

Comparative Study on Thermal Analysis of Flat Face and Curved Face FDM Printed Micro-Channel Fin Holders

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Abstract: This work describes the use of deposition-based additive manufacturing (AM) techniques to fabricate heat exchangers. The paper study focused on a Heating, Ventilation and Air Conditioning of automobile application and used an industry-standard copper/aluminum heat exchanger manufactured with conventional technology as the basis for assessing performance. Conventional methods of producing micro-scale components for water cooling applications such as micro fluidic devices are limited to relatively simple geometries and are inefficient for prototype production. Rapid prototyping techniques may be applied to overcome these limitations. Fused Deposition Modeling is one such rapid prototyping process, which can build parts using layer by layer deposition technique with layers as low as 0.178 mm thick and using a select group of thermoplastic building materials. This paper presents the potential of Fused Deposition Modeling (FDM) system, in building prototypes of scaled micro-channels for experimental study of cooling capacity of water-cooling heat exchanger, scope and application of FDM system as a powerful and flexible rapid prototyping device is described. Micro channels of staggered shape are produced in ABS material on the UP-mini rapid prototyping system and a methodology is presented for thermal analysis study performance of the heat exchanger and its comparison to the conventional flat fin configuration.

Keywords: heat exchanger, additive manufacturing, deposition, FDM, DMLS, thermal systems, Micro channel fin holder.

Abbreviations and Nomenclatures

FMD	Fused Deposition Method
MCHX	Micro channel heat exchanger
MCHS	Micro channel heat sink
PCHX	Printed circuit heat exchanger
FoM	Figure of merit
LPM	Litre per minute
ΔT	Temperature Difference
3D	3 dimensional

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FMD	Fused Deposition Method
DMLS	
MCHX	Micro channel heat exchanger
u	Overall heat transfer coefficient
RH	Relative Humidity
CMM	Cubic meters per minute
CFM	Cubic feet per minute

1. Introduction

The paper work's objective is to determine the heat transfer rate and temperature profiles necessary to determine the effectiveness between flat face and curved face fuse deposition modelling made micro-channel heat exchanger by using thermal analysis. Additive manufacturing (AM) is receiving attention across many application areas. Manufacturing processes continue to be developed that provide increased freedom of design with respect to geometry and material selection. The three-dimensional (3D) printing technology referred to as fused deposition modelling (FDM) was invented in 1989 [1] and has become widely available during the 2000s. The technology has typically been used in applications where high strength, high temperature, and high thermal conductivity are not required. Only recently has AM been considered for heat exchanger (HX) applications because the polymer materials used in typical AM processes do not have the characteristics that are necessary for this type of application. In polymers, heat energy is transported through the material as phonons which are easily scattered at the interfaces between one polymer chain and another, leading to low conductivity (generally in the 0.2–0.5 W/m-K range). On the other hand, in metals, thermal transport is the result of electron flow which results in much higher thermal conductivity, for example, from 16 W/m-K for stainless steel to about 400 W/m-K for copper. Similarly, the strength and temperature limits of polymers are typically much lower than metals. For example, the failure strength of printed specimens made with the base polymer used in this work (polycarbonate, PC) was measured to be approximately 45 Mpa, and the upper working temperature is 115 °C [2]; these are much lower than copper with a yield stress of 70 MPa and a melting temperature of over 1000 °C.

Heat exchangers have historically been manufactured using either computer numerical control (CNC) machining for single stream type applications or with brazing or diffusion bonding processes for multiple-stream applications [3]. In both cases, the manufacturing and assembly processes can be expensive and time-consuming, and these processes limit the geometric configurations that can be considered during the design process. The application of AM processes to heat exchanger technology opens the door to complex internal structures that have the potential for superior thermal performance at an equivalent fluid-hydraulic penalty. These performance improvements may come from both optimizing the internal shape of the geometries as well as from improved mani-folding and flow passage distribution.

