

A Review Article on Natural Fibre Based Thermally Adaptive Fabrics, Development and Performance Evaluation

Vinutha P^{1,2*}, H N Divakar,³ Ashajyothi M¹, K M Subbaiah³, Mohammed Ismail⁴

P.G. Student, Department of Industrial Production and Engineering, The National Institute of Engineering, Mysuru, India¹.

Department of Technical Education, Government Polytechnic Mirle, K R Nagar, Mysuru, India².

Professor, Industrial Production and Engineering, The National Institute of Engineering, Mysuru, India³.

Associate Professor, Industrial Production and Engineering, The National Institute of Engineering, Mysuru, India⁴.

ABSTRACT: Thermal comfort of human body deals with maintaining the heat balance of the body, during various levels of human activity. Besides the thermo-neutral zone of human body is 33.4°C and a fluctuation of $\pm 4.5^{\circ}\text{C}$ leads to physiological discomfort. Consequently, thermally adaptive smart fabrics are gaining significant technological interest. Herein, we summarize various principles involved in the development of temperature regulating fabrics with special emphasis on textile material surface, phase change materials, shape memory polymers and conducting materials. Finally, various advanced tools and techniques towards effective development and characterization of thermally adaptive smart clothing has also been discussed.

KEYWORDS: Text Thermally adaptive smart fabrics, Phase Change Materials (PCMs), Shape memory polymer (SMP)

I. INTRODUCTION

Clothing helps to maintain thermal comfort of the human body by protecting human's body against rain, sun and wind [1]. Along with cultural essence, it also provides comfort, hence may be defined as, a fabric that wraps around the skin and acts as shield to protect [2].

Increasing global warming is one of the concerned area which causes drastic discrepancy in atmospheric temperature. These situations have made everyone to think about need of thermal comfort in fabrics. Thermally adaptive fabrics work automatically to improve and maximize thermal comfort for humans in all climatic conditions [3]. Limitations of conventional fabrics have made researchers to develop new type of fabrics to inhibit thermal comfort in clothing [4-5]. Recent and unique innovations in fabrics like addition of Nano particles can create lightweight fabrics, that regulates temperature and exhibit good strength without changing their inherent fabric function [6-7].

II. CLASSIFICATION OF THERMALLY ADAPTIVE FABRICS

Various types of thermally adaptive fabrics and their working principles are as shown in Figure 1

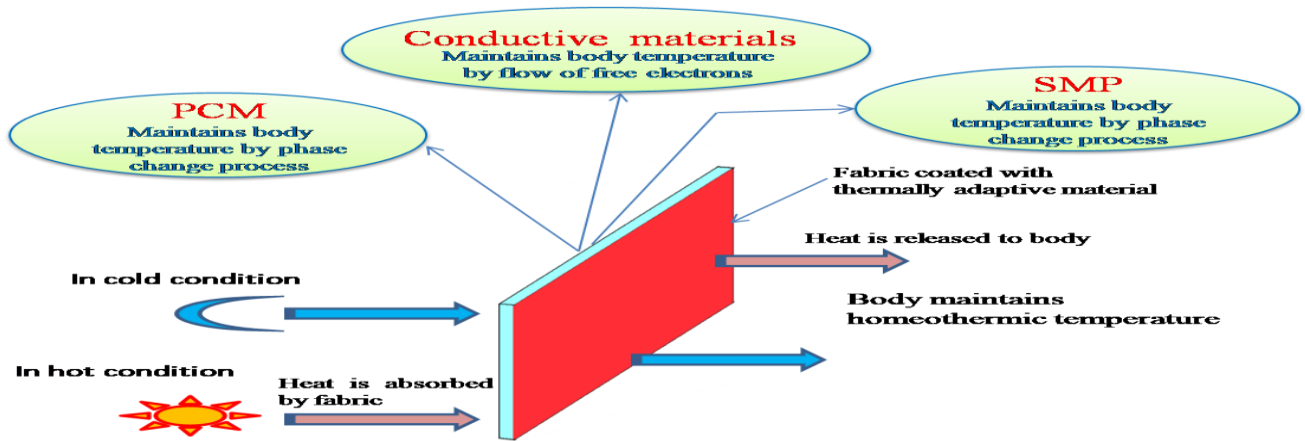


Fig 1. Types of thermally adaptive fabrics and their working principles

1) Phase change materials

Phase change materials are smart materials that respond to the exterior stimulus by absorbing and releasing the thermal energy due to temperature variation in order to maintain thermal comfort [8-10]. This is achieved by solid to liquid and liquid to solid phase change, hence the name phase change materials [11-12]. PCM's can be grouped as sensible heat storage matters and latent heat storage matters [9]. phase change process that takes place in thermo regulated fabric is as shown in Figure 2.

