Evaluation of Erosion Behaviour of Ni based Cladding Developed Through Microwave Energy

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***Abstract*— The SS-304 material is used as turbine blades in some of the hydraulic power plants. In the present work microwave cladding technique was progressed for enhancement of surface properties of Stainless steel (SS-304). The experiments were conducted in domestic microwave oven with the help of Al_2O_3 shield. The clad of thickness, approximately 1 mm was developed by microwave exposure at frequency 2.45 GHz. The developed clads were characterized using FE-SEM, EDS, Vicker's microhardness. Microstructural study reveals that there is a metallurgical bond with substrate. Chromium was observed segregated around the cell boundaries while iron and nickel were identified inside the cells. The average microhardness of 364±70 H_V was observed on the microwave clads.Erosion studies were also conducted on cladded samples. The result ensures wear rate of developed clad surface increases, with increase in rotational speed, duration of test, particles size.**

Keywords*— *Microwave Cladding, Nickel, SS-304, SEM, slurry erosive wear.

I. INTRODUCTION

In the modern industrial world, engineering components are being subjected to increasingly demanding environments. This has made the components prone to more rapid degradation due to mechanisms such as wear, corrosion and oxidation. To full fill numerous industrial applications, an effort to achieve enhanced performance in terms of productivity and efficiency, surface treatment technologies are economical processes as they present a cost-effective way to prevent degradation modes such as the above without sacrificing the bulk properties of the component material. Among the entire surface phenomenon, the problem of wear is of high concern in most of the industrial components. Several forms of wear such as adhesive, abrasive, dry and wet erosion do exist. However, erosion due to cavitations has significant importance in determining the service life of the major components in Hydraulic turbines such as turbine blades of hydro electric power plants and pump impeller.

Cladding is the bonding together of dissimilar materials in metallurgical process. The present work is aimed at developing microwave cladding and investigating the effect of speed, slurry concentration and particle size on Nickel based (EWAC) cladding on Stainless Steel (SS-304) subjected to slurry erosion with the help of Design of Experiment (DOE).The developed cladding is subjected to slurry erosive wear tests to withstand as against erodent.

The clad developed through conventional process contain semi molten powder particles owing to which microstructural defects like porosity and cracks are comparatively more [1,2].The bonding strength of clad developed through conventional process has less than cladding[1]. Laser cladding has been one of the most popular surfacing techniques [1-3]. The laser processing too has some limitations including high distortion, porosity and interface cracking apart from associated in laser cladding process causes non uniform microstructure owing to which clad shows anisotropy in mechanical properties.

A. *Microwave processing of materials:*

Microwave heating/processing of materials largely depends on dielectric and magnetic properties of the materials being processed. Microwaves can be reflected, absorbed and/or transmitted by materials. Reflection and absorption require interaction of the microwaves with the material; while transmission is the result of partial reflection and incomplete absorption. In microwave processing, the heat is generated internally within the material instead of originating from external sources. 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. Heating is rapid as the material is heated by energy conversion rather than energy transfer. There is a 100% conversion of electromagnetic energy into heat. Microwave interaction is through either polarization or conduction process.

Microwave cladding process has recently been explored as a potential cladding technique to enhance surface properties of a target material [4-6]. It was claimed that the novel process possesses high potential to emerge as one of the pragmatic surfacing solutions. Reasonably higher speeds of processing and higher degree of processing uniformity are some of the significant features of this process. The volumetric nature of heating and reverse thermal gradient is the major significance of the process [4-6] owing to which the clad produced through microwave heating exhibit significantly lesser thermal distortion, and are nearly free from solidification cracks and pores. Up to the year 2000, microwave processing was mainly confined to sintering and joining of ceramic and ceramic composites. Ceramic and ceramic composites are good absorbers of microwave radiations at room temperature, consequently, thus couple with microwave at a faster rate and can be performed in a lesser time than conventional methods.

The enhanced properties by microwave processing method are better than conventional processing method [7-12].

Table1. Advantages of Microwave Heating over Conventional Heating.

