DESIGN AND ANALYSIS OF HONEYCOMB STRUCTURE COOLING FIN

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ABSTRACT: Cooling fin is an important component to assist thermal management inside high performance light emitting diode (LED). The area of cooling fin plays an important role to drive the heat away from the LED. It is essential to have good thermal management to optimize the working life of high performance LED and its illuminating efficiency. This paper studies a proposed redesigned honeycomb structure cooling fin for high performance LED. Analysis of thermal base on conduction and natural convection was conducted. Aluminum Alloy was selected as the material of the honeycomb structure cooling fin. 3D modeling was done to create the design of the cooling fins structure. The model was tested with thermal analysis and the results for both cooling fins were compared. The result showed that the honeycomb structure cooling fin achieved the optimum surface area for thermal management of high performance LED street lamp. This study showed that honeycomb structure cooling fin have the potential to increase the working life of high performance LED and its illuminating efficiency. Further study should be conducted in the application of honeycomb structure cooling fin in other electronic or electrical devices.

KEYWORDS: *Design and Analysis, Light Emitting Diode, Honeycomb Structure Cooling Fin*

1.0 INTRODUCTION

Light emitting diode which is also known as LED is becoming one of the most favourable light sources nowadays. It has been applied as lighting purposes such as traffic light lamp, street lamp, stage lamp and many others. Even though many other light sources exist today, LED is predicted to be an ultimate lamp for the future. By the year 2025, high performance LED will become the most dominant lighting technology in the world [1]. LED is becoming the leading choice among the other lamp because of its features which have long operating life with great illumination and low energy consume compared to other lights.

A lot of research has been conducted in industries to improve the durability and lighting quality of lamps towards the greatest phase. An important factor that needs to be highlighted is the thermal management inside a LED lamp [2]. The LED lighting quality is very dependent on its operating temperature. High performance LED lamp can produce a very bright light but in return, it also produces a very high temperature heat. This may affect the durability and the lighting quality of high performance LED lamp.

Nowadays, various structures of cooling have been designed in order to assist the thermal management in the high performance LED lamp [3], [4], [5], [6]. The honeycomb structure cooling fin is one of the new design considerations in helping to conduct the thermal management inside the lamp [2]. Honeycomb structure which having the hexagon shape provides a wide contact area which effectively allows the conduction and natural convection process that conduct the thermal away from the LED. For this study, honeycomb structure cooling fin wasdesigned and several analyses were made to achieve the new optimum design for high performance LED lamp.

2.0 LITERATURE REVIEW

2.1 Light Emitting Diode

Light emitting diode also known as LED is a popular light source nowadays. LED has been used in various applications such as street lamp, traffic light and vehicle back lamp more favourable compared to other lamps such as a high intensity discharge lamp (HID) and compact fluorescent lamp (CFL) because of its advantages where it can provide high lumen with low power electricity and good for the environment as it does not contain mercury such as fluorescent light. Apart from that, LED lifetime hours is much longer and suitable with various applications [1], [7].

2.2 The importance of LED thermal management

High power LED can produce a very bright light but at the same time high heat will be produced. This temperature should be considered because it will affect the LED efficiency. High power LED usually consumes power from the range of 500 milliwatts to 500 watts in a single package. Lack of thermal management may cause the electrical energy in a LED will convert to heat rather than light, where almost 80% will turn to heat while only 10 to 20 % will remain as light energy. Therefore, it is essential to have good thermal management inside the LED to reduce the energy waste and increase the efficiency of the LED.

2.3 Cooling high performance LED

High performance LED consumes a lot of electricity to produce bright light. In the other hand, heat will also produce due to the large energy produced. Therefore, cooling the high performance LED is essential in order to maintain their efficiency.

