INNOVATIVE CHROMIUM-LIKE AND COOL TOUCH PLASTIC SOLUTIONS FOR AUTOMOTIVE INTERIORS

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Abstract
This study assesses the cool touch perception of developed innovative solutions for automotive interior plastic components. Also explores the relation between quantified physical properties and thermal perception of developed solutions with chromium-like properties, as the typical cool touch. Specifically, this study focused on the correlation between the thermal effusivity determined for the developed solutions by an MTPS (Modified Transient Plane Source) method and the thermal perception ratings attributed by a panel of 40 volunteers. The developed loaded polymer composites produce a cool touch. A strong negative correlation was found between thermal effusivity and thermal perception of the substrates.

1. Introduction

Nowadays, the automotive industry faces the need to respond to the latest European legislation and regulations which encourage the growth of the green economy and are oriented towards increasing the sustainability of this industrial sector. Consequently, there has been an increased investment in the development of biodegradable and lower density solutions to reduce the vehicle's weight, and, in technologies that allow the production of lightweight, recyclable and nontoxic components [1]. Considering the environmental and legislative requirements, it is imperative to significantly change the chrome-plating process in order to obtain chrome finishes in the automotive industry. The metallic effects of some plastic components in the door, instrument panels and console, among others are the targeted components.
Specifically, the now effective European Directive 2000/53/EC states that vehicles sold in Europe can't contain hexavalent chromium, demanding the substitution of this dangerous substance in the chrome-plating process [2]. Indeed, hexavalent chromium, used in the finishing processes to obtain the metalized

effect, is a heavy metal, with high toxicity and several associated hazards to the environment and public health [3].

Regarding the vehicle interior, the current strategy of the automotive components' manufacturers is to maintain the user's perceptive sensation of cool touch, commonly associated with metal surfaces. However, the internal components, used in automotive industry don't present the same cool touch as metals at room temperature. Therefore, the approach for this project comprises the development of innovative and sustainable polymer compositions with specific nanomaterials and eliminate the use of chromium in coatings with chromium effect, maintaining, however, their sensory performance equal to metals regarding cool touch. In this sense, the search for the chromium-like effect must go beyond the visual appearance focusing, also, on the metallic sensation when in contact with the skin.

Sensory touch perception is particularly important when referring to a material that is in contact with the user in daily routine, especially if the functionality we want to attribute is directly related to the user's opinion. Nevertheless, sensorial touch perception is still underdeveloped [4].

The skin, which covers about two square meters of an adult's full body surface, represents the largest human sensory organ, containing different receptors that allow the recognition of certain material characteristics, like surface temperature, when subjected to thermal stimuli. These structures are found throughout the surface of the skin, in different concentrations, leading to greater or lesser sensitivity, depending on the area of the human body [5]. The human hand is a very sensitive touch preceptor. When the hand and the material are in contact at different temperatures, a transfer of heat occurs. The thermal interaction between them is a physical process called heat conduction. This explains the cool sensation when touching a metal material, compared to a plastic material, even if both are at the same temperature. The heat flux between the skin and a metal object is higher than that of a plastic material, due to its high thermal conductivity [6]. The incorporation of fillers with high thermal conductivity in the polymer matrix will provide the desired thermally conductive properties to polymeric materials. Thus, some fillers are used in polymeric composites in order to improve the heat dissipation of polymeric materials and, consequently, the cool feel to the touch. Different nanoparticles have been used to improve the thermal conductivity of polymers. This event has been traditionally enhanced by the addition of thermally conductive fillers, including carbon-based, metallic and ceramic fillers. Carbon-based fillers are suggested to be the most promising, coupling high thermal conductivity and lightness. Graphite, carbon fibres and carbon black are well-known traditional carbon-based fillers. Metallic particles used for thermal conductivity improvement include powders of aluminium, silver, copper and nickel. The understanding of high electrical conductivity in metallic particles led to the recognition of high thermal conductivity of several ceramic materials such as aluminium nitride (AlN), boron nitride (BN), silicon carbide (SiC) and beryllium oxide (BeO) [7]. Very different thermal conductivity values between materials lead to differences in the rate of heat transfer between the skin and a material, and is consequently reflected in the touch temperature perception at room temperature.

