(1) Characterization of Aluminum Alloy Coated Steel Made using Friction Surfacing Method

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Abstract— Steel is the most commonly used material in industrial processes like automobile, nuclear power plants and gas turbine industries etc. But it undergoes degradation due to severe operating conditions like high temperature, pressure, large stress, adverse effect of medium etc. To overcome this drawbacks aluminum alloy deposition is carried out using Friction surfacing method. Friction surfacing is a solid state process and it is used here to deposit aluminum alloy 6061 on mild steel. Optimum friction surface processing parameters are axial force, spindle rotation speed and tool transverse speed. Three different samples were made by changing the process parameters. All samples were heat treated in an open atmosphere at 700 °C and 730 °C for 2 hrs. Micro structural analysis, hardness measurement and scratch resistant measurement are conducted using Scanning Electron Microscope equipped with EDS, Vicker's micro hardness tester and Linear Scratch testing machine respectively. Results shows that there is a formation of Fe-Al intermetallic compounds after heat treatment on the aluminide layer and it had very high hardness. And scratch test analysis showed that heat treated samples possessed higher scratch hardness than non-heat treated samples.

Key words: Al6061Alloy, Friction Surfacing, Micro Hardness, Scratch Test, SEM

II. Introduction

Surface damage occurring during life of a component can result in changes in surface condition and dimension of a mechanical component, and this may sometimes cause disastrous failure of an entire mechanical system. One of the cost-effective approaches against surface damage is coating. Various coating techniques have been successfully applied in industry to protect machinery and equipment from surface damage caused by corrosion, oxidation and wear.

In today's world, steel has been the most sought out material for majority of engineering applications. Steel is the material of choice in industrial processes like automobile industries, nuclear power plants, steam and gas turbine industries etc. Steel undergoes degradation due to severe operating conditions like high temperature, pressure, large stresses, presence of corroding media etc. Although steel exhibits excellent mechanical properties, its oxidation and corrosion resistance is poor. This is because the oxide layer forming on the surface of steel is a non-compact one. This limitation can be overcome by modifying the surface of the steel appropriately, either by changing the surface chemistry (alloying the surface) or by deposition of another metal at the surface. The deposited metal may, on its own, give beneficial properties or after appropriate conversion. It allows various dissimilar material combinations. The choice of material and coating method depends on the nature of application. When it comes to oxidation and corrosion resistance especially at high temperature, aluminum alloying is the material of choice. Aluminum layer, when it is oxidized, forms a compact oxide layer, protecting the substrate steel from oxidation, corrosion, and abrasion. A thin layer of aluminum can be obtained on steel by liquid route and solid route. Hot dip aluminizing is a predominant method using liquid route, but this route is handicapped by the formation of brittle intermetallic. Chemical routes like pack aluminizing do involve processing at elevated temperatures for long duration, which may be detrimental to base material. In this context friction surfacing is a promising route. Friction surfacing is a useful method of developing a variety of coatings, to enhance the quality of new components as well as to reclaim worn or wrongly machined parts.

III. Review work carried out

Govardhan et al [5] demonstrated stainless steel deposition over the low carbon steel by friction surfacing. Minimum distortion is obtained owing to less heat affected zone. Gandra et al [4] researched on the friction surfaced coatings in alloy 410 in as-deposited condition can be used for corrosion and wear protection. Prasad Rao et al [11] concluded Thermal profiles for different sets of consumable rod/substrates (tool steel/steel; copper/steel and copper/copper) were recorded and analysed. Macedo et al [9] stated that apart from avoiding defects commonly associated to fusion and solidification mechanisms (porosities, hot cracking), the heat input in friction surfacing is minimum and localized, preventing part distortion and minimizing the HAZ and dilution

IV. Project scheme methodology

A. Development of the Coatings

Mild steel plates were used as substrate plates. The plates were cut into dimensions of 150 mm x 210 mm x 6 mm (thickness). They were machined using a milling machine to produce a roughness of 5-7 µm. Aluminium alloy 6061 was used as consumable rod (diameter: 20 mm, 95 mm length) to deposit Al over the steel surface. The friction surfacing was done using the machine made by M/s ETA technologies, Coimbatore, India. The normal load was varied as 4 and 5 kN, rotation speed was varied as 400 and 600 rpm. The tool plunge depth and tool transverse speed were kept constant as 40 mm and 35 mm/min respectively for all samples. For convenience, the samples were labelled as 1, 2, 3 and they are listed in table1.

