EVALUATION OF SIGNIFICANCE OF PROCESS PARAMETERS BY STATISTICAL METHOD (ANOVA TABLES) FOR FRICTION SURFACED TOOL STEEL M2 DEPOSIT OVER LOW CARBON STEEL

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Abstract

This paper discusses the procedure for to test the significance of process parameters of physical characteristics such as width, height and surface roughness of the friction surfaced tool steel M2 deposit over low carbon steel. This evaluation can be carried out by construction of ANOVA tables, Then write the regression equation after substitution of coefficient of significant factors and afterwards eliminating least important terms, the simplified regression equation can reveals the significance of process parameters corresponding to respective physical quantities of friction surfaced tool steel M2 deposit. These results show the variation of the physical quantities of the deposit corresponding increase or decrease of process parameters such as friction pressure, rotational speed and welding speed.

Index terms- Friction surfacing, ANOVA, tool steel M2, Coefficent of regression equations, Process Parameters etc.

1. INTRODUCTION

The friction surfacing is surface modification process, which is derived from friction welding. This process was first patented as metal coating process by Klopstock and Neelands in 1941[1]. Friction surfacing process is a solid state process for producing corrosion and wear resistant coatings on different combination of metallic surfaces [2]. In this process the rotated consumable rod is fed against substrate, the frictional heat is generated between the consumable and substrate, consequently generates a layer of plasticized metal, which subsequently deposited as coating onto

Substrate.Friction surfacing process has been used for achieving several combination of metal coating like stainless steel over mild steel or tool steel coatings over mild steel [3]. The critical areas of primary applications include depositing hard facing materials on cutting edges of knives of several categories,die,punch, blades and tools necessary for chemical, food processing , medical and agricultural industries. This process is also used for reclamation of worn out railway points and reconditioning of worn out shafts[4]. The benefits of this process such as excellent bonding with absence of porosity, inclusions or oxidation, and produce clean, dense and fine microstructure coatings. M2 Tool steel are commonly used in application like drills, punches, lathe and planner tools, milling cutters, taps, saws and reamers etc. Any attempt to enhance the life of these tools will be useful to increase the productivity. M2 tool steel coating can extend the life of the tools with improved properties. A schematic diagram of friction surfacing process is shown in fig. 1.

The process parameters of friction surfacing is axial force, rotational speed and traverse speed, which influences the physical quantities such as width, thickness and also mechanical and metallurgical properties. In other words, these process parameters are crucial for the final quality of the deposit.

Friction surfacing can also carried out on vertical milling machine, radial drilling machine, and lathe machine with special accessories. The present study focuses on characterization of friction surfaced tool steel M2 coating over low carbon steel.

