Experimental Investigations of Ni/La_2O_3 Composite Micro-Cladding on AISI 1040 Steel through Microwave Irradiation

Arbind Prasad[1*], Dheeraj Gupta[2], M. Ravi Sankar[1], A. Naryana Reddy[1]

[1*]Department of Mechanical Engineering, IIT Guwahati, Guwahati, 781039, India
[2] Department of Mechanical Engineering Thapar University, Patiyala, 147004, India
[1*] arbind.geit@gmail.com, [2]guptadheeraj2001@gmail.com,[1]evmrs@iitg.ernet.in, [1]annem@iitg.ernet.in

Abstract

AISI 1040 steel is widely used material in most of industrial manufacturing applications. In order to meet the increasingly demanding stringent operating conditions, the functional surface of the concerned components which are made of AISI 1040 are modified in such a way that they can sustain in the aggressive environment. In this paper cladding of Ni/La_2O_3 composite powder (particle size ~40µm) has been done through microwave irradiation. This processing has been explored for enhancement of surface properties of AISI 1040 steel. The favourable property of microwave processing is that the volumetric nature of heating of the material results in uniform thermal gradient, which yields uniform material properties in the processed materials. The developed Ni/La_2O_3 composite clad surfaces on AISI 1040 steel substrate was characterized using scanning electron microscope for surface morphology. The average thickness was observed to be ~500 µm and the developed Ni/La_2O_3 composite clad surface shows good metallurgical bonding with the AISI 1040 substrate material. The mechanical property such as hardness were also measured and found to be improved.
Keywords: Microwave, Cladding, SEM, Vicker's hardness

1 Introduction

Small scale, heavy mechanical industries (gas power plant, hydro power plant), automobile industries, defence industries and aviation industries are suffering by failure of component. Sometimes it is also observed that the component which was failed due to these reasons were very much costly and that also take too much time to manufacture because of complex geometry or replacement not possible. To prevent from these problems, either we have to redesign the component taken into consideration of wear, corrosion, oxidation etc, so that purpose get solved or we have to modify the surface property of component so that the specific components would able to resist wear and withstand against the forces acting on it (Aggarwal, 2010).which is known as surface engineering. In these days, surface treatment of the metallic surface of an engineering component is done by either of these processes like improving the chemistry of the surface, surface metallurgy or cladding process(Gupta *et al*.(2012) (Clark *et al.* (2000). There are also so many technologies available to challenge the surface wear which is available mentioned in table 1 along with their primary property benefits.

Table 1 Surface treatment method along with their primary property benefits (Gupta & Sharma, (2011)

S. no.	Surface treatment methods	Primary property benefits
1.	Nitriding	Used primarily for steels for improved wear resistance, increased fatigue resistance.
2.	Carbonitriding	Used primarily for steels for improved wear resistance.
3.	Carburizing	Used primarily for steels for increased resistance to wear.
4.	Physical vapor deposition(PVD)	Improved wear and corrosion resistance.
5.	Chemical vapor deposition(CVD)	Improved wear (eg. tools and dies) ,erosion and corrosion resistance.
6.	Thermal spraying	Primarily used for improved wear resistance and corrosion resistance .

Now in recent years, applications of microwave energy for materials processing has emerged as a novel and innovative technology with many advantage over conventional processing techniques such as reduction in process time, cycle time, resulting in to a substantial energy and cost saving Aggarwal (2010) (Thostenson & Chou, (1999).

2 Introduction to the Microwave

Microwaves are electromagnetic waves in the frequency band from 300 MHz to 300 GHz. The frequencies 2.45 GHz Frequencies are commonly chosen for the microwave heating based on two reasons. The first is that they are in one of the industrial, scientific and medical (ISM) radio bands set aside for non-communication purposes. The second is that penetration depth of microwave is greater for these low frequencies.

3 Interaction of Microwave on Materials

Energy is transferred to materials by interaction of the electromagnetic fields at the molecular level, and the dielectric properties ultimately determine the effect of the electromagnetic field on the material. The microwaves couple directly with the molecules leading to rapid but controllable rise in the temperature (Sharma *et al.*(2001). Two fundamental mechanisms for transferring energy from microwaves to the substance being heated are the dipole rotation and the ionic conduction. Dipole rotation is an interaction between polar molecules, which try to align themselves with the rapidly changing electric field of the microwaves, resulting in transfer of energy. It is related to polarity of the molecules and their ability to align with the electric field. Ionic conduction results if there are free ions or ionic species present in the substance, which try to orient themselves to the rapidly changing electric field, generating ionic motion(Clark *et al.* (2000).The interaction of microwaves with materials has been shown in figure 1.

