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Thermal numerical simulation for metal matrix composite design: Application to weight saving in electronic packaging for aeronautics

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ABSTRACT

This design study aims at replacing aluminium alloy in electronic packaging for aeronautics with a weigh saving objective. In a first time, a classical materials selection method is applied to the problem, showing the most suitable material would be an aluminium alloy reinforced by pitch carbon fibres. In order to define an optimal composite for this application, the thermal dissipation function of the packaging is detailed. An accurate simulation of the heat transfers in the casing was operated thanks to simplified numerical model using finite elements in which the complex geometry of the part has been brought back to a rectangular plate. As a result, the study enhances the interest of anisotropic material, and defines specific directions in which high thermal conductivities are needed.

1. Introduction

The increasing use of electronic devices induces the multiplication of packaging elements whose function is the protection from the environment or from accidents. In the specific domain of aeronautics, security and durability requirements impose following numerous standards, making their design highly constrained.

In front of the increase in cost of energy and new environmental constraints for transportation, a lot of weight saving studies have been carried out in aeronautics. However, none of them concern electronic packaging although they represent an important part of the total mass of electronic systems.

The packaging are currently made of aluminium alloys of different types (most commonly 6061 or 2024 alloys) according to the manufacturer and the part of the plane it is supposed to be located. Indeed, electronics can be found in different places, and are sometimes submitted to intense environmental solicitations, for example near the engines (vibrations, saline atmosphere, wide range of temperatures…). Until nowadays, aluminium alloys kept being the most interesting compromise between thermal properties and cost. However, amongst all the interactions the packaging has to deal with, the cooling function remains the most important because during the last years, the miniaturization and evolution in electronics has led to smaller components with higher electric power. As a consequence, it becomes more and more difficult to dissipate the heat generated by the components, so aeronautics research alternative materials to aluminium to reduce the mass of the packaging. The recent development of pitch carbon fibres allow a huge increase in conductivities and make composites competitive again for this kind of application.

The aim of this study is to find an optimal material to replace aluminium alloys in electronic packaging. In a first part, the set of

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requirements of these products will be detailed, and a preliminary materials selection will be operated. Then, in a second part, numerical simulation will be proposed to define the requirements for anisotropic materials and choose the most suitable architecture.

2. Materials requirements and selection

2.1. Geometry of the packaging

This paper is based on an industrial case study concerning an electronic packaging placed in an avionic storage bay. This packaging has a complex geometry, including locally higher thickness to allow a contact with electronic components to improve conductive heat exchanges, and pin fins on the outer face to facilitate convective heat loss.

Materials selection methods have been developed to choose the most suitable material for an application [1]. This operation can be made in the early steps of the design but it needs an analytical formulation of the problem. As a consequence, the geometry and solicitations of the studied part have to be simplified, and all the more specific problems will be solved during the detailed design steps.

In this case, the complex geometry of the packaging is brought back to a rectangular plate whose length and width correspond to an electronic card size. The thickness of the plate is considered as a free design parameter that will be determined according to the chosen material to fulfil the requirements.

2.2. Set of requirements of the packaging

The objective of the selection of new materials is to minimize the mass of the packaging, while ensuring the protection of the electronic components from various external factors.

The first constraint concerns mechanical loads: the packaging has to stand important vibrations particularly during the take-off or landing. The condition to keep the electronic component safe is that the first resonance frequency has to be higher than the one of the electric card.

The second function of the packaging consists in preventing the components from reaching their maximum service temperature. As the components have been miniaturized, they generate local heat flows that can induce high temperatures if the packaging is not conductive enough.

The set of requirements is then completed with normative constraints dealing with security or interactions with the atmosphere: there must be no water absorption, mushroom development, the material must have a good corrosion resistance, must not be inflammable…

2.3. Materials set of requirements

In order to select a material for his application, some functions have to be translated in performance indices, so that the needs that were formulated for the packaging will result in material requirements. Following Ashby's method, thermal and mechanical constraints can be combined with the minimum mass objective to define two performance indices.

The mass of the plate is given by:

$$m = \rho a_0 b_0 e \tag{1}$$

where ρ is the density of the materials, a_0, b_0 and e are respectively the length (x axis), width (y axis) and thickness (z axis) of the plate.

A first performance index can be derived from the expression of the mass and the first constraint. In order to prevent the component temperature from getting too high, the thermal resistance of the packaging must be inferior or equal to the one of the reference aluminium alloy casing. For an elementary volume of dimensions dx, dy and e, this resistance can be written:

$$R_{plane} = \frac{dx}{\lambda \times e \times dy} \tag{2}$$

where λ is the thermal conductivity of the material. The thickness is deduced from this expression, and put in the performance, so that:

$$m = \rho a_0 b_0 \frac{dx}{\lambda \times R_{plane} \times dy} \tag{3}$$

As all the terms of the Eq. (3) are fixed except the material properties, the highest performance will be reached by the material exhibiting the lowest index I_{th}:

$$I_{th} = \frac{\rho}{\lambda} \tag{4}$$

Generally, the performance indices are used as optimisation criteria, and help the designer selecting the best material. In this case, the study consists in replacing an existing solution made of aluminium alloy, so filtration criteria will be defined according to the performance of 6061 aluminium alloy and will give as solutions the set of materials leading to a lower mass for the plate. To allow a