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Experimental Analysis of Various Brass Compositions for Efficient Heat Dissipation and Cooling

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ABSTRACT: This study looks at the thermal performance of copper-based brass alloys of various compositions in a pin fin cooling system. Four distinct brass compositions were created by varying the copper, zinc, lead, and iron concentration to investigate the effects on heat dissipation and thermal conductivity. The pin fins were evaluated under free and forced convection circumstances using a pin fin equipment. Experiments show that increasing the copper concentration improves thermal conductivity and heat dissipation efficiency, making the material better suited for cooling applications. Among the studied compositions, the alloy with the highest copper content demonstrated best heat transfer performance, indicating its potential for thermal management in industrial and electronic cooling systems.

KEYWORDS: Thermal Conductivity, Heat Transfer, Thermal Efficiency, Heat Transfer Co-Efficient, Pin Fin, Brass, Cooling

I. INTRODUCTION

A key component of engineering design, thermal management has a direct impact on the lifetime, dependability, and efficiency of systems in a variety of sectors, including electronics, automotive engineering, aircraft, and energy generation. In order to avoid overheating, which can impair performance, shorten component lifespan, and present safety hazards, effective heat dissipation is essential. Extended surfaces—also referred to as fins—are frequently used in heat dissipation techniques to improve heat transmission between solid surfaces and the fluid around them.

Fins improve thermal performance by increasing the surface area available for convective and radiative heat transfer. They are usually shaped like rods, plates, or pins. Fins' shape and material choice have a significant impact on how effective they are. Because of its advantageous thermal conductivity, mechanical strength, resistance to corrosion, and simplicity of manufacture, brass—an alloy of copper and zinc—has drawn a lot of interest for fin fabrication. However, the composition of brass has a significant impact on its thermal performance. Zinc adds hardness and cost-effectiveness, copper improves heat conductivity, and trace metals like iron and lead have an impact on structural integrity and machinability.

In order to address the increasing demand for energy-efficient solutions in high-power applications, this research bridges the gap between theoretical material science and practical engineering by providing a framework for designing high-performance thermal systems that balance material cost, environmental sustainability, and technological efficiency. The goals of this study are to examine the impact of brass composition on the thermal efficiency of pin fins, a cylindrical fin geometry frequently used in heat dissipation applications. The research evaluates the impact of composition on thermal conductivity and convective heat transfer under both free and forced convection conditions.

Pin Fin

Conical or cylindrical projections called pin fins are intended to improve heat dissipation efficiency by increasing the surface area available for heat transmission. They are appropriate for heat exchangers, electronic cooling systems, and high-performance thermal applications because of their compact shape, which enables effective cooling in small areas. Pin fins are a popular option in thermal management systems because of their capacity to increase heat transfer rates while preserving structural integrity.

II. HEAT TRANSFER THROUGH PIN FINS

Conduction, convection, and radiation are the three ways that heat is transferred in pin fins, and each is essential to the process of heat dissipation as a whole. The material characteristics, fin shape, and ambient factors all affect how successful a fin is in thermal applications.

Conduction

The main way that heat is transferred inside the fin material is by conduction. Heat travels through the solid fin structure and toward the tip from the fin's base, which is in touch with a heat source. The temperature gradient along the fin and the material's thermal conductivity both affect the rate of conductive heat transfer. Because of their high thermal conductivity, materials like brass and aluminum allow for effective heat transfer, guaranteeing that the most heat is dissipated into the environment.

Convection

Heat is dispersed into the surrounding fluid (air or liquid) by convection after passing through the fin. Heat is carried away from the fin's surface by fluid motion, which powers this heat transfer mechanism. The fin's surface area, the temperature differential between the fin and the fluid, and the convective heat transfer coefficient are some of the variables that affect how well convective heat transfer works. There are two types of convection: forced convection, where external forces like fans or pumps promote fluid movement for better heat dissipation, and free (natural) convection, where heat transfer happens as a result of fluid density fluctuations.

Radiation

Heat is lost from the fin surface by radiation in addition to conduction and convection. Heat transfer through electromagnetic waves that don't need a medium to pass through is referred to as radiation. The surface area, temperature differential between the fin and its surroundings, and the emissivity of the fin material all affect the rate of radiative heat transfer. The fin's total heat dissipation efficiency is influenced by radiation heat loss, which is often less noticeable in low-temperature applications but more noticeable at higher temperatures.

