Chattopadhyaya, Somnath; Mukhopadhyay, Prithviraj; Santos Vilaca da Silva, Pedro

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AN EXPERIMENTAL INVESTIGATION OF THE YIELD PARAMETERS IN FRICTION SURFACING USING FACTORIAL DESIGN OF EXPERIMENT

Somnath Chattopadhyay*,Prithviraj Mukhopadhyay**, Pedro Vilaça***
* Associate Professor; Mechanical Engineering; Indian School of Mines; Dhanbad, India
** M.Tech Final Year; Department of Mechanical Engineering; Indian School of Mines; India
*** Associate Professor; School of Engineering; Aalto University; Finland

ABSTRACT:

This paper aims to present an experimental study on friction surfacing which involves the coating of Aluminium on Mild Steel substrate. Factorial Design of experiment technique is used to design the experiment systematically. This paper also delineates with the Genetic Algorithm approach to optimize the yield parameters of the process.

Keywords – DOE, Factorial Design of Experiments, ANOVA, MOP

I. INTRODUCTION

With the development of different solid state joining processes, friction surfacing is gradually gaining its importance in modern Manufacturing industries. It is a solid state (non-melting) process of coating different materials on to a substrate. **Figure 1** shows different imputes in Friction surfacing process on which the output parameters depend. The process can be very effectively used for reclamation of worn out engineering components. **Chandrasekaran et al. [1]** used this technique to coat dissimilar materials on to a substrate.

This paper aims at developing the relationship between different input and output parameters using Factorial Design of Experiment technique.

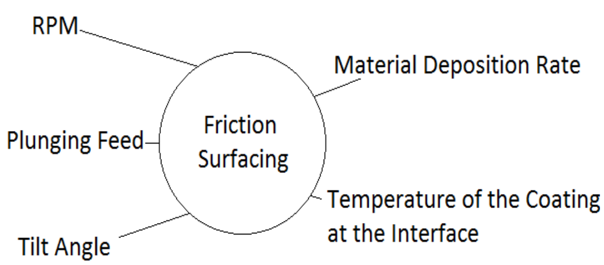

Figure 1: Representation of yield parameters in friction surfacing process.

II. EXPERIMENTAL SETUP

A conventional Lathe Machine is used to carry out this experiment. The tool was held at the live centre of the Lathe machine and was rotated at a certain RPM. The substrate on which the coating is done is mounted on the tool post of the Lathe machine and is made to plunge to the tool at a certain plunging feed. The angle between the tool and the substrate was also considered in this study; so as to investigate the effect of Tilt angle on the output parameters. A thermal Infrared camera was used in this experiment to measure the temperature of the coating at the interface. **Figure 2** shows an Aluminium tool **(MECHTRODE [2])** plunged on to the surface of the Mild Steel substrate.

Fig 2: Aluminium tool plunged on to the surface of Mild Steel.

The consumable rod in made to plunge on to the surface with a plunging feed of say V_x (mm/rev) and the angle between the tool and work piece is say θ (Tilt angle). Different levels of these parameters are set and a relationship is drawn by varying these attributes.

III. DESIGN OF EXPERIMENTS

According to **Douglas C. Montgomery [3],** an experiment is defined as a test or series of tests in which some purposeful changes are made to the input variables of a process or system, in order to identify the changes in the output parameters.

Statistical tools in Design of experiment (DOE) are basically used to carry out the experiment in a structured manner with limited use of the resources that are available. It has been observed that the experiments carried out with Design of experiment are much superior to other approaches. When an experiment involves some errors, statistical methodology is the best way out for analysis of experimental results.

Vitanov et al. [4] presented a study on the application of Response Surface Methodology for the optimisation of Micro Friction Surfacing process and developed the response models.

In statistics, a full factorial experiment is an experiment whose design consists of two or more factors, each with discrete possible values or "levels", and whose experimental units take on all possible combinations of these levels across all such factors. A full factorial design may also be called a fully crossed design. Such an experiment allows the investigator to study the effect of each factor on the response variable, as well as the effects of interactions between factors on the response variable. A full factorial design contains all possible combinations of a set of factors. This is the most fool proof design approach, but it is also the most costly in experimental resources. In full factorial designs, the sample size is the product of the numbers of levels of the factors.

For example, in this study the experiment was designed on the basis of 3^3 Factorial Design of experiment and the total number of runs is 3 x 3 x 3 =27. If the number of combinations in a full factorial design is too high to be logistically feasible, a fractional factorial design may be done, in which some of the possible combinations (usually at least half) are omitted.

