Optimization of Microwave Welding Process Parameters for Hardness Using Taguchi's Method

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ABSTRACT

Joining of metals using microwave radiations is really an innovative idea in the field of research. In this paper, Graphite plate is used as a separator, Nickel based powder is used as the interfacing material, Mild Steel (MS) and Stainless Steel (SS) are used as substrates. This paper elaborates the use of Taguchi experimental design technique for maximizing hardness of microwave welded joints. Using ANOVA and signal to noise ratio of robust design, effect on hardness of Microwave joining process parameters (Exposure Time, Interfacing Material and Substrates) is evaluated and optimum welding condition for maximizing hardness is determined.

KEYWORDS: Microwave joining, Hardness, Substrates, Exposure time, Interfacing Material, Separator.

1.0 INTRODUCTION

Microwave joining is one of the newly developing and advanced techniques. Mostly people are unfamiliar from this type of process. Mainly, the microwave energy is used for cooking in houses. It is a form of fusion welding using frequency of 2.54 GHz. This technique is applied by using microwave energy which interacts with the material at the joint interface. It can be transmitted, reflected or absorbed when interact with materials. It can be utilized to join metals, but it is difficult to their reflective nature. Osepchuk studied and explained various possible applications of microwave energy, power, frequency etc. in details [1][2]. Sutton discussed processing of ceramics and the worth of microwave heating in 1989 [3]. Clarke et al. presented material processing challenges using microwave energy [4]. Microwave energy can also be used for processing materials like glazing of sprayed ceramic composite surfaces [5]. Gupta and Wong studied about sintering Al and Mg using 2-directional microwave [6]. Prabhu et al. concluded that, higher specific surface energy and reduced particle size results better densification of activated tungsten powder [7]. Mondal et al. resulted that microwave absorption rate will be higher when the particle size be smaller with higher porosity. Hence, heating is rapid [8]. Srinath et al. joined copper coin and plates by using microwave energy with 900 s of exposure time. The porosity and hardness at joint area was observed as 1.92 % and 78 ± 7 Hν respectively [9]. Gupta et al. discussed about the joining of steel plates using microwave heating. Microstructure analysis revealed strong joint with no cracks. Small amount of porosity is observed [10]. Gupta and Kumar successfully joined stainless steel plates using microwave hybrid energy. The joint is clearly visible. No cracks were identified. Tensile strength (323.16 MPa), microhardness (145.3 Hν) and percentage elongation (11.30%) of joint are observed [11].

Based on the literature survey, microwave energy is widely used in composites and ceramics because of its nature i.e. microwave absorption. Less work is done in the field of metals as metals tend to reflect microwave radiations. In this paper, author has successfully joint various substrates i.e. MS-MS, SS-SS and SS-MS (MS – mild steel, SS – Stainless steel).

2.0 EXPERIMENTAL SETUP OF MICROWAVE JOINING

Microwave joining arrangement is exposed in **Fig.1**. Mild steel (MS) and stainless steel (SS) used as substrates having dimensions 50mm x 12mm x 3mm. For joining the substrates, butt joint is preferred as it is easy to handle. EWAC 1002 ET (Ni based powder) powder and resin is required to make slurry which is called as interfacing material. Firstly, substrates are dipped in acetone tub and cleaned with emery sheets to remove unnecessary contaminants. Slurry is applied on the faces of substrates to be joined. To separate interfacing material and charcoal, 1mm thick graphite plate is used. Charcoal is used to provide extra heating. Substrates are surrounded by the refractory brick after applying the interfacing material between the faces as shown in **Fig. 1**. To avoid direct interaction of substrates and microwave radiation, refractory brick is used. As the microwave is on, microwave radiations come in contact with charcoal powder and starts burning. Therefore, the temperature at the joint increases. Extremely skinny layer is effected which gets fused with sandwich layer. The faces of substrates get totally wet. The molten region converts into a shape of joint after cooling at atmospheric situation.

