EXPERIMENTAL INVESTIGATION OF FACTORS INFLUENCING THE WEAR PROPERTY OF THERMAL SPRAY COATED PRODUCTS

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Abstract

As the requirements of the improved surface properties increased now days, thermal spray coating has gained lime light. Thermal spray coating being efficient enough finds application in marine Industries ,aviation etc. It is a well known coating technique to improve the hardness, wear resistance and other parameters of the surface coating. This paper deals with the study of wear resistance of the surface which is thermally sprayed using detonation gun.Pin on disc technique has been used to study the wear property of the thermally sprayed surface coat.

Keywords: Thermal Spray Coating, Detonation Gun, WC:CO,Pin on disc, Wear Resistance.

Nomenclature :

η – Objective Function

μ – mean of objective function

Spl/m -Spray litre per minute

MA1 &MA2- effect of factor A in level1 and level2 respectively

I. INTRODUCTION

Researches are being carried out in several area mostly to optimize certain parameters or to enhance the performance of a system[2]. This paper deals with such a technique (*thermal spray coating)*which is widely used now a days to enhance the properties of a coated surface. Thermal spray coated surface are known for their desirable characteristics such as wear resistance[4], hardness[], corrosion resistance etc. The coating technique is used in compressor blades, seals and advance turbines. The coating is knownto enhance the surface chemistry for better efficiency. The thickness of the coating ranges from 20 micrometer to several millimeters [3]depending upon the purpose required to be served. In this experiment thermal coating is done by the help of detonation gun.

WC-12Co, WC-10Co-4Cr, Cr_3C_2-25NiCr is thermally sprayed on the substrate metal using *detonation gun* .Then the wear properties[1] of the coated specimens are studied using *pin on disc* test.

II. EXPERIMENTAL DETAILS

A. Design of Experiment

- Identifying suitable coating material
- Identifying suitable cost effective substrate
- Design of the Experiments through Taguchi's Orthogonal array (L9)
- Performing coating process on selected substrate
- Conduct wear test on pin on disc
- Finding out the best combination of various parameters to obtain best wear resistance.

B. Substrate

SS304 is used as a substrate onto which coating is done. SS304 is a marine grade stainless steel used for making chemical containers. It has good wear control, thermal and electrical conductivity. Square pieces of the substrate had dimension of 100 mm $\times$ 100 mm $\times$ 5 mm.

C. Coating Method

Thermal spray coating process is a surface enhancement technique in which the melted material are sprayed on a metal surface Several methods of thermal spraying are distinguished as follows:

- Plasma Spraying
- Detonation Gun Spraying
- Wire Arc Spraying

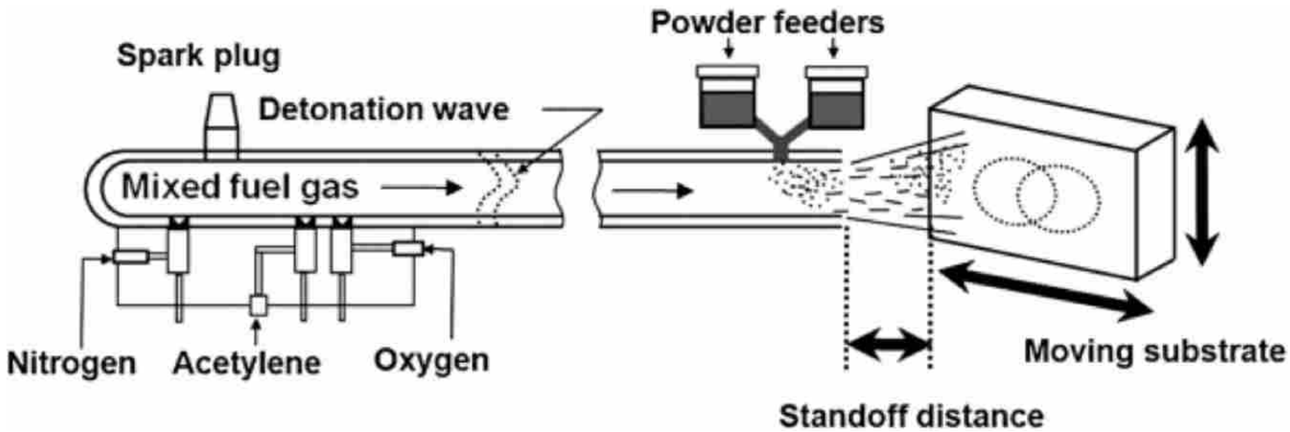

Fig. 1 Detonation gun coating process

- Flame Spraying
- High Velocity Oxy-Fuel Coating Spraying (HVOF)
- Warm Spraying
- Cold Spraying

