Modeling Heat Transfer Phenomenon for Smart Composite Materials

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This paper is a brief characterization of composite materials and experimental system used for the measurement of heat transfer in a multilayer Board with the help of thermocouples. Also determine the temperatures, thermal gradients, thermal flows, in stationary mode, within a range of 570 s for a plate of composite materials (aluminium foil, expanded polystyrene, extruded polystyrene, universal adhesive).

Keywords: composites, heat transfer, heat flow

The concern of researchers, since ancient times, to get a top quality materials has led to the emergence of so-called, nowadays, composite materials. Composite materials are systems of solid objects, deformable obtained by combinations of several materials, at macroscopic scale (e.g. hemp with glue, composite plates of natural fibres, carbon composite, laminated cards) — characterized by the combination of components with high mechanical resistance, together with others that have higher flexibility, thus resulting in a product with a light meal and strength enhancement [1-6].

Composite materials are anisotropic [7]. Due to their properties, physical, chemical and mechanical properties, composite materials are being used in more and more fields (in the process industries, military industry, transport industry, medical field, etc.) [8]. The manufacturing technologies for composite materials, depends on the physical and mechanical properties of the components. Manufacturing technologies can be primary - the product must be subjected to subsequent machining and final technologies - resulting product which has the configuration, sizes and quality pre-estabilished. Composite materials have been tested to obtain both mechanical and thermal properties [9 – 14].

In the last time has increased interest in the use of intelligent composite materials for thermal insulation for metallic and nonmetallic construction. The present experiment comes in support of all those who will be using multilayer thermoabsorbante plates.

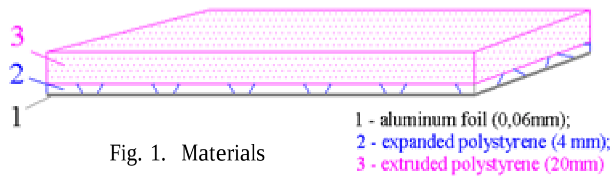

Fig. 1. Materials

Experiment part

For this research used:

I. materials - isofoam foil wich is made from aluminum foil (0.06 mm) and expanded polystyrene foil (4 mm); extruded polystyrene plane (20 mm) showed in figure 1.

II. devices and apparatus: heat source which was puted in the midlle of the multilayer plate, thermocouples which had been set to read the temperatures inside and on the outside of the multilayer plate (TM1-TM4 read the temperatures at outside of plate, TM5 read the temperature at inside plate and TM 8 read the temperature from the heat source), an autotransformer energy which aims to apply the appropriate voltage on each plate.

Given that the first layer of expanded polystyrene was very thin (aluminum foil) therefore impossible to fix

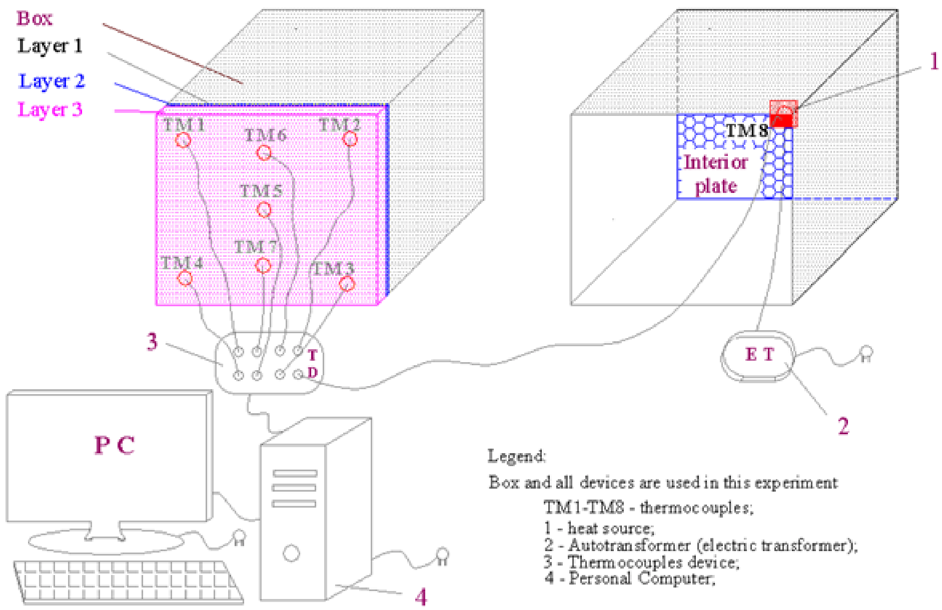

Fig. 2. Device and aparatus for experiment

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No layer	δ [mm]	λ [W/(mK)]	E [MPa]	ν [-]	ρ [kg/m³]
1	0.06	0.015	6300	0.02	2700
2	4	0.036	4220	0.30	154
3	20	0.034	3000	0.30	20
δ – plate thickness; λ – thermal conductivity; E – elasticity module; ν – Poisson's coefficient; ρ – density					