2.4 The function of heat sink

Heat sink is a device that effectively absorbs or dissipate thermal energy from the surroundings using extended surface either fins or spines. The heat sink is widely used in various applications that require efficient heat dissipation such as refrigerator, engine and electronic device. The design of heat sink is mostly made of metal device which has many cooling fins namely fin array [8]. Cooling fins are able to dissipate heat from the functional LED to environment to ensure it operates within safe temperature limits. Various designs of cooling fins assist the thermal management for high performance LED.

Two methods of cooling are passive cooling method and active cooling method. Passive cooling methods require no energy input, include the use of thermal vias, heat spreading mechanisms, phase change materials, heat sinks, heat pipes, and materials with high thermal conductivity [9]. Active cooling methods require external energy, often involve higher cost, volume, and noise than passive methods. Active cool methods include forced convection, liquid loops, thermosyphons, spray cooling, thermoelectric cooling, vapor compression refrigeration, cold plates, and thermoionic cooling [9].

2.5 Cooling fin design consideration.

The conventional cooling fin (Figure 1) is preferred by most manufacturers as it is more reliable and can reduce the heat around the high performance LED without consuming a lot electrical energy. Moreover, no regular maintenance is needed and no noise will be produced when using the cooling fins. In order to have a good cooling function, certain factors need to be highlighted in designing the cooling fin. Firstly, the surface area of the cooling should be focused. An effective cooling fin should have a wide surface area to flow the heat from the LED. Other than that, the material that is being used should also have a good heat conductivity and the design should not be too large or too heavy. Therefore, it is advisable to optimize the structure of the cooling fin into a condition where heat sink is sufficient for cooling demand for high performance LED [10].

Figure 1: Example of cooling fin

2.6 Cooling fin design

Figure 2 shows an example of a radial structure cooling fin. Figure 3 shows an example of cylindrical structure cooling fin. Honeycomb structures metals (Figure 4) have low-density materials that combine a certain stiffness, strength, crushing energy absorption, and thermal characteristics.

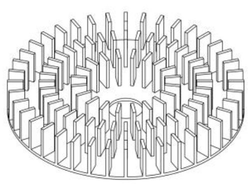


Fig. 2. Radial structure cooling fin

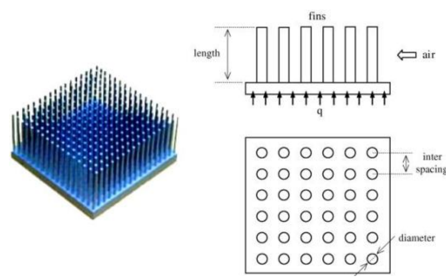


Fig.3. Cylindrical structure cooling fin

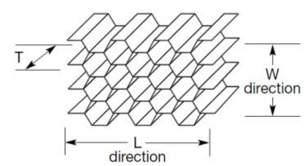


Fig. 4. Honeycomb structure

2.7 Material for honeycomb structure cooling fin

Material selection plays a critical role in producing cooling fin for high performance LED lamp. The goals of material selection include improving device performance, thermal regulation, and manufacturing yield, as well as reducing thermal stresses, warping, size requirements, weight, and cost [9]. Aluminum and copper are favourable thermal management materials used in the production of cooling fins. The reason of applying those materials in cooling fin production is because the high thermal conductivity and reasonably low coefficient of thermal expansion properties exhibited by both materials. As for high performance LED lamp instalment, low density material is preferable in order to reduce the overall weight of the lamp [9].

3.0 METHODOLOGY

3.1 CAD 3D Modeling Design

Initially, 3D CAD modeling for the existing cooling fin as shown in Figure 5 and the proposed honeycomb structure cooling fin design as shown in Figure 6 were produced.