In this experiment detonation gun spraying [7] technique has been used for coating the substrate. The Detonation gun basically consists of a long water cooled barrel with inlet valves for gases and powder. Oxygen and fuel (acetylene most common) is fed into the barrel along with a charge of powder. A spark is used to ignite the gas mixture and the resulting detonation heats and accelerates the powder to supersonic velocity which carries molten metal to be coated on the substrate. A pulse of nitrogen is used to purge the barrel after each detonation. This process is repeated many times a second. The high kinetic energy of the hot powder particles on impact with the substrate result in a build up of a very dense and strong coating. This process is shown in Fig. 1.

The surface to be coated is first cleaned by using acetone and dried. WC-12Co, WC-10Co-4Cr, Cr_3C_2-25NiCr powders are fed into the barrel simultaneously and thermally sprayed onto the surface of the selected substrate.

D. Pin on Disc

A tribotester is the general name given to a machine (pin on disc) or device used to perform tests and simulations of wear, friction [1] and lubrication which are the subject of the study of tribology [6] as shown in Fig. 2.

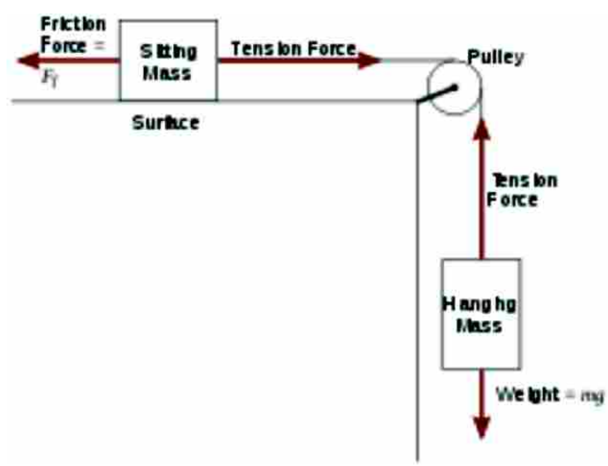

Fig. 2 Pin-on Disc Test Setup

E. Design of Experiment

Taguchi L9 orthogonal array is applied since the current study is having three level and four parameter. The Table:1 shows the L9 Array . As per the L9 Array, to conduct the experiment No.1, Level 1 of Parameter A, Level 1 of Parameter B, Level 1 of Parameter C, and Level 1 of Parameter D should be taken for the process setting. All other eight experiments also can be conducted as given in the various levels in Table 1

Table 1. Taguchi L9 array

Expt. No.	A	B	C	C
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	1	3
9	3	3	2	1

The Experiments are designed with the selected four Parameters in Three levels as shown in the table :2

The sample preparation has been done with grit blasting and acetone cleaning for the surface to be coated. The coating process was carried out for all nine samples as decided in the table 2. The main aim was to enhance the wear resistance. Thus higher the best model was selected for our experiment. The equation (equation no: 1) for higher the best is given below :

$$\eta = -10 \log_{10} (1/Y^2 \qquad ...(1)$$

η – Objective Function

Y – Responses

F. Pin on Disc Test

Coated Samples shown in the Figure 3 are subjected in to wear test [5] with the load of 5 kg for a specified duration. The Satellite Tipped pins shown in the Figure 4 are used for the test and the weight loss on the coated samples are studied. The corresponding Wear index values are tabulated in the table 3.

