Journal of Engineering Science and Technology
Vol. 11, No. 12 (2016) 1818 - 1834

ENGINEERING DESIGN: EICOSANE MICROCAPSULES SYNTHESIS AND APPLICATION IN POLYURETHANE FOAMS AIMING TO DIMINISH WHEELCHAIR CUSHION EFFECT ON SKIN TEMPERATURE

ELISA M. BERETTA[1,*], WAGNER S. ROSSI[1], WILSON KINDLEIN JR[1], LIANE ROLDO[1], TATIANA L. AVILA DE CAMPOS[2]

[1]Laboratory of Design and Material Selection, School of Engineering, UFRGS Av Osvaldo Aranha, 99, Porto Alegre-RS, Brazil
[2]Materials Engineeginrg, Unisinos. Av. Unisinos, 950, São Leopoldo-RS, Brazil
*Corresponding Author: elisa_beretta@yahoo.com.br

Abstract

Thermal comfort of wheelchairs still requires improvements, since users remain on the chair for as long as 12 h a day. Increased sweating makes the skin more susceptible to colonization by fungi and bacteria, and may cause pressure ulcers. In this sense, the microencapsulation of Phase-Change Materials (PCMs) may help to enhance wheelchair cushion comfort by regulating heat exchange. This study describes the production of PCM microcapsules and their application in flexible polyurethane foams after expansion, and assesses improvements in heat exchange. Microcapsules with eicosane core coated with melamine-formaldehyde were produced. Eicosane is a thermoregulation agent whose phase-change temperature is near that of the human body's. Microcapsules were characterized by thermogravimetric analysis, differential scanning calorimetry, scanning electron microscopy, and Fourier transform infrared spectroscopy. Then, microcapsules were applied on polyurethane foams by vacuum filtration and high-pressure air gun. Samples were exposed to a heat source and analysed by infrared thermography. The results indicate that thermal load increased in samples treated with microcapsules, especially by pressure air gun, and show that it is possible to enhance thermal comfort in wheelchair seats. Thereby, this study contributes to enhance quality of life for wheelchair users, focusing on thermal comfort provided by cushion seats made from PU foam.

Keywords: Eicosane microcapsules, Flexible polyurethane foam, Thermal comfort, Wheelchair cushion effect, Engineering design

Abbreviations

DSC	Differential Scanning Calorimetry
FTIR	Fourier Transform Infrared Spectroscopy
PCM	Phase Change Material
PU	Polyurethane
SEM	Scanning Electron Microscope
TGA	Thermogravimetry

1. Introduction

Considerable research efforts are made to enhance thermal comfort of structures made of flexible polyurethane (PU) foams, like seats cushions and beds [1 - 3]. The contact surface with users plays an important role in the heat and moisture dissipation from the skin. Most studies on thermal comfort seats are carried out covering automotive and aerospace applications [4, 5], aiming not only to improve comfort, but also foam preservation, since heat and humidity degenerates foam structure, reducing the product's life cycle.

Wheelchair users are even more affected by the thermal conditions of their cushions, as they remain seated for the most part of the day. This shows the importance of maintaining optimal microclimatic conditions between the skin and contact surfaces. Wheelchair cushions should address the specific requirements by different individuals, including managing comfort, tissue integrity, postural control and alignment and functional enablement [6].

Previous studies have shown that thermal comfort is one if the issues faced by wheelchair users [7, 8]. In order to regulate the temperature on the skin-seat interface, materials like PU foams may be coated with Phase-Change Materials (PCMs), which absorb or release latent heat, ensuring that the temperature remains constant during phase change [9 - 13]. A wide range of organic and inorganic PCMs is known, but the most used for thermal comfort belong to the paraffin family, within the temperature range of 18-37°C (n-Octadecane, n-Hexadecane, n-Nonadecane, n-Eicosane) [12]. Nevertheless, PCM applicability is limited by the change from solid to liquid state, which may result in material contamination as well as PCM loss [14, 15].

The application of PCMs on other materials is usually performed by microencapsulation, which creates a barrier that ensures phase change without damaging the base material [14]. Microencapsulation of PCMs shows a number of advantages, such as lower interference towards phase-change behaviours from the outside environment, controlled volume change, and increased heat transfer area [12 - 15].

Microcapsules are tiny particles with size range of 1-1000 μm in diameter, with an active substance (core) protected by a shell [14 - 17]. Effective encapsulation is mostly provided by a thick shell [15]. The performance of the microcapsule is influenced by the process parameters, which can dictate morphology, chemical nature and shell surface [16]. Most of microcapsules are produced with a polymer shell [15, 18] through the suspension, interfacial, and *in situ* polymerization methods [13].

Recent studies [11- 14, 16, 18, 19] have described the processes currently used to produce PCM microcapsules. Mohaddes et al. [18] studied the amount of heat exchanged by microcapsules, by microencapsulated PCM via ultra-homogenisation of concentrated eicosane emulsion. Marcuzo [19] obtained eicosane microcapsules with a polymeric shell according to the *in situ* method, although the thermoregulation effect was not further discussed. Zhang et al. [13] produced eicosane microcapsules with a shell, with dual function: protection and photoluminescence. Jiang et al. [14] also obtained a dual function shell, with magnetic properties. However, in the present study photoluminescence and magnetic characteristics were not considered interesting properties in terms of wheelchair thermal comfort.

Microencapsulated PCMs have been used in PU foams focusing on the thermal comfort of buildings [20 - 23], as well as in textiles for the apparel industry [13, 14, 18, 24 - 27]. In flexible foams, microcapsules have been most commonly applied during the polymerization reaction, which promotes the dispersion of particles in the polymer matrix. In most of these processes, microcapsules are added and vigorously mixed to the polymer, whereupon a catalyzer is supplied, also with intense shaking, for a short time span (between 5 and 10 s). The resulting mixture is left to rest for about 1 min, for the foam to form and swell [11].