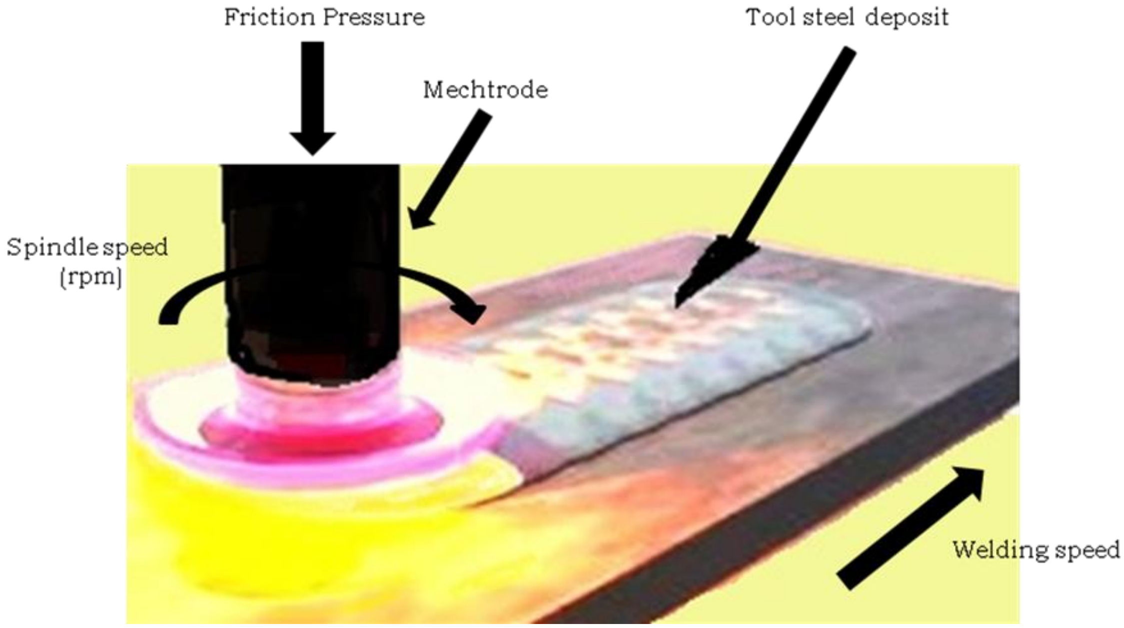


Fig1. Schematic diagram of friction surfacing process

2. EXPERIMENTAL WORK

Low Carbon Steel plate was taken as the substrate, dimensions of substrate were 310 mm length, 220 mm width, and 11 mm thickness, both tool steel M2 and low carbon steel were taken in annealed condition and controlled roughness over low carbon steel was achieved by milling machine. Generally corroded surface of the low carbon steel plate will not accepted for good coating by friction surfacing. Hence it was rough finished with emery paper, at last the substrate was fine finished by surface grinding machine. Prior to this process, the surface of the low carbon steel plate is cleaned with acetone, which was removes all impurities oil, dust, and grease etc and the mechtrode was prepared by cut the 12 mm diameter tool steel M2 rod into 290 mm lengths by cutting machine. Then the tool steel M2 rods are turned by lathe machine for achieve uniform diameters of 10.5 mm and length of 290 mm each. The experimental trails were performed by indigenously developed friction surfacing machine.

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 integrated within the machine.

In this process, rotated tool steel M2 is fed against low carbon steel substrate under certain axial load, consequently frictional heat is liberated between substrate and consumable rod. The rubbing end of the consumable rod gets plasticized, later the substrate moves in horizontal direction relative to consumable rod. Then the plasticized metal gets deposited as coating over the substrate. The coatings obtained due to these eight treatment combinations are shown in table

In this work, the identified range of process parameters is friction pressure: 5-10 KN, mechtrode rotational speed: 100-300 rpm and substrate traverse speed: 40-60 mm/min. These main process parameters with 2^3 factorial designs are adopted for experimental work and used for tool steel AISI M2 is deposited over low carbon steel [5].

3. RESULTS AND DISCUSSION

3.1 Influence of width of the deposit on process parameters

The formation of deposit width is not similar for all treatment combinations. However, the width of the deposit is maximum at starting stage of the deposition and afterwards it remains constant while continuation of the process. The value of the width is not same for all eight treatment combinations and it primarily depends upon the process parameters used in the friction surfacing. The average values of width of deposit for eight treatment combinations are shown in table 1.

Table 1: The value of width for eight treatment combinations

T.C	1	2	3	4	5	6	7	8
Width (mm)	11.48	17.47	11.91	13.59	12.20	15.77	11.89	12.88

Note: TC: Treatment combination

This examination 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 mechtrode diameter to avoid lack of bonding at the sharp corners of the deposit.

The typical procedure for calculation of the regression equations for the width of the deposit as shown in table 2. Hence, TSS designates Total Sum of Squares and where TC is termed as Treatment Combinations. For that response table, the Mean Sum of Squares (MSS) = (sum of responses)^2/8 = (107.19)^2/8 = 1436.21, 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

$$y=13.39+15.28X_1-0.83X_2-0.21X_3-0.86X_1X_2-0.38X_1X_3+0.031X_2X_3+0.21\,X_1X_2X_3.$$

After test of significance of the parameters eliminating the less important (least significant) terms, the regression equation can be re-written as

$$y = 13.39 + 15.28\ X_1 - 0.83\ X_2 - 0.86\ X_1X_2 - 0.38\ X_1X_3 + 0.21\ X_1X_2X_3$$

The Figure 2 shows the influence of the process parameters on the deposit width.

