Surface Deposition of Nano Copper Particles on Steel Substrate by Microwave

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Abstract— The copper nano particles are diffused on the St-42 steel in the microwave oven. The copper particles are prepared as precipitates of chemical reactions. Simple fixture is developed for sintering of particles and diffused on to the super finished steel substrate. The mechanical properties are studied and indicate the use of such surface useful for the tribological applications.

Key words: Tribological significances, Copper, Precipitate, Microwave oven, Deposition

I. INTRODUCTION

In some recent years microwave heating is employed for the development of metallic clads. The volumetric heating of material in presence of microwaves occur from the inside to outside of material surface which in turn develops very uniform micro structural properties which are usually free of cracks, pores and residual stresses. The other merits of microwave cladding over conventional cladding through various welding or laser techniques are ease of operation, economy of time and energy, uniformity in heating with better thermal efficiency.

In twenty century, Dr E. Siores and Mr D. Dorego were the first to explain the application of microwaves for the purpose of material joining [1]. In 1999 E.T.Thosten and T.W.Chou explained the dielectric response essential for optimize the material processing by microwave irradiation[2].A group of U.S. researchers performed sintering of metallic material (Cu 2% and Graphite 0.8%) in a microwave field of 1200 ^{0}C for 30 minutes. The results were up to the mark with an excellent material density [3]. Gupta and Wong, reported two directional microwave assisted rapid sintering of aluminium, magnesium and lead free solder where an increment in micro-hardness and ultimate tensile strength were observed [4]. Latest developments in the field of microwave cladding were observed when M.S. Srinath and Apurbba Kumar gave their idea to join similar bulk metallic materials through this process within 900 seconds for copper to copper joining [5]. Gupta and Sharma performed experiments to form clads for different materials. Nickel coating was formed over austenitic stainless steel (SS-316) through an improved hybrid heating phenomenon due the presence of charcoal which acted as susceptor and graphite as separating material. An improvement in micro-hardness (304$\pm$48 Hv) was obtained as a result of cladding within 6 minutes [6]. Cladding surfaces were then developed by Gupta and Sharma in which clads of carbide reinforced metal matrix composite were formed over substrate of austenitic stainless steel. The average flexural strength of clads were 629 $\pm$ 8 N and respective deformation was around 0.76 mm [7]. Amit Kumar, Dheeraj Gupta and Vivek Jain investigated the joining of similar as well as dissimilar metals through the application of the microwave heating effect. SS 420 and SS 304 were investigated for the similar and dissimilar joining. The results were considerable on the basis of micro-hardness and density of clad material [8]. D. Loganathan investigated the improvement in tensile strength and yield strength of Al-6061 sheet when it is heated through the multimode microwave applicator (2.45 GHz and 850 W) [9]. Dwivedi, Shashi Prakash and Sharma Satpal contributed towards the microwave joining through their research over the effects of variation in power versus the tensile strength of steel plates of mild steel 1018 when they are joined through the nickel based metallic powder acting as a interface material [10]. Most of the research work done in the field of microwave processing of materials for joining purposes has been devoted to the applications of heating effects of microwave and the improvement of mechanical properties as a result of this low cost and energy efficient joining phenomenon. [11].

The current research work deals with the implementation of microwave heating for the development of clad material which serves the tribological purposes.

II. DIFFUSION PROCESS

Initially the individual nano particles get self-diffused to form a thin sheet or a layers but do not diffuse into the surface of dissimilar metal, steel, with time. The diffusion starts into the surface of steel as inter diffusion afterwards. Most of the copper atoms diffuse into steel surface and almost negligible atoms come out of steel as per Kirkindall effect. To get quicker and uniform diffusion, the steel surface is required to be optically flat (Ra≈0.001 micron) and a fixture is required to be made to encase the powder and the steel disc. The powder is pressed on to the steel disc for sintering. The effect of pressure and temperature due to microwave give a faster diffusion. The time taken for sintering is nearly half the time taken for natural diffusion of copper because of more activated sintering.

In general diffusion is made in structures with lower atomic factor, i.e. diffusion is much faster in BCC than the FCC structure. The copper particles are made finer up to nano level for increasing the diffusion rate.

