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Design and Analysis of Straight and Curved fins

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Abstract

A series of fins commonly known as heat sinks are adapted in various thermal appliances the computer and other electronic systems, where large chunks of heat generated have to be dissipated. This project is mainly concerned with developing unconventional fins as a substitute to the conventional rectangular fins.

Heat transfer analysis of curved fins was carried out in this work which can be a substitute for a normal rectangular fins as heat sinks. A detailed evaluation of temperature distribution and heat flux rates with heat sinks made up of curved fins is accomplished and compared to the rectangular fins. This objective was fulfilled for three different types of materials mainly copper, aluminium , magnesium. The entire project was done using CATIA platform for modelling and ANSYS for finite element analysis.

Keywords : *Heat sink, Fins, Temperature distrubustion and heat flux.*

1.0 Objective

The crux of the project is to study the enhancement in heat transfer that can be obtained by using curved fins instead of rectangular fins. The augmentation in heat transfer is also studied through using analytical softwares. The purpose of using curved fins is to increasing the rate of heat transfer comparatively more and analyzed using analytical softwares.

2.0 Literature

Fins find a wide range of applications in mechanical, electrical and electronic devices ranging from computers to heat transfer devices that are used in process plants, power plants, aeronautics etc. There has been an intensive and extensive study or on the usage of fins in a wide spectrum of applications. The studies included were related to the geometry of fins, heat transfer, boundary condition etc. Pulkit Sagar [1] has analyzed the heat transfer rate by varying the shape and surface roughness of fins. Pardeep Singh [2] and Viveksheel Yadav [3] have noticed that fins with curved or notches gives the best results reducing in cost of the material. From the literature survey, it was understood that a study on curved fins could be defined as this particular topic has received little attention.

3.0 Theoretical Design and Calculations

Design theory has been approached and interpreted in many ways from personal statements of design principles, through constructs of the philosophy of design to a search for a design science. In this design we have calculated the heat flux for fins of different geometries. The required heat flux calculations are also done for different shapes of fins.

In this theoretical design we will know all the required parameters to calculate the heat flux for the rectangular fin.

In order to analyze the heat flux for fins of various shapes we have decided to do the project.

T_b = base temperature of the body

T_∞ = ambient temperature

h_l = heat transfer coefficient

k = thermal conductivity of aluminium

Q = heat dissipated

A = Cross section area of the fin

P = perimeter of the fin

L = Length of the fin

$$T_b = 117^o c,\ T_\infty = 22^o c$$

$$h_l = 16\ w/m^2,\ k = 237\ w/(mK)$$

$$L = 62.8mm$$

$$p = 2(w+h) = 2(60+5) = 130mm$$

$$A = (w*h) = (60*5) = 300mm^2$$

$$m = \sqrt{\left(\frac{hp}{kA}\right)} = \sqrt{\left(\frac{16*0.130}{237*0.3*10^{-3}}\right)} = 5.40874$$

$$Q = (T_b - T_\infty)\left\{\frac{\tanh(ml) + (h_l/mk)}{1+\left(h_l/mk\right)\tanh(ml)}\right\}(hpkA)^{0.5}$$

$$= 12.35857092\ W$$

$$Heat\ flux = \left\{\frac{Q}{A}\right\}$$

$$= \left\{\frac{12.35857092\ W}{80*10^{-3}*60*10^{-3}\ m^2}\right\}$$

$$= 2574.702274\ W/m^2$$

For 4 no.of Fins,

$$Heat\ flux\left\{\frac{Q}{A}\right\} = 4*2574.702274\ W/m^2$$

$$= 10{,}298.8091\ \ W/m^2$$

For Aluminium

Heat flux = 10,298.8091

For Copper

Heat flux = 10401.382

For Magnesium

Heat flux = 10150.765

Hence the heat flux of rectangular fin for different materials are calculated. The dimensions are in S.I unit. Hence the theoretical design is done by the above calculations. The design is to formulate a plan for the satisfaction of a special need or to solve a problem.

