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# EXPERIMENTAL INVESTIGATION ON AL6061 SILVER COATED COPPER METAL MATRIX COMPOSITE CIRCULAR EXTENDED SURFACES PRE AND POST HEAT TREATMENT

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## ABSTRACT

Heat alleviation from surfaces exposed to high heat has been of prominence with the advent of new technologies in the electronic industry. The usage of regular materials and alloys has been used to the hilt and the manufacture of new alloys being slow and with the advent of Metal Matrix Composites, their usage as heat dissipation materials has taken a front row. This is the initiation into developing an MMC of Al6061 with silver coated copper particles to be researched. The usage of Al6061 as a heat sink material and the addition of copper to it to enhance the heat dissipation capability of the material are found to yield encouraging results. This composite when further heat treated yielded even good results that surpassed the usual Al6061 capability of heat augmentation by 39%. Taguchi analysis and ANOVA are performed for the given data.

***Keyword:*** *Stir Casting, Al 6061, MMC's, Taguchi Analysis, ANOVA, Heat Dissipation*

## INTRODUCTION

The usage of extended surfaces for enhanced heat transfer is the most used methodology for heat relieval from a hot surface. The characterization and analysis on various shapes of fins have been performed during the recent history to promulgate a good fin material and also the right shape of the fin that can dispense higher heat generated at a smaller place as in electronics. An array of such fins designed and put in a small area for increase in the surface area are being researched as the heat being generated by electronics is on the increase with the innovation and enhancement in the technology. The design of an array of fins had to be optimized since the number of fins if higher may affect the heat transfer adversely. The negative impact may be due to the resistance offered to the flow of air and the boundary layer interferences [1]. The investigations on rectangular fin array are reported extensively in the literature [2-8]. Apart from rectangular fins there are limited studies performed on other fin configurations [9]. 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 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].The size of sink, the number of fins, the gaps between the fins, the area of sink exposed to atmosphere have an close relation on enhancing the convection effect and increasing the heat sink ability [14,15]. Taguchi [16] 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. Optimization of heat sinks is carried out using different techniques for different configurations [18-20].

From the literature it is observed that pin fin coated with carbon nano tubes has made a remarkable enhancement in heat transfer, but very less work is reported on composites being used for manufacturing heat sinks. 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 and better wettability. The produced MMC's heat dissipation rate is compared in as-cast and post heat treated conditions for different heat inputs and velocities of air. Further numerical investigation is carried out using Taguchi and ANOVA, in the subsequent sections. The process of manufacture of the MMC is elaborated in the next section.

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## EXPERIMENTATION

The composite of Al 6061 alloy with the silver coated copper (10% Silver is coated on 90% copper of diameter 30-50microns) is prepared using a stir casting machine as shown in Figure 1. Base material (matrix) chosen is Al 6061 which is the regular heat sink material being used in majority of electronic equipment for heat dissipation. A graphite crucible having a 3 phase bottom pour electric resistance furnace with a cover is used to melt the Al 6061 alloy which is cut into reasonable sizes for introduction into the furnace, and the melting temperature is maintained at 750°C. A mechanical stirrer(made of mild steel) having three blades being run by a 0.5 HP motor is used to stir the composition into which the silver coated copper powder is introduced after proper heating in a hot air oven to remove any incidence of water vapour. This so heated silver coated copper power is added and the composition is stirred for 5 mins before pouring to ensure proper mixing of the matrix and the reinforcement and to remove any gas entrapments. The properly stirred molten liquid is poured into cast iron moulds of 150x100 mm to obtain castings. The reinforcement percentages are chosen as 5, 10 and 15 percent by weight. The as-cast rods are machined and a cylindrical fin is manufactured with the required thread cut at one end so as to enable it to be loaded onto the pin fin apparatus that is used for experimentation. Heat treatment is performed on one set of rods thus manufactured of varying compositions. The rods are furnace heated to a temperature of 540°C and are allowed to soak for a period of 1 hour and are then quenched in a water bath. The as-cast and heat treated bars are loaded on the pin fin apparatus (Figure 2) and experimented upon, the results and analysis of which are shown in the subsequent sections. From the uncertainty analysis [21], it is found that temperature uncertainty is ±0.5%. Experimental validation is carried for pure aluminium as test fin, the result obtained from experiment is compared with correlations of pin fin [22]. It is observed that deviation was around 6% with correlations.

