Evaluation of Convective Heat Transfer Coefficient and Heat Transfer Rate through Aluminium Metal Matrix Composite Fin made by Stir Casting

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Abstract. The pure metals are having their benefits and shortcomings. Some were having good ductility, some having good strength and some were having good thermal properties. If we were in a need of all these properties together it would occupy more space, more cost, and add additional weight to the product. To overcome all these problems, worked on Aluminium Metal Matrix. For this process, considered copper as reinforcement to the Aluminium base metal matrix. Aluminium Metal Matrix composite is produced by using the Stir casting method, which is the easiest and cost-effective method. Produced composite material with different compositions of reinforcement (Plane, 5% Cu, 10% Cu and 15% Cu) to Aluminium base Matrix. For each composition, found the values of thermal properties experimentally analyzed the variation of all properties concerning the change in the composition of copper material.

Keywords: Heat transfer, Stir Casting, Metal Matrix, Fins, Reynolds number, Nusselt number.

1. Introduction
Metal Matrix Composite (MMC)¹ is a macroscopic blend of two or more different materials having a recognizable interface between them, in now a day’s MMC’s are enlightening a lot and also found numerous applications. MMCs are classified into three main categories (i) Particles reinforced MMCs (ii) Short fibers or Whiskers reinforced MMCs and (iii) Continues fibers or sheet reinforced MMCs. The use of the MMC has been noteworthy rise in the field of space vehicle, automobile and under water vehicle. Aluminum and its alloys have involved most immersion as base metal [³, ⁴] in MMC’s. The reinforcements should be steady in the given operational temperature and non-reactive too. Silicon Carbide [⁷, ¹³] (Sic), Aluminum Oxide [⁹] (Al₂O₃), Boron carbide, Titanium oxide [⁶], Graphite are some of the reinforcements which are widely used for better properties. Stir casting is simple and inexpensive, effective in its use of raw material, and has outstanding potential for computerized...
operation at high rates of manufacture. The procedure produces the maximum mechanical properties achievable in a cast product. The stir casting cast products are required for many challenging applications. It is appropriate for high ductility, high strength, and lightweight necessary for advanced components.

2. Experimental Set-Up

Figure 1. shows the main parts of Stir casting [9] apparatus are (A) Electric Motor (B) Stirrer Screw (C) Furnace (D) Crucible (E) Rotor.

Reinforcement may be metal reinforcement. Stirring speed (400 RPM) and stirring time (10 Mins) is important otherwise reinforcement get settled at the bottom or some side. The reinforcement material is embedded into the matrix to enrich or diminish their properties like hardness, porosity, density, wear resistance, mechanical strength, thermal expansion, thermal and electric conductivities.

2.1. Mould preparation

To prepare a piece of component, without any defects a mould plays an important role. The proper preparation of mould ensures defect free component. The moulding sand must be properly rammed to form a stiff structure. It is very essential to retain its geometry and dimensional stability. It should be wear resistant. Here we are using silica and molasses to prepare the mould and chalk powder is used for dusting.

2.2. Weighing of materials

As this research deals with the composites with varying compositions, the accurate weighing of material is very important. A slight change in the composition can result in wrong calculations. A very precise weighing machine is required to weigh smaller compositions.

2.3. Melting

As the materials selected are having different melting temperatures both the matrix and the reinforcement must be separately preheated at some defined temperature. Figure 2 shows the melting of metals in furnace, when the both metals reaches the required temperature, the metals are poured into the stir casting furnace show in figure 3, and is set at some defined temperature.
2.4. Stir casting procedure
The furnace of stir casting shown in Figure 3. is set to preheat at defined temperature. When the matrix and reinforcement is completely melted. Reinforced the reinforcement in the matrix using the stirrer shown in Figure 4 for better bonding of reinforcement with matrix. Stirred in the furnace at average speed of 400 rpm for required time for completely mixing of the metals. Figure 5 show the stirring operation.

2.5. Formation of specimen
The molten metal in the furnace taken out and the mixture is immediately poured into the mould shown in the Figure 6. to avoid any solidification and allow it to cool for nearly 1 hour. The cast product obtained after cooling is shown in Figure 7.

2.6. Micro level finishing
Micro finishing is done on cast product shown in Figure 7. by using emery papers. Emery paper is a type of abrasive paper or sand paper that can be used to remove the material at micro level to obtain
micro level finishing, the finished specimen is shown in Figure 8. Operation was done with 700, 600, 320 and 220 grit papers.

![Finished specimen](image)

**Figure 8.** Finished specimen

2.7. **Produced Components**
The above procedure is used to produce the components of different composition of copper reinforcement (5% Cu, 10% Cu and 15% Cu) in aluminium matrix. The compositions produced are shown in the Table 1.

| Aluminium | Copper |
|-----------|--------|
| 95%       | 5%     |
| 90%       | 10%    |
| 85%       | 15%    |

2.8. **Pin Fin Apparatus Setup**
An aluminium fin of rectangular cross section of length L is fitted in the rectangular duct of pin fin apparatus shown in Figure 9. The base of the fin is fixed to a heater plate for heating the fin. Thermocouples are provided on the surface of the fin. The duct is provided with a suction fan to control the air flow with the help of regulator. A multichannel temperature indicator has been provided to monitor temperature at different points. An anemometer has been provided to measure the air velocity through the duct. Digital wattmeter has been provided to measure power input to the heater. Heat regulator is to vary input power to heater.

