obtaining coatings of dissimilar materials. Quality of the deposit is only depends on selection on process parameters. There is tremendous scope to extend this process to other dissimilar metal combinations for protection against wear and corrosion.

This reveals that there is more quantity of hardness increased at the interface and its value is above the base metal. This increased value is more in transverse direction in comparison with longitudinal direction. This is clearly states that in friction surfacing process, the concentration of energy at the centre of consumable rod. This shows the formation of harder phase of steel crystalline structure i.e. martensite. It is considered that the formation of martensite in the coating because of high cooling rates encountered throughout the friction surfacing process. The decrease in hardness value in the direction of low carbon steel is due to transfer of carbon towards tool steel and also observed that hardness decreased within the heat affected zone[11-12].

During the initial rubbing action of consumable rod with substrate, the machine experiences large vibrations due to influence due to dry friction and the peak torque decreases after a few seconds. The equilibrium torque continues. Hence selection of process parameters for friction surfacing for given combinations of materials plays a vital role in the protection of the machine and getting good bond strength.

Surface finish obtained is not same for all deposits and consists of semicircular ripples. The width, thickness and surface finish of the deposit are not uniform in the entire length. Surface roughness is inversely proportional to frictional pressure, directly proportional to welding speed, combined effect of (i) frictional pressure and rotational speed and (ii) rotational speed and welding speed.

The height and width of the deposit is maximum in the initial stages and uniform while substrate is moving. The height of the deposit is directly proportional to friction pressure and inversely proportional to welding speed and interaction of frictional pressure and welding speed.

The coating width is always less than the diameter of the mechtrode and lies between 2/3 to 3/4 diameter and its value depends on levels of process parameters. From the regression equation it is shows that the width of the deposit is proportional to the frictional pressure, rotational speed and their interactions but inversely proportional to welding speed. But there is a limitation in increasing the frictional pressure as the mechtrode bends at forging temperature.

Shear strength increases on par with the three process parameters. Tensile strength is inversely proportional to (i) welding speed, (ii) combined effect of frictional pressure and rotational speed and (iii) rotational speed and welding speed. Its value increases with increasing value of combined effect of frictional pressure and traverse speed and combination of three process parameters. Tensile strength decreases with transverse speed. The selection of process parameters mainly depends on the requirement of specific application.

APPLICATIONS AND LIMITATIONS

Friction surfacing has potential application in industries due to improved reliability and productivity, suitable for batch production, reduction in cost, superior quality and the achievement what was previously impossible. This process has critical areas of automotive industrial applications include hardfacing materials on cutting edges on knifes of various categories, punches, dies and blades required for food processing, chemical and medical industries. This process can also be attempted in the robotics for full automation.

Friction surfacing is the solid state welding process and it is confirmed that the problems associated with fusion welding are eliminated like porosity, inclusion and other defects normally formed while solidification of weld. The deposit has refined micro structure and with little distortion..

This method is suitable for repair and reclamation of worn and damaged parts. This process also can be performed under water without a sealing mechanism .

This process can be performed in open air and not required any inert gases to prevent oxidation. This process is most suitable for the consumables which are having less thermal conductivity than substrate and poor sliding characteristics It is a clean welding process, does not require fluxes or other consumables and produces no fumes or spatters or harmful radiation

Low thermal conductivity of mechtrode and poor sliding characteristics are required for performing friction surfacing. This evidence can be observed while doing friction surfacing with aluminum and copper mechtrodes which poses difficulties [14-15].

CONCLUSIONS

Experimental results show that the friction surfacing can be used as an alternate method for obtaining coatings of dissimilar materials. Though the vertical milling machine, radial milling machine and lathe machine with special attachments were used for friction surfacing, special purpose friction surfacing machine only is suitable for intended use and it is advisable for effective control of process parameters [16].

Friction surfacing is the best method for obtaining deposits of dissimilar having low thermal conductivity. This process can be carried out in open air without the provision of an inert gas atmosphere. No cracks are found in the HAZ. It shows the suitability of the parameters to give controlled heat input. Integrity of the deposit is excellent with good metallurgical bond.

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