Journal of Materials Science & Nanotechnology
Volume 6 | Issue 3
ISSN: 2348-9812

Research Article Open Access

Temperature Distribution inside a Solid Rectangular Fin with Embossings for I.C. Engines by Finite Element Analysis (FEA)

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Citation: Hemanth J (2018) Temperature Distribution Inside a Solid Rectangular Fin With Embossings for I.C. Engines by Finite Element Analysis (FEA). J Mater Sci Nanotechnol 6(3): 301

Received Date: June 18, 2018 **Accepted Date:** July 20, 2018 **Published Date:** July 23, 2018

Abstract

Fins are the extended surfaces through which heat transfer takes place by conduction and convection to keep the base surface cool. Fins of various configurations are presently used ranging from automobile engines to cooling of chip in a computer. Fins used presently are solid with different shapes but in the present research such solid fins are compared with solid fins having maximum of 10 numbers of embossings that further increase the surface area for maximum heat transfer. Importance in this research is given to variation of temperature along the length of the fins which in turn gives rate of heat transfer. Thus this research is under taken to increase the efficiency of fins (by extracting heat from the base surface) which is highly demanded today for air cooled engines, compressors, refrigerators etc. In the present research, SOLID70 element and SURF152 elements are used for FE analysis. Methodology involves 3D rectangular fin modelling and meshing, creation of surf elements for the modeling, applying the boundary conditions and source temperature, applying the material property (aluminum) to obtain the steady state thermal contours. FEA results are finally compared with analytic and experimental values for validity. In the present research, a solid rectangular aluminum fin and the same rectangular fin with 2, 4, 8 and 10 embossings were compared through finite element analysis for its temperature distribution along the length. FEA analysis of the present research showed that fins having embossings are more efficient compared to that a simple solid fin. Hence it is concluded from the present research that embossings at preferred locations further increases the rate of heat transfer. From the present analysis it is concluded that the mathematical and FEA for a solid rectangular fin without embossings are converging within +/- 1.2 °C and rectangular fin with 10 embossings are converging within +/- 1.4 °C and hence the validity.

Keywords: Fin; FEA; Temperature; Embossing and Surface

Introduction and Literature Review

The basic law that governs the convective heat transfer is Newton's law of cooling wherein the film coefficient of heat transfer or the convective heat transfer coefficient h' is very important which mainly depends on the type of the surface, size, shape, its temperature, surface finish etc. Most of the mathematical and dimensional analyses are confined in finding the film coefficient of heat transfer. In addition to the above, for fins the temperature distribution along its length also become important. The expulsion of excess heat from framework parts is fundamental to abstain from harming impacts of overheating. Thusly the improvement of heat exchange is a vital subject of warm designing [1]. Heat exchange rate might be expanded by expanding the heat exchange coefficient between a surface and its encompassing, or by expanding the heat exchange zone of the surface. Much of the time, the zone of heat exchange is expanded by developing surfaces. These amplified surfaces are called as fins.