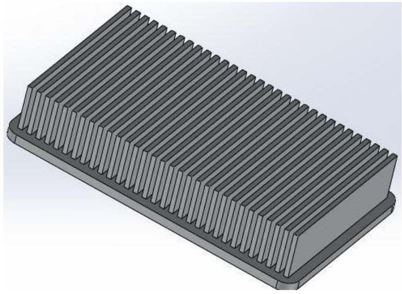


Fig.5. Existing cooling fin design

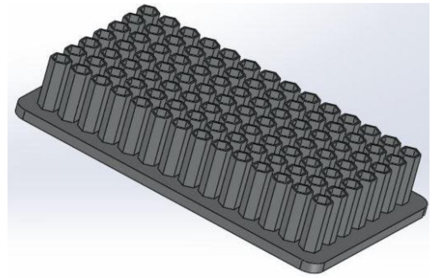


Fig. 6. Proposed honeycomb structure cooling fin design

3.2 Simulation using ANSYS

To perform the simulation of thermal analysis on the cooling fin structure, the entire geometry that was created with a CAD system was then imported to ANSYS for Finite Element Analysis (FEA). The geometry was saved in IGS format to allow the import process. To begin the simulation, new database were created by selecting the ANSYS workbench. A new file was opened and named. A steady state thermal was chosen as a type of analysis . Then, the engineering data were edited by adding the required materials. Next , the geometry was imported from the Solid work software. Then the material was specified by selecting the material that had been added in the previous step. Details of mesh relevance were inserted to the maximum which was 100. The steady state thermal data were inserted such as the temperature and convection properties. Required solutions for the analysis such as temperature, total heat flux and reaction were selected. Then the model analysis wasrun by solver to get the results.

3.3 Aluminum honeycomb structure cooling fin properties

In order to perform the FEA, information such as type of material, surface temperature and ambient temperature has to be set first.

3.4 Analyze the result.

To analyse the result, the comparison of the results obtained for existing cooling fin and honeycomb structure cooling fin design were made. The comparison included properties of both fins such as weight, total surface area, heat flux and also reaction probe.

3.5 Optimization of honeycomb structure cooling fin design

Design optimization was made from the design that had been completed to improve the design performance. The first design might not fully achieve the objective or lack of functionality. Therefore, an optimization was made to fix the problem and to improve it. The optimized design would then undergo a simulation process to verify the improvement.

4.0 RESULT AND DISCUSSION

This section discusses material selection and the analysis result of honeycomb structure cooling fin. Table 1 shows the scoring result for all the selected materials. The property's value and the type of the material are listed in the table. The information related to the material properties was searched in CES Edupack 2010 software. This software provides a comprehensive database of materials and process information. From the table, Aluminum is chosen as the best material for honeycomb structure cooling fin because it has a good thermal conductor with a good maximum service temperature which is 165 °C. It is also cheap, lightweight and easy to be formed and suitable to be welded in production process. Moreover, the yield strength for this material is quite high. Therefore, it can easily deform to its original shape when stress is removed from it.

Besides , an analysis on existing cooling fins for the LED street lamp had also been carried out to ascertain the comparison between these two cooling fins. Based on the results ,the two cooling fins were compared to identify the effectiveness of the new design. An optimization of the design was made to improve the performance of the new design. For this project, a steady state thermal simulation was used to complete the analysis. The steady state thermal analysis was used to determine temperatures, thermal gradient, heat flow rates, and heat fluxes in an object that was caused by thermal loads that did not vary over time. The steady state thermal analysis calculated the effects of the steady thermal loads on a system or component.

Table 1: Scoring result

Properties		**Materials**			
		Aluminum Alloy	**Copper**	**Zinc Alloy**	**Brass**
General	Price, RM	1.68	15.8	5.11	11.93
	Density, kg/m	2.7	8.94	5.98	8.23
Mechanical	Yield strength, MPa	265	190	265	297.5
Thermal	Thermal conductivity, W/m.°C	Good	Good	Good	Good
	Maximum service temperature,°C	165	240	95	210
Process ability	Formability	3.5	4.5	2.5	4.5
	Weldability	3.5	3	1	4.5

4.1 Simulation result

4.1.1 Simulation result for proposed honeycomb structure cooling fin

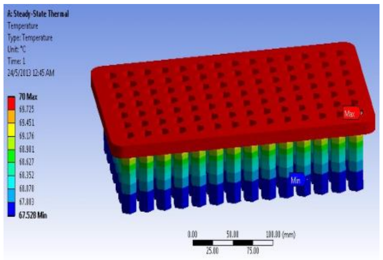
Table 2 shows the honeycomb structure cooling fin design properties, which have been obtained from a CAD and Ansys software. The selected material for existing cooling fin model was Aluminum Alloy. A total mass of this model was 2.604 kg and total of surface area was 682880.7 mm using 98 fins.