sample	Axial force(kN)	Spindle Speed(RPM)	Travel Speed (m/min)
1	5	400	35
2	5	600	35
3	4	600	35

Table 1: Processing Parameters for various sample

B. Specimen Preparation

The cross sections of the specimen were taken by cutting the specimen in slow speed cutting machine. The which had been cut cross sectionally were metallographically polished using 1/0, 2/0, 3/0, 4/0 grade papers respectively followed by disc polishing with diamond paste as abrasive medium and kerosene as polishing medium. Properly dried samples were then etched by using 3 % Nital solution.

C. Characterization Techniques

The surface morphology of the films was examined by Scanning Electron Microscope, (SEM). Compositional analysis was done by energy dispersive spectroscope (EDS) attached to SEM.Graphical analysis was done using ORIGIN PRO software. IMAGE J software was used for width measurements of scratches.

D. Microhardness

Microhardness measurements were carried out using Schimadzu (HMV-G 20ST) microhardness testing machine, in which Vicker's diamond indenter was used.

E. Scratch Hardness

Scratch hardness measurements were carried out using Ericson scratch testing machine. Carbide tool of 1 mm tip diameter was used for scratch with a stroke length of 2 cm and scratch velocity of 35 mm/sec. indenter for all measurements. Fig.1 showed the Ericson scratch testing machine & Indentor.

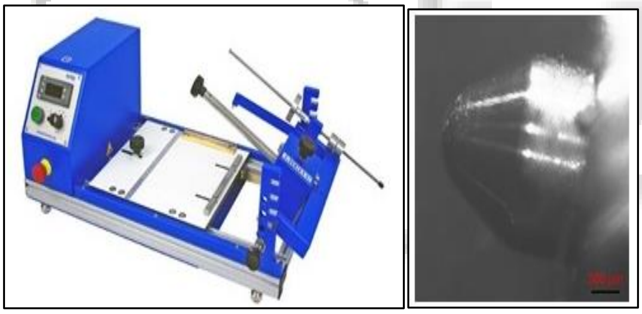


Fig. 1: Ericson scratch testing machine & Indentor

V. RESULTS AND DISCUSSIONS

A. Microhardness Test

Micro hardness measurements were taken across the interface of Al deposit on mild steel substrate. The load used was 25 gf and a dwell time of 15 seconds for all the measurements was used. Similar procedure is followed for all the samples

1) Before Heat Treatment

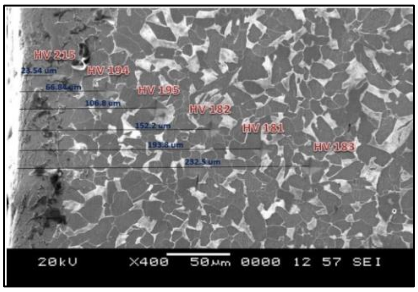


Fig. 2: Hardness measurements across substrate, before heat treatment

From the Fig.2 showed that hardness values tend to decrease towards the right. This can be due to the formation of intermetallic at the interface. During the Friction Surfacing, due to friction between tool and the substrate, the temperature rise is very high at the interface which can be attributed to the formation of intermetallic at the interface

2) After Heat Treatment (700 °C, 2 Hrs)

From the Fig.3 showed that hardness values tend to increase towards the right. After heat treatment, the grains of the substrate which are closer to the interface become coarser. This may be due to recrystallization of the grains after heat treatment. The grains become finer towards the right. This trend, we can see in the microstructure. Due to this trend in the microstructure, the hardness value becomes small near to the interface and large far from the interface.