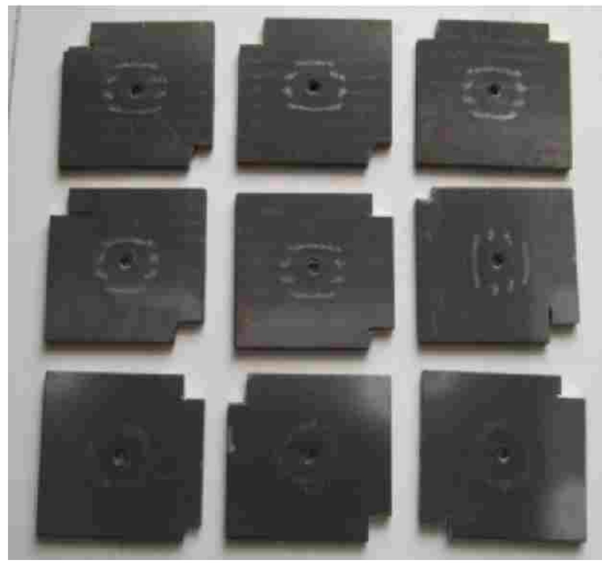

Fig. 3 Coated Samples

Table 2. Substituted matrix Experiments Conducted as Per L9 Orthogonal Array

Exp No.	Powder (A)	Coating Thickness (B) (micron)	Powder Flow rate (C) (spl/m)	Spray Distance (D) (cm)
1	WC12%CO	350	600	160
2	WC12%CO	450	1000	170
3	WC12%CO	550	1400	180
4	WC10%CO4Cr	350	1000	180
5	WC10%CO4Cr	450	1400	160
6	WC10%CO4Cr	550	600	170
7	Cr C2 25% NiCr	350	1400	170
8	Cr C2 25% NiCr	450	600	180
9	Cr C2 25% NiCr	550	1000	160

Fig. 4 Pin used for Pin on Disk Test

The related Objective functions "η" of all the nine responses are calculated by using the Eqn 1 and tabulated in table 3. The effect of various control factors in different levels are found out by the following method:

$$MA1 = (1/3)\ (\eta1 + \eta2 + \eta3) = 58.3$$

$$MA2 = (1/3)\ (\eta4 + \eta5 + \eta6) = 59.57$$

$$MA3 = (1/3)\ (\eta7 + \eta8 + \eta9) = 56.06$$

$$MB1 = (1/3)\ (\eta1 + \eta4 + \eta7) = 58.04$$

$$MB2 = (1/3)\ (\eta2 + \eta5 + \eta8) = 57.19$$

$$MB3 = (1/3)\ (\eta3 + \eta6 + \eta9) = 59.02$$

$$MC1 = (1/3)\ (\eta1 + \eta6 + \eta8) = 58.67$$

$$MC2 = (1/3)\ (\eta2 + \eta4 + \eta9) = 57.06$$

$$MC3 = (1/3)\ (\eta3 + \eta5 + \eta7) = 58.54$$

$$MD1 = (1/3)\ (\eta1 + \eta5 + \eta9) = 58.29$$

$$MD2 = (1/3)\ (\eta2 + \eta6 + \eta7) = 58.69$$

$$MD3 = (1/3)\ (\eta3 + \eta4 + \eta8) = 57.27$$

Where

MA1 – effect of factor A at level 1;

MA2 – effect of factor A at level 2;

MA3 – effect of factor A at level 3;

MB1 – effect of factor Bat level 1

MB2 – effect of factor B at level 2

MB3 – effect of factor B at level 3

MC1 – effect of factor C at level 1;

MC2 – effect of factor C at level 2;

MC3 – effect of factor C at level 3;

MD1 – effect of factor D at level 1

MD2 – effect of factor D at level 2

MD3 – effect of factor D at level 3

Table 3. Responses and Calculated Values of Objective Function

	A	*B*	*C*	*D*	**Wear Resistance Index**	*Y*	η
1	1	1	1	1	0.932	932	59.38
2	1	2	2	2	0.734	734	57.31
3	1	3	3	3	0.914	914	59.21
4	2	1	2	3	0.766	766	57.68
5	2	2	3	1	0.927	927	59.34
6	2	3	1	2	1.216	1216	61.69
7	3	1	3	2	0.714	714	57.07
8	3	2	1	3	0.559	559	54.94
9	3	3	2	1	0.644	644	56.177

Table 4 Effect of factors in various levels

Factors	Effect 1	Effect 2	Effect 3
A	58.3	59.57	56.06
B	58.04	57.19	59.02
C	58.67	57.06	58.54
D	58.29	58.69	57.27

The factor effect diagram was plotted for the values of the above table 4 and shown in Fig. 5.