Despite this, according to literature, the heat transfer process is more complex and depends on the thermal conductive of materials (k) as well as on the specific heat capacity (C_p) and the specific mass ρ. The combination of these materials' properties results in thermal effusivity ($e = \sqrt{k\rho C_p}$) [8]. Thermal effusivity corresponds to the rate at which the material can absorb heat, whereby a material with a high specific heat will exhibit a higher thermal effusivity. Thus, when the user's hand presents a temperature higher than a given material, the greater the thermal effusivity of the material, the greater the cool sensation. When in contact with another body of different temperature, highly effusive materials absorb or yield more thermal energy [9,10]. Overall, the perceived heat of a material depends on the rate of it's and the skin's heat flow, establishing a direct dependence between the rate and the thermal properties of a material [8].

Thus, for the process of interaction skin/material, it's necessary to evaluate the intrinsic properties of these, since it leads to differences in the rate of heat transfer between the skin and a given material and, consequently, to different perceptions of temperature. In this manner, it seems feasible that quantitative correlations can be established between the physical properties of the materials and their tactile perception, enabling predictions of the user's touch perception of a certain material's thermal properties [8].

2. Materials and Methods

2.1. Materials

As a polymeric matrix, it was used a commercial PP copolymer, commonly used for automotive interior applications, with a density of approximately 0,90 g cm^{-3}at 23 °C and an MVR (melt volume rate) of approximately 21 cm^3/ 10 min.
As fillers to enhance the thermal effusivity, it was used carbon-based materials as MWCNTs (multiwall carbon nanotubes) masterbatch and graphite powder, and a ceramic material, BN (boron nitride) powder.

2.2. Composites preparation and moulding

The loaded polymer composites were prepared using a twin screw extruder with a side feeder. The resulting extruded pellet samples were used to prepare plate substrates. The plates were prepared using an injection moulding machine Krauss-Maffei of 150 and 200.
The conditions operated for composites preparation (extrusion temperature profile; torque; pressure and srew rotation speed) so as injection of substrate plates (injection temperature profile; mould temperature; hydraulic pressure and injection speed) were set according to the processing conditions recommended in technical sheets of the materials with a few adjusts depending on type and wt.% of the filler used.

2.3. Thermal effusivity determinations

The thermal effusivity determinations were made using an MTPSs (Modified Transient Plane Source) instrument (C-Therm TCi Thermal Analyzer). The MTPS instrument measures the rate at which two surfaces in contact with each other exchange heat. The Equation 1 describes the way thermal effusivity relates with other thermal properties. An evaluation of coolness can be made, by comparing loaded polymers and polymer bases.

$$e = \sqrt{\lambda \, Cp \, \rho} \tag{1}$$

Where:
e = thermal effusivity, (W $s^{1/2}$) / (m^2 K),
λ = thermal conductivity, W/(m K)
Cp = specific heat capacity, J/ (Kg K) and
ρ = mass density, Kg/m^3

The samples were tested after a stabilization period of more than 12 hours at 20 °C, and the measurements performed using an application pressure of 500 g.

2.4. Sensorial Analysis

2.4.1 Volunteers

Forty volunteers (20 males and 20 females), 39 right-handed and 1 left-handed from CeNTI and Simoldes Plásticos, took part in this study. To participate in the study, recruits were required to be in good general health. Ages ranged from 21 to 52 with a mean age of 42 ± 14.

2.4.2 Testing Procedure

The aim of this test was to investigate the thermal tactile perception of developed solutions by comparison to PP (standard polymer base), and also to explore the correlation between their respective thermal effusivity values and thermal tactile perception.
The experiment was conducted in a climatized room, at $T \approx 22$ °C and RH ≈ 55%
The samples were previously placed on an XPS (Extruded Polystyrene) and conditioned for a minimum period of 24 h at test conditions, as represented in Figure 1. The touch order was aleatory for all the volunteers.

