Investigation on Al6061 Silver Coated Copper Metal Matrix Composite in Pre and Post Heat Treated Condition

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Abstract

Objectives: The usage of Al6061 metal matrix composites as fins (extended surfaces), and the effect of heat treatment on the MMC's is pursued for the variations in fin efficiency. **Methods/Statistical Analysis:** Based on above requirement a metal matrix composite is prepared by the addition of silver treated copper particles in different weight percentages to the base metal Al 6061. Then the prepared MMC's are heat treated and solution zed. Test specimens (as-cast and heat treated) are statistically investigated using Taguchi and ANOVA (Analysis Of Variance). The performance of base metal, pre and post heat treated MMC's are compared on the basis of heat dissipation rate in pin fin apparatus for forced convection. **Findings:** Highest heat input of 65W, concentration of 15% and a distance of 2.7 cm is found to be effective for heat dissipation. Efficiency of heat treated Al 6061 Silver coated Copper MMC has augmented by 39% compared to base metal. **Application:** These MMC's has major application in heat sinks, Fins of condensers and evaporators etc.

Keywords: Al 606, ANOVA, Heat Dissipation, 1Heat Treatment, MMC's, Taguchi Analysis

1. Introduction

The usage of extended surfaces for enhanced heat transfer is the most proposed methodology for heat relieve from a hot surface. The design if of an array the fins have to be optimized in the number as the number if increased may affect the heat transfer adversely. This negative impact will be caused by may be due to the resistance offered to the flow of air and the boundary layer interferences¹. The investigations on rectangular fin array are reported extensively in the literature²⁻⁸. Apart from rectangular fins there limited studies performed on other fin configurations⁹. Thermal performance and mass minimization of extended surfaces was studied for rectangular, pin and triangular shaped arrays for effective heat dissipation from various surfaces by

The size of sink, the number of fins, the gaps between the fins, the area of sink exposed to atmosphere have an intimate relation on enhancing its convection effect and increasing the heat sink ability^{14,15}. Taguchi¹⁶ method for Design of Experiments (DOE) and the Analysis of Variance (ANOVA) that is most widely used in the production process are employed for choosing optimized design parameters. The effect of heat treatment and its impact on heat dissipation on three different aluminum alloys was studied, and it was reported that heat treatment enhances the thermal conductivity of the materials and their micro structural changes were also pursued¹⁷.

different convection models natural and forced^{10,11},

with the availability of various advanced materials and

methodologies of transport of thermal media deposition the landscape of heat dissipation has changed for good^{12,13}.

From the literature it is observed that very less work is carried on composite as heat sink. In the present study regular heat sink material Al 6061 is mixed with silver treated copper particles for preparation of MMC. Silver treated copper particles are selected due to their high thermal conductivity. Then the produced MMC is compared before and after heat treatment for temperature along the fins at different distances and heat dissipation rate (efficiency). Further investigation on optimization is carried out using Taguchi and ANOVA. The error analysis is carried out using regression model.

2. Experimentation

The manufacture of the composite with the requisite composition of silver coated copper (10% Silver is coated on 90% copper of diameter 30-50microns) is done using stir casting machine as shown in Figure 1. Base material chosen is AL 6061 which is regular heat sink material. The graphite crucible using a 3 phase bottom pour electric resistance furnace with a cover is used. The melting temperature is maintained at 750°C. A mechanical stirrer having three blades and run by a 0.5 HP motor is used to stir the composition into which the copper powder is added and further stirred prior to pouring. The properly stirred material is poured into molds and casts of 150x100 mm are obtained. The reinforcement percentages are chosen as 5, 10 and 15 percent by weight. The as cast rods are turned and made into the shape of the fin to be loaded onto the pin fin apparatus that is used for experimentation. One set of rods thus manufactured of varying compositions are sent for heat treatment. The heat treatment performed on the alloy of Al6061 is that of solutionizing at temperature of 540°C for 1 hour and is guenched in a water bath. The hence heat treated bars are loaded on the pin fin apparatus Figure 2 and experimented.



Figure 1. Preparation of MMC.



Figure 2. Pin-Fin Apparatus.

3. Fin Analyses

Efficiency of the fin is calculated from the following equation

$$\eta = \frac{Q_{fin}}{Q_{max}} = \frac{Q_{fin}}{hAsurf(T_b - T_a)}$$
(1)

 Q_{fin} is calculated for short fin with convection at tip from the temperature profile along the fin

$$\frac{T - T_a}{T_b - T_a} = c_1 e^{-mx} + c_2 e^{mx}$$
(2) (where

$$m = \sqrt{\frac{hp}{kA}})$$

$$Q_{fin} = \int_0^L [h\pi d(T - T_a]) dx$$
(3)

4.1 Taguchi Technique

The process/input parameters that influence the output characteristic of temperature are identified and the heat transfer is analyzed. The thus identified process parameters are heat input in watts, distance from the heat input on the fin, composition and their levels are given in Table 1. The design of experiments along with optimization of the process parameters is performed using taguchi method. The three process parameters with three levels yield nine experiments using the L9 orthogonal array. The array is shown in Table 2. The temperatures along the fin surface are found out using an infrared pyrometer that can measure temperatures in the range of -50°C to 500°C.

