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THERMAL ACTUATING SHAPE MEMORY MATERIALS – A CRITICAL REVIEW

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ABSTRACT

Advanced class of materials are being employed and designed for several purposes like; react and sense to various environment conditions, bio mimic, robotics, artificial intelligence, self actuating, ultra-light, high storage capacity, from the artificial or natural occurring materials. Material science engineers and scientists have tailored the properties of such type the engineering materials in a way; that they can respond the mimic smart behaviors of plants, human life and animals. Such materials are termed as smart or intelligent materials. Intelligent materials or Smart materials have ability to sense the various stimuli to respond from temporary to permanents or vice Versa to those stimuli's in predetermined path. Generally smart materials have two functional ability, namely, actuating and sensing. Smart materials can sense the several stimuli such as change in, weather conditions, heat, electricity, magnetic fields, temperature, ph, solutions, load, electromagnetic waves etc. The sensors have ability to detects the changes in the physical environmental conditions and produce a signal correspondence to the external stimuli's encountered.

Keywords: Self Actuating Materials, Shape Memory, Smart Materials.

I. INTRODUCTION

1.1 Intelligent or Smart materials:

New category of materials are being employed and designed for several purposes like; react and sense to various environment conditions, bio mimic, robotics, artificial intelligence, self actuating, ultra-light, high storage capacity, from the artificial or natural occurring materials. Material science engineers and scientists have tailored the properties of such type the engineering materials in a way; that they can respond the mimic smart behaviors of plants, human life and animals. Such materials are termed as smart or intelligent materials. Intelligent materials or Smart materials have ability to sense the various stimuli to respond from temporary to permanents or vice Versa to those stimuli's in predetermined path. Generally smart materials have two functional ability, namely, actuating and sensing. Smart materials can sense the several stimuli such as change in, weather conditions, heat, electricity, magnetic fields, temperature, ph, solutions, load, electromagnetic waves etc. The sensors have ability to detects the changes in the physical environmental conditions and produce a signal correspondence to the external stimuli's encountered. Materials that are used for sensors and actuators are micro-electromechanical systems, optical fibre, piezoelectric materials and electromechanical systems. The actuator is that material in which the receiving input signal from the sensors make predetermined response to the surrounding such as change in the properties of materials or dimension of materials. Actuators are able to convert any form of signal into mechanical work and therefore can act on the surrounding. The smart intelligent materials may be categorized as shape memorized polymers, shape memorized alloys, shape memorized ceramics, and shape memorized gel etc [1-5].

Some smart materials are also act as a sensor as well as actuators for thermo-responsive shape memorized materials which can sense the change in the external stimuli and can respond in shape change to the corresponding change in temperature, thereby, acting as sensor as well as actuator simultaneously. Table 1.1 shows that the stimuli and their response of intelligent materials [3, 6].

Table 1.1 Various stimuli and their response of smart materials [2, 5-8]

Stimuli	Optical	Electrical	Thermal	Magnetic	Mechanical
Electrical	Electro-luminescent, Electro-chromic, Electro-optic		Thermo-electric		Piezoelectric, Electrostrictive, ER Fluids
Magnetic	Magneto-optic				MR Fluids

Optical	Photo-chromic	Photo-conductor			
Thermal	Thermo-luminescent, Thermo-chromic				Shape Memory
Mechanical	Mechano-chromic	Electro-strictive, Piezo-electric		Magneto-strictive	Negative Poisson Ratio

1.2 Shape memory material: shape memorized (memory) material is smart shape recovery materials which are responsible for various stimuli like skin touch, vibration, temperature, water, electrical, magnetic, electromagnetic, microwaves, ph, and solutions, etc. The idea has got from natural Chui Mui (Mimosa Pudica) plant. Chui Mui (Fig.1.1) plant leaf is natural example of shape memory, smart, self-actuating material. The leaf of Chui Mui gets shrink (contract) to each other when the leaf of Chui Mui touch by hand or shake the plant. An exciting feature of Chi Mui plat is sensitive to skin, vibration, light, and thermal may open the door for scientists and researchers for further research in various self-actuating smart shape-memory materials [4, 7]. Self-actuating smart shape-memory materials are those which remember their original shape and size to recover from deformed shape with the application of various stimuli like skin touch, vibration, temperature, water, electrical, magnetic, moisture, electromagnetic, microwaves, ph, and solutions, etc.

