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Study of thermal behaviour of a fabric coated with nanocomposites

K. Abid, S. Dhouib, F. Sakli

Laboratoire de Génie Textile, Institut Supérieur des Etudes Technologique de Ksar Hellal, Université de Monastir, Avenue Hadj Ali Soua, 5070 Ksar Hellal, Tunisia

Email address:

kaledabid2003@yahoo.fr (K. Abid)

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Abstract: In this paper, the thermal insulation of coated fabric by nanocomposites has been studied. In fact, a resin/clay mixture was deposited on a 100 % cotton fabric and tested using a PASOD device for measuring the adiathermic power. The enhancement of fabric thermal insulation was noticed by calculating the difference in temperature between the inside and the outside of fabric. The innovation of this work is that the used clay is a Tunisian natural one which is simply a mixture of several sorts of clays (kaolinite, dolomite, calcite, illite, and quartz) and which has the advantage to be so cheap. Moreover, high clay percentages of 4,17 % to 37,8 % were applied to perform nanocomposites with, which never have been tried before. This clay has been cleaned, purified, dried, and steered with different resins which are actually used in the textile field for several applications such as comfort, elasticity or impermeability. It has been concluded that the increasing quantity of clay enhance significantly the thermal insulation of a 400 g/m^2 sergey fabric 100% cotton. The mathematical equation has proved to be effective in predicting the fabric thermal resistance, simply by knowing the adiathermic power value. In fact, the measure of the thermal resistance demands a long time to be evaluated, but the adiathermic power can be evaluated by a concise operation which lasts only 15 min. This good agreement between these values has been demonstrated by mathematical formulas linking the clay percentage, coating, nanocomposite deposited quantities, and the used resin. The result of theses computations indicates that clay application in nanocomposites proved its importance because the thermal insulation properties of the fabric are really enhanced according to the clay percentage in the coating. The average of this enhancement is about 20 to 30 % and this is upon the used resin, the deposited quantity, and the clay percentage present in the nanocomposite.

Keywords: Nanocomposite, Clay, Coating, Modelling, Thermal Insulation

1. Introduction

Nanotechnology has been heralded as the next major technological leap, as that it is prophesied to yield a variety of substantial advantages in terms of material characteristics: including textile, electronic, and optical and structural characteristics. Nanostructured materials as thin films and coatings possess unique properties due to both size and interface effects (1, 2, 3).

The manufacturing of nanocomposites in this study is considered very delicate because the commercial used resins are frequently mixed with water (problem of mixing with clay which is very hydrophilic). In addition, the analysis of DRX patterns requires a lot of care because the multitude of the spectrum of the different clays is superposed and difficult to analyse. Many researchers tried to give fabrics some new properties by nanoadditives adjunction such as mass spectrometry applications, thermal insulation (4, 5), ignifugation (6), lubricants for space applications (4), flexibility, resistance to organic solvents (8), moisture sensors (9), and surface fonctionnalisation (10) , but their works were carried out using only the montmorillonite clay which has a simple composition (11, 13, 14).

The purpose of this study is to show how the nanocomposite coatings on fabric is carried out and enhance the thermal insulation of this new hybrid fabric in conjunction with the clay percentage and the sort of resin.

2. Experimental

10 g of cleaned and purified Tunisian clay added to 100 mL of methylene chloride (CH_2Cl_2) have been ultrasonicated

for 2h at 25°C (freq. = 28KHz), in order to have a good dispersion of clay particles. Then the prepared clay solution was added to the resin at different loadings of clay: 4,17%, 14,8%, 25,8% and 37,8%. These clay percentages perhaps seem to be high quantities to perform nanocomposites with, but never have been tried before (8-12). In this study we want to examine the coated fabric thermal respond to large sorts of coated fabric with different clay quantities even the nanocomposites formation did not take place, and only a mixture with a good dispersion clay/resin is well applied as a coating on the fabric surface as a uniform layer.

Five sorts of commercial resins were selected to be mixed with clay: modified Dimethylol dihydroxyethylene urea (DMDHEU), Vinyl-Polyacetate (PVAv), Polyacrylate (PAC), elastic Polyurethane (PU1), and rigid Polyurethane (PU2).

