23rd International Conference
ENGINEERING MECHANICS 2017
Svratka, Czech Republic, 15 – 18 May 2017

NUMERICAL THERMAL COMPARISON OF HEAT SINK MATERIALS FOR AUTOMOTIVE LED HEADLAMPS

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Abstract: *Currently, aluminium is the most widely used heat sink material for cooling LEDs in automotive headlamps because of its good thermophysical properties. But the headlamps manufacturers are still looking for other material solutions, which could be better than the aluminium one. One of the possibilities is using plastics with high thermal conductivity, because even if its conductivity is lower than aluminium's, it is much easier to shape to various forms, which could be better for heat transportation and the cost of this solution could be much lower. This paper deals with the comparison of a real heat sink geometry, used in the front headlamp of automobile, where it serves to cool LEDs. A numerical comparison between three materials was made: firstly the actually used aluminium alloy, secondly a imaginative material with isotropic thermal conductivity 20 $W \cdot m^{-1} \cdot K^{-1}$ serving as a comparision between plastic material and thirdly a plastic material with anisotropic thermal conductivity which ranges from 5 to 20 $W \cdot m^{-1} \cdot K^{-1}$.*

Keywords: Heat sink, Aluminium, Plastic, LED, Headlamp.

1. Introduction

Technology is constantly evolving and with this progress many electronic devices are becoming more compact. Not every component works with perfect efficiency and lots of its input power is transformed into heat, which needs to be transferred away from the device. This cooling can be achieved in three ways, by active cooling using a fan, passive cooling using a heat sink or a combination of the previous two.

The second form of cooling, even with lesser efficiency, has its advantages in not using any moving parts (it is needed to only put the component on the heat sink), no external energy for cooling, heat sink transfers heat away by thermal properties of its material. The most common heatsink materials are copper and aluminium for their high thermal conductivity (401 $W \cdot m^{-1} \cdot K^{-1}$, 237 $W \cdot m^{-1} \cdot K^{-1}$ respectively). Aluminium is more widely used, because it is lighter than copper and therefore it puts less stress on the component it is placed on. Its density is 2702 $kg \cdot m^{-3}$ while coppers's density is 8933 $kg \cdot m^{-3}$ (Incropera, 2007).

Today, the world is looking for new materials with better overall properties than aluminium. One of these new materials could be plastics with high thermal conductivity. While their thermal conductivity is lower than aluminium's, they are much lighter, so they put even less stress on the components, easier to mould and could be much cheaper solution.

2. Plastics with high thermal conductivity

Metals have been highly used in the past for the purpose of heat transfer for its excellent thermal properties, but metal parts are costly to produce. Nowadays, these metal materials are being replaced by plastics with high thermal conductivity which provide less expensive solutions. Other advantages of

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replacing metals with plastics are design flexibility, corrosion and chemical resistance and reduction of secondary finishing operations (Stewart, 2004).

Thermally conductive plastics have thermal conductivity of 5 to 500 times higher than conventional plastics. Range of their conductivity is from 1 to 100 $W \cdot m^{-1} \cdot K^{-1}$ (http://coolpolymers.com/eseries.asp). This high thermal conductivity is achieved via thermally conductive fillers. These fillers can be for example aluminium, graphite or aluminium-boron nitride (Heinle, 2010). The main difference between graphite fillers and ceramic fillers is that in graphite, thermal conductivity rises in the direction of graphite flakes while using ceramic fillers makes the materials equally conductive in all directions (Stewart, 2004), (Grundler, 2015).

3. Numerical thermal simulation of a heat sink

A numerical thermal simulation of a heat sink was created, using the software ANSYS CFX 17.2. Heat sink from a real LED headlamp has was as a model. In Fig. 1, a comparison between the actual heat sink and a simplified model is shown.