Table 2 shows different factors and their corresponding responses as per the experimental design used.

Sl No.	Parameters	Level 1	Level 2	Level 3
1.	RPM of the tool	370	540	800
2.	Plunging Feed	0.16	0.2	0.25
3.	Tilt Angle of the tool	0	1	2

Table 1: Levels of different factors used in the experiment.

RPM	PF	TA	Temperature (^{O}C)	MDR (mg/min)
3	3	1	631.74	26.09
2	1	3	535.84	12.65
1	2	3	352.15	9.63
1	3	1	454.80	12.28
1	1	3	356.96	0
2	3	3	580.76	37.03
2	2	3	556.71	17.32
1	3	2	397.14	11.86
3	2	1	581.53	25.55
2	2	2	558.21	16.47
2	3	1	551.47	18.08
1	2	3	392.20	10.76
1	1	1	335.04	12.21
2	1	1	448.78	10.65
2	2	1	482.41	12.30
1	3	3	432.44	20.65
3	3	3	846.95	41.58
3	3	2	842.58	37.13
3	2	3	736.84	27.39
3	1	2	631.12	15.40
1	2	2	370.76	10.07
2	1	2	532.90	8.66
2	3	2	570.37	15.53
3	1	3	702.10	17.12
1	1	2	356.43	0
3	2	2	705.92	25.07
3	1	1	532.89	16.34

Table 2: Factors and their corresponding responses

Where PF denotes the plunging feed in mm/rev; TA denotes the Tilt angle in degrees and MDR denotes the Material Deposition Rate in mg/min. **Figure 3, 5** and **Figure 4, 6** shows the surface plots and the contour plots of different input parameters with respect to the output parameters respectively.

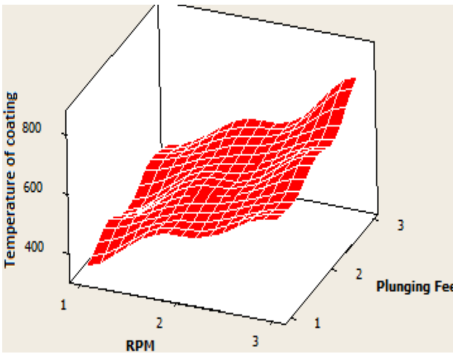

Fig 3(a): Surface Plot b/w RPM, Plunging Feed and Temperature of the coating

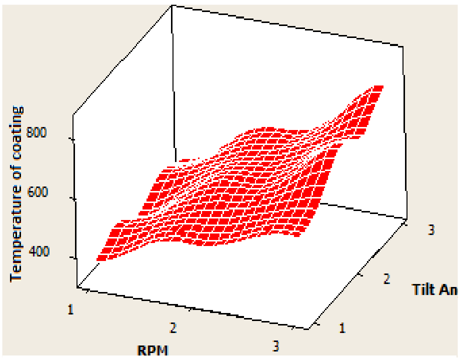

Fig 3(b): Surface Plot b/w RPM, Tilt angle and Temperature of the coating

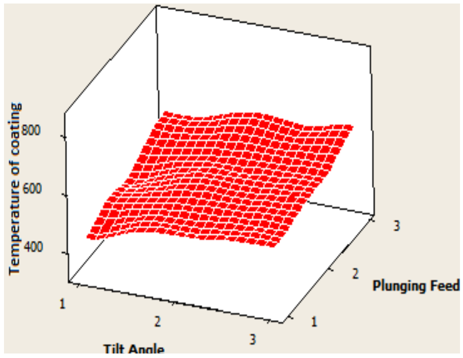

Fig 3(c): Surface Plot b/w Tilt angle, Plunging Feed and Temperature of the coating