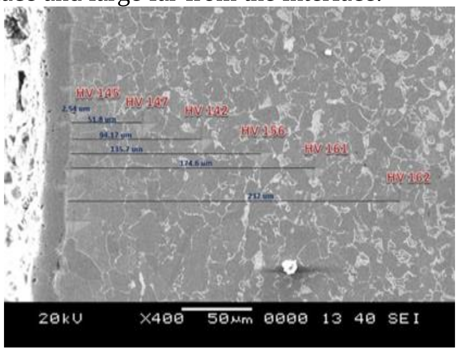


Fig. 3: Hardness measurements across substrate, after heat treatment (700 °C, 2 hrs)

3) After Heat Treatment (730 °C, 2 Hrs)

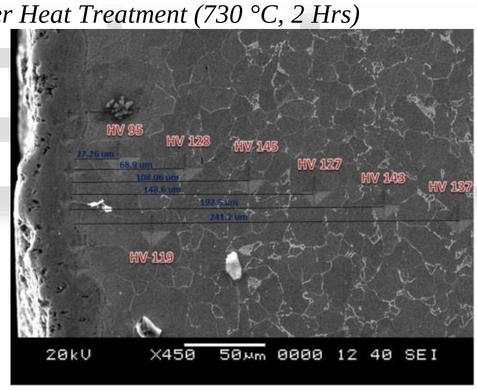


Fig. 4: Hardness measurements across substrate, after heat treatment (730 °C, 2 hrs).

Fig.4 showing that similar trend of variation in hardness values as 700 °C heat treated sample. Due to this trend in the microstructure, the hardness value becomes small near to the interface and large far from the interface

B. Coating

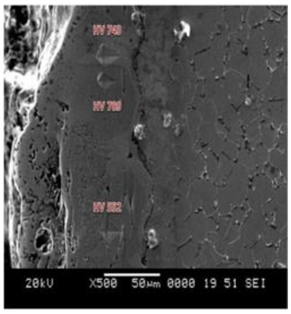
1) Before Heat Treatment

The micro hardness values of the Al coating for all samples were measured. The load used was 50 gf and a dwell time of 15 seconds for all the measurements was used.Table2 showed that various samples and corresponding micro hardness value.

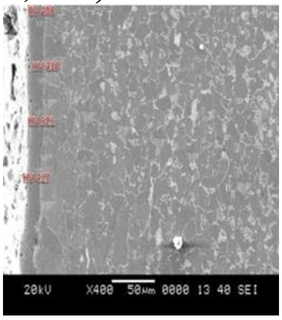
Sample Name	Microhardness Value (H_v)
Sample – 1	71
Sample – 2	79
Sample – 3	76

Table 2: Micro hardness values of all samples before heat treatment

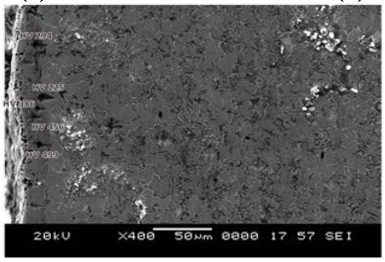
2) After Heat Treatment (700 °C, 2 Hrs)



(a)



(b)



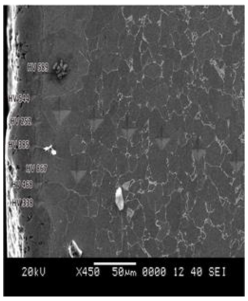
(c)

Fig. 5: Hardness measurements on the coating after heat treatment at 700 °C, 2 hrs: (a) Sample – 1 (b) Sample – 2 (c) Sample – 3.

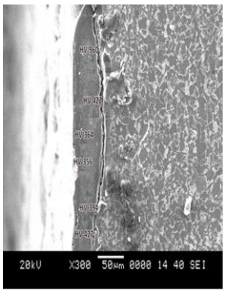
Fig5 showed that Hardness measurements on the coating after heat treatment at 700 °C, 2 hrs. After heat treatment, very high hardness values are found on the coating. This can be due to the presence of various intermetallic compounds on the coating after heat treatment.