These different mixtures resin/clay were deposited on a cotton fabric Sergey (about 400 g/m²) using a coating apparatus with rake pressure and deposited paste regulations. The nanocomposite formation was confirmed in our previous work (15). The polymerisation of these coatings was carried out at 150°C during 5 min (12) and after a drying operation during 5 min permitting to water and CH_2Cl_2 to evaporate.

Then, the thermal isolation properties of the coated materials were determined by measuring the adiathermic characteristics using a PASOD device for measuring the adiathermic power by measuring the necessary voltage to maintain a temperature difference between the inside and the outside of the fabric equals to 20°C.

3. Results

The deposited quantity of nanocomposite on the fabric (Qc) and the adiathermic power (AP) are shown in figure 1 (a-d).

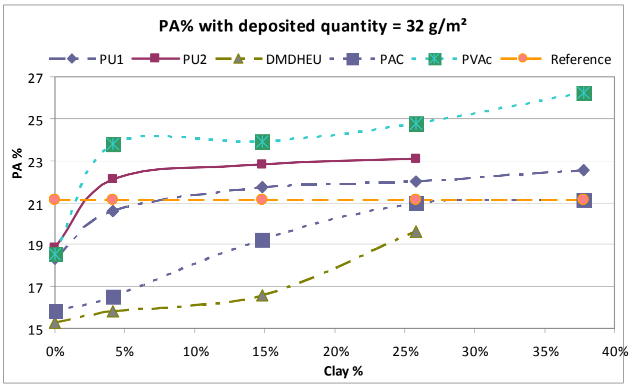
Table 1. Measured viscosities of the used resins.

Resin	Viscosity (cp)
PVAc	30000
PU2	6000
PU1	5000
DMDHEU	1000
PAC	800

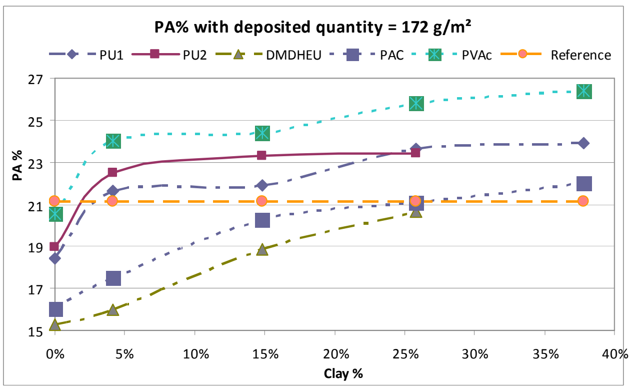
It can be noticed that for all resins having high viscosity (cf. table 1), the AP% increases more or less constantly in conjunction with the clay percentage when the last is more then 4,17%. It is probably due to the uniform nanocomposite layer formed on the fabric surface, and there is no significant penetration of the resin into the fabric. That is why for the other resins like PU1 with low viscosity, the variation of their curves is not regular, and it can be remarked that in some points the AP% can drop slightly. It is noticed also that for both resins DMDHEU and PAC, and at low clay filling, the rising of their curves is very slow in compare with the other resins, this is probably due to their low viscosity. Means that when a product with low viscosity is coated on the fabric, its penetration into the fabric is almost total, and the most pores which were occupied per air are filled now with resin, so that, the AP% will rise but not to the same extent as with high viscosity resin. This fact is more or less general for all resins to explain these phenomenon, but some other effect must be considered to understand well the growing of the AP% like the clay filling, the chemical resin nature etc.

In the case of resins PVAC PU2, the increase of the AP% of the coated fabrics for clay percentages between 0 and 4 % is very significant (20 to 30%). This enhancement becomes less important for the clay percentages from 5% on. It is also noted that for a clay percentages between 5 and 10%, the AP% become greater than the reference’s one. The deposited quantity of 32% seems to be the more adequate quatity in order to obtain a better AP%. In fact, the best result is obtained with the PVAc resin (deposited quantity : 38%) even with a 5% as a clay filling.in term of cost and thermal performance.