There are several competing AM technologies available, each of which can be applied to very-different heat exchanger applications. It is therefore necessary to carefully define the subject of this study. The AM technologies being examined here are deposition-based, considering primarily composite polymers but also metal-injection-moulding (MIM) materials. The application being investigated is a two-fluid heat exchanger in which air exchanges heat with a liquid. The justification for specifically considering deposition-based AM manufacturing techniques follows, and the relatively strict constraints that this process places on the design are described. This paper presents a heat exchanger geometry and design process that is compatible with this specific manufacturing technology/application combination and provides competitive performance to today's commercial units. Prototype heat exchangers demonstrating this approach are tested and shown to meet the design targets in the context of a chilled-water coil application using industry-based performance

metrics. Fabrication challenges prevented the optimal heat exchanger geometry from being fabricated using MIM materials, but the optimal geometry was fabricated and verified using direct

2. Methodology:

metal laser sintering (DMLS) technology, and a sub-optimal geometry was printed and tested using FDM technology.

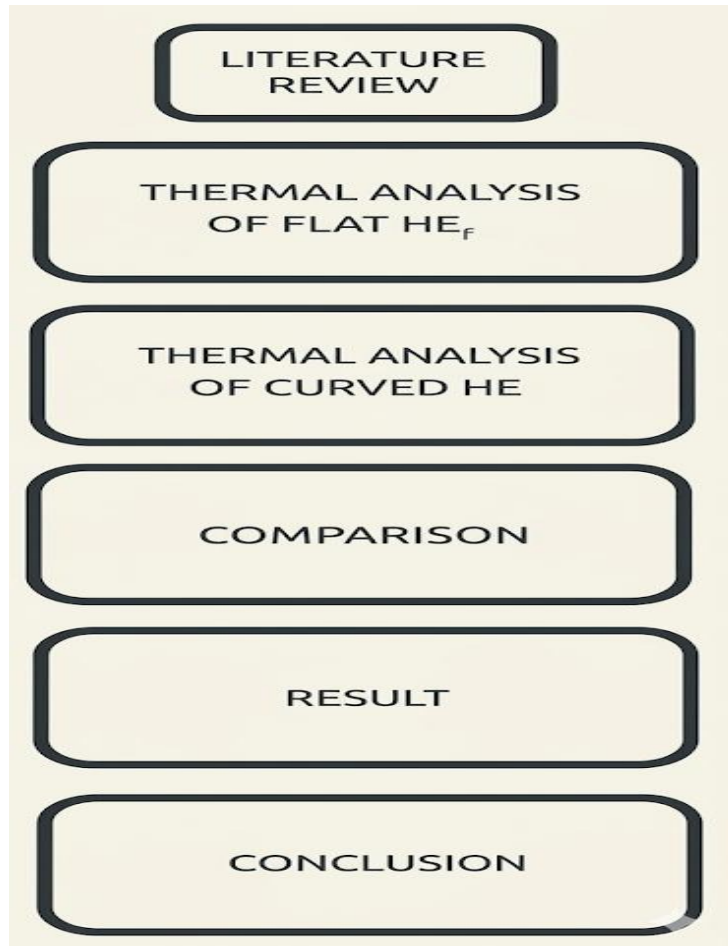


Fig. no.1 Methodology for the proposed work

3. Thermal Analysis:

3.1 Thermal Analysis of Flat and Curved Plate MCHE

A. Geometry and meshing:

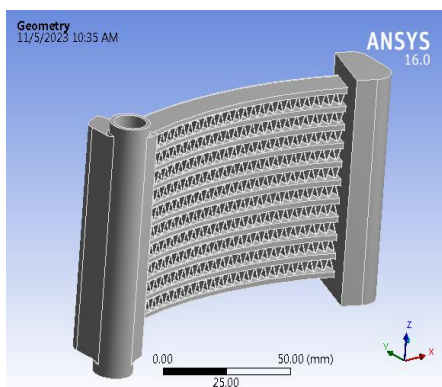
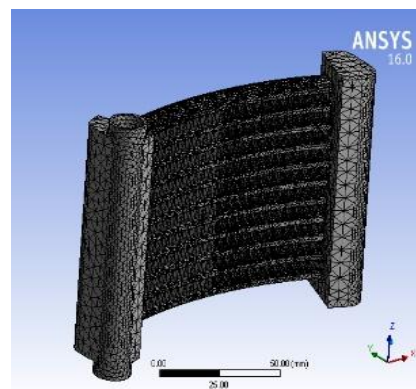


