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Friction Surfacing In Steel 304

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Abstract: - Surface engineering deals with the surface of the solid matter and it is sub-discipline of The surface phase of a solid interacts with the surrounding environment. This interaction can degrade the surface phase over time, may result in loss of material from its surface. Environmental degradation of the surface phase over time can be caused by wear, corrosion, creep, fatigue loads, shear loads, tensile loads, cutting forces or when exposed to higher temperature. Wear can be minimized by modifying the surface properties of solids by surface finishing or by use of lubricants. Friction surfacing not only gives good bond on plane surfaces but also on other contours by design of special purpose machines using CNC technology. Since bond strength is very good, these deposits are expected to serve better during service. These are also used to impart a wide range of functional properties, including physical, chemical, electrical, electronic, magnetic, mechanical, wear-resistant and corrosion-resistant properties at the required substrate surfaces. Almost all types of materials, including metals, ceramics, polymers, and composites can be coated on materials, similar or dissimilar.

Keyword(s):- *bond strength, Surface engineering, bond, fatigue loads, shear loads, tensile loads.*

I. INTRODUCTION

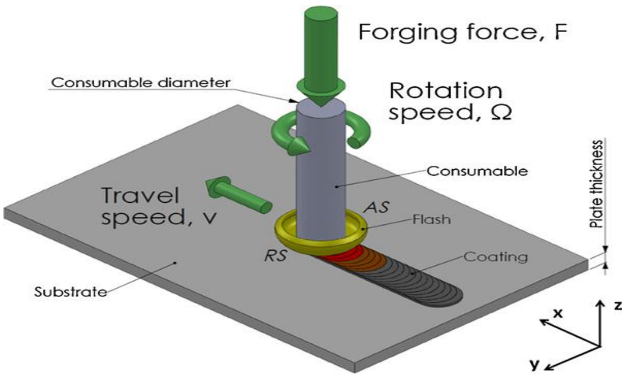

Fig 1.1 Schematic of friction surfacing

Surface engineering has become a relevant research field for manufacturing industries, as it enables advanced component design and a selective functionalization of surfaces. Solid state processing technologies are now mature and reliable alternatives to conventional processes, as stated by Mishra and Ma (2005).

Friction surfacing is a promising new technology for depositing metallurgically bonded coatings on engineering components to combat wear and corrosion. Being a solid state process, friction surfacing elimates the problems such as porosity, hot cracking, segregation, and dilution which are commonly associated with fusion-based techniques. This is attained because no melting is involved in this process.

Hard facing /coating techniques based on fusion welding and thermal spraying are generally employed to protect steel surface from corrosion. But fusion welding based coating techniques generally suffers from dilution and thermal spraying results in mechanical bonding rather than metallurgical bonding

Research so far has revealed that in friction surfacing the mechatrode force (F), mechatrode rotation speed (N) and substrate traverse speed (V_x) are of critical importance for the final quality of the coating and bond.

In the present study, three state variables that reflect coating quality were considered as a subject for optimisation and in this context a target for process parameter selection. These are coating thickness (C_t), coating width (C_w). The optimisation procedure considered in this study involved.

Development of a methodology for in-process precision measurement of axial load, traverse speed and rotational speed.

Development of an empirical model involving process parameters of coating quality state variables i.e coating thickness and coating width.

The friction surfacing machine consists of a power rotor which can move vertically with high precision Z. Under the rotor there is an XY table, which can be positioned and moved accurately. The system is controlled using a serial computer link. The input parameters to the machine being:

Spindle rotation speed

Spindle direction

Table movement

II. LITERATURE REVIEW

H.Khalid Rafi, G.D.Janaki Ram, G.Phanikumar and K.Prasad Rao [1] studied the effects of traverse speed on the geometry, interfacial bond characteristics and mechanical properties of coatings .

M.Chandrasekaran, A.W.Batchelor and S.Jana [2] studied that mild steel bonded well with the substrate and there was evidence of interfacial compound formation whereas in case of stainless steel there was no evidence of mixing and coating.

G.Madhusudhan Reddy and T. Mohandas [3] studied that stainless steel coating of mild steel leads to the formation of carbides in the stainless steel adjacent to the interface as a result of carbon migration from mild steel towards stainless steel.