III. RESULTS AND DISCUSSION

- The combination of A2, B3, C1and D2 gives the maximum wear resistance
- The combination of A3, B2, C2 and D3 gives minimum wear resistance
- From the above graph it is also clear that factor A (Powder) has the maximum influence on the responses.

This graph gives the result based on the nine number of tried combination based on Taguchi method . It means there are rest 72 untried combinations .To get the values of these 72 combinations Taguchi suggested the following formula:

$$\eta = \mu + (MA - mu) + (MB - \mu) + (MC - \mu) + (MD - \mu) \quad ...(2)$$

Where, $\mu -$ average of all η

MA, MB, MC, MD – effect of factors in different levels. For example, if any one wants to find out the result of the untried combinations of A1, B3, C2, D1, the following equation number 3 can be generated:

$$\eta_{1321} = \mu + (MA1 - \mu) + (MB - \mu) + (MC2 - \mu) + (MD1 - \mu) \quad ...(3)$$

From the mentioned equation after finding the value of η_{abcd}, one can easily find out the Y value of the untried combination.

A. Surface Plots for Factors Vs Responses

As mentioned earlier, Taguchi method reduced the number of experiments to be performed from 81 to 9. With these 9 values we can find out the factorial design of the 27 combinations by eliminating the factor

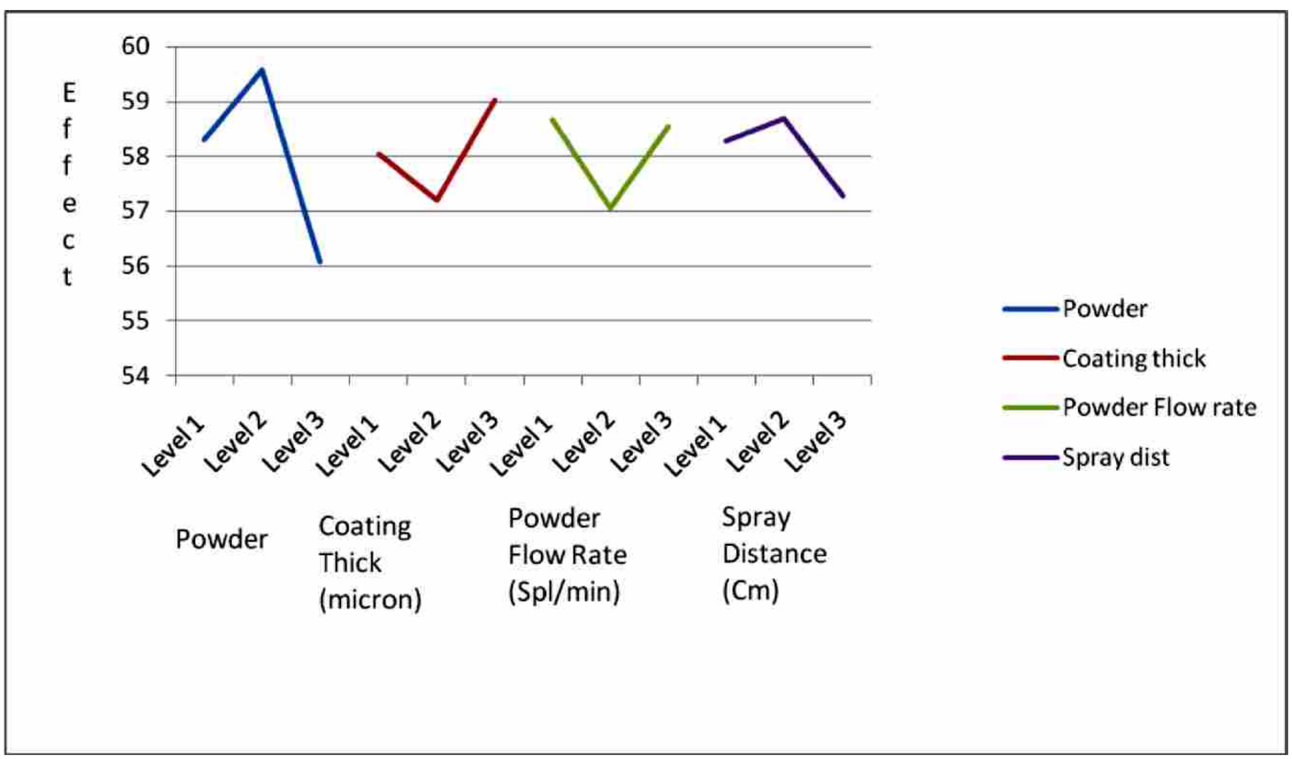

Fig. 5 Factor Effect Diagram

(SPRAY DISTANCE-D) that holds the minimum influence on the result.