III. MATERIAL COMPOSITION AND SELECTION

Four essential ingredients are used in this project to produce the brass alloy: copper (Cu), zinc (Zn), lead (Pb), and iron (Fe). The contributions of each element to mechanical strength, corrosion resistance, thermal conductivity, and manufacturability are carefully considered throughout the selection process. The differences in composition make it possible to compare the structural integrity and heat dissipation efficiency, which aids in identifying the best alloy formulation for improved performance in pin fin applications.

Copper (Cu)

- A higher copper content greatly enhances thermal performance, lowering heat accumulation in high-temperature environments
- It also helps with corrosion resistance, guaranteeing long-term stability and durability in humid or chemically exposed conditions
- copper is the main element responsible for thermal conductivity, making it crucial for effective heat dissipation.
- By increasing the alloy's ductility, copper makes it more suitable for manufacturing techniques like casting and machining.

Zinc (Zn)

- It balances cost-effectiveness with adequate thermal conductivity for heat dissipation applications.
- Zinc is added to improve mechanical strength and hardness, limiting excessive deformation under high thermal loads.
- Analysis of the impact of varying zinc concentration on the alloy's wear resistance and thermal efficiency is possible.

Lead (Pb)

- Lead minimizing friction during manufacturing and assembly without noticeably compromising thermal conductivity

- it is added to improve machinability, reducing tool wear and guaranteeing smoother fabrication processes like drilling, tapping, and threading
- its controlled addition permits an evaluation of its effects on mechanical properties and production ease.

Iron (Fe)

- In applications that are subjected to mechanical loads and extended usage, it improves wear resistance
- stability is ensured without sacrificing the alloy's thermal efficiency; and a small percentage of iron is added to increase structural strength and durability, preventing excessive deformation under operational stress.

S. No	Symbol	Thermal Conductivity(W/mK)	Density (g/cm ³)	Melting Point (°C)
1	Cu	394	8.93	1083
2	Zn	116	7.14	419.5
3	Pb	35	11.34	327.4
4	Fe	80	7.87	1538

IV. COMPOSITION OF FIN

Composition 1

$$\text{Cu} = (58/100) \times 213 = 123.54 \text{ g}$$

$$\text{Zn} = (39/100) \times 213 = 83.07 \text{ g}$$

$$\text{Pb} = (2.5/100) \times 213 = 5.325 \text{ g}$$

$$\text{Fe} = (0.35/100) \times 213 = 0.4809 \text{ g}$$

Composition 2

$$\text{Cu} = (144.75 \times 100) / 218 = 66.39\%$$

$$\text{Zn} = (68.01 \times 100) / 218 = 31.19\%$$

$$\text{Pb} = (4.36 \times 100) / 218 = 2\%$$

$$\text{Fe} = (0.61 \times 100) / 218 = 0.279\%$$

Composition 3

$$\text{Cu} = (165.204 \times 100) / 234 = 70.6\%$$

$$\text{Zn} = (63.88 \times 100) / 234 = 27.299\%$$

$$\text{Pb} = (4.095 \times 100) / 234 = 1.75\%$$

$$\text{Fe} = (0.5733 \times 100) / 234 = 0.245\%$$

Composition 4

$$\text{Cu} = (171.292 \times 100) / 234 = 74.79 \%$$

$$\text{Zn} = (53.586 \times 100) / 234 = 23.4 \%$$

$$\text{Pb} = (3.435 \times 100) / 234 = 1.5 \%$$

$$\text{Fe} = (0.4809 \times 100) / 234 = 0.21$$

V. FABRICATION

In order to obtain exact dimensions, structural integrity, and optimal thermal performance, pin fins must be fabricated using a methodical approach. Preparing the mold, heating the metal, casting, solidifying, polishing the surface, and drilling to install the thermocouple are all steps in the process. Every stage is essential to guaranteeing that the fins fulfill the requirements for effective heat dissipation. The fins' durability and thermal conductivity are improved by the use of a regulated alloy composition and precise machining, which qualifies them for both practical and experimental uses.

Fabrication Process of Pin Fins

Mould preparation

In order to form the pin fins, a sand mold was made using a cylindrical template. The mold was then dried to avoid casting flaws.

Metal Melting

After melting the brass alloy (Cu, Zn, Pb, Fe), flux was applied to provide a homogeneous composition by removing impurities

Casting

The casting process involved pouring the molten metal into the mold cavity while properly gating it to reduce flaws and leaving it undisturbed to allow for full stabilization and filling.

Cooling and Solidification

The mold fractured, and extra material was cut off. The metal hardened inside the mold while being cooled under regulated conditions.