![Pin Fin Apparatus](image)

**Figure 9.** Pin Fin Apparatus
3. Results and Discussions
During evaluation process input and output parameters places very important role. In whole procedure the input parameters kept constant. For each specimen, once steady state is reached the output parameter i.e., temperature is measured along the length of the fin by using thermocouples.

3.1. Input parameters
- Heat Input: constant heat supplied to the fin base 15 W.
- Air Velocity: The air velocity is kept constant at 4.2 m/s.

3.2. Output parameters
- Temperature
- Nusselt Number
- Reynolds Number

3.3. Forced convection analysis equations as follows

\[ T_m = \frac{(T_s + T_a)}{2} \]

Where \( T_m \) = mean surface temperature of fin
\( T_s \) = ambient temperature
\( T_a \) = mean film temperature
Re < 5 \times 10^5 laminar flow

Reynold number,
\[ Re = \frac{\rho V L}{\mu} \]

For laminar flow, \( NU = 0.644 \sqrt{Re} \left( \frac{3}{Pr} \right) \)

Nusselt number, \( NU = h L / K_t \) where \( K_t \) = thermal conductivity of air; \( h \) = heat transfer coefficient

Heat transfer rate,
\[ Q_{fin} = \sqrt{h p K_A c} (T_s - T_a) \tanh (mL) \]

\( m \) = \( \sqrt{h p \sqrt{K_A c}} \)

\( K = \) thermal conductivity of aluminium component = 229.30 W/mK

Dimensions of fin = 100x50x5 mm; Length L =100mm, thickness t =5mm, width w=50mm
\( T_s = (62.8+60.8+59.2+57.3) / 4 = 60.02 \)°C; \( T_a = 33 \)°C; \( T_m = (T_s + T_a)/2 = 47 \)

From data book at 47°C is Density \( (\rho) = 1.0930 \text{ Kg/m}^3 \); absolute viscosity = 0.00001967 Ns/m² ;
\( Pr = 0.698 \); \( K_t = 0.02826 \text{ W/mK} \)

\[ Re = \frac{\rho V L}{\mu} = 23338.08 \text{ i.e.} < 5 \times 10^5 \text{ laminar flow} \]

\[ NU = 0.644 \sqrt{Re} \left( \frac{3}{Pr} \right) = 87.28151366 \]

\( NU = h L / K_t \) ; by substituting the values of L, \( K_t \) and \( Nu \) in \( Nu \) equation we get \( h = 24.67 \text{ W/mK} \)

\( p = 2 (t + w) = 0.11 \text{ m}; \text{ Ac} = \text{ wxt} = 0.00025 \text{ m}^2 \); \( m = \frac{\sqrt{hp}}{\sqrt{K_A c}} = 6.8797321 \text{ m}^{-1} \)

\( K = \) thermal conductivity of aluminium component = 229.30 W/mK

\[ Q_{fin} = \sqrt{h p K_A c (T_s - T_a) \tanh (mL)} = 11.75254 \text{ W} \]

Heat flux \( q_{fin} = K m (T_s - T_a) \tanh (mL) = 47010.17 \text{ W/m}^2 \)

3.4. Discussions
In order to evaluate the current experimental results and generate a base line for comparison, firstly, conducted experiment on plane Al and then experiment was carried on different compositions of Al and Cu (Al95% - Cu5% MMC, Al90% - Cu10% MMC and Al85% - Cu15% MMC) and the results are plotted below.
Figure 10. Heat transfer coefficient

Figure 10. shows that the convective heat transfer coefficient of plane aluminium, Al95%-Cu5% MMC, Al90%-Cu10% MMC and Al85%-Cu15% MMC. The Figure 10 clearly shows that as the percentage increase of Cu reinforcement in Al matrix, the convective heat transfer coefficient also increasing for MMC fin. The minimum value for plane aluminium is 24.57 W/m2K and maximum value for Al85%-Cu15% MMC fin is 26.2 W/m2K.

Figure 11. % increase in h over plane Al

Figure 11. shows that the percentage increase of convective heat transfer coefficient over plane aluminium. The Figure 11. clearly shows that as the percentage increase of Cu reinforcement in Al matrix, the percentage increase of convective heat transfer coefficient also increasing for MMC fin. The minimum value for Al95%-Cu5% MMC fin is 3.088 and maximum value for Al85%-Cu15% MMC fin is 6.235 and the intermediate value for Al90%-Cu10% MMC fin is 4.666.

Figure 12. Rate of Heat Transfer

Figure 12. shows that the rate heat transfer for plane aluminium, Al95%-Cu5% MMC, Al90%-Cu10% MMC and Al85%-Cu15% MMC. The Figure 12. clearly shows that as the percentage increase of Cu reinforcement in Al matrix, the rate heat transfer also increasing for MMC fin. The minimum value for plane aluminium is 11.7525 W and maximum value for Al85%-Cu15% MMC fin is 12.5630 W.

