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ACHIEVING OPTIMUM THERMAL COMFORT PROPERTIES FOR AUTOMOTIVE SEAT FABRICS

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ABSTRACT

An operating air-conditioning (A/C) system is currently the largest ancillary load on automobile engines, negatively impacting both fuel economy and tailpipe emissions. Improving the comfort properties by using PCMs is an effective way to increase thermal comfort at little energy cost, resulting in reduced air conditioning needs and fuel use. Automotive seats fabric is well suited for effective use of PCMs due to their large contact area with and close proximity to the occupants. The thermal comfort improvement can be used to reduce the A/C heat capacity by 4%.

The objective of this study is investigating the impact of fabrics made of chenille yarns containing PCMs on their properties that relate to comfort. These fabrics are mainly designed for seating in public transportation, including automotive.

Keywords: Outlast® Technology, Phase Change Materials (Pcms), Thermal Comfort, Automotive Seats, Fuel Economy, Tailpipe Emissions, Technical Textiles, Chenille Yarns.

I. INTRODUCTION

The automobile industry is the largest user of technical textiles, with about 20 kg in each of the 45 million or so cars made every year worldwide [1]. It is estimated that about 45 square meters of textile material is used in an average car and the percentage of textiles in a car is about 2 % of the overall weight of the car[2]. The weight of textile components in automobiles is expected to rise to 35 kg by 2020 [3].

The 20 kg of textiles in an average car is made up approximately from 3.5 kg seat covers, 4.5 kg carpets, 6.0 kg other parts of the interior and tires and 6.0 kg glass fiber composites [4]. Table (1) shows approximate breakdown of main textiles in an average modern car.

Textiles provide a means of decoration and a warm soft touch to surfaces that are necessary features for human well being and comfort, but textiles are also essential components of the more functional parts of all road vehicles, trains, aircraft and sea vessels[5].

Table (1): Approximate breakdown of main textiles in an average modern car. [1]

Kind of Textile	%
Carpets (including car mats)	33.3
Upholstery (seating fabric)	18.0
Pre- assembled interior components	14.0
Tyres	12.8
Safety belts	8.8
Airbags	3.7
Others	9.4
Total	100.0

1.1 Car Seats

It has been found that around 88% of the fabrics used in the automotive industry are used in seating and door covers [6] .Textiles have become by far the most widely used material in seat coverings and are beginning to be used in other areas of the seat in place of polyurethane foam[4].

1.1.1 Car Seat Thermal Comfort Properties

Today, comfort has become a major quality criterion of cars. Comfort in a car is a complex phenomenon and comprises such different aspects as, for example, noise, driving behavior, or ease of handling. One of the most important factors influencing passenger convenience is thermal comfort [6].

A particularly important aspect of vehicle comfort is the seats; they must also have optimum comfort properties. But seat comfort is much more than just passenger convenience. Scientific findings show that the performance of a driver over long distances significantly decreases if the car seats do not support posture and heat balance as required [6].Fig. (1) Shows rectal temperature of a car driver as a function of time while sitting on a seat with high physiological function (lower line) or a seat with low physiological function (upper line)

The car seat must be comfortable in all senses of the word; psychologically, physiologically and thermally[4].