Balances are utilized to improve convective heat move in an extensive variety of designing applications and offer a handy method for accomplishing a substantial aggregate heat exchange surface range without the utilization of an over the top measure of essential surface zone [2]. Fins are generally connected for heat administration in electrical apparatuses, for example, PC power supplies or substation transformers. Different applications incorporate motor cooling, Condensers in refrigeration and aerating and cooling [3]. Fins as heat exchange improvement gadgets have been very regular. The diverse materials like mild steel, stainless steel, aluminum, and silver, copper and so on are utilized for making fins. As the stretched out surface innovation keeps on developing, new outline thoughts have been risen including fins made of anisotropic composites, permeable media, hindered and punctured plates. Because of popularity for light weight, smaller and sparing fins, the enhancement of balance size is of awesome significance [4]. Along these lines, fins must be intended to accomplish most extreme heat expulsion with least material use considering the simplicity of the balance fabricating. The change in heat exchange coefficient is ascribed to the restarting of the warm limit layer after every interference [5]. Accordingly punctured plates and fins speak to a case of surface intrusion. Current study intends to foresee the temperature drop more than a few round apertures of expansion in number. Different parameters like warm flux and warm inclination are analyzed over various number of round holes [6]. In this investigation ANSYS FEA software is utilized for lattice and unraveling. In the examination of heat trade, cutting edges are surfaces that stretch out from a thing to manufacture the rate of heat trade to or from nature by growing convection. The measure of conduction, convection, or radiation of an article chooses the measure of heat it trades [7]. Extending the temperature incline between the article and the earth, growing the convection heat trade coefficient, or extending the surface zone of the thing constructs the glow trade. Occasionally it is not achievable or down to earth to change the underlying two choices. In this way, adding a cutting edge to a thing assembles the surface zone and can rarely be a calm response for heat trade issues [8]. Finally, it is well known that major heat transfer from the fin is by convection and performance of a fin is evaluated by its efficiency and effectiveness. There are various examination related to heat trade and weight drop of channels with pin cutting edges, which are limited to stick parities with round or couple of different cross territories. The genuine heat trade takes by two modes i.e. by conduction took after by convection. Heat trade through the solid to the surface of the solid happens through conduction whereas from the surface to the surroundings happens by convection. Further heat trade may be by normal convection or by obliged convection. Bayram Sahin and Alparslan Demir from their research concluded that, the use of the square stick cutting edges may incite heat trade change. Both lower elbowroom extent and lower between parity scattering extent and likewise cut down Reynolds numbers are proposed for higher warm execution [9]. R Karthikeyan and R Rathnasamy concluded from their research that, for a given Reynolds number, the pin-edge show with smaller buries fin separation gives higher execution than those with higher cover equalization partitions [10]. Another researcher found that, most in-line square stick equalization bunches have poorer heat move than an in-line round pin fin cluster show wonderful heat trade at high Reynolds number. The perfect between equalization pitches are directed by the greatest Nusselt number at a given pumping power [11]. Connections giving the typical Nusselt number for each outline as a part of the Reynolds number were created few researchers [12]. Amol B, Dhumne, Hemant S. and Farkade focused on the trial examination of on heat exchange upgrade and the relating weight drop over a level surface equipped with barrel molded cross sectional punctured pin equalizations in a rectangular channel [13]. Their research showed that the usage of the barrel formed punctured pin fins prompts heat trade update than the solid round and empty equalizations. Both lower breathing space extent and lower between parity scattering extent and nearly cut down Reynolds numbers are proposed for higher warm execution. In one more investigation the researchers found that, glow trade by short stick edges in staggered plans. According to their results, longer stick equalizations (H/d=4) trade more heat than shorter pin-parities (H/d=½ and 2) and the exhibit found the center estimation of heat trade with eight segments of pin-adjusts to some degree surpasses that with only four lines [14]. Vanfossen G.J. and .Brigham B.A focused their research on the ordinary heat trade coefficient on the pin surface is around 35% greater than that on the end dividers [15]. Metzger et al., investigated the effects of pin-edge shape and show presentation on the glow trade and the weight incident in pin-equalization bunches [16]. They demonstrated by their results that the use of round and empty pin-parities with a group introduction amongst astonished and in-line can now and again propel the glow trade, while fundamentally decreasing weight. Others have also reported from their investigation that, another way to deal with upgrade heat swapping scale is to use spaces which allow the stream to encounter the pieces [17]. Yatendra Singh, Tomar, Sahu M.M mulled over that the warm resistance and weight drop are considered as the distinctive warm execution properties [18]. Their studies have exhibited that the convection heat conversion standard from equalization bunches depends on upon all geometric parameter, parity material and base-to-encompassing temperature contrast. The elliptic pin equalization exhibits the most insignificant weight drops. For the same surface zone at a settled pumping power, the elliptic pin edge has the smallest warm resistance for the stunned course of action [19].

Relevance of the Research

Fins are the extended surfaces through which heat transfer takes place by conduction and convection. In the present investigation the surface area is further increased by providing embossings at preferred locations in the solid fin. This in turn increases effectiveness and efficiency of the fin. So far no attempt has been made to provide embossings in the solid aluminum fin to increase the surface area and hence the present research was under taken to fill the void.

Experimental, Analytical and FE Analysis Procedure

Figure 1 shows the experimantal set up showing temperature recrder, theomocouples etc. along with the the heat source at the center, attached with fins having enbossing's (Maxm. 10). The power supplied was 40 watts to heat the base of the fin in the present research. SOLID70 element and SURF152 elements are used for FE analysis. Methodology involves 3D rectangular fin modelling and meshing, creation of surf elements for the modeling, applying the boundary conditions and source temperature, applying the material property (aluminum) to obtain the steady state thermal contours. Finally the temperature distribution results of solid fin are compared with that of solid fin with 10 embossings at preferred locations along the length of the fin.