Finally, and in the case of DMDHEU resin the deposited quantity (32 g/m² to 540 g/m²) does not seem to be not a crucial parameter in increasing the AP% significantly. In fact, the enhancement of thermal insulation expressed in this study by the AP%, is not very expressive (only 1-2 % for all resins). Comprehensive study of this fact is in progress to make sure that the superposition of multilayer structure with several coated fabric (32 g/m² as a deposited quantity of nanocomposite for each fabric) could provide a better thermal insulation than putting the whole quantity of nanocomposite on one fabric layer.



(a)



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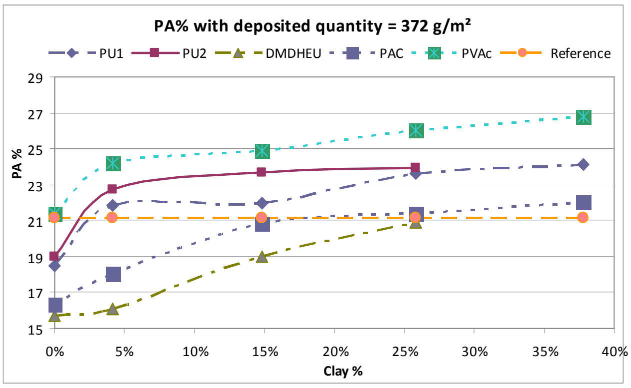

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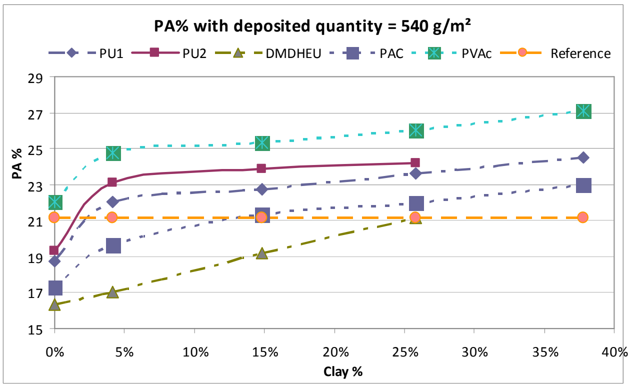


(d)

Fig. 1. *Adiathermic power % in conjunction with the clay quantity, the deposited quantity, and the sort of resin.*

Note: Mixtures PU2/37,8% clay and DMDHEU/70% clay failed because they became too thick.

4. Theoretical Background

In This part, we want to establish a mathematical equation in order to calculate the thermal resistance of coated fabric 100% cotton in conjunction with the heat flow going through, the percentage of clay, and the nanocomposite deposited quantity in order to explain the remarked phenomenon while measuring the adiathermic power. The coating (resin + clay) is performed on one side of the fabric (figure 2):

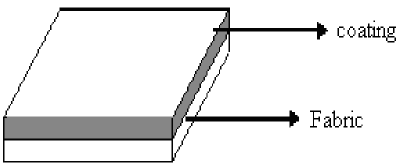


Fig. 2. *Representation of a coated fabric.*

The effective conductivity *Keff* can be determined by considering an analogous circuit model in series, thus:

$\frac{1}{keff} = \frac{1}{kc} + \frac{1}{kf}$; where K_c and K_f are respectively the thermal conductivities of the coating and the fabric.

1 Determination of the fabric conductivity (*Kf*)

A fabric is a mixture of fibres dispersed randomly in all directions with different sorts of pores (interyarn and intrayarn). It can be represented as shown in figure 3:

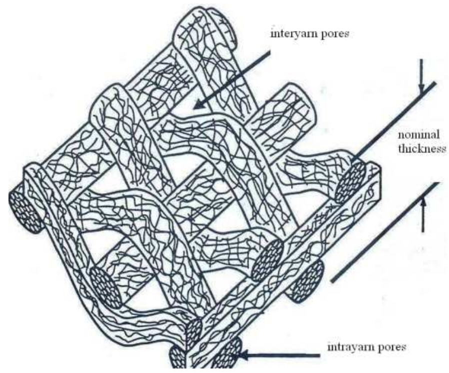


Fig. 3. *Conceptual illustration of a fabric showing interyarn and intrayarn pores(16).*