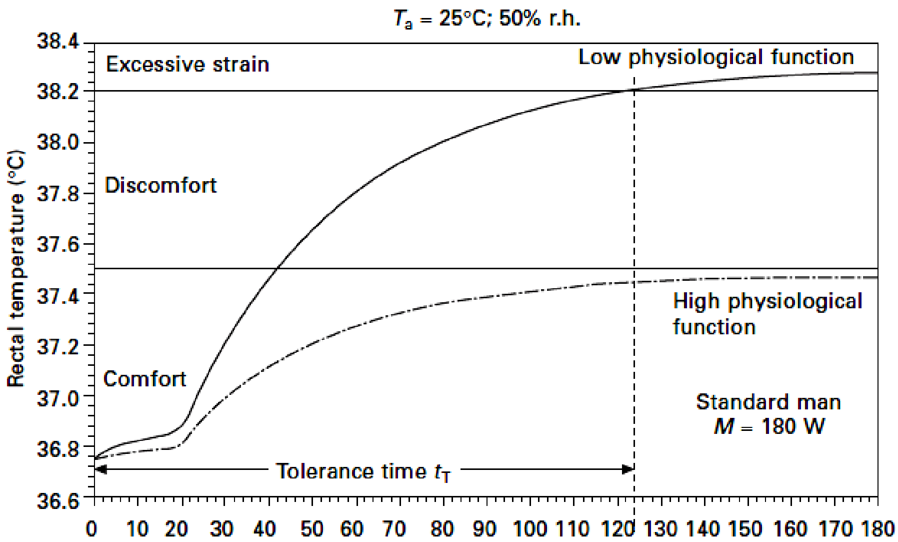

Fig (1) Physiological Impact of Car Seats

1.1.2 Thermo physiological comfort of car seats

From the physiological point of view, seat comfort comprises the following four parameters:

1. The initial heat flow following the first contact with the seat.
2. The dry heat flow on long journeys, i.e. the amount of body heat transferred by the seat.
3. The ability, known as 'breathability', to transport any perspiration formed away from the body. In so-called 'normal' sitting situations, there is no perceptible perspiration, but, nevertheless, the human body constantly releases moisture (so-called 'insensible perspiration'), which has to be taken away from the body.
4. In the event of heavy perspiration (a car in the summer heat, stressful traffic situations) the ability to absorb perspiration without the seat feeling damp [6].

1.1.3 Achieving thermal comfort properties for car seats

Several attempts have been made to achieve enhanced thermal comfort:

- Development a natural fiber Ramie is used as a moisture transport medium.
- Use of ventilated seats using air driven by electric fans.
- Using bead seat, this is used all over the world. There is little doubt that they are cooler, presumably because polished wooden or plastic beads are cooler to the touch in hot weather than fabric and also because they create an air gap between the skin and the car seat thus allowing some air circulation and sweat evaporation. However the bead seat is far from ideal when aesthetics and other comfort aspects are considered [4].
- Installation of air conditioning in new American cars has been increasing and reached over 90% by the 1990s. In Europe, Installation of air conditioning in vehicles has also been growing steadily from about 12% in 1990 to70% in 2000. This luxury item, now becoming regarded as standard [4].

An operating air-conditioning (A/C) system is currently the largest ancillary load on automobile engines, negatively impacting both fuel economy and tailpipe emissions. In a conventional vehicle, A/C use can decrease vehicle fuel economy by 21%-24% over a Unified Cycle (California ARB inventory test cycle). Vehicle tests, over the Unified Drive Cycle, indicate oxides of nitrogen (NOx) and carbon monoxide (CO) increases of 13%-66% and 60%-120% respectively. These effects are even larger for advanced high efficiency vehicles. On a national level, the impact of air conditioning fuel use is immense[7].

The thermal comfort improvement can be used to reduce the A/C heat capacity by 4% resulting in a predicted A/C fuel use reduction of 2.8% on a highway cycle and 4.5% on a city cycle. This is a 0.3%-0.5% reduction in total vehicle fuel use when the A/C system is on; [7].

Thermal energy storage via phase change materials (PCMs) is one of the most promising candidates as zero power usage means to decrease the temperature profile fluctuation in the car cabin for both summer and winter months[8].

Phase-change material (PCM) is one such smart material which has the ability to store and release energy in a certain temperature range. Whenever the supply of or demand for energy does not change dependently with time, energy storage is required. The thermal energy storage (TES) system bridges the time gap between energy requirements and energy use and plays an important role in energy management of textile products to enhance thermal comfort. TES by PCM to improve thermal performance of clothing during environmental temperature fluctuation is becoming an attractive option [9].