3.0 METHODOLOGY

Dr. Genichi Taguchi developed a method to improve the quality of manufacturing goods which is called as Taguchi's method. It

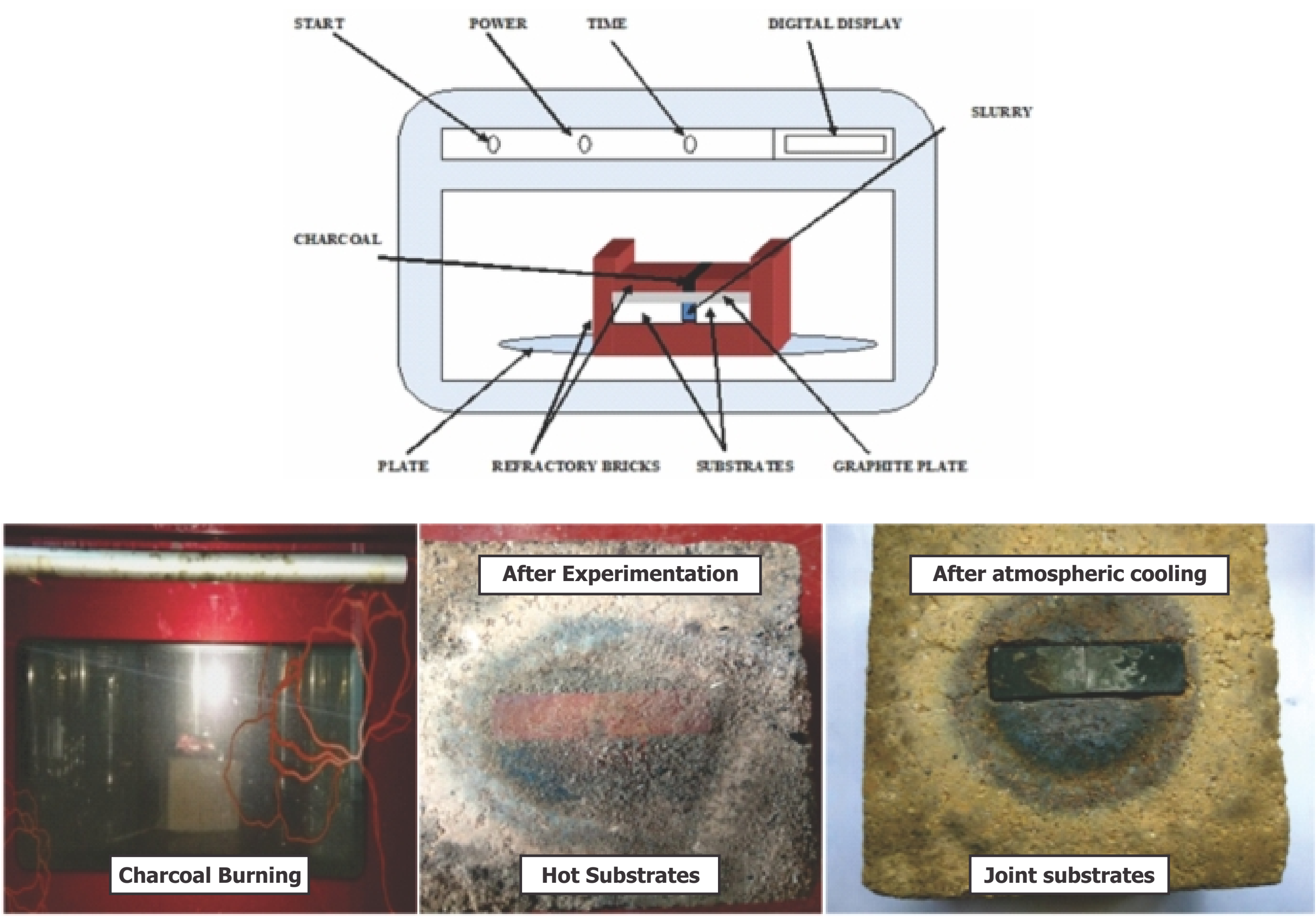

Fig. 1: Microwave welding setup

is also applied in engineering field.

The greatest achievement in engineering is Quality engineering set by Dr. Taguchi in 20th century. He mainly focuses on engineering strategies which includes upstream and shop-floor quality engineering. Small-scale experiments and robust designs for large-scale production is used in upstream method while cost based real time system is used in shop floor technique.

Taguchi's philosophy is based on three concepts:

- Quality should be planned into the manufactured goods.
- Best worth is achieved by reducing the deviations on or after the target.
- The expenditure of quality should be calculated as a function of deviation from the standard and the losses should be measured system-wide.

Taguchi's proposed 3 stage processes: tolerance design, system design and parameter design [12] In this paper, parameter design is followed to analyze the effect of parameters on hardness. Larger–the-better principle concept is applied to maximize the hardness. The loss function is expressed as follows: [12]

$$\frac{S}{N} = -10\log\left(\frac{1}{n}\sum_{i}\frac{1}{\gamma_i^2}\right)$$

Where, n = No. of observation and γ = Data observed.