Microwave Heating	Conventional Heating
Energy transfer	Heat transfer
Non contact heating	Conduction or radiation heating
Rapid heating possible	Heating rate limited by thermal diffusion
Volumetric heating	Surface heating
Energy may be transported to material through hollow wave guide	Heat must be transmitted by medium to material causing heat loses.

II. LITERATURE REVIEW

In history of microwave application for heating, metal heating had been a minor application area, because the bulk metals are not possibly heated well, different from other materials, such as food, organics, and some kinds of ceramics. But in recent times, the utilization of microwaves for processing of metal powders and metal parts is an unexpected and rapidly developing method. In recent years microwave processing of metal/alloys have gained a considerable potential in the field of material synthesis. Microwave heating is recognized for its various advantages such as: time and energy saving, very rapid heating rates, considerably reduced processing cycle time and temperature, fine microstructures and improved mechanical properties better product performance. One of the reasons for the initial slow development of microwave technology for industrial applications was perhaps incomplete understanding of mechanisms involved. For many years the way microwaves interacted with a given material was not understood, and even now, research is continuing and new potential benefits associated with this technology are still being discovered. There various ongoing experimented on microwave heating of metals which are intended to prove how this technology could be a potential replacement in conventional heating techniques.

There have been various experiments conducted in the recent past on various mechanical processes like sintering, brazing, melting and joining etc. which have upheld the essence of microwave heating technology. The literatures available indicate the reliable and adequate knowledge on microwave heating and indisputably some of the best journals connected with this field.

Sintering of metallic materials with a composition of iron, copper and graphite (Fe+Cu (2%)+graphite (0.8%)) was first reported in the year 1999. The sintering was carried out at 1200 °C with an exposure to microwave radiation for 30 min which resulted in excellent sintered density. An innovative work carried out by Agarwal in sintering, brazing and melting was accomplished. The implications of application of microwave energy in processing metallic materials proved some advantages to be obvious in the fields of metallurgy. Joining of austenitic [stainless steel (SS 316) was successfully performed by Srinath et.al. In this joining of austenitic stainless steel was achieved while processing in a multimode microwave system. Metallurgical fusion in the joint area was almost complete and showed cellular like growth in the entire joint region which could be attributed to the rapid and volumetric heating throughout the joint with minimum thermal gradient. Micro-hardness in the interference region are significantly higher due to martensitic structure with carbide precipitation and preferential columnar grain growth.

The joint exhibited reasonably good tensile strength with significant elongation owing to superior melting of sandwich layer with subsequent interface bonding. It is observed from literature survey that no work has been carried out in the pertaining area of development of cavitation erosion cladding. This has prompted us to choose it as a challenging endeavour.

III. EXPERIMENTAL DETAILS

A. *Materials*

Grade SS-304 steel:

One of the most versatile and commonly used Stainless steels in the market is Grade 304 Stainless steel. Essentially, Grade 304 is an austenitic chromium alloy which is also known as an “18/8” Stainless as the alloy of the steel which is 18% chromium 8% nickel. SS-304 steel which is austenitic steel and has austenitic as their primary phase (face centered cubic crystal).

Chemical Composition:

The major elements of SS-304 are chromium and nickel and chemical composition of the SS-304 is as shown in Table (2).

Table2: Chemical Composition % of grade SS-304 steel

Composition	Cr	Ni	C	P	Mn	Si	S	Fe
Weight %	18-20	8-12	0.08 Max	0.045 Max	2.00 Max	0.75 Max	0.03 Max	Balance

Nickel based (EWAC) Powder:

In order to develop Nickel based cladding on austenitic Stainless steel EWAC powder is used. EWAC powder is having an average particle size of 40 μm diameter and the particles are largely spherical in shape. Composition of the EWAC powder is as shown in the Table (3).

Table3: Chemical Composition % of Nickel based (EWAC) Powder

Nickel	Chromium	Silicon	Carbon
96.83%	0.17%	2.8%	0.2%

B. Development of cladding:

Development of Nickel based cladding on SS-304 through microwave energy, schematic as shown Fig.1.

