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MODELLING OF HEAT DIFFUSION IN COMPOSITES

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Abstract

Composites structures are widely using in varied fields of industry, where it has to take into account changes of temperature or it is possibility of fire hazards. Heat transfer and fire conditions in composites are very often analysis issues nowadays. A large amount of research in area of modelling heat transfer and fire loading of composites has been performed for both experimental studies and modelling and simulation. The most common areas of analysis of thermal composite structures are: multiscale modelling of heat transfer, simultaneous fire and mechanical loading, fire involved failure and temperature distribution under fire and elevated temperature conditions.

This paper presents analysis of heat transfer in composites with taking into account their shape and thickness. The models include a convection mode of heat transfer. The first composite plate is 10 cm wide by 10 cm tall with a thickness of 1 cm. The modified structure has also second part, smaller plate on top 5 cm wide by 5 cm in right corner. They made of glass/vinylester composite. The plates are heating in one, two and three directions. The results are shown in forms of contours of temperature distribution and thermal gradient. Comparison of results for the modelled structures shows differences in the shape and thickness of the analysed structure.

Keywords: *finite element method, glass reinforced composites, heat diffusion, fire*

1. Introduction

Composite structures are widely using in many fields of industry (aviation, offshore oil drilling platforms, ships) where heat transfer is significant issue. Sometimes composites are even used in constructions exposed to fire hazards. This situation means that it is very important to obtain the greatest knowledge about heat diffusion in composites. Behaviour of composites in fire are studied and analysed using mathematical and numerical models presented in analysis for example by Looyeh and Mouritz [1, 7, 9].

There are several thermal properties, which effect on thermal resistance, such as low thermal conductivity, structural integrity and significantly, the endothermic decomposition of the matrix, which results in a slower heat diffusion through the laminate [3]. Fire properties experimentally can be determined with using two kinds of experimental tests, which carried out to describe properties of composites: small-scale tests such as non-combustibility, ignitability, surface spread of flame and cone calorimeter and large-scale test that simulates realistic conditions [3].

Modelling of realistic thermal behaviour of heat transfer in composite under fire hazards will help to minimize the number of experimental tests and predict thermal response in realistic situations the engineer, whose is working with new materials or applications [3]. Finite element method is very good and powerful for analysis solutions of such analysis [11].

Modelling of structural behaviour of composites in fire requires detailed describing heat transfer in composites and taking into accounting types of fire damages in composites. Fig. 1 shows the possible different types of temperature-involve damages in composite under fire loading. In fire hazards, in the matrix at the fiber-matrix interface pores with gas inside develop under the high internal pressure. Delaminations in composites under fire are due to the internal pressure rise; thermally induced strains caused by thermal expansion and reduce interlaminar fracture toughness. Decomposition and char formatting are also very important to analysing structural response of composites in fire [10].

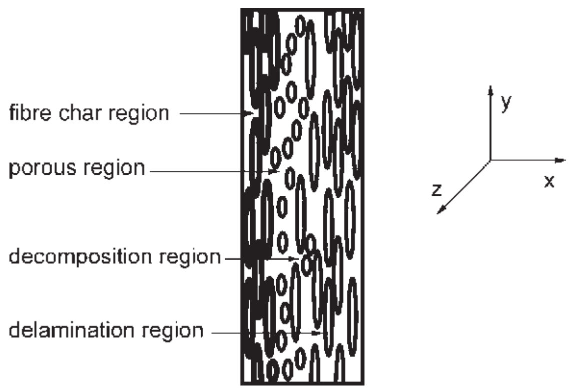

Fig. 1. Cross-sectional view of the fire-damaged laminate [3]

Typically, damages processes under loading by fire or elevated temperatures are shown in Fig. 2. They depend of thickness of composite. Another possibility to classify gives the dependence types of damages from temperature (see Fig. 3).

Models of heat transfer in composites are basis for much more complicated analysis connected with fire hazards [8]. Fire and elevated temperature induced damages and the heat transfer anisotropy [12] cause that describing of behaviour composite in elevated temperatures result the need to take a closer look at the dependence of the thickness and shape of the composite structure on the distribution of temperature.