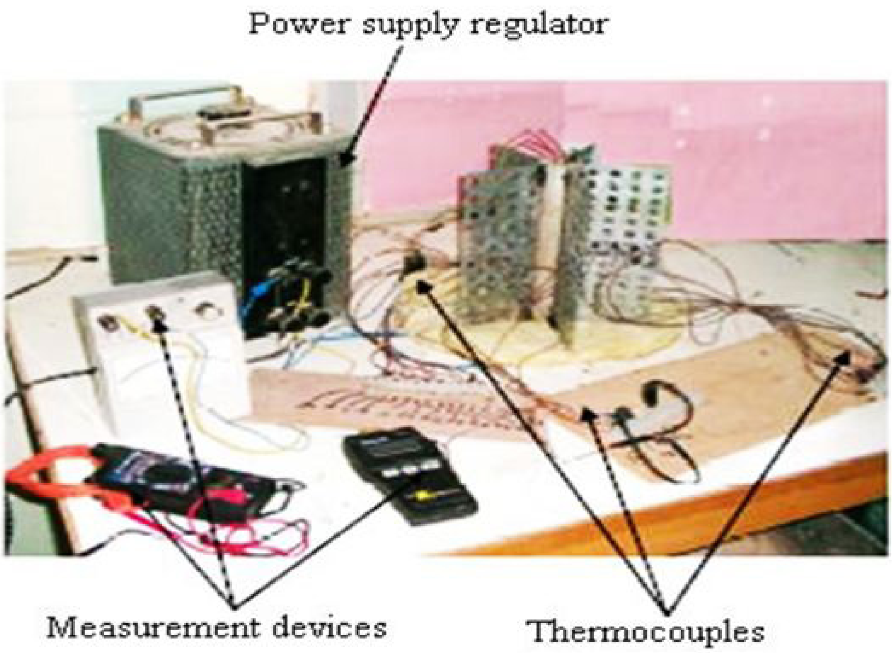


Figure 1: Experimental setup

Mathematical Analysis for a Solid Fin Temperature Gradient

Figure 2 shows a rectangular aluminum fin indicating the details regarding area, perimeter, temperature etc. The most popular energy balance equation used to find the heat transfer through fins mathematically (for steady state condition) is given by:

$$Q = \sqrt{hpKA}\left(C_2 - C_1\right) --- \quad (1)$$

C1, C2 are constants obtained by applying the limits.

Equation (1) is modified to find temperature distribution based on the tip condition.

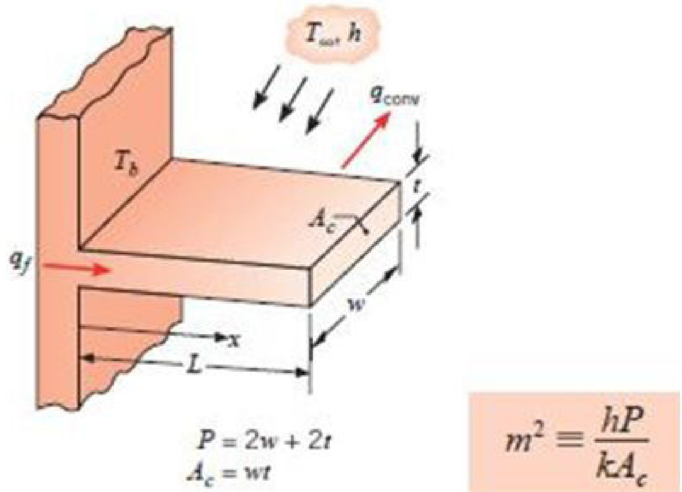


Figure 2: 3D view of rectangular fin

Equation (2) is used to find analytically the fin temperature over a distance with given boundary conditions [20].

$$T\left(X\right) = T_\infty + \left(T_b - T_\infty\right) * \frac{Nr}{Dr} --- (2)$$

where, $Nr = \cosh m\left(L - x\right) + \left(\frac{h}{mk}\right) + \sinh m\left(L - x\right)$

$$Dr = \cosh mL + \left(\frac{h}{mk}\right) + \sinh mL$$

Heat Transfer Coefficient Using Vertical Plate Correlation

Correlations given below are used to find the heat transfer coefficient using dimensional analysis for vertical plate [21].