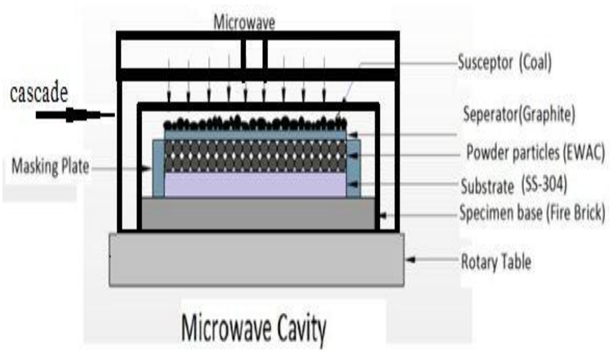

Fig:1. Schematic diagram of Experimental setup.

Preparation of raw powder and substrate is critical in development of cladding. The powder was preplaced manually on SS-304 substrate maintaining an approximately uniform thickness (1 mm). Melting of the powder was achieved in a domestic multimode microwave oven at the 2.45 GHz frequency and 900W power while exposed for 1380 s.

In the present investigation, experimental trials were carried out at the constant power 900W while varying interaction time from 600 s to 1380 s for a constant thickness of preplaced powder layer (approximately 1 mm). The corresponding observations are presented in Table4. It was observed that the cladding process (melting and dilution) largely depends on microwave exposure (interaction) time because temperature raise of the nickel powder is directly proportional to the exposure time.

Table4: Microwave exposure time and its effect on cladding.

Trial	Processing Time (s)	Observation
1	600	No melting, hence no cladding
2	900	Partial melting of the powder particles and poor bonding with substrate
3	1080	Better melting of the powder particles, poor bonding with Substrate
4	1380	Cladding with good metallurgical bonding

C. *Characterization of the Clads:*

The developed clads were subsequently washed thoroughly with acetone in order to proceeding for characterization. The prepared clad samples were cut along the clad thickness at the center using a low speed diamond cutter (Model: BAINCUT - LSS, Make: Chennai Metco, India). The clad samples were polished by different grades of SiC, and finally with 1µm diamond paste. The clad samples were then cleaned by water and dried in hot air. Etching is done prior to the microstructure analysis; the specimens were immersed in etchant for about 15 seconds.

The microstructure and chemical composition of the prepared clad samples were analyzed in a scanning electron microscope at an acceleration voltage of 20 kV equipped with energy dispersive x-ray detector (Make: FEI, Model: Quanta 200 FEG). The microhardness tester (Mini load, Leitz, Germany) was used to measure the hardness at the load of 50g for 10 s, applied on the clad samples and substrate. The distance between two successive indentations; of an interval of 125 µm was maintained for the measurement of Vicker's hardness.

IV. RESULTS AND DISCUSSION

The experimental trails were conducted at different exposure time of microwave radiation from 600 s to 1380 s; and the cladding achieved at exposure of 1380 s, the obtained clads were found well metallurgically bonded with the substrate. Results of various characterization method employed are discussed in the following sections.

A. The Study of Microstructure:

The cross section of the prepared clad samples were observed through scanning electron microscope is shown in Fig. 1. The developed clad is metallurgically bonded with the substrate by partial mutual diffusion of elements. Microwave heating is known for molecular heating whereby entire volume of exposed material is heated simultaneously (volume heating). The volumetric heating causes the exposed materials to get rapidly heated to elevated temperature with less thermal grdient.