Table 1: Boundary conditions

Variables	Units	Value
Heat Transfer Coefficient	W/m^2-K	16
Ambient Temperature	K	295
Power Input	W	50, 100, 150

Table 2: Material Properties

Material	Property	Value
Aluminium	Density	2770 Kg/m^3
	Youngs Modulus	7.1*10^10 Pa
	Poissons Ratio	0.33
	Bulk Modulus	6.9608*10^10 Pa
	Thermal Conductivity	237 W/m-K
	Specific Heat	875 J/kg-k
Copper	Density	8920 kg/m^3
	Youngs Modulus	100 GPa
	Poissons Ratio	0.33
	Bulk Modulus	129 GPa
	Thermal Conductivity	398 W/m-K
	Specific Heat	384 J/kg-K
Magnesium	Density	1800 kg/m^3
	Youngs Modulus	4.5*10^10 Pa
	Poissons Ratio	0.35
	Bulk Modulus	1.66*10^10 Pa
	Thermal Conductivity	156 W/m-K
	Specific Heat	1024 J/kg-k

4.0 3D Modelling of the Fins

Part design environment is used to create 3D models from the basic 2D sketches created in sketcher environment.

- Creating the base part 2D sketch
- Converting 2D sketch to required 3D model by using features like extrude, extrude cut, revolve, sweep, chamfers, fillets, holes, spiral etc.
- Saving the file with desired part name.

5.0 FEA of Fins using ANSYS

Procedure in Ansys:

Step 1: Start an ANSYS Workbench Project

Step 2: Create a Steady-State Thermal Analysis System

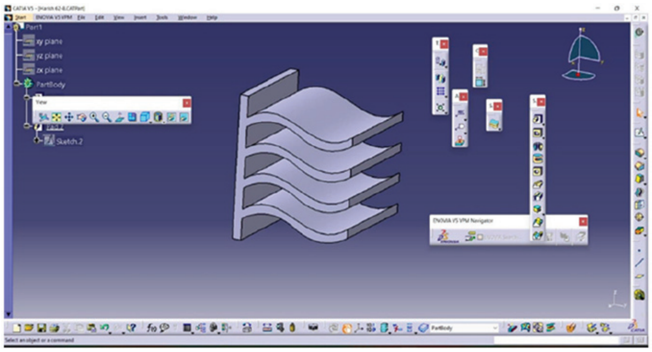

Figure 1: Modelling of curved fins

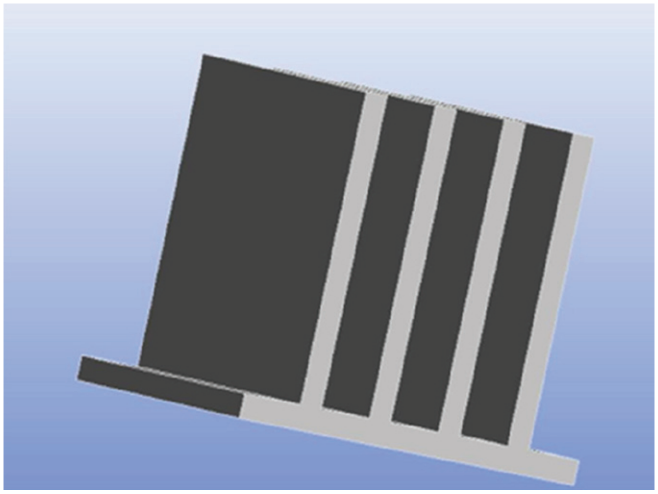

Figure 2: Modelling of straight fins

Step 3: Add a New Material
Step 4: Insert Geometry
Step 5: Create a Profile Sketch To customize units
Step 6: Create an Extruded Body
Step 7: Launch the Steady-State Thermal Program
Step 8: Generate Mesh
Step 9: Apply Boundary Conditions
Step 10: Solve and Retrieve Results.

Temperature distribution

The temperature distribution for curved and rectangle fins obtained through FEA analysis for different energy inputs is specified in Tables 1 to 10.

It can be observed that the temperarure has increased with the increase in input energy. It can also be observed that for any given energy input, the temperature is more uniform in copper as compared to other materails since it possess higher thermal conductivity. It can also be observed that the maximum temperature of the fin is least for copper among the materials choosen.

