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Optimization of Diffusion Bonding Process Parameters of Aluminium AA6061-Fly Ash Composites using Taguchi Method

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ABSTRACT:

This paper focused to determine optimal bonding parameters based on Taguchi method for maximizing bonding strength. The experiments were conducted on diffusion bonding machine using aluminium fly ash (AFA) composites. Three bonding parameters such as temperature, pressure and time, each at three levels were examined. Taguchi L27 orthogonal array was used as a design of experiment. The response table and the analysis of variance (ANOVA) were calculated to determine which process parameters significantly affect the bonding strength and also the % contribution of each parameter. The results show that the combination of factors and their levels of A2B3C3 i.e. the bonding done at a temperature of 475°C with a pressure of 10 MPa and time for 20 minutes yielded the optimum i.e. maximum bonding strength. Finally, ANOVA results indicated that all three process parameters significantly affected the bonding strength with a maximum contribution from the bonding temperature (85.93%), followed by bonding time (12.6%) and bonding pressure (1.48%). It is also observed that the bonding strength of the diffusion bonding process can be improved effectively through this approach.

KEYWORDS:

Diffusion bonding; Aluminium fly ash; Analysis of variance; Bonding strength

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1. Introduction

Now-a-days use of metal matrix composites (MMC) more because of their improved mechanical properties like high specific strength, good wear resistance and lower thermal expansion. These composites are commonly used in automobiles, structural and aerospace applications [1]. From the various reinforcements, fly ash (FA) is one of the cheapest and it has low-density one and it obtained from the combustion of coal in thermal power plants [2]. Aluminum fly ash (AFA) composite gives many potential applications, especially for engine parts such as engine pistons and brake rotors because of their improved mechanical properties [3]. Application of MMC is more in an industrial field but they are not commonly used because of a joining of MMC is tedious. Mixing of matrix material with filler material difficult one due to low flow ability and a greater viscosity at the liquid welding pool and it makes unsatisfactory welded joints [4].

By means of diffusion bonding, is impossible join all the materials whose chemical and metallurgical properties are different and it widely used in the fabrication of critical components in aerospace and nuclear engineering. The quality of diffusion bonding depends on its bonding strength, for getting the maximum bonding strength, selection of the process parameters is an essential one [5-9]. Most of the researcher successfully utilized the process of optimization by Taguchi orthogonal arrays [10]. The aim of the present work is to study the effect of diffusion bonding process parameters such as bonding temperature, bonding pressure and bonding time for bonding strength (BS) while bonding of AFA composites. By the application of Taguchi method, optimum process parameters are identified.

2. Experimental Set-up and Testing

2.1. Materials and composite preparation

In this investigation, aluminium alloy (AA6061) used as the base metal and its chemical composition shown in Table 1. It possesses good formability, weld ability, high corrosion resistance. The aluminium matrix was reinforced with 6 wt % of fly ash with the particle size 1-100µm and the chemical composition of fly ash (%) shown Table 2. AFA composites were cast using stir casting process and it has a uniform distribution of reinforcements.

Table 1: Chemical composition of AA6061 alloy by % wt

Mg	Si	Fe	Mn	Cu	Ti	Cr	V	Al
0.9	0.68	0.18	0.03	0.22	0.01	0.09	0.01	Bal

Table 2: Chemical composition of fly ash by % wt

SiO_2	Al_2O_3	CuO	K_2O	CaO	MgO	TiO_2	FeO
51.4	29.65	4.86	1.57	2.87	1.72	2.54	5.39

2.2. Design of experiments

Taguchi is the effective method to select the optimal combination of input parameters (10). In this research the effect of three process parameters with three levels is considered and it is presented in Table 3. The process parameters set in this experiment using L27 orthogonal array are tabulated in Table 4. Bonding strength is the response of this experiment. Larger the better (LB) criteria are taken for bonding strength.

Table 3: Process parameters and their levels

Parameters	Unit	Range	Notation	Level		
				1	2	3
Bonding temperature	ºC	450 - 500	A	450	475	500
Bonding pressure	MPa	8 – 10	B	8	9	10
Bonding time	Min	20 - 45	C	45	30	20

2.3. Experimental procedure

The fabricated AFA composite samples (45 x 45 x 8mm) were polished and cleaned before bonding the joints. The samples were bonded in the diffusion bonding machine based on Table 4. The prepared specimen was placed in the die setup, then the die setup was placed inside the vacuum chamber of the diffusion bonding machine and maintained the vacuum level of 10^3mm of Hg. The specimens were kept up to the temperature mentioned in Table 4, by using induction furnace simultaneously the required pressure and time. After completion of bonding, the samples were cooled to room temperature and then withdrew from the furnace. Diffusion bonding machine setup as showed in Fig. 1. The bonding strength (ram tensile) of the diffusion bonded samples was measured by the universal testing machine. In this analysis, diffusion bonded joints were not enough of a standard test specimen so a non standard test sample was used and it shown in Fig. 2.

