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REVIEW ARTICLE

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INVESTIGATION OF ALLOYS AND ANALYSIS OF COATING PARAMETER IN FRICTION SURFACING: A TECHNICAL REVIEW

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ABSTRACT

The variety of material combination have been deposited by friction surfacing, mainly Aluminium and stainless steels. Nickel-chromium combination, stellite alloys have been investigated, which also consists of metal matrix composites. Friction surfacing is the solid phase technique which deals with increasing industrial application of engineering worn out parts, corrosion resistance.

On starting with short introduction, this review paper presents the detailed description of microstructure analysis, types of alloys as well as methodology implemented. From parameter optimization, increasing traverse speed results thinner coatings. The alloy investigation shows that mild steel can be readily coated on aluminium. Coatings prepared under water produce 20% thinner those prepared in air.

The present review paper provides a broad view throughout basics of friction surfacing and most emerging technology development which promotes both technical and theoretical aspects for new researchers and industrial sector seeking for new coating alternatives.

Key words: Friction surfacing, parameter optimization, coating, microstructure.

1. INTRODUCTION TO FRICTION SURFACING

Friction surfacing is a solid state technique for depositing materials including tool steels, stainless steels, titanium, satellite, aluminium and other alloys to improve the performance of a coating surface.

The process involves rotating a solid consumable rod with one of its ends pressed hard against a substrate material. Heat is generated at the tip of the consumable rod, which produces plasticized layer. Traverse movement of the substrate, relative to the rotating consumable, deposits this melted material on to the substrate.

Hence there is no melting of the substrate material and therefore no disturbance of the substrate into the deposit. The composition of the deposit is the same as that of the consumable.

The deposit has good mechanical strength and adherence. The interface region usually remains intact, even after resisting force or loads equal to the ultimate tensile strength of the fragile material. However, the bond quality at the edges of the deposit is normally poor, and these areas are to be removed. With high strength surfacing materials, the thickness of the deposit is little. The surface appearance depends on the material deposited, and the parameters used.

Friction surfacing is a solid phase process, which is most need for alternative coating in industry. Special combinations of material properties can be achieved by friction surfacing. Thus it reduces usage of more expensive or strategic materials.

The process has been unmitigated to deposit metal matrix composites (MMCs), combinations of various alloy which can be both used for rod and substrate. In MMC, The material of the bar becomes the matrix, with the hard particles distributed throughout it.

2. Identification of process parameter

Friction surface welding falls into numerous challenging parameters. The variables are classified into two types, input and output parameters. The relationship between input and output variables were clearly explained by Vitanov et al. (2010). The input parameters are identified as axial force, rotational speed of rod and traverse speed of substrate. The bonding strength and coating thickness were the most provoking output parameter. The stellite 6 material is coated on stainless steel 316. Response surface methodology is used to optimize the relationship between input and output parameters. Theoretical regression model was developed to express the study about process parameters. Higher the level of velocity ratio produces good coating quality. But increase in feed rate reduces the quality of coating. While reaching the peak temperature during the process was obtain for values of input parameter resulting poor coating quality. Further empirical investigations could benefit better, since the relationship between process variable were non linear.

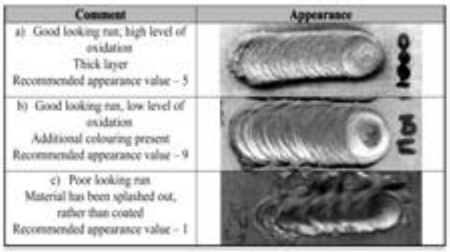
The input parameters constitute a major role in coating and bonding strength. A study about impact of input parameters (axial load, rotational speed of rod and traverse speed of substrate) was reported by Khalid Rafi et al. (2010). Stainless steel 310 is plasticized on low carbon steel. Coatings were performed with different traverse speed. Bending tests were carried out to notify the bonding strength. It was identified that thinner coatings and high bonding strength resulted with higher traverse speed. Incase lower traverse speed more amount of heat is transferred to substrate resulting in wider heat affected zone (HAZ). Table 1 suggested the input parameters to achieve fine coating are summarized.