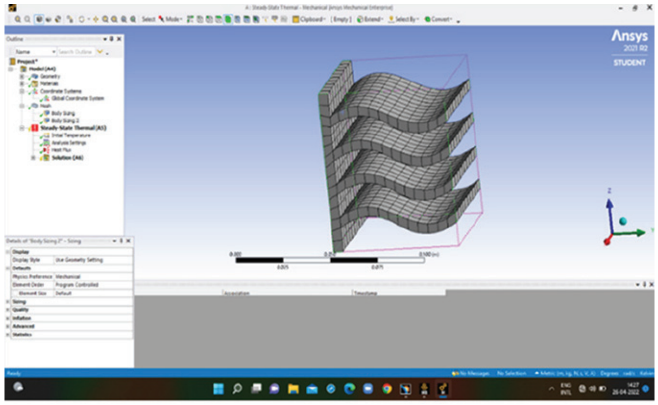

Figure 3: Meshing of fins

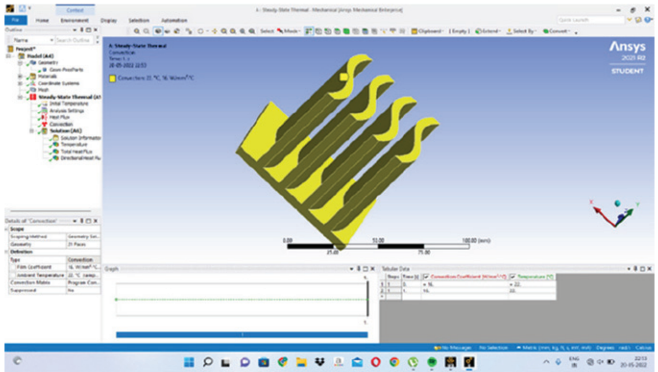

Figure 4: Applying boundary condition for FEA

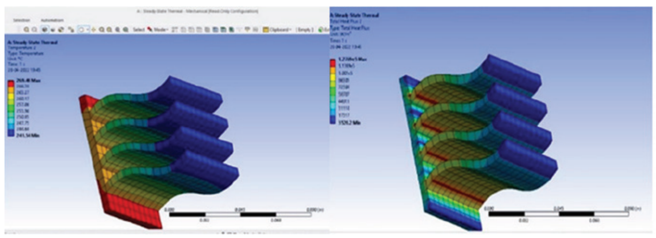

Figure 5: (a) Temperature distribution (b) Heat flux distribution of Horizontal curved fins

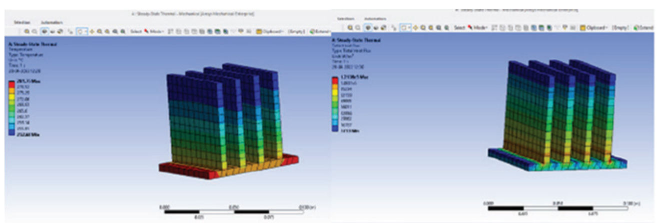

Figure 6: (a) Temperature distribution (b) Heat flux distribution of rectangular fins

Comparison between rectangular and curved fins can be inferred that the temperature in rectangular is moderatively higher than the curved fin for any material at a given energy input. This can be attributed to the higher heat transfer surface area for cuved fin.

Heat Flux Distribution

The heat flux distribution for curved and rectangle fins obtained through FEA analysis for different energy inputs is specified in tables.

It can be observed that the heat flux has increased with the increase in input energy. It can also be observed that for any given energy input, the heat flux is more uniform in copper as compared to other materials since it possess higher thermal conductivity. It can also be observed that the maximum heat flux of the fin is high for copper among the materials choosen.

Comparison between rectangular and curved fins can be inferred that the heat flux in rectangular is moderately higher than the curved fin for any material at a given energy input. This can be attributed to the higher heat transfer surface area for curved fin. The results of FEA are tabulated in Tables 3 to 11.

Table 3: FEA Analysis of Rectangular Fin at 50 Watts

Material	Temperature (Min)ºC	Temperature (Max)ºC	Temperature (Avg)ºC	Total heat Flux (Min) W/m^2	Total heat Flux (Max) W/m^2	Total Heatflux (Avg)
Copper	101.01	104.85	102.67	1264.9	40656	16945
Aluminium	99.077	108.23	103.03	1235.3	40426	16740
Magnesium	98.888	108.58	103.07	1231.8	40416	16721

Table 4: FEA Analysis of Rectangular Fin at 100Watts

Material	Temperature (Min)ºC	Temperature (Max)ºC	Temperature (Avg)ºC	Total heat Flux (Min) W/m^2	Total heat Flux (Max) W/m^2	Total Heatflux (Avg)
Copper	180.03	187.71	183.36	2529.8	81316	33891
Aluminium	176.46	193.93	184.01	2475.7	80849	33508
Magnesium	175.78	195.17	184.14	2463.8	80836	33443

