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Feasibility study on MoCoCrSi/WC-Co cladding developed on austenitic stainless steel using microwave hybrid heating

Partial dilution of clad powder and the substrate to form a new protective layer is called as cladding. The present article focuses on development of a novel surface modification technique for better resistance to wear/erosion using microwaves as the source of heat. Clads of MoCoCrSi/WC-Co were produced on austenitic stainless steel (SS-316) using microwave irradiation techniques. Composite clads were established by irradiating microwaves at 2.45 GHz frequency and power of 900W using a domestic microwave applicator for a duration of 30 minutes. Characterization of the developed clads were 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 to be 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: Hybrid heating; microwave; surface modification; composite claddings

1.0 Introduction

One of the important properties of solid materials significantly is known to be surface morphology. The effective surface area is governed by morphology which is greater than the macroscopic geometrical area almost every time. As the surface energy of liquids facilitates smooth surfaces, solid materials are usually manufactured from liquids. The smoothness of the surface remains even after complete solidification. In numerous applications coating easily adheres on to rough surfaces forming a strong bond and is often essential. By carrying out etching or deposition the surface area usually increases more than the actual geometric area. Etching can be carried out with the use of either liquid or gaseous media. Etching by liquid media has its drawbacks, such as inadequate morphology and as they cause environmental pollution, even though the process is less time consuming and thus serves industrial applications in a better manner. Number of surface modification techniques like CVD, PVD, nitriding, etc. are available to alter the properties of the material surface to make them suitable for the desired applications. However, they suffer from significant drawbacks. To overcome the drawbacks of the available techniques, a novel non-conventional route for processing material could utilize in the form of microwave hybrid heating (MHH). The present article describes development of cladding by using irradiating microwaves as a source of heat energy.

Microwave cladding of stainless steel (SS-316) and mild steel (MS) in bulk form has been carried out using a microwave applicator at 2.45 GHz frequency and a power of 900 W. A susceptor medium was used to induce coupling of microwaves with metals while using microwave hybrid heating technique. A nickel based metallic powder was used as a cladding medium. Microwaves were irradiated on to the samples under atmospheric conditions. Microhardness tester and universal testing machine were used to characterize the clads after the process. Well fused faying surfaces were revealed on either side of the base material after studying the microstructure. Vicker's microhardness test gave the hardness of the developed clad to be around 133 H_v [11]. The composition of the bulk material differs from the composition of the surface. The arbitrary wettability of the solid materials are allowed by the functional groups [1,6,7]. Various types of materials have been cladded and reported. Overall, it has been evident that the developed clads have superior resistance to wear/erosion and corrosion. Some of the reports also indicate development of multi-layer clads on metallic substrates, which delivered still better performance than single layer clads. However, none of the researchers have reported on

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development of MoCoCrSi/WC-Co composite clad on stainless steel substrate. Hence, an opportunity exists to develop MoCoCrSi/WC-Co clads on stainless steel (SS-316) substrate and characterize.

2.0 Experimental section

2.1 Experimental procedure

The present investigation deals with MoCoCrSi/WC-Co powder and SS-316 as base material. Higher strength and resistance to wear and corrosion is usually found in cladding powder. Simple home microwave oven is used in cladding operation. Below mentioned sections will explain the whole process. Tungsten carbide-cobalt has high hardness and it is wear-resistant material used in various applications.

Fig.1 illustrates the flow in which the work is conducted. Initially, low temperature microwave is applied to the powder will be in interaction with the substrate. The temperature will get higher simultaneously when the exposure time increases. To form the metallurgical bond powder particle starts diffusing into the substrate material. The exposure time determines the relation of the bonding of the powder and the substrate. Homogeneity of the cladding surface depends on the mode and frequency of heating (normal or hybrid).