In the sunny days especially in the summer, when the cars are parked in the parking facing the sun or even during the driving, the drivers feel severe thermal discomfort just after entering an automobile. Therefore a huge amount of cooling energy from the air conditioning must be used to lower down the temperature to the comfort condition. This results in consuming more cooling energy and therefore burning more fuels that causes more costs and more pollution released to the atmosphere[8].

On the other hand, during winter months, after turning on the heating system, it usually takes minutes before the comfort condition is reached. Some car models have extra heating systems installed in their seats to tackle the problem. The electrical energy necessary for running the seat heating system is provided by the car's battery. In order to prevent demands for further increases in the battery's capacity, and increasing the battery lifetime energy savings are necessary. [10, 8]An up-to-date solution for thermal comfort control of a car seat is to use microcapsules containing phase change material (PCM) [11].

1.2 Phase Change Materials (PCMs) Definitions

PCMs are latent heat storage materials that thermal energy transfer occurs when a material changes from solid to liquid, or vice versa. Unlike conventional (sensible) storage materials, PCM absorbs and releases heat at a nearly constant temperature. The high heat transfer during the melting process and the crystallization process, both without any temperature change, is responsible for the PCM's appeal as a source of heat storage [8].

PCMs are materials that can absorb, store and release large amounts of energy, in the form of latent heat, over a narrowly defined temperature range, also known as the phase change range, while that material changes phase or state (from solid to liquid or liquid to solid)[12]. As shown in fig. (2) & fig. (3).

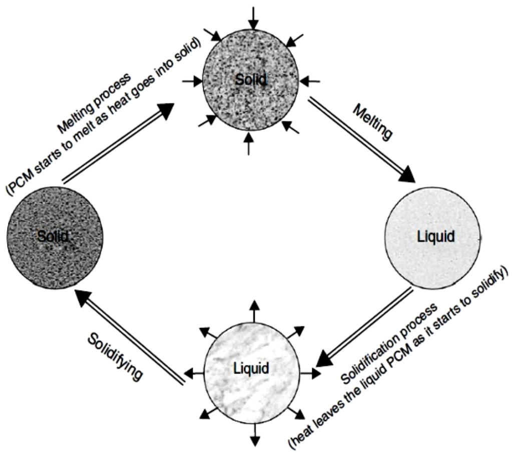

Fig (2): Schematic of phase cycle of phase change material.

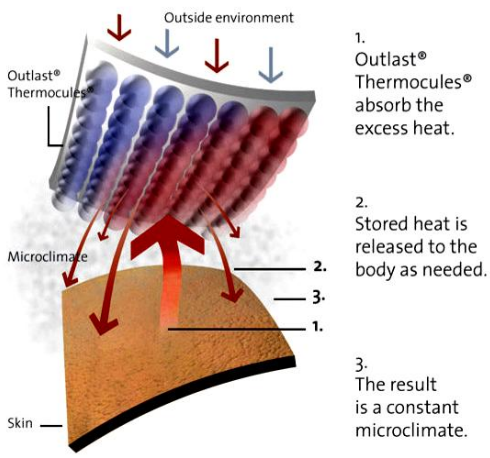

Fig. (3) Functioning principle of PCM in a fabric. (Outlast Europe)

1.2.1 Microencapsulation of Phase Change Materials (PCMs).

One of the major disadvantages of the use of latent heat storage materials is the useful life of a PCM's container system and the number of cycles it can withstand before degradation of its functional properties. Before application of PCM on the textile substrate, PCMs need to be kept in a very small container to protect them while in a liquid state [9].The microencapsulation of the PCMs involves enclosing them in thin and resilient polymer shells so that the PCMs can be changed from solid to liquid and back again within the shells. Fig. (4) Shows a structure of a single-shell microcapsule [13].