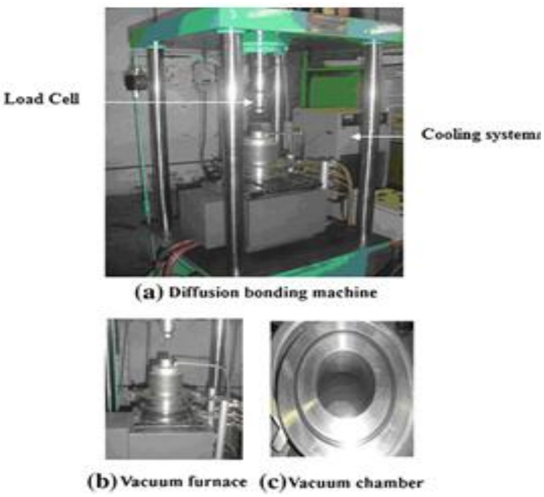

Fig. 1: Diffusion bonding machine setup

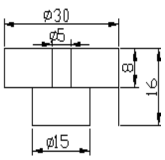

Fig. 2: Ram tensile strength

3. Results and Discussion

Taguchi approach is efficient method to optimize the process parameters and it reduces number of experiments. Taguchi analysis is achieved through signal to noise (S/N) ratio. The aim of this study is to achieve maximize the bonding strength for that S/N ratio of larger the better criteria is used. S/N ratio of bonding strength calculated by using the Eqn. (1) and populated in Table 4.

$$S/N\ ratio\ LB = -10\log\left[\frac{1}{n}\Sigma_{i=1}^{n}\frac{1}{y_i^{\ 2}}\right] \quad (1)$$

Table 4: Experimental data and S/N ratio for bonding strength

Bonding temperature	Bonding pressure	Bonding time	Bonding strength	S/N ratio of bonding strength
1	1	1	26	28.30
1	1	2	24	27.60
1	1	3	23	27.23
1	2	1	27	28.63
1	2	2	25	27.96
1	2	3	24	27.60
1	3	1	28	28.94
1	3	2	26	28.30
1	3	3	25	27.96
2	1	1	35	30.88
2	1	2	34	30.63
2	1	3	32	30.10
2	2	1	38	31.60
2	2	2	36	31.13
2	2	3	35	30.88
2	3	1	37	31.36
2	3	2	35	30.88
2	3	3	34	30.63
3	1	1	29	29.25
3	1	2	26	28.30
3	1	3	25	27.96
3	2	1	30	29.54
3	2	2	27	28.63
3	2	3	23	27.23
3	3	1	29	29.25
3	3	2	27	28.63
3	3	3	24	27.60

The response table was developed by the application of Taguchi approach. It is used to find the optimal parameters to achieve high yield of responses. Values of the response table are used to calculate the average value of each level of the column in the orthogonal array. Table 5 shows the response table for bonding strength (S/N ratio). Optimal bonding parameters for high yield of bonding strength (S/N ratio) are A2, B3, C3, such as 475°C of temperature, 10 MPa of pressure and 20 minutes of time. ANOVA is used to investigate process parameters and identify which process parameters are significantly affecting bonding strength. ANOVA calculated and presented the Table 6. From the ANOVA table, most significant parameter is bonding temperature it influences 85.93% followed by 12.6% of bonding time and 1.48% of bonding pressure. Both Taguchi and ANOVA analysis identify bonding temperature most significant factor than the others.

Table 5: Response table for bonding strength (S/N ratio)

Level	A	B	C
1	28.96	29.21	29.11
2	29.80	29.31	29.27
3	29.09	29.32	29.46
Delta	0.84	0.11	0.35
Rank	1	3	2

Table 6: Analysis of variance S/N for bonding strength

Source	Degrees of freedom	Sum of squares	Mean square	F-value	% contribution
A	2	42.20	21.10	218.95	85.93
B	2	0.73	0.36	3.77	1.48
C	2	6.19	3.09	32.09	12.6
Error	20	1.93	0.10		
Total	26	51.04			

Fig. 3 shows main effect plots (S/N ratio) drawn from the response table for bonding temperature, bonding pressure and bonding time. Fig. 4 shows the normal probability plot for bonding strength and the values placed approximately straight line depicts a good correlation between the actual and predicted values.

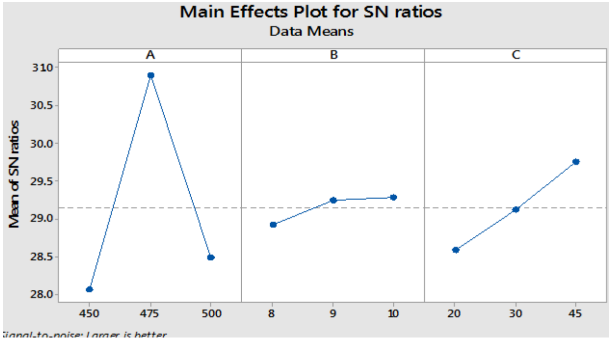

Fig. 3: Effect of factors on bonding strength S/N ratio

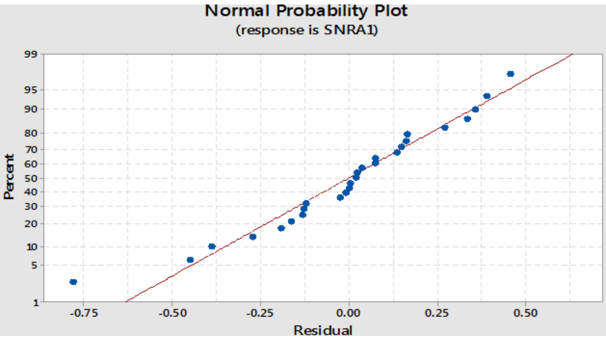

Fig. 4: Normal probability plot for bonding strength (S/N ratio)

4. Conclusion

In this investigation aluminium fly ash composites were successfully joined through diffusion bonding process, by using the Taguchi approach. The results were summarized as follows: The L27 Taguchi orthogonal designed experiments of diffusion bonding of AFA composites were successfully conducted. The optimum bonding parameters for the bonding strength are 475°C of bonding temperature, 10 MPa of bonding pressure and 20 minutes of bonding time. The percentage contributions of diffusion bonding process parameters were examined. It is found that the bonding temperature, bonding pressure and bonding time contributes 85.93%, 1.48% and 12.6% respectively.

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