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ARTIFICIAL NEURAL NETWORK (ANN) BASED MULTI-OBJECTIVE OPTIMIZATION OF CYLINDRICAL HEAT SINKS WITH ALTERNATELY ARRANGED HYBRID FINS

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ABSTRACT

In this study, multi-objective optimization was conducted on a cylindrical-base heat sink with straight and forked fins for Light Emitting Diodes (LEDs) applications. Experimental tests, numerical simulations, and an artificial neural network (ANN) were employed. Validation was performed by comparing experimental data, numerical-simulation results, and ANN predictions. Simulation results showed that, at a 20 °C temperature difference between ambient air and the heat sink, the forked-fin heat sink achieved a thermal resistance of 2.25 K/W—18 % lower than the 2.75 K/W of the straight-fin heat sink—demonstrating enhanced cooling performance. The ANN model produced predictions with a maximum error of just 1.08 %, outperforming conventional correlation-based estimations. Among the Pareto-front optimization results based on mass and thermal resistance, one design achieved a 12.14 % reduction in mass and an 11.59 % improvement in cooling performance relative to the reference model, proving that lighter and more efficient designs are feasible.

KEYWORD

Natural convection, Heat sink, Thermal resistance, Artificial neural network, Multi-objective optimization

INTRODUCTION

LEDs have become a key technology in modern lighting due to their high energy efficiency and low operating costs. With improvements in luminous efficiency, the LED market has grown explosively and is now widely used in general lighting, automotive systems, and display technologies. However, in such LED applications, heat generation poses a critical issue as it shortens device lifespan and degrades performance. To address this, heat sinks (Figure 1) that utilize natural convection have been adopted as cost-effective thermal management solutions without requiring additional power input. The thermal performance of a heat sink is greatly influenced by the geometry of its base and fins. Numerous studies have aimed to improve heat dissipation by optimizing fin shapes, among which forked fins have shown potential in enhancing heat transfer. Despite these efforts, there has been limited research on how alternative arrangements of straight and forked fins affect thermal performance. Therefore, this study investigates the thermal performance improvements of a heat sink with alternately arranged straight and forked fins. In addition, artificial neural networks (ANNs), which have recently emerged as powerful tools for prediction and optimization with higher accuracy than conventional regression models, were used to predict thermal resistance and perform multi-objective optimization based on mass and thermal resistance.

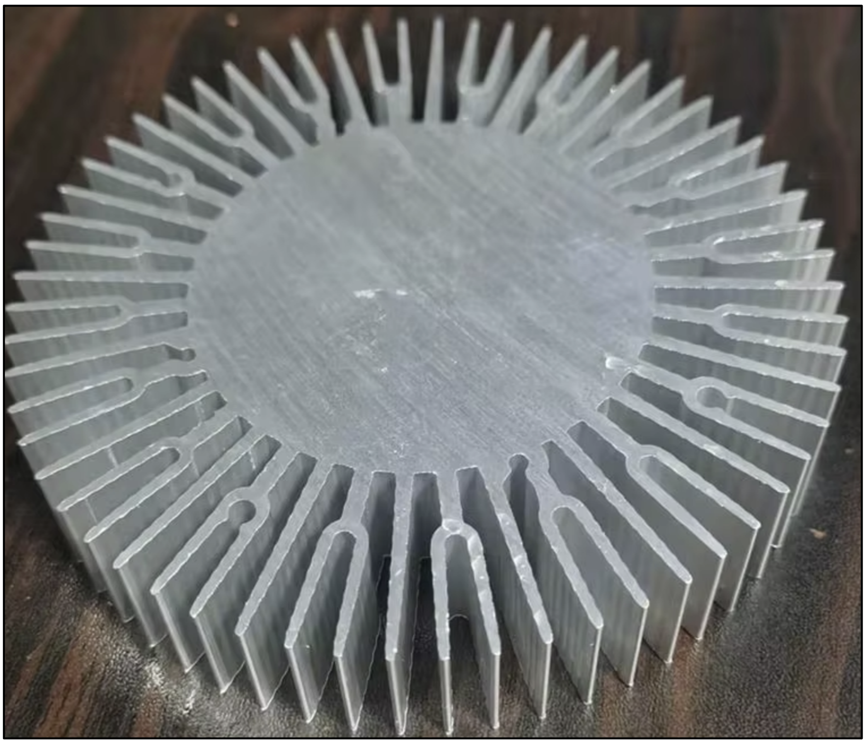
Figure 1: Heat sink with straight and forked fins.

METHODOLOGY

Figure 2 illustrates the overall workflow for heat sink optimization, which consists of three main steps: experiment, numerical analysis, and optimization. In the experimental stage, the temperature difference between the heat sink and ambient air was measured, and thermal resistance was evaluated based on the supplied power. A numerical simulation replicating the experimental setup was performed and validated against the experimental results, followed by a parametric study. Based on the simulation data, an artificial neural network (ANN) model was developed to predict thermal resistance. After verifying the performance of the ANN model, multi-objective optimization was carried out using the predicted data.

