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MICROWAVE CLADDING OF NICKEL ON S45C STEEL

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ABSTRACT

Mechanical components in turbines and power plants fail frequently due to wear, corrosion, and oxidation. Cladding is a surface modification technique to minimize surface degeneration. In the present work, microwave cladding of Nickel performed for the surface and mechanical enhancement of S45C mild steel. The home microwave was successfully used to carry out the cladding procedures by Microwave Hybrid Heating (MHH) method. Physical and mechanical properties improved with microwave cladding. The devolved microwave clad has potential application in wear resistance product manufacturing.

Keywords: microwave, cladding, nickel, S45C steel, microwave hybrid heating.

INTRODUCTION

The application of microwave radiation in heating of materials is a new application. Conventional heating requires higher energy, higher processing time, costly installations, inevitable defects and many limitations [1-4]. Microwave processing can improve the material processing rate, reduce power usage and reduce processing time, which indirectly reduces processing costs as well as it is eco-friendly. The transfer of energy does not depend on the diffusion of heat from the surface, and thick materials can be heated quickly and uniformly [5]. The experimental work carried out by researchers [6-10] concluded that the time and power needed to process different materials in the microwave are significantly lower than conventional routes. Cladding is a process where one material provides a coating for another material mainly for protective purposes. A base material, usually metal can be selected for structural or cost properties, and another metal possessing good erosion properties, surface protection or wear resistance is to be added. The cladding developed by conventional process contains semi-molten powder particles, which are relatively more cause microstructural defects such as porosity and cracks [11, 12]. One of the most popular surface techniques is laser cladding. Laser processing has certain limitations, including high distortion, porosity and cracking of the interface apart from the process associated with laser cladding, which causes non-uniform microstructure due to which clad shows anisotropy in mechanical properties [13].

Charcoal powder is used as the susceptor to initiate the rapid heating process to ensure microwaves do not get reflected off [14]. The energy produced by the microwave is transformed into heat and radiated to the powder particles through the graphite sheet [15]. Fiberglass wool is composed of inorganic materials such as glass fabrics which are non-combustible where flammability is of concern thus making it a good heat and flame-resistant material. Low in cost, rapid heat dissipation properties and a good insulator are some of the characteristic of fiberglass wools [16]. Microwave hybrid heating is a uniform and volumetric heating besides able to heat the materials from within. In order to prevent energy losses to the surroundings, selective heating of the specimen is crucial to reducing energy consumption during the cladding process, thus being an eco-friendly method.

Methodology

The nickel based clads were produced in a domestic microwave oven with a frequency of 2.45 GHz and 900 W. Mild steel specimens of size 30mm x 15mm x 2mm placed on an alumina chamber. Then, preheated nickel powder placed on the specimen with uniform thickness. On top of nickel a graphite sheets were placed. Finally, charcoal powder sprinkled on top of the graphite sheets. The alumina boats were then placed on top of the fiberglass weaves inside of the microwave shown in Figure-1. The entire setup was exposed to microwaves heating for several minutes. After heating, the specimens are left to cool inside the microwave for some time then only taken out to avoid rapid change of temperature from the microwave to ambient surroundings to avoid non-uniform material properties across the specimens.

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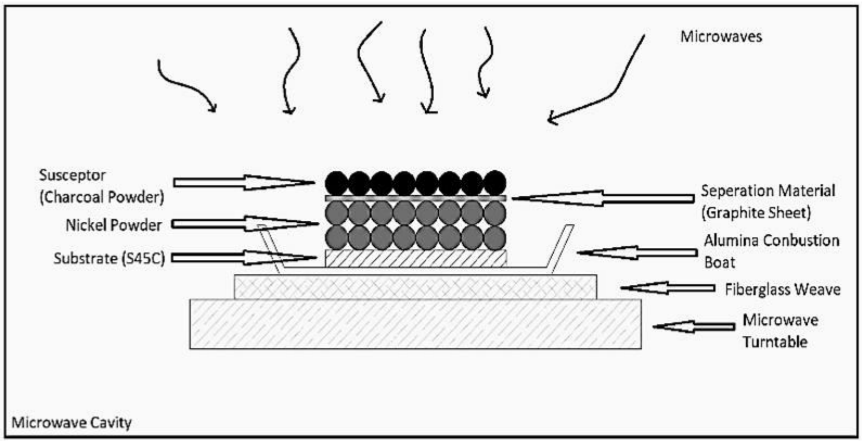

Figure-1. Schematic arrangement for microwave hybrid heating.

