PVC-based synthetic leather to provide more comfortable and sustainable vehicles

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Abstract. Consumers are increasingly demanding the interior of cars to be comfortable even in the case of more economic commercial segments. Thus, the development of materials with thermoregulation properties has assumed renewed interest for these particular applications. An attempt has been made to prepare a multilayer PVC-based synthetic leather with paraffinic PCMs to be applied on a car seat. The thermal behaviour of the material was analysed using Alambeta apparatus, a thermo-camera and a thermal manikin. The results obtained show that the synthetic leather with incorporated PCMs gives cooler feeling and has higher reaction times regarding environmental temperature variations than the material without PCMs incorporation. Globally, the new designed material allowed greater thermal comfort to the cars’ inhabitants. In addition, the material quality was evaluated according to the standard of the customer, BMW 9,210,275; Edition / Version 4, 2010-10-01 revealing that the material meets all the requirements under test, except for the performance in terms of flexibility.

1. Introduction
Technological car improvements in terms of comfort and fuel consumption, even in the less expensive segments, are forced by the tremendous market competitiveness. The level of comfort inside the vehicle, for the driver and for other inhabitants, depends on the stabilisation of the interior temperature. Usually, this thermal environmental stabilisation is achieved by means of air conditioning systems. However, these systems require a lot of energy that influences performance and car’s fuel consumption. The impact on advanced vehicles such as electric hybrid and fuel cell vehicles is even greater because the air conditioning systems can reduce drastically the battery performance as well. Therefore, any solutions aiming the control of ambience car temperature are considered to be very attractive. In this context, the use of phase change material’s technology for the design of automotive interior can induce energy savings and also the thermal comfort inside cars [1, 2].

Thermal comfort is described as the human satisfaction with environmental thermal conditions. The comfort sensation depends on the possibility to harmonize the human body and the surrounding temperature [3]. This thermal equilibrium is influenced by the combination of physiological, psychological and physical factors such as air temperature, radiant temperature, air velocity, and relative humidity. Other issues, e.g. solar radiation intensity and incidence, size and position of glass surfaces, the limited amount of insulation material can influence heat exchange phenomena [4, 5].

The automotive upholstery plays an important role in the thermal comfort of the driver. The most commonly used materials are polyester, leather and synthetic leather comprising fibrous substrate and synthetic polymer coating layers [6].
Phase Change Materials (PCMs) are typically polymers, which change from a solid to a high-viscosity liquid (or semi-solid) state at a certain transition temperature. These materials store, release or absorb heat (called latent heat) as they oscillate from one physical state to another. They are either organic or salt-based inorganic compounds. Paraffin hydrocarbons and salt hydrates are the most representative PCMs of each group. They can also be eutectic mixtures. These materials can cover the temperature range between 0°C to about 200°C but the heat absorption and release temperature interval is usually between 20-40°C [7, 8].

The effect of the PCM in a certain product depends on its specific thermal capacity. Moreover, the necessary quantity must consider the application conditions, the required thermal and duration effect.

PCMs are usually supplied in encapsulated forms. In fact, encapsulation techniques provide opportunity to fabricate PCMs with a greater heat transfer area, reduced reactivity with the outside environment and controlled volume changes during the phase transition, which are important characteristics to ensure PCM performance for some specific application [8, 9]. Depending on substrate’s type, they can be incorporated on materials by different methods. However, coating and lamination are the most common processes for incorporation of PCMs into textile substrates [10].

Different applications of PCMs are used in the automotive industry. Pre-heating catalytic converters, engine cooling and internal combustion engines are some examples [11]. For many years, the automotive industry has been concerned with designing innovative solutions to improve the car cabin comfort (U.S. Pat. Nos. 2007/0001507 and 2006/7083227, WO 2002083440 A2).

The present study aims to integrate PCMs on the materials of the cars’ cover seats in order to save energy spent for the stabilization of the temperature, while improving thermal comfort for passengers.