4.0 RESULTS AND DISCUSSION ON THE BASICS OF TAGUCHI'S METHOD

Table 1 show various experiments and average hardness value which were done using L9 orthogonal array

4.1 Analysis Of S/N Ratio

Both the parameters are combined by S/N ratio i.e. mean level of the quality characteristic and variance around this mean into a single metric. Higher value of S/N indicates that the signal is higher than the random effects of noise factors.

4.2 Experimental Results for Hardness

Investigation of Vicker's microhardness was done on MS-MS, SS-SS, MS-SS joint using a load of 10 gm for 30 s. At different intervals, reading was taken. From table, it can be concluded that SS-SS joint has maximum hardness (160.2 Hv) at a Time of 800 s with Ni powder (95%).

Table 1 : Test Data Summary for Hardness

Exp.	Time, $T_{(s)}$	Ni(%)	Sub-strates	Hard-ness	S/N Ratio (dB)	TS Mean Value
1	600	85	MS-MS	129.2	41.870	123.96
2	600	90	SS-SS	145.3	42.770	137.60
3	600	95	MS-SS	130.2	42.328	130.83
4	700	85	SS-SS	142.8	42.629	135.43
5	700	90	MS-SS	133.2	42.487	133.06
6	700	95	MS-MS	155.1	42.566	134.40
7	800	85	MS-SS	120.3	42.028	126.30
8	800	90	MS-MS	143.7	42.408	132.03
9	800	95	SS-SS	160.2	43.007	141.26
Average					42.455	132.76

Table 2 : Response table for Means and for S/N ratios, HB

Response Table for Means				Response Table for S/N ratios			
Level	T	Ni (%)	S	Level	T	Ni (%)	S
1	130.8	128.6	130.1	1	42.32	42.18	42.28
2	134.3	134.2	138.1	2	42.56	42.56	42.80
3	133.2	135.5	130.1	3	42.48	42.63	42.28
Delta	3.5	6.9	8.0	Delta	0.24	0.46	0.52
Rank	3	2	1	Rank	3	2	1

4.3 Anova for Hardness

Table 3, shows the analysis of variance outcome for S/N ratio. Out of three parameters, substrates have maximum percentage contribution that is 55.71 and % Ni based powder 35.59 % and time 8.36 %. The worth of R-Sq is nearby to 1. R-Sq (0.997) show good quality contract with R-Sq (adj) (0.987).

4.4 Influence of Process Parameters on Hardness

4.4.1 Time

At 600 sec, the value of hardness is lower as the material doesn't fuse properly than 700 s and 800 s. Due to excessive heat at 800 s, there is decrease in hardness.

4.4.2 Ni based Powder

If, percentage of interfacing powder increases, there will be proper fusion and less porosity will be observed which is shown by the **Fig. 2 (b)** and **Fig. 2 (c)**.

Table 3 : ANOVA for S/N Ratios (Hardness)

Source	DF	Seq SS	Adj SS	Adj MS	F	P	% PC
T	2	0.08786	0.08786	0.04393	22.77	0.042	8.83
% Ni	2	0.36004	0.36004	0.18002	93.31	0.011	36.2
S	2	0.54244	0.54244	0.27122	140.5	0.007	54.5
Residual Error	2	0.00385	0.00385	0.00192			
Total	8	0.994214					
S = 0.04392 R-Sq = 99.6% R-Sq(adj) = 98.4%							
Order of significance 1. Substrates 2. Ni Powder 3. Time							
*Significance at 95 % level							

