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Microstructural characterisation of microwave cladding on stainless steel

Partial dilution of clad powder and the substrate to form a new protective layer is called cladding. The present article focuses on the development of a novel surface modification technique for better resistance to wear/erosion using microwaves as a source of heat. Clads of MoCoCrSi/flyash were produced on austenitic stainless steel (SS-316) using microwave irradiation. Composite clads were established by irradiating microwaves at 2.45 GHz frequency and power of 900W using a domestic microwave applicator for 42 minutes. Characterization of the developed clads was performed in the form of metallographic (microstructure) and mechanical (hardness) tests. Careful observation of the microstructures revealed uniform grain structures, free from defects on the surface of the cladded substrate. Further, no significant cracks were found on the transverse section of the clad, characterizing good bonding between clad particles and substrate. The developed clad demonstrates significantly higher hardness than the substrate.

Keywords: Cladding, microwave, composite powder, flyash

1.0 Introduction

Surface modification is a technique of changing the characteristics of the surface of a material in order to make them suitable for the desired application. Effective surface area is governed by morphology which is greater than the macroscopic geometrical area almost every time. Because the surface energy of liquids facilitates smooth surfaces, solid materials are usually manufactured from liquids. Surface modification can be achieved in many ways. Some of them include processes like chemical vapour deposition (CVD), physical vapour deposition (PVD), nitriding, cyaniding, cladding etc. Cladding is the most effective way of surface modification in which layer of material with desired properties for the required application is deposited on the surface of the substrate. The surface film governs most of the functional properties, apart from the morphology. Surface energy results when an attractive force is felt between the surface atoms. Cladding minimizes spallation and downstream erosion. It can also minimize material/component cost. Degradation of materials occurs because of interaction between the structural material and the exposure environment. These interactions are generally undesired chemical reactions that can lead to accelerated wastage and alter the functional requirements and structural integrity of the materials. To overcome the drawbacks of available surface modification techniques, microwave cladding can be used as a novel form of material processing which can serve with better prospects. Microwave cladding of stainless steel (SS-316) onto mild steel (MS) in bulk form has been carried out using a microwave applicator of 2.45 GHz frequency and a power of 900 W.

Microwave processing of materials is different from the conventional thermal processing methods. Microwave energy heats the material in molecular level, which eventually leads to uniform bulk heating. As the heating originates at the molecules throughout the bulk, the heating process is essentially faster than the known modes heating in which heating of the entire volume of the material depends on the conventional modes of heat transfer. In conventional heating systems, the material gets heated from the surface to the interior with associated thermal gradient which results in changes in microstructure with varying mechanical properties. Microwave heating, on the other hand, is well characterized by volumetric heating owing to which reduced thermal gradient, less residual stresses and thermal distortion on the target material have been observed while compared to other thermal processes. Thus, application of microwave energy as a source of heating in developing clad could be a cost-effective option in the material processing industry.

After studying the microstructure, well fused faying surfaces were revealed on either side of the base material. H_v was found to be the average Vicker's microhardness of the joint area of the core. The composition of the bulk material differs from the composition of the surface. The arbitrary wettability of the solid materials is allowed by the functional groups. Surface functionalization uses the processing of non-equilibrium gaseous plasma which is widely used [1, 2, 3]. The

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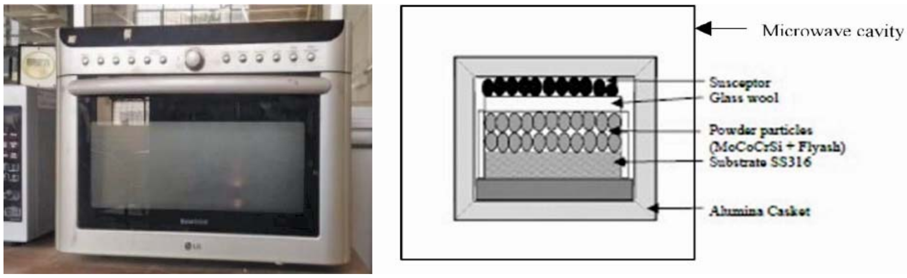
intent was to develop MoCoCrSi/flyash clads by MHH technique in order to make metal harder and characterize the development of clads for microstructure and hardness. Development of multi-layer clads on metallic substrates, which delivered better performance than single layer clads can be seen on some of the reports. Composite clad with the composition of MoCoCrSi/flyash has not been developed so far. However, an opportunity exists to develop MoCoCrSi/flyash clad on stainless steel (SS-316) substrate by using microwave hybrid eeating technique (MHH).



