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Improving the Operational Efficiency through Optimization of Process Parameters of Friction Surfacing of Aluminium Alloy 7075 over Mild Steel and Stainless Steel

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Abstract

In the manufacturing and management sectors, the optimization of process parameters—such as rotational speed and axial force in friction surfacing—is essential for ensuring superior quality and cost-effective production. Employing techniques like Taguchi's orthogonal array allows manufacturers to pinpoint the critical factors affecting coating performance, leading to more efficient material utilization and consistent product quality. The method not only enhances manufacturing precision but also strengthens management practices by minimizing waste, reducing costs, and boosting overall operational efficiency. The future of this approach is highly promising, as it facilitates more efficient and adaptable manufacturing processes that can be finely tuned to meet specific production requirements. By continuously refining these parameters, manufacturers can maintain a competitive edge, fostering long-term success and driving innovation within the industry.

Keywords: Cladding; Friction Surfacing; Taguchi Orthogonal Array; Optimization; Coating thickness; Coating Width.

1. Introduction:

Presently, industries are looking for wear- and corrosion resistant coating the reclamation of worn-out parts. They are striving hard to increase the life of the product once the customers start to put the product to use. For producing such a product, the operational efficiency is considered to be one of the important factors. For any process, the operational efficiency should be high. The process of providing metal coatings by depositing metals is termed "cladding." There are many methods available for cladding. Friction surfacing is one such cladding process. It is a method of merging solid states. It is applicable to developing similar and/or dissimilar coatings that provide good mechanical characteristics. It avoids a few of the issue that are connected to the traditional coating techniques where fusion is involved. It is also an environmentally friendly process and provides more energy efficiency. Another major industrial requirement is having the flexibility in changing the process parameters according to the materials used in the friction surfacing process with respect to the suitable applications, and it should be cost effective too. In this connection, the present work concentrates on providing a solid-state cladding by friction surfacing of aluminium alloy 7075 over substrate materials such as mild steel and stainless steel. The effects of process parameters impacts on the mechanical properties of coatings were studied, and the most influential parameters were identified. Until recently, the process of friction surfacing was carried out with the help of special purpose machines. In this work, an attempt is made to perform the process of friction surfacing with the help of a conventional vertical milling machine and process parameters were optimized to improve the operational efficiency.

2. Literature survey:

Literatures that were referred to, with respect to the current work and outcomes is presented below:

In their study, Govardhan et al. (2012) discussed the principle and process parameters involved in friction surfacing techniques and their bonding mechanisms. They also discussed the various factors that must be considered for selecting the process parameters and different approaches available for the conduct of the experiments, and further, they studied various methods of testing the bond quality. They also optimised the process parameters for better output. In their work, Madhusudhan Reddy et al. (2008) studied the wear and corrosion resistance of the surface coating of SiCp reinforced AA 2124 aluminium alloy composite onto the surface of aluminium alloy A356. They characterised the coating using metallography techniques along with dry sliding wear tests and dynamic polarisation testing. They concluded that aluminium alloys can be successfully friction surfaced with any metal matrix composite. Li and Shinoda (1999) conducted underwater friction surfacing experiments. They conducted the experiments with the objective of finding the suitability of friction surfacing for real underwater applications. They attempted to provide some clarification with respect to the effect of the surrounding medium that prevails over the process and its deposits. They concluded that underwater friction surfacing has more efficiency in terms of deposition, which is greater than that of air, after analysing the results with respect to the transverse section of the deposit exhibits a refined microstructure and a homogeneous distribution of hardness. Suhuddin et al. (2012) studied microstructure evolution that happens during the process of friction surfacing with respect to dissimilar aluminium alloys. Khalid Rafi et al. (2010) analysed the effects of transverse travel speed during friction surfacing of austenitic stainless steel on low carbon steel. Janakiraman and Udaya Bhat (2012) studied the formation of composite surfaces that have been developed while friction surfacing of steel with aluminium. Sugandhi and Ravi Shankar (2012) used response surface methodology for optimising the friction surfacing process parameters for coating