Table 1: Input parameters to achieve fine coating

Axial load [kN]	Rotational speed [rpm]	Traverse speed [mm/s] (Varied from 1.2 to 5.6)	Thickness [mm]
10	800	1.2	3
10	80	5.6	1.2

Beyond the traverse speed of 5.6 mm/s, a regular coating was not attained due to discontinuous distribution of plasticized metal.

The output parameters can be classified briefly into two sectors, on-line measurable and on-line non-measurable. On-line measurable parameters (friction torque M, applied force F) were readily observed and measured as not as on-line non-measurable parameters (bond width, bond strength, coating thickness). In order to meet the successful requirement set by the non-measurable group of parameters in an online feedback, it should be bonded in a relationship with measurable parameters was dealt by Voutchkov et al. (2001). The optimization method of on-line non-measurable parameters can be branched into three main types, visual optimization, applications of mathematical models and use of intelligent techniques. In visual optimization, the appearance of run and measurement of coating thickness and bond width are investigated visually. At the end of the experiment run is declined a number between 0 (no coating) to 10 (ideal smooth coating). The good looking run with low level of oxidation can recommend a high appearance value, as shown in Fig. 1.



Comment	Appearance
a) Good looking run; high level of oxidation Thick layer Recommended appearance value - 5	
b) Good looking run, low level of oxidation Additional colouring present Recommended appearance value - 9	
c) Poor looking run Material has been splashed out, rather than coated Recommended appearance value - 1	

Fig. 1. Numbering of runs based on visual optimization.

Mathematical model uses a least square method to develop second order polynomial regression (r) to represent thickness, width and bonding strength. The r value closer to 1 can be satisfactory model. The values of r are listed in Table 2.

Table 2 : Values of r in mathematical model

Value of regression coefficient	Coating thickness	Bond width	Bond strength
r	0.85	0.83	0.56
r value should be greater than 0.95 consider as satisfactory model			

Use of intelligent technique implements a vast technology called "Neural networks". The corresponding values of r were summarized in Table 3. Although the neural networks show better results than conventional regression models, sometimes it goes unpredictable.

Table 3: Values of r in neural network method

Value of regression coefficient	Coating thickness	Bond width	Bond strength
r	0.96	0.95	0.75

<table>
<tr><td rowspan="2">Input parameter</td><td>Rotational speed [rpm]</td><td>Axial force [N/mm^2]</td><td colspan="2">Traverse speed [mm/s]</td></tr>
<tr><td>14</td><td>2500</td><td colspan="2">16</td></tr>
<tr><td rowspan="2">Deposit geometry</td><td colspan="2">Coating thickness[mm]</td><td colspan="2">Coating width [mm]</td></tr>
<tr><td colspan="2">0.89</td><td colspan="2">20.22</td></tr>
<tr><td colspan="5">Since values of r were probably more than r, a satisfactory model</td></tr>
</table>

To achieve the good deposit geometry (coating thickness and coating width) it should be bounded in an empirical relationship with friction surfacing parameters (rotational speed, axial force, and traverse speed) which was deeply explained by Sugandhi and Ravishankar (2012). Friction surface parameters were optimized using response surface methodology (RSM) to attain minimum thickness and maximum width. In this paper, aluminium alloy is coated on mild steel. The development of experimental design matrix is formed by using RSM technique and response dictated by design matrix was recorded. The empirical relationship was developed to obtain sufficient coating thickness and width. The effect of process parameters on deposit geometry are presented in Table 4.

Table 4 : Effect of process parameter on deposit geometry

Input parameters	Effects of deposit geometry	Reason
Rotational speed	Greater Thickness and lesser width with increase of rotational speed	Increased rate of deformation of consumable rod
Axial force	Thickness is decreased with increase of axial force	Similar to rotational speed
Traverse speed	Width tends to decrease	Effect of traverse speed is limited

Predicted deposit geometry values were obtained from response surface methodology. The values were verified using Minitab software and optimized in Table 5.

Table 5

Optimum conditions

The quality state variables (coating thickness, bonding strength) are most challenging parameter which should be optimized. The friction surfacing process parameters were combined with intelligent modeling technique which was proposed by Vitanov et al. (2005). The functional relationship between process parameter and state variables on combined with fuzzy logic technology, some interpretations were derived. Axial force is directly proportional to bonding strength since if more force applied results in increase of bonding strength. The coating thickness reduces with increase of force. On accounting with traverse speed, it increases fall out with reduction of coating thickness, bonding time as well as bonding strength. Thus, the further investigation should be focus on traverse speed to achieve better bonding strength.