(a) (a)

Fig.2: (a) Microwave applicator used. (b) Schematic representation of the processing setup

2.0 Material and method used

The present research deals with flyash, cobalt-based powder, and SS-316 as substrate. The powder material has more strength and resistance to wear and corrosion. Cladding on stainless steel is done in the domestic microwave apparatus as shown in Fig.1. The following sections will describe the process. Flyash has high hardness and it is wear-resistant material used in various applications [9].

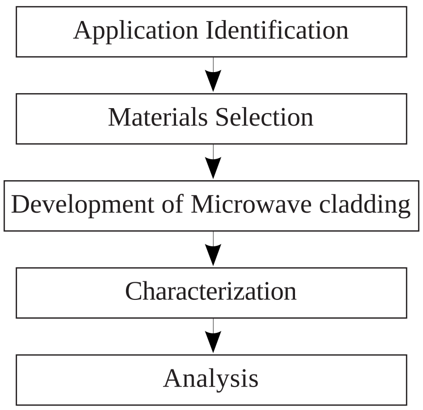


Fig.1: Methodology

Initially, with the application of microwave, the powder material is just in contact with the substrate when the temperature is low and the temperature around the exposed section is higher simultaneously with the increase in exposure time. The powder particles start diffusing into the substrate material to form the metallurgical bond with the substrate. The exposure time is in direct relation to the bonding of the powder and substrate. The homogeneity of the cladding surface is dependent upon the frequency, mode of heating (i.e., normal or hybrid heating), and power of microwave [5].

2.1 Procedure of microwave cladding

- The surface is washed with acetone or a similar kind of organic compound to remove unwanted impurities from the substrate.
- MoCoCrSi flyash mixture is made into a slurry by mixing it with an adhesive (araldite) so that the powder stays in place without dripping.
- The slurry is smeared to the cleaned surface.
- To prevent the loss of heat and damage to the cavity, the substrate is enclosed with a masking material made of alumina. However, there is further scope to improve the cladding performance by using a susceptor that increases the rate of heat transfer
- Schematic of the process set up as shown in Fig.2.
- The set up is exposed to microwave radiations from a domestic microwave oven as shown in Fig.2 for 42 minutes

2.2 Material details

Silicon carbide is used as a susceptor material for cladding. The susceptor absorbs microwave radiation and increases the rate of heat transfer. MoCoCrSi is the base powder that is mixed with composite powder (flyash) in the proportion 70%-30%. Clads of flyash powder on stainless steel (SS-316) are produced as a result of microwave hybrid heating.

The main component in the case of microwave cladding can be given as:

- Stainless steel sample (SS 316)
- Powder (base powder + flyash)
- Alumina insulation [Fig. 3]
- Susceptor (SiC)
- Glass wool

2.3 Development of clad

For the development of cladding, a proper blending of clad powder in appropriate ratio and preparation of substrate plays a vital role. In this work, acetone is used to clean the surface of the substrates and a paste of powder mixture is prepared with the help of resin [7]. This mixture approximately uniform in thickness is then applied to the substrate. Then the substrate material is placed inside a casket. Using a domestic microwave oven, several tests were carried out to develop clads. Microwave interaction is majorly dependent on the material property [4].

TABLE 1: COMPONENT ELEMENT DETAILS

	Elements	Composition (wt.%)	Properties
1.	Molybdenum	2.10	Creep, strength, hardenability, and wear resistance.
2.	Cobalt	2.5	High melting point and hard-wearing.
3.	Chromium	17.12	Rigidity, good impact resistance, and the case of fabrication.
4.	Silicon	0.7	Brittle and crystalline.
5.	Carbon	0.04	Good toughness, ductility, relatively good strength, can be hardened by quenching.
6.	Sulphur	0.013	It improves machinability, but lowers transverse ductility, and notched toughness, and has little effect on longitudinal mechanical properties.
7.	Nickel	11.2	Malleable, ductile, corrosion-resistant, and has superior strength.
8.	Iron	Balance	Lustrous, ductile, malleable.