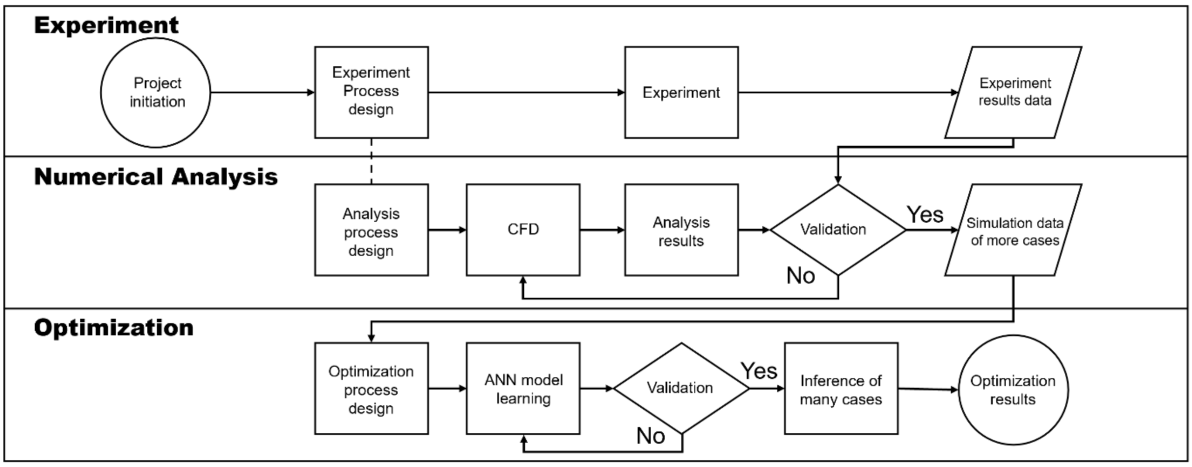

Figure 2: The overall workflow.

RESULT AND DISCUSSION

The cylindrical heat sink has a structural characteristic where the spacing between fins decreases toward the center, which restricts airflow pathways. This geometric feature hinders the flow of cooling air and reduces heat transfer efficiency. In the heat sink composed solely of straight fins, this characteristic of the cylindrical base directly affects the thermal performance—resulting in a reduced temperature gradient near the center due to increased core temperatures, which weakens the driving force for heat transfer. In contrast, the heat sink with alternately arranged forked fins exhibits a significantly lower core temperature. This leads to an increased temperature difference between the surface and the center of the heat sink, thereby enhancing the driving force for heat transfer and improving the overall cooling performance. Under the same fin count condition (N = 60), the alternately arranged forked-fin heat sink—with a branch length of 38.5 mm from the center and a temperature difference of 20 K—achieved a thermal resistance of 2.25 K/W, which is approximately 18% lower than the 2.75 K/W of the straight-fin-only design, indicating improved thermal performance.

The optimization results were derived based on two factors—total fin mass and thermal resistance—under a specific temperature difference condition. Each axis represents a performance-related objective variable, and since lower values indicate better performance, the Pareto front forms a downward-convex curve. From an optimization perspective, a solution is considered non-dominated if no other solution can improve both objectives simultaneously, and such a solution is regarded as optimal. Among these, one optimal design exhibited a thermal resistance of 1.99 K/W and a fin mass of 93.7 g, representing a 12.14% reduction in mass and an 11.59% improvement in thermal performance compared to the reference heat sink. These results demonstrate the feasibility of achieving both enhanced thermal performance and improved material efficiency simultaneously. However, the internal workings of the model are relatively difficult to interpret due to its structure, especially the inclusion of hidden layers. To overcome this limitation, this study introduces an optimization-driven method that provides optimal solutions without requiring extra computational effort and supports web-based prediction of cooling performance for user-specified configurations. The model is available at:
https://sites.google.com/g.seoultech.ac.kr/nel/design-tool/cylindrical-hs-with-straight-and-forked-fins

CONCLUSION

The forked fin structure significantly improved heat transfer efficiency by mitigating airflow reduction found in conventional straight-fin cylindrical heat sinks. By creating additional space around the fins, it reduced thermal resistance from 2.75 K/W to 2.25 K/W—an 18.2% improvement. Furthermore, Pareto Front-based optimization revealed a trade-off between thermal resistance and fin mass. One optimized design achieved 1.99 K/W with a fin mass of 93.7 g, marking a 12.14% reduction in mass and an 11.59% performance gain. These results clearly demonstrate that both enhanced thermal performance and material savings can indeed be achieved simultaneously through the forked fin design.

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