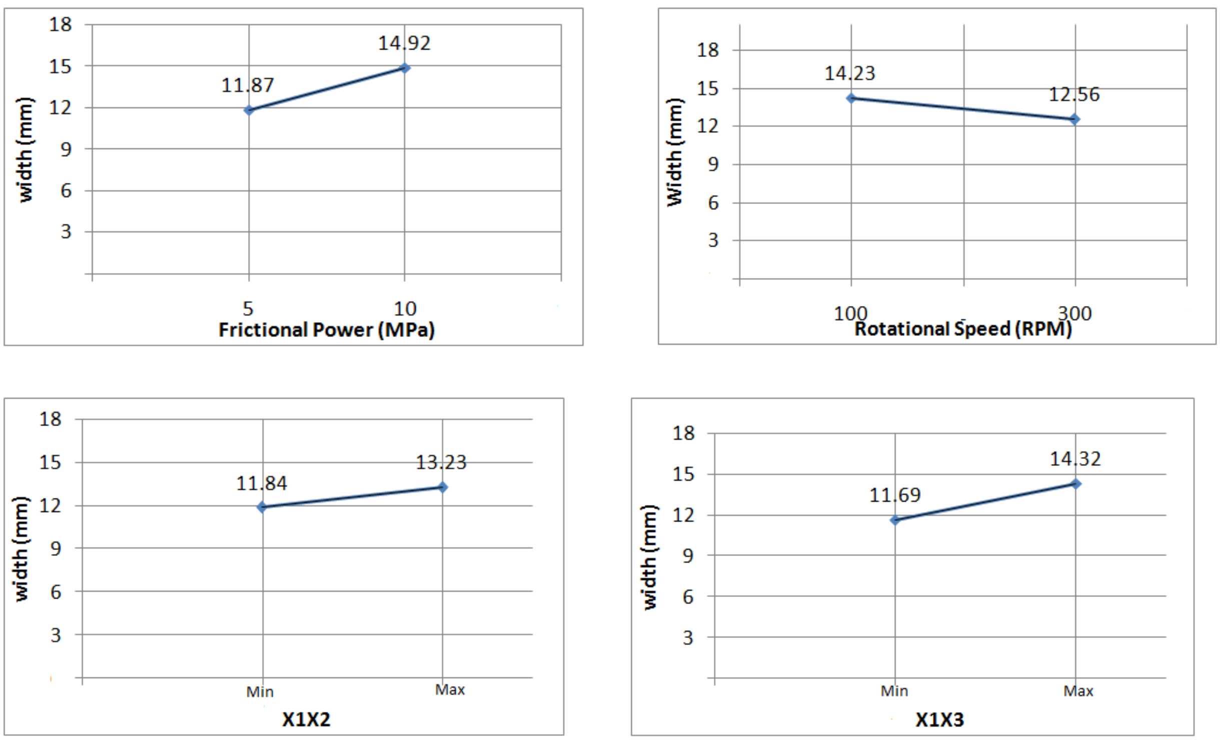


Fig 2: The effect of process parameters and their interactions on the width of the deposit.

Table 2: Coefficients for regression equation for width response

S.No	T.C	Response (y)	Column 1	Column 2	Column 3(z)	TSS $(z^2/8)$	F Ratio= (TSS/MSS)	Significant Factors(z/8),

								(β coef.'s)
1	1	11.48	28.95	54.45	107.19	1436.2	1	----
2	X_1	17.47	25.50	52.74	12.23	18.69	0.01301*****	15.28, (β_1)
3	X_2	11.91	27.97	7.67	-6.65	5.52	0.00384 ***	-0.83,(β_2)
4	X_1X_2	13.59	24.77	4.56	-6.89	5.93	0.00412****	-0.86,(β_{12})
5	X_3	12.20	5.99	-3.45	-1.71	0.36	0.000250	-0.21,(β_3)
6	X_1X_3	15.77	1.68	-3.20	-3.11	1.20	0.000835**	-0.38,(β_{13}
7	X_2X_3	11.89	3.57	-4.31	0.25	0.007	0.0000048	0.031,(β_{23})
8	$X_1X_2X_3$	12.88	0.99	-2.58	1.73	0.37	0.000257*	0.21,(β_{123})

Note: Where TC: Treatment combinations, TSS: Total Sum of Squares and MSS: Mean Sum Squares

3.2 Influence of height of the deposit on process parameters

While deposition on marine components or aerospace parts the height of the deposit plays crucial role in reducing thickness of the deposit correspondingly lowering the weight of the component or part and also deposition on facilitating vessels and tanks for storage and handling of corrosive solutions. It is observed from the primary inspection, the height of the deposit is maximum at starting stage and later remains constant height while continuation of the process.