However, when the aim is to produce custom seats for wheelchair users, for whom posture is an essential factor, the geometry of the user is copied by 3D scanning system and milled into the PU foam, replicating the user's body [29]. A considerable amount of foam is wasted in the production of customized wheelchair seats. If the microcapsules were applied before the foam is milled, material would be wasted, increasing final cost. In order to reduce microcapsule waste, a method to insert microcapsules after the polymerization reaction was considered. Marcuzzo [19] applied eicosane microcapsules into PU foams through impregnation. Samples were immersed into a solution with water and microcapsules and submitted to mild agitation. The quantity of microcapsules was not specified. Similarly, the rate of microcapsules that were impregnated in the foam is also unknown.

Therefore, the present study describes the production and application of PCM microcapsules in PU foams after expansion, and characterizes thermal comfort of the product using infrared thermography (IR). The rationale of this study is to enhance quality of life for wheelchair users, since most part of the disabled population does not have access to custom equipment in Brazil.

2. Materials and Methods

Flexible PU foam was chosen as seat material, as it is widely used for wheelchair custom seats. The flexible PU foam used presented density of 50 kg/m^3, the most widely used to manufacture wheelchair seats. The material was cut to 1-cm-thick and 10-cm-diameter samples. Microcapsule core was produced with eicosane, since the material's phase-change temperature is approximately 37 ^{o}C (the normal human body temperature), crystallization temperature is 30.6 ^{o}C, and phase-change heat is 247 kJ/kg [7, 16].

The emulsion to produce microcapsules was prepared using 200 ml deionized water, 1 g Tween 20 (polyoxyethylene sorbitan monolaurate 20) as surfactant emulsifier, 3 g eicosane, and acetic acid (as much as needed to adjust pH). The pre-polymer was prepared with 7 ml deionized water, 6 ml formaldehyde, 2.5 g melamine, and a 60% triethanolamine solution. The microcapsule solution was made with between 4 g and 8 g microcapsules, 45 ml deionized water, and 2.5 ml water-base resin (instead of solvent-base, which could damage the foam structure). The resin was used to ensure the adhesion of microcapsules onto the foam.

2.1. Production of microcapsules

Microcapsules were produced by *in situ* polymerization, which, in most cases, is carried out in an aqueous medium prepared with a dispersal agent (water), the monomer, a surfactant, and an initiator. The reaction conditions were based on previous studies by Escobar et al. [28].

Initially, 200 ml deionized water were added to a 600-ml double-wall beaker. Then, the surfactant was supplemented, and the mixture obtained was completely mixed. The hoses of a double bath were connected to the plugs of the beaker, and the bath temperature was adjusted to 60ºC. In another container, eicosane was melted using a magnetic mixer at 60ºC. The melted paraffin was added and mixed with the contents of the beaker, which were already hot. The mixture produced was transferred to another beaker and placed in an ultrasonic processor (Cole Parmer CP 750) set at 60% amplitude for 10 min. The solution pH was adjusted to 4.5 using acetic acid.

To prepare the pre-polymer mix, 7 ml of deionized water were placed in a 50-ml beaker. Then, 6 ml formaldehyde was added, and the solution was heated to 70ºC in magnetic mixer using a suitable rod, under mild stirring. Melamine was added and thoroughly mixed in, until the solution became clear. The pH of the mixture was adjusted to 8.5 using a triethanolamine solution.

To produce the microcapsules, the emulsion and the pre-polymer were mixed as above, and shaken in a mechanical shaker at 500 rpm. The pre-polymer was added slowly, using a dropping funnel. Next, the mixture was stirred for 1.5 h, when speed was reduced to 100 rpm and pH was adjusted to 9.0 using triethanolamine. The stirring time was kept constant until the specified pH was achieved. The solution was then placed in a centrifuge and spun at the equipment's top speed for 20 min, in order to separate phases. The liquid phase was disposed of by filtration, while the solid phase containing the microcapsules was dried in a desiccator. Figure 1 shows a flowchart to represent the production steps.

The microcapsules obtained were applied on the PU foam samples, which were weighed before and after application to assess mass variation.

2.2. Application of microcapsules

Microcapsules were applied on the whole sample, in order to guarantee the generation of uniform microclimatic conditions across the material. Two application techniques were tested. First, microcapsules were applied by vacuum using a 10-cm Büchner funnel, a Kitasato flask, and a vacuum pump. The foam

sample was accurately fit onto the Büchner funnel, which was placed on the top of the Kitasato flask, where the vacuum pump hoses were plugged onto (Fig. 2). Sample 1 was produced using 2.5 g resin and 45 ml deionized water and without microcapsules, in order to evaluate whether the resin interfered in the thermoregulation capacity of the foam. Then, 4 g microcapsules were diluted in deionized water and water-based resin to prepare sample 2. The mixture was poured on the foam, and the samples thus obtained were left to dry for 48 h in a controlled environment (20ºC, 40% relative humidity).

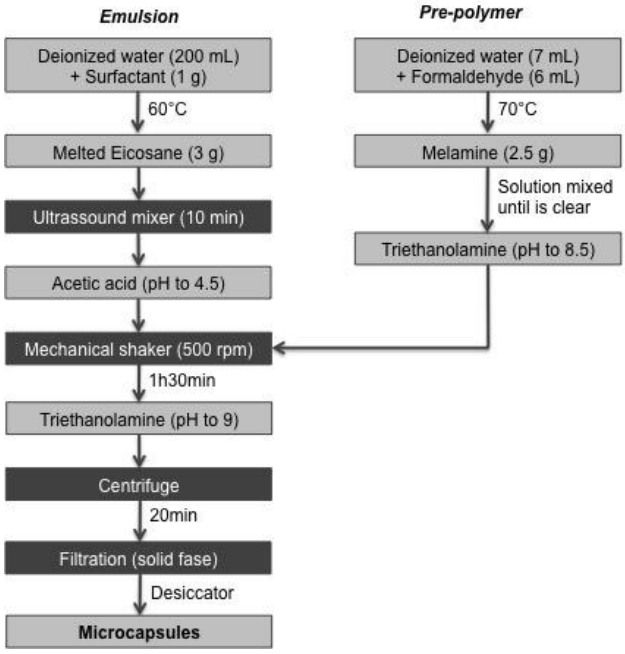


Fig. 1. Production steps flowchart.

