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Shape-Memory Applications in Textile Design

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Abstract

Extensive efforts have been made in the research and development of smart textile systems in recent years. One of these developments in smart materials is shape memory applications. Shape memory materials (SMM) are smart materials that can remember and recover substantial programmed deformation upon activation and exposing to an external stimulus such as chemicals, temperature, pH, light, a magnetic field, etc. Shape memory materials have been used in many areas and textile application of this technology has covered a wide usage recently. Today's textile concept isn't the similar to past and expectations of people from textile have been changing more and more. In this point, shape memory materials can answer these needs in textile due to its smart features. Shape-memory materials can be used in textile as clothing, yarn and fabric. The application possibilities are only limited by our imagination and creativity, so shape-memory productions have been able to gain a different aspect to textile.

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1. Introduction

Shape memory materials (SMM) are smart materials that can remember and recover substantial programmed deformation upon activation and exposing to an external stimulus (Parys M. V., 2001 and Christophorov L. N., 1996). Shape-memory applications are applied either alloy or polymer in textile. Arne Oelander discovered that Au-Cd alloy could be deformed in its cold state and returned to its original state when heated in 1932 (Mac, T., Houis,

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S., Gries, T., 2004). It was the first shape-memory alloy and in the following years NiTi was found by Buehler and Wang in 1963 at the U.S. Naval Ordnance Laboratory (NOL) (Varadan V. V., Chin L. C. and Varadan V. K., 1992). Shape memory polymers were discovered after alloys. Shape memory polymers were first developed in France and commercialized by Nippon Zeon Co. in Japan in 1984. Both alloys and polymers have gained momentum to shape-memory smart textiles. They have been able to used in many areas of textiles. Before starting to shape-memory textile applications, firstly we must understand more how alloys and polymers work.

2. Shape-memory alloys

Shape memory alloys are metals that show two unique properties. The first is the shape memory effect characterized by the capability of a material. With the changing temperature, the material deformed or revert to first shape. The second is superplasticity. In this state, material to exhibit large recoverable strains. There are a lot of alloy species but NiTi is the most used alloy in sector today. It shows different behaviours according to activation temperature. Below the activation temperature, the alloy is easily deformed. At the activation temperature, the alloy exerts a force to return to a previously adopted shape and becomes much stiffer (Parys M. V., 2001). The two phases present in shape memory alloys are called martensite and austenite. It's structure have been given in Figure 1. As seen Figure 1, NiTi alloy has two phase named Martensite (low temperature phase) and Austenite (high temperature phase). Austenite is a stronger phase of SMAs which occurs at higher temperatures.

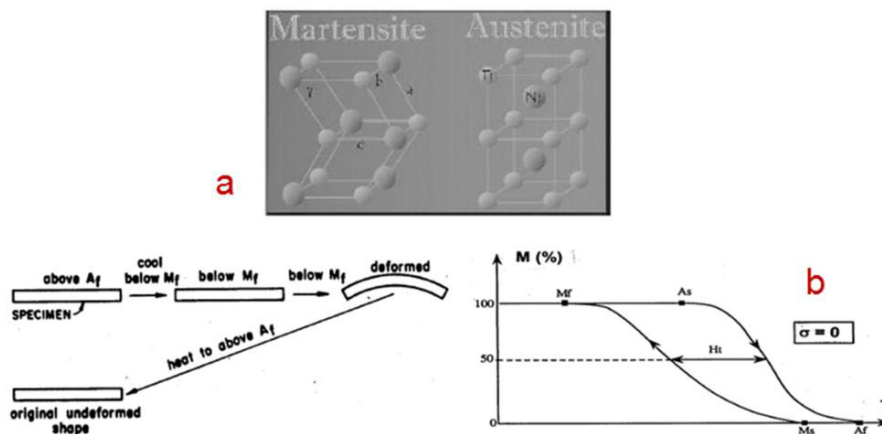


Fig. 1. (a) Martensite and austenite structure; (b) principle of shape memory effect (SmartLab Texas A&M, "Definition of a shape memory alloy", <http://smart.tamu.edu/overview/smaintro/simple/definition.html>, March 8th, 2006) and (Boussu F., Bailleul G., Petitniot J. L. & Vinchon H, 2002)

Below MF temperature, the alloy is completely in a martensitic phase; above AF temperature, it is an austenitic state. AF temperature is critic temperature for shaping so when we heat the material above AF, it will return to its original shape again. This specific alloy has very good electric and mechanical properties and a high resistance against corrosion. Moreover, Nitinol has the quality of inducing the transformation by means of electric energy. When sufficient electric power is transmitted through the wire, the generated warmth will produce the transformation (Clevertex Report). There are alot of shape memory alloys in industry. SMM have been given in Table 1.