Initial stage of exposure of composite to fire is linked with heat diffusion through the laminate without chemical reactions. However, when temperature equal to 200°C it begin to appear more complicated reactions and analysis of heat transfer in composite is more difficult. Presence charring in higher temperatures due to low thermal conductivity causes to keeping interior of laminate cool [2].

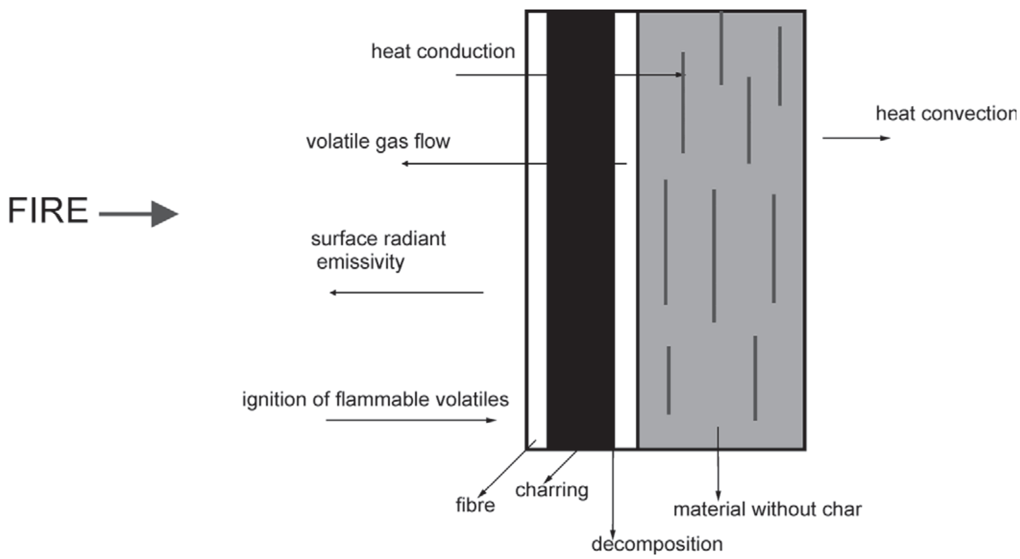

Fig. 2. Schematic of the fire processes of charring polymer under fire in the through-thickness direction [3]

2. Methods

The governing equation [6] for heat transfer in composites plate heated from one side through a solid material with no internal heat generation is:

