EVALUATING THE THERMAL PERFORMANCE OF TOPOLOGY OPTIMIZED LOW-COST 3D PRINTED HEAT SINK MADE OF COPPER.

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THESIS

Presented to the Faculty of the Graduate School of

The University of Texas at Arlington

in partial fulfillment of the requirements

for the degree of

MASTER OF SCIENCE IN MECHANICAL ENGINEERING

THE UNIVERSITY OF TEXAS AT ARLINGTON

MAY 2021

Acknowledgments

I would like to thank my supervising advisor, Dr. Brian Dennis, for letting me be a part of the CFD Lab and the CREST Lab. I am grateful to him for his constant support and guidance throughout my Master's thesis.

I would like to thank my colleagues from the CFD lab and CREST lab for their support. I would also like to acknowledge the effort and contribution made towards my research by Dr.Sandeep Patil and Dr. Fern by helping and guiding me in carrying out my experiments. Their support meant a lot to me as it saved time in carrying out the experiments.

Finally, I would like to express my gratitude to my friend Hasintha for helping me out with CFD simulations. Last but not the least I am grateful to my family for their ceaseless support and love that they have demonstrated through my education and all my life.

Abstract

EVALUATING THE THERMAL PERFORMANCE OF TOPOLOGY OPTIMIZED LOW-COST 3D PRINTED HEAT-EXCHANGER MADE OF COPPER.

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The University of Texas at Arlington, 2021

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The performance of a heat sink is highly dependent on the overall surface area available for heat transfer. Designing heat sinks with greater surface areas meant bigger size, weight, and volume of heat-exchanger thus making it unfeasible to produce. Design and manufacture of compact-sized heat sinks is a difficult task, as it would require the use of complex surface modeling and complex surface cutting. But with the advent of 3D printing technology, it has become easier to manufacture heat sinks having complex designs producing larger surface areas as they add material layer by layer rather than cutting it away.

The focus of this thesis is to design, manufacture and evaluate the thermal performance of 3D printed heat sinks. A unique method of carrying out thermal topology optimization on cylindrical heat sinks using ANSYS workbench has been discussed. The results from the topology optimization have been used to achieve complex designs. A comparative study was carried out between the topology optimized designs and the conventional straight fin heat sink design to analyze their thermal performance using steady-state thermal analysis. The designs were then 3D printed on a Lultz-Bot 3D printer using a copper-PLA filament. To achieve parts made of pure copper, the

sintering process was carried out and various sintering techniques were explored to combat issues like oxidations, loss of structural integrity, and porosity in the sintered parts. The results from the initial validation study showed that the optimized design performed better. It reduced the heater temperature 12% more than the conventional design Results from the sintering process showed that the best-sintered parts were achieved when sintering was done in an inert environment at 1070 C and above for longer periods. Lastly, experimental setups were designed using N2 gas tanks, heaters, and cylindrical tubes to simulate the flow of fluid through the heat sink and study its performance. Effective thermal conductivity was calculated and studied. The pressure drop was measured to be around 26 pascals.

Table of Contents

List of Illustrations

List of Tables

Chapter 1

Introduction

1.1 Problem Statement

Heat sinks, and heat spreaders have long been used in the automotive, aerospace, and electronics industries. With improvement in technologies their designs have evolved over time. While designing a heat spreader or a heat sink a major challenge faced by the designer, is the need to improve the total heat transfer rate through a heat spreader while maintaining the size, weight, and dimension of a heat spreader. The performance of any type of heat sink or a heat spreader is dependent on its surface area .Heat spreaders and heat sinks are designed with the intention to maximize the convection area to get the best performance for a given heat sink weight and size. Although the heat transfer process in heat sinks is a complex phenomenon and depends on several factors like fluid velocity, material, fin-type and fin arrangements, etc., it is known that for a set of fixed given conditions the performance of the heat sink depends on the overall surface area.