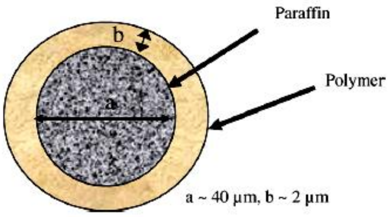

Figure (4) Structure of microcapsule [14]

1.2.2 Incorporation of PCMs in textile.

In applications of PCM technology to textile industry, microcapsules containing selected PCM can be applied to fibers in a wet-spinning process, incorporated into foam or embedded into a binder and applied to fabric topically, or contained in a cell structure made of a textile reinforced synthetic material.

1.Coating.A typical coating composition includes wetted microspheres containing PCMs dispersed throughout the polymer binder, surfactant, dispersant, antifoaming agent and thickener. The coating paste can then be applied to the textile substrate by a suitable coating method. [14, 9].

2. Lamination.PCM could be incorporated into the thin polymer film and applied to the inner side of the fabric system by lamination. [14] The quality of lamination primarily depends on the strength of adhesion of films to the textile substrate, which may be lost due to mechanical and/ or extreme environmental conditions. [9].

3. In-fiber technology. The incorporation of PCM within a fiber requires first that the PCM be microencapsulated. PCMs would be added to the liquid polymer, polymer solution, or base material and fiber is then spun according to the conventional methods such as dry or wet spinning and extrusion of molten polymer. The microencapsulated PCM fibers could store heat over long periods, as temperature drops, the fibers slowly radiate heat[14, 9].

Fabrics can be formed from the fibers containing where the advantages of incorporating microPCM into fibers are as follows:

- Micro PCMs are permanently locked within the fibers
- Fiber is processed with no need for variations in yarn spinning, fabric or dyeing.
- Properties of fabrics (drape, softness, tenacity, etc.) are not altered in comparison with fabrics made from conventional acrylic fibers [13].

Recently, the use of melt spinning was accomplished by producing a multi-component fiber comprises a temperature regulating material core, and a sheath surrounds the core member [15].Fig. (5) Shows microphotographs of Outlast polyester fiber, it is melt spun bi-component process uses a PCM core with standard polyester as the sheath. This delivers a temperature managing fiber without compromising standard polyester fiber downstream processing, dyeing and finishing properties.

Figure (5) SEM of Outlast® Polyester [16].

4. Impregnation and exhaustion method. Micro PCMs can be applied on the textile substrate by impregnation or by the exhaustion method with acrylic resin. Treated fabric can then be heat treated in order to fix the microcapsules on the textile substrate.

II. Materials and Methods

2.1 Chenille Yarn

Chenille yarns are fancy yarns with beautiful, soft and fuzzy surfaces. They have become the choice of designers for many items, in Apparel (sweater, out wears, blankets) Home textile (upholstery, curtains, bed-spread-rugs) Automotive (decorative fabrics, seats fabrics) [17].Chenille yarn consists of short lengths of spun yarn or filament that are held together by two ends of highly twisted fine strong yarn. The short lengths are called the pile and the highly twisted yarns are called the core or lock yarn. [18] As shown in fig. (6)

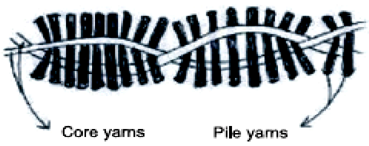

Figure (6) Chenille Yarn Structure [19]

Chenille yarn can be made from many different types of fibres and yarns, most commonly cotton, viscose, acrylic, polyester and polypropylene. The core and pile yarn can be of the same or a different material. [18] .The careful choice of the lock and pile materials is very important to increase the inter-fiber friction may also assist in reducing the rate of pile loss [17].Different methods of the chenille yarn production exist; weaving, knitting, flocking and twisting methods. Where the later method used is greater than the previous methods [20].

As a starting point, the methodology of using Chenille yarns for automotive car seats fabric was based on these facts.

- Chenille yarns are fancy yarns with beautiful, soft and fuzzy surface. They have become the choice of designers for many items.
- The research objective is to enhance a large % of PCMs materials in the fabrics, this cannot be achieved by using Traditional yarns, and so fancy yarns offered a big deal in this issue, especially chenille yarn.