Table 1
THERMO – MECHANICAL CHARACTERISTICS OF THE LAYERS LAMINATED PLATE [3]

i	Time [s]	TM1 T_i [°C]	TM3 T_i [°C]	TM5 T_i [°C]	TM8 T_i [°C]	TM1 $\Delta T_{i,0}$ [K]	TM3 $\Delta T_{i,0}$ [K]	TM5 $\Delta T_{i,0}$ [K]	TM8 $\Delta T_{i,0}$ [K]
0	0	26.11	25.42	71.31	102.51	0	0	0	0
1	300	26.29	25.57	72.15	103.92	0.18	0.15	0.84	1.41
2	330	26.33	25.6	72.3	104.08	0.22	0.18	0.99	1.57
3	360	26.35	25.63	72.43	104.2	0.24	0.21	1.12	1.69
4	390	26.37	25.64	72.52	104.25	0.26	0.22	1.21	1.74
5	420	26.39	25.66	72.6	104.29	0.28	0.24	1.29	1.78
6	450	26.42	25.7	72.69	104.35	0.31	0.28	1.38	1.84
7	480	26.43	25.72	72.76	104.43	0.32	0.3	1.45	1.92
8	510	26.45	25.74	72.83	104.48	0.34	0.32	1.52	1.97
9	540	26.48	25.76	72.92	104.56	0.37	0.34	1.61	2.05
10	570	26.53	25.79	73.01	104.66	0.42	0.37	1.7	2.15
11	600	26.56	25.83	73.07	104.73	0.45	0.41	1.76	2.22
12	630	26.6	25.86	73.13	104.82	0.49	0.44	1.82	2.31
13	660	26.63	2588	73.17	104.83	0.52	0.46	1.86	2.32
14	690	26.64	25.89	73.18	104.91	0.53	0.47	1.87	2.4
15	720	26.65	25.9	7323	105.03	0.54	0.48	1.92	2.52
16	750	26.66	25.93	73.3	105.12	0.55	0.51	1.99	2.61
17	780	26.68	25.94	73.39	105.16	0.57	0.52	2.08	2.65
18	810	26.68	25.94	73.44	105.06	0.57	0.52	2.13	2.55
19	840	26.69	25.97	73.45	104.91	0.58	0.55	2.14	2.4
20	870	26.71	25.98	73.41	104.75	0.6	0.56	2.1	2.24

Table 2
TEMPERATURE DIFFERENCE [K] FOR EACH THERMOCOUPLE BETWEEN THE TEMPERATURE T_i AT THE TIME t_i AND THE TEMPERATURE AT t = 0

thermocouples in this, a first layer formed by adding the following unitary extruded polystyrene layer.

The materials were glued with universal adhesive. It is not suitable for gluing materials of polyethylene, polypropylene and metals [3].

The thermocouples (TM1-TM5) fixed in diferent points on the plate and TM8 fixed in back of the heat source. After that they conected on the thermocouples device. The thermocouples device transmited on the PC the temperatures read by thermocouples.

The experimental device and aparatus can be shown in figure 2. Thermal insulation capacity of a material is expressed through thermal conductivity coefficient, denoted λ [W/mK]**.**

Thermal conductivity is dependent on the physical properties of the material: density, porosity, humidity, ranging obviously from one material to another. The thermal conductivity is direct proportional to the density of the material. For this reason light materials (polystyrene, mineral wool) have a coefficient λ less and therefore better thermal insulation properties. Thermal conductivity coefficient varies in direct proportion to the humidity (because the water conductivity is considerably higher-approx. 20 times-than that of air), so a material will have better insulating properties with the dry [15]. Thermo-mechanical characteristics of the layers laminated plate are showed in tabel 1.