$$Nu_L = \frac{h * L}{k} = C\left(\frac{g\beta L^3}{va} * (T_s - T_\infty)\right)^n ------(3)$$

Where,

$$h = C * \frac{k}{L}\left(\frac{g\beta L^3}{va} * (T_s - T_\infty)\right)^n = FKcons\tan t * (T_s - T_\infty)^n$$

(Where c=0.59, n=0.25)

Mathematical and Finite Element Modeling of Rectangular Fin with Number of Embossings (2,4,8 and 10)

For analysis and comparison purpose, rectangular aluminum fin with 2,4,8 and 10 embossings was considered but for discussion only fin with 10 embossings is presented in the present paper. Mathematically, the heat transfer coefficient is calculated using the vertical plate correlation. Using the following correlation

$$h_{ps} = h * \left(1 + 0.75 * \frac{1130.9}{1696.45}\right) = 2.28 ---(4)$$

Note that the number of embossings considered in this research is taken care in Eq (2) and Eq (3) by the constants embedded in the equations according to Yanfossen and Brigham (15)

Results and Discussion

Solid Rectangular Fin (without Embossings)

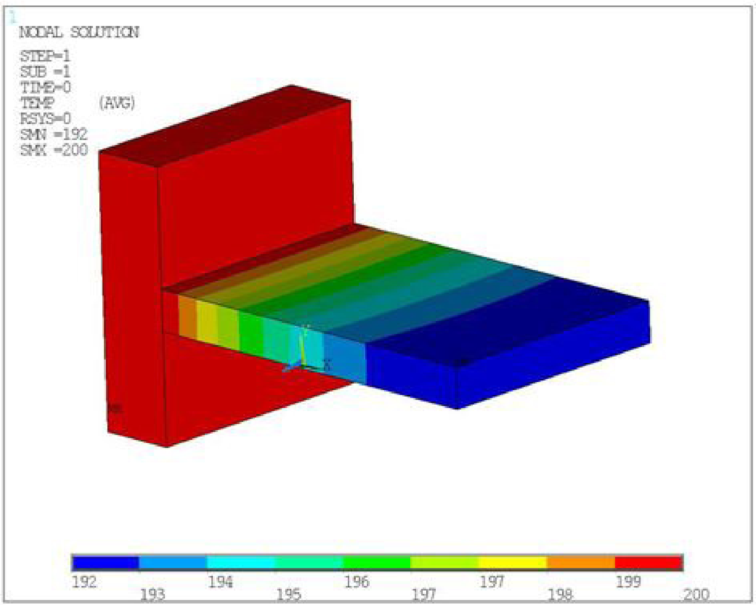


Figure 3: Thermal contour (FE analysis)

Where,

Figure 3 shows FE modeling and analysis for a rectangular fin indicating thermal contour. Temperature along the length of the fin (0.15 m) calculated analytically is tabulated in (Table 1). Figure 4 shows the superpose of FE analysis (Figure 3) and analytical results as indicated in (Table 1).

Analytic calculation to find temperature at distance x					
L, Length of the fin			0.15 m		
w, width of the fin			0.1 m		
t, thickness of the fin			0.015 m		
h, heat transfer coeff.			5.489 w/m2-k (for Al)		
p, perimeter			0.23 m		
Ac, cross section Area			0.0015 m2		
k, thermal conductivity			236 w/m-k (for Al)		
m			1.888		
T base			200 °C		
T infinity			20 °C		
L(in m)	x(in m)	Numerator	Denominator	Theta(a)/theta(b)	T(x), °C
0.15	0	1.0439	1.0439	1.0000	200.0
	0.015	1.0358	1.0439	0.9923	198.6
	0.03	1.0286	1.0439	0.9823	197.4
	0.045	1.0222	1.0439	0.9792	196.3
	0.06	1.0166	1.0439	0.9738	195.3
	0.075	1.0118	1.0439	0.9692	194.5
	0.09	1.0078	1.0439	0.9654	193.8
	0.105	1.0047	1.0439	0.9624	193.2
	0.12	1.0023	1.0439	0.9601	192.8
	0.135	1.0008	1.0439	0.9586	192.6
	0.15	1.0000	1.0439	0.9579	192.4

