MODELING AND OPTIMIZATION OF DIFFUSION BONDING PARAMETERS FOR ALUMINIUM AA6061 – SIC COMPOSITES USING RESPONSE SURFACE METHODOLOGY

Sittaramane. A₁, Mahendran. G.²,
₁Research Scholar, Department of Mechanical Engineering, Sathyabama University, Chennai, India
²Principal, IFET College of Engineering, Villupuram, Tamil Nadu, India
Email: ₁ a.sittaramane@gmail.com

Abstract

The Diffusion Bonding (DB) process parameters play an important role in joining characteristics of similar and dissimilar metals. Response surface methodology (RSM) technique is used to predict Lap shear strength of the diffusion bonded Aluminium AA6061-SiC composites (ASC). The experiments were conducted based on three factors namely bonding temperature, bonding pressure and bonding time. Using RSM technique empirical relationship developed by utilizing the parameters such as bonding temperature, bonding pressure and bonding time on lap shear.

Keywords: Diffusion bonding, Aluminium Silicon carbide composites, Lap shear strength, ASC, RSM

I. INTRODUCTION

Aluminium reinforced Silicon carbide used for military, aerospace and manufacturing industries because of their high modulus, strength, wear and fatigue resistance (1). Diffusion bonding techniques useful for joining metals when the metals not possible to join the conventional welding methods and it join similar and dissimilar metals (2). The quality of a diffusion bonding depends on its lap shear strength, for getting the maximum strength, selection of the process parameter is essentially one. Many researchers proved through the various statistical methods to maximize the output variables. Among the various optimization methods RSM useful for analysis the performance characteristics effectively (3-5). In this study to predict lap shear strength of diffusion bonded Aluminium AA6061-SiC composites using response surface methodology.

II. MATERIALS AND EXPERIMENTAL PROCEDURE

AA6061 Aluminium alloy used in this study and its chemical composition is shown in Table 1. Reinforcement used in this study was silicon carbide and its mesh size. The Aluminium reinforced with silicon carbide (6%) prepared by stir casting process. The fabricated ASC composite samples (45mmX45mmX8mm) were joined by DB process and the machine setup shown in Figure 1.

Table 1. Chemical composition of Aluminium AA6061

|    | 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 |

Experimental factor and their levels are presented in Table 2.
### Table 2. Process parameters and their levels

| Parameters               | Unit | Range     | Notation | Level 1 | Level 2 | Level 3 |
|--------------------------|------|-----------|----------|---------|---------|---------|
| Bonding temperature     | ºC   | 450 - 500 | A        | 450     | 475     | 500     |
| Bonding pressure         | MPa  | 10 – 14   | B        | 10      | 12      | 14      |
| Bonding time             | Min  | 30 - 60   | C        | 60      | 45      | 30      |

### III. DESIGN OF EXPERIMENTS

In the present work bonding parameters viz. bonding temperature, bonding pressure and bonding time on lap shear strength of ASC bonded joints were evaluated. L27 orthogonal array was used with three process parameters and three levels and it was tabulated in Table 3.

### IV. RESPONSE OF THE EXPERIMENT

**Lab shear strength:**

The lap shear strength 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. For that a non standard diffusion bonded test samples was used and its specimen diagram as shown in Fig. 2. The optical micrographs of Experiment No 25. shows in Fig. 3.

![Fig 2 Lap shear test specimen diagram](image1)

Fig 2 Lap shear test specimen diagram

**Fig 3. Optical micrographs of Experiment No 25**

### V. RESULTS AND DISCUSSION

**Mathematical Model for lap shear strength**

Response surface methodology is a combination of statistical and mathematical method to develop a response by the influence of input parameters and it is expressed as follows;

\[
LS = -1174.1 + 4.690 A + 17.50 B - 0.293 C - 0.004800 A^2 - 0.500 B^2 - 0.00015 C^2 - 0.01667 A B + 0.001053 A C - 0.0061 B C
\]  

ANOVA was used to examine the adequacy and the confidence interval of the mathematical model (6). In the ANOVA analysis F value is used to examine the adequacy of the mathematical model. Calculated F value is greater than F table value and satisfies 95% confidence levels which improve that this model is an adequate one. Table 4 shows Adequacy checking by ANOVA. The calculated R-squared \((R^2)\) value is 96.23% and it indicated the goodness of fit the model. The actual and predicted value also shows less difference. Table 5 shows R-squared \((R^2)\) value.