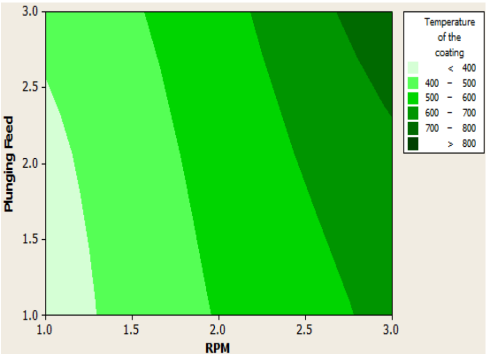

Fig 4(a): Contour plot b/w RPM, Plunging Feed and Temperature of the coating

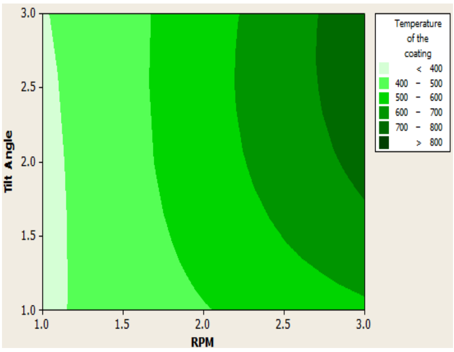

Fig 4(b): Contour plot b/w RPM, Tilt Angle and Temperature of the coating

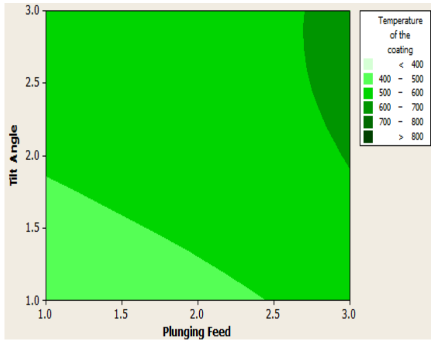

Fig 4(c): Contour plot b/w Tilt Angle, Plunging Feed and Temperature of the coating

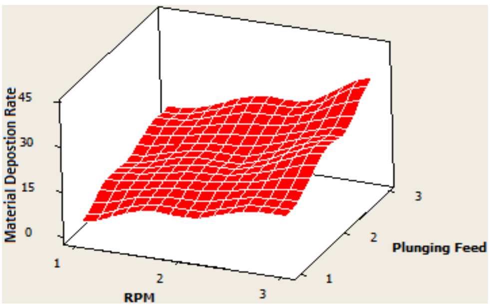

Fig 5(a): Surface plot b/w RPM, Plunging Feed and Material Deposition Rate

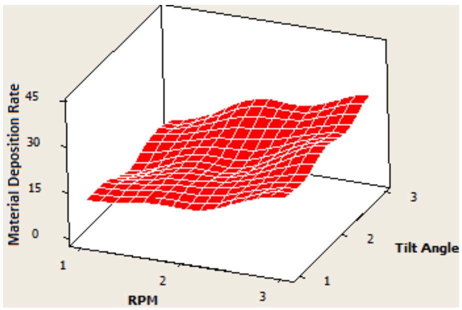

Fig 5(b): Surface plot b/w RPM, Tilt Angle and Material Deposition Rate

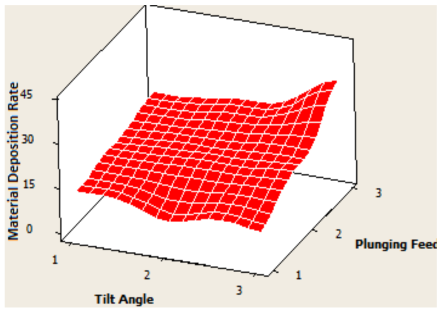

Fig 5(c): Surface plot b/w Tilt Angle, Plunging Feed and Material Deposition Rate

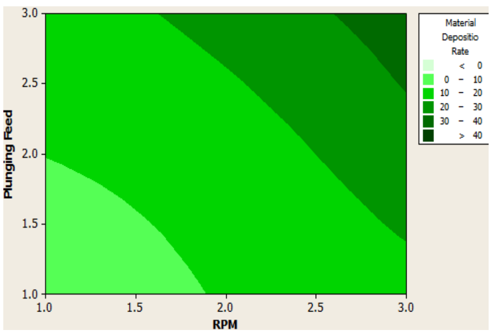

Fig 6(a): Contour plot b/w RPM, Plunging Feed and Material Deposition Rate

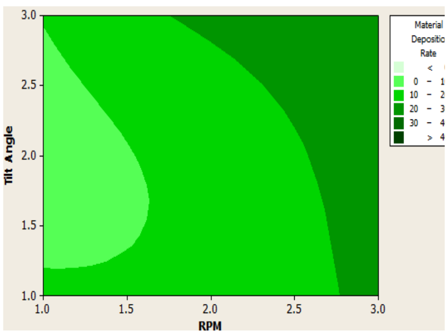

Fig 6(b): Contour plot b/w RPM, Tilt Angle and Material Deposition Rate

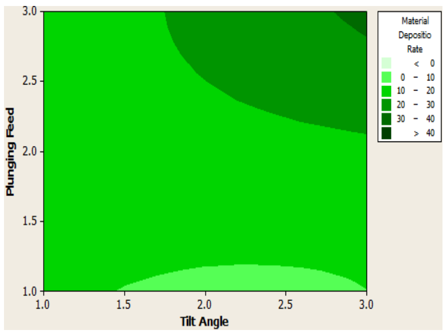

Fig 6(c): Contour plot b/w Tilt Angle, Plunging Feed and Material Deposition Rate

