Simulation of the anisotropic thermal conductivity generated by graphene integration in aluminium matrices

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Abstract

The growing power density of electronic devices and components requires the development of new cooling methods and systems by which large heat fluxes can be dissipated. Nowadays, because of their good thermal conductivity for electronic components, Aluminium and Copper are mostly used as heat sink material. Recent developments on carbon-based materials such as Graphene could further expand the application and foster the realisation of significantly improved high-tech parts. Graphene has a 9-times higher thermal conductivity than Aluminium, but behaves anisotropic. The heat conduction occurs almost exclusively in the plane. Perpendicular to the plane the thermal conductivity is very low. This physical phenomenon is to be used technically, e.g. by introducing Graphene layers into Aluminium composites. Thus, simulations of the anisotropic heat flux in Al-MMC are conducted within this study.

1. Introduction

With integrating Graphene as thermal conductive layers that lead the heat through the part without significantly warming it, 'thermal highways' are created. A design approach is given in Figure 1. So far, there is no information about the phenomena occurring or the efficient design of such composite structures. With the help of appropriate simulation software, a knowledge base for the design of those thermal highways will be created. For the simulation, COMSOL Multiphysics™ is applied to design, evaluate and optimise. Main aim is to maximise the heat transfer from the heat source into the thermal highways within the part and from the thermal highways to a cooling area. Special attention is paid to the dissipation of heat along the surface and in the area around the thermal highways, since the usability of the part is dependent on the thermal load of the structural Aluminium part. Previous investigations

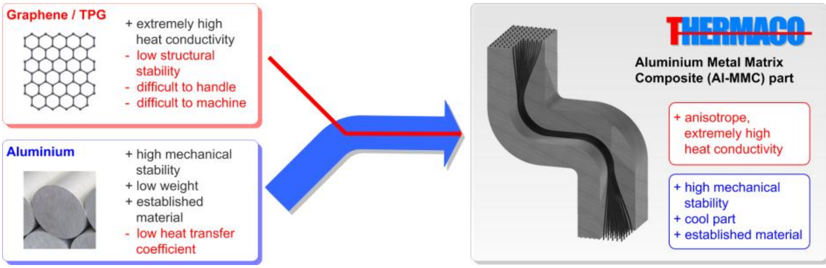

Figure 1: THERMACO approach for thermal highway integrated composite parts

show that by structuring the surface, the heat dissipation could be maximised [1]. Simulations are conducted for Graphene and thermal pyrolytic Graphite (TPG), taking anisotropic properties into consideration. As a first approach, base models are created, changing the volume of TPG integrated in Aluminium.

2. Model of TPG integrated in Aluminium

The model is created by using the two different physical modules of non-isothermal flow and heat transport, both coupled. By using two different physics it is possible to use even two different meshes, making the simulation more stable and run faster.

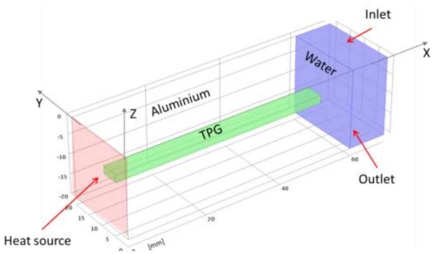

Figure 2: Model for the simulation of heat transfer of TPG integrated in Aluminium

Figure 2 shows an example of the investigated geometries, a rectangular Aluminium domain with an integrated TPG part and a water domain. Within all studies the geometric specifications of Aluminium and Water were maintained, but the volume of TPG was varied. The variation of geometry is given in Table 1. At study TPG 0 only the thermal conductivity of Aluminium is investigated. In studies with nomenclature TPG X.1, TPG is fully encapsulated by Aluminium, in TPG X.2 the TPG is plain to the boundary of Aluminium and therefore contacted to the heat sink. Further on, the different simulation models will be named by the nomenclature of the TPG insert.

Table 1: Geometric specifications defined from the starting point (0;0;0)

Domain	X-coordinate [mm]	Y-coordinate [mm]	Z-coordinate [mm]
Aluminium	0 – 60	0 – 20	0 – -20
Water	60 – 70	0 – 20	0 – -20
TPG 1.1	2.5 – 57.5	7.75 – 12.25	-9 – -11
TPG 1.2	2.5 – 60	7.75 – 12.25	-9 – -11
TPG 2.1	2.5 – 57.5	2 – 16	-9 – -11
TPG 2.2	2.5 – 60	2 – 16	-9 – -11
TPG 3.1	2.5 – 57.5	5 – 15	-5 – -15
TPG 3.2	2.5 – 60	5 – 15	-5 – -15

Non-isothermal flow is used to create a heat sink at the boundary between the domains of Aluminium and Water, instead of using a constant temperature or a negative heat source. The boundary conditions for non-isothermal flow are given in Table 2.

Table 2: Boundary conditions non-isothermal flow

Boundary	Condition	Value
Inlet	Laminar average velocity	1 [m/s]
Outlet	Pressure	1 [atm]
Wall	No-slip	-

The boundaries around the domain of Water are defined as wall with a fluid velocity of 0 m/s, except the inlet and the outlet. The flow of the fluid is defined as laminar flow condition. The calculated flow profile is coupled with the simulation of heat transfer in solids, to create a heat sink.

Boundary conditions for simulation of the heat transfer in solids are T_{in} = 293.15 K inlet-temperature and T_{hs} = 443.15 K heat source temperature. The outlet is defined as outflow. The fluid domain itself is defined by heat transfer in fluids with the pressure and velocity field given by the non-isothermal simulation.

As already mentioned, the thermal conductivity of TPG behaves anisotropic. So, the thermal conductivity is defined according to the direction of the coordinate system. The anisotropic and the isotropic thermal conductivities of TPG are 1500 W/m*K in XY, 7 W/m*K in Z direction and for Aluminium (A356) 150 W/m*K. [2, 3]

3. Results and discussion

By creating a slice plot in x-y-plain, the conductive heat flux is shown (figure 3). Nearly most of the heat flux occurs in the TPG, while in the centre the maximum is located. However, the goal is to maximise the heat dissipation at the surface, which in this case is covered by water. To compare the different models it is necessary to

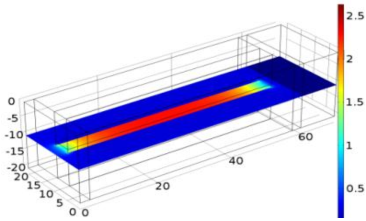

Figure 3: Slice plot of the conductive heat flux in x-y-plain

Integrate the conductive heat flux at this surface of the heat sink to calculate the dissipated thermal energy. Table 4 shows a comparison of the dissipated thermal energy. With rising volume fraction of TPG as insert in A356, even more energy is dissipated at the surface of the cooling area. Whether TPG is encapsulated influences a dissipation of energy only slightly.

Table 4: Comparison of investigated models

Model	Encapsulated	Area [mm²]	TPG Volume in %	Energy [W]
TPG 0	-	400	0	136.17
TPG 1.1	yes	400	2.06	150.70
TPG 1.2	no	400	2.15	152.68
TPG 2.1	yes	400	7.33	179.17
TPG 2.2	no	400	7.66	181.53
TPG 3.1	yes	400	22.91	227.54
TPG 3.2	no	400	23.95	236.34

4 Conclusion

The efficient arrangement and volume fraction of TPG highways and its influence on the heat flux was investigated. Further simulations will take place to investigate the thermal resistance at the boundary surfaces between TPG and A356.

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