The thermal conductivity determination will take count of air and fibres conductivity in both radial and longitudinal directions. The heat flow will go through the fabric as shown in figure 4:

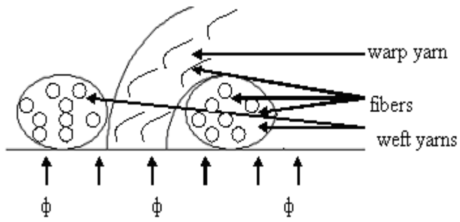


Fig. 4. *Conceptual illustration of heat flow (ϕ) going through a fabric.*

The heat flow will encounter fibres and air, and its going through the fabric can follow two ways or more specifically two models: series and parallel models. The schema represented in figure 5 shows the function mode of these two models, knowing:

Kf: fabric thermal conductivity,

K1: air thermal conductivity,

K2: fibre thermal conductivity,

Φ: heat flow.

Two temperatures will be recorded T_1 and T_2 respectively below and above the fibrous material in a distance called "dx" which represents the fabric thickness.

The flow equation is represented by the fourrier law equation as below:

$$\Phi = -K_f \frac{dT}{dx}$$

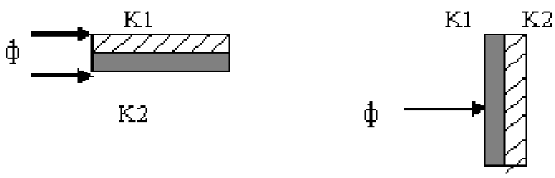


Fig. 5. *Series and parallel models.*

In the case of parallel model $K_{fp} = K_1 + K_2$ and in the case of series model:

$$\frac{1}{K_{fs}} = \frac{1}{K_1} + \frac{1}{K_2}$$

In our study (textile fabric) there is a combined model represented in the same time by a series model and a parallel model is used (figure 6):

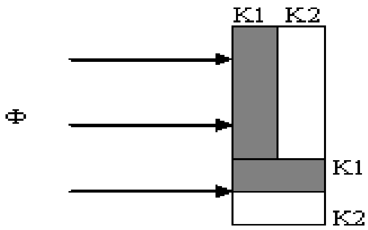


Fig. 6. *Combined model.*

So that, the fabric global and effective conductivity can be expressed as:

$K_f = \alpha K_{fs} + \beta K_{fp}$ where:

α : massic fraction coefficient in relation with the series model,

β : massic fraction coefficient in relation with the parallel model,

K_{fs} : series model thermal conductivity,

K_{fp} : parallel model thermal conductivity.

2 Determination of the coating conductivity (Kc)

The coating is represented by the mixture resin/clay as shown in figure 7.

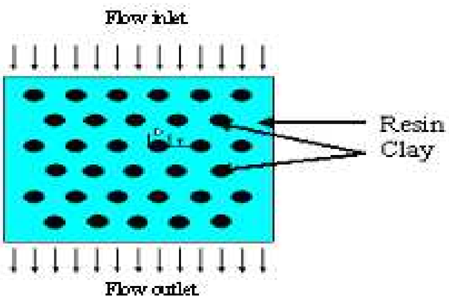


Fig. 7. *Coating resin + clay matrix configuration.*

The coated fabric thermal conductivity Kc follows a combined model:

$Kc = \gamma Kcs + \lambda Kcp$; where:

γ: massic fraction coefficient in relation with the series model,

λ: massic fraction coefficient in relation with the parallel model,

K_{cs} : series model thermal conductivity,

K_{cp} : parallel model thermal conductivity.

3 Determination of the Coated Fabric Theoretical Thermal Resistance (Reff)

We want to calculate the coated fabric thermal resistance R_{eff} in conjunction with the clay percentage put in the resin.