IV. ANALYSIS OF RESULTS

From the above figures it can be protruded that with the increase in RPM, the temperature of the coating at the interface also increases. But, at lower plunging feed, Tilt angle has no appreciable effect on the Temperature of the coating at the interface. From **Figure 6**, it is observed that the Material Deposition Rate increases with the increase in RPM. It was also observed that, relatively a good Deposition Rate is obtained at higher plunging feed with lower RPM of the Mechtrode.

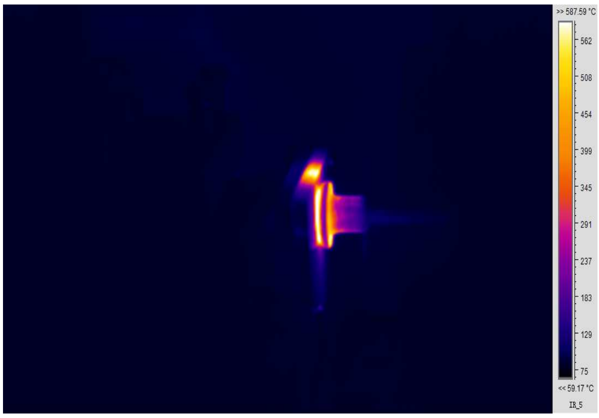

Fig 7: Thermal Image of Aluminum tool plunged on to the surface of Mild Steel

Table 6 and 7 shows the corresponding values of P-Test. From the table it can be concluded that in case of temperature of the coating at the interface RPM, Plunging Feed, Tilt Angle and the interaction between RPM and Tilt angle plays an important role, whereas in case of Material Deposition Rate, RPM, Plunging Feed, Tilt Angle and the interaction between the Plunging Feed and RPM. Equation 1 and 2 represents the corresponding mathematical models for Temperature of the coating at interface and Material Deposition Rate.

$$\text{Temperature of the coating at the Interface} = 243.6390+28.1621*RPM-37.8193*PF+61.9376*TA+1.3730*RPM*RPM+14.8261*PF*PF-23.2924*TA*TA+18.2677*RPM*PF-4.6719*PF*TA+41.6763*RPM*TA \quad \textbf{(1)}$$

$$\text{Material Deposition Rate} = 28.2479-4.1818*RPM-6.4503*PF-20.3731*TA+1.2084*RPM*RPM+0.2292*PF*PF+2.6238*TA*TA+1.9461*RPM*PF+4.3534*PF*TA+1.7342*RPM*TA \quad \textbf{(2)}$$

V. MULTI-OBJECTIVE OPTIMIZATION

According to **Kalyanmoy Deb [5]**, Optimization is a procedure of finding and comparing feasible solutions until no better solution is obtained. Evolution Algorithm is a way for solving Multi objective optimization problems.

In this study, there are two objective functions (Equation 1 and 2) that needs to be optimized simultaneously, such that the values of the objective functions remain within the limits set by the user.