The intelligent system has been used for parameter selection which was reported by Vitanov and Voutchkov (2005). The appropriate mathematical model was developed and optimization of parameter carried out. It includes new frame of artificial intelligence with real time feedback system. The empirical model was developed based on control variables and quality parameters. Development of interference mechanism engine logic was developed to obtain desired values for quality variables. Although the measurement and data analysis technique has been developed, further improvement requires in development of mathematical model.

The traverse speed has greater influence on coating thickness. Special investigation on traverse speed and coating thickness was implemented by Sekharbabu et al. (2013). In this paper, D2 tool steel mechtrode was coated on low carbon steel. Wear performance were investigated using Pin-on-Disk wear tests. The hardness obtained around 700Hv. The effect of traverse speed is shown in Table 6. Among various alloy systems, ferrous alloy (high speed steel, tool steel, stainless steel) combination would be perfect for friction surfacing. The combinations of ferrous and non ferrous material, (both rod and substrate) would be promising as it require wide-range of parameter optimization. Thus by increasing traverse speed of substrate gave thinner coating and promote better bonding strength.

Table 6: Effect of traverse speed on thickness

Traverse speed [mm/s]	Thickness [mm]
3	0.5
2	0.8
1	1.05
0.2	2.05

3. Investigation of alloy types

3.1. Steel

Steel has greater influence in friction surfacing process. Various types of steel have been used for both consumable rod as well as substrate material. Ramesh puli et al. (2011) has proposed the coating martensitic stainless steel on low carbon steel (0.13% of carbon). Single track coating was established. Coating microstructures were by scanning electron microscope and X-ray diffraction. Bend and shear tests were taken to indicate the coating or substrate bonding. Comparison of friction surfaced coating and ASTM A263 clad plate was depicted in Table 7. It is possible to utilize friction surfaced coating in an environment for both wear and corrosions safety.

Table 7: Shear and bending test comparison

Test	Friction surfaced coating	ASTM A263 Clad plate
Bending test [HV]	460	260
Shear test [MPa]	380	140

It is found that friction coated microstructure tends more hardness than clad plate.

Ramesh Puli and Janaki Ram (2012) reported the dynamic recrystallization of friction surfacing in stainless steel coatings. Austenitic stainless steel was surfaced on mild steel. The coating was investigated by electron backscattered diffraction and transmission microscopy. More amount of temperature is transferred to heat affected zone results in serious grain size defect. Such a case, the necessary cooling rate should be provided by optimizing dwell time. The scans were conducted at three different places listed in Table 8.

Table 8 : Grain size improvement in friction surfaced coatings

Locations	Grain size [μm]
Coating/substrate interface	4.8 ± 1.5
Middle of the coating thickness	6.4 ± 2.3
Near the coating surface	9.4 ± 3.2
Dwell time = 30seconds preferred	

3.2. Stellite

The evolution of satellite in friction surfacing was plotted out by Prasad Rao et al. (2012). Satellite 6 rod was coated on steel material (0.13% C). In this paper, comparison of friction surfacing with gas tungsten arc welding (GTAW), plasma transferred arc welding (PTAW) and cast rod. Hardness tests were shown in Table 9. Among four, friction surfacing (using satellite 6) shows better hardness because of good chemical homogeneity. More closely distributed carbide particles were observed in friction surfacing than GTA and PTA coatings and cast rod. This shows the reason why friction surfacing showed higher hardness than others.

Table 9: Hardness comparison

Methods	Hardness [HRC]
Friction surfacing (satellite 6)	53
PTAW	44
GTAW	49
Cast rod	44

3.4 Aluminium alloys

Most over friction surfacing are optimized for reclamation of worn out engineering components. The impact of aluminium combinations in friction surfacing was presented by Ashok kumar and Laxminarayana (2014). Aluminum was plasticized on mild steel material substrate. Hence this friction surfacing has been performed in vertical CNC machine. Bending test was conducted in universal testing machine and breakage of material was detected listed in Table 10. As aluminium has quick melting state due to its high thermal conductivity, necessary cooling is introduced. It was found that good bonding has been achieved with no defects.