Table 1: Tabulation of analytic values of temperature along the length of the fin

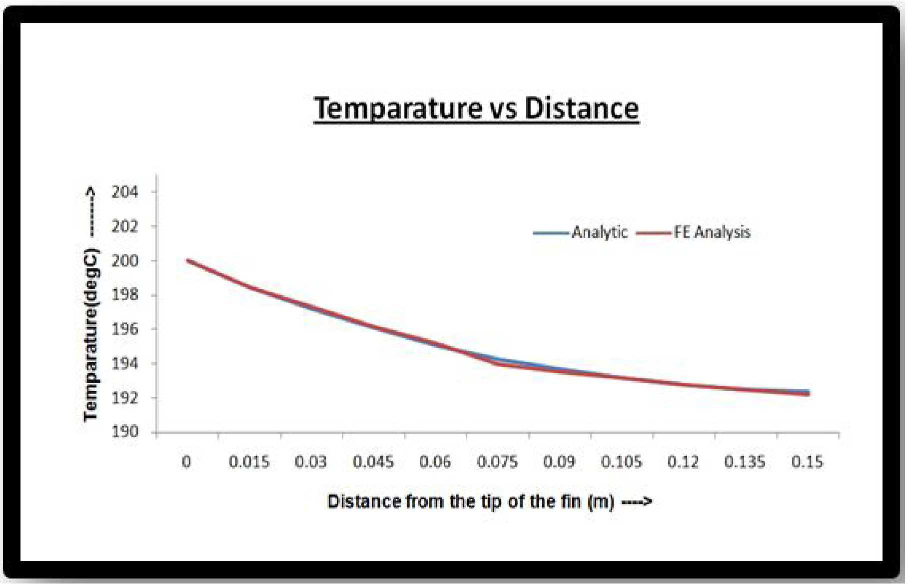


Figure 4: Variation of temperature along the fin length (analytical and FEA superposed)

It is observed from Table 1 that the root temperature 200 °C goes on decreases as fin length increases and reaches 192.4 °C at the tip. From Figure 3 it is again observed that the FE analysis follows the same pattern that the temperature monotonically decreases from 199 °C to 192 °C as the length of the fin increases from root to the tip. Hence, it is observed from the present research that keeping the base (root) temperature at 200 °C with power supply of 40 watts, a solid rectangular fin reaches a temperature of 192.4 °C at the tip indicating a heat dissipation of 7.6 °C over a length of 0,15 m. From Figure 4 it is observed that the mathematical and FEA that for a solid rectangular fin without embossings are converging within +/- 1.2 °C and hence the validity of FEA with mathematical analysis.

Solid Rectangular Fin with Embossings

Figure 5 below shows the experimental results of temperature measurements along the length of the fin with a power supply of 40 watts for a rectangular fin with 2,4,8 and 10 embossings. Temperature was measured using thermocouples along the length of the fin.