**Figure 1.** Stir Casting Machine

**Figure 2.** Pin-Fin apparatus

### Taguchi Technique

The process/input parameters that influence the output characteristic of temperature are identified and the heat transferred is experimented and tabulated in this section. The identified process parameters are heat input in watts, distance from the heat input on the fin in mm and composition of the MMC in percentages of silver coated copper particles, their levels are shown in Table 1. Length of the fin and diameter considered for the experiment are 15.2 and 1.1 cm. 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 recorded using an infrared pyrometer (fluke 59 max) that can measure temperatures in the range of -50$^o$C to 500$^o$C.

**Table 1.** Input parameters with chosen their levels

| **Input parameter** | **Level 1** | **Level 2** | **Level 3** |
|---|---|---|---|
| Heat input(Watts) | 35 | 50 | 65 |
| Distance from source(mm) | 27 | 54 | 81 |
| Composition (wt %) | 5 | 10 | 15 |

**Table 2.** L9 orthogonal array

| **Experiment Number** | **Heat input (W)** | **Distance from source (mm)** | **Composition (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 is accumulated and populated into Tables 3 and 4;these tables illustrate the data for various inputs on the materials prior to heat treatment and after heat treatment. S/N ratio's for the data recorded are also shown in 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. S/N ratios for the data accumulated in the tables are analysed using equation 1 wherein the smaller the value of the ratio the better is the result [18].

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

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

| **Exp. No.** | **Heat input (W)** | **Distance from source (mm)** | **Composition (Wt %)** | **Temperature ($^o$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 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 |

The data accumulated is further used to do an efficiency analysis to find the efficiency of the fin with the best composition that can be used; this is elaborated in the next section.

### Fin Analysis

Analysis that is performed on the as-cast and heat treated samples of varying compositions are accomplished using the efficiency formulations [18,22] for analysing the performance of the fins manufactured. Efficiency of the fin is calculated from the following equation;

$$\eta = \frac{Q_{fin}}{Q_{max}} = \frac{Q_{fin}}{hA_{surf}(T_b - T_a)} \tag{2}$$

Where $Q_{fin}$ is calculated for short fin with convection at tip from the temperature profile along the fin by considering temperature at 15 different points

$$\frac{T - T_a}{T_b - T_a} = c_1 e^{-mx} + c_2 e^{mx} \tag{3}$$

Where

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

$$Q_{fin} = \int_0^L h\pi d(T - T_a)dx \tag{4}$$

The data and the analysis performed to find the efficiency of the fin are discussed in the following section.

## RESULTS AND DISCUSSION

S/N ratio is calculated based on quality of the characteristics. The objective function of this method is to improve the heat dissipating rate through heat transfer apparatus. If heat is transferred effectively, the corresponding surface temperature will be lower. If the calculated S/N ratio (smaller the best) is smaller that will give best results. Interestingly, Heat input at the highest level of 65W, Distance from source at the lower level of 27mm and Composition at 15% is the best combination that gives the maximum surface temperature for MMC in as-cast and post heat treated condition. S/N ratio from Figure 3 and 4 ascertains the above statement [18].From the factor effect graph shows that heat input and distance from source giving more impact to improve the temperature distribution of fin (Figure 3 and 4).

### ANOVA Analysis

The main purpose of performing Analysis Of Variance (ANOVA) is to categorically find the significant factors and their contribution in the variation of the temperature relieval from the fin. The P-Value shows the significance of the inputs chosen for analysis on temperature. From Table 5 and Table 6 it can be stated that Distance from source and heat input are more significant in both cases for Al 6061 MMC before and after heat treatment, as P-value is less than 0.05 it shows that we have a 95% agreement.