Table 5: FEA Analysis of Rectangular Fin at 150 Watts

Material	Temperature (Min)ºC	Temperature (Max)ºC	Temperature (Avg)ºC	Total heat Flux (Min) W/m^2	Total heat Flux (Max) W/m^2	Total Heatflux (Avg)
Copper	259.05	270.56	264.04	3794.8	$1.2198*10^5$	50837
Aluminium	253.79	279.79	265	3713	$1.2138*10^5$	50283
Magnesium	252.68	281.75	265.21	3695.7	$1.2126*10^5$	50165

Table 6: FEA Analysis of Horizontal Curved Fin at 50 Watts

Material	Temperature (Min)ºC	Temperature (Max)ºC	Temperature (Avg)ºC	Total heat Flux (Min) W/m^2	Total heat Flux (Max) W/m^2	Total Heatflux (Avg)
Copper	132.4	144.64	137.71	3521.9	1.2788*10^5	52850
Aluminium	126.59	154.67	138.7	3525.9	1.2613*10^5	51467
Magnesium	125.82	156.12	138.84	3528	1.2588*10^5	51277

Table 7: FEA Analysis of Horizontal Curved Fin at 100 Watts

Material	Temperature (Min)ºC	Temperature (Max)ºC	Temperature (Avg)ºC	Total heat Flux (Min) W/m^2	Total heat Flux (Max) W/m^2	Total Heatflux (Avg)
Copper	132.4	144.64	137.71	3521.9	1.2788*10^5	52850
Aluminium	126.59	154.67	138.7	3525.9	1.2613*10^5	51467
Magnesium	125.82	156.12	138.84	3528	1.2588*10^5	51277

Table 8: FEA Analysis of Horizontal Curved Fin at 150 Watts

Material	Temperature (Min)ºC	Temperature (Max)ºC	Temperature (Avg)ºC	Total heat Flux (Min) W/m^2	Total heat Flux (Max) W/m^2	Total Heatflux (Avg)
Copper	247.3	259.69	252.69	3531.6	1.2858*10^5	53378
Aluminium	241.54	269.48	253.64	3520.2	1.2769*10^5	52701
Magnesium	240.33	271.57	253.85	3519	1.2751*10^5	52558

Table 9: FEA Analysis of Vertical Curved Fin at 50 Watts

Material	Temperature (Min)ºC	Temperature (Max)ºC	Temperature (Avg)ºC	Total heat Flux (Min) W/m^2	Total heat Flux (Max) W/m^2	Total Heatflux (Avg)
Copper	96.245	100.18	97.81	1077.8	41789	17245
Aluminium	92.564	102.68	98.23	1072.6	41520	17155
Magnesium	91.498	103.91	98.65	1072.9	41415	17059

Table 10: FEA Analysis of Vertical Curved FIN at 100 Watts

Material	Temperature (Min)°C	Temperature (Max)°C	Temperature (Avg)°C	Total heat Flux (Min) W/m^2	Total heat Flux (Max) W/m^2	Total Heatflux (Avg)
Copper	121.26	125.68	123.80	3112.76	$1.4643*10^5$	74532
Aluminium	113.71	134.52	126.19.7	3083.18	$1.3858*10^5$	71624
Magnesium	107.53	138.75	128.56	2998.41	$1.3145*10^5$	69432

Table 11: FEA Analysis of Vertical Curved FIN at 150 Watts

Material	Temperature (Min)°C	Temperature (Max)°C	Temperature (Avg)°C	Total heat Flux (Min) W/m^2	Total heat Flux (Max) W/m^2	Total Heatflux (Avg)
Copper	117.76	131.84	124.11	34237	$1.2954*10^5$	63589
Aluminium	108.96	132.54	120.56	3472.6	$1.2876*10^5$	62431
Magnesium	105.92	136.61	121.52	33212	$1.2732*10^5$	61986

Table 12: Temperature Distribution in °C Compression at 50W input

Material	Rectangular Fin	Horizontal Curved Fin	Vertical Curved Fin
Copper	102.67	98.891	97.81
Aluminium	103.03	99.244	98.23
Magnesium	103.07	99.278	98.65

