DETERMINATION OF THERMAL CONDUCTIVITY, AND HEAT RESISTANCE OF SOME POLYURETHANE RUBBERS, AND THEIR DEPENDENCE FROM THE THICKNESS AND DENSITY.

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Abstract

Thermal conductivity is the property of the material to transport the heat from high temperature areas to low temperature areas. Polymers are generally good insulators, as long as their temperature of use is under the temperature of their thermal stability. Heat transmission is realized through the oscillation and rotation of the polymer molecular chain. Thermal conductivity of the polymer depends on the molecular weight and increases with increasing of the molecular weight.

Also thermal conductivity depends, from the degree of the cristallinity of the polymer. A polymer with high degree of crystallinity has a higher thermal conductivity than the equivalent amorphous material. This is due to effective coordination of vibrational molecular chains in the crystalline state. The samples used in this paper are polyurethanes rubber at different density and thickness. Polyurethanes rubber are widely used in daily life, because they have a number of important and useful properties. The samples considered in this article, are used as shoe layer.

Through the thermal conductivity apparatus was defined thermal conductivity of these polyurethane rubber. The flow of energy depends on the size of the sample surface and of the temperature differences inside and outside the walls of the samples and inside and outside of the apparatus.

It was calculated and compared thermal conductivity and heat transition resistance of rubbers with the same thickness but with different density and rubbers with the same density but different thickness.

It was analyzed the dependence of the thermal conductivity and heat transition resistance form the density and thickness of the samples.

Keywords: *rubber, thermal conductivity, heat transmission, resistance*.

INTRODUCTION

Three basic ways of heat transfer are: conductivity, convection and radiation. In gas the atoms transfer energy to each other through molecular hits are: conductivity, convection and radiation. In conductivity the heat is transmitted by the transfer of the energy of movement between neighbors' molecules in liquid, gas or solids. In a gas, the atoms transfer energy to each other through the strikes between molecules. In metallic solids is important the process of heat transfer through the free electrons [1,2]. To convection the heat transfers through voluminous transport and mixture of macroscopic fluid elements. Radiation is the transfer of heat through the electromagnetic waves. Thermal conduction is the phenomenon by which heat is transported from high to low-temperature regions of a substance. The property that characterizes the ability of a material to transfer heat is the thermal conductivity**,** while heat capacity is a property that is indicative of a material's ability to absorb heat from the external surroundings; it represents the amount of energy required to produce a unit temperature rise [2,3].

In mathematical terms, the heat capacity *C* is expressed as follows: $C = \frac{dQ}{dT}$ (1)

It is best defined in terms of the expression: $q = -\lambda \frac{dT}{dx}$ (2)

where *q* denotes the heat flux, or heat flow, per unit time per unit area (area being taken as that perpendicular to the flow direction), *λ* is the thermal conductivity, and *dT/dx* is the temperature gradient through the conducting medium. Equation (2) is valid only for steady-state heat flow, that is, for situations in which the heat flux does not change with time. Also, the minus sign in the expression indicates that the direction of heat flow is from hot to cold, or down the temperature gradient. Equation (2) is similar in form to Fick's first law for atomic diffusion. For these expressions, *λ* is analogous to the diffusion coefficient *D*, and the temperature gradient parallels the concentration gradient, *dC*/*dx* [1].
Polymers are often utilized as thermal insulators because of their low thermal conductivities. For these materials, energy transfer is accomplished by the vibration and rotation of the molecular chain.

MATERIAL AND METHODS

A model house with replaceable side walls is used for determining the thermal conductivity and heat resistance (1/k values) of different materials [4].

Fig.1. Thermal conductivity apparatus

For this purpose the temperatures on the inside and outside of the walls are measured at a constant interior and outer air temperature (in the steady state). Inner and outer wall and air temperatures have to be measured in each case. Holes in the corner posts of the model house are used for the insertion of thermocouples to measure the interior and inside wall temperatures.Thermocouples are connected to two COBRA.4-Mobile-Link., equipped with a memory card, which is inserted in, so the measurements can be recorded and processed in PC. Two thermocouples are used for measuring the inside and outside of the wall temperatures of the Polyurethanes rubber (PU). The other two thermocouples are used for measuring the inside and outside air temperatures. A 100 W incandescent lamp with a covering cap is used for heating purposes, the interior temperature being kept virtually constant by a heating thermostat. A 150 W incandescent lamp illuminate the Polyurethane walls from a distance of about 15 cm. The thermal energy flow P through a homogeneous, flat wall is determined in the steady state by means of the air-wall heat transfer and the heat conduction in the wall. The energy flow is governed by the surface area of the wall A and the particular temperature differences [4]:

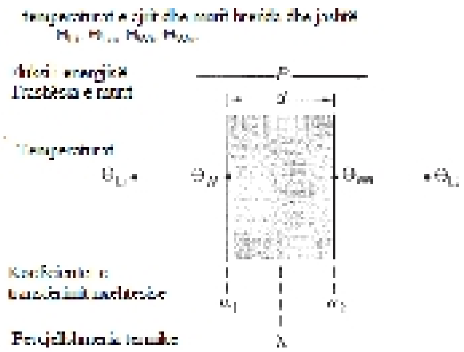

Fig.2. Heat energy flow through the wall

Air-wall heat transfer, internal ($\sim_i$ = internal heat transfer coefficient)

$$P = \sim_i \cdot A \cdot \left(\Theta_{Li} - \Theta_{Wi}\right) \quad (3)$$

Wall-air heat transmission, external ($\sim_a$ = external heat transfer coefficient)

$$P = \sim_a \cdot A \cdot \left(\Theta_{Wa} - \Theta_{La}\right) \quad (4)$$

Heat conduction in the wall (d = thickness, a = heat conductivity)

$$P = \frac{a}{d} \cdot A \cdot \left(\Theta_{Wi} - \Theta_{Wa}\right) \quad (5)$$

Rearrangement and summation of these three equations yields:

$$P = k \cdot A\left(\Theta_{Li} - \Theta_{La}\right) \quad (6)$$

in which k = heat transition coefficient or k value.
Equation (4) yields P/A
Equation (6) yields k
Equation (5) yields λ
The samples studied are Polyurethanes rubber at different density and thickness. Polyurethane polymer (PUR or PU) is composed of organic units chains joined by urethane bonds -NHCOO-

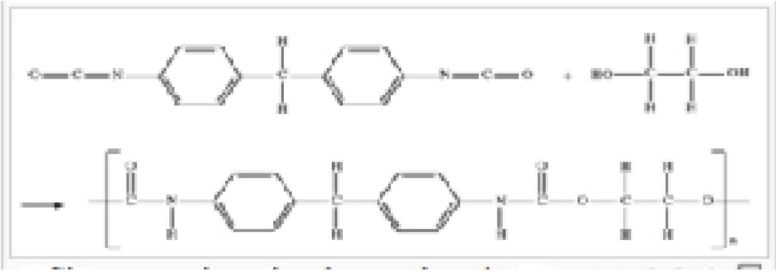

Fig.3. The synthesis of polyurethane.

Polyurethane belongs to the family of thermoset polymers; it is a polymeric chain obtained by polyaddition reaction between a polyisocyanate and a polyol, forming a sequence of urethane bonds (-NH-(CO)-O-). This reaction is exothermic and has no by-products [3,4,5].

RESULTS AND DISCUSSION

The samples of polyurethane rubber (PUR), were placed one after the other in the window of model house used to determine the thermal conductivity. According to principle given in **MATERIAL AND METHODS,** were measured respectively the inside and outside rubber's wall temperatures and air temperatures. Measurements through the Cobra 4-Mobile Link were registered every 5 sec [4]. The results of average values of the calculations made by respective formulas (4), (5), (6) presented above to about 200 values of temperatures, are presented to the following table. In calculating the errors made during measurements is considered that $\Delta\theta=0.1°C$, $\Delta d=0.001m$.

Tab.1. Air and wall temperatures and averages calculated values of the respective quantities for Polyurethane rubber 240g/l, thickness 0.004m.

Material	Thickness (m)	θLi (°C)	θLa (°C)	θWi (°C)	θWa (°C)	P/A (W/m²)	λ (W/Km)	1/k (Km²/W)	ΔP/A (W/m²)	Δλ/λ %
PUR240g/l	0.004	45.0	20.4	38.0	30.4	80.57	0.042	0.305	1.62	2.64

Tab.2. The average values of thermal conductivity and heat transition resistance depending on the density and thickness of Polyurethane rubber.

Nr	Density (g/l)	Thickness (m)	λ (W/Km)	1/k (Km²/W)
1	240	0.004	0.042	0.305
2		0.014	0.032	0.508
3	850	0.004	0076	0.33
4		0.014	0.064	0.68

By data processing through the "Measure" software, are presented the temperature dependencies vs. time of the interior and exterior polyurethane walls.