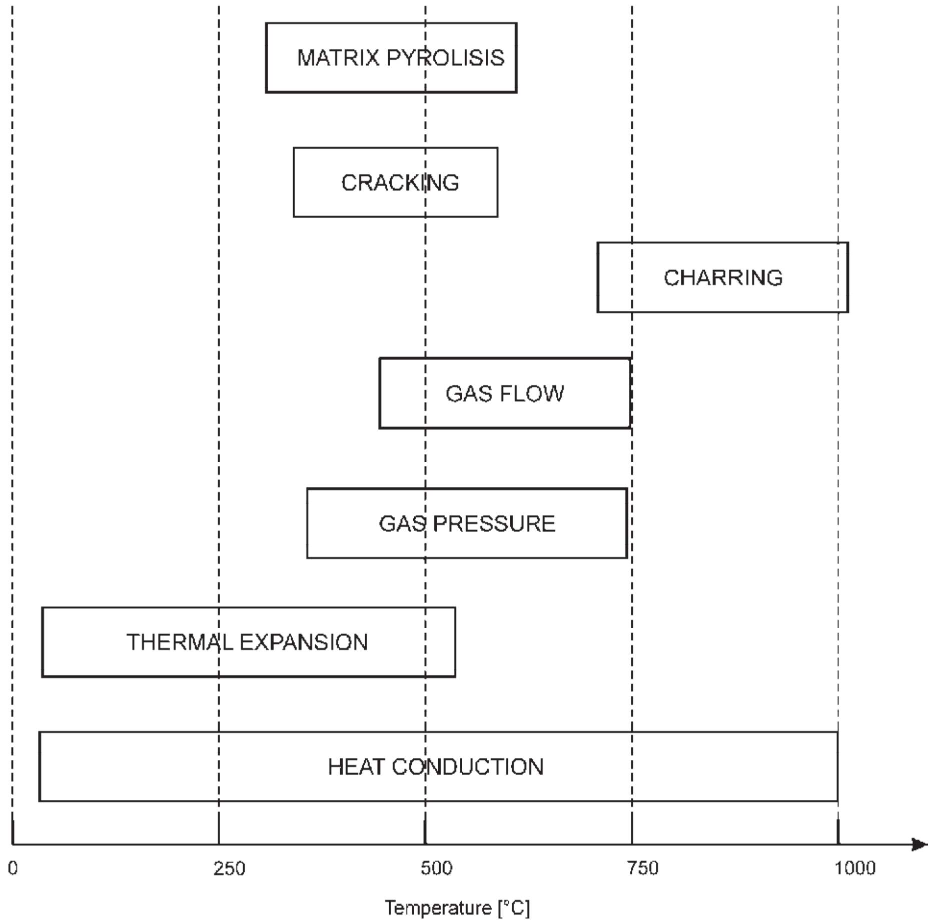

Fig. 3. Various responses of fiberglass laminate with temperatures [3]

$$\rho C\frac{\partial T}{\partial t}=\frac{\partial}{\partial x}\left(k\frac{\partial T}{\partial x}\right), \tag{1}$$

where:
ρ – density,
T – temperature,
t – time,
C – specific heat capacity.

Temperature distribution with fire loading from the 1-D heat diffusion equation is described by Fourier's differential equation for heat conduction:

$$\rho_{comp}C_p^{comp}\frac{\partial T}{\partial t}=\frac{\partial}{\partial x}\left(k_{comp}\frac{\partial T}{\partial x}\right)+m_g C_{pg}\frac{\partial T}{\partial x}+\frac{\partial \rho_{comp}}{\partial t}[Q_p-Q_p+h_{comp}+h_g], \tag{2}$$

where:
m_g – mass flux,
Q_p – resin heat by decomposition (2.3446E–06 J/kg),
k_{komp} – enthalpy of composite,
h_{komp} – enthalpy of gas.

The heat distribution when the model is loading in three directions is given by:

$$\rho C\frac{\partial T}{\partial t}=\frac{\partial}{\partial x}\left(k_x(T)\frac{\partial T}{\partial x}\right)+\frac{\partial}{\partial y}\left(k_y(T)\frac{\partial T}{\partial y}\right)+\frac{\partial}{\partial z}\left(k_z(T)\frac{\partial T}{\partial z}\right), \tag{3}$$

where $k_x(T)$, $k_y(T)$, $k_z(Y)$ are the thermal conductivities in the x, y, z directions, respectively.

These equations show how complicated the response of the material to heat along with a more accurate way to analyse the diffusion of heat. This paper is focused on presented changes of temperature distribution according to the type of heat loading and thickness or shape of composite structure.

In this paper, we consider two types of composite structure (see Fig. 4). In the first case, composite plate is 10 cm wide by 10 cm tall with a thickness of 1 cm. The plate is made of a unidirectional composite material, Eglass/8084 fibres within a vinylester resin. The plate is under thermal convection loading from one side. Material properties are from literature [5], material and heat properties are shown in Tab. 1.

Tab. 1. Material and heat properties for unidirectional Eglass fiber composite reinforce by vinylester resin [5, 8]

E_{11} [GPa]	E_{22}, E_{33} [GPa]	ν_{12}, ν_{13} [–]	ν_{23} [–]	G_{12}, G_{13} [GPa]	G_{23} [GPa]	α_{11} [με/K]	α_{22}, α_{33} [με/K]	K_{xx} [W/mK]
38.5	11.6	0.273	0.343	4.74	4.33	9.47	39	0.43

In the second case, analysing composite structure have different shape and thickness. Plate is made from two parts with uniform thickness, smaller plate is glued to the top right corner of the first structure.