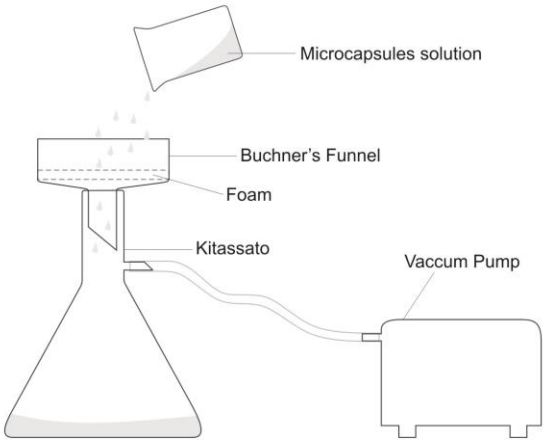


Fig. 2. Schematic of the application of microcapsules by vacuum.

The second method of application consisted of using a high-pressure air gun for painting (HVLP TMX PPG14). The system was gravity-fed, and the 1.4-mm gun nozzle afforded a 180- to 260-mm stroke length at 190 ml/min and a working pressure of 30 to 43 psi (3 bar). Microcapsules were diluted in the water and resin mixture at the same ratio as used in the vacuum method (section 2.1), though three tests were carried out. For each test, mixtures were placed separate gun containers and sprayed on the samples, as shown in Fig. 3.

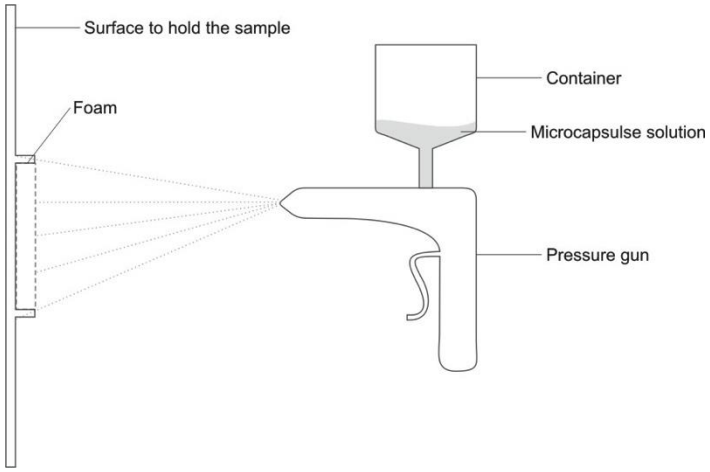


Fig. 3. Schematic of the application of microcapsules by high-pressure air gun.

Sample 3 was prepared by spraying a mixture of 4.0 g microcapsules, 2.5 g resin, and 45 ml deionized water on one side of the foam. Sample 4 was made applying a mixture of 8 g microcapsules and 45 ml deionized water. This preparation was divided in two parts, which were applied bilaterally, on both sides of the foam so as to ensure that microcapsules were able to reach the midsection of the foam. Sample 5 was prepared with 8 g microcapsules, 2.5 g resin, and 45 ml deionized water applied as in Sample 4, on both sides of the foam. The aim was to evaluate the influence of resin on the thermal effect of the PU foam. As above, samples were left to dry in a controlled environment (20ºC, 40% relative humidity). Sample 00 was used as standard for later comparison, thus it was not sprayed with microcapsules or resin. All samples made can be seen in Table 1.

Table 1. Samples obtained for thermography analysis

	Method	Microcapsules (g)	Resin (g)
Sample 00	-	-	-
Sample 1	Vacuum filtration	-	2,5
Sample 2	Vacuum filtration	4	2,5
Sample 3	Air gun	4	2,5
Sample 4	Air gun	8 (4 on each side)	-
Sample 5	Air gun	8 (4 on each side)	2,5

2.3. Characterization of microcapsules and methods of application

Scanning Electron Microscopy (SEM), Thermogravimetric Analysis (TGA), and Differential Scanning Calorimetry (DSC) were used to characterize the microcapsules. SEM affords to visualize the formation, the morphology, and the size of microcapsules. In turn, TGA evaluates the variation in mass with time, while DSC measures the difference in energy provided to a substance against a reference material (which, in this case, has to be thermostable), as a function of temperature.

TGA was used to analyse the microcapsules produced, the core material (eicosane), and the melamine-formaldehyde shell, in two different gaseous media (air and an inert gas). DSC also was used to evaluate these samples. Since the thermal stability of samples was unknown, a wide set of TGA parameters was chosen. The analysis started at 35ºC, with a 10ºC/min heating gradient, up to 700ºC. DSC started at -40ºC, with a 2-min isothermal cycle. A 10ºC/min heating gradient was adopted until the temperature of 110ºC was reached. Another 2-min isothermal cycle was observed, followed by a 10ºC/min cooling gradient, down to -40ºC.

SEM was utilized to observe whether microcapsules had permeated onto the foam samples and how they were dispersed. IR spectra of eicosane, of the melamine-formaldehyde shell, and of macerated microcapsules were obtained by Fourier Transform Infrared Spectroscopy (FTIR) in order to detect traces of the compound in microcapsules and, therefore, prove that the substance was indeed microencapsulated.

IR thermography was used to assay the thermoregulatory capacity and thermal dissipation of foams with eicosane microcapsules. Samples were heated in an oven for 12 min at 40ºC, which is near the phase-change temperature of eicosane. The samples were removed from the oven, and thermographs were immediately obtained from their surfaces. The measurement was repeated while samples were cooling down, at 2-min intervals.