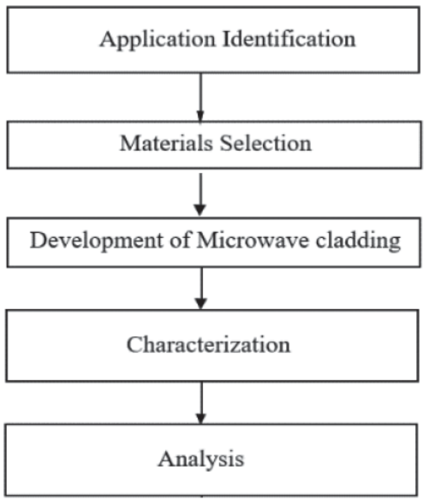


Fig.1: Methodology used in the present work

2.2 Material details

For cladding, the susceptor material used is silicon carbide. Susceptor is the material which soaks up the microwave radiation and converts it into heat which further transfers to the functional surface. Microwave energy was used to produce clads of clads of MoCoCrSi/WC-Co powder on austenitic stainless steel (SS-316). Using a domestic microwave oven of 900W power, the clads were established by introducing the powder to microwave radiations at a frequency of 2.45 GHz as shown in Fig.2. The base powder (MoCoCrSi) and the composite powder (WC-Co) were mixed in the proportions of 70%-30%.

Fig.2: Domestic microwave oven used in present work

Fig.3(a) represents the microstructure of the composite powder used. Ceramic tungsten carbide and the ductile cobalt, are combined to form the hard alloy of tungsten carbide-cobalt. Tough cermet is formed when tungsten carbide-cobalt which is a hard, brittle ceramic which is combined with 6% to 10% cobalt. WC or WC_2 forms can be achieved depending on the conditions of synthesis [1]. Weight of cobalt content can range from 1% to 30%, depending on the application under consideration. Tungsten carbide-cobalt nanoparticles have a nearly spherical morphology and appear as a black powder. Tungsten carbide-cobalt can be tan to dark grey depending upon its chemical and mineral composition. Due to the iron content the colour typically has a brownish note. Due to elevated unburnt carbon content the colour is usually observed to be dark grey to black colour. The colour of tungsten carbide cobalt is usually the same.

2.3 Development of cladding

For the development of cladding, 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 substrates and a paste of powder mixture is prepared with the help of resin. This mixture approximately uniform thickness is

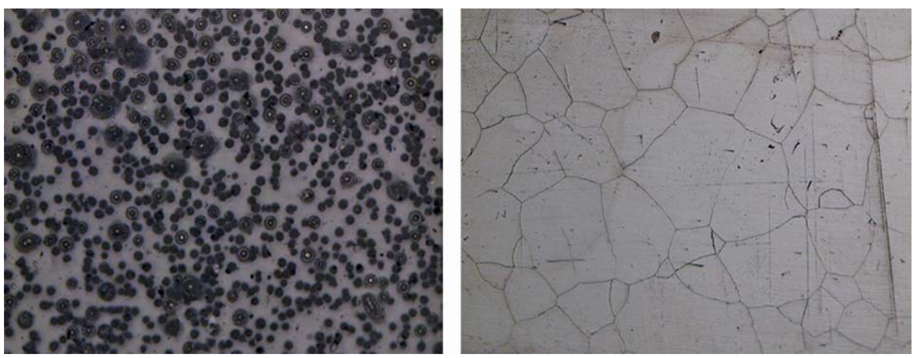


Fig.3: Microstructure of (a) MoCoCrSi/WC-Co particles (b) SS-316 substrate

then applied on the substrate. Then the substrate material is placed inside a casket. Using multimode microwave oven, several tests carried out to develop clads. Clad powder in the form of slurry was applied on SS-316. Microwave interaction is majorly dependent on material property [4].