J.John Samuel Dilip and G.D.Janaki Ram [4] studied the individual layers upto the thickness of 1mm to 2mm can be added up successively by friction deposition. A solid cylinder of 20mm diameter and 50mm height was successfully produced with austenitic stainless steel AISI 304.

H. Khalid rafi, N.Kishore babu, G.Phanikumar and K.Prasad Rao [5] studied the microstructural evolution of stainless steel AISI 304 on low carbon steel using optical microscopy,electron back scattered diffraction and transmission electron microscopy.

Ramesh Puli, E. Nandha Kumar and G.D. Janaki Ram [6] showed that the microstructure tests showed good hardness results when stainless steel is coated over mild steel. Bend and shear tests indicated excellent coating/substrate bonding.

J.Gandra, R.M.Miranda and P.Vilac [7] studied the influence of axial force, rotation and traverse speed on interfacial bond properties were investigated.

G.M. Bedford, V.I. Vitanov and I.I. Voutchkov [8] studied the mechanism of auto hardening of the mechatrode coating on substrate is studied.

B.Jaworski, G.M.Bedford, I.Voutchkov and V.I.Vitanov [9] studied the procedures for data collection, management and optimization of friction surfacing process and found that the thickness of the coated layer is typically between 0.5-3mm depending on the mechatrode material and diameter.

V.I.Vitanov, I.I.Voutchkov and G.M.Bedford [10] studied the three state variables, that reflect coating quality were considered as a subject for optimization and in this context a target for process parameter selection which are coating thickness, coating width, coating bond strength.

M.Chandrasekaran, A.W.Batchelor and S.Jana [11] studied that a nominal contact pressure as high as 21.9Mpa was required to obtain an adherent coating of uniform quality for mild steel with tool steel and inconel.

D.Govardhan, A.C.S.Kumar, K.G.K.Murti and G.Madhusudhan Reddy [12] studied the effect of process parameters such as frictional pressure, rotational speed of the mechatrode and welding speed .Their interaction effects on the deposit for the consumable rod are identified.

III.EXPERIMENTAL WORK AND GEOMETRY MEASUREMENT

Fig 4.1 Substrate before grinding **Fig 4.2 Substrate after grinding**

4.1 Specimen Preparation (Substrate)

Step 1: Making to a proper dimension
Initially the ductile iron plate was of 1500*1000*8 mm dimension. After cutting the raw material with gas arc cutter, it became 100*150*8 mm which is perfect for our friction surfacing process.

Step 2: Rough finishing by emery paper
Initially the ductile iron material got from shop is fully corroded. But with corroded surface friction surfacing will not be good, and thus must be removed. Emery is a type of paper that can be used for sanding down hard and rough surfaces. Even after hard rubbing with emery paper the ductile iron plate is still corroded. Hence fine finishing with surface grinding machine is a must after rough finishing.

Step 3: Fine finishing with surface grinding
This is used to get a fine finish over the roughly finished surface obtained by emery paper. Surface grinding machine is being used.

Step 4: Applying acetone solution over the surface.
The surface of the SG iron is cleaned with acetone. Acetone removes all impurities like oil, grease, dust etc.

Step 5: Corrosion free surface
Finally we get a ductile iron plate without any corrosive layer. After the fine finis0hing process followed by acetone cleaning, our material is completely ready to use for friction surfacing.

IV .Specimen Preparation (Mechatrode)
22mm diameter 304 stainless steel rod is cut into 105 mm length pieces.
These rods are turned by holding between the centers of lathe to get uniform 20mm in diameter with a 100 mm length.

V.Result and Discussion

Fig 4.3 Experimental setup of friction surfacing machine

VI.Experimental Work with Friction Surfacing Machine
Mechatrode stainless steel is fitted in a mechatrode holder, which consists of splines at its outside surface along with its axis to allow the movement in the axial direction while doing friction surfacing. The mechatrode holder is fixed in a spindle and locked by using threading. In this condition the mechatrode can move along with the axis and simultaneously rotate with the spindle. Bush is fitted at the end of the spindle with locking screws to allow the mechatrode to rotate the axis of the spindle perfectly, under axial load.
The process parameters as per treatment combination are set on the computer of the machine. Dwell time of 5 seconds is found to get the mechatrode reach plastic state as per the initial trials conducted before start of experimental trials.