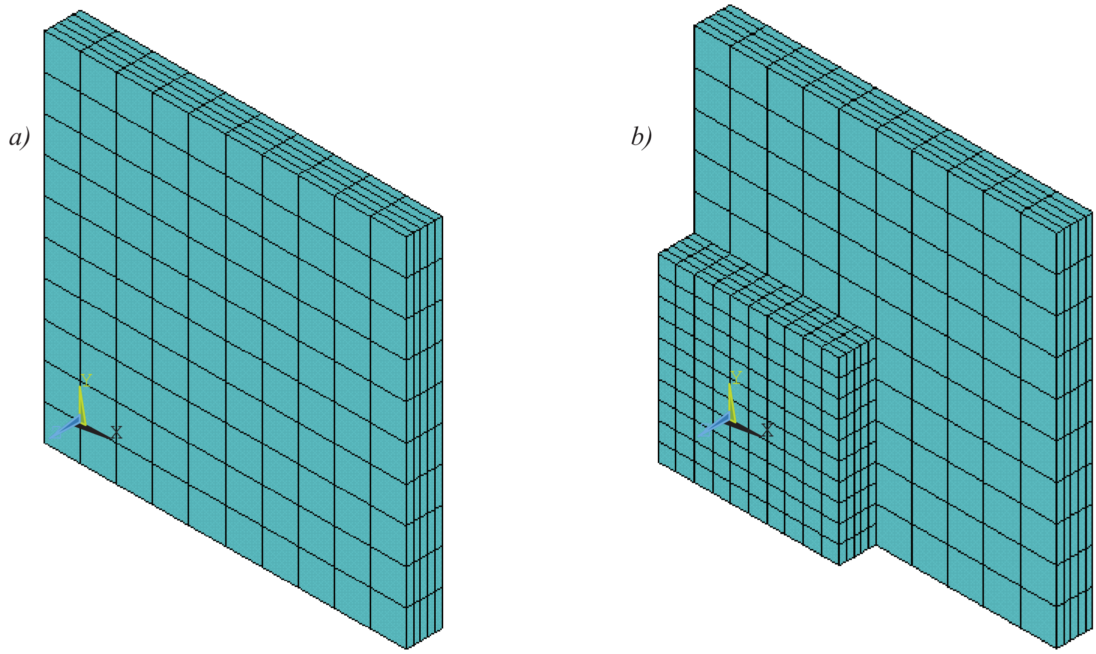

Fig. 4. Partial view of the meshed structures: a) simply plate, b) plate with two parts

3. Results

In this analisis we consider three types of heat loading: one-side heat heating; heat on one side of plate and according to *x* direction; one side and according to *x* and *y* directions. Results are shown in Fig. 5 in forms of temperature distribution and thermal gradient. Differences in maximum values of temperature distribution in nodes and maximum values of thermal gradient are quiet low when the temperature of heat loading is the same in case of simply plate.

