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Mechanical Behaviour of Rotary Friction Surfaced Aluminum Deposit on Low Carbon Steel

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Abstract: Friction surfacing is one such solid state processes currently being pursued extensively for various surfacing applications requiring wear and tear and corrosion resistance properties.

In this process the metals do not involve in melting and solidification processes, hence they give rise to deposits which are free from solidification related defects and are the amenable processes for many incompatible dissimilar metals owing to the short interaction time available for the extensive formation of deleterious intermetallics.

Keeping the afore mentioned in view the present study on rotary friction surfacing has been taken up to have a preliminary understanding on the friction surfacing of metallic substrates with metal/metallic alloys.

This method is forming a coating of a first material on a second material by rotary friction surfacing. A coating of a relative soft material can be formed on a hard material by using friction developed between the two materials when come in contact with each other. The substrate is in rotary motion and the mechatrode is in fixed position with their axes were perpendicularly. This process is being done on a lathe machine taking a carbon steel as substrate and aluminum alloy as consumable rod as mechatrode.

The bonding between these materials are observed under the microscope, and hardness tests were conducted on substrate.

Found the different parameters required for the application of this process on lathe machine .and the range of parameters that can be acceptable for a safe operation and good quality deposits.

1. FRICTION SURFACING

Friction surfacing is a variation of a friction joining technique which Neelands [1] first patented by Klopstock and in 1941. During the 1980's of interest [2-4]. I rotated and forced axially against a metallic substrate. The heat generated by the bar rubbing against the substrate causes the end of the bar to soften and plastics.. The substrate is traversed across the end of the bar transferring a strip of the bar material onto the substrate.The width, thickness and quality of the adhesive bond between the deposited strip of material and the substrate are dependent on the process parameters and the materials used [5-7]. Typically for deposits made at low frictional pressures, the width of the deposited material is 60-90% of the original bar diameter and the deposit can be 1-3mm thick. Results from through thickness tensile tests indicate that bond strengths approaching the ultimate yield strength of the deposited material can be achieved by optimization of the process [8-9]. Area coverage of a substrate can be achieved by the deposition of several adjacent strips of the consumable bar material. This process is most suitable for protection surfaces from corrosion, abrasion and etc. Figure 1: Schematic representation of friction surfacing process [10].

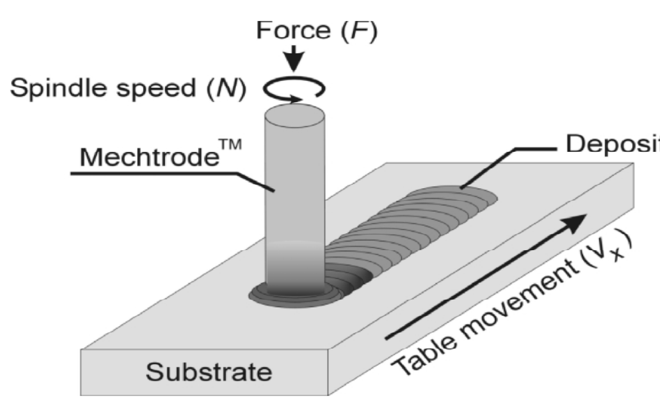

Figure 1: Schematic representation of friction surfacing process

(a) Rotating metal bar brought to required speed above metal plate.

(b) Rotating bar loaded axially against plate until plasticized layer forms at end of bar.

(c) Metal plate traversed across rotating bar leaving behind a well bonded deposit[11].

One type of the surface modification method that allows highly functional materials to be adhered onto the surface of the plate for enhanced functionality is friction surfacing, which is yet to be commercialized but achieves hard deposits with relatively simple equipment. Examined friction surfacing of both aluminium alloys onto the surface of the mild steel rod which observed the shape and structure of the deposit and the mechanical properties.

Such methods are clearly advantageous in industrial applications of friction surfacing as they reduce both the total cost and process time required.