Machine is started and, once the consumable is sufficiently heated to acquire forging temperature, the welding speed is automatically switched on. The hot consumable material flows plastically over the substrate to form a coating. Since the machine is designed to deposit the consumable material in one direction of table, after completion of required length of the weld, the consumable which is fitted in the spindle automatically detach from the substrate by moving spindle in upward direction by stopping immediately the spindle rotation and welding speed.

VII Friction Surfaced Sample Photos

4.7.1 Coating Thickness (C_t) on Deposit Geometry

Table 4.3

S. No	Substrate	Mechatrode	Coating Thickness c_t (mm)
1	Sg Iron	Stainless Steel 304	2.9
2			2.36
3			1.45
4			2.73
5			2.21
6			2.36
7			2.33
8			2.55
9			1.95

In stainless steels, the coating thickness is inversely proportional to the traverse speed.
In higher traverse speed, the time of deposition of plasticized material on the work piece is less. Hence gives less coating thickness and less heat affected zone in work piece.
Coating with minimum thickness is more advisable automobile parts applications. Higher coating thickness will give increase in weight of the component.

4.7.2 Coating Width (C_W) on Deposit Geometry

Table 4.4

S. No	Substrate	Mechatrode	Coating Width c_t (mm)
1	Sg Iron	Stainless Steel 304	19.72
2			16.83
3			14.49
4			18.9
5			17.29
6			16.14
7			19.23
8			19.44
9			16.02

The width of the flash formed in the substrate is usually 0.9 times the diameter of the mechatrode used.
Our results show approximately the same value.

4.7.3 Length of Mechatrode

Fig 4.4 Length of mechatrode after friction surfacing

Mechatrode	Set No	Length	
		Before(mm)	After(mm)
Stainless Steel 304	1	100	69
	2	100	67

	3	100	79
	4	100	72
	5	100	71
	6	100	65
	7	100	70
	8	100	62
	9	100	69

According to the machine specification the length of the mechatrode rod must be in 90-120mm.
Difference in mechatrode length before and after experiment shows the material consumption during the process.
The loss of volume of material during the process is equal to the volume of coating.

4.7.4 Diameter of Mechatrode

Fig 4.5 Diameter of mechatrode after friction surfacing

Table 4.6

Mechatrode	**Set No**	**Diameter**	
		Before(mm)	**After(mm)**
Stainless Steel 304	1	20	38
	2	20	33
	3	20	35
	4	20	34
	5	20	33
	6	20	35
	7	20	35
	8	20	36
	9	20	34

According to the machine specification the diameter of the mechatrode rod must be in 16-24mm.
During the process material temperature reaches above 700^0C
In that high temperature plasticization occurs. Some material melts and deposited on the work piece called coating.
The remaining material stick around the mechatrode edge, after some time in the atmospheric air get cooled and looks bigger in diameter than the initial diameter.

III. INSPECTION AND TESTING RESULTS

5.1 Hardness Measurement

Hardness of the obtained samples is tested using a micro Vickers hardness tester. The specifications of which are as follows

Machine Name : Micro Vickers Hardness Tester
Testing load range : 10 grams to 1 Kg Load
Make : Wilson Wolpert – Germany
Micrometer least count : 0.01 mm
Hardness testing Scales : HV, HR"A", HR"B", HR"C", 15N, 30N & 45N, 15T, 30T & 45T
Hardness Values in H.V. @ 0.5 Kg load.

Fig 5.1 Micro hardness test apparatus

Hardness measurements were carried out in the samples sectioned in transverse direction.
Diamond intender is used in this machine. Tests were carried at a load of 0.5 Kg and the following results were obtained.