Grinding & Finishing

To guarantee correct dimensions and adequate heat dissipation, surface defects were smoothed out using grinding tools.

Drilling and Tapping

To connect thermocouples, 5 mm taps were bored at 25 mm intervals
Prior to testing, the fins were examined for accuracy

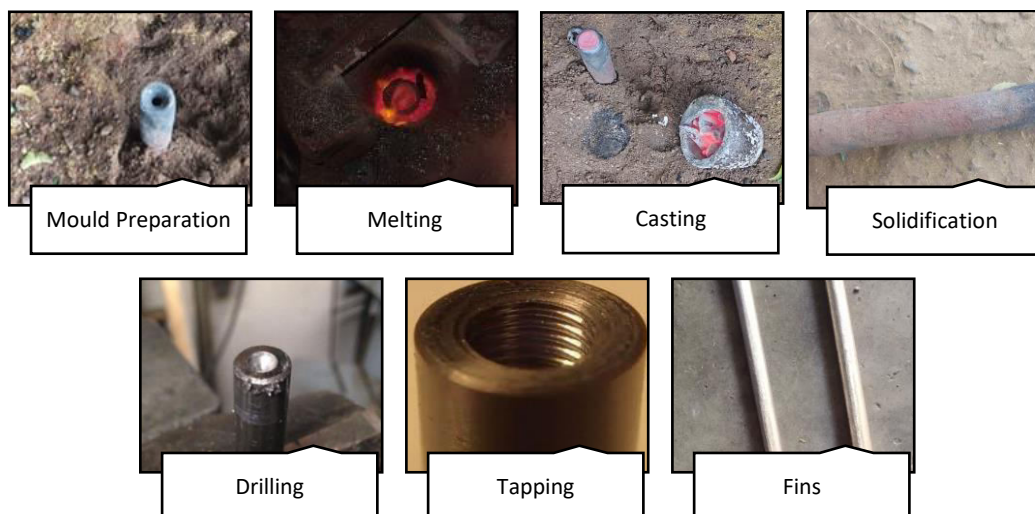


Fig 1 Fabrication

VI. THERMAL PERFORMANCE TESTING PROCEDURE

Temperature Measurements:

- Record temperature values at multiple points along the fin ($T_1, T_2, T_3, T_4, T_5, T_6$).
- Calculate the mean surface temperature (T_s).

Film Temperature Calculation:

- compute the film temperature (T) as the average of T_s and ambient temperature (T_∞).

Dimensionless Numbers Calculation:

For Free Convection:

- Calculate the thermal expansion coefficient (β).
- Determine the Grashof number (Gr) and the product $Gr \times$ Prandtl number ($GrPr$).

$$Gr = \frac{g \beta (T_s - T_\infty) L^3}{\nu^2}$$

For Forced Convection:

- Compute the velocity (μ) and Reynolds number (Re).

Nusselt Number (Nu) Calculation:

- Use empirical correlations to determine Nu based on $GrPr$ (free convection) or Re (forced convection).

$$Nu = C (GrPr)^m$$

Heat Transfer Coefficient (h) Computation:

- Derive h using the Nusselt number and thermal conductivity (k).

$$h = \frac{Nu \times k_f}{L_c}$$

Fin Parameter (m) Calculation:

- Compute m based on material properties and convective heat transfer coefficient.
- Determine the fin length ratio (mL).

Fin Efficiency (η) Evaluation:

- Use hyperbolic tangent functions to compute η .
- Compare results for free and forced convection to analyze performance.

Thermal Conductivity

S.No	Thermal conductivity (W/m K)
1	112.54
2	143.05
3	147.45
4	154.27

Heat Transfer Co-Efficient(W/m^2K)

S.No	Free convection(W/m^2K)	Forced convection(W/m^2K)
1	8.3821	19.3655
2	9.141	19.3874
3	9.033	19.4066
4	8.8187	19.63

Thermal Efficiency(%)

S.No	Free convection(%)	Forced convection (%)
1	75.30	58.7
2	77.8	63.75
3	78.56	64.35
4	79.9	65.44