It would appear at first glance that increasing the diameter of the coating material would increase the surface area of the deposit; however, it actually results in an increase in frictional force during surfacing process, which is detrimental to the equipment employed.

Another method that has potential is multilayer friction surfacing; a technique that involves repeated friction surfacing[12-14].

In this study, the multilayer friction surfacing was conducted with mild steel as a substrate and aluminium alloys rod which has different compositions as a coating material, and examined the surfacing conditions, particularly focusing on the effects of phase applied to the coating material on the structures and mechanical properties of the multilayer friction surfaced materials

2. EXPERIMENTAL METHOD

2.1. Materials Selected for Rotary Friction Surfacing

The metallographic and mechanical tests were performed for mechatrode and substrate materials according to the standards are: 7739 Part 1 and IS 1608 respectively. The composition and tests results are tabulated in table 1.

Table 1
Chemical composition of base metals. (Mass %)

Materials		*Si*	*Fe*	*Cu*	*Mn*	*Mg*	*Cr*	*Zn*	*Al*
Substrate	Carbonsteel rod	_	99.26	_	0.74	_	_	_	_
Mechatrode	Aluminum rod	_	0.36	0.03	_	_	_	0.06	99.55

2.2. Specimen Preparation for Experimental work (Mechatrode and substrate).

The mechatrode was the consumables rod and it was made from 12 mm diameter aluminum rod. The bars were cut into 100 mm lengths. The consumables were screwed into a tool holder which was designed to be clamped firmly to prevent vibrations.

Substrates was prepared from 40 mm diameter bright mild steel bar. It was turned to get a diameter of 35 mm and to have perfect turning/truing. The surface roughness obtained is approximately 0.7 μm and1.5 μm on the surface of mechatrode and substrate respectively. Consumables and substrates are shown in fig. 2, were cleaned with ethanol perfectly before use.

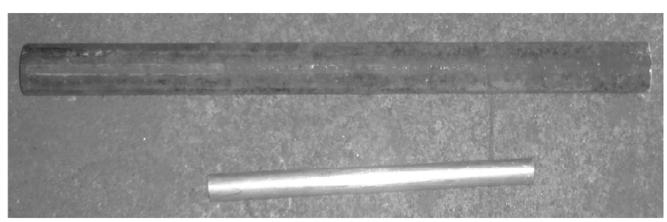

Figure 2: Machining of raw material

In the experiment, the substrate is rotated with preferable speed and the mechatrode is made to contact with that rotating substrate. Here the substrate and mechatrode are in perpendicular planes as shown in diagram

2.3 Friction Surfacing Equipment: Capstan lathe with Motor capacity of 5H.P and max. Motor speed: 1440 RPM is employed for low-pressure friction surfacing is shown in figure 3.

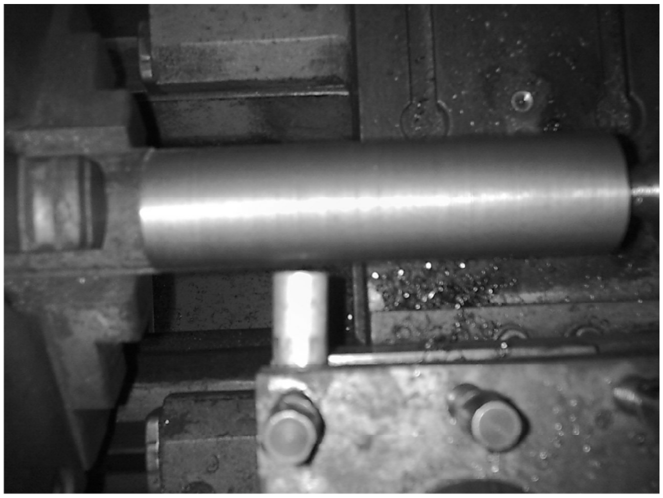

Figure 3: Equipment used for friction surfacing

A substrate is fitted in a chuck of a standard lathe of 5HP. The maximum axial load permissible with the standard lathe headstock bearing system is 4.9kN. The Mechatrode was fixed to the cross feed mechanism of tool post of the lathe.