3. Shape-memory polymers (SMPs)

SMPs have the ability to sense and respond to external stimuli such as temperature, pH, chemicals, and light in a predetermined way (Figure 2). These materials have various elasticities from hard glass to soft rubber. SMPs have very low cost in comparison with Shape-Memory Alloys. After 1984, A lot of SMPs have been found such as polynorbornene, trans-polyisoprene, styrene-butadiene copolymer, crystalline polyethylene, some block copolymer, ethylene-vinyl acetate copolymer and segmented polyurethane 2-13, 54-56 etc. (Mondal S., Hu J., Yang Z., Liu Y & Szete Y. S., 2002).

Table 1. Shape-Memory Alloys and Properties (Novotny M. & Kilpi J., 2001)

ITEM	Ni-Ti	Cu-Cu-Zn-Al	Cu-Al-Ni
Melting point (°C)	1250	1020	1050
Density (Kg/m ³)	6450	7900	7150
Electrical Resistivity ($\Omega \cdot m \cdot 10E-6$)	0.5-1.1	0.07-0.12	0.1-0.14
Thermal Conductivity, RT (W/m ² *K)	10-18	120	75
Thermal Expansion Coeff. (10E-6/K)	6.6-10	17	17
Specific Heat (J/Kg*K)	490	390	440
Transformation Enthalpy (J/Kg)	28,000	7,000	9,000
E-modulus (GPa)	95	70-100	80-100
UTS, mart. MPa)	800-1000	800-900	1000
Elongation at Fracture, mart. (%)	30-50	15	8-10
Fatigue Strength N=10E+6 (MPa)	350	270	350
Grain size (m*10E-6)	20-100	50-150	30-100
Transformation Temp. Range (°C.)	-100 to +110	-200 to +110	-150 to +200
Hysteresis (K)	30	15	20
Max one-way memory (%)	7	4	6
Normal two-way memory (%)	3.2	.8	1
Normal working Stress (MPa)	100-130	40	70
Normal number of thermal cycles	+100 000	+10 000	+5 000
Max. Overheating Temp. (°C)	400	150	300
Damping capacity (SDC %)	20	85	20
Corrosion Resistance	Excellent	Fair	Good
Biological Compatibility	Excellent	Bad	Bad

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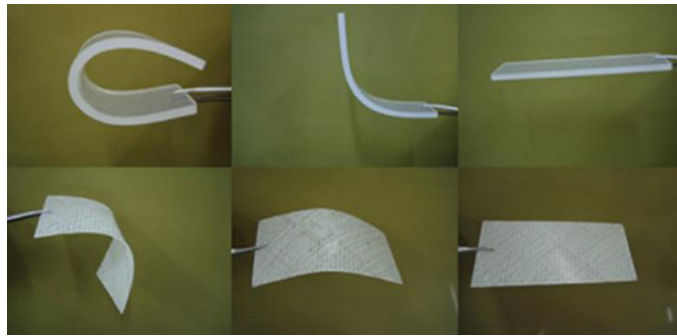


Fig. 2. Time series photographs that show the recovery of a pure SMP (top row), and a glass-fiber-reinforced SMP (bottom row) (Leng J., Lan X, Liu Y. & Du S., 2011)

Shape memory polymers consist of two polymer components and resulting two phases, one with a higher melting temperature than the other (Cook F. L., Jacob C. I., Polk M., Pourdeyhimi B., 2005). The first SMP polynorborene is difficult to tailor because of its high molecular weight, so Styrene butadiene SMPs were found but its process was so poor (Leng J., Lan X, Liu Y. & Du S., 2011). Styrene-based and thermoplastic polyurethane based SMPs have been discovered. In figure 3, we can see the structure, stimulus and shape-memory functions of SMPs clearly.

Composition & structure	Stimulus	Shape memory function
Block-copolymer 	Temperature 	One way SME
Supramolecular polymer 	Electricity Magnetic 	Two way SME
Polymer blend / composite 	Water sensitive 	Triple shape SME
Polymer IPN/semi IPN 	Light/radiation 	Multi shape SME
Crosslinked Homopolymer 	Oxidation-reduction 	Multi functionality

Fig. 3. Integrated insight into SMPs based on structure, stimulus, and shape-memory function (Hu J., Zhu Y, Huang H. & Lu J., 2012)

SMPs can be activated with electric, light, chemical, magnetic field in addition to heat. Their programming ways are rather wide, they can be programmed with multi-steps. They can be used comfortably with human skin because of their low weight and softness. In the Table 2, we can see the differences of SMAs and SMPs.