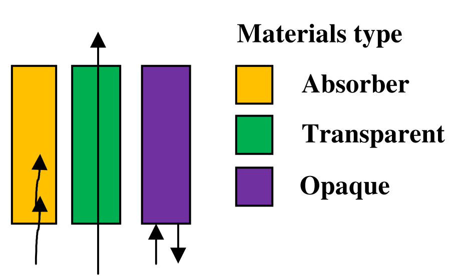

Figure 1 Material type and their penetration phenomenon during exposure of microwave

This can be classified into the following categories.

3.1 Opaque materials

These are typically conducting materials with free electron, such as metals, that reflect and do not allow electromagnetic waves to pass through(Thostenson & Chou, (1999).

3.2Transparent materials

These are low dielectric loss materials or insulating materials, such as glass, ceramics and air which reflect and absorb electromagnetic waves to a negligible extent and allow microwaves to pass through easily with little attenuation(Thostenson & Chou, (1999).

3.3 Absorbing materials

It consists of materials whose properties range from conductors to insulators. They are usually referred to as 'lossy dielectrics or high dielectric loss materials'. These materials absorb electromagnetic energy readily and convert it to heat (Sharma & Gupta(2012).

The main reason for this present little work in microwave heating/sintering of metal was due to misconception that all metal reflects microwave and/or cause plasma formation. Hence it cannot treated/heated in microwave field. Now it has been proved that all metallic materials in powder form do absorbs microwave at room temperature(Srinath *et al.*(2011).

4 Experimental Procedure

In this paper, Metallic Substrate is AISI 1040 steel. which is normally considered to have carbon contents up to 0.25% C with about 0.4 to 0.7% Mn, 0.1 to 0.5% Si, and some residuals of sulfur, phosphorus, and other elements. AISI 1040 steel is used in almost all forms of industrial applications and industrial manufacturing. It is a cheaper alternative to steel, lowest cost and should be considered first. Hard facing powder is Ni/La_2O_3 composite powder, an inorganic compound containing the rare earth element lanthanum and oxygen. Nickel is a silvery-white lustrous metal with a slight golden tinge. Nickel is characteristically tough metals and has high oxidation and corrosion resistance at room and elevated temperature.

4.1 Sample Preparation

For the cladding, the substrates were cut into average size of 10mm×10mm pieces. The approximate dimensions of the substrates were 10mm×10mm× 5mm. Then the substrates were polished by emery papers (80, 120, 400, 800, 1x, 2x and 3x) in order to get artificial texture.

4.2 Development of Cladding

In the present work, AISI 1040 steel substrate were cleaned in acetone in weaker for 5 minutes prior to deposition .The nickel based lanthanum oxide composite powder particle of average size 40µM were preheated at 100^0c for 24 hours in a conventional muffle furnace .Preheating removes possible moisture in the powder. The powder was preplaced manually on AISI 1040 steel substrate. After this, graphite flake of same dimension with thickness approximate 1mm was kept over the powder. Lastly fine powder of charcoal was also used as a susceptor. The whole arrangement has been shown by figure 2.

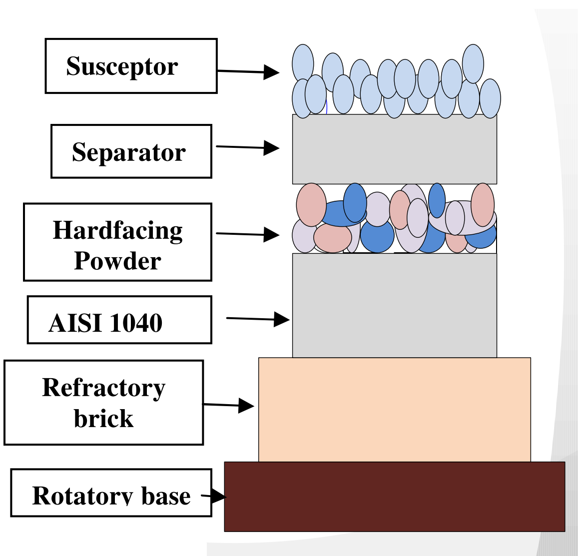

Figure 2 Schematics of development of cladding inside microwave cavity

5 RESULTS AND DISCUSSION

In order to develop, Ni/La_2O_3 composite cladding on AISI 1040 steel, the powder of Ni/La_2O_3 Composite having an average particle size of 40µm was used. Microwave cladding of Ni/La_2O_3 composite powder was successfully carried out on AISI 1040 steel substrate using a domestic microwave oven at 2.45 GHz frequency and power 900 W. Experimental trials were carried out at constant power 900 W while varying interaction time from 90 s to 240 s. The corresponding observations are presented in table 2.