3. EXPERIMENTAL PROCEDURE

Rotating friction surfacing is a method of forming coating of a first material on a second material. In Rotary friction surfacing a relative motion is produced between the two materials i.e, "substrate" and "mechatrode".

In our experimentation a relative motion is produced between the substrate and mechatrode by rotating the substrate material and mechatrode material as stationary. As in experimentation, carbon steel is taken as substrate material having low thermal conductivity and aluminum as mechatrode is having high thermal conductivity. In the experiment, the substrate is rotated with preferable speed and the mechatrode is made to contact with that rotating substrate. Here the substrate and mechatrode are in perpendicular planes.

Subsequently the by advancing the tool post the mechatrode was engaged at the pre-set load forcing the substrate into contact when its rotating. The frictional energy which was dissipated during operation and generates a layer of plasticized metal, the layer of plasticized metal being deposited as a coating without the need for external heat source. A dwell time between 5 and 7 seconds was sufficient for the region near the end of the consumable to politicize and glow white hot. As the deformation or melting of the mechatrode is observed a uniform pressure is applied to the mechatrode against the rotating substrate. It been observed that a thin layer of mechatrode material is been coated on the substrate material.

Initially before coating a considerable high amount of pressure is applied to mechatrode against the substrate, since the contact is between different materials .i.e, carbon steel and aluminum. On further coating by surfacing a less amount of pressure is required. This is because of the contact is between same mechatrode and substrate material i.e, aluminum to aluminum. Then move the consumable rod of coating metal relative to the substrate in linear direction under the action of external load while substrate was rotating.

In order to obtain a good quality of coating of mechatrode material onto the substrate material, the rotating speed, the in feed and the transverse speed has to be maintained properly. So, a good amount of bonding had formed between mechatrode material and substrate material.

The process conditions required to produce aluminum deposits of uniform thickness at the lowest possible frictional pressure are listed in Table 2. In this process the deposits were made on the substrate by mechatrode, when their axes are perpendicular to each other. The figure 4 shows the deposition of aluminum over the mild steel rod and the figure 5 is the deformed mechatrode in rotary friction surfacing.

The above mentioned aspect is been observed in experimentation and later on the microstructure is observed and it is observed that the mechatrode material is been deposited on the substrate material.

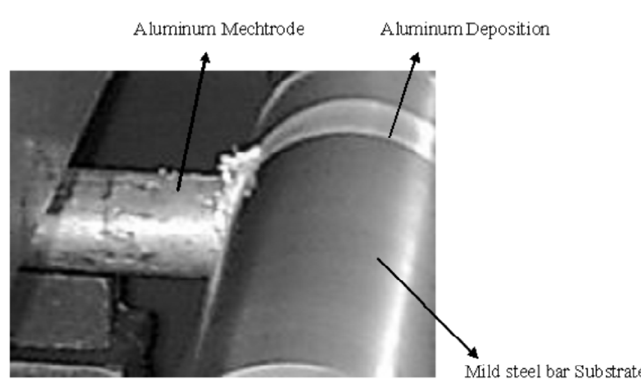

Figure 4: Deposition of mechatrode material on to the substrate material by rotary friction

Table 2
Parameters for Quality Rotary Friction Surfacing

S.No	Spindle Speed (rpm)	Transverse Speed (mm/s)	Cross feed (mm/s)	Surface Speed (m/s)	Force (N)	Deposition result
1	558	_	0.15	0.99	179.06	Good
2	558	0.92	0.17	1.02	191	Average
3	471	0.67	0.125	0.8	191	Good

Figure 5: Shows the deformation of the Aluminum mechatrode in friction surfacing process

4. EVALUATION OF THE QUALITY OF FRICTION SURFACED DEPOSIT

It is very essential to find the quality of the deposit made by friction surfacing process to determine its suitability for various applications. Since dissimilar metals are involved, selection of test methods poses some difficulty. This is due to wide differences in physical properties of the base metals i.e. rotating consumable and substrate.