Table shows the hardness results

Trial 1 Table 5.1

From the Weld	Weld Ss side	S.g Iron Side
Edge	197.5	155.9
0.1	225.4	152.0
0.2	223.3	141.8
0.3	220.9	149.8
0.4	225.0	147.1
0.5	223.0	149.1
0.6	218.2	149.1
0.7	214.8	149.6
0.8	213.2	148.2
0.9	210.3	148.2
1.0	200.2	151.2
1.1	197.5	164.3
1.2	207.6	150.4
1.3	208.1	149.6
1.4	208.1	151.3

Trial 2
Table 5.2

From the Weld	Weld Ss side	S.g Iron Side
Edge	201.6	153.4
0.1	227.2	151.8
0.2	227.3	148.1
0.3	224.3	148.8
0.4	225.9	147.6
0.5	224.5	146.7
0.6	225.7	147.8
0.7	219.8	146.1
0.8	215.9	147.7
0.9	215.5	147.4
1.0	212.4	148.7
1.1	215.9	147.1
1.2	212.8	150.9

Trial 3
Table 5.3

From the Weld	Weld Ss side	S.g Iron Side
Edge	200.4	158.4
0.1	225.8	153.2
0.2	226.6	152.2
0.3	227.4	151.9
0.4	225.7	152.2
0.5	225.1	149.5

0.6	222.7	148.5
0.7	219.4	147.2
0.8	218.8	147.0
0.9	216.3	148.8
1.0	214.8	147.8
1.1	112.6	146.0
1.2	203.5	156.8

Trial 4
Table 5.4

From the Weld	Weld Ss side	S.g Iron Side
Edge	270.7	174.9
0.1	271.9	168.3
0.2	249.2	143.8
0.3	236.5	159.6
0.4	239.9	163.3
0.5	229.7	158.8
0.6	231.1	154.1
0.7	229.4	1598
0.8	225.8	166.4
0.9	221.1	153.7
1.0	226.3	159.4
1.1	203.8	154.2
1.2	201.7	149.6

Trial 5
Table 5.5

From the Weld	Weld Ss side	S.g Iron Side
Edge	271.4	170.4
0.1	271.4	160.2
0.2	244.6	141.2
0.3	239.8	151.9
0.4	235.3	161.2
0.5	224.5	156.5
0.6	222.0	156.5
0.7	221.8	155.2
0.8	220.9	160.0
0.9	216.5	154.8
1.0	204.4	154.8
1.1	199.9	157.0
1.2	200.8	156.8

Trial 6
Table 5.6

From the Weld	Weld Ss side	S.g Iron Side
Edge	275.1	172.4
0.1	273.3	165.2
0.2	247.8	140.2
0.3	232.5	151.9
0.4	239.7	149.2
0.5	224.1	156.5
0.6	219.5	141.5
0.7	229.0	151.2
0.8	212.5	150.0
0.9	221.3	158.8
1.0	238.9	151.8
1.1	197.3	155.0
1.2	216.6	152.8

Trial 7
Table 5.7

From the Weld	Weld Ss side	S.g Iron Side
Edge	231.4	136.3
0.1	134.7	153.4
0.2	232.7	154.8
0.3	229.4	155.4
0.4	217.7	157.6
0.5	216.3	153.5
0.6	206.7	152.8
0.7	209.5	155.4
0.8	204.3	151.7
0.9	202.5	155.2
1.0	200.3	153.3
1.1	198.2	158.2

Trial 8
Table 5.8

From the Weld	Weld Ss side	S.g Iron Side
Edge	235.3	135.3
0.1	138.6	156.8
0.2	234.3	157.1
0.3	229.6	155.4
0.4	217.4	154.6
0.5	202.8	153.3
0.6	205.4	151.8
0.7	207.8	151.3
0.8	200.2	152.6
0.9	201.5	152.2
1.0	194.3	155.4
1.1	196.2	156.3

Trial 9
Table 5.9

From the Weld	Weld Ss side	S.g Iron Side
Edge	233.0	138.1
0.1	133.1	152.9
0.2	233.2	153.3
0.3	229.5	154.8
0.4	214.3	153.7
0.5	206.9	153.0
0.6	204.5	151.3
0.7	207.8	150.8
0.8	201.9	151.0
0.9	200.8	152.4
1.0	197.3	154.1
1.1	198.0	156.5

Hardness is the property of a material that enables it to resist plastic deformation, usually by penetration. Hardness value of material is directly proportional to the strength of that material

5.2 Bend Test

Mechanical testing machine is used for this purpose. The point to be noted is that the test is carried out as per ASTM E-8. Here the sample is cut to the required dimensions so that it can be held. The sample is placed at the top of the support. Following which uniform load is applied at its centre. The sample starts bending. The point where it is about to break is noted and the corresponding load is the maximum that it can withstand. The following is a mechanical testing machine.