Determination of the adiathermic power in conjunction with the heat flow:

We know that $AP = (1-(\frac{U_1}{U_0})^2)100$

Where:

U_1= electric voltage to make a temperature difference of $\Delta T = 20°C$ between the inside and the outside of the fabric.

U_0= electric voltage to make a temperature difference of 20°C in the absence of fabric.

U_1 can correspond to the heat flow Φ ($=\frac{P}{S}$) going through the fabric, and equals to $\sqrt{PR}$, where:

P: calorific power of the wires inside the apparatus,

R: the electric resistance of the wires inside the apparatus.

So, the adiathermic power can be in this form:

$$AP = \frac{100}{U_0^2}(U_0^2 - \phi.S.R)$$

Knowing:

$$\Phi = -\frac{\Delta T}{R_{eff}}$$

We can do the deduction:

$$\text{Reff} = \frac{\Delta T.S.P}{U_0^2(1-AP)}$$

Supposing $\frac{S.R}{U_0^2} = a$

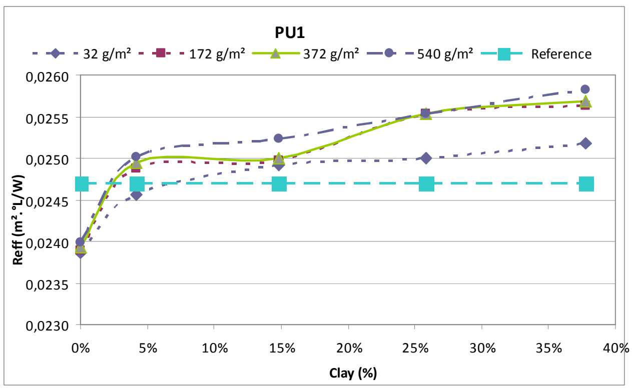
Calculating the arbitrary coefficient "a":

We know by measurement that the thermal conductivity of reference fabric (cellulose), without coating, is 0.04 W/m°K, and in this case, the clay percentage "P" = Qc = 0, so that a = -1025,6.

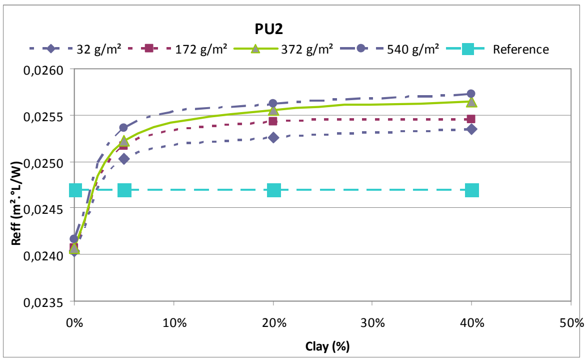
And

$$\text{Reff} = \frac{20}{1025.6(1-PA)} = \frac{0.0195}{(1-PA)}$$

From the figure 1(a-d) and the formula above, the coated fabric thermal resistance in conjunction with clay percentage and resin, can be determined (figure 8 (a-e)).



(a)



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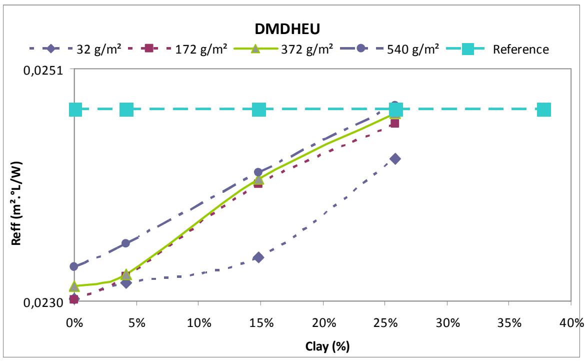

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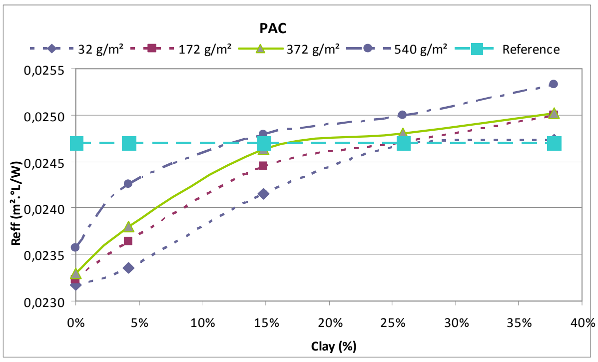