With the increase in demand for more economical heat sinks, the designers are being encouraged to design heat sinks which are more efficient yet compact in size. The rapid growth in electronic industries has significantly increased the research on low-cost, highly efficient heat sink designs. Similarly, with more companies entering the aerospace industry, the demand for lightweight and compact heat sink design has increased. Apart from that, the communication cable industries alongside the lighting industries are now taking advantage of novel low-cost, compact, and lightweight heat sink designs to compete in the market.

The need for lightweight, compact, and high-performing heat sink design is growing and thus much more research is needed to design and manufacture such types of heat sinks. But designing such high-performance heat sinks (spreaders) poses a major issue as increasing the overall surface area for a given volume introduces design complexities.

These complex designs are very difficult to manufacture using conventional manufacturing technologies.

Thus, there is a great requirement to explore and investigate new design methodologies and manufacturing methods that can produce highly complex and compact designs.

1.2 Topology Optimization

There are several methods to achieve a new optimized design. Amongst them topology optimization is quite a famous technique that is used to optimize the material layout within a given design space subjected to some fixed constraints while maximizing the overall performance of a system. In comparison to other optimization techniques like size optimization or shape optimization, the topology optimization technique does not use a predefined configuration. In fact, it operates within a defined design space and puts material in places where it is highly needed and makes sure the constraints are met as well. The topology optimization generally uses finite element analysis (FEA) to evaluate the design performance and the design is optimized using the optimality criteria algorithm.

The application of topology optimization is quite vast. It is majorly used in structural mechanics to attain structures that are lightweight yet have great strength. Such types of designs having higher strength to weight ratio are highly desirable in the aerospace industry where weight and space are both an expensive commodity. The use of topology optimization for heat sink designs has become quite common over the past few years. Many new novel designs have become popular. Conventionally, thermal topology optimization for heat sink design is carried out using self-written codes. These codes are written with an objective function of maximizing the overall thermal conductivity within a given design space while having a mass or volume constraint. The results produced through the topology optimization techniques are quite organic in shape and thus require few manufacturing constraints that are applied so as to achieve designs that can be manufactured. The biggest advantage of using the topology optimization technique is that it enhances the performance (leading to larger surface areas) while reducing the overall size and weight of a design. In terms of heat sink designs, this means that achieving designs having higher bulk thermal conductivity or higher heat transfer rate while at the same time reducing the overall weight of the heat sink.

In this thesis, we will present a novel method of performing topology optimization on a hollow cylindrical heat sink/heat spreader using ANSYS workbench software.

1.3 Additive Manufacturing

The topology optimized designs are generally quite complex in nature thus cannot be produced by conventional methods. With the advent of additive manufacturing technology, it has become quite feasible to produce such complex designs without any additional cost or time. This is because the conventional machining process requires a careful and detailed analysis of the part geometry, to determine things like what order should the features produced, what material and fixtures must be used for the process[1]. On the contrary, additive manufacturing technology only needs some basic dimensional details and little understanding of the working of AM machines to carry out the manufacturing process. The working of an AM process is such that it uses a layer-by-layer approach of adding material. Each body is cut into small thin cross-sections and the thinner the layer is, the closer the design will be to the original part. Thus for designing complex geometries the conventional processes become quite cumbersome, while it is easy to manufacture using the AM process.

There are many types of AM processes that have been developed over the years. Of the many AM technologies, the Fused Deposition Modeling technique has become quite popular. This is mainly due to their ease of operation and lower cost of FDM printers. Other processes like Selective laser Sintering (SLS) have also been there for a while and have gained popularity in metal 3D printing. The SLS process uses high powered- laser to "sinter" powdered metallic or polymer materials. Sintering is done in a very localized manner with very little energy. In an SLS process, a re-coater applies a thin layer of the powder onto the bed surface where the powdered are sintered according to the geometry of the part being designed. Once one layer is complete, the bed moves