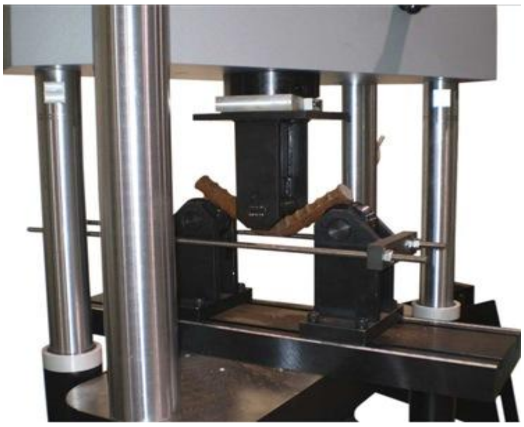

Fig 5.2 Bend test apparatus

T1

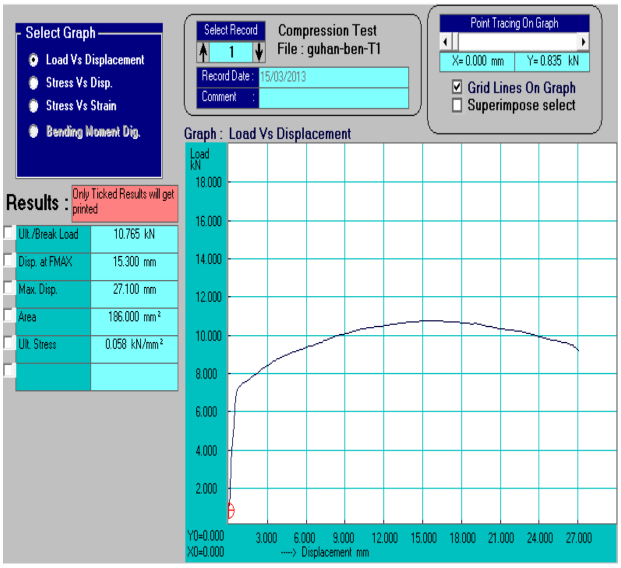

Fig 5.3 Load Vs Displacement Graph for Bend Test

Table shows the bend test results
Table 5.10

S. No	Max Load (kN)	Max Displacement (mm)
1	10.765	27.1
2	10.825	26.9
3	10.729	26.6
4	10.211	23.1
5	10.195	24.3
6	10.301	24.0
7	10.002	27.1
8	10.114	27.4
9	10.065	26.8

Bend testing determines the ductility or the strength of a material.
Experiment results show that the strength of a work piece has increased after the coating. Because coating surface provide resistance towards bending.

Fig 5.4 Sample before the bend test

Fig shows the work piece before the load acted on it while under-going the bending test.

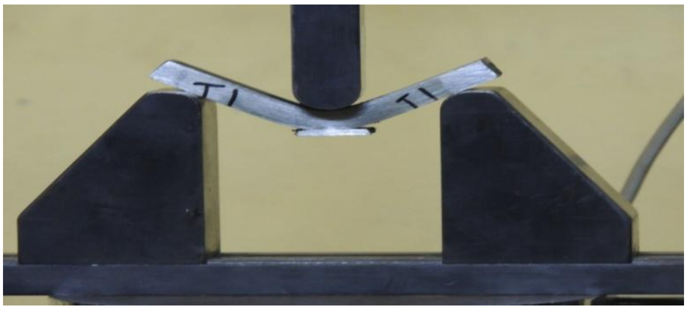

Fig 5.5 Sample after the bend test

Fig shows the work piece after the load is acted on it.

5.3 Microstructure
Sample T1

Image 1

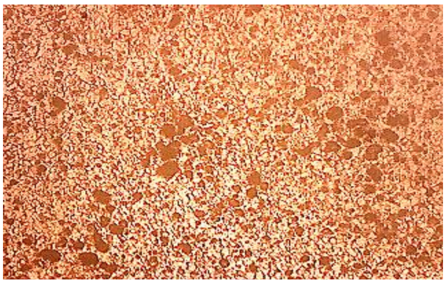

Image 2

Image 1: shows the base metal SG iron with surfaced SS by friction. The base metal shows fine spheroidal graphite's in ferrite-pearlite matrix.
Image 2: shows the base metal microstructure (SG Ir on).