The value of the height is not same for all eight treatment combinations and it is completely depends on the ranges of the process parameters used. The average value of height of the deposit for eight treatment combinations is shown in table 3. It is noticed from the table that the height of the deposit is obtained in the range between 0.5 mm to 1.50 mm and its value influenced by magnitude of the process parameters used.

Table 3: The values of the deposit height for eight treatment combinations

T.C	1	2	3	4	5	6	7	8
Height (mm)	1.12	1.34	0.86	0.62	0.93	1.33	0.95	0.54

TC: Treatment Combinations

The normal procedure for calculating the regression equations for the height responses are shown in table 4. Where Mean Sum of Squares, MSS= (Sum of the responses) ^{2} /8 = $(7.69)^2/8$ = 7.39, Where TC: Treatment Combinations and TSS: Total sum of the Squares.

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)

$$y = 0.961-0.0037X_1-0.2187X_2 -0.023X_3-0.158X_1X_2+ 0.00125 X_1X_3+0.026 X_2X_3 - 0.043X_1X_2X_3$$

Then the significant values which are closer to the (According to the 2^3 factorial 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

$$y= 0.961-0.2187 X_2-0.023 X_3-0.158 X_1X_2+0.026 X_2X_3-0.043X_1X_2X_3$$

Table 4: Coefficients for regression equation for height response

S.No	T.C	Response (y)	Column 1	Column 2	Column 3(z)	TSS ($z^2/8$)	F Ratio= (TSS/MSS)	Significant Factors(z/8), (β coef.'s)
1	1	1.12	2.46	3.94	7.69	7.39	1	----
2	X_1	1.34	1.48	3.75	-0.03	0.0001	0.0000135	-0.0037, (β_1)
3	X_2	0.86	2.26	-0.02	-1.75	0.3828	0.05179****	-0.2187,(β_2)
4	X_1X_2	0.62	1.49	-0.01	-1.27	1.6129	0.2182*****	-0.158,(β_{12})
5	X_3	0.93	0.22	-0.98	-0.19	0.0045	0.000608*	-0.023,(β_3)
6	X_1X_3	1.33	-0.24	-0.77	0.01	0.00125	0.0001691	0.00125,(β_{13})
7	X_2X_3	0.95	0.4	-0.46	0.21	0.00551	0.000745**	0.026,(β_{23})
8	$X_1X_2X_3$	0.54	-0.41	-0.81	-0.35	0.0153	0.00207***	-0.043,(β_{123})

Note: TC: Treatment Combinations, TSS: Total Sum of Squares, MSS: Mean Sum of Squares.