RESULTS AND DISCUSSIONS

Figure 2(a) shows the graph of mean hardness of the cladded specimens. The hardness of the base specimen is recorded at 128.84 HV. No cladding was observed for the 5-minutes heated specimen, but there is minimal increase in hardness recorded to 141.74 HV. This slight increase in hardness could be due to heat treatment to the specimen and no melting of powder. The 10-minute heated specimen also showed a modest increase in hardness with a difference of 32.92 HV resulting to a hardness of 161.76 HV. This specimen had an extremely poor bonding of nickel powder particles to the substrate yet with the presence of the little melted powder. Significant improvements in hardness can be observed from the graph, beginning from the 15-minute cladded specimen, with a hardness value of 271.94 HV. The hardness at this point is slightly above double the hardness. Cladding has successfully occurred at the 15-minutes thus the molten nickel powder particles provide a layer of protection for the substrate, hence the significant increase in hardness. On the other hand, for the 20 and 25-minue cladded specimens, the hardness value is at a staggering 369.72 HV and 433.52 HV respectively. Compared to the base specimen, it has an increase of 240.88% and 304.68% for the 20-minute and 25-minute cladded specimens. The cladding strengthens the substrate with the coating of molten nickel powder.

Figure-2(b) illustrates the 15- minute cladded specimen has the highest tensile strength with a reading of 147.57 MPa followed by both the 5-minute heat-treated and the 15-minute heat treated specimens with a tensile strength of 146.35 MPa. The base specimen recorded a value of 141.75 MPa for its tensile strength. The maximum displacements for the cladded specimens are higher compared to that of the heat-treated, this indicates that the cladded specimens have an increase in ductility compared to the heat-treated specimens. Grain refinement has occurred at the 15-minute specimen timings as the strength has increased from 141.75 MPa of the base specimen to 147.57 MPa of the 15-minute cladded specimen. This is an increase of 4.11% in tensile strength over the base specimen. This phenomenon occurs as when more heating is used, new smaller grains start forming and replace the original structure of the grain hence strengthening the structure and resulting in higher tensile strength.

On the other hand, as the heating continues to the 25-minute specimens, the tensile strength decreases to 146.18 MPa and 144.01 MPa for the cladded and heat-treated specimens respectively. The further heating of these materials causes the specimen to become brittle thus exhibiting a reduced tensile strength compared to that of the 15-minute specimens. Comparing the cladded and heat-treated specimens for the 25-minute tensile specimens, it can be observed that the heat-treated specimen has a lower tensile strength compared to that of the cladded specimen thus indicating that the cladding does in fact provide improved mechanical properties. This can be further confirmed by the trendline found in the graph depicted in Figure 2(b) where the starting from the 15-minute mark, the cladding specimens have a higher tensile strength. For the 5-minute specimens, no cladding occurred thus the heat-treated specimen has the higher tensile strength. Cladded specimens were studied for grain size and observations for nickel particles in the microstructure of the substrate. Nickel particles that are bonded within the microstructure can be observed starting from the 10-minute cladded specimen.

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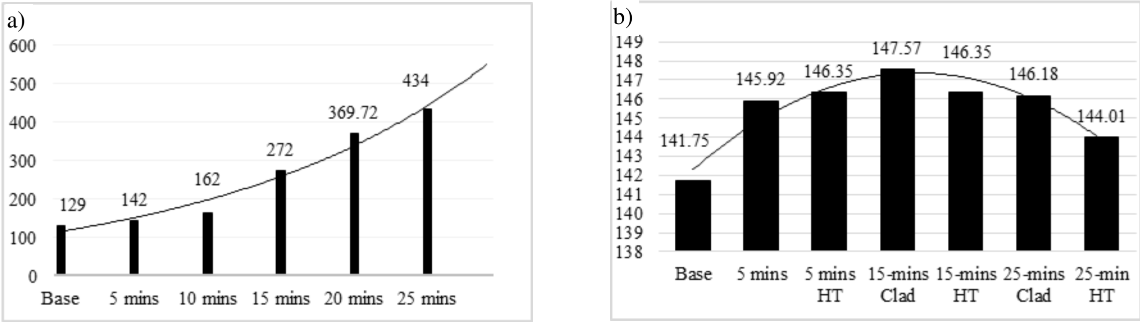

Figure-2. (a) Hardness test results of cladded specimens (b) Tensile test results of cladded specimens.

Figure-3(a) illustrates the 10-minute cladded specimen with visible nickel particles melted and bonded to the specimen. Since the melting of the powder for this specimen timings weren't excellent, the nickel particles are very isolated and far apart from each other. The microstructure of the specimen and nickel particles are free from crack and pores. With the 50x magnification in Figure-3(a), the nickel particles are clearly visible, and their grain size were measured using the software with the metallurgical microscope. The height and width of the nickel particles with particle one having a height and width 28.24 and 20.40 microns respectively. On the other hand, particle two measures 32.64 and 48.24 microns for its width and height respectively.

Figure-3(b) depicts the microstructure of the 15-minute cladded specimen, upon observation it can be deduced that the 15-minute specimen had more nickel particles embedded in the substrate's microstructure compared to the 10-minute specimen. The 15-minute clad has more molten nickel powder particles in the microstructure. The nickel particles could bond with each other and with the microstructure better compared to the 10-minute cladded specimen, as the nickel particles are larger and more in quantity. The nickel particles sizes found that have bonded with the microstructure of the mild steel. The biggest particle is particle number 4 with a height and width of 100.69 and 107.18 microns respectively. On the other hand, the smallest particle size can be observed to be 26.96 and 32.64 microns as the height and width, respectively. This large variation in particle size displays that the particle sizes across the microstructure is not uniform. Particle number 3 has the same height and width of 49.54 microns.