Table 1. Input parameters v	vith level	s	
Input parameter	Level 1	Level 2	Level 3
A. Heat input(Watts)	35	50	65
B. Distance from source(mm)	27	54	81
C. Composition (Wt %)	5	10	15

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Table 2. L 9 orthogonal arra	Table 2.	L 9	orthogonal	array
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Experiment	Heat input	Distance from	Composition
Number	(W)	source (mm)	(Wt %)
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2

The data thus accumulated is populated and the Tables 3 and 4 illustrate the data for various inputs on the materials prior to heat treatment and after heat treatment. S/N ratio's for the data collected are also dumped into the tables for clear understanding of the outputs gathered. The smaller S/N ratio is computed based on the quality of the characteristics. The objective of the experimentation is to enhance the heat transfer rate; the objective of enhancement of heat transfer is illuminated by the reduction in the surface temperature on the fin. The smaller the S/N ratio computed using equation 1 the best result.

$$\frac{S}{N} = -10 \log_{10} \left(\sum \frac{y^2}{n} \right) \tag{1}$$

The predicted temperature for MMC before heat treatment (T) = $84.6 \, {}^{\circ}C.$

Actual temperature through experiment for MMC before heat treatment (T) = $84.3 \, {}^{\circ}C$.

Level 3 of A, Level 1 of B and Level 3 of C which gives the maximum effect of improving temperature distribution.

The predicted temperature for MMC after heat treatment fin $(T) = 88.95^{\circ}C$

Actual temperature through experiment for MMC after heat treatment fin $(T) = 88.7^{\circ}C$.

Exp. No.	Heat input (W)	Distance from source (mm)	Composition (Wt %)	Temperature (°C)
1	1	1	1	54.2
2	1	2	2	44.2
3	1	3	3	38.1
4	2	1	2	69.5
5	2	2	3	54.7
6	2	3	1	42.3
7	3	1	3	84.3
8	3	2	1	61.1
9	3	3	2	50.2

Table 3. Data accumulated for temperatures on the pin fins prior to heat treatment

Table 4. Data accumulated for temperatures on the pin fins after to heat treatment

Exp. No.	Heat input (W)	Distance from source (mm)	Composition (Wt %)	Temperature (°C)
1	1	1	1	57.0
2	1	2	2	48.1
3	1	3	3	41.1
4	2	1	2	72.8
5	2	2	3	60.4
6	2	3	1	45.1
7	3	1	3	88.7
8	3	2	1	62.8
9	3	3	2	53.9

Interestingly, A3, B1 and C1 is the best combination for heat input 65W, fin distance of 27 mm and MMC composition of 15% will give the minimum surface Temperature for Base metal and MMC. From the S/N ratio graph shows that heat input giving more impact to improve the temperature distribution of fin Figures 3 and 4. In fin analysis, the main variables are heat input, fin distance and MMC composition among these three parameters in optimization technique heat input is ranked one for both base metal and MMC which influences the heat transfer characteristics.



Figure 3. S/N Ratios for fin in As-Cast Condition.



Figure 4. Main Effects Plot for fin in As-cast Condition.

4.2 ANOVA Analysis

The main purpose of performance of analysis of variance is to categorically find the significant factors and their contribution in the variation of the temperature relieve from the fin. The P-Value shows the significance of the inputs taken for analysis on temperature. From Table 5 & 6 it can be stated that Distance from base and heat input is more significant in the both cases for Al 6061 MMC before and after heat treatment, as P value is less than 0.05. The regression equation for the data accumulated is also found using regression analysis and is shown as equation (2).

4.3 Regression Analysis

Regression model is determining the relationship between independent variable with dependent variables. Here heat input, fin distance and percentage of composition are independent variables and temperature is a dependent variable

Temperature(C) = 55.0 + 9.85 * Heat input- 12.9 *Distance along Fin + 3.25* Composition (Wt %) (2)

Temperature(C) = 56.8 + 9.87 Heat input - 13.1 *Distance along Fin + 4.22* Composition (Wt %) (3)

Equation 2 and 3 shows the regression equation for MMC prior and post heat treatment.

The error between the regression model and experimental analysis were tabulated in Table 7.

The maximum residual between experimental analysis and regression analysis before heat treatment is 3.95% and after heat treatment is 3.5%. This method is suitable for predicting temperature within acceptable range of error. From the residuals it is obtained that error percentage is less in MMC after heat treatment.