Three chenille yarns were produced by using below specification:

Core yarn material: 30/1 spun polyester yarn.	**Pile yarn material: Outlast® Polyester 80/36**
Number of pile yarn: (2 ply & 3ply & 4 ply)	**Twist direction of chenille yarn : S**
Pile length: 1mm.	**Twist level : 750 twist per meter**

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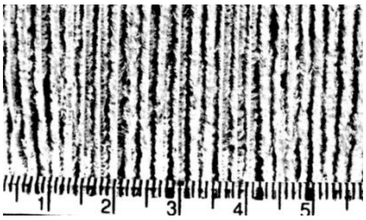
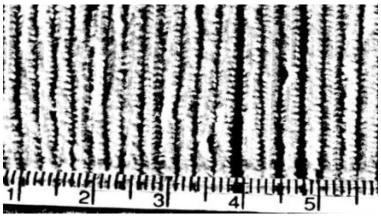
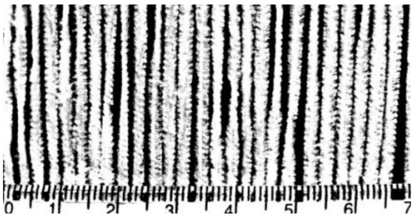


2 x 80/36 Outlast Polyester Filament DTY



3 x 80/36 Outlast Polyester Filament DTY



4 x 80/36 Outlast Polyester Filament DTY

Figure (7) produced chenille yarns.

2.2 Produced Chenille Fabrics

The previous 3 chenille yarns were used for producing the chenille fabrics (3 samples) as shown in fig (8), with the same weave structures as shown in fig. (9)

Table (2) Specification of produced fabrics.

Parameters	2 ply	3 ply	4 ply
Warp (material & count)	Polyester 150 denier	Polyester 150 denier	Polyester 150 denier
Auxiliary Weft (material & count)	Polyester 150 denier	Polyester 150 denier	Polyester 150 denier
Number of Chenille's pile yarn	2	3	4
Chenille Weft count (Denier)	1820	1960	2590
Number of picks per Cm	28	28	28

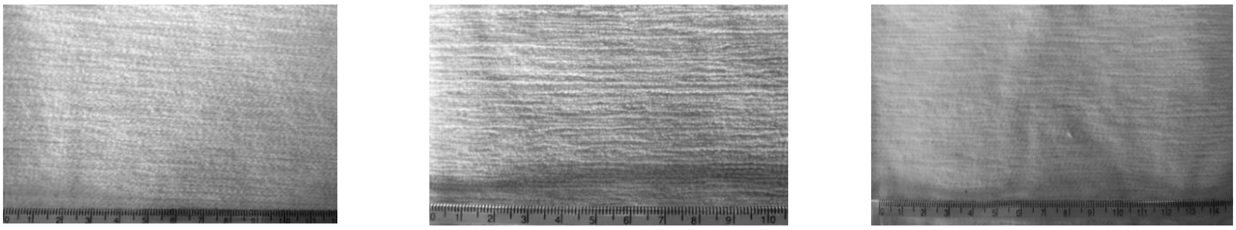


Figure (8) Produced chenille fabrics .

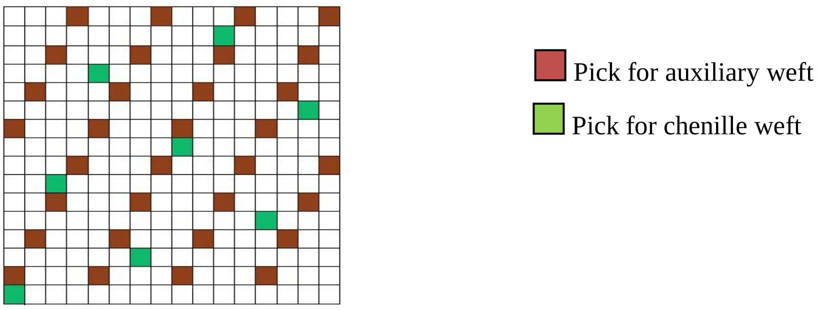


Figure (9) chenille fabrics structure.