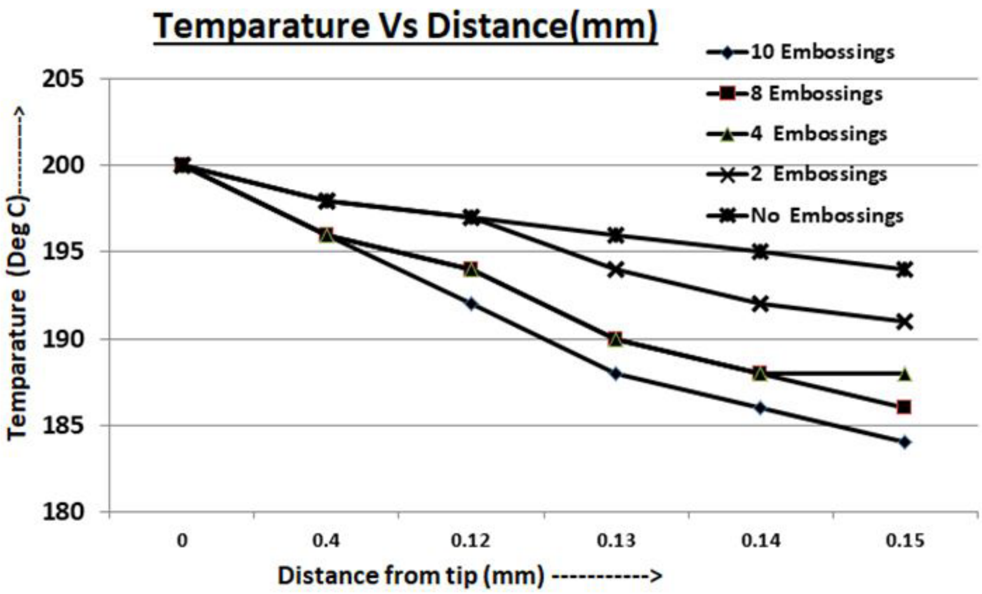


Figure 5: Plot of temperature Vs. length for a rectangular fin with embossings

It is observed firm Figure 5 that the temperature is coincident with no embossings and 2 embossings up to a distance of 0.12 m and later the same type of coincidence was observed between 4 and 8 embossings up to a distance of 0.14 m. The main reason for this coincidence up to a particular distance w.r.t number of embosings is the saturation time required for the fin to reach its effectiveness since number of embossings increases. Figure 6 below shows the temperature calculated using mathematical analysis for a rectangular fin containing 2, 4, 8 and 10 embossings.

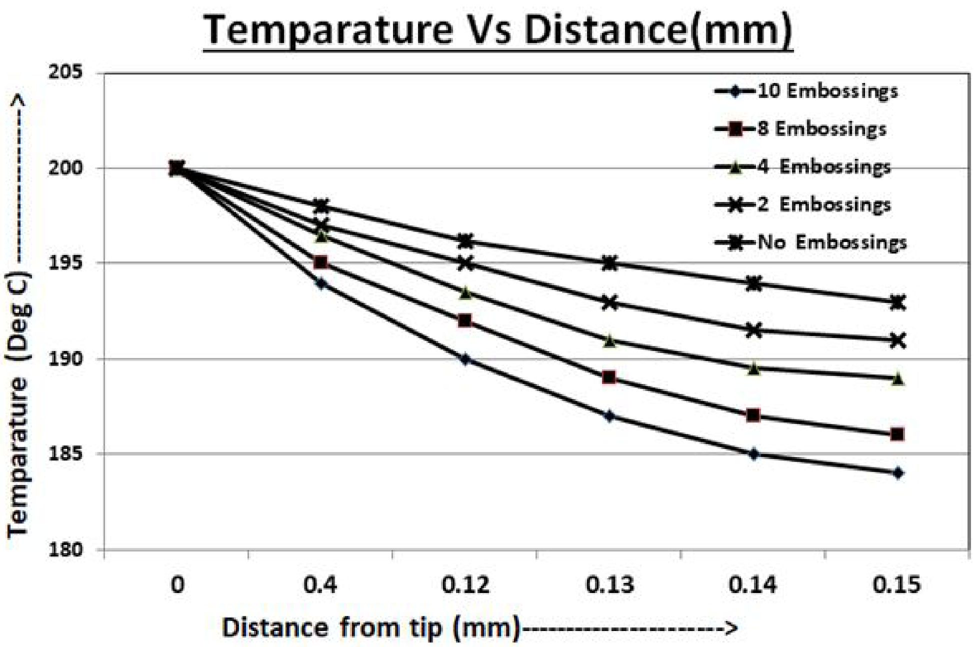


Figure 6: Plot showing temperature Vs distance for a rectangular fin with 2,4,8 and 10embossings by mathematical analysis

Figures 7, 8, 9, 10 below shows the FE models for geometry, meshing, steady state thermal contour and heat flux for a rectangular fin containing 10 embossings.