AA 1100 aluminium alloy with mild steel as the substrate material. Ashok Kumar and Laxminarayana (2018) used the Taguchi approach for optimising the electrode tool wear in micro-hole machining using EDM and they also studied the tool wear optimization. Sreeharan et al (2022), stated the application of aluminium alloys which realized by many manufacturing processes in which joining processes are inevitable. They also employed Taguchi's orthogonal array for conducting and optimizing the parameters. Hidekazu Sakihama et al. (2003) analysed the rotation speed and the magnitude of pressure that was applied to the subtract from the consumable rod. They studied the effect of surfacing conditions with respect to the characteristics of deposits. They observed that circular patterns appeared on the surface of the deposit because of the rotation of the consumable rod. They used 5052 aluminium alloy as the substrate. They friction surfaced with the help of a fully numerically controlled automated friction welding machine. They concluded that during the friction surfacing process, the rotation speed and the pressure play very important roles in getting the required coating characteristics.

From the literature review that has been done, it has been identified that studying and optimising the process parameters that influence the friction surfacing is very much necessary for providing the required quality coating over the parent material to prevent or reduce corrosion which is required to improve the operational efficiency. In this aspect, the present study was executed in order to investigate the impact of friction process parameters surfacing to assure the quality of the coating by optimizing the same.

3. Experimental work:

The material used is MS A142 and Stainless Steel 403, over which Aluminium Alloy 7075 is coated. The experiments were designed and carried out using one of the statistical design of experiments techniques, the Taguchi L9 orthogonal array. The orthogonal array was selected based on the parameters from the input process the axial force and rotating speed along with 3 levels of each parameter. With the help of the literature reviews and after conducting a few trial runs, the minimum value and maximum values for each input process parameter were fixed. The middle value was fixed as the mid value of the maximum and minimum values. Experiments were conducted on the vertical milling machine shown in fig. 1 as per the design table.

From the specimen shown in fig. 2, output responses viz. coating thickness and coating width were measured. After measuring the output responses, the S/N ratio with respect to the larger the better criteria was calculated by using the equation

$$-10log\left(\frac{1}{n}\sum_{i=0}^{n}\frac{1}{y_i^2}\right)$$

and are tabulated in tables 1 and 2. Table 1 shows the output responses of aluminium alloy 7075 with a friction surface applied to mild steel is shown in Table 2, while aluminium alloy 7075 is applied to stainless steel.

After calculating the S/N ratios, response tables for both coating thickness and coating width for friction surfaced aluminium alloy 7075 over mild steel and aluminium alloy 7075 over stainless steel were developed and are given as table nos. 3, 4, 5, and 6, respectively.

FIG. 1 (a) Vertical Milling Machine – Experimental Setup (b) Tool (C) Sample Specimen

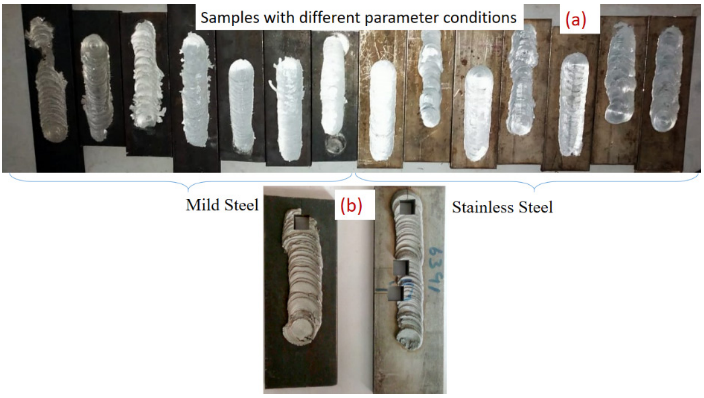


FIG. 2 Specimen – Friction Surfaced (a) samples with different parameter condition (b) prepared test specimen

From the above table, it is found that rotational speed influences the coating thickness more than axial force, and the optimised parameters were also found to be rotational speed of 400 rpm and axial force of 4 N, which can be validated with the actual input parameters used for conducting the experimental run no. 1.