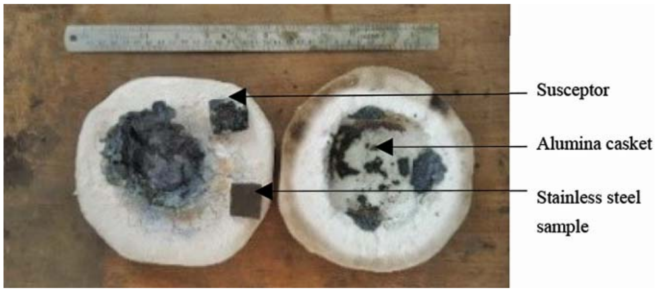


Fig.3: Materials used in the cladding process

The limitations of microwave metal heating are as follows:

i. At room temperature, the microwave absorption coefficient is less for metals.

ii. Thermal unsteadiness can lead to thermal runaway.

Microwave hybrid heating (MHH) is the new and effective method of absorption where powders with low absorption coefficient are melted using microwave energy. To absorb microwave energy susceptor materials are usually used. The susceptor materials like silicon carbide, charcoal, etc. can absorb all the microwave radiations passing through it. After the clad powder is applied on the substrate a thin parchment of separator material (glass wool) is placed before placing the susceptor material on top of it; the susceptor soaks up the microwave radiations and converts it to mechanical energy (heat) and transfers it to the clad material placed beneath it. To avoid adulteration, the separator is placed in between silicon carbide and MoCoCrSi-flyash powder, and to avoid heat loss, a refractory material (aluminium oxide/alumina) surrounds the set up. Alumina helps to prevent the microwaves from escaping and to be confined within the set up. The microwave cladding arrangement is done. In the present work, several trials were carried out by varying the clad time from 35-42 min whereas the power was kept constant at 900W. It gives a clear picture that microwave exposure time is an important factor in the condensation and dilution of clad powder. The clad materials were exposed for 42 min to microwave radiation and were left to cool for 10 min between the successive experiments. The mounted specimen was polished first by emery paper of 320 grit, then by using emery papers of grades 400, 600, 800, 1200, 1500, 2000, and finally with 1-micron diamond paste on a velvet cloth placed on the polishing machine, and the specimen is etched to enhance the appearance, prevent contamination, remove oxidation, to create a reflective surface and to observe the crystal structure more effectively. After this, the etched specimen is observed using a metallurgical microscope to observe the grain structure and examine the presence of irregularities.

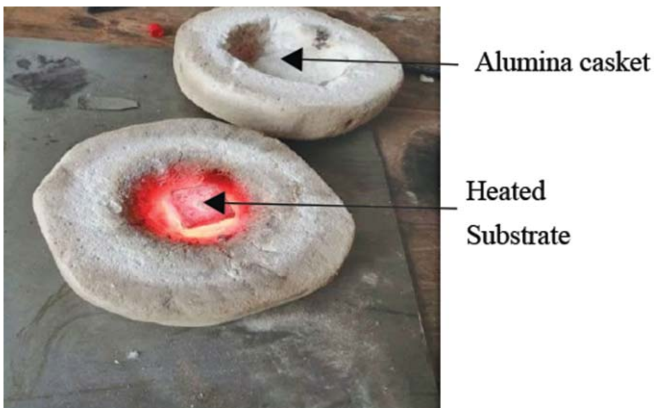


Fig.4: Heated substrate in the casket used in the present work

The substrate [stainless steel (SS-316)] is cladded using microwave using the composition of base powder (MoCoCrSi) along with the composite flyash which has more efficiency in terms of hardness number, grain size when compared to the stainless steel of grade 316 (substrate). The outcome of the project is that it can be used in various fields like ship propellers, turbines blades and also in the areas where the efficiency of the metal must be required effectively and can also be used in the area where the replacement of material is critical, in such situations the developed clad material of used composition has the best resistance when compared to the substrate.

3.0 Result and discussion

The substrate (stainless steel (SS-316)) is cladded using microwave using the composition of base powder (MoCoCrSi) along with the composite flyash which has more efficiency in terms of hardness number, grain size when compared to the

TABLE 2: OBSERVATION TABLE

	Processing time (min.)	Observations
1	10	Sufficient heat is not supplied to melt particles.
2	25	Improper melting of clad powders.
3	30	Powders are partially melted but poorly bonded.
4	35	Clad is partially developed but poorly bonded.
5	42	Clad is developed with partial melting of particles and good bonding with a substrate is observed.
6	45	Overheating takes place which causes poor bonding and the material gets deformed.

substrate that is stainless steel of grade 316. The outcome of the project is that it can be used in various fields like ship propellers, turbines blades and also in the area where the efficiency of the metal must be required effectively and can be used in the area where the replacement of material is critical, in such situations the developed clad material of used composition has the best resistance when compared to the substrate. The clads which were observed have a better grain structure than the substrate (SS-316). They have high resistance to wear.