The response surface plot curve of all these 27 combinations and the intermediate combinations are depicted in the graphs below table 5.

Table 5 Calculated Wear Index of 27 combinations

	Powder	Coating thick (Micron)	Powder Flow rate (Spl/Min)	Wear Resistance Index
1	WC-12Co	350	600	931.1
2	WC-12Co	350	1000	726.44
3	WC-12Co	350	1400	861.139
4	WC-12Co	450	600	889.61
5	WC-12Co	450	1000	733.66
6	WC-12Co	450	1400	781.09
7	WC-12Co	550	600	978.81
8	WC-12Co	550	1000	813.2
9	WC-12Co	550	1400	913.06
10	WC-10Co-4Cr	350	600	1012.05
11	WC-10Co-4Cr	350	1000	765.59
12	WC-10Co-4Cr	350	1400	997.01
13	WC-10Co-4Cr	450	600	917.69
14	WC-10Co-4Cr	450	1000	762.43
15	WC-10Co-4Cr	450	1400	926.83
16	WC-10Co-4Cr	550	600	1214.78
17	WC-10Co-4Cr	550	1000	941.24
18	WC-10Co-4Cr	550	1400	1116.09
19	Cr_2C_3-25NiCr	350	600	675.62
20	Cr_2C_3-25NiCr	350	1000	561.31
21	Cr_2C_3-25NiCr	350	1400	713.67
22	Cr_2C_3-25NiCr	450	600	558.47
23	Cr_2C_3-25NiCr	450	1000	508.98
24	Cr_2C_3-25NiCr	450	1400	603.53
25	Cr_2C_3-25NiCr	550	600	756.31
26	Cr_2C_3-25NiCr	550	1000	643.95
27	Cr_2C_3-25NiCr	550	1400	745.08

Analysis of response between various factors by Surface Plot Method

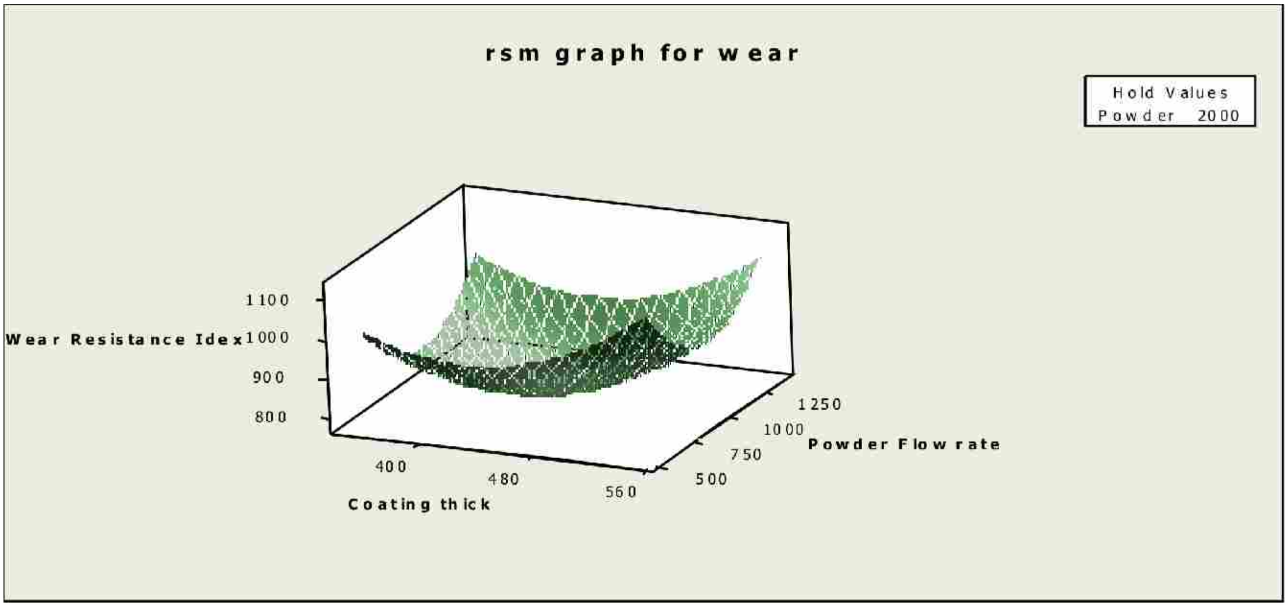

Fig. 6 Surface plot for wear (Different Powder Vs Coating thickness)