Fig.no.2.(a) Geometry of Cuved HE



(b) Meshing Of Cuved HE

B. Boundary Conditions applied on curved face HE

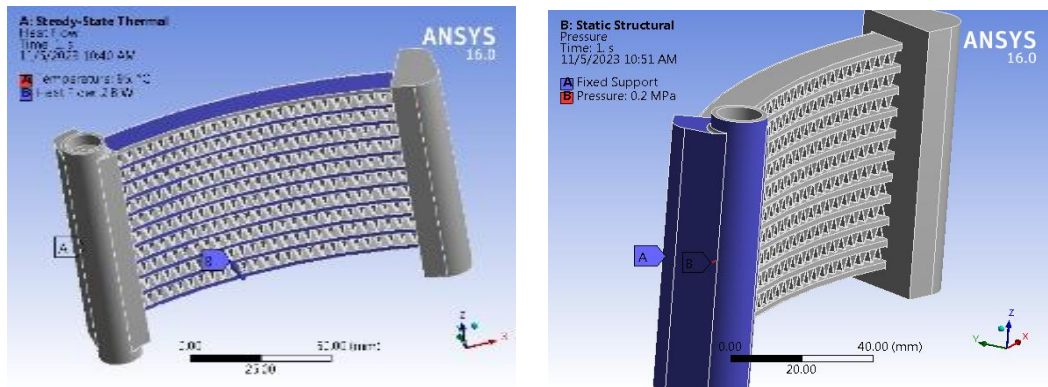


Fig.no.3.(a) Boundary Conditions: state thermal (b) Boundary Conditions: static structural

For analyzing the plates, we applied same boundary conditions to all the plates.

[1] Inlet Temperature = 80° C And Pressure= 0.2mp_a.

[2] At the surface of the fins natural convection takes place whose ambient temperature is taken as 35 °C and film coefficient 22 W/m² °C.

C. Temperature variation contour in Flat and Curved heat exchanger

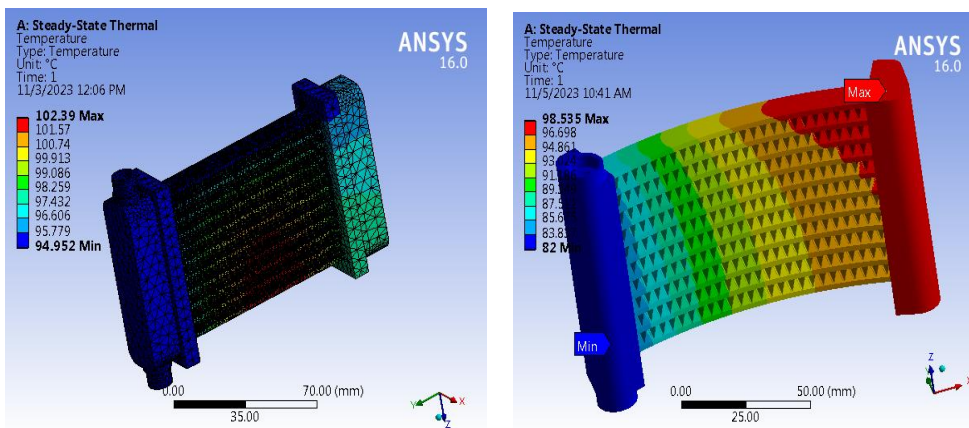


Fig.no.4 (a) Temp. Variation contour Flat HE (b) Temp. Variation contour of Curved HE