Table 2: Honeycomb structure cooling fin design properties

Material	Aluminium Alloy
Mass	2.604 kg
Total no. Of fins	98 fins
Total surface area	682880.7 mm^2

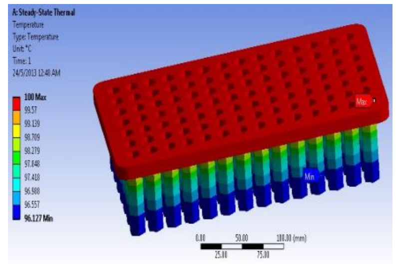
4.1.2 Temperature distribution result for proposed honeycomb structure cooling fin

Based on the result in Figure 7 and 8 for temperature of 70 °C and 100 °C, the maximum temperature area is at the top of the cooling fin model which is the area closest to the LED lamp location. When the LED lamp operated, heat was produced. Therefore, the closest fin area would absorb and disperse the heat away. The minimum temperature area was at the bottom of the fin which was located far from the LED lamp. For 70°C temperature, the minimum value at the bottom of the fin was 67.528 °C whereas for 100 °C temperature, the minimum value at the bottom of the fin was 98.367 °C.



- Maximum value: 70°C.
- Minimum value: 67.528 °C.

Figure 7: Total heat flux distribution result for proposed cooling fin design at 70^0

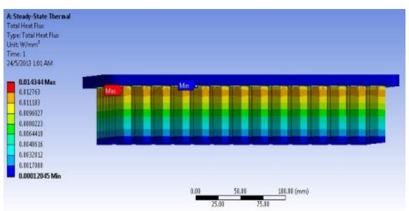


- Maximum value: 100°C.
- Minimum value: 98.367 °C.

Figure 8: Total heat flux distribution result for proposed cooling fin design at 100^0

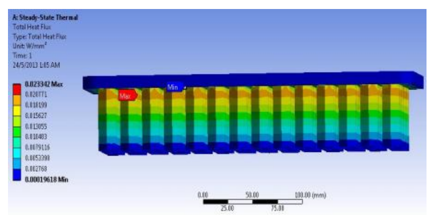
4.1.3 Total Heat Flux distribution result

Figure 9 and 10 show the results of total heat flux.Red region on the cooling fin design surface shows the area where the maximum total heat flux is present while the blue region shows the area of surface where the minimum total heat flux is present. For temperature of 70 °C, the maximum total heat flux present was 1.4344e-2 W/mm² and the minimum total heat flux present was 1.2045e-4 W/mm². For 100 °C temperature, the maximum total heat flux was 2.3342e-2 W/mm² and the minimum total heat flux value was 1.9618e-4 W/mm².



- Maximum : 1.4344e-2 W/mm²
- Minimum: 1.2045e-4 W/mm²

Fig. 9. Total Heat Flux at 70°C temperature



- Maximum: 2.3342e-2 W/mm²
- Minimum: 1.9618e-4 W/mm²

Fig. 10. Total Heat Flux at 100°C temperature

4.1.4 Reaction probe result

Table 3 shows the reaction probe result for existing fin design. Reaction probe simulation was used to measure the heat flow rate. For 70 °C temperature, the maximum and minimum value over time was 147.58 W. For 100 °C temperature, the maximum and minimum value over time was 240.1 W.