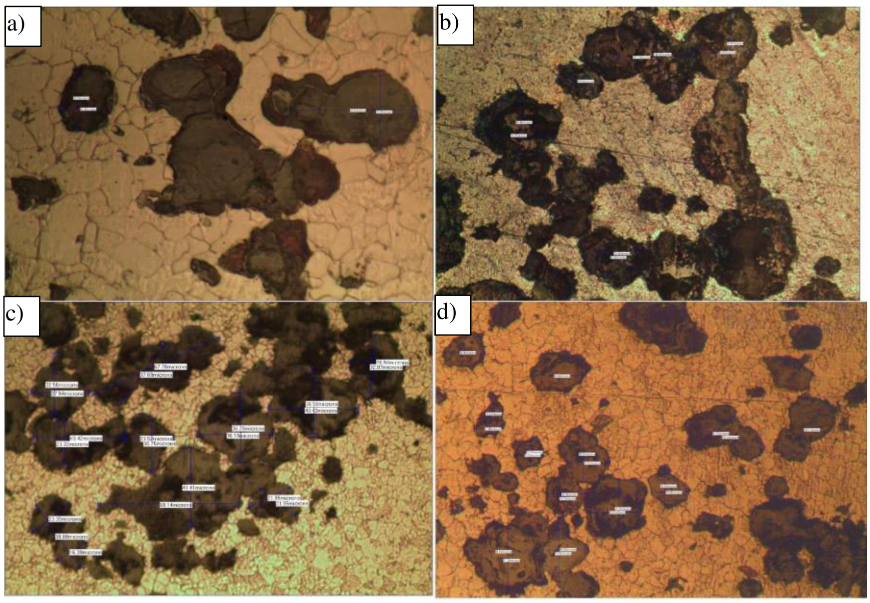

Figure-3. Cladded specimens Nickel particle sizes (a) 10 minutes, (b) 15 minutes, (c) 20 minutes and (d) 25 minutes.

The nickel particle size found in Figure-3(c) depicts the 20-minute cladded specimen in 20x magnification. It is clearly visible that the nickel particles are embedded and molten into little clumps and the nickel particles are darker compared to the earlier specimen detailing that the nickel particles have undergone a longer heating period. This directly exhibits that the molten nickel particles have harder bulk hardness as confirmed from the Vickers hardness test performed on the same 20-minute cladded specimen. Nickel particle sizes can be observed to be much more uniform compared to that of the 15-minute cladded specimen. Particles number 2, 7, 8, and 9 have very similar height and width measurements indicating a much more uniform particle size across the substrate. The biggest particle measures 41.41 and 68.14 microns as its height and width respectively. The nickel particles are homogenous and almost uniform for the 20-minute cladded specimen.

Figure-3(d) depicts the microstructure of the 25-minute cladded specimen using 20x magnification. It can be observed that the coating of nickel cladding that occurred in the 25-minute cladding specimen is layered. This means that the nickel particles melt in groups over each other, providing a tougher and thicker layer of cladding, as highlighted by the red circles. This also confirms that the same parameters for wet grinding and polishing process that were used for the other specimens didn't eat off much layers of the cladding, thus exhibiting good wear properties. The nickel particles also are much darker in colour portraying excellent melting and bonding of nickel particles to substrate.

CONCLUSIONS

The microwave energy was successfully used to carry out the cladding procedures using the Microwave Hybrid Heating (MHH) method. Microstructural study reveals that there is metallurgical bonding of nickel particles with S45C steel substrate. The developed microwave clads and nickel particles also exhibit no visible cracks from solidification process. The microwave energy has successfully sintered the nickel powder and caused it to bond well with the substrate. From the recorded results for the hardness indicated that 25-minute cladded specimen had the greatest hardness value of 433.52 HV compared to a mere 128.84 HV of the base specimen. This is an increase of 304.68% in hardness for the 25-minute cladded specimen. The hardness of the specimens increases exponentially with the microwave irradiation time. The nickel cladding is proven to provide a protective layer for the substrate.

Tensile testing exhibited that the ultimate tensile strength for the 15-minute cladded specimen was the highest with 147.57 MPa which is an increase of 4.11% in tensile strength compared to the base specimen. In conclusion, microwave cladding was performed successfully using the MHH technique. The 25-minute cladded specimen displayed the highest hardness value of 433.52 HV; 3.36 times harder than the base specimen. Grain structures were perfectly visible and formation of pearlites and ferrites could also be spotted. Homogeneity and uniformity of nickel particles sizes increased with the microwave timings too. The results show that the cladding procedure had been successfully developed and the tested observed specimens shows improvement in mechanical properties.

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