TABLE 1: COMPOSITION OF THE POWDER

	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

2.4 CLADDING PROCESS SET UP

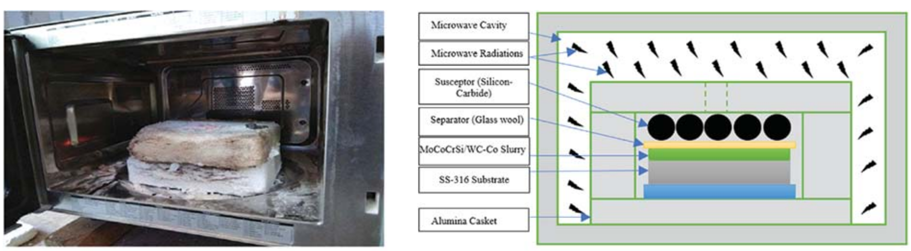
MoCoCrSi/WC-Co powder was applied on the substrate SS-316 maintaining uniform thickness. Al_2O_3 shield (specimen enclosure) was used to prevent damage to the microwave source by the spark generated due to the contact of microwaves with the metallic materials inside oven cavity.

Silicon-carbide susceptor was used to absorb microwaves which raises the temperature of powder particles. Because of high temperature preplaced powder starts to melt. In a domestic microwave oven fixing exposure time about 30 min and frequency at 2.45 GHz the desired clads were established using microwave energy as shown in Fig.4. Around 15 trials were conducted with varying time intervals to get the suitable clad thickness.

Fig.5 shows the way in which the composite powder slurry was applied uniformly on the SS-316 substrate and

Fig.5: Slurry coated substrate placed in alumina casket

placed in an alumina casket with susceptor(Si-C) and separator(Glass Wool). Microwave hybrid heating (MHH) is the new and effective method of absorption in the present work 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-WC Co powder. 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. As shown in Fig.4 the microwave cladding arrangement is done. In the present work, several trials were carried out by varying the clad time from 25-30min whereas the power was kept constant at 900W. It gives the clear picture that microwave exposure time is an important factor in condensation and dilution of clad powder. The clad materials were exposed for 30 min to microwave radiation and was left to cool for 10 min. between the successive experiments. For characterization acetone is used for subsequent washing of tungsten carbide cobalt clads. The mounted specimen was polished first by emery paper of 320 grit, then by polishing 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 and to create a reflective surface and to observe the crystal structure in a more effective way. After this the etched specimen is observed using a metallurgical microscope to observe the grain structure and



(a) (b)

Fig.4: (a) Actual experimental setup (b) Schematic representaion of processing setup

examine the presence of irregularities.

The substrate [stainless steel (SS-316)] which is cladded using microwave using the composition of base powder (MoCoCrSi) along with the composite tungsten carbide-cobalt (WC-Co) which has more efficiency in terms of hardness number, grain size, when compared to the substrate that is 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 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 best resistance when compared to the substrate.

3.0 Results and discussion

The cladding experiment was carried out between SS-316 substrate and MoCoCrSi/WC-Co composite powder with the help of a domestic microwave set up at 2.45 Hz frequency and 900W power for various intervals of time with a difference of 5 min. The optimal clad was observed at around 30 min. The observed clads were found to be having a better grain structure than the substrate.

3.1 Microstructural study

Optical micrographs of the cladded substrate have been presented in Fig.6. Careful observation of the micrograph in

TABLE 2: OBSERVATION OF CLAD FORMATION WITH TIME

	Processing time (min.)	Observations
1.	05	Sufficient heat is not supplied to melt particles
2.	10	Improper melting of clad powders
3.	15	Powders are partially melted but poor bonding
4.	20	Clad is partially developed but again poor bonding
5.	25	Clad is developed with partial melting of particles and good bonding with substrate is observed
6.	30	Overheating takes place which causes poor bonding and the material gets deformed

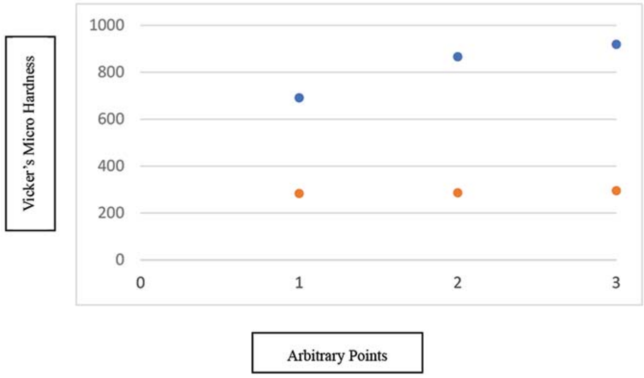


Fig.7: Vickers microhardness plot of substrate (SS-316) and MoCoCrSi/ WC-Co clad

Fig.6(b) reveals significant clad formation, with nearly uniform thickness. Also, the clad appears to be free from any form of defects by visual inspection.