Table 13: Total Heat Flux Distribution in W/m^2 Compression at 50W input

Material	Rectangular Fin	Horizontal Curved Fin	Vertical Curved Fin
Copper	16945	17792	17245
Aluminium	16740	17541	17155
Magnesium	16721	17518	17059

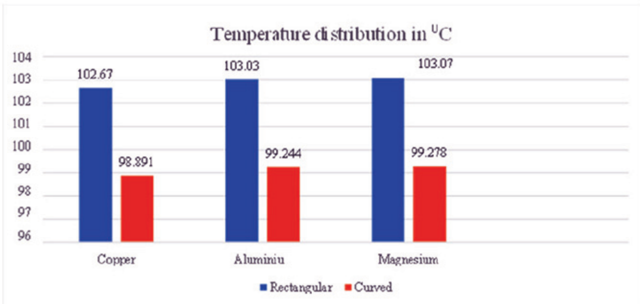

Figure 7: Temperature distribution Rectangular vs Curved

6.0 Results and Discussion

The present work has dealt with the study of heat transfer from curved fins by analytically using software. In comparison with curved fins and rectangular fins was also accomplished to obtain an idea on the effectiveness of curved fins.

This study was carried out assuming similar boundary conditions for rectangular and curved fins. The curved fins and rectangular fins are assumed to be of same length and thickness.

The study was done for three different types of materials i.e copper, aluminum. magnesium. This materials were chosen as fins are generally fabricated of high thermal conductivity materials. Further the analysis was done for three different heat fluxes.

A detailed study of temperature and heat flux distribution was achieved for both the configurations chosen under the considered heat fluxes for three different materials.

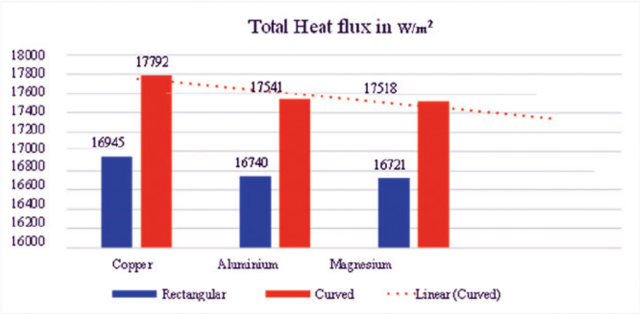

Figure 8: Total Heat Flux Distribution (Rect. vs Curved)

The temperature distribution for curved and rectangle fins obtained through FEA analysis for different energy inputs. It can be observed that the temperature has increase with the increase in input energy. It can also be observed that for any given energy input, the temperature is more uniform in copper as compared to other materials since it possess higher thermal conductivity. It can also be observed that the maximum temperature of the fin is least for copper among the materials choosen

Comparison between rectangular and curved fins can be inferred that the temperature in rectangular is moderately higher than the curved fin for any material at a given energy input. This can be attributed to the higher heat transfer surface area for curved fin.

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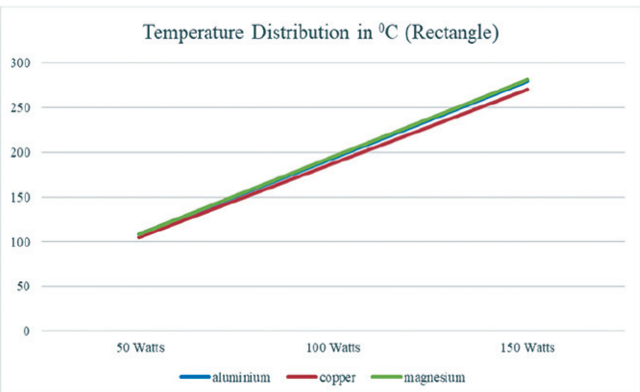

Figure 9: Temperature distribution of Rectangular Fin for three different materials

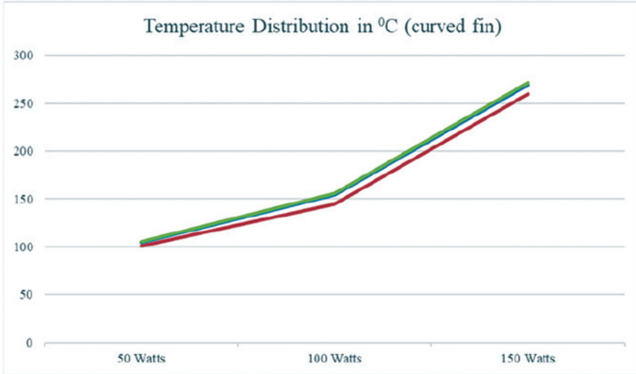

Figure 10: Temperature distribution of Rectangular Fin for three different materials

Comparison between rectangular and curved fins can be inferred that the heat flux in rectangular is moderately higher than the curved fin for any material at a given energy input.This can be attributed to the higher heat transfer surface area for curved fin.