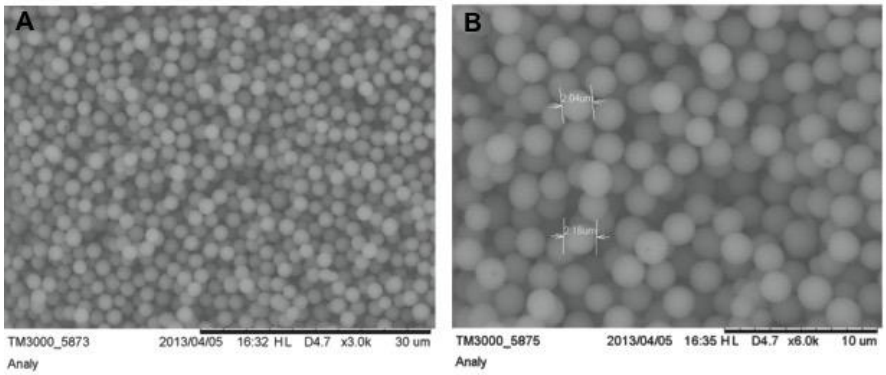
3. Results and discussion

3.1. Characterization of microcapsules

The microcapsule production process afforded satisfactory results, with minimal losses. SEM analysis showed that microcapsules had uniform morphology, as observed in Fig. 4(a), and varied little in size, between 2.04 μm and 2.16 μm, with mean size of 2.1 μm, as shown in Fig. 4(b). The parameters that were critical in the production process of the microcapsules was eicosane state and pre-polymer addition to the emulsion. Since it is essential that eicosane remains liquid throughout the process, the temperature inside the beaker has to remain under constant control. The pre-polymer was added using a dropping funnel at 3-s intervals. The shell did not form when the pre-polymer was added at longer intervals.

Microcapsules size and morphology are influenced by the surfactant, as previous work from Escobar et al. [28] has shown. This study indicates that Tween 20 affords better microcapsule formation, compared with emulsifiers such as CTAB (cetyl trimethylammonium bromide) and SLS (sodium lauryl sulfate). It

also showed that Tween 80 (polyoxyethylene sorbitan monooleate 80) has very rough surface, compared with the other emulsifiers.



(a) 3,000 x magnification. **(b) 6,000 x magnification.**

Fig. 4. SEM image of microcapsules with eicosane core.

TGA revealed that residual mass of the material decreases with increasing temperature, as expected, due to material degradation, plotted in Fig. 5.

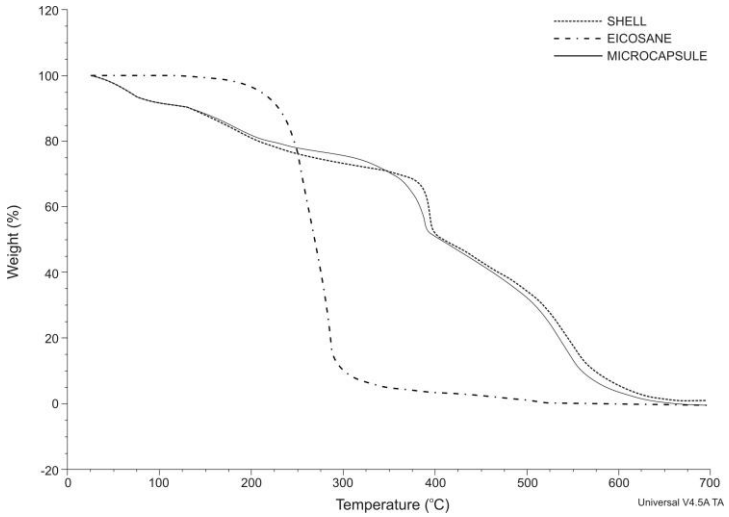


Fig. 5. TGA thermogram of eicosane, shell and microcapsule.

The eicosane thermogram showed that mass loss occurs at one stage only, starting at around 200ºC and ending at 325ºC, which corresponds to the temperature interval in which eicosane decomposes. A very small loss of material was observed at approximately 500ºC. In turn, the thermogram of the melamine-formaldehyde shell has four perceptible slopes associated with different moments in the mass loss process typical of a thermoset polymer. There are two slopes that indicate low mass loss, near 60ºC and 150ºC, which normally are linked with the

volatilization of water, with residual reactants, and with low molecular weight oligomers. However, a significant mass loss was observed at 380ºC and onwards, due to the decomposition of melamine-formaldehyde. Therefore, the temperature at which eicosane starts to loose mass significantly is much lower than that observed for melamine-formaldehyde, which indicates that the thermal stability of the shell prepared is better than that of pure eicosane. This finding justifies the microencapsulation of eicosane with a melamine-formaldehyde shell as a means to protect the microcapsule core. The thermogram of microcapsules presented a similar pattern to that of the shell, confirming that the shell produced is thick enough to protect the core material against thermal decomposition.

The thermal properties of microcapsules were analysed using a calorimeter in order to observe the phase change of the material. The curves are presented in Fig. 6. For the sake of comparison, eicosane, shell, and the eicosane microcapsules obtained were analysed in separate.

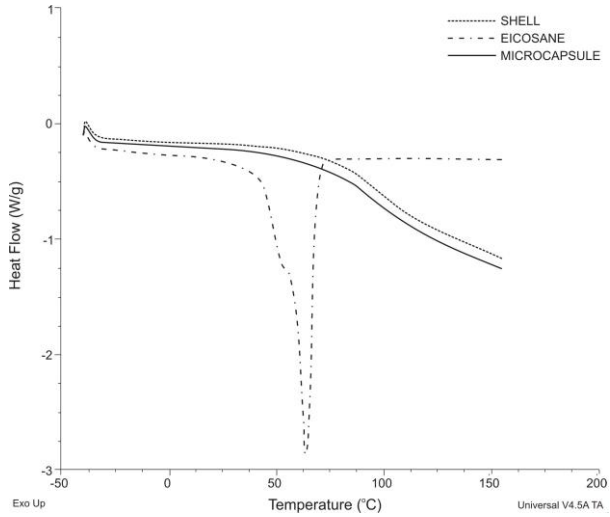


Fig. 6. DSC curve for microcapsule, eicosane, and shell.