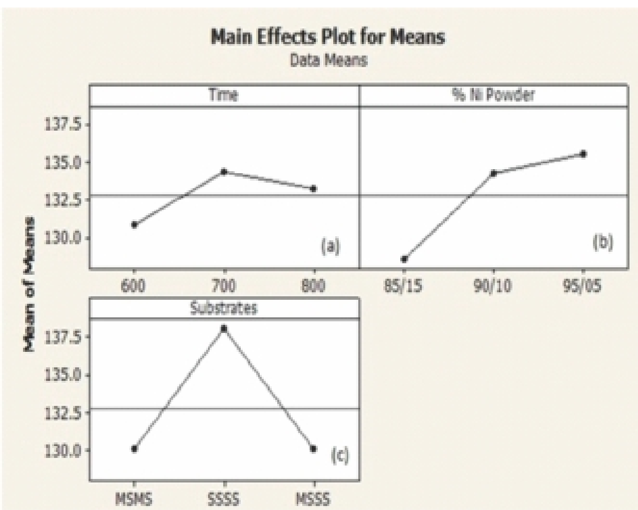

Figure 2 (a, b & c) : Main effects on Hardness

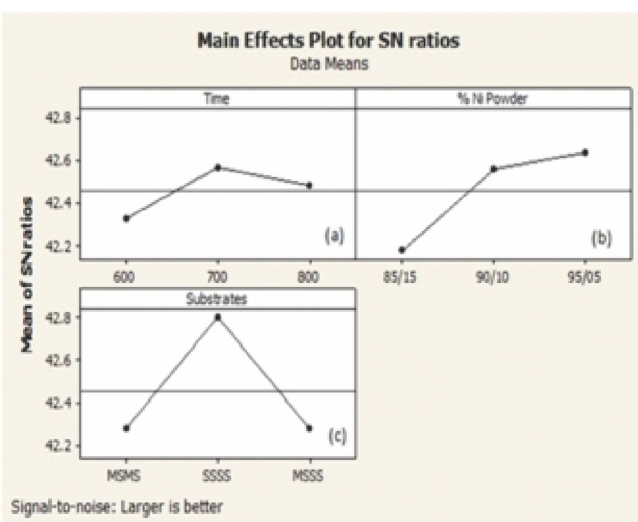

Fig 3: (a, b & c) : S/N Effects on Hardness

4.4.3 Substrates

The SS-SS joint, which is fabricated, has higher hardness because the hardness of the stainless steel base metal is higher than mild steel base metal. So, MS – MS joint has less hardness than SS-SS joint. MS-SS joint has higher joint strength than MS-MS joint, as the average hardness of the MS –SS base metal is higher in comparison to MS- MS.

4.5 Calculation for Hardness

$\mu_H = T_H + (\bar{T}_3 - T_H) + (\bar{Ni}_3 - T_H) + (\bar{S}_2 - T_H)$

where, T_H = Overall mean hardness = 132.76 Hv

$\bar{T}^3$ = At level 3, avg. hardness of time = 133.2 Hv

$\bar{N}_{i3}$ = At level 3, avg. hardness of Ni Powder = 135.5 Hv

$\bar{S}_2$ = At level 2, avg. hardness of Substrates = 138.1 Hv

μH = 141.3 Hv

Confidence interval (CI) can be calculated as follows [12]

$$CI_{CE} = \sqrt{F_a\,(1,f_e)\,V_e\left[\frac{1}{\eta_{eff}} + \frac{1}{R}\right]}$$

Using the value V_e = 0.3733 and f_e = 2, the CI can be calculated. Total degree of freedom associated with the estimation of mean (μ_{TF}) = 2+2+2 = 6, Total number of experiments (N) = 3 x 9 = 27.

$$\eta_{eff} = \frac{N}{1 + \text{total DOF involved in estimation of mean}} \quad [12]$$

The effective number of replication can be calculated as follows: [12]

η_{eff} = Effective number of replication = 27/7 = 3.857

Sample size, R = 3

Tabulated F ratio at 95 % CI (α = 0.05): $F_{0.05}$ (1, 2) = 18.5

$$So,\ CI_{CE} = \pm 2.0223$$

Predicted optimal hardness at 95% CI

$$(\mu_H - CI_{CE}) < \mu_H < (\mu_H + CI_{CE})$$

$$139.277 < \mu_H < 143.32$$

At the optimal stage, three confirmation experiments are conducted (Time: 700 s, % Ni Powder 95 % and Substrates MS-MS). **Table 4** shows the hardness (Avg. mean value) of the welded joint with CI.

Table 4 : Optimum level of process parameter (Hardness)

Responses	Predicted mean values	Exp. values (avg.)	CI
Hardness (Hv)	142.36	141.92	$139.277 < \mu_H < 143.32$

5.0 CONCLUSIONS

1. Joining of MS-MS, SS-SS and MS-SS plates is successfully achieved using microwave hybrid energy.
2. Out of the three parameters, Substrates has the major influence on the hardness followed by % Ni based powder used and Time.
3. The predicted optimal range is: $139.277 < \mu_H < 143.32$

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