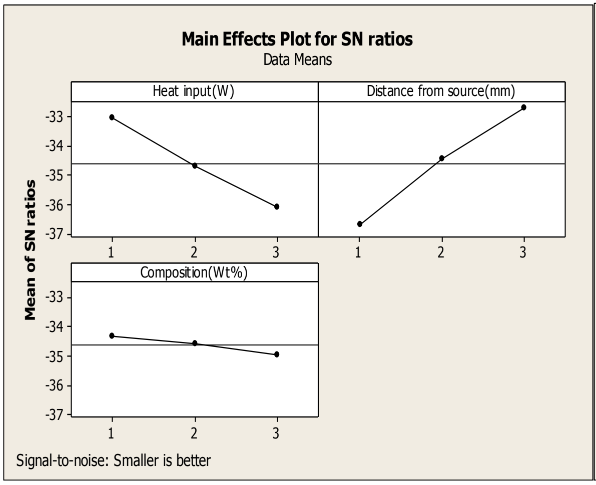


**Figure 3.** S/N ratios for fin in as-cast condition

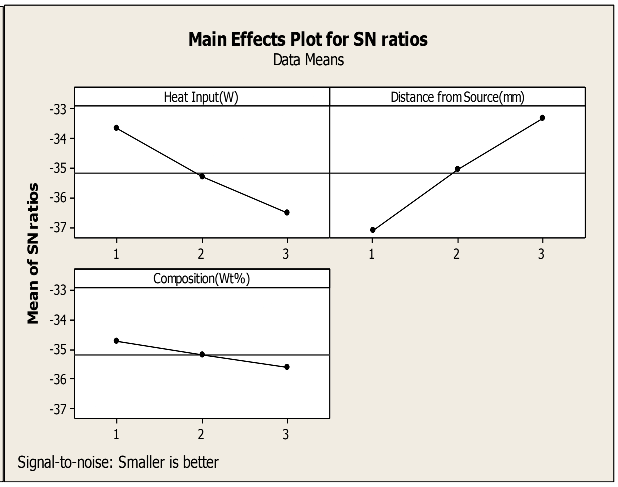


**Figure 4.** S/N ratio for fin in post heat treated condition

**Table 5.** ANOVA table for data acquired for fin in as-cast condition

| Source | DF | Seq SS | Adj SS | Adj MS | F | P |
|---|---|---|---|---|---|---|
| Heat Input(W) | 2 | 582.18 | 582.18 | 291.09 | 22.44 | 0.043 |
| Distance from Source(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% | | |

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

| Source | DF | Seq SS | Adj SS | Adj MS | F | P |
|---|---|---|---|---|---|---|
| Heat Input(W) | 2 | 585.5 | 585.5 | 292.75 | 31.26 | 0.031 |
| Distance from Source(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-Sq(adj) = 95.72% | | |

## Heat Dissipation and Temperature Distribution

The comparison of temperature distribution for AL 6061 alloy and different compositions of the MMC in as-cast state are shown in Figure 5. This data is accumulated when force convection is employed at an air velocity of 2.8 m/sec and at the highest heat input of 65 W. The wattage of 65 is chosen as it is proven to showcase higher temperatures.

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 6). This enhancement is also because of the precipitation of mgsi [17]. 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. This shows that the 15% composition MMC is having greater heat dissipation capability and further research is concentrated on this composition for greater clarity.

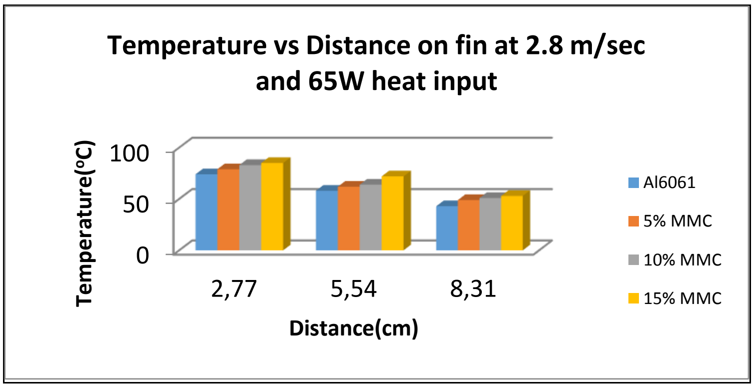


**Figure 5.** Temperature distribution before heat treatment

Experimentation is performed on 15% MMC at varying wind velocities of 1.2, 2, 2.8 m/sec. Figure 6 illustrates that the amount of temperature being alleviated is more at higher velocity of 2.8 m/sec. the amount of heat available to be dissipated for the MMC in the post heat treated samples is higher as can be seen which might be due to precipitation hardening.

Fin efficiency calculated from equation 2 presented in Figure 7 is found for high heat input at various velocities for Al 6061, 15% MMC in as-cast and post heat treated conditions as this percentage of composition is promising and at higher heat input of 65 W. The heat treated fin proves to be the best alternative for the regular Al 6061 alloy to be the fin material as its efficiency is a good 39% more.