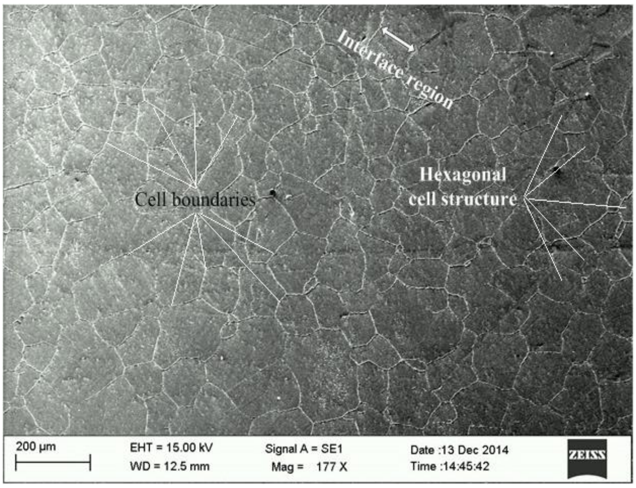

Fig: 2. Microstructure of nickel based clad cross section.

The microstructure of clad cross section shows no transition from cellular to dendrites which are one of the major significances of the process. This is attributed to volumetric nature of heating in which the resultant mean temperature profile is relatively uniform throughout the volume of the target material. In MHH, however, the relatively uniform temperature profile reduces the possibilities of non-uniformity in the resulting micro structure as microwave cladding process is relatively faster (maximum exposure time: 1080s only). The SEM micrograph (Fig.2) of clad section represents the planner growth of nickel based clad, following which the entire clad exhibits cellular structure. The elemental distribution from the clad surface was analyzed through EDS; the typical results are shown in Fig.3.

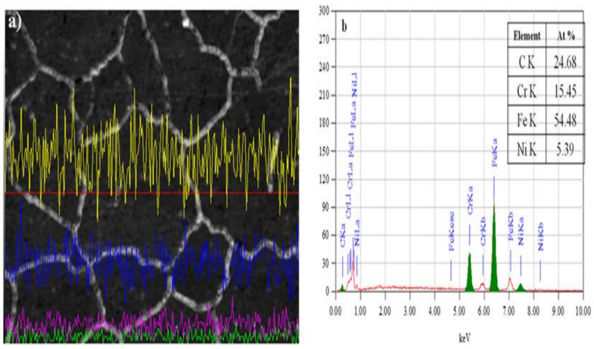

Fig: 3. Typical EDS analysis of the (SS-304): (a) SEM image showing location of EDS analysis, (b) EDS spectrum of clad with corresponding chemical composition.

The EDS study of the line scanning showed that iron and chromium from the substrate (SS304) got partially diluted to the clad during microwave hybrid heating by way of convection current of the melt-pool which helps in formation of metallurgical bonds. The diluted chromium had further effected with carbon and formed chromium carbide. The increased chromium level is also attributed to the formation of chromium carbide as identified in the clad in two phases Cr3C2 and $Cr_{23}C_6$ and discussed in Fig.3.

B.*Study of Microhardness:*

The prepared clad cross section was tested through Vicker's microhardness by maintaining a distance of 125µm between two indentations (Vicker's) and also some other indentations on the interface and the substrate. The mean average was considered for every five indentations. The average microhardness of the developed clad is 364±70 H_v and that of the SS-304 substrate microhardness is 215 H_v. The microhardness checked at the interface is 251H_v.The elemental studies (in Fig. 3) clearly showed that the clad microstructure constitutes various phases like hard chromium carbides, inter-metallic's and even soft free carbon. The distribution of microhardness is illustrated Fig. 4.

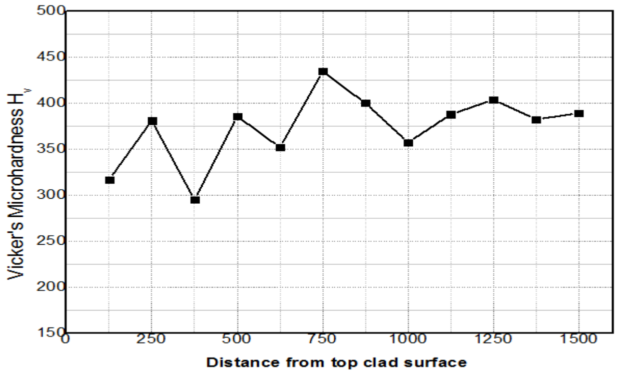

Fig: 4. Identifications of Vicker's microhardness across a section of Nickel based clad.