Surface plots for temperature for various inputs are analyzed before and after heat treatment as shown in Figure 5 and 6. It can be seen that as the heat input is

Table 5. ANOVA table for data acquired for	or fin in as-cast condition
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Source	DF	Seq SS	Adj SS	Adj MS	F	Р
Heat Input(W)	2	582.18	582.18	291.09	22.44	0.043
Distance from Base(mm)	2	1017.68	1017.68	508.84	39.23	0.025
Composition (Wt%)	2	66.02	66.02	33.01	2.55	0.282
Error	2	25.94	25.94	12.97		
Total	8	1691.82				
S = 3.60139		R-Sq = 98.47%		R-Sq(adj) = 93.87%		

Source	DF	Seq SS	Adj SS	Adj MS	F	Р
Heat Input(W)	2	585.5	585.5	292.75	31.26	0.031
Distance from Base(mm)	2	1038.65	1038.65	519.32	55.46	0.018
Composition(Wt%)	2	108.36	108.36	54.18	5.79	0.147
Error	2	18.73	18.73	9.36		
Total	8	1751.24				
S = 3.06014		R-Sq =	98.93%	R-Se	q(adj) = 95.	72%

 Table 6.
 ANOVA table for data acquired for fin after heat treatment

Table 7. Experin	ental and I	Regression	Results
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Experiment	Before Heat treatment Temperature (°C)		After Heat Treatment Temperature (°C	
No.	Experimental results	Regression Results	Experimental Results	Regression Results
1	54.2	55.2	57.0	57.861
2	44.2	45.55	48.1	49.011
3	38.1	35.90	41.1	41.161
4	69.5	68.3	72.8	71.944
5	54.7	58.6	60.4	63.094
6	42.3	39.2	45.1	41.594
7	84.3	81.4	88.7	86.028
8	61.1	62	62.8	64.528
9	50.2	52.35	53.9	55.678

enhanced the amount of heat available to be transferred is more at the end of the given rod having a composition of copper mixed by weight in the MMC. It also highlights that at the higher heat input the temperature keeps on increasing at the farthest point from the base. The variation in temperature observed with respect to the composition is small at the maximum length when compared to the one closer to the base. This shows that at the base the amount of heat available to be transferred is higher.



Figure 5. Surface Plots for Variations in Temperature for Various input Parameters on Samples in as-cast Condition.



Figure 6. Surface Plots for Temperature with Varying input Parameters for Samples after Heat Treatment.

At high heat input according to the surface plot shown in the temperature tends to reduce with an enhancement in the composition and increase with the weight percentage of copper. This enhancement is due to the higher percentage of the copper present in the composite.

The higher dissipation of heat is shown in the 15 % composition composite and this can be seen in the this is an indication that the 15 % composition composite is well suited for heat sink applications when compared to the other compositions of 5 and 10.

4.4 Heat Dissipation and Temperature Distribution

The comparison of temperature distribution for AL 6061 and different composition MMC are shown in Figure 7. It clearly indicates that as the temperature is augmented with composition and thus the heat transfer rate.







Figure 7. Temperature Distribution before Heat Treatment.

The post heat treatment data when compared to the ones extracted from experimentation on as-cast fins

shows a genuine updraft in the heat dissipation capability of the composite this is primarily due to the effective diffusion of grain boundaries of the alloy Figure 8. This enhancement is also because of the precipitation of mgsi¹⁷. Artificial aging has brought about this capability of effectively increasing the heat dissipation capability of the composite. Hence the temperature on the surface of Post heat treated fin is greater at different velocity and distance compared to prior heat treatment. There is 39% approx. Increase in the efficiency of base AL 6061 compared to 15% composition heat treated composite Figure 9 for any velocity of air.



Figure 8. Temperature Vs Distance for 15% MMC before and after Heat Treatment.



Figure 9. Efficiency Vs. Velocity of Air.

5. Conclusions

The present study brings about the forced convection on Base metal AL 6061, AL 6061 MMC prior heat treatment and AL 6061 post heat treatment. Experimental analysis shows that temperature on MMC is higher than base metal which indicates the higher heat dissipation.

Prior and Post heat treated AL 6061 MMC was investigated and optimized using Taguchi and ANOVA analysis. Interestingly for both cases higher heat input, least distance and high composition are the best part where high amount of heat is dispersed into surrounding. Among the cases post heat treatment is showing high dissipation due to high thermal conductivity of reinforced particles, precipitation formed and diffusion of grain boundaries. Error are tabulated which are carried out through regression analysis.

The efficiency has increased by 39% compared to base metal which indicates that Heat treated AL 6061 MMC can be used as replacement to heat sink material. Further the investigation can be carried for natural convection and different heat treatment processes.

Nomenclature

MMC	Metal Matrix Composite
Н	Convective heat transfer coefficient
	(W/m^2K)
А	Area of Cross-section (m ²)
Р	Wetted Perimeter (m)
Κ	Thermal Conductivity (W/m K)
Q_{fin}	Heat Dissipation from fin W
Q_{max}	Maximum Heat dissipation W
A	Surf Surface area m ²
η	Efficiency
T	Ambient Temperature ^o C
T	Surface Temperature ^o C
T	Base Temperature ^o C
D	Diameter of rod mm
Wt%	Weight in percentage
L	Length of Fin (m)

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