Table 2 Microwave processing equipment and conditions.

PARAMETER	DESCRIPTION
Microwave applicator	Multimode (make LG;Solardom)
Frequency	2.45 GHz
Exposure time	240 S
Exposure power	900 W
powders	Ni and La_2O_3
Preheating powder temperature	100^0C
Substrate	AISI 1040 steel (10mmx10mmx5mm)

It was observed that for a given powder particle size and microwave power the formation of cladding largely depend upon microwave exposure time. Microwave exposure time of 240 s was maintained throughout the cladding process. The processing parameter which was used during this process are presented in the table 3.

Table 3 Effects of microwave exposure with time

Trial	Processing time	Microwave Power (w)	Observations
1	30	900	No melting hence no cladding
2	90	900	Powders in red hot conditions
3	120	900	Partial melting of powder particles and poor bonding with substrate
4	220	900	Better melting of powder particles and poor bonding with substrate
5	240	900	Cladding with good metallurgical bonding

The back scattered electron (BSE) image of a typical transverse section of the Ni/La2O3 composite clad is shown in figure 3(a). The dense, uniform and homogenous cladding of the metallic deposit is shown by obtained surface morphology. This is the result of the volumetric nature of heating associated with microwave processing of materials.

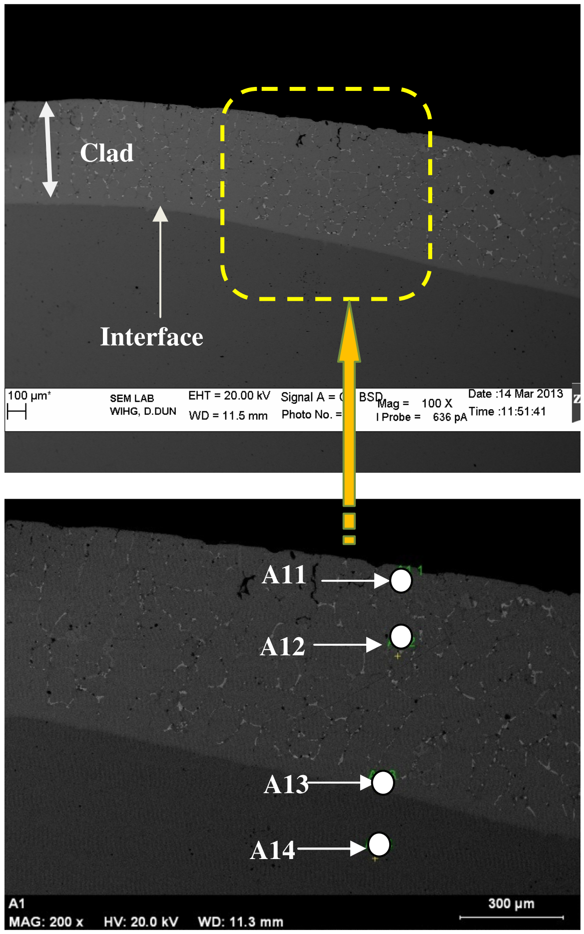

Figure 3 Scanning electron micrographs showing (a) typical transverse section of Ni/La_2O_3 composite clad and (b) indicative points on the Ni/La_2O_3 composite clad to show the elemental analysis.

Four points on the specimen were taken as A11, A12, A13 and A14 shown in figure 3(b) and observations were made on the basis of these points. Results of typical EDS spectra of metallic coating shows the presence of Nickel, Silicon and lanthanum peaks at their own energy bands (Figure 4-7). The metallic cladding also seems to have localized presence of diffused carbon (C-k energy bands) presence of oxygen (O-k) results in formation of oxides of iron owing to the fact that deposition process was open to the atmospheric contamination. Better coupling of microwaves in the powder layer is facilitated due to oxide formation. The weight percentage of each presence element is quantitatively shown in table 4-7, which indicates good metallurgical bonding with the base metals.