TABLE 1. Output responses of friction surfaced aluminium alloy 7075 over mild steel

Exp. No.	Rotational Speed (rpm)	Axial Force (N)	Coating Thickness (mm)	Coating Width (mm)	S/N ratio Coating Thickness	S/N ratio Coating Width
1	400	4	8.53	29.3	18.62	29.34
2	400	6	8.27	29.7	18.35	29.46
3	400	8	8.15	29.4	18.22	29.37
4	800	4	6.84	26.7	16.70	28.53
5	800	6	6.72	26.4	16.55	28.43
6	800	8	6.59	26.1	16.38	28.33
7	1200	4	7.15	27.3	17.09	28.72
8	1200	6	7.07	27.8	16.99	28.88
9	1200	8	7.03	27.2	16.94	28.69

TABLE 2. Output responses of friction surfaced aluminium alloy 7075 over Stainless Steel

Exp. No.	Rotational Speed (rpm)	Axial Force (N)	Coating Thickness (mm)	Coating Width (mm)	S/N ratio Coating Thickness	S/N ratio Coating Width
1	400	4	7.54	27.7	17.55	28.85
2	400	6	7.47	27.4	17.47	28.76
3	400	8	7.13	27.3	17.06	28.72
4	800	4	5.87	24.6	15.37	27.82
5	800	6	5.68	24.4	15.09	27.75
6	800	8	5.57	24.3	14.92	27.71
7	1200	4	6.68	26.5	16.50	28.46
8	1200	6	6.39	26.3	16.11	28.40
9	1200	8	6.13	26.1	15.75	28.33

TABLE 3. Response table for S/N ratio of coating thickness (Aluminium alloy over Mild Steel)

Levels	Rotating Speed (rpm)	Axial Force (N)
Level 1	18.40	17.47
Level 2	16.54	17.30
Level 3	17.00	17.18
Delta	1.86	0.29
Rank	1	2
Optimized Parameters	**400**	**4**

TABLE 4. Response table for S/N ratio of coating width (Aluminium alloy over Mild Steel)

Levels	Rotating Speed (rpm)	Axial Force (N)
Level 1	29.39	28.86
Level 2	28.43	28.92
Level 3	28.77	28.80
Delta	0.95	0.13
Rank	1	2
Optimized Parameters	**400**	**6**

From the above table, it is inferred that a rotational speed of 400 rpm and an axial force of 6 N were the optimised parameters. This is validated with the actual input parameters used for conducting the experimental run no. 2. Further, it is observed that rotational speed influences more than axial force with respect to coating width.

TABLE 5. Response table for S/N ratio of coating thickness (Aluminium alloy over Stainless Steel)

Levels	Rotating Speed (rpm)	Axial Force (N)
Level 1	17.36	16.47
Level 2	15.13	16.22
Level 3	16.12	15.91
Delta	2.23	0.56
Rank	1	1
Optimized Parameters	**400**	**4**

From the above table, the optimised parameters were found to be rotational speed of 400 rpm and axial force of 4 N, which can be validated with the actual input parameters used for conducting the experimental run no. 1. Here also, with respect to friction surfacing aluminium alloy over stainless steel, it is observed that rotational speed influences coating thickness to a greater extent than that of axial force provided to the rod.

TABLE 6. Response table for S/N ratio of coating width (Aluminium alloy over Stainless steel)

Levels	Rotating Speed (rpm)	Axial Force (N)
Level 1	29.39	28.86
Level 2	28.43	28.92
Level 3	28.77	28.80
Delta	0.95	0.13
Rank	1	2
Optimized Parameters	**400**	**6**

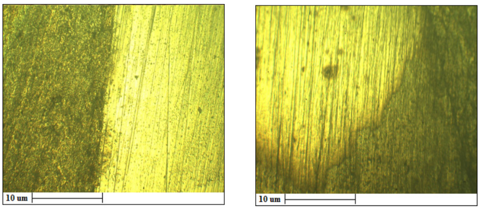
From the above table, it is observed that a rotational speed of 400 rpm and an axial force of 6 N were the optimised parameters. This is validated with the actual input parameters used for conducting the experimental run no. 2. In addition to finding the optimised parameters, from the table, it has been noted that rotating speed influences the breadth of the coating when compared with the axial force of the rod.