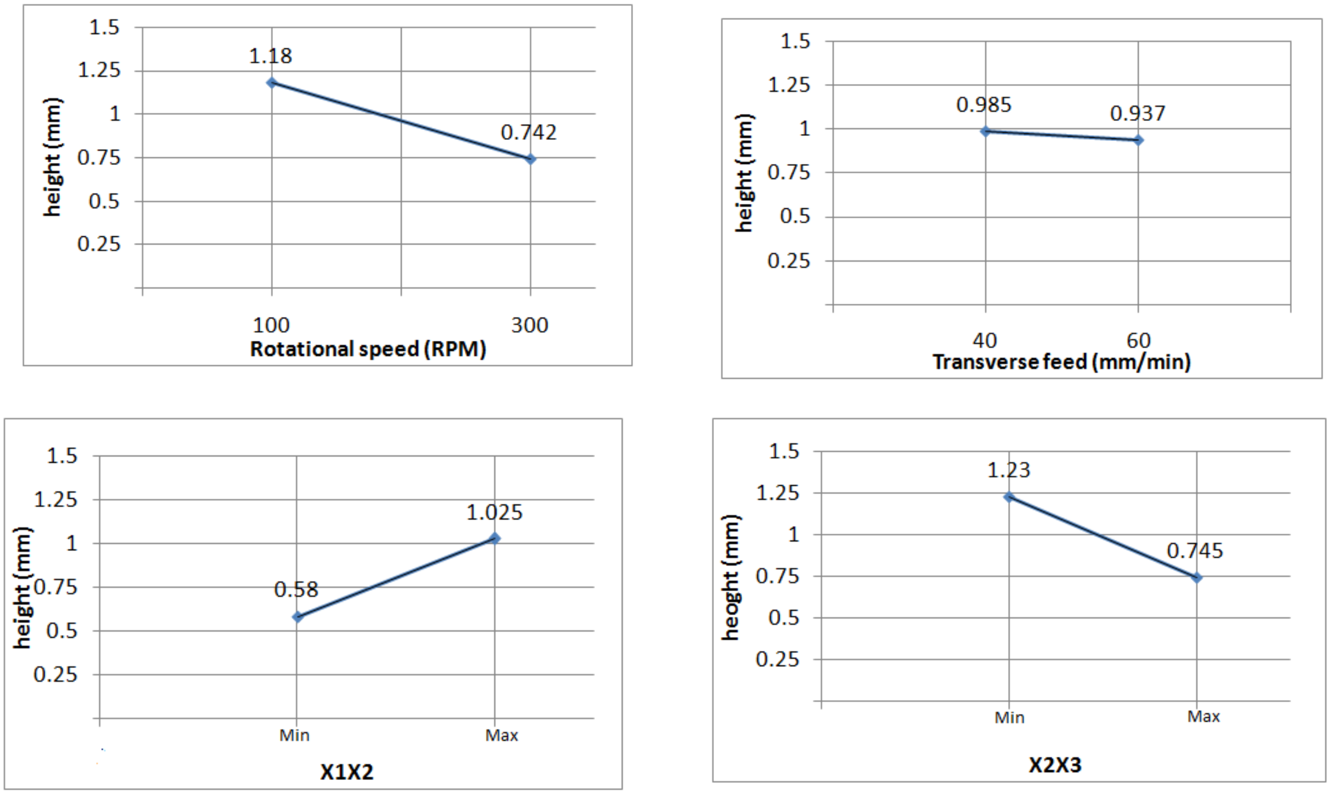


Fig 3: The effect of process parameters and their interactions on the height of deposit.

3.3 Influence of surface roughness of the deposit on process parameters

Top surface of the coating consists of regularly spaced ripples in the form of semi circular due to existence of these ripples can leads to formation of roughness on the surface of the deposit. The average height of these ripples is nearly 0.1 mm. The ripple formation is related to nature of material transfer from consumable rod to substrate. But surface roughness of the deposit is not constant for all treatment combinations. High intensity of ripple formation can be caused to more surface finish on the deposit. These ripples can be eliminated by machining process based on particular applications. The intensity and uniformity of these ripples on the surface of the deposit will indicate the selection of correct process parameters.

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. The average values of surface roughness response of eight treatment combinations are shown in table 8.6.

Table 5: The average values of deposit surface roughness (response)

TC	1	2	3	4	5	6	7	8
Surface roughness (μ)	0.38	0.97	1.43	2.85	1.24	4.45	1.71	3.12

TC: Treatment Combinations

The procedure for calculation of the regression equations for the surface roughness is shown in table 6. Where, TSS specifies Total Sum of Squares and TC is designates as Treatment Combinations.

Mean sum of Squares (MSS) = (sum of the responses)^2/8 = $(16.15)^2/8=32.60$.

y_0= Mean of the surface roughness response = 2.02 μm and Standard Deviation (σ) = 1.257.

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

$$y= 2.02+0.828X_1+0.258X_2+0.611X_3-0.121 X_1 X_2+0.326 X_1 X_3-0.473 X_2 X_3-0.328 X_1 X_2 X_3$$

Later test of significance, Eliminating the less important (least significant) terms, the regression equation can be re-written as

$$y= 2.02+0.828X_1+0.611X_3+0.326 X_1 X_3-0.473 X_2 X_3-0.328 X_1 X_2 X_3$$

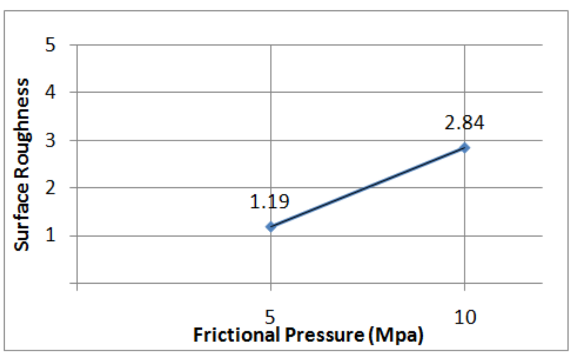
Table 6: Coefficients for regression equation of surface roughness response