Metallographic examination reveals the micro structural changes occurring near the interface on deposit layers and on substrate. Metallographic examination involves study of prepared metal surfaces for microstructural studies using higher magnification to predict the likely behavior of the metal for a particular service condition with reasonable accuracy. Structure at the interface reveals deposit condition whether bond is there or not

4.1. Primary Inspections

The quality of the deposit is evaluated at the shop floor after deposition. These are for the qualitative analysis, to give status of the deposit, whether it is acceptable or not. The NDT techniques such as appearance and adhesion tests such as lifting test, impact test and chisel and hammer test are performed for evaluation of bonding and quality of friction surfaced deposits.

4.1.1. Visual Inspection

The deposit is inspected for the physical appearance and damage. It is also inspected by visual inspection using magnifying glass for visible defects such as blisters, pits, roughness, and cracks or under cut areas.

Visual examination reveals surface flaws, and is a valuable indication in weld quality. It is a simple, accessible, low-cost inspection method, but it requires a trained inspector Visual examination only identifies surface discontinuities.

The most important instrument in visual testing is the human eye. Hence, the visual acuity of inspector is prime importantance aspect in visual testing. It can be natural or aided by other instruments like magnifying lenses.

The Visual examination is conducted for all deposits after the completion of friction surfacing to detect gaps, lack of bond, surface cracks, pores etc with eye and also using magnifier and results are recorded in table 3.

4.1.2. Adhesion Test

The adhesions are generally used to test the deposit whether it has bond with substrate or not. The following tests are used for the evaluation bond in the shop floor viz i). Deposit is rubbed with a scriber using medium force, or ii). A sharp tool is used to lift the coating from the base metal, or iii). The plated surface was subjected to repeated hammer blows of a definite weight or force, or iv). The plated wheel is held against a rough abrasive wheel, v). A chisel is driven through the heavy deposit by hammer with a moderate force. This is a severe test that indicates weak bonds by separating the deposit from the base metal.

4.2. Measurements of Dimensions of the Deposit

The Thickness and surface roughness of the deposits are determined. It also be confirmed in the metallography.

4.3. Non Destructive Testing (NDT)

Non-destructive testing methods have limitations for testing dissimilar metal joints. However ultrasonic testing with special probes and equipment can be used to detect the defects at the interface like lack of bonding and any cracks formed after friction surfacing. Surface defects like cracks and voids can be detected by dye-penetrant examination. Radiography technique is normally best suited for the detection of the volumenar kind of defects [79-82].

4.3.1. Liquid Penetration Test (LPT)

Liquid Penetration Test (LPT) is also generally called as Dye Penetration Test (DPT). In practice, the liquid penetrant process is relatively simple to utilize and control. The major advantages of penetrant testing include, portability, low cost, easy to use. Generally used for detecting discontinuities that are open to surface such as cracks, seams, laps, cold shuts laminations, porosity and shrinkage [15]. Dye penetrant test is conducted on the stainless steel friction surfaced deposit according to the standard ASME Sec V SE 165.

5. RESULT AND CONCLUSION

5.1. Primary Inspections

When the deposit was observed under microscope it is found that the surface of the deposit is free of cracks, blisters, pits, roughness, or under cut problems, which are generally encountered in fusion welding process as in some magnitude or other. These are also indicating, the friction surfacing process is the solid state welding []

The surface when observed carefully revealed that it is free of porosity, which indicates that the selected welding speed is correct and allow any entrapped gases if formed during the process escape. The nature of this solid state process eliminates this type of defect.

The primary adhesion test such as rubbing with hand, lifting test, and impact test, grinding wheel test, chisel and hammer test results are indicating the deposit had sufficient bond and the test results are shown in table 3. These results revealed that the friction surfacing is one of the best metal joining processes, which can be used to surface this dissimilar metal combination conveniently.