Figure.4. shows that in the clad section, the distribution of microhardness is not uniform, which is due to the presence of different phases of varying microhardness. The indentation mark on the clad is shown in Fig.5.

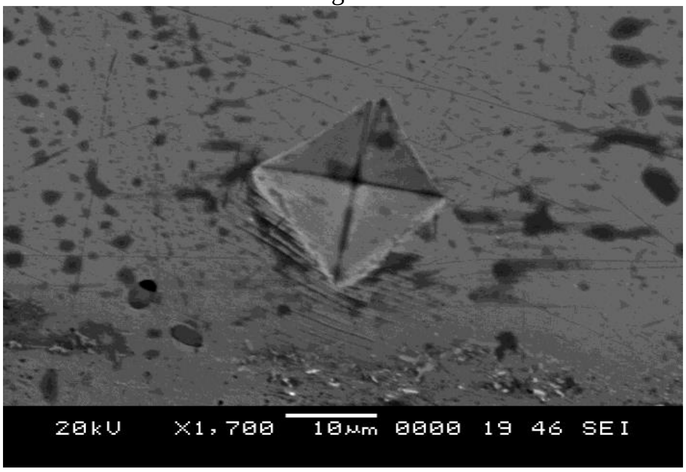

Fig: 5. Vicker's indentations on a clad section.

C. Slurry erosion test:

The slurry erosion tests were performed through slurry pot tester with various parameters, such as duration of test, impinging particle size and rotational speed. The wear rate for all the parameters were calculated and compared by plotting graphs for all the parameters. It has been observed the results varied from one parameter to the other. Erosion wear of the samples is calculated on the basis of their mass loss in milligrams. The developed microwave clad samples were weighed at weighing machine of 0.0001 accuracy. The variation of weight loss with different speed is illustrated in Fig.6.

Increased mass loss with increase in silica sand concentration can be attributed to fact that, the higher the concentration of sand particles in the slurry, higher will be probability of sand impingement on the surface of target material irrespective of the particle size. This in turn results in increased deterioration of material from its surface. Further, with increase in concentration of solid mass in the slurry, probability of interactions between the sand particles and the target surface will be higher leading to larger material removal from the target surface. The worn surface of clad shown in fig.7.

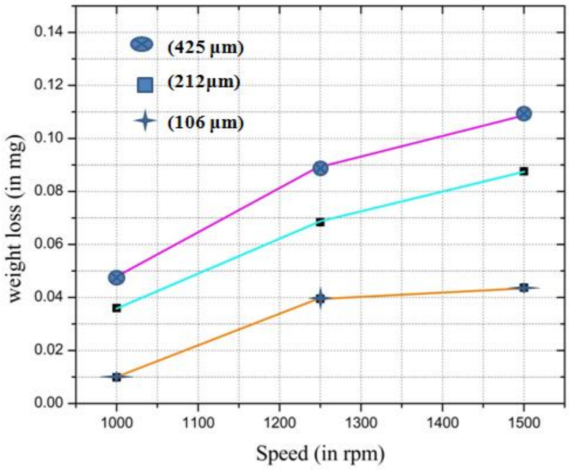

Fig: 6. Weight loss of clad with different speed.