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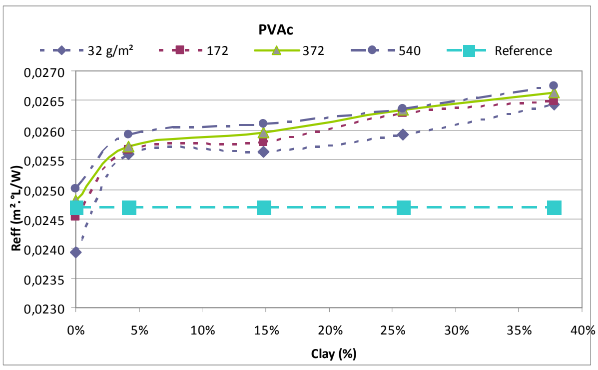

(e)

Fig. 8(a-e). *Coated fabric thermal resistance (m^2.°K/w) in conjunction with clay percentage and resin.*

5. Discussion

According to figure 1(a-d), adiathermic powers of all fabrics increase in conjunction with the clay percentage, but it is specific from one resin to another. For example, PVAc resin present higher AP% than DMDHEU and this is because DMDHEU conductivity is higher than PVAc conductivity. The results of these calculations, given in figure 8 (a-e), indicate that the thermal resistances for all samples are ranging from 0.023 to 0.026 m²°K/W. It is noted that the AP% increases for a constant clay percentage and an increasing deposited quantity. According to figure 8 (a-e), fabric thermal resistances can be classed for each coating resin. The reference fabric thermal resistance is higher than the rest of coated fabric when there is no applied clay (corresponding to an AP = 21.11%) due to the presence of air in the interyarn and intrayarn pores (figure 3) (air conductivity = 0.02 W/m°C). In fact, the resin will replace the air, and the fabric becomes more thermally conductive. The thermal resistance increases in conjunction with the clay percentage for all resins. When a fabric is coated with nanocomposites resin/clay, the thermal resistance becomes higher than the reference when the clay percentage exceeds a specific value (ex. 4,17 % for the PU2 resin). The fabric thermal resistances of the coatings with the nanocomposite DMDHEU/clay are all the time below the reference thermal resistance, even for high clay percentages (37,8 %). This is probably due to the high fluidity of the considered resin, which replaces all the pores which were occupied per air.

In this study, we tried several quantities of nanocomposites deposited on the fabric. Thus, to enlarge this investigation, great quantity of such deposited quantities should be used to derive equations that link the thermal conductivities and resistances to not only the clay percentage but also the quantity of nanocomposites deposited on the fabric, and even more, to the fabric surface weight and its contexture.

6. Conclusion

In this study, we have developed a method of mathematical stimulating the fabric thermal resistance. The clay percentage is a very important parameter since the high clay quantities in the nanocomposite generally present the better thermal resistances. The mathematical equation has proved to be effective in predicting the fabric thermal resistance, simply by knowing the adiathermic power value. In fact, the measure of the thermal resistance demands a long time to be evaluated, but the adiathermic power can be evaluated by a concise operation which lasts only 15 min. This good agreement between these values has been demonstrated by mathematical formulas linking the clay percentage, coating, nanocomposite deposited quantities, and the used resin. The result of theses computations indicates that clay application in nanocomposites proved its importance because the thermal insulation properties of the fabric are really enhanced according to the clay percentage in the coating. The average of this enhancement is about 20 to 30 % and this is upon the used resin, the deposited quantity, and the clay percentage present in the nanocomposite.

Validation of these results is only possible through direct conductivity measurements. In this case, then, several parameters like α, β, γ, and λ, predicting the percentages of the series and parallel models in the coated fabric, can be determined. Work is in progress to develop some theoretical model to evaluate these findings.

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