Table 3
Results of Primary Inspection Tests

S.No	*Testing method*	*Purpose*	*Result*	*Remarks*
1	Visual Inspection	Surface finish	Good	Depositisgood
		Thickness	A initial is more	
		Porosity, Cracks and voids	No defects	
2	Chisel and Hammer test	Adhesion	Bond is not separated	Depositisgood
3	Impact test			
4	Lifting test:			
5	Grinding wheel test			

5.2. Dye Penetration Test

When the dry penetration test is conducted for the deposit, it is found that the surfaces are free of defects such as cracks or voids or holes. It indicates that the obtained joint is perfect. This process can be carried out in open air without the provision of an inert gas atmosphere

5.3. Metallography

Microscopic observation figure 6 and 7 reveals there is inter mixing of aluminum and low carbon steel due to hot rotational forging, and hence exhibiting good bonding strength by metallic bond and mechanical interlocking.

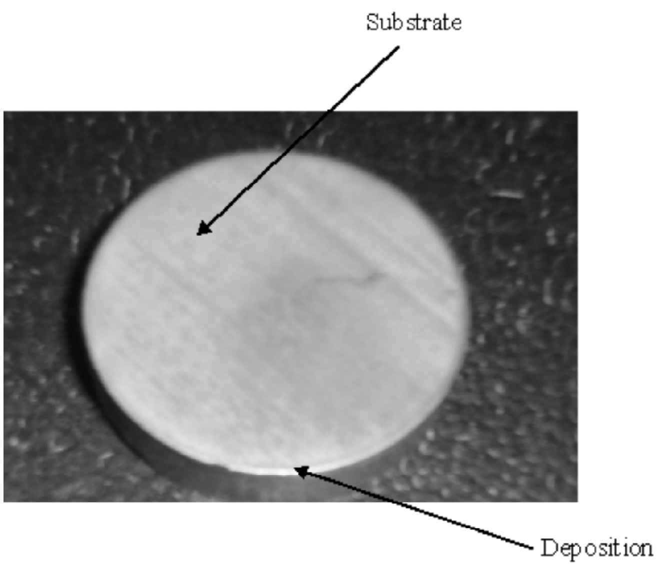

Figure 6: Specimen used for Metallography

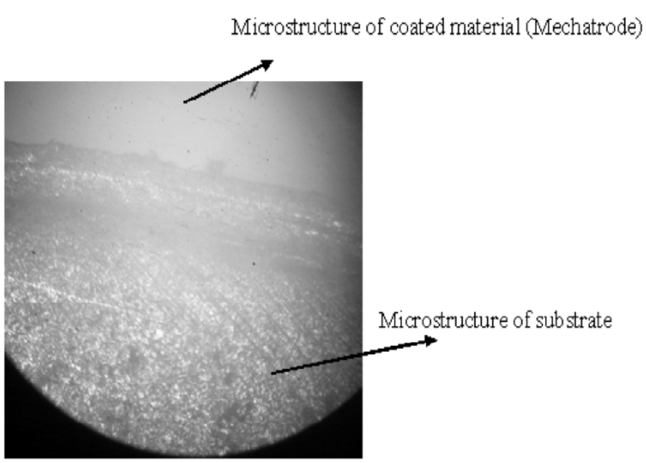

Figure 7: Microstructure of substrate and Microstructure of coated material (Mechatrode)

6. CONCLUSIONS

Experimental results show that the friction surfacing can be used as an alternate method for obtaining coatings of dissimilar materials.

i) It is observed that the heat affected zones are developed on substrate material near to the contact of substrate and mechatrode material surfaces.

ii) It is observed a high amount of pressure is applied to mechatrode material during the first coating, since the contact is between carbon steel and aluminum and on further coating the pressure required is less, since now the contact is between aluminium to aluminium .

iii) A large amount of heat is developed during the experiment due to rubbing of the surfaces and huge sound of rubbing is observed during the deposition of the mechatrode material onto the substrate at initial position.