Shape memory self-actuating materials are generally classified as shape memorized ceramic, shape memorized alloy, and shape memorized polymer. Shape memorized self-actuating devices are recently used in field of bio-medical, aerospace, industries of automobiles, robotics, industries, sensors and, actuators. Shape memorized polymer (SMP) is polymeric self-actuating intellectual materials which exhibits shape memory effect above and below its transition temperature of glassy state glass. Glass transition (Tg) temperature is that point of temperature where particular polymer shift from glassy state (hard) to rubbery (soft) state or vice versa. Shape memory polymers have certain advantage and disadvantage over existing shape memory alloys and shape memory ceramics [5, 8]. Shape memory polymer has high shape recovery (almost 100%), low processing temperature, high biocompatiblity, erosion & corrosion-free, easy processing, less expensive setup, transparency over shape memory alloys and shape memory ceramics. But certain disadvantage of shape memory polymer like low recovery force, lower temperature applications, and low recovery speed, etc. shape memory materials are generally categorized into shape memory alloys, shape memory polymer, shape memory ceramics, and shape memory gel/thin film.

1.2.1 Shape memory alloys:

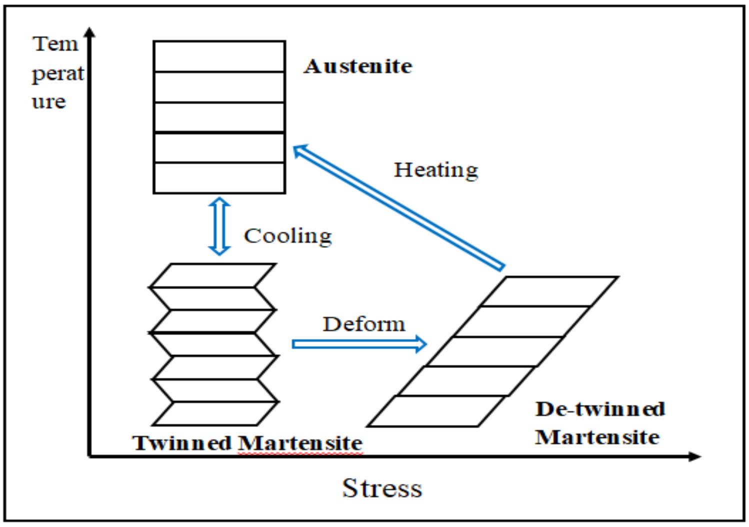


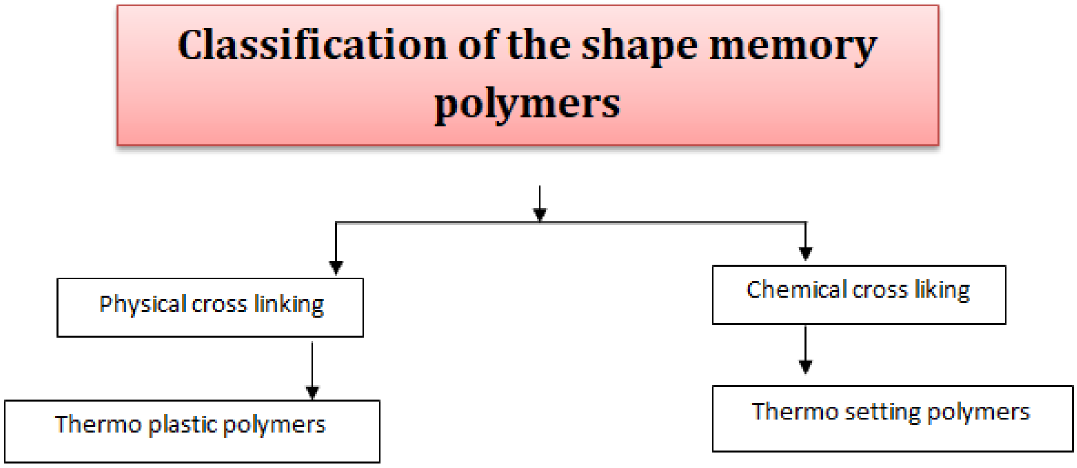
Fig. 1.1 Basic principle of thermal response shape memorized effects [1, 3]