The research samples were produced at ***Textile Design &Technology centre – Faculty of Applied Arts, Helwan University***, using an electronic Jacquard machine with the specifications shown in table (3). Figure (8) shows chenille fabrics production.

Table (3) Specifications of the loom used in producing research samples.

No.	Property	Specification
1	Type of the machine (weft insertion device)	Rapier
2	Manufacturing company	SMIT
3	Date of Manufacturing	2008
4	Manufacturing country	Italy
5	Speed of the machine	280 picks / min.
6	Shedding device	Jacquard
7	Manufacturing company	Stäubli
8	Design hooks	2560 hook
9	Width of warp without selvedge	140 cm
10	Reed used (dents per cm)	9 dents / cm
11	Denting	8 ends / dent

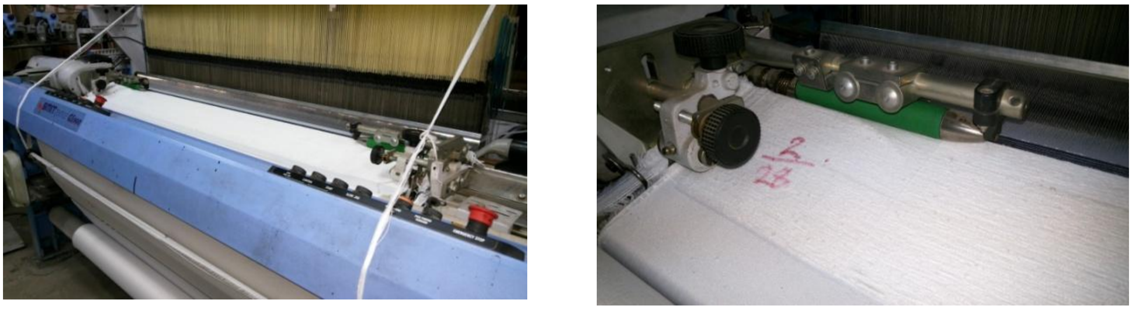


Figure (10) Chenille fabric containing PCMs production on jacquard loom.

2.3 Laboratory Test

2.3.1 Determination of the yarn count

The yarn count was determined by using Denier system, the test was done according to American standard Specification of (ASTM D 1907 – 01) [21].

2.3.2 Fabric weight test

This test was carried out by using Precisa 1300 c apparatus according to the American Standard Specification of (ASTM D3776:09) [22].

2.3.3 Differential Scanning Calorimetric (DSC) test

This test was carried out by Outlast ® Company according to the American Standard Specification of (ASTM E793-01)[23].

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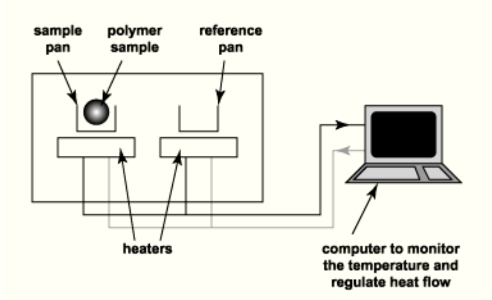

Figure (11) Schematic of DSC test method.

III. RESULT AND DISCUSSION

3.1 Yarn test

Table (4) yarn count result.