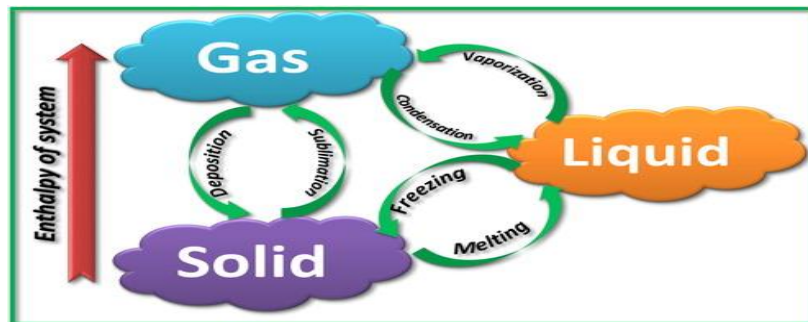


Fig 2: schematic representation of phase change process in thermo regulated fabric. (Reproduced from Ref 13)

When body temperature rises, solid to liquid phase change process occurs in PCM by absorbing latent heat from external system. Consequently the reverse process occurs when the body temperature is reduced as shown in Figure 2. This course of action takes place at isothermal condition [14]. PCM's has ability to store huge heat with low volume change, due to this capacity of Solid-liquid PCMs is frequently used in thermal regulation fabrics [15]. As the state of matter of PCM varies with rise and fall of temperature, integration of the microencapsulation is essential for best possible use of PCM in clothing. Therefore micro encapsulation technique of PCM has been integrated and widely used in thermo regulating fabrics [16-17]. PCM's with melting temperature 15⁰C TO 35⁰C are best suited for thermal regulating fabrics. As a result n-octadecane PCM with melting temperature 28⁰C is widely used in thermal adaptive fabric. The various other types of PCM's that suits thermal adaptive fabrics are Hydrated inorganic salt, Linear long chain hydrocarbons etc [18-19].The PCM are widely classified as Organic, inorganic and eutectic [12, 18].

2) Shape memory materials

Shape memory materials (SMM) are smart materials that change their shape temporarily when subjected to external stimulate and returns to its original shape when external stimulate is removed. The external stimulate that are

responsible for shape change are temperature, light, moisture etc [20-22]. The reason behind temporary shape change in SMM's is molecular rearrangement due to phase change between martensitic and austenitic state as shown in figure [22].

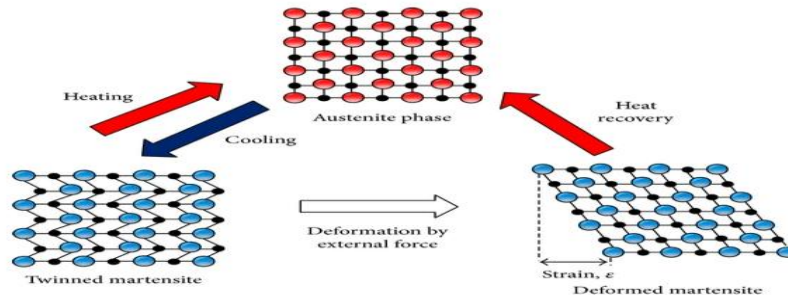


Fig 3: schematic representation of shape change process in SMP (Reproduced from Ref 23)

Superelastic property of SMM that expand and retract due to variation in temperature above and below glass transition temperature makes SMM to use easily and efficiently in thermo regulating fabrics [7]. Shape memory polymers such as Polynorborene, trans-polyisoprene polyurethane, Polyethylene, block copolymer etc are used in thermo regulating fabrics [24](36). Various methods like dry, wet and melt spinning processes can be used to develop shape memory fabrics can be developed [25].

