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Technical Paper

Microwave cladding: A new approach in surface engineering

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ABSTRACT

Cladding is generally characterized by partial dilution of the substrate and hence formation of metallurgical bonding between the substrate and the deposits. Laser cladding is one of the most widely practiced surface engineering techniques. The present work mainly focuses on a novel development in surface engineering techniques in the form of microwave cladding. Clads of tungsten carbide (WC) based WC10Co2Ni powder on austenitic stainless steel were produced using microwave hybrid heating. Microwave clads were developed by exposing the preplaced, preheated powder for a duration of 120 s to microwave radiation at 2.45 GHz frequency and 900 W power in a home microwave system. Characterization of the clads was carried out in the form of microstructural and elemental composition studies. Investigations show crack-free interface revealing good metallurgical bond associated with partial dilution of the stainless steel substrate and full melting of WC particles. Typical X-ray diffraction results confirm presence of metallic carbides in the clad which is primarily responsible for significantly higher microhardness of the clad. Process mechanism has been discussed.

1. Introduction

Austenitic stainless steels have excellent corrosion resistance and are extensively used in various industrial applications. Although they have better utility for high strength and higher corrosion resistance; designers are concerned with their poor tribological properties. They often fail due to progressive wear while subjected to surfacial loads.

Surface engineering is often a pragmatic solution for controlling wear in materials. There are various established methods of surface engineering including nitriding, cyaniding, carburizing, and cladding [1]. Cladding, in general, is a widely used surface modification technique to develop an overlay of suitable materials on substrates of desired properties by partial melting of substrate along with fully melting of intentionally added powder(s) on to the substrate. The basic characteristic of the cladding process is good metallurgical bonding with minimal dilution of the base material. There exists a small zone of the substrate (base) material that does get melted during cladding, and therefore create a good metallurgical bond with the molten wear resistant material, mostly in the form of powder. Laser cladding is a widely practiced and competitive method to produce surfaces of desired properties. However, there are a few limitations of laser cladding including high set up cost, high operating and maintenance cost and low deposition efficiency. High cooling rate in the existing processes also increases the possibility of solidification cracking in clad. Further, intense heat source as in laser, might cause localized thermal distortion and induces residual stresses on the substrate during cladding. Thus, it is important to investigate alternative processing technique(s) having potential to overcome the limitations of laser cladding while producing improved microstructure and properties. New processes, however, are welcomed by the industries once they are cost effective with higher speed of processing.

In the recent years, microwave processing of materials has emerged as one of the fastest material processing techniques and is being recently investigated in surface engineering applications [2–4]. 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 [5,6] 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

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developing clad could be a cost effective option in the material processing industry.

Studies on processing of ceramics and ceramic composites using microwave energy have been widely reported; edges of microwave processing of such materials over conventional processing techniques have also been well illustrated [5–12]. Such processing includes several surface engineering applications as well [2]. In microwave based surface engineering methods, uniformity in processing including homogeneous microstructure, reduced porosity, reduced level of stress cracking, and enhanced microhardness have been reported by many authors [2,5,6,13,14].

However, adaptability of microwave energy in processing metallic material is challenging owing to the fact that microwave absorption coefficient for metals at 2.45 GHz radiation is significantly less at room temperature [15]. This makes it extremely difficult to achieve heating in metallic materials without using hybrid-heating (conduction and/or convection + microwave) technique [16,17]. In microwave hybrid heating (MHH), a passive heating is used through microwave absorbing material, called susceptor. In 1999, an US research group reported sintering of metallic materials [18]. Later, several authors have reported sintering of metallic materials through microwave heating [19–23]. Gupta and Wong [24] reported sintering of aluminum, magnesium and lead. Cho and Lee [25] reported metal recovery from stainless steel mill scale using microwave heating. Takayama et al. [26] have reported production of pig iron by microwave processing of mixed magnetite and carbon powder at 2.45 GHz and 30 GHz microwave frequency. Sharma et al. [27] have reported joining of bulk metallic materials using microwave irradiation. Borneman and Saylor [28] reported coating of friction reducing alloys using CuNiIn powder on Ti–6Al–4V substrate using microwave radiation. Borneman and Saylor's [28] work has been the pioneering work in processing metal-based materials using microwave energy for surface engineering application. The present authors have succeeded in developing pure metallic cladding on metallic substrates [29].

Development of cladding on metallic substrates, however, has hardly been reported. The present work shows the feasibility to develop wear resistant cladding of high melting temperature (~2600 °C) cermet powder (WC10Co2Ni) on austenitic stainless steel substrate using microwave hybrid heating. The clads were characterized using X-ray diffraction (XRD), field emission scanning electron microscope (FE-SEM), energy dispersive X-ray spectroscope (EDS) and Vicker's microhardness; initial results are reported.