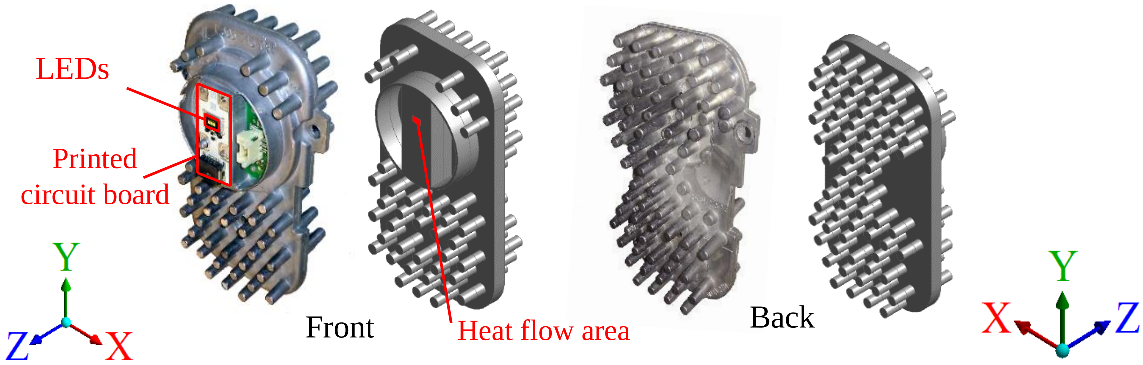

Fig. 1: Comparison between real heat sink (left) and a simplified model for the simulation (right).

In the simulation the LEDs were replaced by an area with the heat flow and natural convection with turbulent flow and non-constant air density have been considered. The thermal resistance between an aluminium plate with a printed circuit board with LEDs and the heat sink were neglected, the heat flow was placed as shown in Fig. 1. Furthermore, heat transfer by radiation was not considered, either.

A comparison between different materials was made. Firstly, aluminium alloy AlSi12(Cu) used in the real heat sink with a thermal conductivity between 120 $W \cdot m^{-1} \cdot K^{-1}$ and 150 $W \cdot m^{-1} \cdot K^{-1}$ (https://www.matbase.com/material-categories/metals/non-ferrous-metals/cast-aluminium/material-properties-of-g-alsi12cu-231-cast-aluminium-grade.html#properties). For the purpose of simulation, an average value was chosen to be 135 $W \cdot m^{-1} \cdot K^{-1}$. Secondly, an imaginative material with isotropic thermal conductivity 20 $W \cdot m^{-1} \cdot K^{-1}$ was chosen. And thirdly, for the thermally conductive plastic material, a material marked as E5101 from company Cool Polymers was selected. It is a thermally conductive Polyphenylene Sulphide (PPS). Its in-plane thermal conductivity was 20 $W \cdot m^{-1} \cdot K^{-1}$ (http://coolpolymers.com/Files/DS/Datasheet_e5101.pdf). Thermal conductivity through-plane was measured in Heat Transfer and Fluid Flow Laboratory and it was equal to 5 $W \cdot m^{-1} \cdot K^{-1}$. This anisotropy is result of the orientation of filler particles by injection molding (Grundler, 2015).

Five different simulations were made. The first one was with the aluminium alloy, for the second one a material with 20 $W \cdot m^{-1} \cdot K^{-1}$ isotropic thermal conductivity for the comparison with anisotropic plastic and three more simulations, where the plane with high thermal conductivity changed between XY, YZ and XZ planes. For the ambient air, the temperature of 20 °C was chosen for all five cases.

4. Results

Average temperature of the heat flow area and distribution of temperature across the heat sink was monitored to show the difference between usage of different materials.

Average temperature of the heat flow area

The most important part of the heat sink, as far as temperature is concerned, is the area of the heat flow, because it is the part where the heat source is placed and which needs to be cooled down. The comparison between different simulations is shown in Tab. 1. The aluminium alloy is used as a reference material.

Tab. 1: Comparison of average heat flow area temperature between materials with different thermal conductivity.

Material	AlSi12(Cu) (135 $W \cdot m^{-1} \cdot K^{-1}$)	20 $W \cdot m^{-1} \cdot K^{-1}$	E5101 (in-plane = XY)	E5101 (in-plane = YZ)	E5101 (in-plane = XZ)
Temperature [°C]	53	78	110	87	96
Percentage difference [%]	-	147	208	164	181

Distribution of temperature across heat sink

A comparison of temperature distribution is showed in Fig. 2. A front view was used, to show the difference between temperature on the heat flow area and the rest of the heat sink. Temperature range is constant for all five cases and is from 30 to 120 °C.

