

# Joining of SS316-SS316 through microwave hybrid heating by using Nickel nano-powder

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## Abstract

Micro-interface-powder based joints have been investigated earlier but effect of using nano-powder as interface material during microwave joining of SS316-SS316 were not investigated earlier. In this work, Nickel nano-powder has been used as an interfacing material with an objective to produce joints having better physical and mechanical properties than micro-size Nickel powder based counterparts. Experiments were carried out for joining SS-316 workpieces in microwave applicator working on 800 W and 2.45 Hz. Performance of nano-powder based joints have been compared with micro-powder based joints after conducting physical and mechanical tests. Results of physical tests show well fusion of Nickel with base material. Hardness tests show that hardness of the joints was 450 Hv which was considerably higher than 420 Hv reported in previous literature related to micro-powder based joints. Tensile strength of joints was 385 MPa which is much higher than 309 MPa value measured earlier for micro-powder based joints. Overall, nano-powder based joints exhibited better physical as well as mechanical properties than micro-powder based joints.

**Keywords:** Microwave hybrid heating; Microwave joining; SS-316; Nickel nano-powder

## INTRODUCTION

In the era of emerging technologies, manufacturers are looking forward to new and refined joining processes, which can be used for joining wide range of materials. Conventional joining processes generally have some demerits like thermal gradient, large heat affected zone (HAZ), power consuming, non eco-friendly etc. In recent years, microwave hybrid heating (MHH) has emerged as a green technology with little thermal gradient, small HAZ, low power consumption, eco-friendly and high productivity. In conventional processes heat transfer takes place from surface to inner material; while in MHH microwave absorption takes place at atomic level which results in volumetric heating throughout the material. Volumetric heating reduces the time and power requirement as well as thermal gradient [1].

Selection of material to be processed by MHH depends upon their dielectric properties. Materials like ceramics, ceramics composites, semiconductor and polymers can be easily processed by MHH because they are good absorber of microwaves. However, materials like metals used in many industrial applications are hard to be processed by

microwaves because of their low skin depth. Owing to their low skin depth, metals reflect microwaves at room temperature. Roy et al.[2] reported that nearly all metals can be processed by MHH in powdered form because it increases their skin depth. Siros and Rago [3] successfully joined thin sheets of metals having thickness 0.1 to 0.3 mm.

Selective heating is one of the important features of MHH in which bulk material is covered by masking material while area to be joined is exposed to microwaves. Srinath et al. [4] joined SS-316 in bulk using MHH in which charcoal was used as susceptor and Nickel was used as filler material. The joints exhibited reasonably good tensile strength and hardness in the interface region. They also joined copper in bulk and found that change in atomic structure of copper takes place [5]. It was also interpreted that small size of filler material results in good welding joint. They extended their work and successfully joined dissimilar materials MS and SS-316 in bulk using Nickel as filler material [6]. Testing of joints showed a volumetric uniform heating and complete melting of interfacing layer. Bansal et al. [7] successfully joined MS in bulk. Characterization of the joints was carried out using X-ray diffraction, SEM, and Vickers micro indentation. The joint exhibited average tensile strength of 250 MPa with an elongation of 6%. Lucky et al. [8] compared the performance of joints of SS304-SS304 under the influence of Nickel based EWAC powder and 99.9% pure Nickel powder. Nickel based EWAC powder produced better weld-ability results than 99.9% pure Nickel based joints.

Lucky et al. [9] studied the effect of size of micro-size interface material on MHH processed SS304-SS304 butt joints. Experimental results showed that size of interface powder is a deciding factor in determining joint properties such as grain formation, hardness and tensile strength.

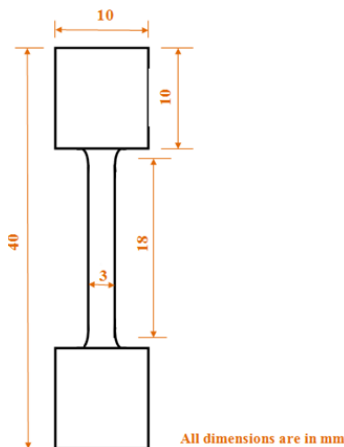
Micro-powder based joints of SS316 were developed earlier by Srinath et al. [4]. However, effects of nano-powder on properties of SS316-SS316 joints were not investigated earlier. This paper reports on development of nano-powder based joints wherein Nickel nano particles have been used as interfacing (filler) material. The developed joints were characterized through SEM, EDS, Vickers micro indentation and tensile testing. Test results of nano-powder based joints have been compared with published literature of micro-powder based joints. Nano-powder based joints show better physical and mechanical properties compared to their micro-powder based counterparts.

## METHODOLOGY

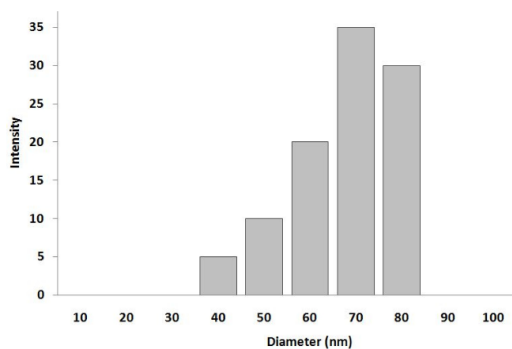
Selection of workpieces material, interfacing material and proper arrangements of insulation bricks are some important factors which decide quality of joints. These factors were decided after number of trial experiments. Following sections illustrate detailed methodology adopted for fabrication of joints.