To calculate diffusion rate of copper at 700◦c as per the Arrhenius equation

$$D_{AB} = Ae^{-E/RT} \quad (1)$$

Where.
A = Frequency factor,
E = Activation energy,
R = Gas constant,
T = Absolute temperature
Putting the value, $A = 4.9 \times 10^{-10} m^2/s$,
And E = 153.2 KJ/mol we get,

$$D_{AB} = 1.3 \times 10^{-13} m^2/s.=$$

From the Fick's 2nd law in a simple unsteady state condition and assuming that diffusion does not change much with time

$$\frac{\partial \widetilde{\theta_m}}{\partial \tilde{t}} = D_{AB} \frac{\partial^2 \widetilde{\theta_m}}{\partial \tilde{x}^2} \quad (2)$$

The solution to the above differential equation can be approximately written as

$$\widetilde{\theta_m} = \frac{m_A - m_{A,0}}{m_{A,S} - m_{A,0}} = \frac{x}{2\sqrt{D_{AB}t}} \quad (3)$$

Where

$m_{A,0}$ = Concentration at the start of process (at t =0)

t = time in seconds

$m_{A,S}$= Required Concentration at the end of the process.

x = Penetration depth.

The error function $\widetilde{\theta_m}$ lies in between 0.05 to 0.1 [12].

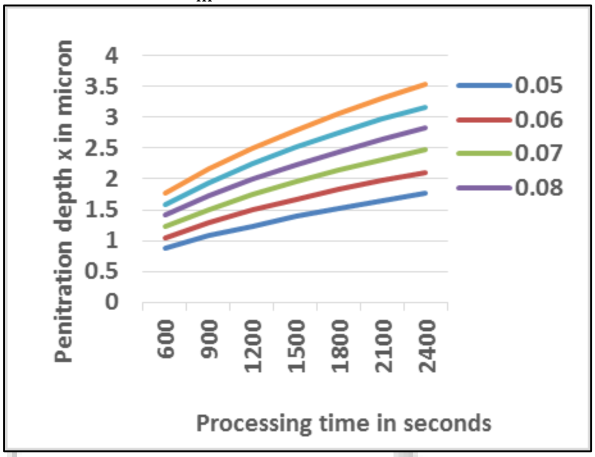

Fig. 1: Penetration depth vs. processing time

III. EXPERIMENTAL WORK

The microwave material processing of copper is performed through the domestic microwave oven (2.45 GHz and 900 W). The experimentation is performed in different phases for various specimens of mild steel (St-42) machined as coins of specific diameter and thickness. For the first phase of experimental work, the pre-existing procedures were adopted [5]. The copper particles were used to be diffused over the mild steel substrate. A uniform layer is obtained with sufficient bond strength and regular thickness.

Copper particles are precipitated as per the reaction

$$Fe_{(s)} + CuSO_{4(aq)} \rightarrow FeSO_{4(aq)} + Cu_{(s)}.$$

In this reaction, 2.24 g of Fe fine powder with 8.00 g of $CuSO_4$ gives 2.55 g of Cu.

The following arrangement is prepared for the microwave processing of copper powder to clad with St-42 steel as substrate. The size of the coins is taken as 6 mm thick and 24 mm in diameter.

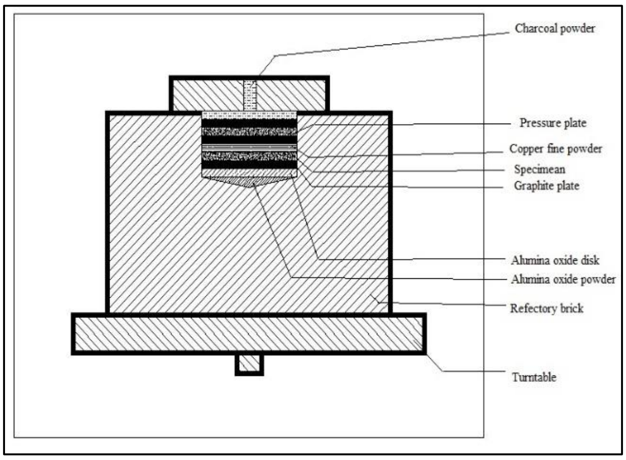

Fig. 2: Experimental setup drawing

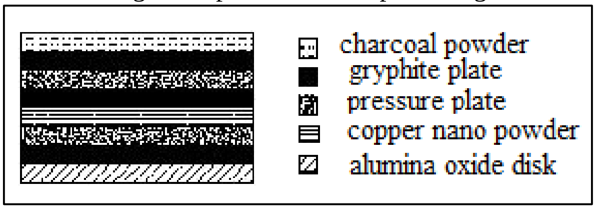

Fig. 3: Sequential arrangement

Fig. 4: Actual microwave oven setup

For the surface preparation of the steel coins surface grinding, lapping, polishing and ultrasonic cleaning are performed. The heating time is varied up to max. 40 minutes with an interval of 5 minutes.