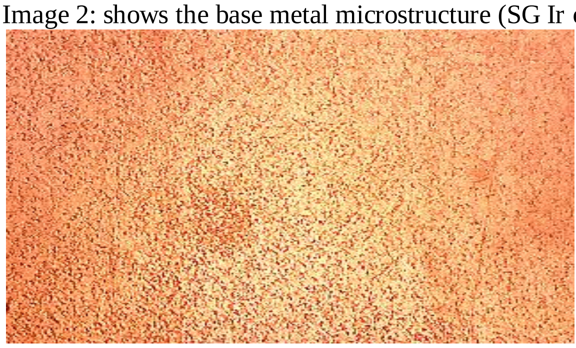

Image 3

Image 4

Image 3: shows the etched surfaced SS matrix with fine austenite grains.
Image 4:shows the same SS matrix at higher magnification.

Sample T5

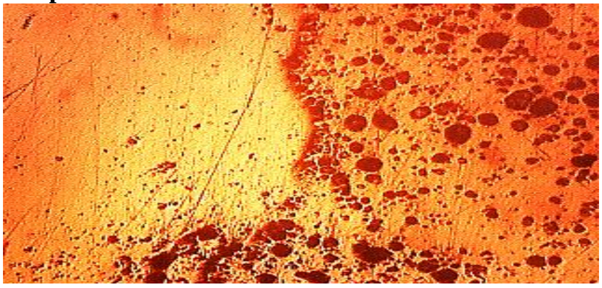


Image 1 **Image 2**

Image 1: shows the base metal SG iron with surfaced SS by friction. The base metal shows fine spheroidal graphite's in ferrite-pearlite matrix.
Image 2: shows the base metal microstructure (SG Iron).

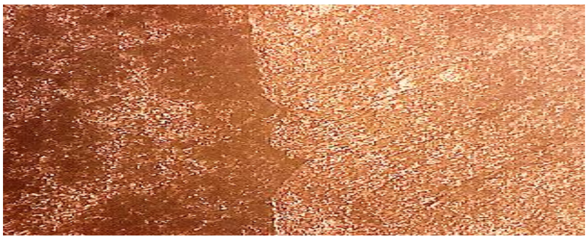


Image 3 **Image 4**

Image 3: shows the base metal SG iron with surfaced SS by friction. The base metal shows fine spheroidal graphite's in ferrite-pearlite matrix. The surfaced metal shows fine austenite grains.
Image 4: shows the same SS matrix at higher magnification.

Sample T9

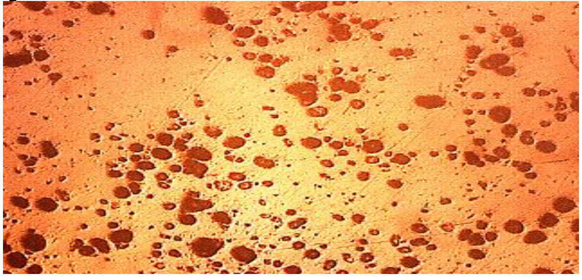
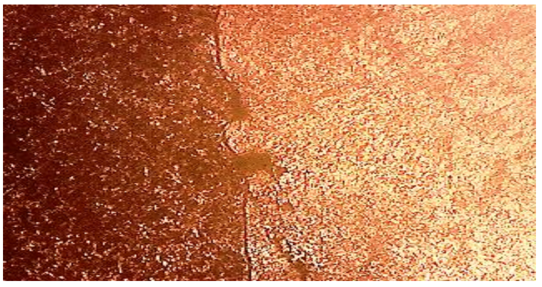

Image 1 **Image 2**

Image 1: shows the base metal SG iron with surfaced SS by friction. The base metal shows fine spheroidal graphite's in ferrite-pearlite matrix. Surfaced metal not etched.
Image 2: shows the base metal microstructure (SG Iron).