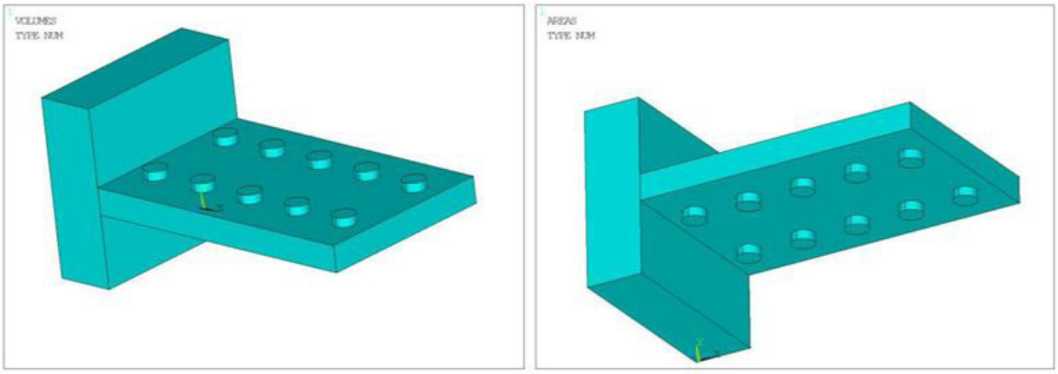


Figure 7: Geometry of fin with 10 embossings

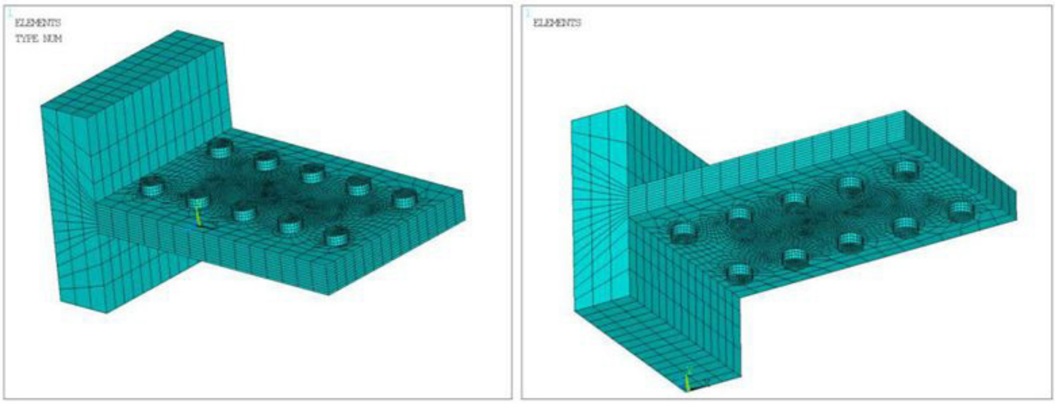
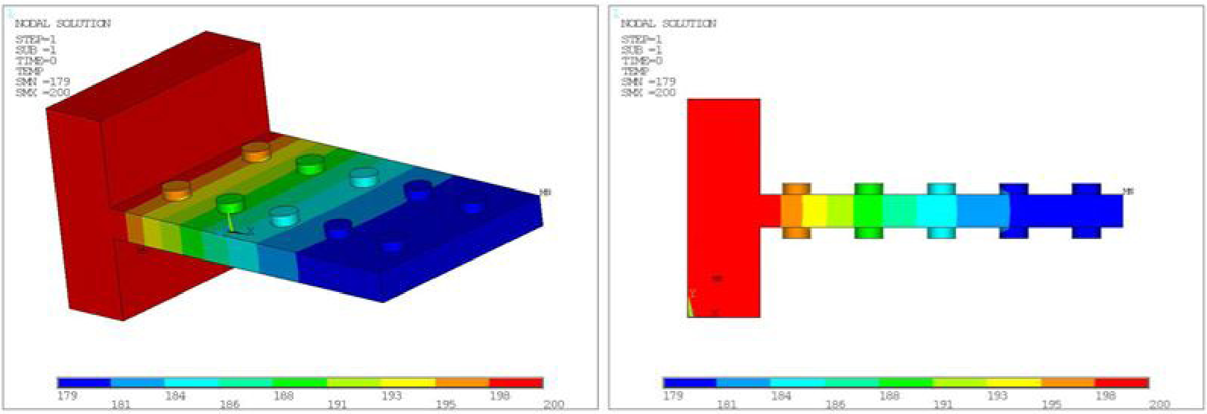