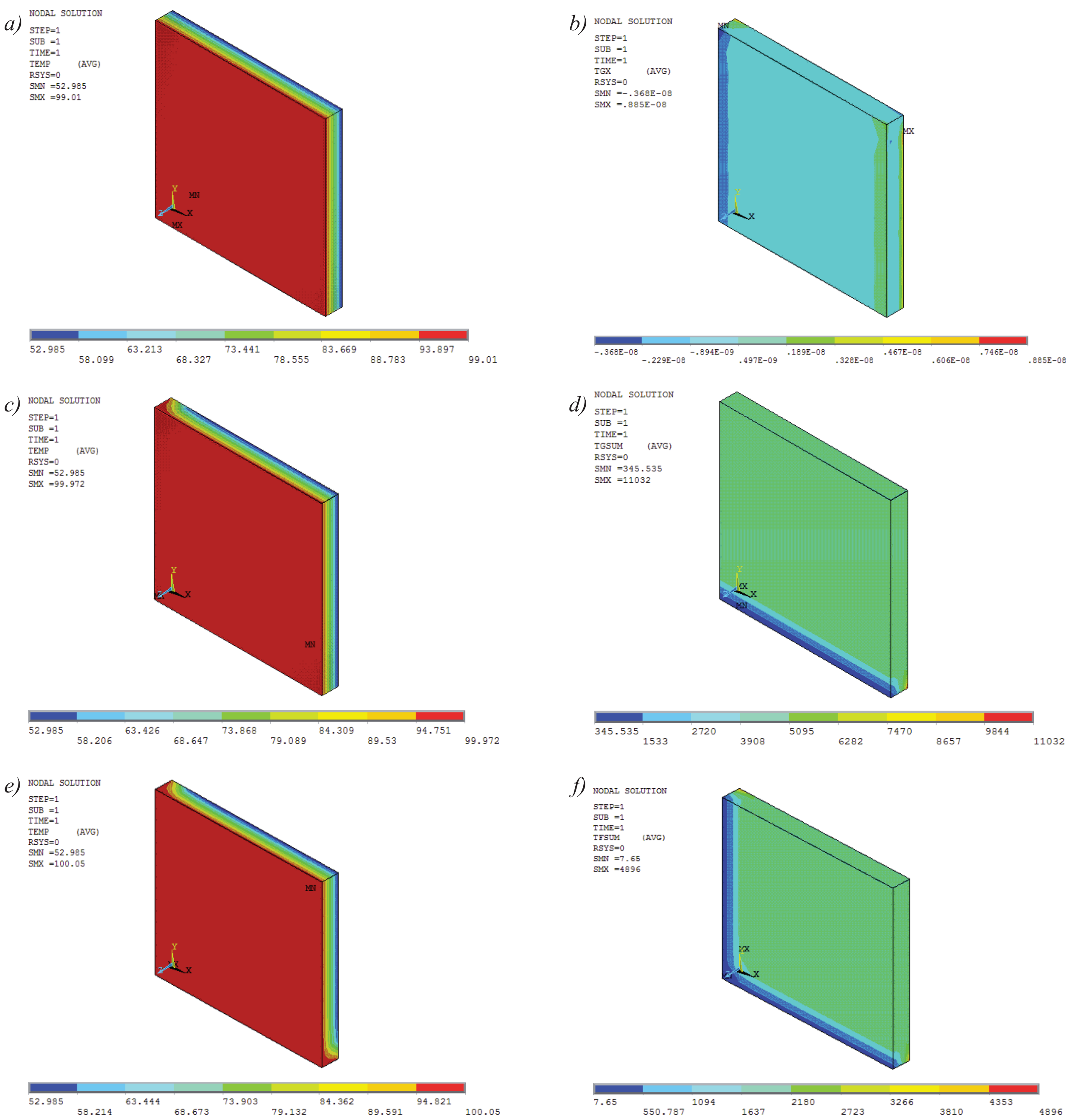

Fig. 5. Contours of temperature distribution and thermal gradient of simple composite plate – three types of heat loading

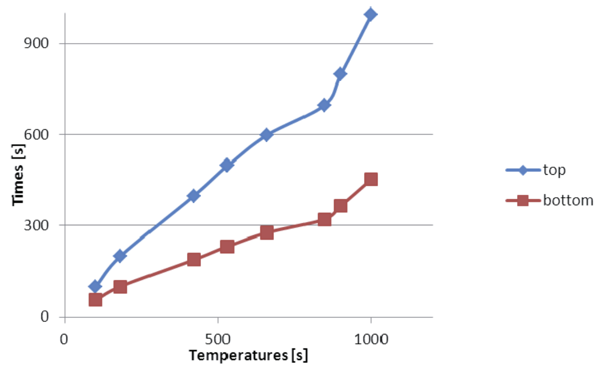

Fig. 6. Comparison of the data points from top and bottom layers in a laminate one-side heating in model with non-homogenous thickness

Next model was complicated to form of structure with two thickness. Relationship between hot and cold side of complex model was exactly the same as simple plate model in literature [5]:

Temperature distribution and thermal gradient for complicated structures are shown in Fig. 7. In this case dependences types of heat loading and heat distribution are more complex and the maximal values of temperature are higher.