**Effect of process parameters on Lap shear strength**

Among the various statistical methods desirability approach resolve the response problems effectively (6). It is simple, flexible and easily accessible in MINTAB 17. It has
dimensionless number it between 0 to 1. The predicted optimal results from the desirability value on lap shear strength as 22.96 MPa and the composite desirability values is 0.9953. Fig 4 shows the optimization plots.

Table 3. Experimental data for Lap shear strength

| S.NO | Bonding Temperature | Bonding Pressure | Bonding Time | Lap shear strength |
|------|---------------------|------------------|--------------|-------------------|
| 1    | 450                 | 8                | 45           | 18                |
| 2    | 450                 | 8                | 30           | 16                |
| 3    | 450                 | 8                | 20           | 15                |
| 4    | 450                 | 9                | 45           | 19                |
| 5    | 450                 | 9                | 30           | 17                |
| 6    | 450                 | 9                | 20           | 16                |
| 7    | 450                 | 10               | 45           | 20                |
| 8    | 450                 | 10               | 30           | 18                |
| 9    | 450                 | 10               | 20           | 17                |
| 10   | 475                 | 8                | 45           | 22                |
| 11   | 475                 | 8                | 30           | 21                |
| 12   | 475                 | 8                | 20           | 18                |
| 13   | 475                 | 9                | 45           | 23                |
| 14   | 475                 | 9                | 30           | 21                |
| 15   | 475                 | 9                | 20           | 20                |
| 16   | 475                 | 10               | 45           | 22                |
| 17   | 475                 | 10               | 30           | 20                |
| 18   | 475                 | 10               | 20           | 19                |
| 19   | 500                 | 8                | 45           | 20                |
| 20   | 500                 | 8                | 30           | 17                |
| 21   | 500                 | 8                | 20           | 16                |
| 22   | 500                 | 9                | 45           | 21                |
| 23   | 500                 | 9                | 30           | 18                |
| 24   | 500                 | 9                | 20           | 16                |
| 25   | 500                 | 10               | 45           | 20                |
| 26   | 500                 | 10               | 30           | 18                |
| 27   | 500                 | 10               | 20           | 16                |

In normal probability, data’s are placed approximately in a straight line and it gives good correlation between the predicted and actual values and it shows in Fig 5. In residual versus predicted value shows minimal variation between them and it shows in Fig 6.

Fig 4. Optimization plot

Fig 5. Normal Probability plot for lap shear strength

Fig 6. Residuals versus Fitted value for lap shear strength
### Table 4. Adequacy checking (ANOVA)

| Source of variation | Degree of freedom | Sum of squares | Mean sum of square | F – value (calculated) |
|---------------------|------------------|----------------|--------------------|-----------------------|
| Regression          | 9                | 121.249        | 13.4721            | 48.20                 |
| Residual error      | 17               | 4.751          | 0.2745             |                       |

### Table 5. Tests on the three factors, square effects and their interactions for lap shear strength

| Effect | Coefficient | t-value | Probability | R²       |
|--------|-------------|---------|-------------|----------|
| constant | -1174       | -13.93  | 0.000       | 96.23%   |
| A      | 4.690       | 14.08   | 0.000       |          |
| B      | 17.500      | 3.60    | 0.002       |          |
| C      | -0.293      | -1.08   | 0.297       |          |
| A²     | -0.004800   | -13.90  | 0.000       |          |
| B²     | -0.500      | -2.73   | 0.033       |          |
| C²     | -0.00015    | -0.10   | 0.920       |          |
| A*B    | -0.01667    | -2.73   | 0.014       |          |
| A*C    | 0.001053    | 2.17    | 0.044       |          |
| B*C    | -0.0061     | -0.51   | 0.619       |          |

### VI. CONCLUSIONS

The optimum range of bonding parameters for high quality diffusion bonded joints of ASC composite has been achieved. RSM is used as a technique to optimize the diffusion bonded parameters to obtain the optimum lap shear strength. From these investigations, the following conclusions have been achieved. The relationship between the bonding parameters for diffusion bonding of ASC composites has been established using RSM technique and it was checked by the ANOVA test, Normality diagrams and scatter diagrams was found to be satisfactory.

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