2. Materials and methods
2.1. PVC-based synthetic leather
A woven polyester/cotton fabric (65%/35%; ~150 g/m²) was coated with three different polymeric layers (a compact layer with 0.3 mm; a foaming layer with 0.5 mm; a lacquer layer with 15 μm). Polymeric formulations applied are composed by PVC resin, plasticizers, extenders, stabilizers, lubricants, fillers, colorants, flame retardant agents and other additives. PCMs with melting point at 28°C were supplied by Devan (Portugal) and they were introduced in PVC foaming layer (5 or 10%), compact layer (2%), adhesive foam layer (5 or 10%) and lacquer layer (2%). The formulations were prepared for application by adding thickener to adjust the viscosity, mixing at ~1600 rpm during 5 min and processed in vacuum for 30 min. The coating was carried out on a Werner Mathis AG machine and the different weight add-ons were defined: 350 g/m² for compact layer, 250 g/m² for foaming layer, 120 g/m² for adhesive layer and 12 g/m² for lacquer layer. Briefly, the coating process consists in the application of the compact layer on transfer paper followed by coagulation process at 210°C by 1min. Then, the foam paste was applied and coagulated at 140°C by 1min. The adhesive paste was added and the textile lamination carried out at 200°C during 1 min. Finally, a lacquer formulation was added and dried at 120°C during 15s.

2.2. Tests
A Nicolet Avatar 360 FTIR spectrophotometer with ATR was used to record the spectra of the synthetic leather samples. To characterize the PCMs, KBr pellets were prepared. The IR spectra were collected at a 16 cm⁻¹ resolution, with 60 scans, over the range 400–4000 cm⁻¹.

Viscosity of the coating formulations were determined by Rheomat 115 Viscometer with coaxial measuring system. PCMs and materials with PCMs were analysed according to ASTM D 3417:83 in a DSC TA Instrument. The temperature distributions of the samples with and without PCMs (pre-heated at 40°C, time considered as zero, and then cooled to room temperature) were evaluated by an infrared and visible camera Fluke Ti25. The images were downloaded using Fluke SmartViewTM software.

The thermal conductivity, thermal resistance and thermal absorptivity of the materials were used to characterize thermal comfort and were carried out using ALAMBETA instrument according to ISO EN 31092-1994 standard procedure. Thermal physiological comfort was analysed using thermal manikin and the tests were made according to the described requirements of ISO 15831 standard test.
All tests included in BMW 9,210,275; Edition / Version 4, 2010-10-01 standard were performed.

3. Results and Discussion

PCMs were introduced in synthetic leather by direct incorporation into PVC compact and foaming layers, as well as into adhesive and lacquer formulations. The viscosity of each PVC paste was analysed at 20±2°C and compared with similar formulation without PCMs. In Figures 1 and 2 it is possible to observe that viscosity of foaming and adhesive formulations did not change even when a concentration of 10% of PCMs was used. Similar results were observed for compact and lacquer preparations. Consequently, application process wasn’t influenced by PCMs incorporation on polymer formulation, on what viscosity of the paste is concerned.

![Figure 1. Viscosity of foaming formulation with different PCM concentrations (0%, 5%, and 10%).](image1.png)

The FTIR spectra of the synthetic leather samples are complex due to the different compounds included in the coating. However, it is possible to identify the C-Cl stretching vibration peak at ~610 cm⁻¹ characteristic of PVC (results not shown).

DSC equipment is used to evaluate melting temperature and latent heat of PCM (free or incorporated in material) during the exothermic or endothermic phase transition process. Figures 3 and 4 show the DSC thermograms of PCMs and the synthetic leather with PCMs incorporated according to the description presented in materials and methods. The latent heat of PCMs was confirmed to be around 276 J/g (Figure 3). Therefore, the melting temperatures of PCMs and synthetic leather with PCMs were recorded at 29.97°C and 29.07°C respectively. The temperature change on this phase is appropriate to the envisaged application regarding the comfort provided to human body [12].

![Figure 3. Thermograms of PCMs](image3.png)

![Figure 4. Thermograms of synthetic leather with PCMs](image4.png)
The synthetic leather with incorporated PCM presents a melting enthalpy of 7.38 J/g (Table 1). The cooling curve represents exothermic phase transitions in lower range of temperature when compared with its endothermic fusion range (Table 2). Similar behaviour was reported by other researchers for different paraffin waxes. Onder and co-workers analysed n-eicosane, n-hexadecane and n-octadecane, alone, combined between them or with PEG600 or PEG 1000 and they found that the polymer ordered structures were gradually changing towards the disordered structures in liquid phase during heating. However, heterogeneous structure behaviour was noted in phase transitions during cooling. Additionally, multiple crystallization peaks were observed due to the regain by some capsules of the heat released by others [13].

**Table 1.** Differential scanning calorimetry results of synthetic leather with PCM

| Melting point (°C) | Melting enthalpy (J/g) | Crystallization point (°C) | Crystallization enthalpy (J/g) |
|-------------------|------------------------|----------------------------|-------------------------------|
| 29.07             | 7.38                   | 21.71/15.86                | 4.4/2.74                      |

The thermal conductivity, thermal resistance and thermal absorptivity that characterize thermal comfort of fabrics were carried out using Alambeta instrument. The average values calculated for each parameter are shown in table 6.