Heat flow **Φ** in the steady state have been calculated with the formula for the plan wall [16]:

$$\Phi = \Delta T_{i,0} / R_t \quad [\mathrm{W/m^2}] \tag{1}$$

$$R_{tp} = \sum_{i=1}^{3} \frac{\delta_i}{\lambda_i} = 0{,}703\ [(\mathrm{m^2\,K})/\mathrm{W}] \tag{2}$$

where: **Φ** – heat flow; $\Delta T_{i,0}$ - temperature difference [K] for each thermocouple between the temperature T_i at the time t_i and the temperature at the t = 0; R_{tp} – thermic rezistance of the plate; δ- wall thickness [mm]; λ - the thermal conductivity coefficient [W/mK]

The effective thermal conductivity is an important parameter that can quantitatively assess the ability of heat transfer in composite [16, 17]. Effective thermal conductivity of composite can be influenced by the distribution of the particles inside the material [18, 19]. The curve of the heat flow was plotted depending on time with the Excel programme.

A new approach polymer composites is represented by increase thermal conductivity adding nano- micro sized fillers. The shape and the size of the some properties is taken into account to determine the thermal conductivity [20].

At the end of the experiments we showed the temperature value registered and after that we calculated temperature difference ΔT (table 2).

After the thermic rezistance R_t calculation and temperature difference ΔT, one generated the heat flow graphics (figs. 3-6) taking into account eq. (1).

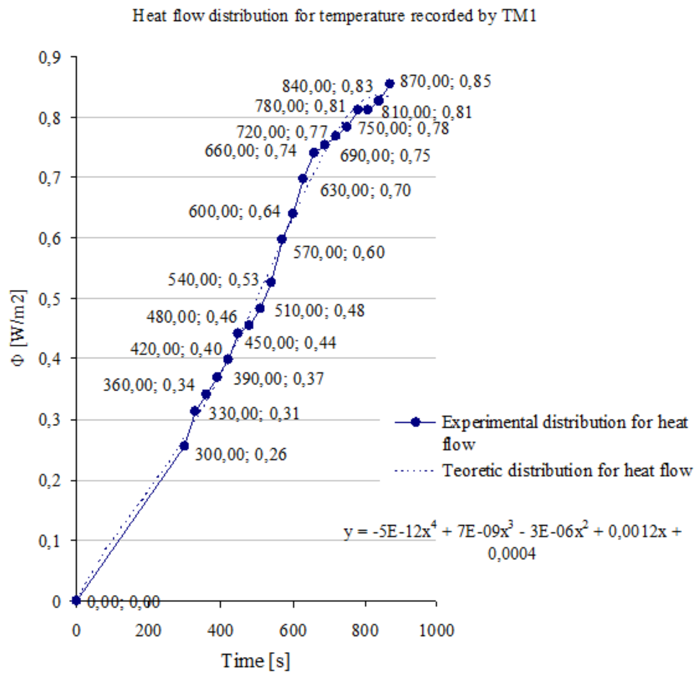

Fig. 3. Graphic representation of the heat flow for temperature recorded by TM1 (Φ = y; t = x)

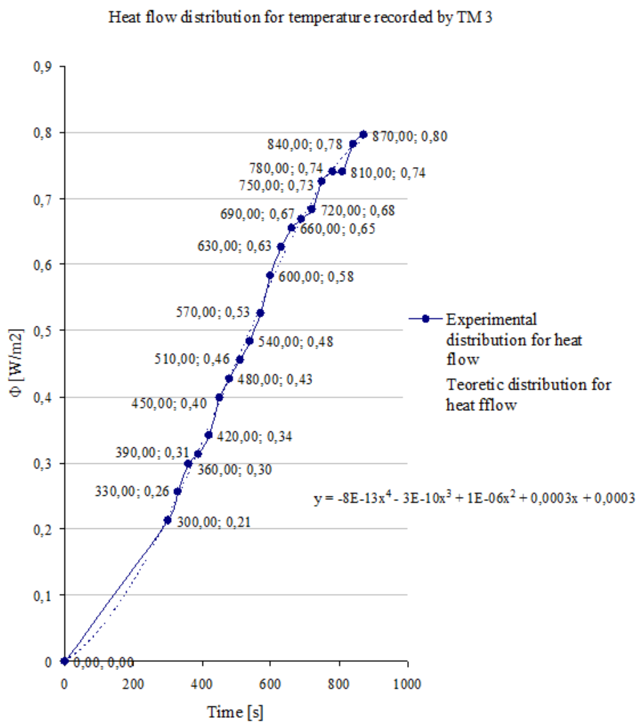

Fig. 4. Graphic representation of the heat flow for temperature recorded by TM 3 (Φ = y; t = x)