Figure 13. % increase in Qfin over plane Al

Figure 13. shows that the percentage increase of heat transfer rate over plane aluminium. The Figure 13. clearly shows that as the percentage increase of Cu reinforcement in Al matrix, the percentage increase of heat transfer rate also increasing for MMC fin. The minimum value for Al95%-Cu5% MMC fin is 2.504 and maximum value for Al85%-Cu15% MMC fin is 6.896 and the intermediate value for Al90%-Cu10% MMC fin is 4.545.
Figure 14. Heat Flux

Figure 14. shows that the rate of heat flux for plane aluminium, Al95%-Cu5% MMC, Al90%-Cu10% MMC and Al85%-Cu15% MMC. The Figure 14. clearly shows that as the percentage increase of Cu reinforcement in Al matrix. The rate of heat flux also increasing for MMC fin. The minimum value for plane aluminium is 47010.17 W/m² and maximum value for Al85%-Cu15% MMC fin is 50252.31 W/m². Figure 15. shows that the percentage increase of rate of heat transfer flux over plane aluminium. The Figure 15. clearly shows that as the percentage increase of Cu reinforcement in Al matrix, the percentage increase of rate of heat transfer flux also increasing for MMC fin. The minimum value for Al95%-Cu5% MMC fin is 2.50 and maximum value for Al85%-Cu15% MMC fin is 6.9 and the intermediate value for Al90%-Cu10% MMC fin is 4.55.

Figure 16. Effectiveness

Figure 16. shows that the Effectiveness for plane aluminium, Al95%-Cu5% MMC, Al90%-Cu10% MMC and Al85%-Cu15% MMC. The Figure 16. clearly shows that as the percentage increase of Cu reinforcement in Al matrix. The Effectiveness also increasing for MMC fin. The minimum value for plane aluminium is 63.94 and maximum value for Al85%-Cu15% MMC fin is 65.69. Figure.17 shows that the percentage increase of Effectiveness over plane aluminium. The Figure.17 clearly shows that as the percentage increase of Cu reinforcement in Al matrix, the percentage increase of rate of Effectiveness also increasing for MMC fin. The minimum value for Al95%-Cu5% MMC fin is 0.45 and maximum value for Al85%-Cu15% MMC fin is 2.74 and the intermediate value for Al90%-Cu10% MMC fin is 1.60.
Figure 18. shows that the Efficiency for plane aluminium, Al95%-Cu5% MMC, Al90%-Cu10% MMC and Al85%-Cu15% MMC. The Figure 18. clearly shows that as the percentage increase of Cu reinforcement in Al matrix. The Efficiency also increasing for MMC fin. The minimum value for plane aluminium is 14.53 and maximum value for Al85%-Cu15% MMC fin is 14.93. Figure 19. shows that the percentage increase of efficiency over plane aluminium. The Figure 19. clearly shows that as the percentage increase of Cu reinforcement in Al matrix, the percentage increase of rate of efficiency also increasing for MMC fin. The minimum value for Al95%-Cu5% MMC fin is 0.48 and maximum value for Al85%-Cu15% MMC fin is 2.75 and the intermediate value for Al90%-Cu10% MMC fin is 1.58.

4. Conclusions
This experimental work explores the heat transfer coefficient, rate of heat transfer, heat flux, Effectiveness and Efficiency for a newly designed fin, the emphasis is given on variations of heat transfer coefficient, rate of heat transfer and heat flux resulting from various parameters, including different composition of Al and Cu (Al95%-Cu5% MMC, Al90% - Cu10% MMC and Al85% - Cu15% MMC) and flow rate. The Conclusions as fallows

1. Aluminium Metal Matrix composite is produced by using the Stir casting method, which is the easiest and cost-effective method.
2. The minimum value of heat transfer coefficient for plane aluminium is 24.57 W/m²K and maximum value for Al85%-Cu15% MMC fin is 26.2 W/m²K
3. The percentage increase in heat transfer coefficient over base aluminum is 3.08%, 4.66%, & 6.23% when considered 5% Copper, 10% Copper & 15% Copper.
4. The minimum value of heat transfer rate for plane aluminium is 11.7525 W and maximum value for Al85%-Cu15% MMC fin is 12.5630 W.
5. The percentage increase in heat transfer rate over base aluminum is 2.50%, 4.54%, & 6.89% when considered 5% Copper, 10% Copper & 15% Copper.
6. The percentage increase in Effectiveness over base aluminum is 0.45%, 1.60%, & 2.74% when considered 5% Copper, 10% Copper & 15% Copper.
7. The percentage increase in Efficiency over base aluminum is 0.48%, 1.58%, & 2.75% when considered 5% Copper, 10% Copper & 15% Copper.
8. As the composition of copper in aluminum base matrix increases it was observed that an increase in the heat transfer coefficient, Effectiveness, Efficiency and rate of heat transfer from the fin.

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