Table 2. Characteristics of SMPs compared with SMAs (Ishizawa J., Imagawa K., Minami S., Hayashi S., Miwa N.,2003)

Property	Shape memory alloys	Shape memory polymers
Recovery Volume	7%	400–500%
Density	6.5 gm/cm ³	1 gm/cm ³
Wokability	Good (thermoplastic)	Poor
Cost	\$1000/kg	\$50/kg

4. Shape-Memory Applications in Textile

Shape-memory fibers based on SMPs can be implemented to develop smart textiles that respond to thermal stimulus (Ji F, Zhu Y, Hu J, Liu Y, Yeung L & Ye G., 2006). Shape-memory materials can be used for clothing, textile as yarn, fabric or fibre. SMP fiber can be produced with the spinning methods, so it provides us to produce SMP yarns, too. As shape-memory textile, SMA or SMP can be used in accordance with needs. Although SMAs also have some applications such as in brassieres and flame retardant laminates, SMPs have better potential for textile and clothing and related products. These products are shoes, various breathable fabrics, thermal insulating fabrics and crease, shrink-resistant finishes for apparel fabrics, etc. These products can be made with finishing, coating, laminating, blending, and other innovative structures (Tobushi H., Hara H. and Yamada E., 1996(a); Tobushi H., Hara H. and Yamada E., 1996(b); Tobushi H., Hashimoto T., Ito N., Hayashi S. and Yamada E., 1998; Zeng Y. M., Yan H. J. and Hu J. L., 2000).

George K. Stylios and Taoyu Wan have made a study on some SMM. In Figure 4, a fabric surface weaved with NiTi wire can be seen. This material is affected with heat. When the fabric is heated to 50oC with different times, it started to act to way that is teached the material before.

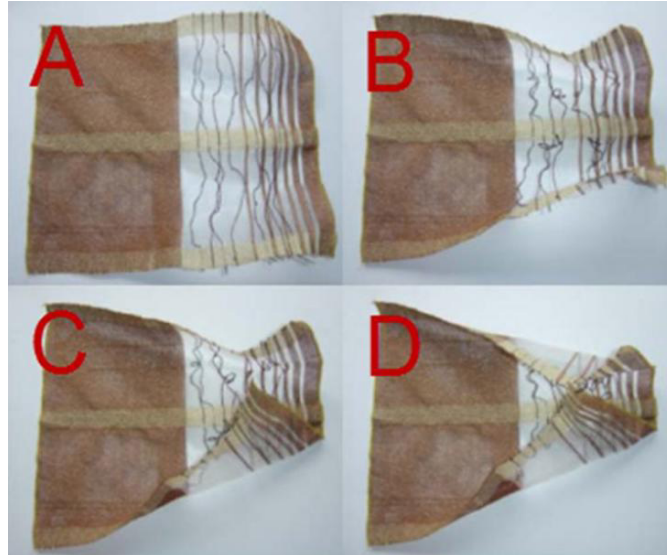


Fig. 4. Shape memory recovery of smart textile having SMA spring varied with temperature when T=50oC: (a) 0 s; (b) 10 s; (c) 20 s (George K. Stylios and Taoyu W., 2007)

The other study of George K. and his team is about intelligent curtains affected with heat. This curtains can act when they expose to the heat (Figure 5). Such applications can be made with SMP, too, so curtains can act with the sun.



Fig. 5. An intelligent window curtain application (George K. Stylios and Taoyu W., 2007)

The SMP yarn was woven sparsely and loosely across the fabric weft to allow room for the SME to take place. In contrast with the sample shown in Figure 6. Different times of 50 oC application can change the structure of fabric.

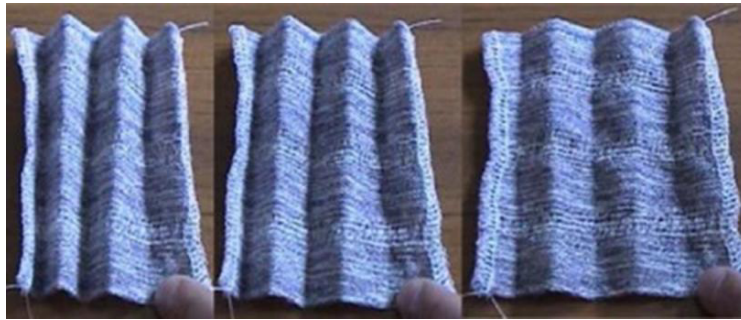


Fig. 6. Shape memory recovery of SMP composite woven uniformly and densely of SMP yarn at 50oC with recovery time (a) 0 s, (b) 15 s, and (c) 30 s (George K. Stylios and Taoyu W., 2007)

NiTi wires can be used as a part of garments as seen in Figure 7. When the wire is heated, skirt rises and flower is closing. This example is a good sample for fashion design of shape-memory materials.