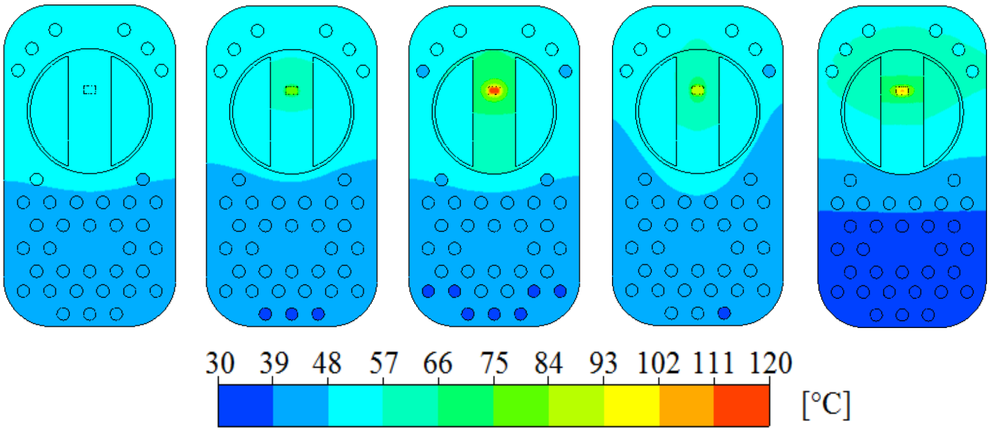

Fig. 2: Distribution of temperature across heat sink, from left to right: AlSi12(Cu), material with conductivity 20 $W \cdot m^{-1} \cdot K^{1}$, E5101 (in-plane = XY), E5101 (in-plane = YZ), E5101 (in-plane = XZ).

Temperature on the farthest pin

Next, the temperature on the farthest pin from the heat source was compared. The place of this pin is showed in Fig. 3 and the temperatures with percentage differences are shown in Tab. 2. The aluminium alloy is used as a reference material.

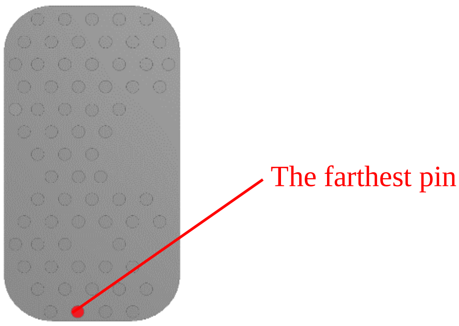

Fig. 3 The farthest pin from the heat source.

Tab. 2 Comparison between temperatures of the most distant pin from the heat source.

Material	AlSi12(Cu) (135 $W \cdot m^{-1} \cdot K^{-1}$)	20 $W \cdot m^{-1} \cdot K^{-1}$	E5101 (in-plane = XY)	E5101 (in-plane = YZ)	E5101 (in-plane = XZ)
Temperature [°C]	47	39	39	40	31
Percentage difference [%]	-	83	83	85	64

5. Conclusion

A comparison of simulations of different heat sink materials was made. The first one was a material used for the heat sink in practice. It was an aluminium alloy with thermal conductivity 135 $W \cdot m^{-1} \cdot K^{-1}$. Second one was an imaginative material with conductivity 20 $W \cdot m^{-1} \cdot K^{-1}$, serving as a comparison for the anisotropic plastic material, used for the other three instances, where the plane with high conductivity varied.

The results show that for this exact geometry a replacement of aluminium alloy for plastic material with high thermal conductivity is not such a good option, because the LEDs would have a temperature 164 % higher in the best case (from 53 to 87 °C), where the plane with the high thermal conductivity is YZ plane. This solution was the closest one to using the isotropic material where the temperature on the heat flow area was 79 °C, so the difference between temperatures was only 8 °C. In the case of the XZ plane as the one with high conductivity, half of the heat sink had a temperature below 39 °C, which means, that this half has almost no usefulness. Still, the worst solution was the one with high conductivity in the XY plane, temperature on the heat flow area was 110 °C.

However, using plastics with high thermal conductivity as an aluminium replacement could be a solution for different geometries, where the heat source isn't placed on a ledge like in this case and the heat can be transferred through the entire base, not only in one direction to even reach the heat sink base.

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