iv) It is observed that during coating of material without transverse motion of the mechatrode on the surface of the substrate the deposition obtained is uniform. When the transverse motion is given it is observed that the deposition is not uniform, because of non uniform (because of manually) in feed over the length of the substrate material. Hence a special portable equipment has to be designed in order to give automation to the in feed

v) It is observed the bending of mechatrode during the experiment when it was in contact with the rotating substrate.

vi) It is observed the spindle speed is reduced because of large amount of frictional force between mechatrode and substrate in solid state .When the mechatrode get plasticized frictional force becomes less and hence it runs normally

vii) Scratch test is done and it is observed that the bonding between the substrate and mechatrode material and found it is good.

viii) The mechatrode holder gets heated due to high thermal conductivity, hence more required to cool the holder to room temperature. So this process is most suitable for the materials which have low thermal conductivity.

viiii) There is tremendous scope to extend this process to other dissimilar metal combinations for protection against wear and corrosion.

7. ADVANTAGES

Friction Surfacing has significant advantages over competing processes. It introduces machine tool technology to surface engineering, making the process reliable and repeatable. In friction Surfacing processes, metallurgical bond obtained is free of the problems of porosity, slag inclusions or dilution experienced with traditional welding processes.

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References

[1] H. Klopstock and A.R. Neelands - Patent specification"An Improved Method of Joining or Welding Metals", Ref.572789,application date 17Oct. 1941.

[2] Wayne M.Thomas, Edward D Nicholas TWI England,1990 "Surfacing Method", U.S Patent No.4, 959, 241.

[3] K.G.K.Murti "Friction welding of some dissimilar combination" A thesis submitted for the degree of "Doctor of Philosophy" in Metallurgical Engineering, Department of Metallurgical Engineering, Regional Engineering College, Thiruchirapalli, India, 1986.

[4] E.D.Nicholas, "Friction Processing Technologies". Friction and Forging Process Group, 2003, TWI. Lld (UK).

[5] G.M. Bedford and P.J. Richards, "On the Absence of Dilution" in Friction Surfacing and Lateral Friction",1st International Conference on Surface Engineering Proc., Brighton UK, paper 70, June 1985.

[6] W.M. Thomas and S.B. Dunkerton, Friction Surfacing", The Welding Institute Research Bul.,vol. 25, PP. 327-331, Oct. 1984

[7] W.M. Thomas, E.D. Nicholas and S.B. Dunkerton, "Feasibility Studies into Surfacing by FrictionWelding", The Welding Institute Research Report, No. 236,Apr. 1984.

[8] B.M. Jenkins and E.D. Doyle, "Advances in Friction Deposition – Low Pressure Friction Surfacing", International Tribology Conference Proc., Melbourne Aust.,pp. 87-94,Dec. 1987.

[9] A. J.W. Elmer and D.D. Kautz, "Fundamentals of Friction Welding", ASM Hand Book, Vol. 6, pp 503-508

[10] P. Lambrineas, B.M. Jenkins and E.D.Doyle, "Low Pressure Friction Surfacing: Adhesion of Stainless Steel Coatings on Mild Steel",International Tribology ConferenceProc.,Brisbane Aust., pp. 12-15,1 Dec. 1990.IVB2-9.

[11] Professor Monty Bedford "friction surfacing process" Frictec, friction surfacing technology.

[12] Horoshi. TOKISUE, Kaazuyoshi KATOH, Toshikatsu ASHAINA and Toshio USHIYAMA "Structural and Mechanical Properties of Multilayer Friction surfaced AL Alloys". Industrial Technology Nihon University Nov 78, 2005.

[13] A.W.Batchlor, S. Jana, C .P. Koh and C .S .Tan "The effect of metal type and multi-layering on friction surfacing" Journal of materials processing technology- 57 (1996) 172-181.

[14] Benoit Jaworski of frictec "Deposition of aluminum by friction surfacing", 36 Aluminum International Today Sep/ Oct 2005

[15] J.S. Borucki, Ardrox "Liquid Penetrant Inspection" ASM Hand book , Vol 17 Nondestructive Evaluation and Quality Control 1992, pp. 136-139.