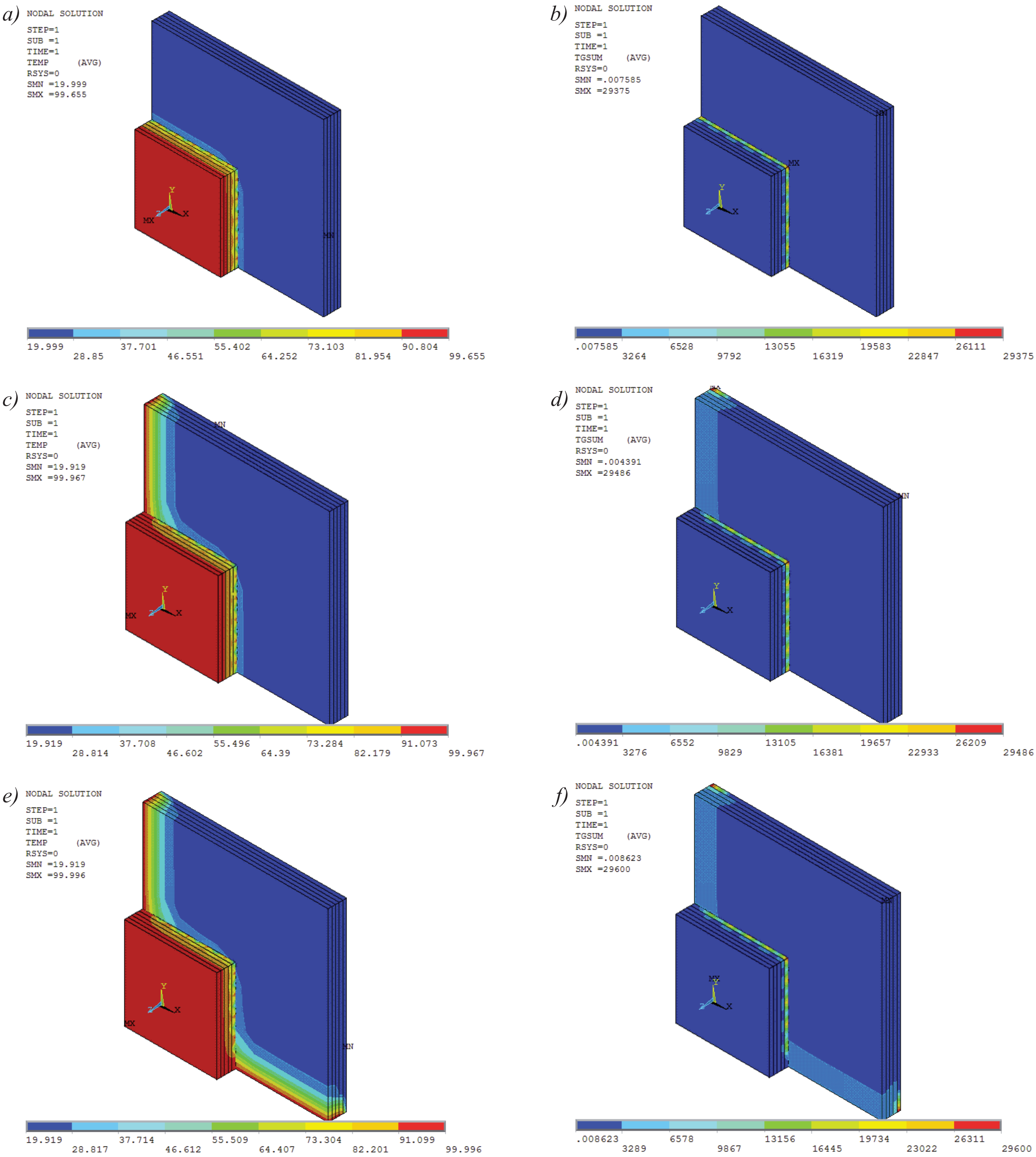

Fig. 7. Contours of temperature distribution and thermal gradient of two glued composite plates – three types of heat loading

4. Conclusions

This paper presents modelling of heat diffusion in composites. Two types of composite structures models are consider. Applying of heat loading in three different ways was next stage of presented analysis. Performed simulations showed that in analysis of heat transfer in composites it is necessary to taking into consideration the overall heat loading. This is the more important the more complex the shape of the structure is. Furthermore this factor is particularly important in analysis of fire hazards.

Results from this paper and literature [4] show, that simply analysis of one side plate is not sufficient to describe behaviour of composite structures under fire loading, because fire hazards connect with non-homogenous heat transfer from fire distribution.

Based on this approach in the future work is possible a more accurate analysis of composite structures under fire load.

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