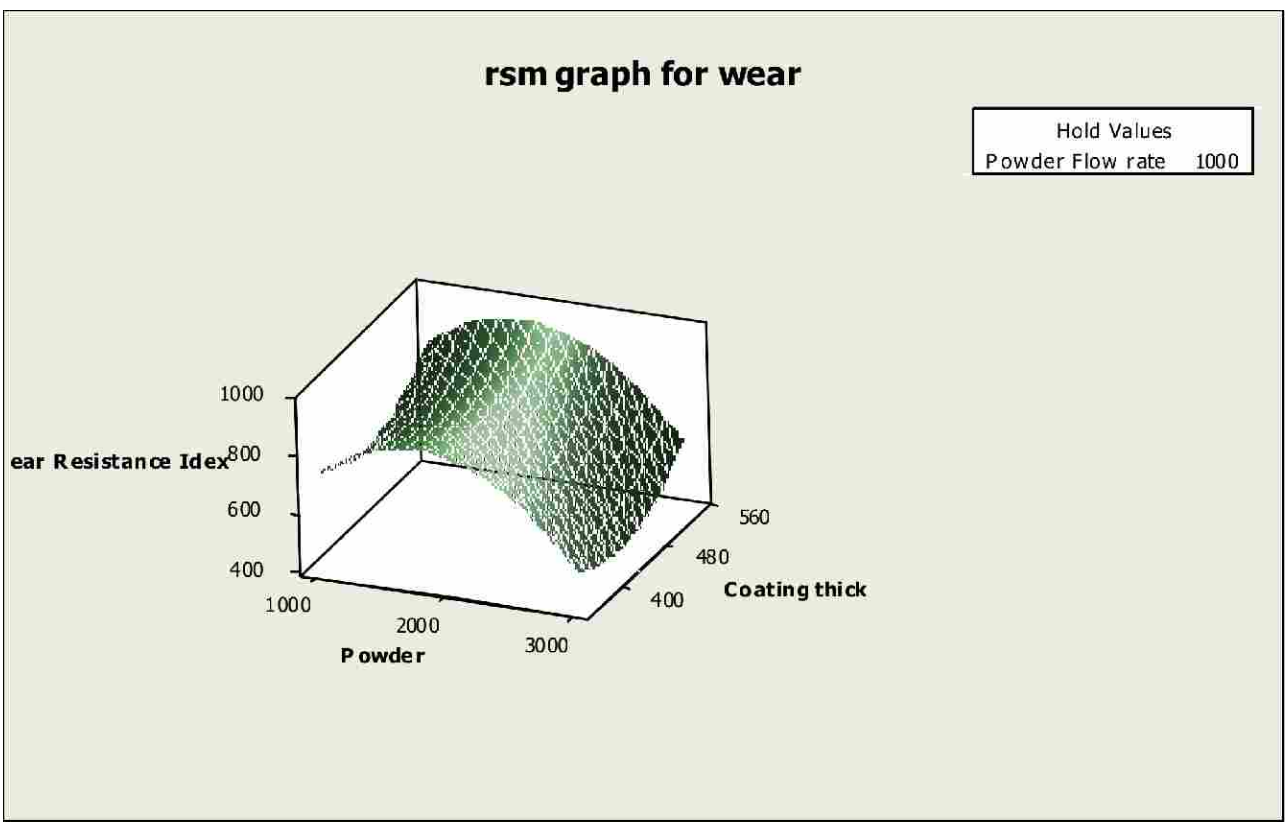

Fig. 7 Surface plot for wear (coating thickness Vs powder flow rate)