shape memorized alloys are metallic materials that recovery there permanent shape from pre-deformed temporary shape with the help of various outside stimuli's such as; heat, temperature, light, and microwave irradiations etc. Fig. 1.2 showing pictorial representation of phase changes of shape memory alloys and its effect.

The recoverable strain of shape memory alloys is generally maximum 8% only. The operating temperatures of shape memorized alloy are high as comparison to shape memorized polymer. The shape transition temperature of shape memory alloys was calculated above and below martensite and austenite temperature. Shape memory alloys are generally categorized into three alloys systems [2, 7, 8].

a. Ni-Ti based shape memory alloys such as NiTiCu, NiTi NiTiPd, ...
b. Fe based shape memory alloys such as FeNiC, FeMnSi, FePt,…
c. Cu-Al based shape memory alloys such as CuZn, CuAlNi, CuZnAl, CuAlNiMn, CuSn,…

1.2.2 Shape memory polymers: Shape memorized Polymers (SMP) are a versatile intelligent functionally graded material that exhibits shape memory effect bellow and above below the transition of glass state temperature (Tg). Shape memory polymer exhibits long covalent crosslink bonds. The properties of these polymers drastically change at transition zone. In glassy state i.e. below Tg, the movement of the soft segment of polymers segment is frozen and above Tg segments are flexible. The shape changes with the help of soft segment. Shape memory materials are generally categorized as shape memorized alloy, shape memorized polymer, shape memorized gels and, shape memorized ceramics which play significant role in smart and functionally graded materials [9-11]. In SMP the glass transition temperature is that in which the polymer change its state from glassy state to rubbery state or vies versa. Glassy is a low temperature, hard state where as rubbery is high, soft (elastic) state. SMPs can be triggered by means of outside stimuli's various like thermal, electricals, lights, waters, PHs and magnetic etc. SMPs are large deformation, low density, light weight, transparent, high thermal responsive, biocompatible and various switching methods such as microwaves, light, temperature, water, ph, electromagnetics etc. therefore SMP are widely accepted materials [1, 9, 10]. Cross linking the net point act as a fix one shape. The cross link may be either physical bond, chemical bond or net point. Due to physical cross linking the net point of polymer at below glass transition temperature get frozen. Besides the net points, matrix contains flexible type component is in the form of chain segments of amorphous in nature. And when the temperature are above the temperature of transition the network will be become elastic (Fig. 1.3). During cooling permanent shape of SMPs network stabilized by net points. In general shape memory polymer exhibit two way effects, one temporary upon mechanical deform cooling and one permanent upon heating. Two important properties of SMP are strain recovery and rate of strain fixity, recovery strain is quality of specimen to memorized its permanent position while shape rate of strain rate fixity describe to the quality of transferring segment to the fix the physical deformation. Shape memory polymers are either thermo-setting or thermoplastic. Thermoplastic shape memory polymers are preferred over thermo-setting shape memory polymers. PTFE, SMTPU, PE, PMMA, PEEKS, Epoxy resin, Polycaprolactone etc are some commonly used shape memorized polymer.