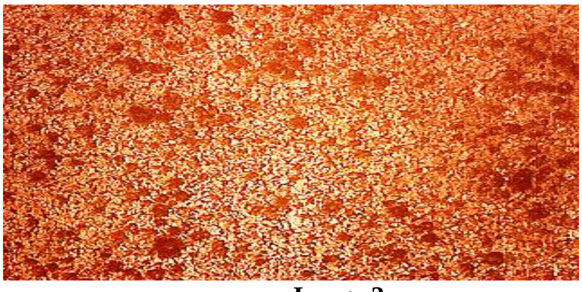
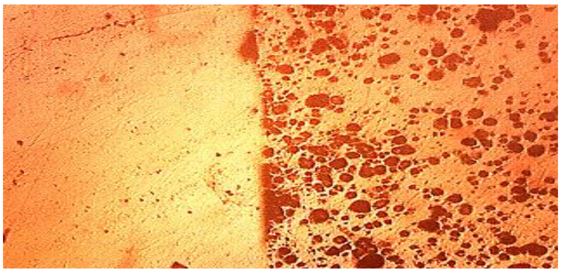

Image 3 **Image 4**

Image 3: shows the base metal SG iron with surfaced SS by friction. The base metal shows fine spheroidal graphite's in ferrite-pearlite matrix. The surfaced metal shows fine austenite grains.
Image 4: shows the base metal microstructure (SG Iron) with ferrite-pearlite matrix.

5.4 Corrosion Test: As per ASTM B117M (Salt Spray fog test)

Fig 5.6 Salt spray test chamber apparatus

5.4.1 Salt Spray Apparatus

Specimens are first cut to the size as specified by ASTM. Holes are drilled at the top of each specimen so that they could be held steadily. The weight of the individual specimens are noted before the test starts. The chamber has a provision at the side for spraying NaCl. Sodium chloride is sprayed in the form of fine droplets similar to fog. The purpose of spraying NaCl is because the chlorine atoms react with the coating material of individual specimens and causes its removal. It is sprayed for about 48hours. Following which the specimen is carefully removed and washed with distilled water. Now it is stirred in alcohol on a warm base. After the residues are dissolved it is once again weighed. Comparison of weights before and after the test is now done. The following satisfactory results were obtained.

5.4.2 Salt Spray Test Parameters

Temperature of the test: 33 degrees Centigrade.
Concentration of the Salt solution: 1.0M
Air pressure: 2.0 Kg per Sq. Centimeters.
Ph of the Solution followed : 7.0
Humidity of the chamber: 95% to 98%.
Exposure Time: 48 Hours.
Post cleaning: Cleaned in distilled water followed by rinsing in alcohol

5.4.3 Weight Details for Corrosion Test
Table 5.11

	T1	**T5**	**T9**	**S.g Iron**
Initial Weight	42.51	38.74	47.18	67.80
Final Weight	42.49	38.68	46.99	67.50
Weight Loss	0.02	0.06	0.19	0.30
Corrosion Rate Loss/Day	0.000948	0.00233	0.00916	0.0083

5.4.4 Corrosion Rate Conversion

The most used expression for corrosion rate in the US is the mpy (Miles per year).
To convert corrosion rate (corrosion rate conversion) between the mpy and the equivalent in the metric unit mm/y (millimeter per year).
1 mpy= 0.024 mm/y =22.4 microns/year
To calculate the corrosion rate from metal loss:
Mm/y=87.6*(W/DAT)
Where:
W=weight loss in milligrams
D=metal density in g/cm^3
A=area of sample in cm^2
T=time of exposure of the metal sample in hours

IV. CONCLUSION

Experimental results show that the friction surfacing could be used as a method for obtaining coatings of dissimilar materials. Friction surfacing is the best method for obtaining deposits of stainless steel over ductile iron for critical applications. Adequate bond strength and good coating integrity of deposit is obtained by optimizing of process parameters The microstructure reveals good bond between stainless steel and ductile iron which is obtained by the results of the combined forging and shear action of mechatrode at the plastic state with ductile iron. The interface layer zone is the intermixed materials of substrate and mechatrode.The deposit observed by the microscope showed dense, clear and fine microstructure of ferrite and pearlite on ductile iron side which clearly proves the superiority of the process Corrosion test and bend tests results proved that this method is can be for manufacture of petrochemical vessels, pumps for chemicals and other corrosion resistant applications. There is tremendous scope to extend this process to other dissimilar metal combinations for protection against wear and corrosion.

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