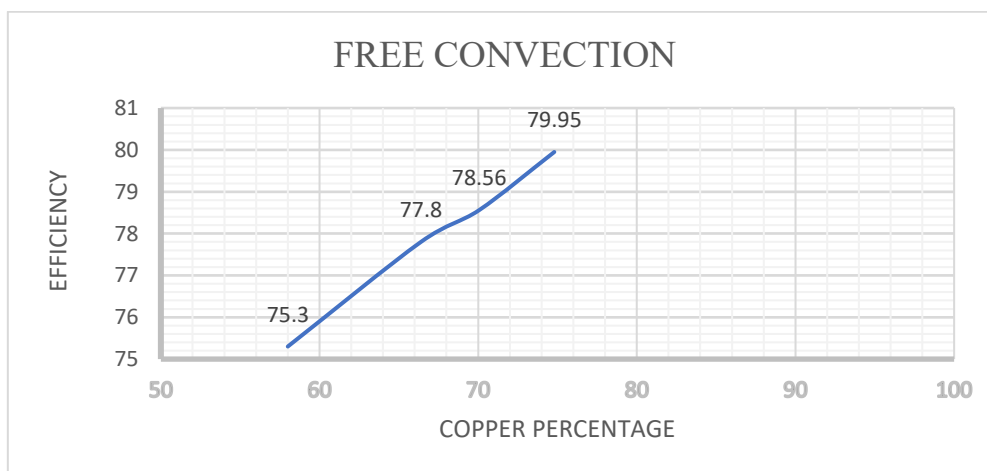


Fig 2 Free Convection Graph

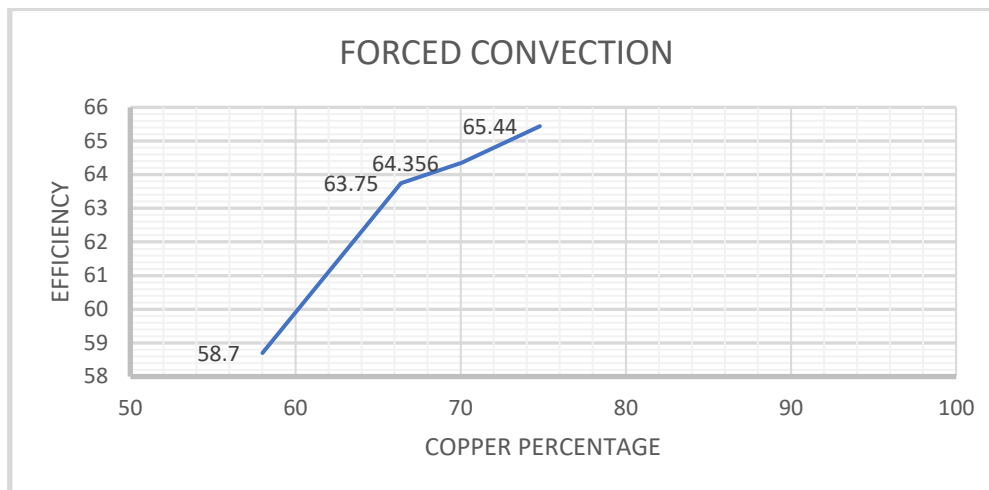


Fig 3 Forced Convection Graph

VII. FUTURE SCOPE

This study provides valuable insights into the influence of brass composition on heat dissipation in pin fins. However, further research can focus on estimating the physical and mechanical properties of the fabricated fins, including density, hardness, surface roughness, and tensile strength, to evaluate their structural suitability. Additionally, microstructural analysis can be conducted to examine the grain structure and phase distribution, optimizing material properties for enhanced thermal performance. The use of advanced surface coatings such as graphene, ceramic layers, or oxidation treatments can be explored to improve emissivity and corrosion resistance, further increasing the efficiency of heat dissipation. Computational simulations, including Finite Element Analysis (FEA) and Computational Fluid Dynamics (CFD), can provide a more detailed understanding of heat flow, temperature distribution, and convective effects. Furthermore, the findings from this research can be extended to industrial applications such as engine cooling systems, heat exchangers, and power electronics, with modifications tailored to practical requirements. By expanding on these aspects, this study can contribute to the development of more efficient, durable, and cost-effective heat dissipation solutions.

VIII. CONCLUSION

This study investigated the thermal performance of brass-based pin fins with varying copper compositions to determine the optimal alloy for efficient heat dissipation. Through experimental analysis under both free and forced convection, the influence of material composition on thermal conductivity and fin efficiency was evaluated. The results demonstrate that increasing copper content improves thermal conductivity, enhancing heat dissipation, while zinc, lead, and iron contribute to mechanical strength and manufacturability. The fabricated fins exhibited distinct performance variations, highlighting the importance of material selection in thermal management applications. Future studies can further analyze physical and mechanical properties to optimize fin designs for industrial applications. The findings of this research contribute to the advancement of efficient heat sink materials for use in automotive, electronic cooling, and power generation systems, promoting improved energy efficiency and system reliability.

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