D. Total Heat Flux

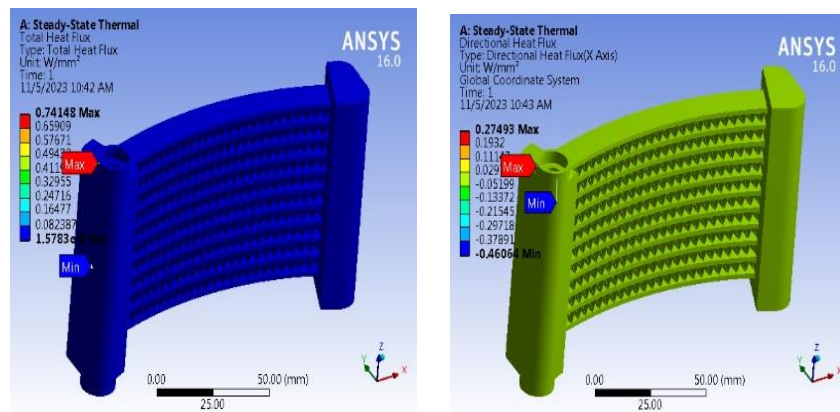
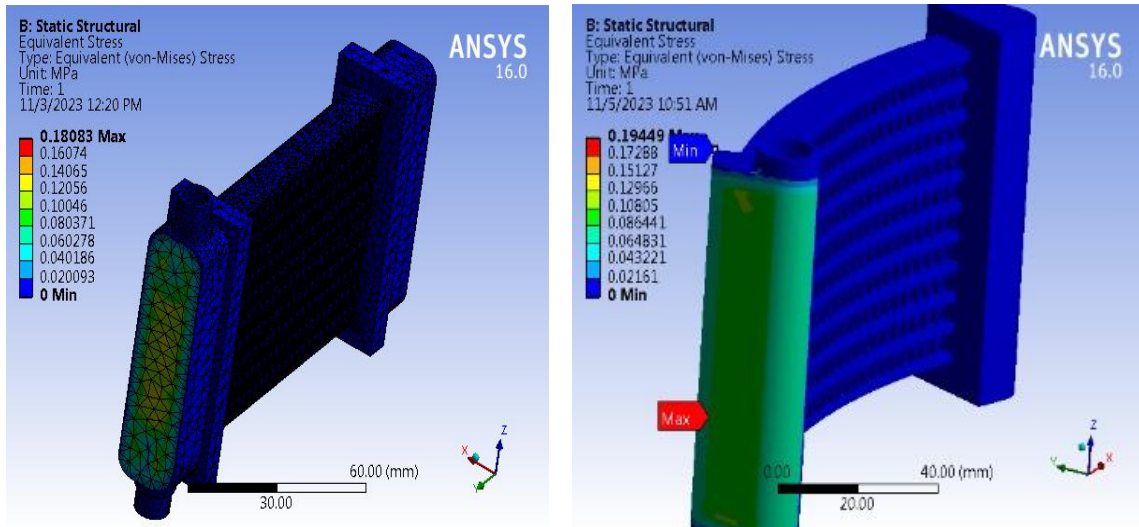