	2ply	3ply	4ply
Chenille yarn count (Denier)	1820	1960	2590

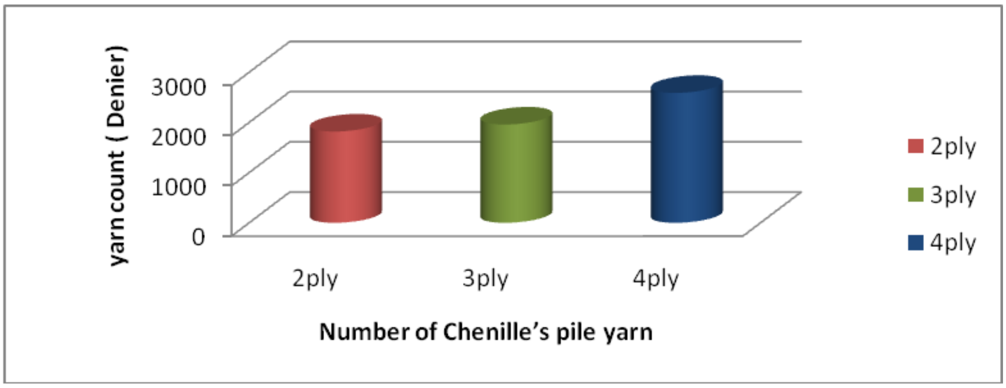

Figure (12) Relation between Chenille's pile yarn number and yarn count.

$y1 = 385x + 1353.3$ $R^2 = 0.8811$

Where, y1 = yarn count x = number of Chenille's pile yarn.

From the previous equation and figure (12) it is obvious that there is a direct relationship between chenille yarn count and number of pile yarn , as by increasing the number of pile yarn , the chenille yarn count increase and vice versa. This is because of the fact that increase number of pile yarn increases the pile density in the unit length which leads to increase the yarn count.

3.2 Fabric Test

Table (5)Fabric test result.

	2ply	**3ply**	**4ply**
Fabric Weight (g/m^2)	462	497	605
Latent heat (J/g)	2.2	2.4	2.7
Fabric latent heat (J/m^2)	1016.4	1192.8	1633.5

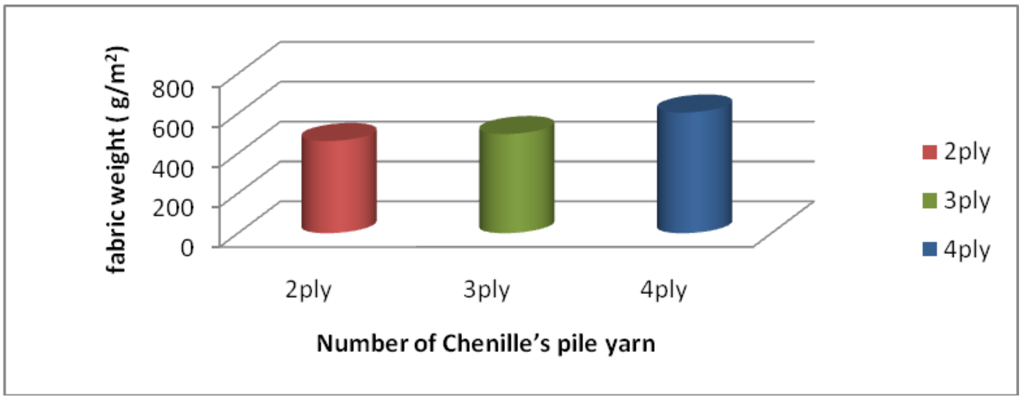

Figure (13) Relation between number of pile yarn and fabric weight.

y2 = 71.5x + 378.33 R^2 = 0.9201

Where, y2 = fabric weight x = number of Chenille's pile yarn

From the statistical analysis of results and figure (13) , it can be seen that, there is a direct relationship between fabric weight and Chenille's pile yarn number , this is because of the increase in number of pile yarn increase the yarn count which leads to an increase in the weight of the fabrics and vice versa.