### Selection of material for workpieces and interfacing powder

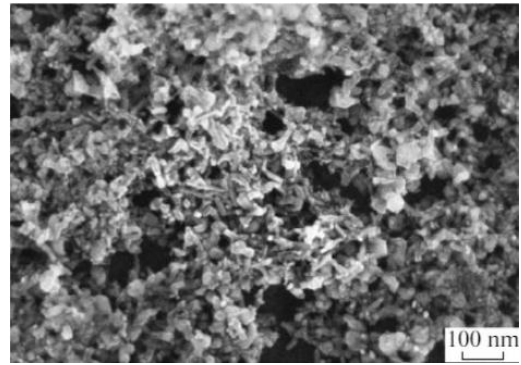
Selection of metallic material was based on its industrial application. SS-316 is useful in many industrial applications such as food preparation equipment, laboratory benches, heat exchangers, springs, chemical containers etc. Experiments were carried out on dumbbell shaped SS-316 pieces of 6 mm thickness as drawn in Fig. 1. Nickel nano particles with specific surface area lesser than  $12 \text{ m}^2/\text{g}$  and with melting point  $1455^\circ\text{C}$  were used as interfacing material. Particles size analysis and morphology of Nickel nano particles are shown in Fig. 2 and 3 respectively.



**Figure 1.** Dimensions of SS-316 workpieces



**Figure 2.** Particles size analysis of Nickel nano powder



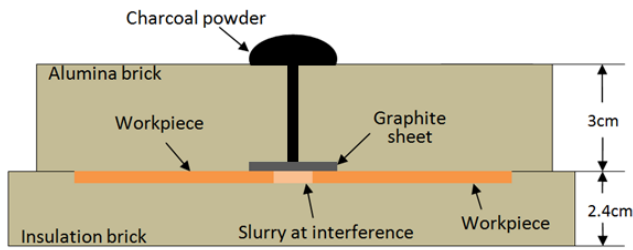
**Figure 3.** SEM image of Nickel nano particles

### Experimental setup

Experiments were performed using microwave oven operating on 800 W at 2.45 GHz. Workpieces were placed inside the cavity made on top face of an insulation brick. Slurry of Nickel powder and Blumer 1400XX mixture was placed at the interface where joint was to be made. A thin graphite sheet of thickness  $\sim 1\text{mm}$  was placed above the interface region. Graphite sheet acts as a separator between slurry and charcoal. 25% alumina brick was used as a charcoal feeder. It also separates metal from direct contact with microwaves. Charcoal powder acts as a susceptor. Schematic of the whole assembly is shown in Fig 4. During trial experiments, it was observed that location of assembly inside the microwave oven cavity plays significant role in effectiveness of the joining process. Therefore location of assembly was decided after number of trials. It was also observed that thickness 2.4 cm and 3 cm for insulation brick and alumina brick respectively results in good welded joints.

### Experimental work

Before joining, workpieces were cleaned using emery papers. Cleaned workpieces were then preheated in an oven. Slurry was uniformly applied on the surfaces to be joined. Workpieces along with the slurry were then placed inside the cavity made in the insulation brick. Interface region was then covered with a graphite sheet as shown in **Figure 5**. Graphite sheet acts as a separator between slurry and charcoal powder. 25% alumina brick was placed above the insulation brick; it was ensured that both bricks were in uniform surface contact. Alumina brick had a vertical hole located centrally which acts as charcoal feeder. Charcoal was gently filled inside the charcoal feeder. The whole assembly was then put inside microwave for 5 minutes. As the process starts, charcoal powder starts burning instantaneously and starts transferring heat to the workpieces by conventional heat transfer method.



**Figure 4.** Schematic of experimental set-up (Not to scale)

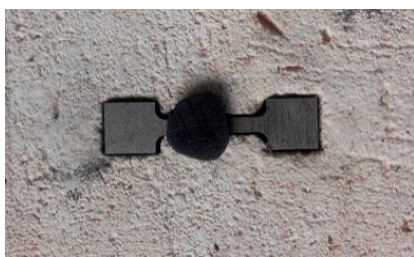
As the process starts, charcoal powder starts burning instantaneously and starts transferring heat to the workpieces by conventional heat transfer method. As the temperature of metals rises, skin depth of the metals increases and they start absorbing microwaves. Fig. 6 shows image of red hot workpieces after processing for 5 minutes.

**RESULTS AND DISCUSSIONS**

After successful fabrication of joints, they were characterized through various physical and mechanical tests. Results of characterization test are discussed in following sub-sections.