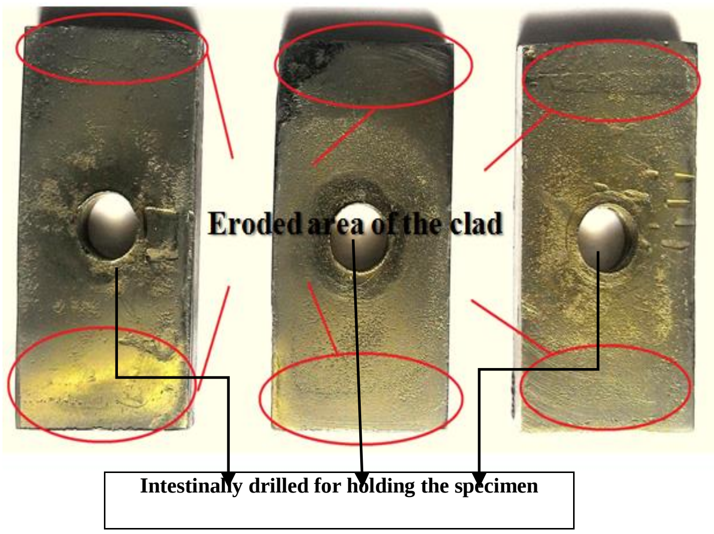

Fig: 7. Eroded samples of microwave Ni based clad.

V.CONCLUSION

The major conclusions drawn from the present work can be summarized as follows.

- A novel surface engineering approach in the form of microwave cladding has been discussed.
- The metallic nickel based powder could be melted by using domestic microwave oven with power 900W at frequency 2.45GHz to cause the dilution and form the clad.
- The controlled dilution of elements (substrate or/and clad) results in good metallurgical bonding of the molten particles with the substrate.
- The prepared clads exhibit reasonably uniform solidification microstructure.
- The phases of NiSi, $FeNi_3$, and carbides of chromium, intermetallic are formed during microwave cladding using hybrid heating.
- The average microhardness of the clad section is 364±70 H_v, which is due to the formation of carbides and intermetalic.
- The slurry erosive wear rate of developed clad increases with increase in duration of test, rotational speed of slurry,and size of impinging particles.

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REFERENCES

[1] A.K. Sharma and D. Gupta, A Method of Cladding/Coating of Metallic and Non-metallic Powders on Metallic Substrates by Microwave Irradiation, Indian Patent Application no. 527/Del/201025.
[2] D. Gupta and A.K. Sharma, Development and Microstructural Characterization of Microwave Cladding on Austenitic Stainless Steel, Surf. Coat. Technol., 2011, 205, p 5147–5155
[3] Agrawal D, Roy R, Cheng J, and Gedevanishvili S, 1999, Full sintering of powdered metal parts in microwaves, Nature, Vol. 399, pp. 668-670.
[4] A.K. Sharma, M.S. Srinath, and P. Kumar, Microwave Joining of Metallic Materials, Indian Patent Application no. 1994/Del/2009
[5] Srinath M.S., Sharma A.K. and Kumar P., 2011, A new approach to joining of bulk copper using microwave energy, Materials and Design, Vol. 32, No. 4, pp. 2685-2694.
[6] A.K. Sharma, S. Aravindhan, R. Krishnamurthy, Mater. Lett. 50,(2001),295.
[7] Shengfeng Zhou, Xiaoyan Zeng, Hu. Qianwu, Yongjun Huang, Appl. Surf. Sci. 255, (2008), 1646.
[8] Sharma Kr Apurbba, R. Krishnamurthy, J. Eur. Ceram. Soc. 22, (2002), 2849.
[9] Y. Sun, T. Bell, Wear. 253, (2002), 689.
[10] E.T. Thostenson, T.W. Chou, Composites (Part A). 30,(1999),1055.
[11] Morteza Oghbaei, Omid Mirzaee, J. Alloys Compd. 494, (2010),175
[12] David E. Clark, Willard H. Sutton, Annu. Rev. Mater. Sci. 26, (1996), 299.
[13] David E. Clark, Diane C. Folz, Jon K. West, Mater. Sci. Eng. A. 287, (2000), 153.
[14] J. Cheng, D. Agrawal, Y. Zhang, R. Roy, J. Mater. Sci. Lett. 20, (2001), 77.
[15] J.G. Fisher, S.K. Woo, K. Bai, J. Eur. Ceram. Soc. 23, (2003), 791.
[16] Chris Y. Fang, Clive A. Randal, Lanagan T. Michael, Dinesh K. Agrawal, J. Electroceram. 22,(2009),125.
[17] Leonelli, P. Veronesi, L. Denti, A. Gatto, L. Iuliano, J. Mater. Process. Technol. 205, (2008), 489.