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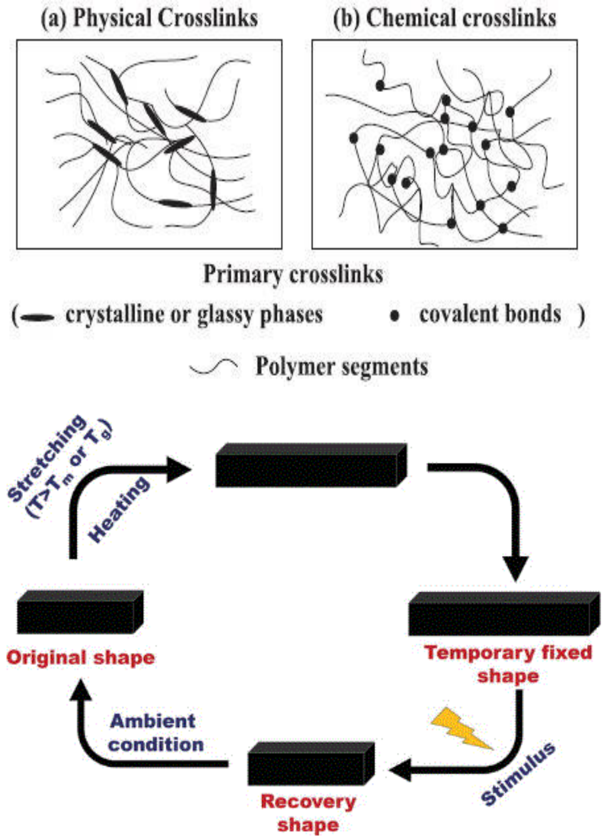

Fig. 1.3 Flow chart of working principle of shape memory smart materials [3]

1.3 History of shape memory polymer: First time shape memorized polymers norbornene (polys) based were discovered by CDF-Chime, in France country year 1984 and it commercially available in same year by Nipponzeon, Japan by trade name Norsorex. The transition of the glassy temperature of this polymers material were 30°C -40°C only and applications were limited. Kurara Corporation, Japan developed second shape memory polymer it's Poly (Trans-isoprene) in year 1987. Third commercial shape memory polymer was developed by Asmer, Japan in 1990s its diisocyanate/polyol based shape memorized polymers traded by Mitsubishi company Heavy Industries, in Japan [1, 5]. But the major breakthrough into the field of the shape memorized polymer was began after polyurethane (Ether) based SMP is available over the various trade names Like Diary MM-4510, MM-6520, polyol a poly-ester base poly (urethanes) and Diary MMs-4520, a polyether polyols base poly(urethanes) MP5410, MP5510 etc [14-18]. Shape memorised polyurethanes are available in both thermoplastics as well as thermosettings. Thermoplastic shape memory polyurethane (SMTPU) is generally preferred over shape memory thermo setting polyurethane (SMPU).

1.4 Applications of shape memory polymer:

1.4.1 Bio-medical applications: shape memory polymer smart devises are used for various sophisticated bio-medical applications[2, 19-20]. The polymeric materials are high skin compatible as well as bio-compatible and degradable in most of the cases. Energy dissipation factor of polyurethane based composites are very close to human skin which is nearly 0.5. Now a days, shape memory polymer reinforced composites take place over shape memory alloys devices due to ease of fabrication, bio-degradability, bio-compatibility and high recovery strain etc. Some commonly used shape memory polymer composites are shown in Fig. 1.8.