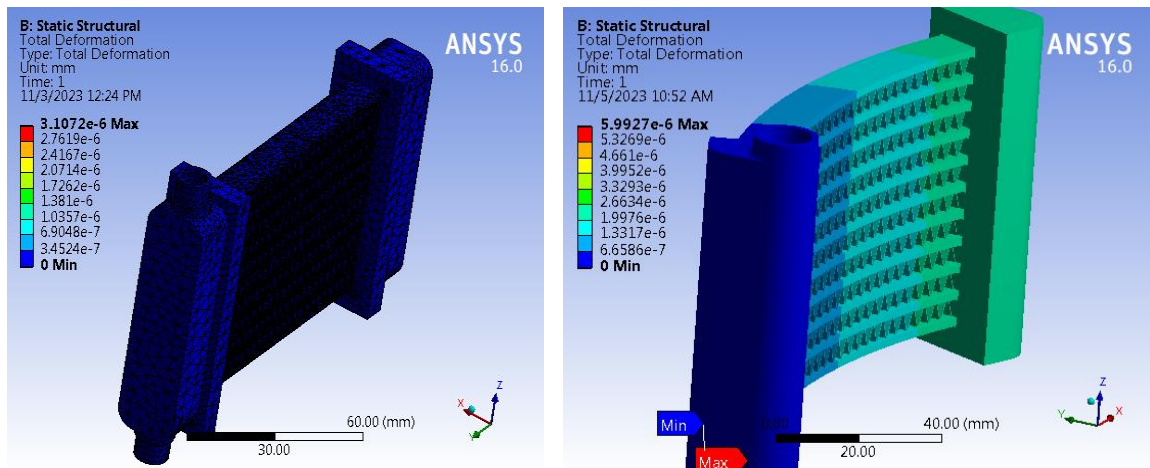
Fig.no.5 (a) Total Heat Flux of flat HE

(b) Total Heat Flux of curved HE

E. Maximum Stress induced in Flat and Curved heat exchanger material



F. Maximum Deformation induced in Flat and curved heat exchanger material



3.2 Observation Table:

Observation table no:1

	Flat face	Curved face
Applying Boundary conditions	At inlet Temp-80° C, Pressure -0.2 MP _a	At inlet temp-80° C, pressure -0.2 MP _a
Total heat flux	0.060008	0.74148
Directional heat flux	0.042534	0.27493

3.3 Calculation:

Q(Flat) By Thermal Analysis:

Applying Governing equation,

$$Q = \text{Area of Heat exchanger} \times \text{Surface area of the Heat exchanger} \text{-----(1)}$$

$$Q_{(\text{Flat})} \text{ Thermal} = 0.042534 \times 19.43 = 0.826 \text{ KJ [1]}$$

$$Q_{(\text{Flat})} \text{ Thermal} = 0.826 \text{ KJ} \text{-----(2)}$$

Q(Curve)Thermal= Area of Heat exchanger x Surface area of the Heat exchanger

$$Q_{(\text{Curve})} \text{ Thermal} = 0.274 \times 4.9 = 1.3426 \text{ KJ [2]} \text{-----(3)}$$

Effectiveness of the Curved Heat Exchanger over that of the Flat Heat Exchanger

$$\text{Effectiveness } (\epsilon) = Q \text{ curved} / Q \text{ flat} = 1.3426 / 0.826$$

$$\text{Effectiveness } (\epsilon) = 1.62$$

Thus, the Curved heat exchanger is 1.62 times effective that the flat heat exchanger.

4. Result and discussion:

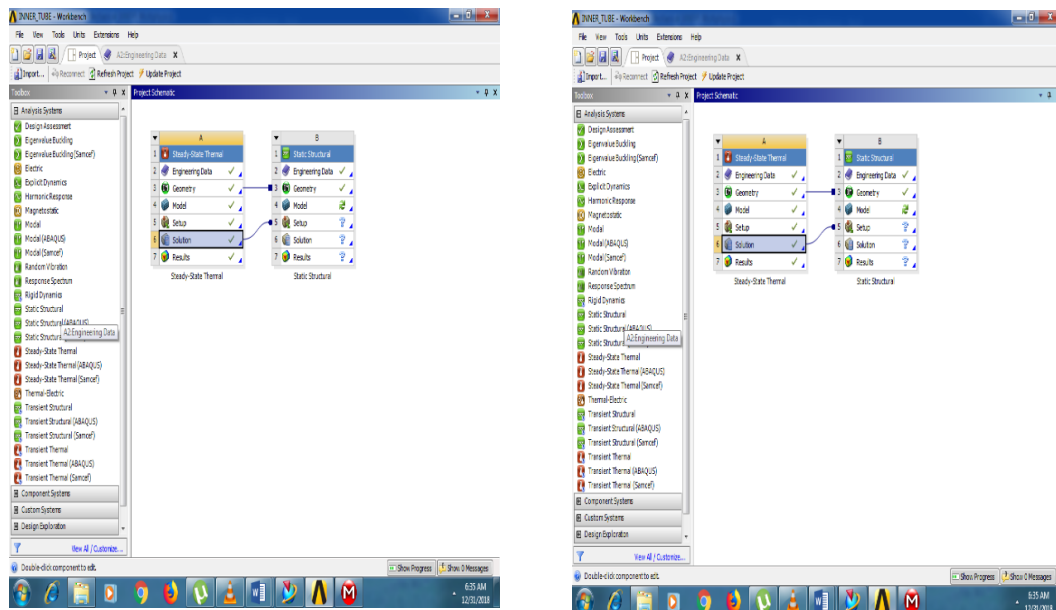


Fig.no.8 (a) Coupling of result Flat HE (b) Coupling of result curved HE

Result Table no:2

	Flat face	Curved face
Total heat flux	0.060008	0.74148
Directional heat flux	0.042534	0.27493
Maximum stress induced	0.18083	0.19449
Maximum deformation induced	3.1072	5.9927
Effectiveness	Curved face (ϵ) = 1.62 over flat heat exchanger	