Figure 8: Finite element model (meshing) of the fin with embossings



Max temperature=200 °C at base Min temperature=179 °C at fin tip

Figure 9: Steady state thermal contour of embossed fin

It is observed from fig. 5 and 6 that both experimental and mathematical analysis follows almost the same pattern of temperature distribution along the length of the embossed fin. It is also observed from figure 5 and 6 that the temperature of fin at the trailing surface is decreasing with increase the number of embossings in the fin. This indicates that heat transfer increases with embossings having full connectivity between the base and the fin. It is observed from the present research that keeping the base (root) temperature at 200 °C with power supply of 40 watts, rectangular fin with 10 embossings reaches 179 °C at the tip (Figure 9). This shows that rectangular fin with embossings removes more heat compared to solid fin. From Figure 9 it is observed that FE analysis follows the same pattern as that of mathematical and experimental values (calculations not shown) i.e., the root temperature 200 °C continuously decreases to 179 °C at the tip. It is finally observed that the mathematical and FEA of rectangular fin with 10 embossings are converging within +/- 1.4 °C and hence the validity of FEA with mathematical and experimental analysis. Note that a small variation in FE and mathematical analysis for fin with embossings is due to the mesh used and the presence of embossings.

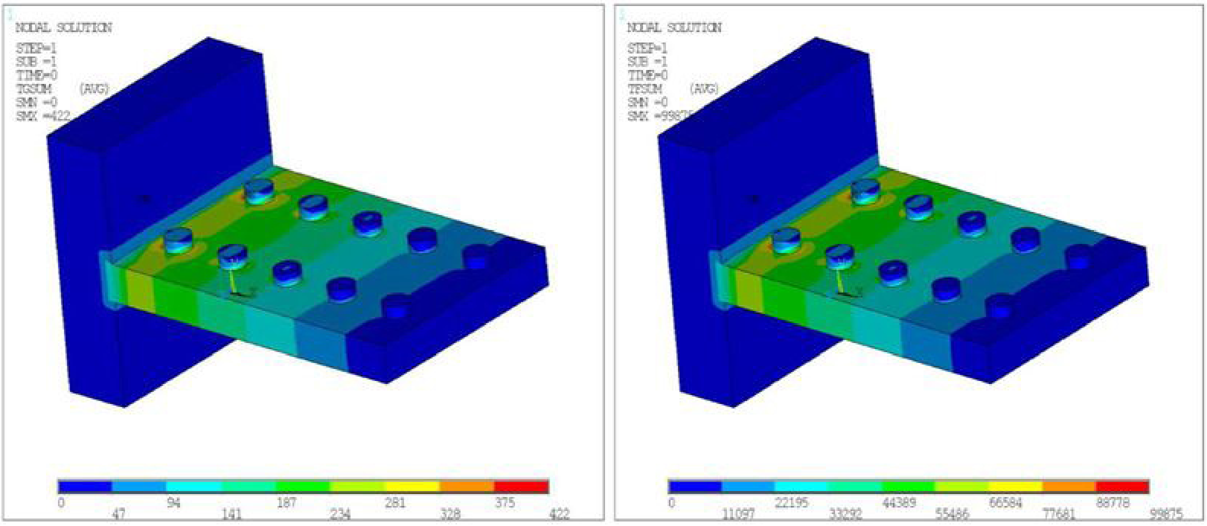


Figure 10: Contours of thermal gradient & heat flux of embossed fin

Conclusion

It is observed from the present research that keeping the base (root) temperature at 200 °C with power supply of 40 watts, a solid rectangular fin reaches a temperature of 192 °C at the tip whereas the same fin with 10 embossings reaches 179 °C at the tip. This shows that rectangular fin with embossings removes more heat compared to that of a solid fin. It is also observed from the research that this temperature fall is gradual from fin with 2, 4, 8 and 10 embossings thus the heat removal gradually decreases with increase in embossings. Heat flux also follows the same pattern along the length of the fin as that of the temperature. In the present research it is also observed from the mathematical and FEA that for a solid rectangular fin without embossings are converging within +/- 1.2 °C and rectangular fin with 10 embossings are converging within +/- 1.4 °C and hence the validity.

Acknowledgement

Author thank the Govt. sponsored R&D center, HMSIT, Tumkur, INDIA for extending its facilities for carrying out the research and to Mr. J Joy Gideon, Research Asst. of the R&D center for assisting in graphics, typing and final setting of this research paper.

Nomenclature

Q: rate of hear transfer, watts
h: convective heat transfer coefficient w/m^2 °C,
P: the perimeter of the fin, m,
K: thermal conductivity, w/m °C,
A: area, m2, L: length, m and W: width, m

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