Fig. 7. Rising skirt and closing flower garment applications (Berzowska J. & Coelho M., 2005)

Shape-Memory textiles can be used a technical garments. In figure 8, you can see a schematic drawings. At low temperatures, the smart garment assumes the configuration shown in Figure (a). Here, shape memory fibers are impregnated to this structure by such a way. With the increasing temperature in the layer, the air pocket expands (Figure b and figure c). Hence, this garment makes the firefighter less susceptible to burn injuries.

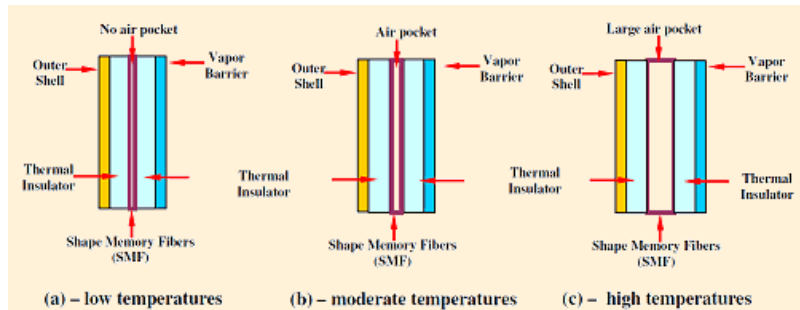


Fig. 8. An example of shape-memory smart garment (<http://www.baz.umd.edu/labs/firefighter.html>)

The other study as about bra design of SMM. Women's brassieres have both esthetic as well as structural requirements. The application of superelastic NiTi alloy to the wire re-enforcement, called the underwire. NiTi underwires offer improved comfort due to the much lower elastic modulus than the conventional steel wires. An additional advantage is the fact that the superelastic NiTi wires are resistance to permanent deformation which can be the result of washing and drying cycles (Figure 9) (Ming H. Wu & L. McD. Schetky, 2000).

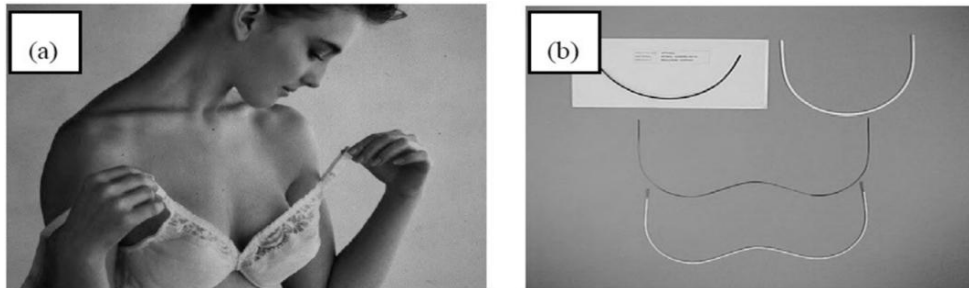


Fig. 9. Photographs of (a) brassiere and (b) various designs of superelastic NiTi underwires

Corpo Nove developed Oricalco shirt. In the shirt, the sleeves are programmed in such a way that the sleeves shorten when temperatures increases with a few degrees. Moreover, the fabric can be pleated, plied, crushed and crease (Figure 10).

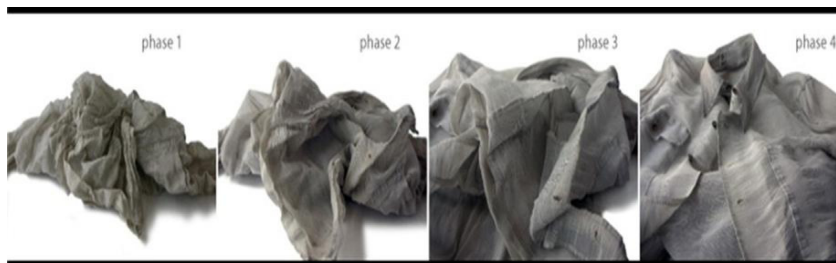


Fig. 10. Oricalco Shirt (Parys M. V., 2001; <http://www.gradozero.eu/gzenew/index.php?pg=oricalco&lang=en>)

Mitsubishi have discovered Diaplex® membrane as Shape-Memory Polymer. Diaplex® is affected by heat or moisture, so this provide users thermal comfortability (Figure 11).