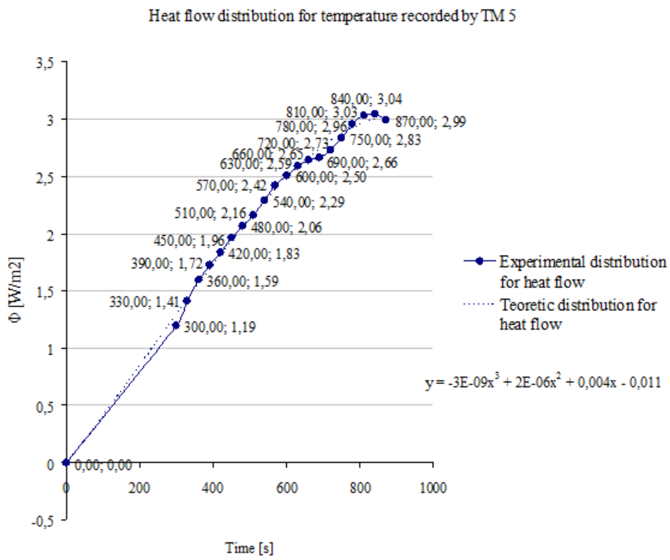

Fig. 5. Graphic representation of the heat flow for temperature recorded by TM 5 (Φ = y; t = x)

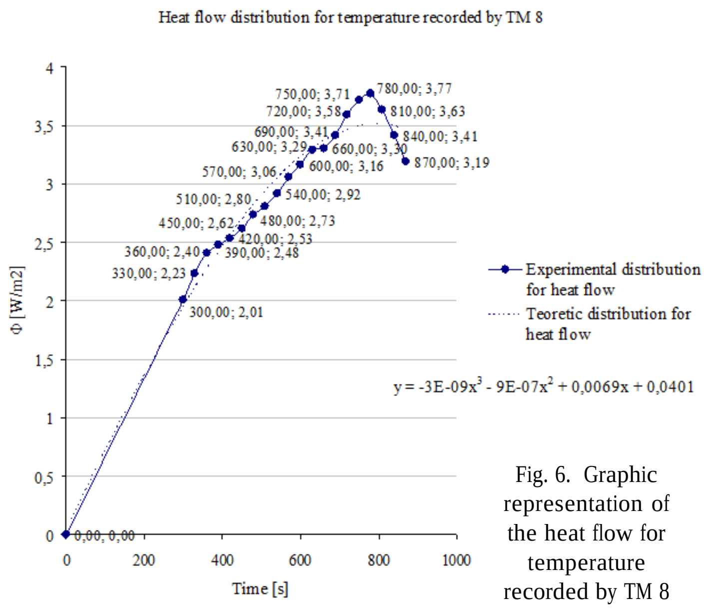

Fig. 6. Graphic representation of the heat flow for temperature recorded by TM 8

Analyzing the records of the 4 thermocouple (TM1, TM3, TM8, TM5) were found informations about the heat flow and the thermal resistance:

Measurements recorded by the termocuplele TM1 and TM3 generated graphs which have been approximated with polynomial function of 4 degree (fig. 3 and fig. 4). Heat flow values for TM1 and TM3 are ascending from 0.26 to 0.85 respectively from 0.21 to 0.80. Measurements recorded by termocuplele TM5 and TM8 generated graphs which have been approximated with polynomial function of 3 degree (fig. 5 and fig. 6). Heat flow values for TM5 and TM8 are ascending from 1.19 to 3.04 respectively from 2.01 to 3.77. The degree of polynomial function is great when the value of the heat flow is small. The degree of polynomial function is small when the value of the heat flow is high.

Rtp (thermal resistance of the stratification plate) has the value 0.703 [m^2K/W]. Rtp is greater than the thermal resistance of the first layer (Rtp1), which has the value of 0.004 [m^2K/W]. Rtp is greater than the thermal resistance of the second layer (Rt2), which has the value of 0.111 [m^2K/w]. Rtp is greater than the thermal resistance of the third layer (Rt3), which has the value of 0.588 [m^2K/w].

Conclusions

Thermal resistance of the plate layered composite materials tested is greater than the thermal resistance of each component separately.

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