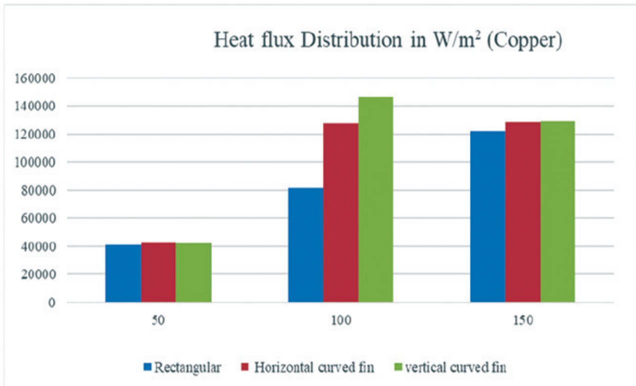

Figure 11: Heat Flux Distribution of Copper Fins

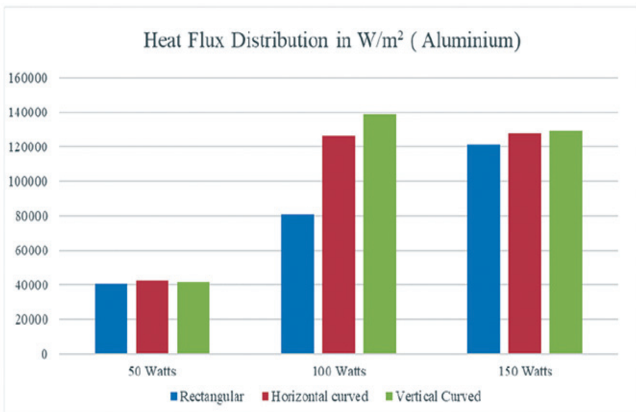

Figure 12: Heat Flux Distribution of Aluminium Fins

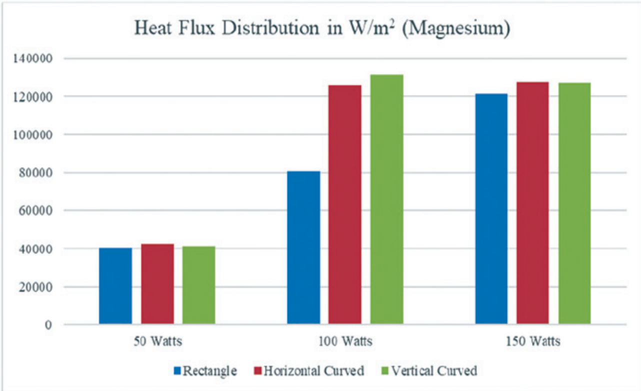

Figure 13: Heat Flux Distribution of Magnesium Fins

From the graph, It can also be observed that for any given energy input, the temperature is more uniform in copper as compared to other materials since it possess higher thermal conductivity. It can also be observed that the maximum temperature of the fin is least for copper among the materials choosen.

From the graph, It can also be observed that for any given energy input, the temperature is more uniform in copper as compared to other materials since it possess higher thermal conductivity. It can also be observed that the maximum temperature of the fin is least for copper among the materials choosen.

From the graph it can be inferred that the temperature in rectangular is moderately higher than the curved fin for any material at a given energy input. This can be attributed to the higher heat transfer surface area for curved fin.