**Table 2.** Thermal conductivity (**λ**), thermal diffusivity (**a**), thermal absorptivity (**b**), maximum heat flow (**q**\textsubscript{max}) and thickness of coating (**h**) of tested materials

| Material                                      | λ (W/mºK) | a (m\textsuperscript{2}/s) | b (Ws\textsuperscript{1/2}/mºK) | q\textsubscript{max}(W/m\textsuperscript{2}) | h (mm) |
|-----------------------------------------------|-----------|-----------------------------|----------------------------------|---------------------------------------------|--------|
| Synthetic leather                             | 66.2      | 0.076                       | 240                              | 1.20                                        | 1.22   |
| Synthetic leather with 5% (w/w) of PCMs       | 71.2      | 0.052                       | 306                              | 1.24                                        | 1.01   |
| Synthetic leather with 10% (w/w) of PCMs      | 71.6      | 0.054                       | 313                              | 1.28                                        | 1.12   |

According to the expectations, the materials with PCMs are characterized by high values of thermal conductivity (**λ**). However, the increase of PCMs concentration doesn’t mean a significant increase in the quantity of heat flux transmitted through the material (**q**\textsubscript{max}).

The thermal absorptivity (**b**) is a surface property which allows to define the material’s character in terms of “cool/warm” feeling sensation when human skin briefly touches the material [14]. In this sense, a low thermal absorptivity value means that the material is warm and a higher absorptivity value means that it is cool. Thus, synthetic leather with PCMs is cooler than the material without PCMs. Moreover, there is no significant difference between the value of the thermal absorption of the material with 10% and 5% of PCMs.

The surface temperature of the material was measured by thermography. Materials (with and without PCM) were placed simultaneously in infrared camera and the results of the variation of their temperature with time showed significant differences between samples with and without PCMs during the cooling process (results not shown).

The differences of temperature of surface of samples are observed after 1 minute and 51 seconds, 2 minutes and 12 seconds, 2 minutes and 30 seconds and 2 minutes and 53 seconds, after infrared heating. As it is observed in Figure 5 the cooling takes only a few minutes. Heating the sample with PCMs is slightly shorter than that without PCMs when placed on IR camera in similar conditions.
However, in both materials tested the temperature falls quickly to 25°C. Besides, the drop of temperature in the material without PCMs is slower than in the material with PCMs.

![Figure 5](image)

**Figure 5.** Sample thermograms during the cooling process; after 1 minute and 51 seconds; after 2 min 12 sec; after 2 min 30 sec; after 2 min 53 sec. Left side of each image is the material without PCMs and right side the material with PCMs.

The biophysical analysis of synthetic leather covering an automobile seat was analyzed by using a thermal manikin in a climatic chamber. The difference between the materials with and without PCMs was evaluated in terms of heat flow (W/m²) when subjected to different temperatures. After stabilization of practical conditions, a temperature scan (23°C to 30°C) was made. As observed in figures 4 and 5, the material with PCMs has a slightly lower temperature than without PCMs.

Moreover, the body temperature recovery was faster in the case of material with PCMs as observed in figures 6 to 9 obtained from thermal manikin trials. The thermoregulatory response was focused on four skin zones (buttocks, back and thighs) assuming the user was seated on the car. For each body section, temperature and heat flux are measured.

![Figure 6](image)

**Figure 6.** Total buttocks heat loss when manikin was seated on chair with material with PCMs (....) and (___) without PCMs

![Figure 7](image)

**Figure 7.** Total heat loss of back when manikin was seated on chair with material with PCMs (....) and (___) without PCMs.
Figure 8. Total heat loss of right thigh when manikin was seated on chair with material with PCMs (...) and (__) without PCMs.

Figure 9. Total heat loss of left thigh when manikin was seated on chair with material with PCMs (...) and (__) without PCMs.

These results indicate a higher thermal comfort for the user in the summer when material with PCMs integrates the composition of a vehicle seat.

4. Conclusions
The information gathered in the present study suggests that the PCMs was successfully incorporated into synthetic leather without problems concerning process ability. Durability of the effect must be confirmed.

The synthetic leather with PCM took longer to reach a specified temperature and cooling conditions as illustrated in images of Figure 1 for the different samples tested. It is also cooler to the touch (higher thermal absorbity and heat flux). Additionally, the results concerning the thermal properties showed that the new material allowed greater thermal comfort to the user than the synthetic leather without PCMs.

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