Figure 6 shows the DSC curve for microcapsules. The DSC curve for eicosane showed that the temperature at which PCM phase change occurs is 56.86ºC. The endothermal peak area corresponded to the fusion heat of eicosane during phase change (185 J/g). The microcapsule curve showed that this material behaves similarly to the melamine-formaldehyde shell. This proved that the shell, whose thickness was appropriate for this end, protects the eicosane core.

FTIR spectra are plotted in Fig. 7. In the macerated microcapsule spectra, a remarkable peak was observed near 2953.66 cm^{-1}. This was not observed in the spectra obtained for the shell. This peak may be associated to the eicosane peak shown in its spectra. This indicates that eicosane was encapsulated in the microcapsules.

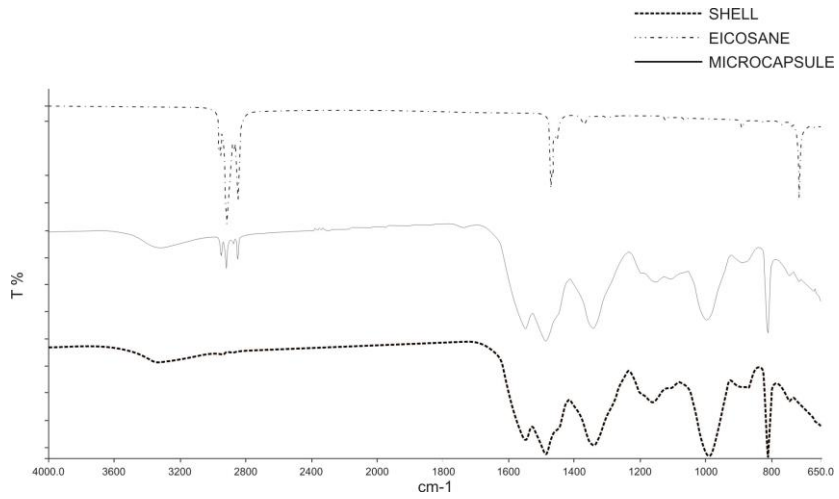


Fig. 7. FTIR spectra of macerated microcapsule, eicosane, and shell.

3.2. Characterization of the methods used to analyse the samples after the application of microcapsules on PU foam

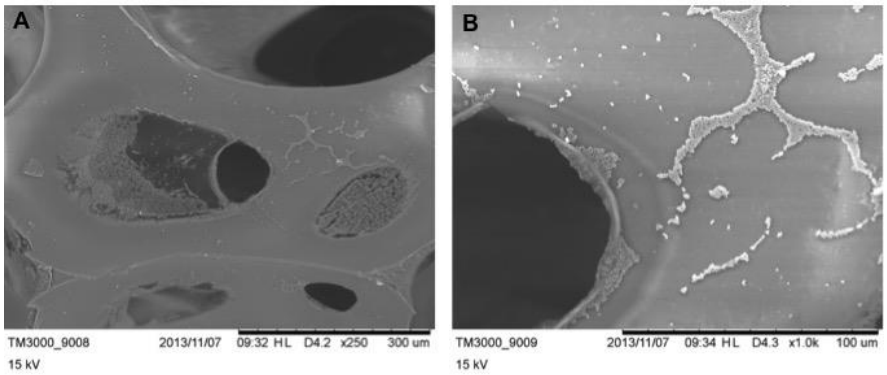
Samples were weighed before and after application of microcapsules. Table 2 shows that mass gain in the samples in which the microcapsules were applied by vacuum filtration was lower, compared to the application by high-pressure air gun. This indicates that vacuum filtration is not as effective as a means of delivering microparticles used as thermoregulating material. A control sample, called sample 00, did not receive microcapsules and weighed 4.382 g.

Table 2. Mass of PU foams before and after application of microcapsules

	Before application (g)	**After application (g)**
Sample 00 (no application)	4.382	-
Sample 1 (2.5g resin)	4.206	8.953
Sample 2 (4 g microcapsules, resin; vacuum filtration)	4.362	5.410
Sample 3 (4 g microcapsules, resin; air gun)	5.518	11.497
Sample 4 (8 g microcapsules, 4 g on each side, no resin; air gun)	5.091	9.357
Sample 5 (8 g microcapsules, 4 g on each side, resin; air gun)	5.715	13.295

SEM analysis was carried out in dry samples. It is important to note that the heat dissipation capacity of a PU foam is due to its beehive structure. Therefore, the voids should not be filled with microcapsules, which ideally are to be spread onto the outer surface of the foam, enhancing this material's thermoregulatory power.

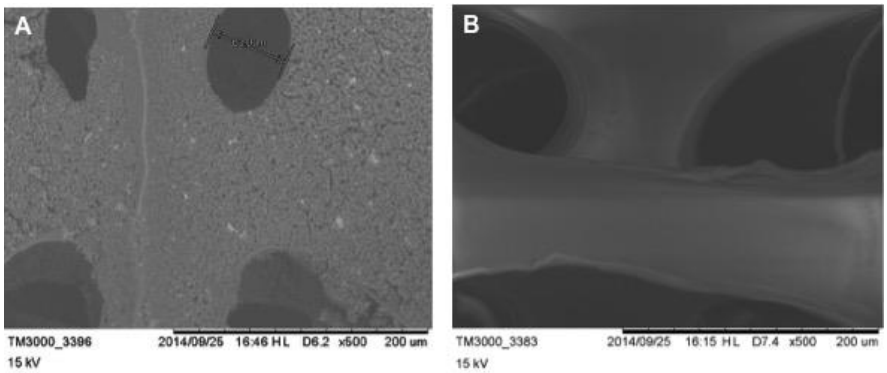
The SEM images of sample 2 (application by vacuum filtration) show that microcapsules permeated onto the cellular structure of the material, as observed in Fig. 8(a). Microcapsules were anchored on the surface of foam material itself, leaving the voids free, not obstructing heat dissipation. Figure 8(b) reveals how microcapsules permeated onto the surface of the foam, as small patches.