From three Figs.11 to 13, It can be observed that the heat flux has increased with the increase in input energy. It can also be observed that for any given energy input, the heat flux is more uniform in copper as compared to other matereails

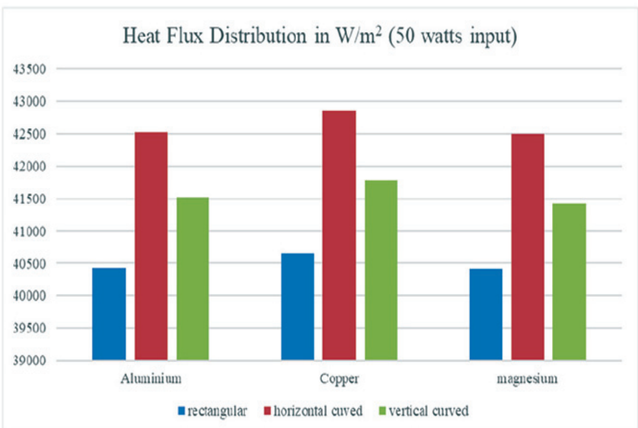

Figure 14: Heat Flux Distribution of Materials At 50 Watts

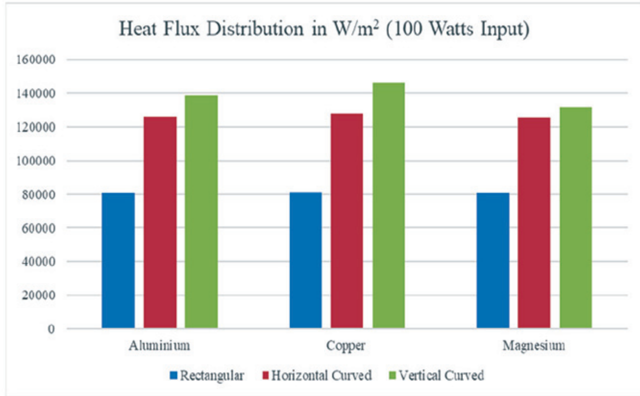

Figure 15: Heat Flux Distribution of Materials At 100 Watts

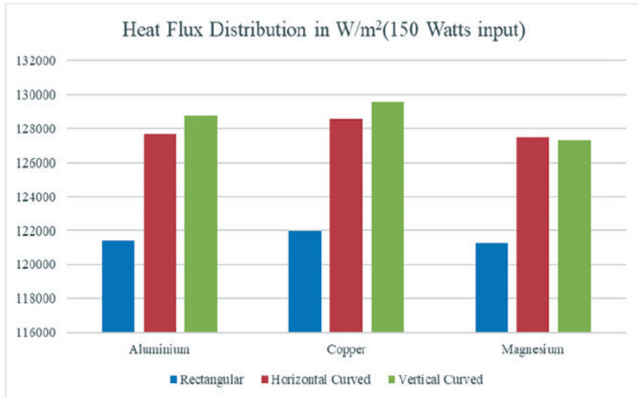

Figure 16: Heat Flux Distribution of Materials At 150 Watts

since it possess higher thermal conductivity. It can also be observed that the maximum heat flux of the fin is high for copper among the materials choosen.

Comparison between rectangular and curved fins can be inferred that the heat flux in rectangular is moderately higher than the curved fin for any material at a given energy input.This can be attributed to the higher heat transfer surface area for curved fin.

From the Figs. 14 to 16, It can be observed that the heat flux has increased with the increase in input energy. It can also be observed that for any given energy input, the heat flux is more uniform in copper as compared to other materials since it possesses higher thermal conductivity. It can also be observed that the maximum heat flux of the fin is high for copper among the materials choosen.

Comparison between rectangular and curved fins can be inferred that the heat flux in rectangular is moderately higher than the curved fin for any material at a given energy input. This can be attributed to the higher heat transfer surface area for curved fin.

7.0 Conclusions

The present work proposes to use curved fins instead of regular rectangular fins and study their heat transfer performance. This objective has been fulfilled by adopting analytical methods. The curved fins are compared to rectangular fins with reference to the temperature distribution and heat flux. The modelling and analysis was carried out by using CATIA and ANSYS workbench respectively. The following conclusions were drawn from the steady state thermal analysis of both the fins.

- The analysis was done for three materials i.e copper, aluminium and magnesium.
- Copper exhibited the best results in terms of temperature distribution and heat flux due to its high thermal conductivity.
- The curved fins were better off when compared to rectangular fins as they have high heat transfer area.
- When comparison of horizontal and vertical configurations gave best results as the heat dissipation rate was higher.
- The enhancement and heat transfer rate with curved fins when compared to rectangular fins is in the ratio 1:1.2.

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