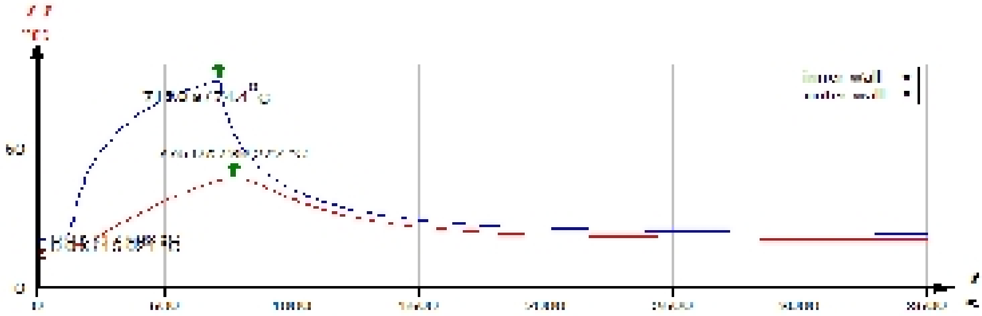

Fig.4. The dependence of temperature vs. time for inside and outside of the Polyurethane wall 240g/l, thickness 0.004m

The time difference between the two maximums is 60 sec. The temperature difference between the maximums of two sides the wall is 35.1° C

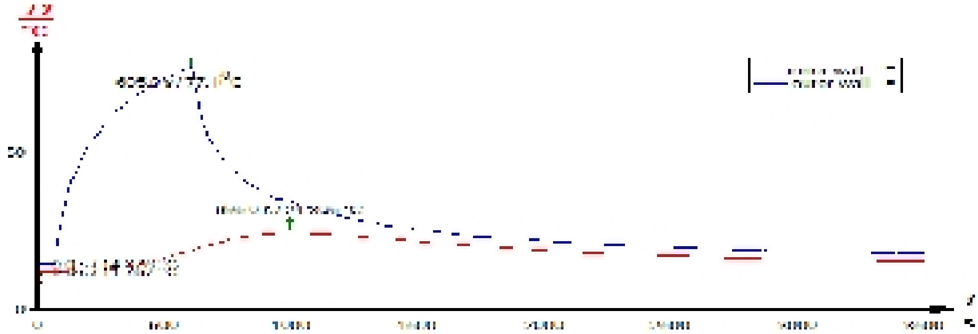

Fig.5. The dependence of temperature vs. time for inside and outside of the Polyurethane wall 240g/l, thickness 0.014m.

The time difference between the two maximums is 390 sec. The temperature difference between the maximums of two sides the wall is 52.2° C

By two graphical dependence above, it is observed that the samples with the same density: 240g/l but with different thickness have a different difference of temperatures between the inner and outer side of respectively samples walls.

Referring to Tab.2 is apparent that the sample of 240g/l of density and 0.004m of thickness has less heat transition resistance than the sample of the same density but of 0.014m thickness. Due to small thickness, the heat could be transmitted more easily between molecular chains [1]. During heating-up stage, the temperature outside wall of the Polyurethane rubber at Fig.4, rises approximately from 17.7°C to 74.4°C. The maximum of temperature in the inner wall is reached for about 995 sec during the illumination of the lamp. The illumination of the outside wall of Polyurethane rubber at Fig.5 gives up a rises of temperature from 14.4°C to 77.1°C within 606 sec.