3) Conductive materials

Conducting materials are smart materials that conduct heat and electric energy due to flow to free electrons. Conducting materials are available in various forms like conducting polymers, conducting fabrics or yarn, coating and ink etc [26-27]. Mulberry silk is considered as well identified natural Conductive fabric. Conductivity in the fabrics can be induced during production or after treatment of the fabrics [27]. Conductive fabric are one that disperse stagnant energy and shield fabric from electro-magnetic radiation, beside that it also helps to adapt optimum temperature required by the humans to maintain thermal balance [28]. Due to these excellent properties of various conductive materials like carbon nano tubes, nanoparticles of silver, copper titanium oxide, graphine etc, has been tremendously used in thermal adaptive fabrics [29]. Conducting polymers, found in 1970 has fabulous application in various fields [30]. While fabricating conducting polymers, few factors are to be considered such as oxide concentration, degree of doping and polymerization duration etc, which could directly influence the conductivity of the material [31].

III. METHODS FOR GENERATION OF THERMALLY ADAPTIVE FABRICS

To enhance the functionalities of thermally adaptive fabrics, various methods are available for fabrication, they are

4) Coating method and Printing

The process of depositing one or more layers on to the top most layer of the fabric is termed as coating. In thermally adaptive fabrics, PCM's can be effectively incorporated in fabrics by coating polymer-matrix substance like acrylic, polyurethane, poly-hydric alcohol, n-octadecane, rubber latex with the help of binders [7,10,9]. Shape memory materials are coated with hydrogels like polythiophene gel and polymers like polyester, polyurethane etc [7,21]. Conducting materials are coated on to the fabric either by insitu polymerization, vapour or liquid phase method using Polypyrrole polymer, coating polymers and metal nano particles like silver nano wires etc [32]. Fabrication of Conductive fabrics can be achieved through thin deposition of nano-metals on to the outer surface through various deposition techniques like atomic layer deposition, electrochemical deposition, electroless deposition (ELD) etc [23]. In manufacturing of conductive fabrics, silk-screen printing is the easiest and low price conventional printing technique [26]. Another commonly used printing technique is ink jet printing which uses gold, silver and copper etc to provide conductivity to the fabric [2].

5) Lamination

Foam containing micro phase change materials can be laminated on to the fabric using liquid polymers or elastomers [7] To carry out this method, laminating PU foam is mixed with 20–60% PCM capsules and water is removed through drying process [13] By lamination process internal heat stress will be reduced [33]. The lamination technique is the one of the common method of obtaining conducting fabric [26].



6) Fibre-spinning

PCMs with microcapsules can be imbibed into fibre using acrylic by wet spinning process [7]. The shape memory fibre can be obtained by melt spin, Wet spinning, dry spinning; method etc [34] Composite conductive fabrics can be produced by melting, wet or solution spinning methods [26].

IV. APPLICATIONS OF THERMALLY ADAPTIVE FABRICS

TABLE1: Various methods of development, application and advantages of thermally adaptive fabrics

Thermally adaptive fabric material	Operating temperature	Thermal conductivity	Method of development	Advantages	Application	Ref no
Hydrated inorganic salt	20 ⁰ -40 ⁰ C	~0.5W/m0C		High volume storage density High thermal conductivity relatively low cost	thermo-regulated textiles	13
polyacrylic fibres with PCM		0.0398 W/m ⁰ C	coating		blankets, sleeping bags, underwear, jackets, sports garments, socks, ski boots, helmets	13
PEG-coated fabrics			coating	Antibacterial properties esiliency/antiwrinkling wear, toughness	ski- and sportswear	13
paraffin Rubitherm with PCM			coating	soft touch, vapor or moisture permeability and wearing comfort	apparel, blankets, insulation, protective clothing	35
Shape memory poly urethane with nano fillers			Melt spun method	Good mechanical property	apparel, blankets, medical field	36
PCM with carbon nano filler	30 ⁰ -34 ⁰ C		Shear mixing and melting technique	Enhances thermal conductivity	Apparel, blankets, medical field	37
PCM Encapsulated Paraffins in Modified Pectin			coating	low costs and have a large heat storage capacity	textile apparel	38
PEG based smart copolymer	10–50 ⁰ C		Melt spinning	Low breaking elongation	Apparel and home textile	39

V. CONCLUSION

One of the methods of achieving thermal comfort in fabric is by using thermally adaptive fabrics. Hence in this study, authors tried to explore various materials available in the development of temperature adaptive fabrics. Shed light on Principle methodology like lamination, spinning and coating involved in the production and fabrication of various thermal adaptive fabrics has been assessed. The future avenue will be thoroughly focused on thermally adaptive smart fabric for defense persons, which will be light-weighted and regulate temperature effectively and helps to boost overall performance of the wearer.

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