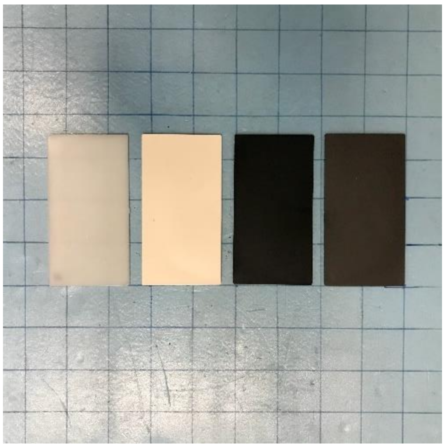

Figure 1. Polymer substrates placed on an XPS plate. From left to right: PP + graphite; PP + MWCNT; PP + BN and PP (standard polymer base).

The volunteers were asked to:
1. Wash and dry their hands;
2. Put a blindfold on their eyes;
3. Use their dominant palm hand to touch the samples for a time up to 3 s, with a time interval of 5 s between samples;
4. Rate the samples on a scale from 1 to 4, where 1 is the cooler sample and 4 the less cool sample

2.4.3 Data analysis

It was created a thermal perception scale from 1 to 4, where 1 corresponds to the coolest sample and 4 to the sample that transmits a less cool sensation. Thus, based on the ratings given by the volunteers, a mean perceptual property for each sample was calculated. Then, the average ratings were correlated to the thermal effusivity values previously determined by MTPS method, through the graphic representation of $f\,(e) = thermal\ perception\ rating$. The strength of correlation between the physical property and the thermal perception rating was evaluated by calculating the correlation coefficient R.

3. Results

3.1. Thermal effusivity determinations

Thermal effusivity of the loaded polymer composites and the percentual increased compared to PP are presented in Table 1.

Table 1. Mean thermal effusivity values (3 determinations in different areas of the sample) of the developed samples, and its percentual increase compared to PP

Polymer substrate	Measurement T (°C)	$e \pm \sigma$ (W $s^{1/2}$) / (m^2 K)	e increase (%)
PP	20.4	594 ± 23	-
PP + graphite	21.0	1231 ± 8	107
PP + BN	21.4	795 ± 4	22
PP + MWCNT	21.2	645 ± 7	8

3.1. Sensorial Analysis

To investigate the thermal perception of the different loaded polymer composites when compared to PP (standard polymer base), recruited volunteers ordered the samples from the cooler (rating 1) to the less cool (rating 4). The mean thermal perception results of 40 volunteers are presented in Figure 2.