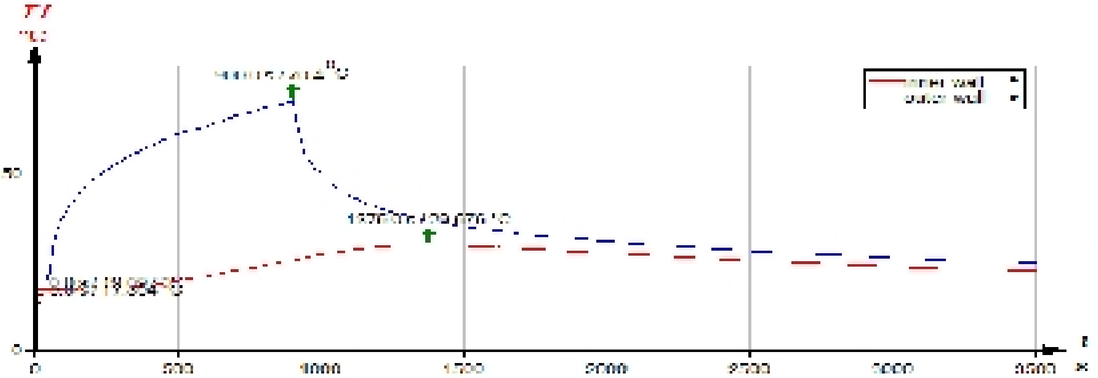

Fig.6. The dependence of temperature vs. time for inside and outside of the Polyurethane wall 850g/l, thickness 0.014m.

The time difference between the two maximums is 475 sec. The temperature difference between the maximums of two sides the wall is 40.7° C

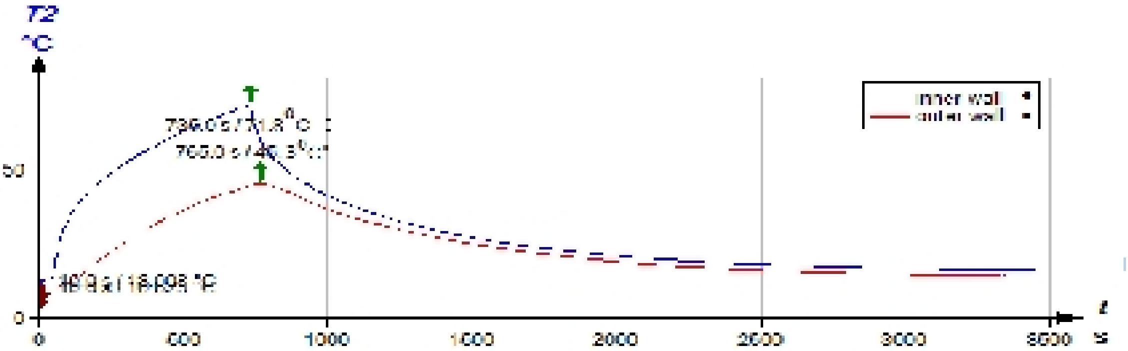

Fig.7. The dependence of temperature vs. time for inside and outside of the Polyurethane wall 840g/l, thickness 0.004m.

The time difference between the two maximums is 30 sec. The temperature difference between the maximums of two sides the wall is 26.5 ° C

By graphical dependence of Fig.6. and Fig.7, it is observed that Polyurethane rubber of 850g/l density and 0.014m of thickness, has a difference of temperatures between the inner and outer side wall, higher than the other polyurethane sample at approximately the same density but at the 0.004m of thickness. Referring to Tab.2 is apparent that the sample of density 840 g/l and 0.004m of thickness has less heat transition resistance than the sample of the same density and of 0.014m thickness. Due to small thickness, the heat could be transmitted more easily between molecular chains. The illumination of the outside wall for Polyurethane rubber at Fig.6 gives up a rises of temperature from 19.9°C to 70.4°C within 900 sec. The illumination of the outside wall for Polyurethane rubber at Fig.7 gives up a rises of temperature from 13°C to 71.8°C within 735 sec. The heat is transmitted to the inner wall, heating it to an amplitude of about 35°C. After disconnection of the lamp the temperature on both the inside and outside wall, fall to the initial values within 1765 sec. So the Polyurethane sample of 0.004m has higher thermal conductivity than the sample of the same density, but of different thickness.

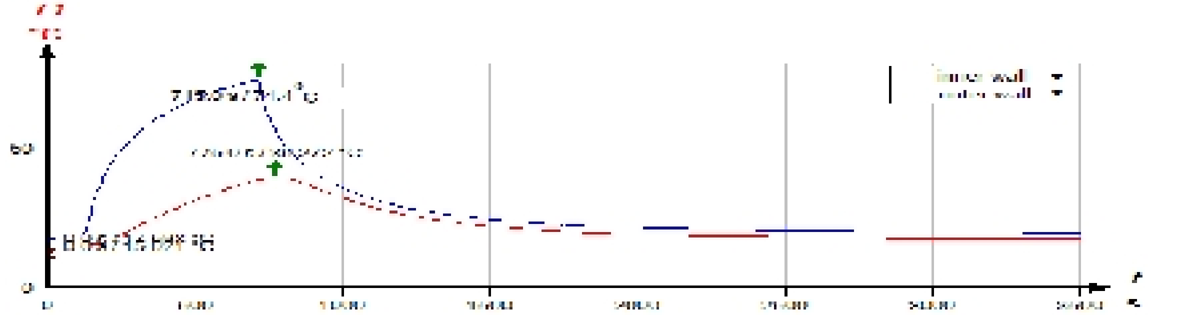

Fig.4. The dependence of temperature vs. time for inside and outside of the Polyurethane wall 240g/l, thickness 0.004m