4.1 Comparison of Overall heat transfer Coeff. Of Curved & Flat heat exchanger:

4.2 Comparison of Pressure drop Of Curved & Flat heat exchanger:

Fig.no.9(a)

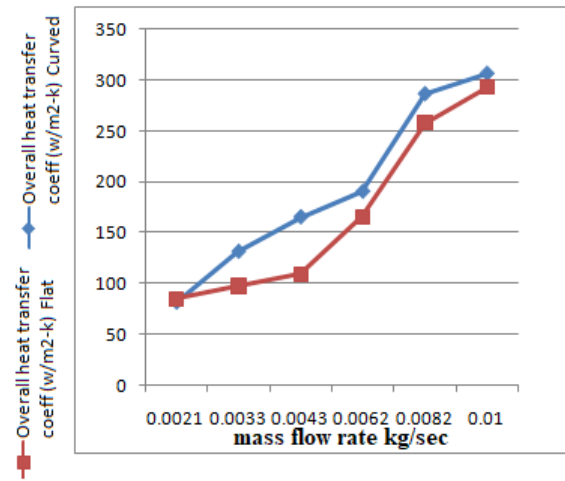


Fig.no.9(b)

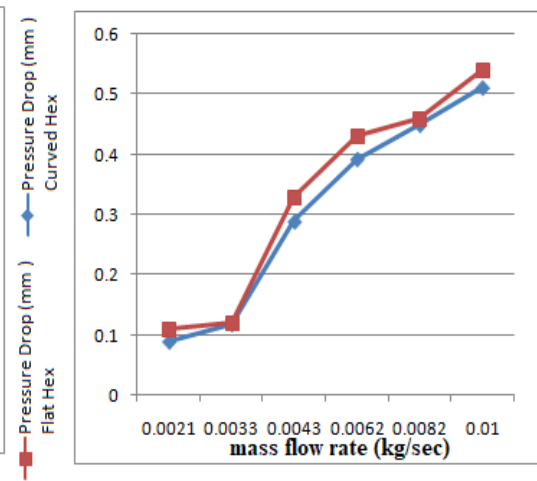


Fig.no.9 (a)

Fig.no.9 (b)

Fig.no.9 (a) Comparison graph of Overall heat transfer Coeff. Of Curved & Flat HE

Fig.no.(b) Comparison graph of Pressure drop Of Curved & Flat HE

➤ With reference to Fig.no9 (a) (graph of Overall heat transfer coefficient Of Curved & Flat heat exchanger)The heat transfer coefficient of the curved heat exchanger is found to be maximum of 306.78 w/m²k where as that of the flat heat exchanger is found to be 292 .6 thus the curved heat exchanger shows better performance than the flat heat exchanger.

➤ With reference to Fig.no.9 (b) (Graph no. Comparison of Pressure drop Of Curved & Flat heat exchanger) The pressure drop of the flat heat exchanger is found to be maximum of 0.544 where as that of the curved heat exchanger is found to be 0.511, thus the curved heat exchanger shows better performance than the flat heat exchanger.

➤ With reference to the result table no.2 calculated value of effectiveness (ϵ) =1.62, Effectiveness of the Curved Heat Exchanger is effective over that of the Flat Heat Exchanger

5. Conclusion

As Per Paper Study, Q_{Thermal} of Curved Face Heat Exchanger Is (1.22 KJ) and Q_{Thermal} of Flat Face Heat Exchanger Is (0.826 KJ).The Value of Heat Transfer through Curve Face Heat Exchanger Is Higher than Flat Heat Exchanger. The Obtained Effectiveness (ϵ) Value of Curved Face MCHE Is 1.62 Over Flat Plate Heat Exchanger. So, By

comparing the heat transfer and effectiveness between flat-face and curved-face FDM-printed micro-channels, it is observed that the curved-face heat exchanger demonstrates superior overall cooling performance.

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