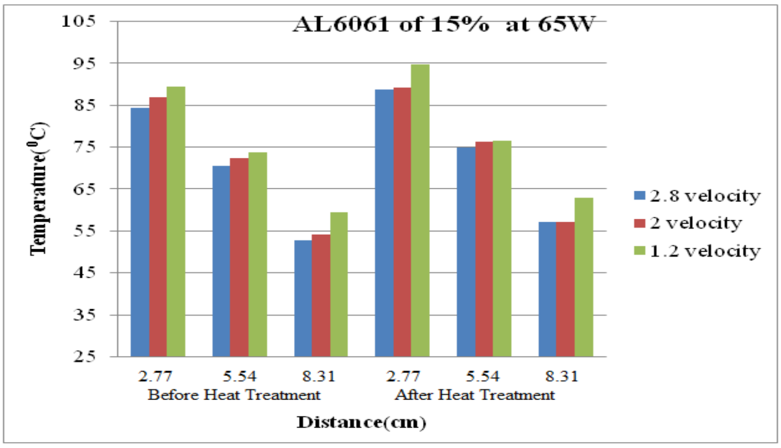


**Figure 6.** Temperature Vs Distance for 15% MMC before and after heat treatment

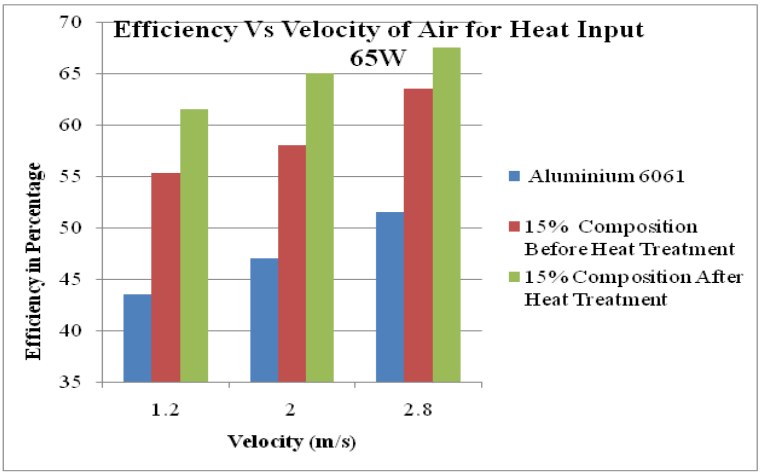


**Figure 7.** Efficiency Vs Velocity of air

## CONCLUSIONS

The present study brings about the forced convection on experimentation on AL 6061, AL 6061 MMC as-cast and AL 6061 post heat treatment conditions. Experimental analysis shows that surface temperature on MMC is higher than base metal which indicates higher heat dissipation being realized.

Prior and Post heat treated AL 6061 MMC is investigated and optimized using Taguchi and ANOVA analysis. Interestingly for both cases higher heat input, least distance and high composition are yielding best results where high amount of heat is dispersed into the surroundings. Among the cases post heat treatment is showing high heat dissipation due to higher thermal conductivity of reinforced particles, precipitation formed and diffusion of grain boundaries.

The efficiency increased by 39% compared to Al 6061 alloy which indicates that heat treated Al 6061 MMC having 15% by weight silver treated copper can be used as a replacement. Further the investigation can be carried for natural convection and different heat treatment processes.

## Nomenclature

| | |
|---|---|
| MMC | Metal Matrix Composite |
| H | Convective heat transfer coefficient ($W/m^2K$) |
| A | Area of Cross-section ($m^2$) |
| P | Wetted Perimeter (m) |
| K | Thermal Conductivity (W/mK) |
| $Q_{fin}$ | Heat Dissipation from fin (W) |
| $Q_{max}$ | Maximum Heat dissipation (W) |
| $A_{surf}$ | Surface area ($m^2$) |
| $\eta$ | Efficiency |
| $T_a$ | Ambient Temperature ($^0C$) |
| T | Surface Temperature ($^0C$) |
| $T_b$ | Base Temperature ($^0C$) |
| D | Diameter of rod (cm) |
| Wt% | Weight in percentage |
| L | Length of Fin (cm) |

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