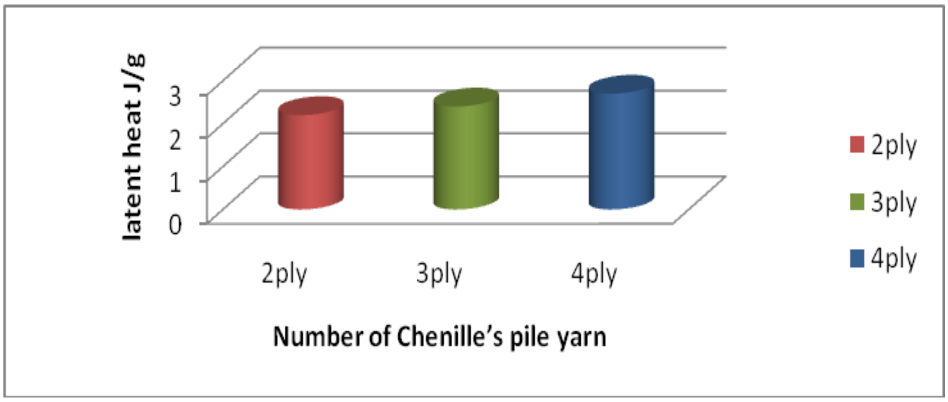

Figure (14) Relation between Chenille's pile yarn number and fabric latent heat.

y3 = 0.25x + 1.9333 R^2 = 0.9868

Where,y3 = latent heat (J/g) x = number of Chenille's pile yarn

From the previous equation and figure (14) it is obvious that there is a relationship between chenille fabric's latent heat and number of pile yarn , as increasing the number of pile yarn , the latent heat of chenille fabric increase and vice versa. This is because of the fact that increase number of pile yarn increases the PCMs percentage inside the produced yarns & fabrics which leads to an increase in the latent heat.

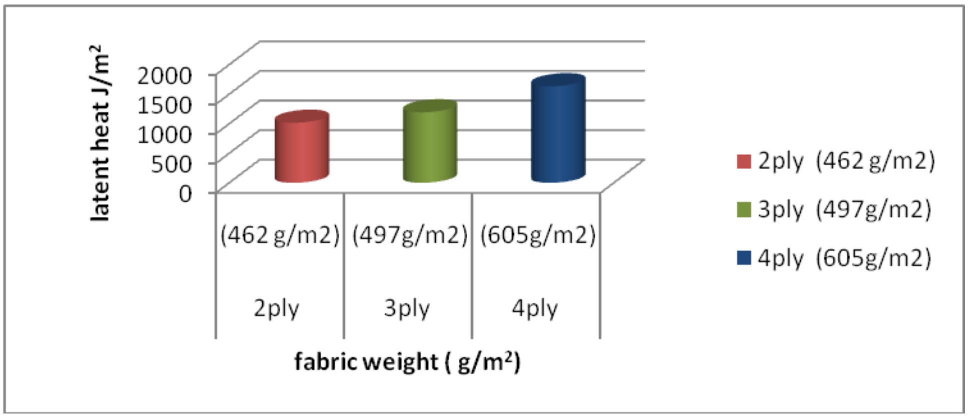

Figure (15) Relation between fabric weight and fabric's latent heat per meter square.

$y4 = 4.26x - 939.9$ $R^2 = 0.998$

Where, $y4$ = latent heat (J/m^2) x = fabric weight (g/m^2)

From the statistical analysis of results and figure (15), it can be concluded that, there is a direct relationship between the fabric weight and latent heat of fabric's meter square; this is because of the increase in fabric weight increases the PCMs percentage in the fabrics which leads to an in increase the latent heat per meter square. Whereas increasing the percentage of PCMs leads to an increase in the capacity of heat absorb and release for the produced fabrics which affects car seat thermal comfort properties and vice versa.

IV. CONCLUSIONS

1. Chenille yarns containing phase change materials (PCMs) were achieved overcoming several technical production procedures.
2. Our findings show that there is a tendency to an increase in latent heat readings with the increase in number of Chenille's pile yarn. That's to say Chenille yarns number plays a critical role in holding latent heat within the structure.
3. We also conclude that increasing PCMs percentage in the produced fabrics lead to an increase in thermal comfort of car seat fabrics (latent heat %)
4. Improving the comfort properties by using PCMs is an effective way to increase thermal comfort at little energy cost, resulting in reducing air conditioning and fuel consumption.

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