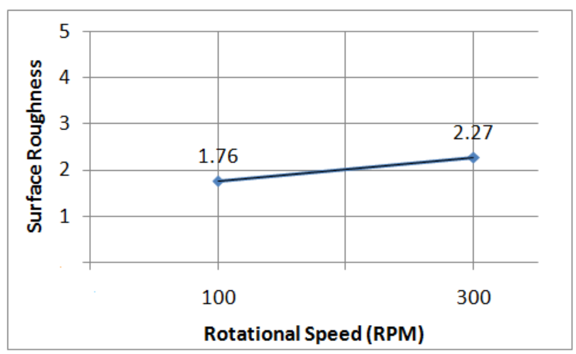
S.No.	T.C.	Responses (y)	Column1	Column 2	Column 3 (z)	TSS ($z^2/8$)	F Ratio = (TSS/MSS)	Significant Factors(z/8), (β coef.'s)
1	1	0.38	1.35	5.63	16.15	32.60	1	--
2	X_1	0.97	4.28	10.52	6.63	5.494	0.1685*****	0.828,(β_1)
3	X_2	1.43	5.69	2.01	2.07	0.535	0.01641	0.258,(β_2)
4	X_1X_2	2.85	4.83	4.62	-0.97	0.1176	0.00360	-0.121,(β_{12})
5	X_3	1.24	0.59	2.93	4.89	2.989	0.09168**	0.6112,(β_3)

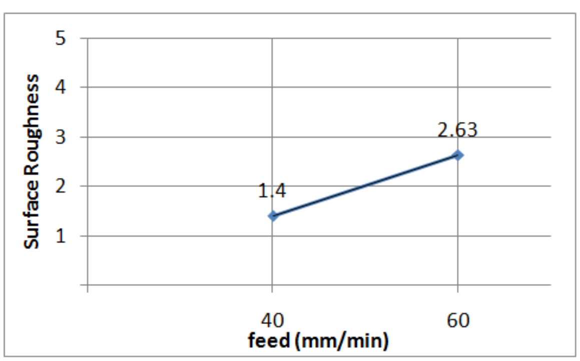
							**	
6	X_1X_3	4.45	1.42	- 0.86	2.61	0.851	0.0261*	0.326,(β_{13})
7	X_2X_3	1.71	3.21	0.83	-3.79	1.795	0.05506***	-0.473,(β_{23})
8	$X_1X_2X_3$	3,12	1.41	- 0.80	-2.63	0.864	0.02650**	-0.328,(β_{123})

Note:

Where T.C: Treatment Combinations, T.S.S: Total Sum of Squares and M.S.S: Mean Sum of Squares.







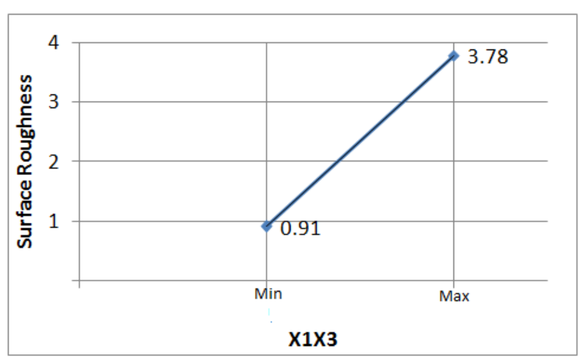


Fig 4: The effect of process parameters and their interactions on the surface roughness of the deposit.

4. CONCLUSIONS

1. It is observed from the regression equation, the deposit width 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, combined effect of friction pressure, rotational speed and welding speed. But higher levels of rotational speed contribute for lower width.

2. From the regression equation it is found that the height of the deposit is inversely proportional to rotational speed, welding speed and also interaction of friction pressure, rotational speed and welding speed.

3. It is observed that surface roughness is directly proportional to friction pressure, welding speed and combined effect of (i) friction pressure and rotational speed and inversely proportional to combined effect of (ii) welding speed and rotational speed and (iii) frictional pressure, welding speed and rotational speed.

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