Poznan University of Technology
Mechanical Engineering and Management Faculty
Institute of Applied Mechanics

Dissertation title
Modelling and FEM analysis of dynamic properties of thermally optimal composite materials

Author: mgr inż. Maria Nienartowicz
Thesis supervisor: dr hab. Tomasz Stręk, prof. nadzw. PP

ABSTRACT

Modelling and analysis of properties of new composite materials is often difficult and costly. Numerical methods have offered a great support as they help to determine material parameters and give greater opportunities. Numerical modelling combines disciplines like mathematics, physics and computer science to examine the behaviour of complex systems by means of computer simulations. A numerical model usually contains many variables which describe the examined system. A simulation is carried out by modification of those variables and by observation of how those changes influence the results. Results obtained during a simulation render it possible to predict the behaviour of a real system.

Numerical modelling methods of composite materials are widely used, e.g. in design and construction of cooling structures or advanced radiators [Dag2012], [Ded2012]. Another example is the application of numerical modelling to design programmable matter. To achieve the 4D aspect, the initial configuration is created by 3D printing, and next the programmed action of the shape memory fibres creates time dependence of the configuration as a reaction to heating or cooling [Cam2014]. Numerical modelling is also used in military and aerospace industry, where the final product must meet specific stringent requirements [Mon2013].

Aims of the dissertation:
1. Application of numerical design to achieve a composite or a structure with indicated thermal properties. Demonstration of favourable parameters of designed composites in comparison with often used layer composites like laminates.
2. Analysis of dynamic properties of thermally optimal composites. Comparison of dynamical properties of optimal composites with properties of laminates.
3. Proposal of structure of a multilayer panel with an inside layer made of two-phase composite. The structure allows to achieve the minimal thermal energy under given boundary conditions.

Thesis of the dissertation:
It is possible to design structure of two-phase composite, whose properties, such as the average temperature value, the average magnitude of temperature gradient, the average thermal energy and the average strain energy, are better than in classic layer composites (laminates). Additionally, having designed the structure of thermally optimal composite, it is possible to analyse its dynamic properties, i.e. determine eigenvalues, determine the frequency response and the mode shapes for a particular eigenvalue.

The following dissertation presents the issue of modelling and analysis of dynamic parameters of thermally optimal composite. In order to achieve thermally optimal composite, a number of optimizations of properties was performed, such as: the average value of the temperature, the average magnitude of temperature gradient, the average value of thermal energy and the average value of strain energy. Optimization was performed by means of proposed algorithms for 1D and 2D models with different shapes and different boundary conditions. For 1D models, the combination of Nelder-Mead algorithm and finite element method was used, while for the analysis of 2D models, the combination of SNOPT optimization method and finite element method was applied. Optimization results performed for a 2D composite panel were compared with results for models of laminates. COMSOL facilitated the performance of all the simulations, as well as the analysis of how the applied finite element mesh and the parameters of the method have influenced the achieved new topologies of the structures.

The first chapters of the dissertation present a review of literature and theoretical introduction of the discussed issue. Numerical results carried out by means of various methods were presented in chapters six to nine. In the first part of the research, optimization of the average value of the temperature and theaverage magnitude of temperature gradient was performed. Calculations were made for models defined on areas with different shapes and with different boundary conditions. Numerical results for newly created composites were compared with laminate composites. This leads to a conclusion that the proposed topology allows to obtain better results (lower in the case of minimization and higher in the case of maximization) than in traditional laminates [Nie2013].

Next, optimization calculations were performed for a composite panel with a core made of two-phase composite, in which the average value of the thermal energy was minimized. Likewise, in this case the obtained results were compared with laminates in the form of three panels with the same boundary conditions. The results of the average value of the thermal energy were the lowest in the composite plate [Nie2014a]. When the minimization of the average thermal

energy and strain energy was performed simultaneously, with equal scales for both energies, the distribution of the control variable was similar to the distribution of the control variable in the case when only the average thermal energy was minimized. This leads to a conclusion that thermal energy dominates in this calculation case. The reverse is true in a situation when results of the minimization of the average thermal energy and strain energy are analysed simultaneously with different scales.

The last stage of the research was to carry out the analysis of dynamic parameters of the thermally optimal composite panel. The eigenfrequency, the frequency response and the mode shapes for the particular eigenvalue were determined. The analysis of dynamic properties was carried out also for three types of laminate panels. For most of the subsequent eigenvalues of the thermally optimal composite, the values of those eigenvalues were higher than the eigenvalues for the laminate panels [Nie2014b].

The proposed methods and composite structures with thermal boundary conditions or thermo-mechanical boundary conditions can be applied in design and construction of: a) optimal cooling devices (radiators); b) electronic devices; c) building elements (e.g. bricks with increased insulation, along with simultaneous increase in strength); d) battery electrodes for energy recovery in the case of small temperature differences using the galvanic effect.

The results obtained during the numerical research and their analysis lead to a conclusion that the thesis and the aims of the dissertation have been confirmed. Conclusions from the performed numerical research show that the use of computational methods such as the optimization of topology structure of two-phase materials allow to achieve composite materials with better thermal properties than thermal properties in classic layer composites (laminates). The achieved materials and composite structures can vent the heat generated by the device better and thus cool it. In the optimized structures, the distribution of the temperature and thermal energy was minimized, which allowed to achieve more optimal structures, different from those commonly known. Literature studies show that similar structures are analysed in some automotive concerns. Further research will enable their use in other areas related to thermal issues.

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