Fig.6(a) shows longitudinal section of the clad, revealing distinct grain structure. Defects like porosity and inclusions are found to be absent. Grain boundary of cladded surface was observed to be comparatively smaller than that of the substrate (Fig.3b).

3.2 Hardness Report

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

- The test was conducted at 3 arbitrary points along the surface of both the substrate and the clad product.
- While performing microhardness test the impressions were made at load of 500g and the indenter was held for 10 sec.
- The cladded area was observed to have greater microhardness value than that of the boundary and substrate area.
- As shown in Fig.7, the average micro hardness value of clad and substrate were found to be 817 Hv and 289 Hv are respectively.

Applications requiring better erosion and corrosion resistance demand for better surface modified materials. The present article describes an attempt to develop MoCoCrSi/ WC-Co composite clad on stainless steel (SS-316) substrate through a novel material processing technique called as microwave hybrid geating (MHH). Clads were developed using a 900W domestic microwave applicator at 2.45 GHz frequency. On examination, the cladded grain size is found to be

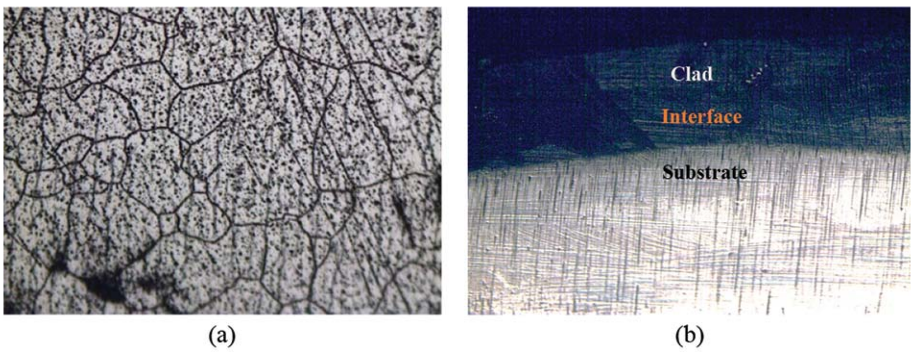
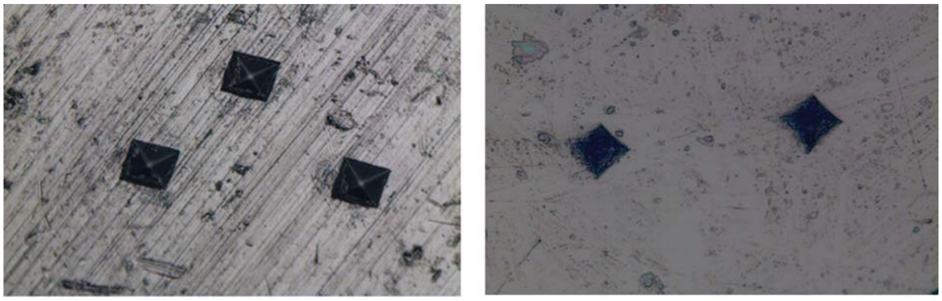


Fig.6: Microstructure of MoCoCrSi/WC-Co clad (a) longitudinal view (b) Transverse view



(a) (b)

Fig.8: Micro indentations on (a) SS-316 (b) Cladded substrate

smaller than the substrate, which depicts better hardness of the clad formed, evident from the microhardness of the clads, which provides detailed information regarding their erosion/corrosion behaviour.

4.0 Conclusions

Microwave hybrid heating (MHH) was imparted to develop MoCoCrSi/WC-Co clad on SS-316, and characterized. The following conclusions are drawn from the present work:

- MoCoCrSi/WC-Co 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 (~817 Hv) than that of the uncladded substrate (285.6 Hv).

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