(a) 250 x magnification. **(b) 1,000 x magnification.**

Fig. 8. SEM image of eicosane microcapsules applied by vacuum filtration on PU foam (clusters of capsules around and inside the polyurethane foam orifices).

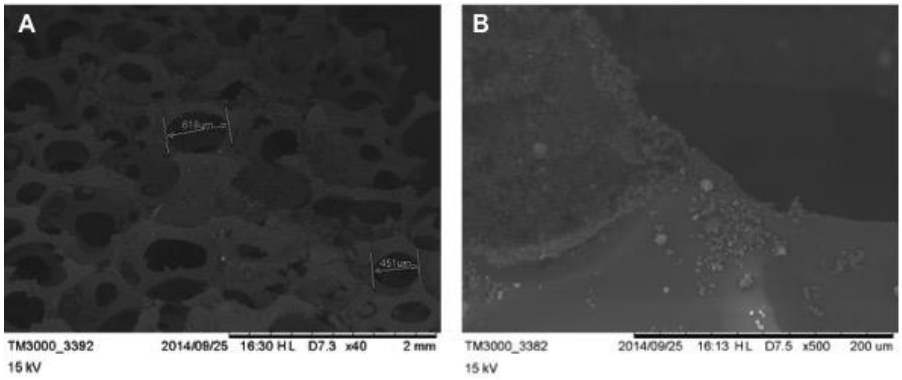
Sample 3 (air gun application on one side of the foam only) showed that particles permeated only onto the foam surface, in which microcapsules were directly applied, as observed in Fig. 9(a). The back side of the sample did not exhibit the presence of microcapsules, showing that application by air gun did not afford sufficient pressure to make microcapsules cross the foam layer. Figure 9(b) shows the black side of the foam with no microcapsules. The pressure applied by the pressure gun was not high enough to induce damage to the foam structure.



(a) Front side (500 x magnification). **(b) Back side (500 x magnification).**

Fig. 9. SEM image of eicosane microcapsules applied by air gun on one side of a PU foam (sample 3).

Permeation in samples 4 and 5 was comparatively more uniform, with microcapsules applied on the two surfaces of the foam. However, the patches formed more sparsely, Fig. 10(a), because the mixture was divided in two parts, which altogether reduced the concentration of microcapsules on each side. Figure 10(b) shows the back side of the foam, with patches of microcapsules, as observed in the sample on which microparticles were applied by vacuum. However, the amounts are higher, proving that the high-pressure air gun is more effective than the vacuum system.



(a) Front side (40 x magnification). (b) Back side (500 x magnification).

Fig. 10. SEM images after application of eicosane microcapsules by air gun on one side of a PU foam (sample 4).

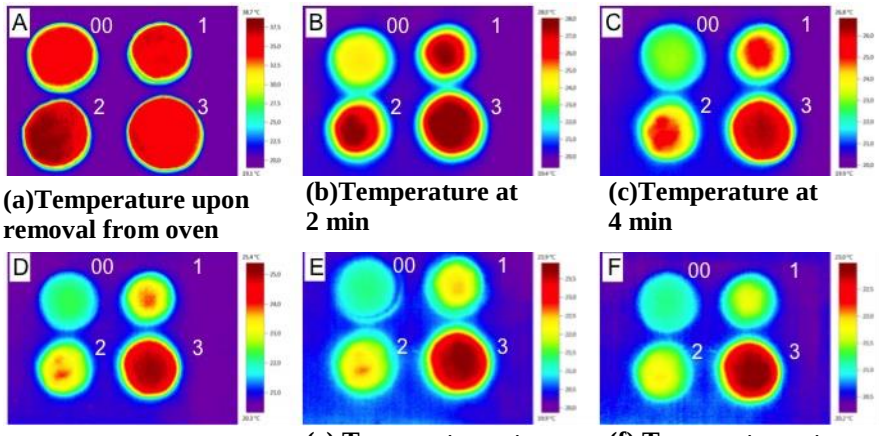
Previous research by Marcuzzo [19] performed the first tests concerning the application of microcapsules in flexible PU foam. The results showed that the application through immersion process was not efficient because of the leftover microcapsules on the surface of the PU foam. The tested methods of the present study showed that the air gun process is more efficient in terms of microcapsule waste, as the microcapsules are applied directly on the foam surface. Nonetheless, the vacuum process showed waste, as the solution with microcapsules passed through the foam, therefore, not all microcapsules were impregnated into the foam structure, same as previous studies presented [19].

3.3. Characterization of the foams thermal effect

A thermographic analysis was carried out on all the samples prepared. Sample 1 (only resin) and the sample not treated with microcapsules (sample 00) were included for comparison. Figure 11 shows the images generated.

The temperatures of all samples when they were removed from the oven were similar, around 36.7ºC. After 2 min, the temperature of the sample 00 dropped to 24.8ºC. In the same interval, the temperature of samples 1, 2, and 3 fell to 27.1ºC, 27.6ºC, and 28.0ºC, respectively. After cooling for 4, 6 and 8 minutes the temperature drop begins to differentiate samples, as shown in Figs. 11(c), (d), and (e). Samples 1 and 2 had similar thermoregulatory capacities, which indicate that the resin influences this attribute. Sample 3, as previously analysed in SEM

images, had the highest amount of microcapsules, and the best thermoregulatory effect. This sample had the lowest heat loss, reaching 23ºC, while samples 1 and 2 reached 20.8ºC, as shown in Fig. 11(f). Previous studies [19] demonstrated that resin did not influence the thermoregulatory effect. Oppositely, although the resin exhibited such ability in the present study, it was not as significant as that observed for the microcapsules.