Table 3: Reaction probe result for honeycomb structure cooling fin design

Temperature, °C	Maximum value over time, W	Minimum value over time, W
70	147.58 W	147.58 W
100	240.1 W	240.1 W

5.0 RESULT COMPARISON

Based on the results in Table 4, there are significant difference between the existing cooling fin design and the proposed honeycomb structure cooling fin design. A total mass for the existing design is 5.48 kg meanwhile for the proposed honeycomb structure is 2.604 kg which is lighter compared to the existing design. The existing cooling fin design posseses more solid fin that cause it to be heavier unlike the honeycomb structure which posseses more hollow design that cause it to be lighter in mass. Cooling fin with lighter mass can indirectly reduce the mass of the LED street lamp part. Therefore, it is more beneficial to have cooling fin with light mass. Total numbers of fins for the existing cooling fin design are 31 fins while total number of fins for proposed honeycomb structure cooling fin is 98 fins. Although the proposed honeycomb structure cooling fin has more fins compared to existing cooling fin design, it still has lesser surface area compared to the existing cooling fin design. The total surface area for the existing cooling fin design is 690736.2 mm2 while the total surface area for proposed honeycomb structure cooling fin is 682880.7 mm2.

Cooling fin with wide surface area is important to increase the fin efficiency in conducting the heat away from the operating LED street lamp. Therefore the proposed design needs to be improved further to get wider surface than the existing design. For total heat flux result, both cooling fin models gives positive heat flux value which indicates a positive flow of heat in the direction of decreasing temperature. Overall, the proposed honeycomb structure cooling fin has higher maximum total heat flux compared to existing cooling fin design. Although the total heat flux is quite high for the proposed honeycomb structure cooling fin, the region of high temperature is quite small. Therefore, it is still acceptable because the temperature decreases starting from the top to the bottom of the fin.

Table 4: Reaction probe result for honeycomb structure cooling fin design

Type of fins	Existing cooling fin design	Honeycomb structure cooling fin design
Mass	5.48 kg	2.604 kg
Total no. of fins	31 fins	98 fins
Total surface area	690736.2 mm^2	682880.7 mm^2
Total heat flux	For 70 °C Min: 3.3198e-5 W/mm Max: 4.6864e-3 W/mm^2	For 70 °C Min: 1.2045e-4 W/mm^2 Max: 1.4344e-2 W/mm^2
	For 100 °C Min: 5.3656e-5 W/mm^2 Max: 7.6206e-3 W/mm^2	For 100 °C Min: 1.9618e-4 W/mm^2 Max: 2.3342e-2 W/mm^2
Reaction probe	For 70 °C Max value /time= 148.54W	For 70 °C Max value /time =147.58 W
	For 100 °C Max value /time = 241.51 W	For 100 °C Max value /time = 240.1 W

6.0 CONCLUSION

In conclusion, this study has successfully achieved the objective which is to design a honeycomb structure cooling fin for high performance light emitting diode (LED) and to perform simulation and analysis on thermal base on conduction and natural convection cooling fin structure as well as to optimize the design based on simulation result. Both cooling fins have undergone thermal analysis. After the simulation process, the results of both cooling fins were compared. The proposed honeycomb structure cooling fin design total area is smaller compared to the existing cooling fin design and the rate of heat flow is also smaller compared to the existing cooling fin design. Therefore, it can be concluded that the objective to design a honeycomb structure cooling fin for high performance LED with optimum surface area is achieved as the design of honeycomb structure provides a wider surface area than the existing cooling fin design. Other than that, the second objective which is to perform simulation and analysis on thermal and thermal stress based on conduction and natural convection cooling fin structure is also performed for both cooling fin structure. Therefore, the weaknesses and strength of each design are finally developed. As a result, a better design of high performance LED with honeycomb structure has been developed with a better thermal management and wider surface area. This study showed that honeycomb structure cooling fin have the potential to increase the working life of high performance LED and its illuminating efficiency. Further study should be conducted in the application of honeycomb structure cooling fin in other electronic or electrical devices.

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