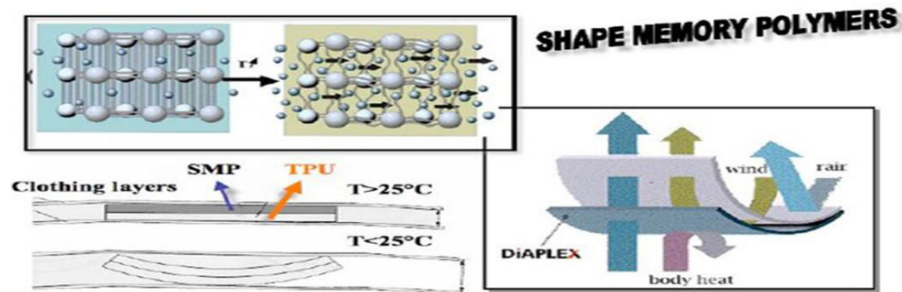


Fig. 11. Diaplex® adaptive membrane (Parys M. V., 2001).

The other example of Shape-Memory polymer is Dermizax®. This textile polymer is affected by microclimates. As the microclimate rises, the openings between the polymer molecules in the membrane expand, thereby increasing the fabric moisture permeability. As the temperature drops the pores close, thereby trapping heat (Figure 12).

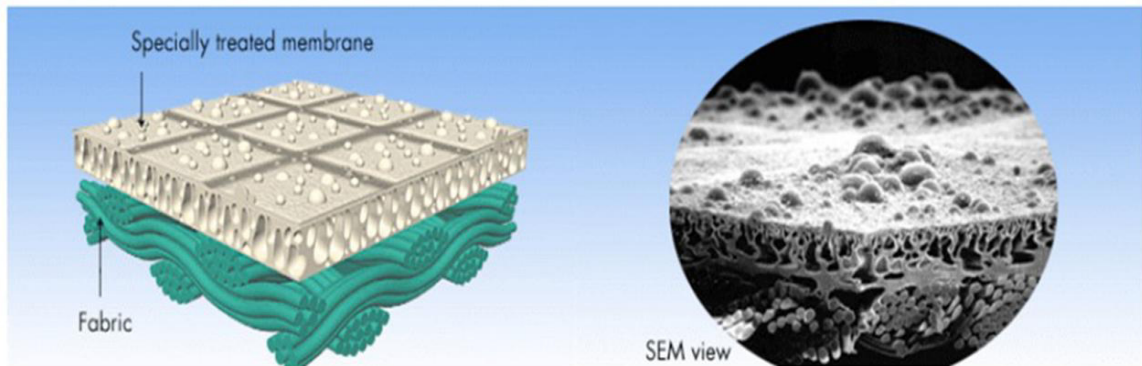


Fig. 12. Dermizax® textile application (<http://www.tamarackoutdoors.co.uk/PBCPPlayer.asp?ID=1518574>)

Figure 13 shows shape memory foams. Bayer developed a pillow, this pillow can adjust its shape to the contour of the neck and shoulder according to body temperature. SMP foams can be used as memory mattresses to provide body comfort. SMP foams can be used to prepare insoles, which can effectively improve shoe fitting (Gefen A, Megido-Ravid M, Itzhak Y. & Arcan M., 2002).



Fig. 13. Shape-Memory Foam Applications (Hu J., Meng H., Li G. & Ibekwe S., 2012)

Sphere React Shirt has been made to be affected by user's heat. This shirt has vents on it when user start to make performance because of high temperature of body. This vents open and air starts to enter the body so sweat can be evaporate fast (Figure 14).



Fig. 14. Back of a Nike 'Sphere React Shirt' with a smart vent structure (<http://store.nike.com/?country=US&lang locale=en US&l=shop,pdp,ctr-inline/cid-100701/pid-240998#l=shop,pdp,ctr-inline/cid-100701/pid-240998>)

5. Conclusion

This study is aimed at showing shape-memory material usage in textile design. Shape-memory materials are one of the methods of making smart textiles. Although there are a lot of shape-memory materials in sector, NiTi and polyurethane materials are ahead in terms of usage. These materials can be used with different production methods. SMM catches attentions of people with magical acts. In addition to its magical acts, SMMs are useful in many technical textile, so it is obvious that interest on SMMs will continue to improve in future.

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