In Fig.5(a), we can observe the microstructure of the cladded substrate. A dark spot-on substrate in the microstructural view represents a cladded surface; grain boundary of cladded surface will be comparatively larger than grain boundary of a substrate. Also in Fig.5(b), transverse view of the cladded substrate, we can easily distinguish cladded and uncladded region

3.1 HARDNESS REPORT

The ability of indentation resistance can be determined by the hardness of materials. A microhardness test was conducted across the surface of both the stainless steel (SS-316) and the cladded substrate using Vickers microhardness tester.

The unit of hardness given by the test is known as the Vickers Pyramid

Fig.7: Indentation on the specimen after a Vickers hardness test

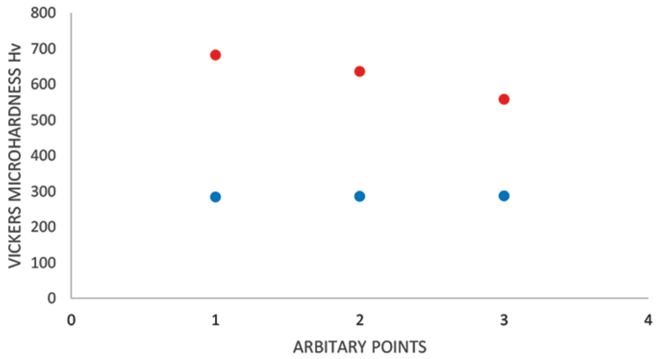


Fig.6: Vickers microhardness test report of cladded stainless steel (SS-316) and stainless steel (SS-316)

Number (H_v) or Diamond Pyramid Hardness (DPH).

Average microhardness of SS-316 is found to be 285.66 H_v, while that of MoCoCrSi/flyash clad is 625.33 H_v. The test report shows a significant increase in the hardness of the sample.

Information regarding microhardness test:

- The microhardness test of the clad-interface-substrate zone was carried out at three different sections across the cross-section of the clad sample [6].
- The indentations as shown in Fig.8 were made at 500 g load and a dwell time of 10s
- The cladded area was observed to have a greater microhardness value than that of the boundary and substrate area

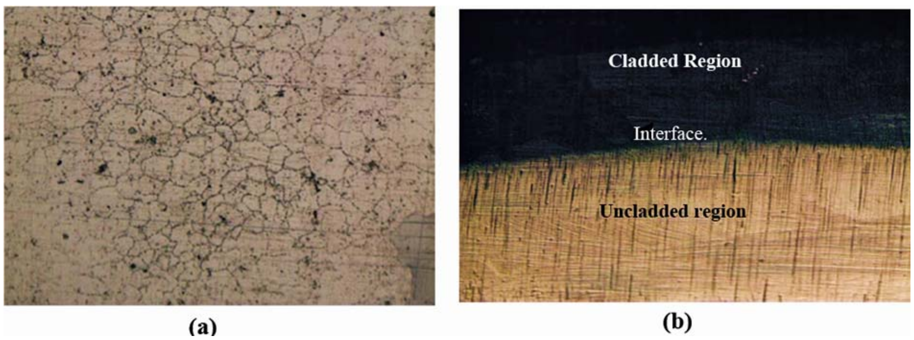


Fig.5: Microstructure of MoCoCrSi/flyash (a) Longitudinal view (b) Transverse view

Better surface modified materials are required for the better erosion and corrosion resistance based applications. This article is based on novel material processing technique named microwave hybrid heating (MHH), wherein an attempt is made to develop MoCoCrSi/Flyash composite clad on stainless steel(SS-316) substrate. Here, 900 W domestic microwave applicator with 2.45 GHz frequency is used to develop clads.

On examination, it is found that the cladded grain size is smaller than the substrate, it depicts the better hardness of the clad formed

4.0 Conclusions

MoCoCrSi/flyash clad on SS-316 is obtained by microwave hybrid heating (MHH) in order to develop and characterize the clad. Conclusions made from the present work are as follows:

- MoCoCrSi/flyash clads can be developed by MHH technique.
- Microstructural study reveals defect-free grain structure on the surface of the developed clads and better interfacial bonding.
- Hardness of the developed clad was found to be notably higher (~625.33 H_v) than that of the uncladded substrate (285.6 H_v).

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