4. Results and discussions

4.1 Microstructure Study:

A microstructure study was conducted over the optimised parameters for the coating width for both the friction surfaced aluminium alloy over mild steel and stainless steel. It was conducted with respect to 200 X magnification.

Interface micrographs of Al 7075 over mild steel and stainless steel are shown in Fig. 3. Interface regions for different regions can be identified as defect free. At minimum rotational speed, more volumes of Al 7075 metal are formed on the base metal due to its prolonged plastic deformation. The coating thickness gets thinner for heavy axial force with medium rotational speeds due to the effective distribution of plasticized metal. This further resulted in a clear coating-substrate interface without any un-joined regions. The interface corresponding to higher axial force with medium rotational speed shows well bonded coatings with good bond integrity.



(a) (b)

FIG. 3. Optical micrograph at the interface (a) over Stainless Steel (SS) (b) Over Mild Steel (MS)

4.2 SEM and EDX Analysis:

From the SEM images given in fig. 4, it is observed that there are uniformly distributed aluminium alloy particles found throughout the coating, which can be correlated with the bonding strength, when aluminium alloy was friction surfaced with mild steel and stainless steel.

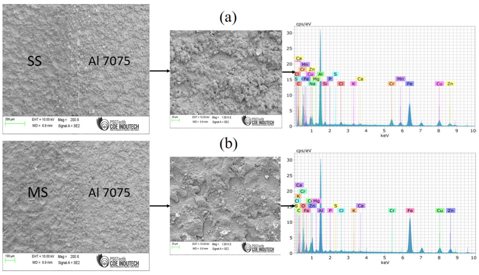


FIG. 4 SEM and EDX images of Interface region (a) over stainless steel and (b) Over mild steel

4.3 Microhardness

Fig. 5 shows the Vickers microhardness distribution in the direction perpendicular to the substrate-coating interface. The microhardness of the substrate and coating near the interface region shows higher hardness as compared to the base metal. The combination of heat energy and plastic deformation decreases the grain size of the metal and will lead to an increase in the hardness [Ghader Faraji et al., 2018]. In the interface region, the hardness value is increased by around 10% higher than both stainless steel and mild steel.

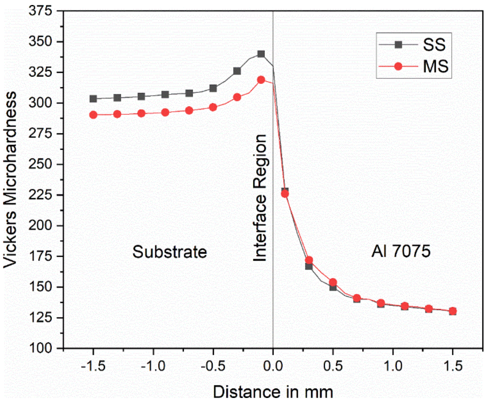


FIG. 5 Microhardness survey across the interface

5. Conclusions

Because coating is expected to increase the life of any part and can be used to repair worn out or damaged parts, the process parameters used to provide coatings must be examined. In this regard, friction surfacing, one of the cladding processes used to provide coating, is considered in this work. In this work, aluminium alloy 7075 was surface finished with mild steel as well as over stainless steel. For carrying out the experimental work, an L9 orthogonal array was used. Rotational speed and axial force were considered as input process parameters, and coating thickness and coating width were considered as output responses. From this experimental study, the following conclusions were derived after subjecting them to a few investigations, viz., microstructure study, SEM, and EDX analysis: Rotational speed influences coating thickness and coating width more than the other process parameter, the axial load, Optimized parameters found for coating thickness when the aluminium alloy 7075 friction surfaced over mild steel are 400 rpm and 4 N, and for coating width it is 400 rpm and 6 N. Similarly, for coating thickness when the aluminium alloy 7075 friction surfaced over stainless steel is 400 rpm and 4 N, and for coating width it is 400 rpm and 6 N. When optimised parameters were used for friction surfacing, it was observed that finely distributed aluminium alloy particles were uniformly distributed throughout the coating when ensuring the proper bonding strength. These ensures that there is improvement in operational efficiency as compared to earlier non-optimized methods.

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