**SEM observation**

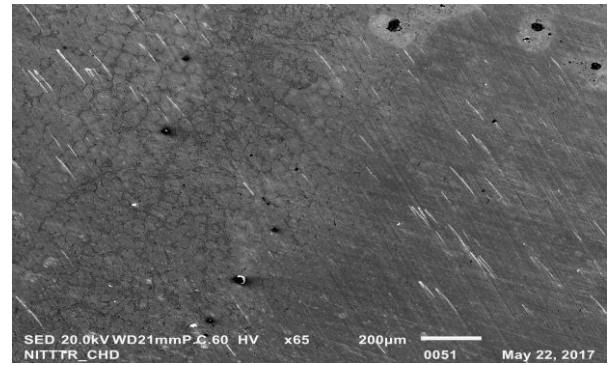
SEM images of Nickel nano powder based SS-316 joints are shown in Fig. 7. Fig. 7(a) shows complete melting of Nickel nano particles at interfacing surfaces. Fig. 7(b) shows well diffusion of interfacing material with base material. Equiaxed type grain structure in welded region was observed in Fig. 7(c). A well diffusion of Nickel particles and SS-316 can be seen. Volumetric heating results in homogeneous joints.



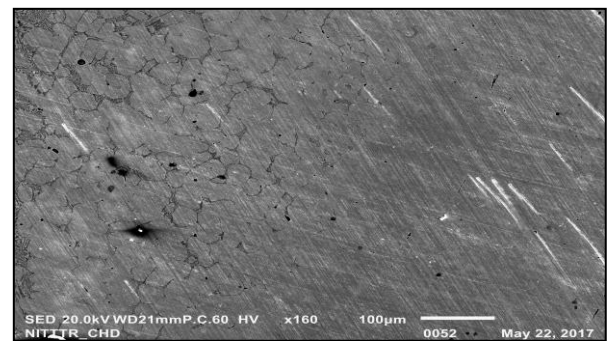
**Figure 5.** Workpieces placed inside insulation brick cavity



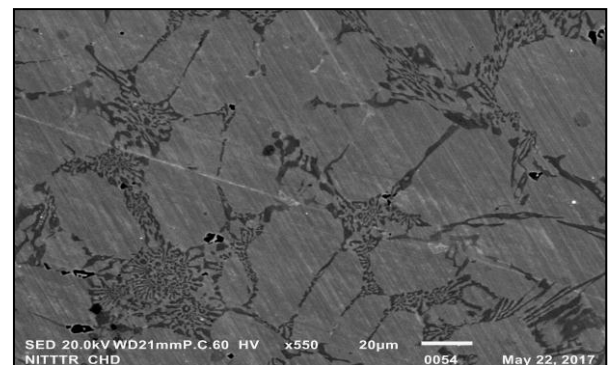
**Figure 6.** Red hot workpieces just after joining



**Figure 7(a).** SEM image of interfacing surfaces



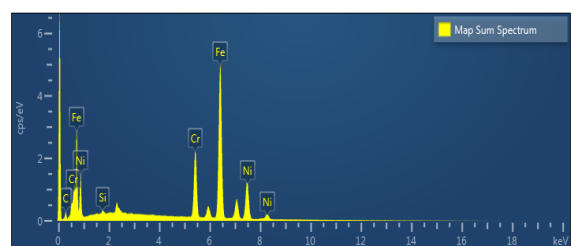
**Figure 7(b).** SEM image showing boundary between Nickel nano particles and SS316 workpiece



**Figure 7(c).** Grain structure in welded zone

**EDS observation**

Fig. 8 shows composition of welded zone. Presence of Nickel shows well fusion of interfacing material and base metal. A slight increase in percentage of carbon in welded zone can be attributed to presence of graphite and charcoal powder.



**Figure 8.** EDS spectra of welded joint

### Observation on tensile strength of joint

Tensile properties of MHH fabricated joints were determined by universal testing machine of maximum 100 kN force. The joints were subjected to uniform extension rate of 0.2 mm/s. An average tensile strength of 385 MPa was observed; which was 74% of tensile strength of the base metal SS-316 (515 MPa). This can be attributed to homogeneity of joint. Earlier, Srinath et al. [4] had reported tensile strength (~309 MPa) of SS-316 MHH welded joint using micro size Nickel powder of 40µm. Thus it is observed that tensile strength of nano powder based joints was nearly 24% higher than their micro powder based counterparts.

### Observation on hardness of joint

Hardness of welded joint was measured through Vickers hardness tests. An average hardness of 450 Hv was observed in welded zone. Earlier, Srinath et al. [4] had reported average joint hardness of 420 Hv at joint interference of SS-316 MHH welded joints using micro size Nickel powder. Hardness of nano based joints is better than their micro powder based counterparts. This can attributed to small size of Nickel nano particles.

### CONCLUSION

In the present work, SS-316 butt joints have been successfully developed using Nickel nano particles as interfacing material. The joints are free from any micro cracks due to uniform heating. Homogeneity of joints increases due to the use of nano particles. Tensile strength of nano-powder based joints is 24% higher than their micro size powder based counterparts. Use of nano-powder helps in increasing hardness of the joints by 7% compared to micro based counterparts. In welded joints, crack-free joints, homogeneity, tensile strength, hardness are important parameters. Therefore, nano powder based joints are concluded to be superior to the micro powder based joints.

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