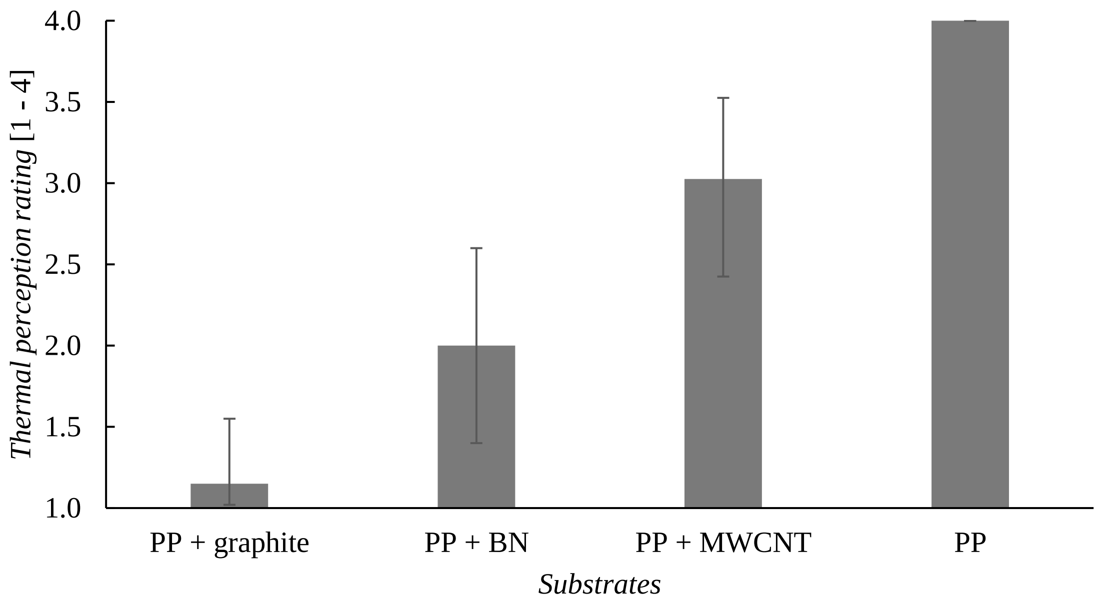

Figure 2. Plot of the mean ratings of the variable "Thermal perception" and its respective standard deviation of the polymer substrates.

To explore the relationship between the thermal effusivity of the materials and their coolness, mean values of thermal perception ratings were compared to thermal effusivity values obtained previously by MTPS method. The thermal perception data was plotted against the corresponding physical property data, and the strength of correlation between them was evaluated by calculating the correlation coefficient R. Results are presented in Figure 3 and 4, respectively.

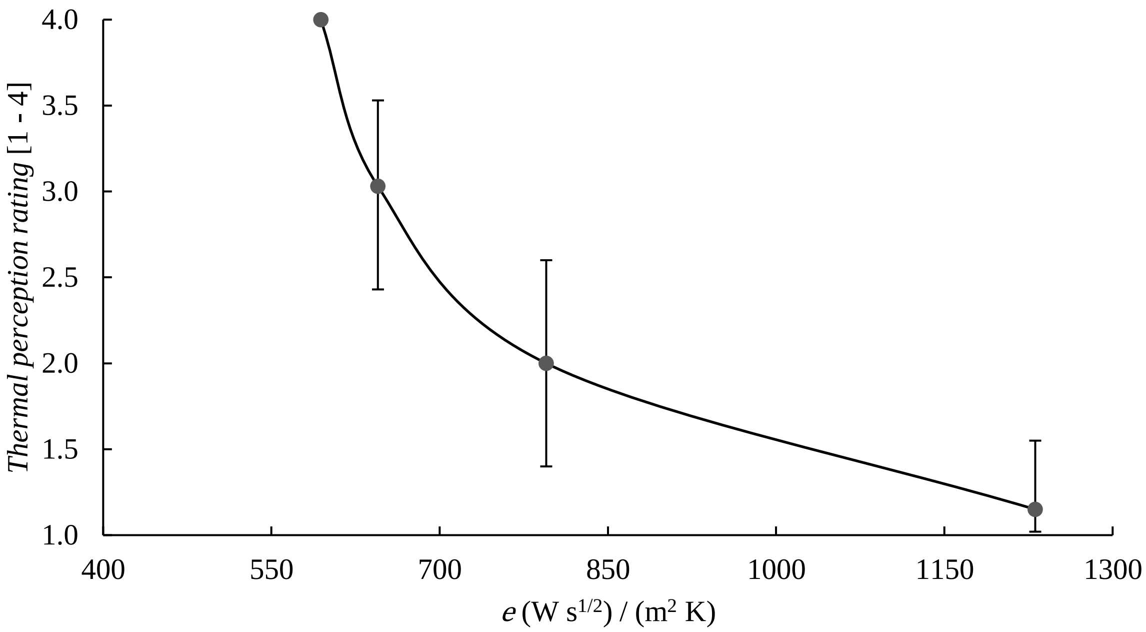

Figure 3. Plot of the mean ratings of the variable "Thermal perception" and its respective standard deviation against thermal effusivity values obtained by MTPS method for developed solutions and PP.