2. Experimental procedure

In the present work, microwave cladding of cermet material on austenitic stainless steel substrate have been developed using a multimode domestic microwave oven (f = 2.45 GHz, 1 kW). The following sections briefly describe the development and characterization of the cladding.

2.1. Materials details

Hardness as well as toughness is important for better wear performance of a mating surface in sliding type of tribocontact. Carbides of tungsten and nickel characteristically provide excellent resistance to abrasion and erosion wear [30,31]. Tungsten carbide has good hardness and wear resistance, but poor toughness. Tungsten carbide provides better wear resistance while bonded with/dispersed in a tough phase. Thus, WC–Co–Ni can be one of the best systems for a combination of high hardness and toughness. In this system, cobalt (Co) acts as a binder, which is responsible for densification through wetting, spreading and formation of agglomerates during liquid phase sintering [32]. Thus, the functional surface of components that require high wear resistance with high structural strength can be cladded with such materials using suitable techniques. Therefore, WC10Co2Ni system has been chosen as the clad material for the present study.

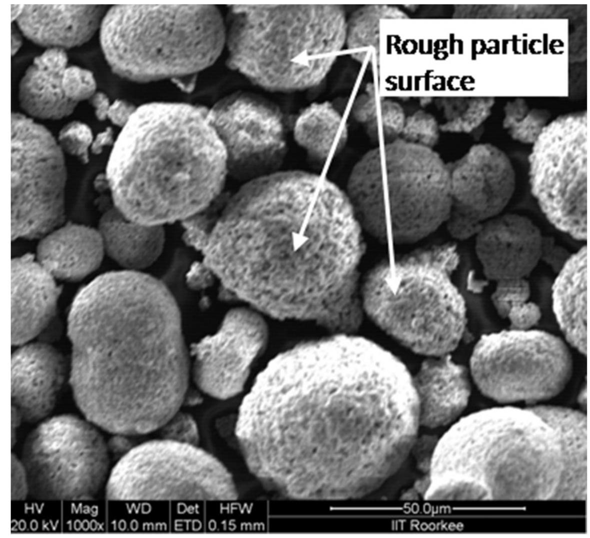

Fig. 1. Morphology of raw powder (WC10Co2Ni).

In order to develop WC10Co2Ni clad on austenitic stainless steel, WC10Co2Ni powder having average grain size of 40 μm was used. Typical morphology of raw WC10Co2Ni used for deposition is illustrated in Fig. 1. Spherical morphology of the raw powder is seen clearly. The surface roughness of the powder particles was also studied using atomic force microscope (NT-MDT: NTEGRA Model) in semi-contact mode. The measured average roughness (R_a) of the powder particles is 280 nm. The surface roughness increases the surface area of the particles and thus helps in absorbing microwave faster. The X-ray diffraction spectrum of the raw powder as shown in Fig. 2 confirms the presence of wear resistant tungsten carbide (WC) along with cobalt and nickel phase. Austenitic stainless steel (SS-316) plates having dimensions 35 mm × 12 mm × 1 mm were used as substrate material for development of cladding. The

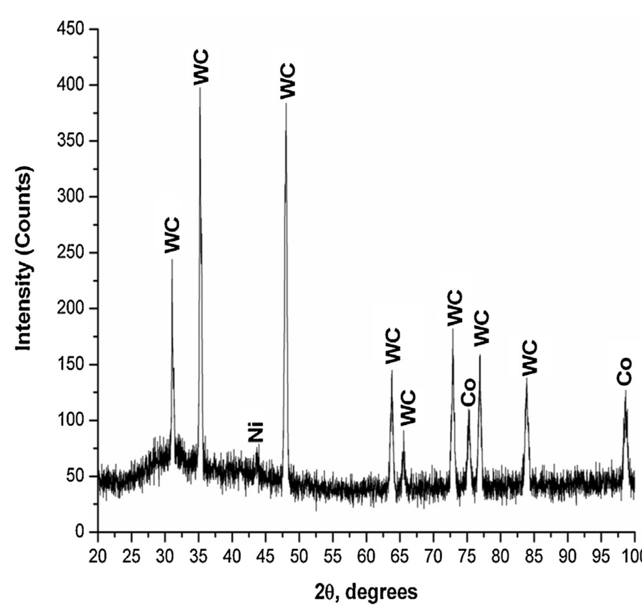

Fig. 2. Typical XRD spectrum of the raw powder – WC10Co2Ni (radiation: Cu$K\alpha$).