Table 4 Typical Elemental composition for the point A11

Point A11	
Element	Wt%
Iron	76.09
Nickel	18.97
Lanthanum	0.82
Silicon	4.12

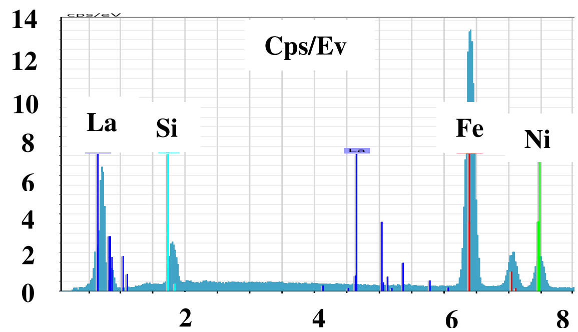

Figure 4 Typical EDS spectra for the point A11

Table 5 Typical Elemental composition for the point A12

Point A12	
Element	Wt%
Iron	74.63
Nickel	22.10
Lanthanum	0.57
Silicon	2.09

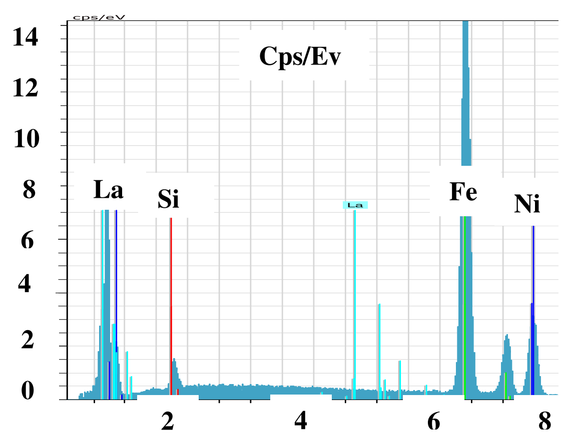

Figure 5 Typical EDS spectra for the point A12

Table 6 Typical Elemental composition for the point A13

Point	A13
Element	Wt%
Iron	83.38
Nickel	14.75
Lanthanum	0.44
Silicon	1.42

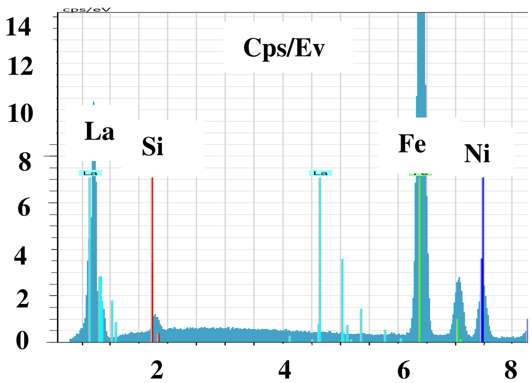

Figure 6 Typical EDS spectra for the point A13

Table 7 Typical Elemental composition for the point A14

Point	A14
Element	Wt%
Iron	98.27
Lanthanum	1.73

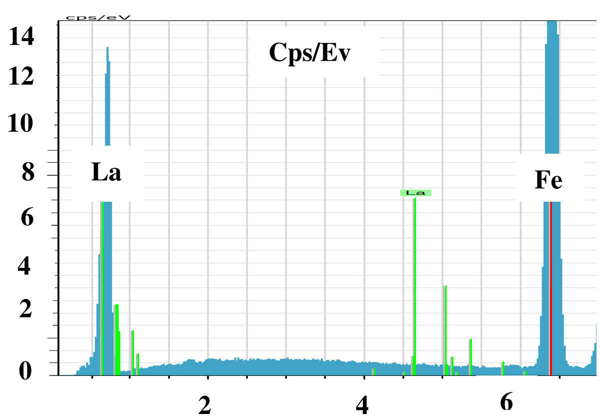

Figure 7 Typical EDS spectra for the point A14

4.3 Microhardness study

Hardness of a material is one of the most important factor, which influences wear performance of the material.The Vicker's microhardness of clad layer over the cross section has been evaluated. Microhardness of the transverse section of cladding and substrate were evaluated at the load of 25 gm applied for 30 s . The indentation were made at the interval of 120 µm starting from the top of the clad to substrate material. The distribution of microhardness is shown in figure 8.