The images of this improved procedure are shown below.

Fig. 5: Metallic fixture and clad surface

IV. RESULTS AND DISCUSSION

Initially no considerable results were obtained when the microwave irradiation was performed with the copper powder. The clad could easily be whipped off even with a bare hand. The non-uniformity in the copper powder spreading over the steel might be the reason for this. For the clad with the transfer of copper from the thin copper foil, some improvement in diffusion and bonding is observed. The coating could not be easily whipped off by bar hands, but a continuous rubbing over emery paper of fine grade could remove the coating which showed that the bonding happened but only at surface level. No molecular diffusion could be stated in sub surface. The formation of clad with an outer ring explains that a proper surface preparation of steel specimen is required for uniform coating along with a continuous surface contact between copper powder or film and the steel coin. This leads to the development of a sintering fixture for maintaining the continuous surface contact and building constant pressure during microwave processing. The observation table is made on the basis of different observation.

Sr.no.	Processing time (sec.)	Observation
1	300	Powder particles show partial diffusion with no melting
2	900	Single layer of copper powder been diffused uniformly with partial melting
3	1200	Melting is observed with uniform layer, might be at Nano level thickness
4	1500	Diffusion is enough but melting is not proper due to unknown reasons
5	1800	Thin layer with melting and diffusion is observed
6	2100	Diffusion is high with proper bonding
7	2400	Multi-layered clad can be seen

Table 1: Observation and Microwave effect

(a) Optical flat substrate (b) copper clad substrate
Fig. 6: Microscopic images

V. CONCLUSION

The technique for the cladding development is improved by maintaining a constant pressure between the clad material and the substrate. The surface preparation techniques affect the bonding strength and the thickness of the coating.

The cladding of copper in the form of nanoparticles over the mild steel (St-42) substrate is performed in domestic microwave oven (2.45 GHz and 900 W). Copper in form of nano precipitates was used. The results were remarkable and clads of sufficiently thick coating of copper over mild steel coins were developed.

The following conclusions can be drawn from the results that are drawn for the microwave sintering process.

1) Microwave sintering process is a potential process for copper based clad .Since it is very difficult for copper to get coated or diffused
2) Microscopic views show that uniformity in the layer of copper clad is achieved.
3) Due to the presence of the graphite plate carbon is absorbed with the clad material which increases the hardness of clad.
4) Very less porosity is observed in the clad material when microscopic analysis is performed. Lower defect in the clad surface is observed.
5) Hardness value of the clad is 73.266 HRB.

VI. FUTURE SCOPE

In the field of tribology, surface coating by microwave irradiation is found to be very useful especially for the bush bearings used in hydrostatic / hydrodynamic bearings. The copper coated steel bush can be processed by microwave heating with systematic setup.

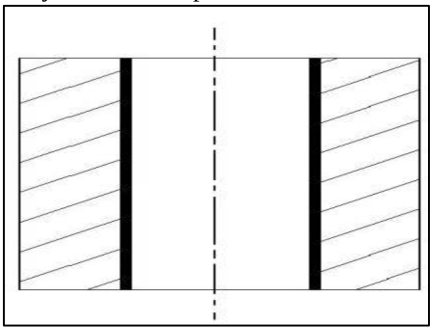

Fig. 7: Copper cladded bush

Evaluation of coated surface structure and the thickness would be done with the help of X-ray diffraction and Scanning electron microscope. Computational work on surface deposition by microwave heating may also be done

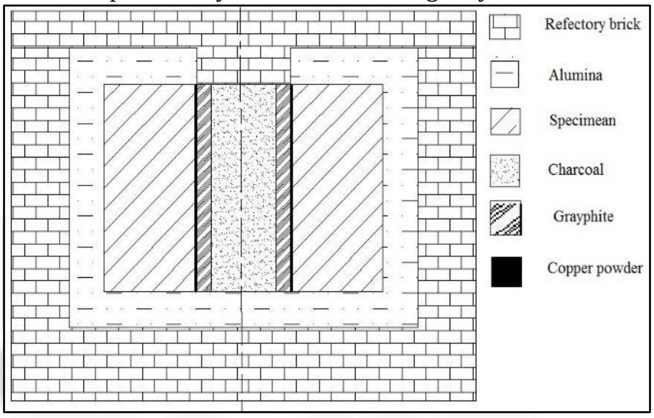

Fig. 8: Copper cladding setup for bushes

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