(a)Temperature upon removal from oven

(b)Temperature at 2 min

(c)Temperature at 4 min

(d) Temperature at 6 min

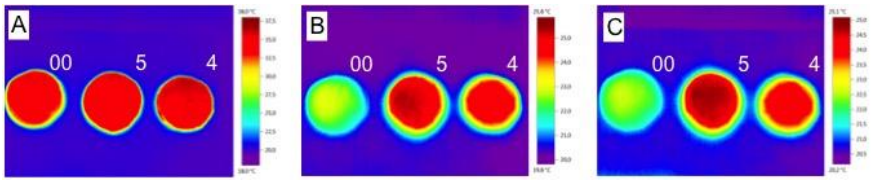
(e) Temperature at 8 min

(f) Temperature at 12 min

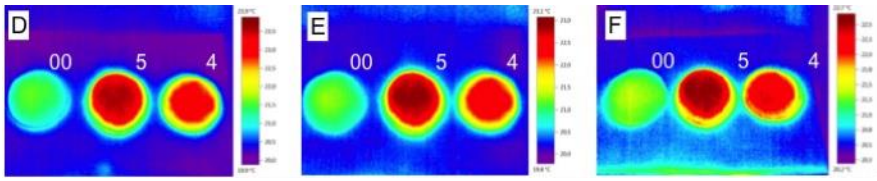
Fig. 11. Thermography images of samples 00, 1, 2 and 3 (clockwise).

Samples 00, 4 and 5 were analysed by thermography to evaluate the influence of resin in heat dissipation (Fig. 12). The first measurement was made immediately after samples were removed from the oven, as illustrated in Fig. 12(a). Figure 12(b) shows the samples 2 minutes after cooling. The temperature of sample 00 was 36.4ºC. Samples 4 and 5 were at 37.8ºC and 38ºC, respectively in Fig. 12(b). A 12ºC drop in temperature was observed for sample 00. In turn, the temperatures of samples 4 and 5 decreased by 10ºC and 9.5ºC. In the third, fourth and fifth measurements (4 and 6 min after removal from the oven), illustrated by Figs. 12(c), (d) and (e), the temperatures fell by 3ºC in sample 00, by 2ºC in sample 4, and 1.8ºC in sample 5. In the fifth measurement, 8 min after samples were removed from the oven, temperature drops were constant, shown in Fig. 12(e). The sixth measurement was made after 12 min, when it was observed that samples 4 and 5 had a smaller temperature decrease, compared with sample 00, as shown in Fig. 12(f).

The variation in the temperature of sample 00 was 16ºC, and the mean temperature drop of 13ºC for the other samples. The maximum temperatures at the last measurement was 23ºC for sample 5 and 22.6ºC for sample 4, showing that resin influences the thermoregulating effect of foam, though microcapsules also increased this property. A considerable amount of the microparticles in the sample where they were applied by vacuum did not adhere to the foam, remaining in solution. It may be concluded that microcapsules improve the thermal properties of the material.



(a) Temperature upon removal from oven **(b) Temperature at 2 min** **(c) Temperature at 4 min**



(d) Temperature at 6 min **(e) Temperature at 8 min** **(f) Temperature at 12 min**

Fig. 12. Thermography images of samples 00, 5 and 4.

4. Conclusions

This article discussed the options of application of microcapsules in PU foams, minimizing the waste of microcapsules observed when foams are used in the production of customized seats for wheelchairs. It was concluded that:

- Eicosane microcapsules, whose phase-change temperature is similar to that of the human body, increase the thermoregulatory effect of this material.
- The application by vacuum filtration spreads microcapsules evenly across the foam, though a considerable amount is lost, since the microparticles cross the foam voids.
- Application using high-pressure air gun is thermally efficient. The thermoregulatory effect generated when microcapsules are applied on one front side only is similar to that obtained in foams in which microparticles were applied by vacuum filtration, because they concentrated on one side only.
- The thermoregulatory effect generated in foams was similar with both methods of applications, although the samples with microcapsules on both sides showed temperature slightly higher.

Eicosane microcapsules tend to diminish the wheelchair cushion effect on skin temperature, specifically in terms of thermoregulatory power of foams used in the seats of wheelchairs affords to improve the microclimate between the foam surface and the user, enhancing thermal comfort and mitigating the consequences of excessive heat, such as intense sweating. This effect should improve the quality of life of the wheelchair users and prolong the life cycle of foams used for this purpose. Further studies should be conducted to determine the amount of microcapsules that has to be applied on the foam so as to improve even more the thermoregulation process.

As a further development of this study, the influence of vibration in particle size and size distribution is being analysed in detail. In addition, the use of other emulsifiers, besides tween 20, is also under consideration to investigate particle formation.

Acknowledgements

The authors gratefully acknowledge the financial support of the Brazilian Research Agency CNPq - *Conselho Nacional de Desenvolvimento Científico e Tecnológico*.