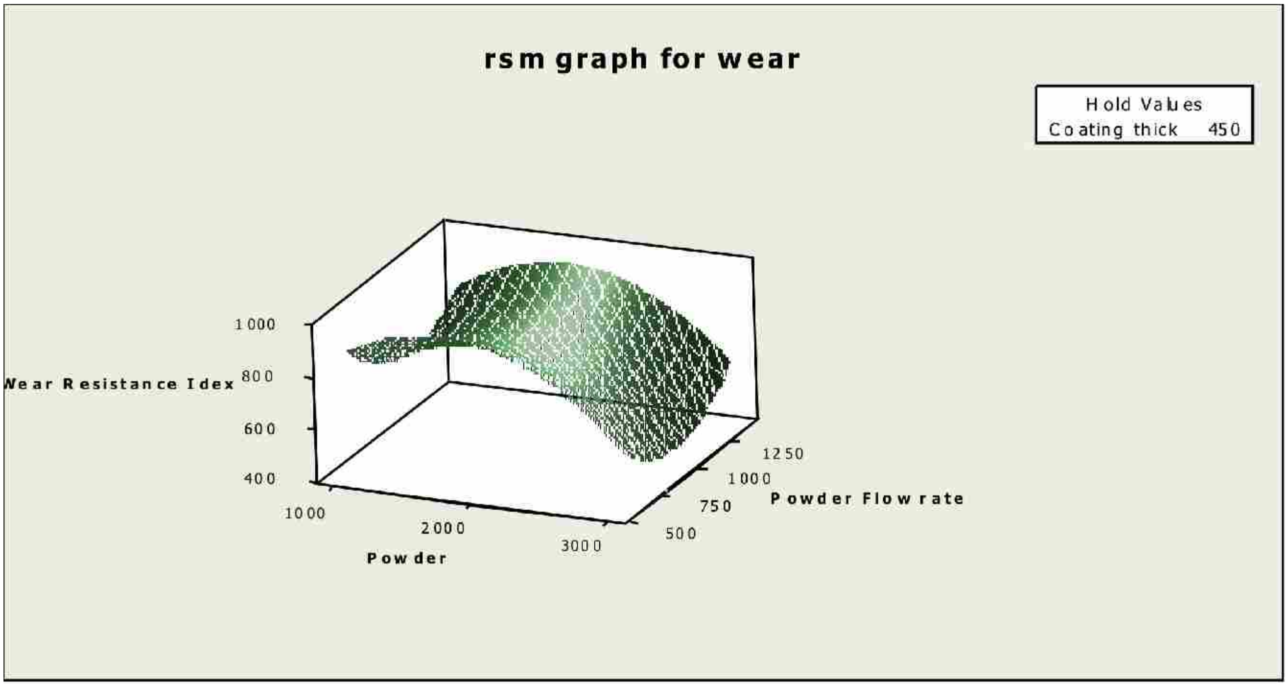

Fig. 8 Surface plot for wear (Different powder Vs powder flow rate)

The surface plots for the interaction between Various Parameters are obtained for the calculated values in table 5

The Figure 6 shows that the wear index for powder 1000 (WC-12Co)reaches nominal value as for all coating thickness, for powder 2000 (WC-10Co-4Cr) the wear index reaches higher value for all coating thickness and powder 3000 (Cr_2C_3-25NiCr)reaches lower wear index value for all thickness. In all powders it was observed that the slight reduction in wear index when the coating thickness of 450micron.

The Figure 7 shows that the wear index as minimum when the coating thickness of 450micron and powder flow rate of 800 spl/m

The Figure 8 shows that the wear index for powder 1000(WC-12Co)reaches nominal value as for all powder flow rate ,for powder 2000(WC-10Co-4Cr) the wear index reaches higher value for all powder flow rate and powder 3000(Cr_2C_3-25NiCr)reaches lower wear index value for all powder flow rate. In all powders it was observed that the slight reduction in wear index when the powder flow rate of 800spl/m.

IV. CONCLUSION

- Taguchi proved to be very efficient method to optimize the process parameters to achieve higher wear resistance property of the coated surface.
- From the factor effect diagram we can conclude that the combination of Powder (WC10%CO4Cr), Thickness (550 micron),Powder flow rate (600 spl/m), Spray distance (170 cm) gave the highest wear resistance property.
- Powder will have the more influencing factor as for as the Wear properties concern.
- Not only the results of tried combination of process parameters could be found out , but also the result of untried combinations can be inferred easily.
- The effects of the intermediate values of different factors are also obtained through the surface plot.

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