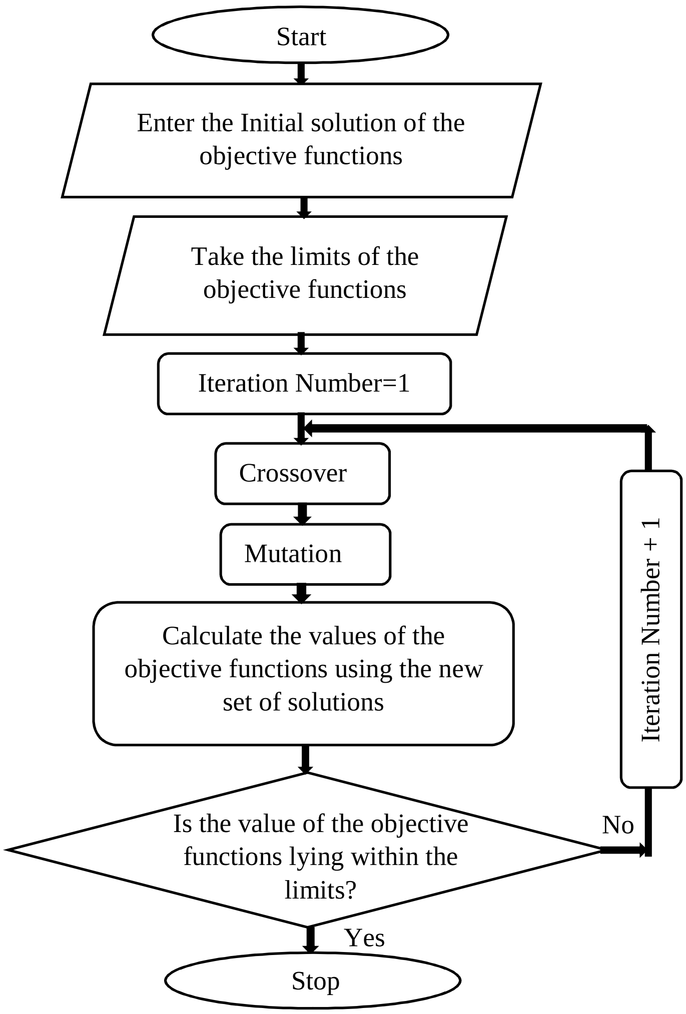

Fig 8: Flowchart for Genetic Algorithm

```
Analysis of Variance for Temperature of the coating, using Adjusted SS for
     Tests

Source                     DF  Seq SS  Adj SS  Adj MS       F      P
RPM                         2  424365  424365  212183  240.45  0.000
Plunging Feed               2   43968   43968   21984   24.91  0.000
Tilt Angle                  2   36192   36192   18096   20.51  0.001
RPM*Plunging Feed           4    7238    7238    1809    2.05  0.180
RPM*Tilt Angle              4   26486   26486    6621    7.50  0.008
Plunging Feed*Tilt Angle    4     372     372      93    0.11  0.977
Error                       8    7059    7059     882
Total                      26  545681


S = 29.7056   R-Sq = 98.71%   R-Sq(adj) = 95.80%
```

Table 6: ANOVA for Temperature of the Coating at the Interface

```
Analysis of Variance for Material Deposition Rate, using Adjusted SS for Tests

Source                     DF   Seq SS   Adj SS  Adj MS      F      P
RPM                         2  1164.36  1164.36  582.18  53.51  0.000
Plunging Feed               2   898.89   898.89  449.45  41.31  0.000
Tilt Angle                  2   136.33   136.33   68.17   6.26  0.023
RPM*Plunging Feed           4    55.79    55.79   13.95   1.28  0.353
RPM*Tilt Angle              4    97.56    97.56   24.39   2.24  0.154
Plunging Feed*Tilt Angle    4   258.16   258.16   64.54   5.93  0.016
Error                       8    87.04    87.04   10.88
Total                      26  2698.13


S = 3.29858   R-Sq = 96.77%   R-Sq(adj) = 89.52%
```

Table 7: ANOVA for Material Deposition Rate

Figure 8 shows the flowchart of Genetic Algorithm approach used in this experiment to optimize the objective functions. In this method, the bad solutions are discarded and a new set of solution is generated that will cause the objective functions to remain within its limit. The value of the mutation rate is obtained from the user and in this case, the value is generally taken to be as 0.15 and the number of iterations is 1000. **Table 8** shows the inputs obtained from the user and **Table 9** shows the output window containing the solutions within the constraints defined by the user. However, if the step size of the parameters taken are very small, it can provide better solutions with higher accuracy.

```
                TA            RPM             PF

Attributes =

                1              1               1

                2              2               2

                3              3               3


Enter the number of iterations: 1000

Enter the maximum value of Temperature: 600

Enter the minimum value of Material
Deposition rate: 20.56

Enter the value of mutation rate: 0.15
```

Table 8: Input taken from the user

```
              RPM       PF        TA
Attributes =
               3        3         1
               2        1         3
Temperature =
  407.1172
  588.0846
Material_Deposition_Rate =
   20.7028
   22.4310
   Time taken to find the solution =
13.91
```

Table 9: Output window showing the solutions

VI. Conclusion

From this study it can be concluded that, RPM, Plunging feed, Tilt angle and the interaction between RPM and tilt angle has a great impact on the Temperature of the coating at the interface of the tool and the work piece. It was also found that at higher RPM and plunging feed the Material deposition rate also increases with the increase in Tilt angle. The Genetic Algorithm approach presented in this study can be used to predict the useful parameters for generating the desired outputs. This method can be extensively used in modern industries to improve the quality of their production.

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