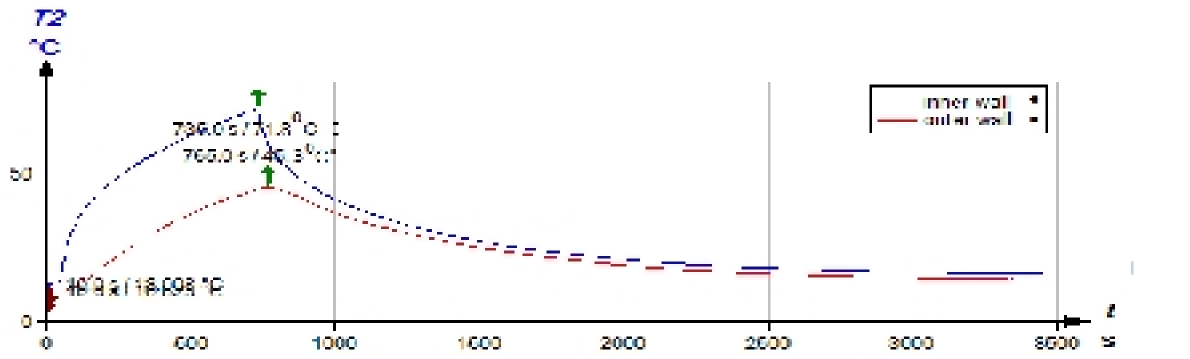

Fig.7. The dependence of temperature vs. time for inside and outside of the Polyurethane wall 840g/l, thickness 0.004m.

In the figure above are presented Polyurethane samples of the same thickness but of different densities. The time difference between two maximums of the samples at Fig.4. is 60 sec, while the same difference for the samples of Fig.7. is 30 sec.

The walls of Polyurethane sample of density 840g/l, during heating up stage presents a higher heat storage capacity than the same sample at different density but at identical thickness [7]. Due to higher heat storage capacity the temperature of the internal wall of the sample at Fig.7 rises quicker than that to Fig.4 and reaches higher amplitude.

CONCLUSIONS

- By comparison made to the Polyurethane samples with same density, it was observed that the sample of higher thickness has less thermal conductivity λ than the other.
- Heat transition resistance for Polyurethane rubbers with the same density, is higher to the samples of higher thickness.
- Heat transition resistance for Polyurethane rubbers with the same thickness, is higher to the samples of higher density.
- Samples of different densities but of the same thickness exhibit different heat storage capacity during heating up stage.

REFERENCES

[1] Brian S. Mitchell, 2004, *An Introduction to Materials Engineering and Science,* Canada, John Wiley & Sons, Inc.

[2] William D. Callister, 2007, Thermal properties, *Material Science and Engineering*(7th ed), (pp713-729), New York(USA), John Wiley & Sons, Inc

[3] Joel I. Gersten & Frederick W. Smith, 2001, *The physics and chemistry of materials*, New York, Chichester, Weinheim, Brisbane, Singapore, Toronto, John Wiley & sons, inc.

[4] PHYWE SYSTEM GMBH & Co . KG Laboratory experiments. D-37070 Gottingen, *Heat insulation / Heat conduction*, LEP 3.6.03-00

[5] Mir Hamid Reza Ghoreishy & Ghasem Naderi, A new method for the determination of the thermal conductivity of rubber compounds, *Iranian Polymer Journal,* Vol 10/5 (2001), pp.315-320

[6] D.J. dos Santos, & L.B. Tavares & G.F. Batalha, Mechanical and physical properties investigation of polyurethane material obtained from renewable natural source, *Journal of Achievements in Materials and Manufacturing Engineering* 54/2 (2012) pp 211-217.

[7] P Dasora & G Gupta & J Dashora, Thermal conductivity, diffusivity and heat capacity of plasticized polyvinyl chloride, *Indian Journal of Pure & Applied Physics*, Vol 43(2005) pp 132-136.