References

1. Nicholson, G. P.; Scales, J. T.; Clark, R P.; Raymond, P.; Calcina-Goff, M. L. A. (1999). A method for determining the heat transfer and water vapour permeability of patient support systems. *Medical Engineering & Physics*, 21, 701-712.
2. Fazlollahtabar, H. (2010). A subjective framework for seat comfort based on a heuristic multi criteria decision making technique and anthropometry. *Applied Ergonomics*, 42, 16-28.
3. Liu, Z.; Cascioli, V.; Heusch, A. I.; McCarthy, P. W. (2011). Studying thermal characteristics of seating materials by recording temperature from 3 positions at the seat-subject interface. *Journal of Tissue Viability*, 20, 73-80.
4. Alahmer, A.; Abdelhamid, M.; Omar, M. (2012). Design for thermal sensation and comfort states in vehicles cabins. *Applied Thermal Engineering*, 36, 126-140.
5. Oi, H.; Tabata, K.; Naka, Y.; Takeda, A.; Tochihara, Y. Effects of heated seats in vehicles on thermal comfort during the initial warm-up period. (2012). *Applied Ergonomics*, 43, 360-367.
6. Hollington, J.; Hillman, S. J.; Torres-Sánchez, C.; Boeckx, J.; Crossan, N. (2014). ISO 16840-2:2007 load deflection and hysteresis measurements for a sample of wheelchair seating cushions. *Medical Engineering & Physics*, 36, 509-515.
7. Bulcao, C. F.; Frank, S. M.; Steven, M.; Rajab, S. N.; Srinivasa, N.; Tranc, K. M.; Goldstein, D. S. (2000). Relative contribution of core and skin temperatures to thermal comfort in humans. *Journal of Thermal Biololy*, 25, 147-150.
8. Prestes, R. C. (2011). *Tecnologia Assistiva: Atributos de Design de Produto Para Adequação Postural Personalizada na Posição Sentada*. MSc dissertation, Universidade Federal do Rio Grade do Sul, Brazil [in Portuguese].
9. Bajaj, P. Thermally sensitive materials. In: Tao, X. M. (Ed.). *Smart Fibres, Fabrics and Clothing*. (2001). Woodhead Publishing Ltd, Cambridge, England, p. 58-82.
10. Mäkinen, M. Introduction to phase change materials. In: Mattila, H. R. (Ed.). *Intelligent Textiles and Clothing* (2006). Woodhead Publishing LTD, Cambridge, England, p. 19-32.
11. You, M.; Zhang, X. X.; Li, W.; Wang, X. C. (2008). Effects of MicroPCMs on the fabrication of MicroPCMs/polyurethane composite foams. *Thermochimica Acta*, 472, 20-24.
12. Nejman, A.; Cieslak, M.; Gajdzicki, B.; Goetzendorf-Grabowskaa, B.; Karaszewska, A. (2014). Methods of PCM microcapsules application and the

thermal properties of modified knitted fabric. *Thermochimica Acta*, 589, 2014, 158-163.

13. Zhang, Y.; Wang, X.; Wu , D. (2015). Design and fabrication of dual-functional microcapsules containing phase change material core and zirconium oxide shell with fluorescent characteristics. *Solar Energy Materials & Solar Cells*, 133, 56-68.
14. Jiang, F.; Wang, X.; Wu, D. (2014). Design and synthesis of magnetic microcapsules based on n-eicosane core and Fe3O4/SiO2 hybrid shell for dual-functional phase change materials. *Applied Energy*, 134, 456-468.
15. Dao, T. D.; Jeong H. M. (2015). Novel stearic acid/graphene core-shell composite microcapsule as a phase change material exhibiting high shape stability and performance. *Solar Energy Materials & Solar Cells*, 137, 227-234.
16. Salaün, F.; Vroman, I.; Elmajid, I. (2012). A novel approach to synthesize and to fix microparticles on cotton fabric. *Chemical Engineering Journal*, 213, 78-87.
17. Gil, S.; Jiménez-Borja, C.; Martin-Campo, J.; Romero, A.; Valverde, J. L.; Sánchez-Silva, L. (2014). Stabilizer effects on the synthesis of gold-containing microparticles. Application to the liquid phase oxidation of glycerol. *Journal of Colloid and Interface Science*, 431, 105-111.
18. Mohaddes; F.; Islam, S.; Shanks, R.; Fergusson, M.; Wang, L.; Padhye, R. (2014). Modification and evaluation of thermal properties of melamine-formaldehyde/n-eicosane microcapsules for thermo-regulation applications. *Applied Thermal Engineering*, 71, 11-15.
19. Marcuzzo, L. C. (2012). *Obtenção, caracterização e aplicação de microcápsulas em espumas de poliuretano visando o conforto térmico para potencial uso na tecnologia assistiva*. MSc dissertation, Universidade Federal do Rio Grade do Sul, Brazil [in Portuguese].
20. Saha, M. C.; Kabir, M. E.; Jeelani, S. (2008). Enhancement in thermal and mechanical properties of polyurethane foam infused with nanoparticles. *Materials Science and Engineering*, 479, 213-222.
21. Borreguero, A. M.; Valverde, J. L.; Peijs, T.; Rodríguez, J. F.; Carmona, M. (2010) Characterization of rigid polyurethane foams containing microencapsulated Rubitherm RT27 Part I. *Journal of Materials Science*, 45, 4462-4469.
22. You, M.; Zhang, X.; Wang, X.; Zhang, L.; Wen, W. (2010). Effects of type and contents of microencapsuled n-alkanes on properties of soft polyurethane foams. *Thermochimica Acta*, 500, 69 - 75.
23. Da Silva, N. T. D. F. (2009) *Incorporação de materiais de mudança de fase em materiais de construção*. MSc dissertation, Universidade do Minho, Portugal [in Portuguese].
24. Pause, B. (2003). Nonwoven protective garments with thermo-regulating properties. *Journal of Industrial Textiles*, 33, 33-93.
25. Erkan, G. (2004). Enhancing The Thermal Properties of Textiles With Phase Change Materials. *Research Journal of Textile and Apparel*, 8, 57-64.

26. Salaüna, F.; Devauxa, E.; Bourbigota, S.; Rumeau, P. (2010). Thermoregulating response of cotton fabric containing microencapsulated phase change materials. *Thermochimica Acta*, 506, 82-93.
27. Sánchez, L.; Lacasa, E.; Carmona, M.; Rodríguez, J. F.; Sánchez, P. (2008). Applying an Experimental Design to Improve the Characteristics of Microcapsules Containing Phase Change Materials for Fabric Uses. *Industrial and Engineering Chemistry Research*, 47 (23), 9783 - 9790.
28. Escobar, C. F.; Rocha, T. L. A. C.; Roldo, L.; Kindlein Jr, W. (2011) Influence of molar ratio melamine-formaldehyde and types of surfactants used in interfacial polymerization microencapsulation of fragrant oil. In: *VI Congreso Internacional de Materiales* - CIM, Bogotá.
29. Silva, F. P. (2011). *Usinagem de Espumas de Poliuretano e Digitalização Tridimensional para Fabricação de Assentos Personalizados para Pessoas com Deficiência.* Ph.D. thesis, Universidade Federal do Rio Grade do Sul, Brazil [in Portuguese].