Table 10: Breakage detection

Load [N]	Displacement [mm]
52000	18.5
Material breakage occurs beyond these values	

The series combination of steel and aluminium was exposed by Margam Chandrasekaran et al. (1997). (i) inconel, tool steel, titanium and aluminium rods coated on mild steel substrate and (ii) mild steel, inconel, stainless steel rods coated over aluminium substrate. It was found that inconel and tool steel can be deposited onto steel because it forms dense stronger coating. Titanium could not be coated onto mild steel owing to its high degree of plasticity. So, necessary pretreatment can be given to obtain desired level of coating. In series (ii) combination, inconel and mild steel can be deposited on to aluminium substrate while stainless steel possess some intermetallic compound formation with aluminium. Due to poor adhesion of aluminium with substrate it was not successful. Mild steel can be readily plasticized onto aluminium substrate because of low hardening and plasticizing temperature results in better bonding. Hence it require low pressure and speed for coating.

4. Additional methodology used

4.1. Cavitation

The components in seawater are seriously affecting by corrosion. In order to overcome the challenges against corrosion NiAl-Bronze alloy was selected and investigated by Stefanie Hanke et al. (2011). Since those combinations were selected owing to its good resistance against corrosion erosion (e.g. for ship propellers). The samples were prepared and surfaced in distilled water. Cavitation mechanism were characterized by optical and electron microscope. Layers prepared under water are 20% thinner those prepared in air. The wear behavior of both coated and untreated substrate material was observed by calculating average wear rate in period between incubation time (period in which no loss can be detected) and experiment time. Table 11 summarizes the wear rate of samples tested. Samples coated by friction surfacing have an improved resistance against cavitation erosion in distilled water when compared to the untreated material.

Table 11: Wear rate

Samples	Wear rate [μg/min]
Friction surfaced layer	11±6
Untreated substrate	20±7

Friction surfacing of Cr60Ni40 alloy system was developed by Hanke et al. (2012). The Cr60Ni40 alloy combination was coated on Nimonic 80A material substrate. The cavitation tests were carried out to analyze the wear performance. Coating of brittle material (Cr60Ni40) over ductile material (Nimonic 80A) was achieved. Improved wear resistance rate than normal substrate. Hardness obtained in coating material can ranges from 420-550 HV. The wear loss during the process is shown in Table 12. Although void free and multiple coatings can be possible, the molecular bonding suffers more by cavitation. It was later equalized by solid solution hardening.

Table 12: Effect of wear obtained

Timing [min]	Impact and wear [mg/min]	
Upto 120	Steady wear	
After 120	Microstructure leads to worn out	
After 180	Formations of less cracks and pull outs	
After 360	Wear formed lower than cast and heat treated samples	
After 420	Coating	0.013
	Cast & heat treated	0.037

4.2. Additive manufacturing

Additive manufacturing is the layer by layer production technology of three dimensional parts controlled by computer. The current paper dealt with additive manufacturing in which material addition by friction deposition similar to surfacing was reported by John Samuel Dillip et al. (2011). Tensile tests were carried out and compared between original stainless steel rod and friction deposited specimen. Friction deposition results better than original standard rods. Parts produced using this technology suffers from serious residual stress. Therefore further investigation is needed to control the layer thickness for reducing stress.

4.3. Composite combinations

Composite material enhances it surveillance in friction surfacing technology. The metal matrix composite coating performed on aluminium silicon alloy was demonstrated by Madhusudhan Reddy et al. (2009). In order to develop good wear and corrosion resistance metal matrix (SiC_p) reinforced composite was plasticized on aluminium silicon alloy combination. Wear rates were conducted on four types of samples and listed in Table 13. Improved wear rate was identified in metal matrix composite coating with aluminium silicon alloy (AA 2124 SiC_p).

Table 13: Wear rate performance

Material	Wear rate [mm s^{-1}]
A356 Al-Si alloy in cast condition	0.216
A356 Al-Si alloy in T6 condition	0.103
AA 2124 SiC_p MMC	0.0197
AA 2124 SiC_p MMC Coating	0.003

The combination of titanium alloy friction surfacing with aluminium metal matrix was reported by Madhusudhan Reddy et al. (2011). It was found that titanium alloy could be friction surfaced with MMCs for first time. The improvement in wear properties could be noted. Strong bonding between the titanium alloy and substrate material (aluminium metal matrix composite) may be attributed due to the formation of nanocrystalline layer at interface and interdiffusion of elements of titanium.