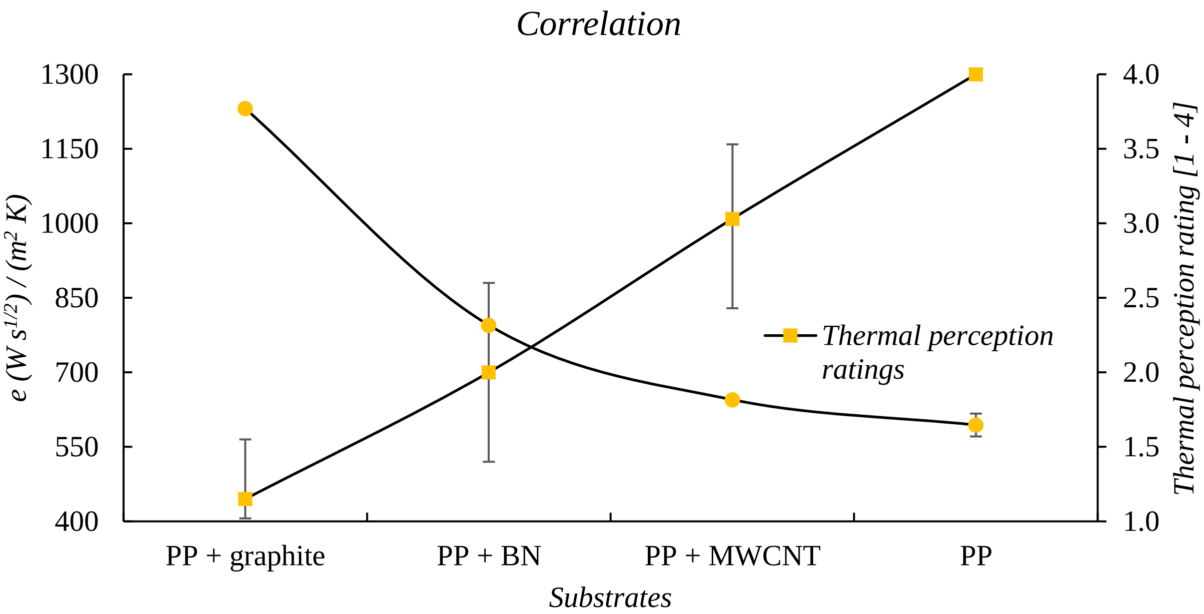

Figure 4. Correlation between variables "Thermal perception" and *e* and its respective standard deviation against the polymer substrates.

The coefficient correlation *R* between thermal perception mean ratings and thermal effusivity mean values obtained for the experiment was - 0,91 which indicates a negative correlation, so as thermal perception rating increases, *e* decreases, as observed in Figures 3 and 4.

4. Discussion and Conclusions

In this experiment, the volunteers were required to touch different developed solutions for enhancement of cool touch, and a standard PP used in automotive interior applications.
As can be seen in Figure 2, the volunteers were capable of discriminate subjective coolness of the polymer substrates, at room temperature. PP, as the standard polymer, without any filler, was the substrate plate with less cold sensation, with 100 % of volunteers rating it with a classification of 4. PP + graphite was the cooler substrate with a mean rating of 1.2 ± 0.4, followed by PP + BN (2.0 ± 0.6) and PP + MWCNT (3.0 ± 0.5). Also, we investigate the correlation between a specific physical parameter of the materials and the perception of coolness. Regarding the determined e values of these substrate plates, it seems they are related to the thermal perception ratings obtained. As can be seen in Figures 3 and 4, the thermal perception rating increases, as e decreases. The calculation of R proves the negative and strong correlation between these two variables (R = - 0.91). In conclusion, the results of this study show that the developed solutions are capable of produce a cool touch sensation to the user, as it is possible to relate coolness experience to a measurable technical parameter. The results of the correlation analysis confirm that the thermal effusivity is a good indicator of warmth/cool perception.

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