3) After Heat Treatment (730 °C, 2 Hrs)

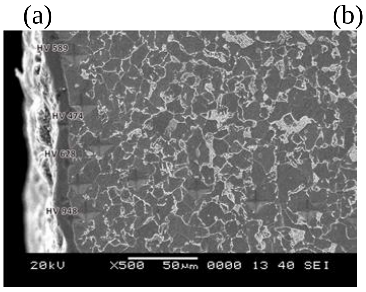
Micro hardness measurements were taken on the Al coating. The load used was 25 gf and a dwell time of 15 seconds for all the measurements was used. Fig6 showed that Hardness measurements on the coating after heat treatment at 730 °C, 2 hrs. After heat treatment, very high hardness values are found on the coating. This can be due to the presence of various intermetallic compounds on the coating after heat treatment.



(a)



(b)



(c)

Fig. 6: Hardness measurements on the coating after heat treatment at 730 °C, 2 hrs: (a) Sample – 1 (b) Sample – 2 (c) Sample – 3

The hardness values of various intermetallic compounds are shown in the table3 below. With the help of this table, we can identify the corresponding intermetallic compound with respect to the hardness value obtained on the coating

Phases	Vicker's Hardness Value Range
FeAl(β2)	(491-667)
Fe_3Al(β1)	(344-368)
$FeAl_2$(δ)	(1058-1070)
Fe_2Al_5(ε)	(1000-1158)
$FeAl_3$	(772-1017)

Table 3: Vicker's Hardness value range of various Fe-Al inter metallics

C. Scratch Testing

1) Before Heat Treatment

Before heat treatment, the normal load is varied as 2N and 8N.Table3 showed that scratch hardness values of all samples after heat treatment

Sample Name	Load (N)	Width (µm)	Scratch Hardness, H_s (GPa)	Avg. H_s (GPa)
Sample – 1	2	92.85	0.59	0.625
	4	150.4	0.45	
	6	150.9	0.67	
	8	160.1	0.79	
Sample – 2	2	95	0.565	0.563
	4	124.7	0.655	
	6	157	0.621	
	8	224	0.41	
Sample – 3	2	101.4	0.5	0.713
	4	121	0.69	
	6	140.5	0.77	
	8	151	0.89	

Table 3: Scratch hardness values of all samples before heat treatment.

2) After Heat Treatment

After heat treatment, the normal load is varied as 8N and 10N. It has been observed that, after the heat treatment, the scratch hardness values were observed almost doubled compared to the previous scratch hardness values of non-heat treated samples. Table4 showed that scratch hardness values of all samples after heat treatment

Sample Name	Load (N)	Width (µm)		Scratch Hardness, H_s (GPa)		Avg. H_s (GPa)	
		700 °C	730 °C	700 °C	730 °C	700 °C	730 °C
Sample – 1	8	127.8	120.5	1.25	1.41	1.2	1.64
	10	148.4	115.8	1.15	1.86		
Sample – 2	8	107.5	100.7	1.76	2.01	1.9	1.89
	10	112	120.5	2.03	1.76		
Sample – 3	8	114.3	115.5	1.56	1.53	1.81	1.45
	10	111	136.8	2.06	1.36		

Table 4: scratch hardness values of all samples after heat treatment.

VI. Conclusion

- Commercial aluminum was used as consumable tool(diameter: 20 mm, 95 mm length) for coating on mild steel substrate of dimensions of 150 mm x 210 mm x 8 mm (thickness) with a roughness varying from 5-7 µm by Friction Surfacing.
- Friction surfacing was done with two spindle speeds, i.e., 400 and 600 rpm, two loads, i.e.,4 kN and 5 kN. Out of these, sample processed using 5 kN load and speed 400 rpm, gave a deposition which was continuous and uniform in width. Slight tool bulge was observed.
- Sample processed using 5 kN load and speed 600 rpm, gave a deposition which was also continuous and uniform in width. But high tool bulge and condensing of coating material was observed. Sample processed using 5 kN load and speed 600 rpm, gave a deposition which was better than 1st and 2nd samples in appearance and less tool bulge was noticed.
- Before heat treatment: No intermetallics were found in the coating before heat treatment.
- After heat treatment: Fe-Al intermetallics were found in the coating and the mechanical properties such as micro hardness and scratch hardness of the coating were found more compared to the non-heat treated samples.

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