5. Micro-structural analysis

Most microscopic images have been scanned by scanning electric microscope (SEM) and X-ray diffraction microscope. Microstructural analysis of tool steel H13 in friction surfacing was explained by Khalid Rafi et al. (2011). Microstructure and micro hardness were analyzed using scanning electron microscope. The grain size observed from the top of the surface interface lies between 2 to 10 μm. In addition, the coated tool steel deposit showed higher hardness of 740 HV. SEM scans in Fig. 2 showed the coating of top surface microstructure includes (a) advance side, (b) retreating side, (c) center.

The presence of carbide particle decreases the friction between rod and substrate material. Adequate cooling rates can be provided to prevent carbide particle precipitation.

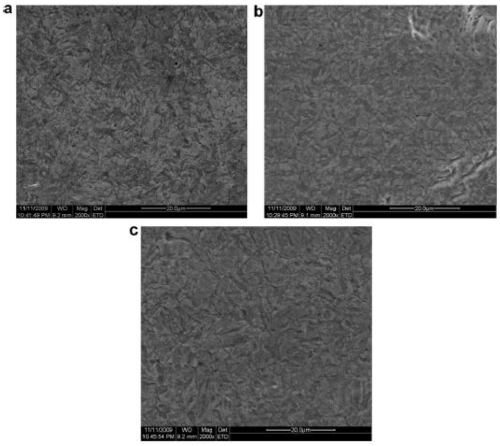


Fig. 2. (a) advance side, (b) retreating side, (c) center.

Friction surfacing of stainless steel and tool steel over mild steel was reported by Khalid Rafi et al. (2010). Microstructural analysis was carried out by optical and scanning electron microscope. Shear tests and bending tests were conducted to evaluate integrity of coating. Parameters used were listed out in Table 14. Various types of images were optimized by SEM showed in Fig. 3. Hardness obtained in friction deposit (780 HV) higher than base material. Shear tests were conducted and shear strength of stainless steel (340 MPa) and tool steel (223 MPa). Since the grain bonding strength changes from metal to metal resulted in parameter variation.

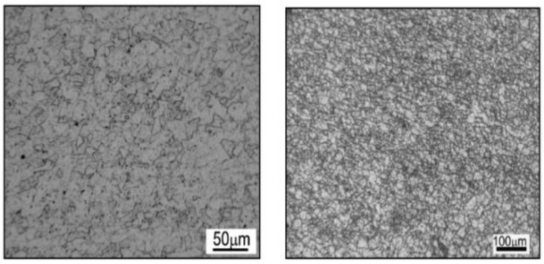


Fig. 3. Stainless steel and Tool steel deposit microstructure

Table 14: Parameters used

Parameter	Mechtrode speed [rpm]	Axial pressure [kN]	Feed rate [mm/s]
Coating			
Stainless steel	2000	5	2.4
Tool steel	800	10	4

Single and multi tracking coating were developed in friction surfacing was reported by Ramesh Puli and Janaki Ram (2012). Martensitic stainless steel was coated onto low carbon steel. Hardness and shear tests were carried out. Hardness of friction surfacing (590 ± 10 HV) was somewhat lower than heat treated material (650 ± 12 HV). Microstructure images were showed in scanned electron microscope plotted in Fig 4. In other case, shear strength of friction surfaced coating (450 ± 20 MPa) was higher than normal clad plate (140 MPa). Further investigation has to be analyzed in mechtrode positioning since it is one of the critical parameter.

6. Summary

From the above literature surveys, it is concluded that single and multi coating can be possible with fine grain size. The micro structural analysis can be performed using various types of microscopes. Artificial intelligent technology can be preferred in FS welding to enhance optimum output variable range. Different types of investigations like bending, shear, wear and corrosion test can be performed. Necessary cooling rate can be given by allowing suitable dwell time. In Cavitation method, improved wear resistance is observed than normal substrate. Three main parameters (rotating speed of rod, axial load, traverse speed) should be optimized. Lower rotational speed of rod and Higher the traverse speed, thinner coating is achieved. Layers prepared under water are 20% thinner than those prepared in air. Finally, Friction surface coated samples shows better results than heat treated or normal substrate.

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