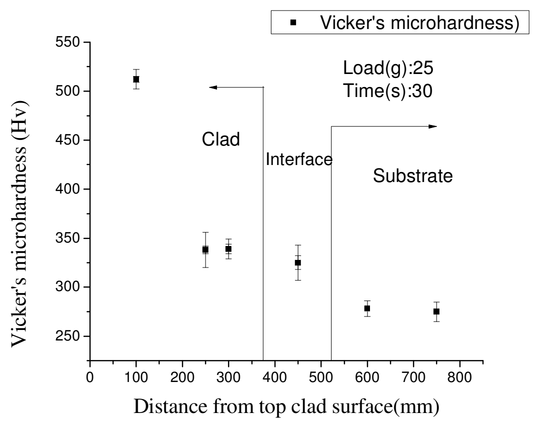

Figure 8 Vicker's microhardness profile at various zones

The average microhardness of the clad section is 337 Hv. The distribution of microhardness in the clad section is observed to be non uniform. An increasing tendency in hardness away from the substrate is seen. The microhardness from the second point to the half of the clad is approximately uniform. Which however reduces and approaches ~320 Hv at the clad substrate interface. The observed high micro hardness in the clad could be attributed to the presence of hard nickel phase. However, as observed from the figure 8, the drop in the clad hardness from second point to the interface point is due to reduction of metallic density. The micro hardness at the interface was found to be about 319 Hv

5 Conclusions

In this present paper, investigations of Ni/La_2O_3 composite micro-cladding on AISI 1040 steel through microwave irradiation has been successfully described. Microwave cladding on metallic materials demonstrated a route for surface modification of poor wear resistant materials. The conclusion can be made as following

- It is possible to clad bulk metallic material (for example, AISI 1040 steel) with different hardfacing powder(for example, Ni/La_2O_3)
- The clad thickness~500µm has been developed by exposure of microwave irradiation at 2.45 GHz frequency and power 900 W for the duration of 240 seconds.
- The averaged Vicker's microhardness of developed clad was observed 319 Hv.

References

Aggarwal,D.(2010),Latest Development in microwave materials process, *Journals of materials research innovation*,vol.1, pp. 3-7.

Chandrasekaran, S., Tanmay, Basak, Ramanathan, S. (2011),Journal of material processing technology,vol.211,pp. 482-487.

Clark, D. E., Folz, D. C., & West, J. K. (2000), Processing materials with microwave energy, *Materials Science and Engineering: A*, vol.*287*(2),pp. 153–158.

Engene, Wong., wai, leong and gupta Manoj. (2010),Characteristic of aluminum and magnesium based nanocomposites processed using hybrid microwave sintering. J*ournal of microwave power electromagnetic energy*,vol.44(1),pp.14-27.

Gupta, D., Bhovi, P. M., Sharma, A. K. & Dutta, S. (2012). Development and characterization of microwave composite cladding. *Journal of Manufacturing Processes*, vol.*14*(3), pp.243–249.

Gupta, D., & Sharma, A. K. (2011), Development and microstructural characterization of microwave cladding on austenitic stainless steel, *Surface and Coatings Technology*, vol.205(21-22), pp.5147–5155.

Gupta, D., & Sharma, A. K. (2011), Investigation on sliding wear performance of WC10Co2Ni cladding developed through microwave irradiation, *Wear*, vol.271(9-10), pp.1642–1650.

Manchanda, V K (2008), Material & Metallurgy, ,*Khanna pub*,pp.254 .

Srinivasan,R (2009),Engineering materials and Metallurgy , TMH Pub, pp. 217-221

Sharma, A. K., Aravindhan,S. and Krishnamurthy,R.(2001),Microwave glazing of alumina–titania ceramic composite coatings, Materials Letters ,vol.50 pp. 295-301.

Sharma, A. K., & Gupta, D. (2012). On microstructure and flexural strength of metal–ceramic composite cladding developed through microwave heating. Applied Surface Science,vol.258(15), pp.5583–5592.

Srinath, M. S., Sharma, A. K., & Kumar, P. (2011), A new approach to joining of bulk copper using microwave energy. *Materials & Design*, vol.*32*(5), pp.2685–2694.

Sutton W H. (1996), Microwave processing of materials, *Annual Review of material science*.

Thostenson, E. T. and Chou, T. W. (1999), Microwave processing: fundamentals and applications, *Composites Part A: Applied Science and Manufacturing*, vol.30, pp.1055–1071.