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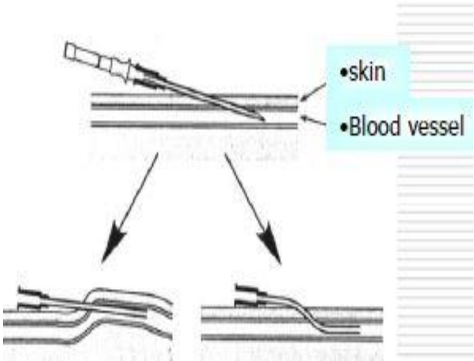
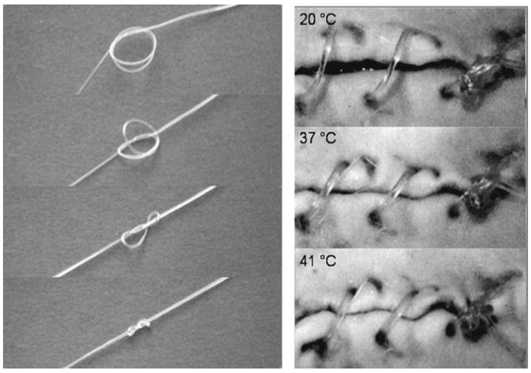
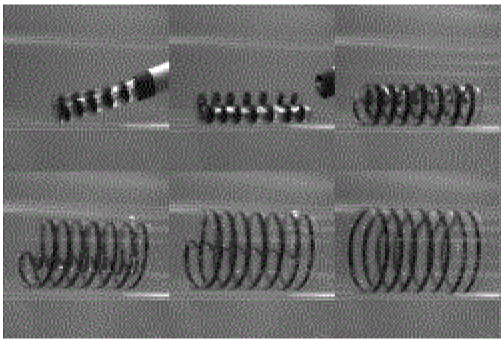


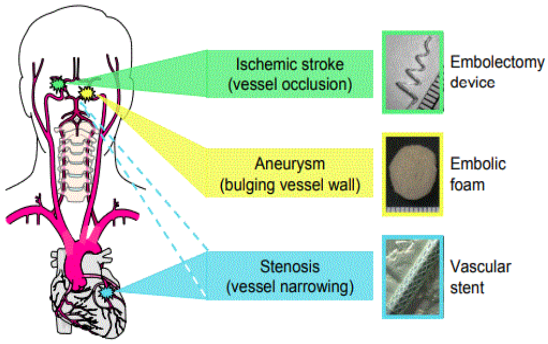
a) Intravenous syringe cannula



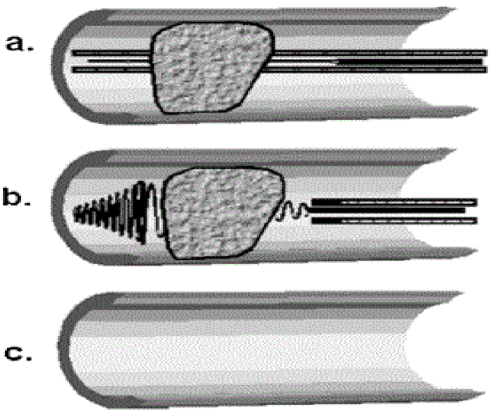
b) smart surgical suture self-tightening



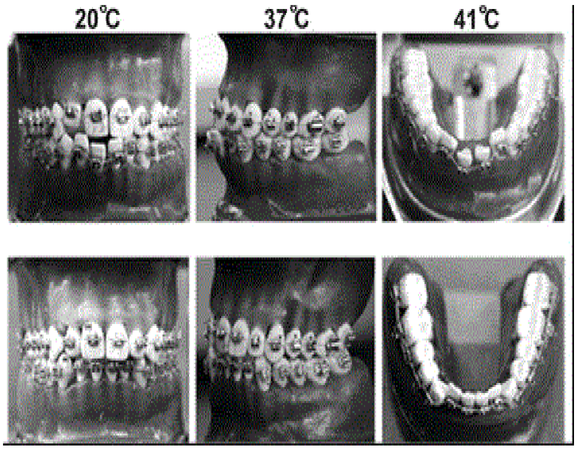
c)Cardiovascular Stents catheter



d) Interventional applications of SMP devices



e)Shape memory polymer ischemic stroke showing (a) guided catheter to pushed the clot, (b) SMP wa released and (c) clot is removed



f) Application of SMP in orthoontic misalignment treatment bottom after and (top) before treatment.

Fig. 1.8 Various bio-medicine application of shape memorized polymer composites [2-5, 19]

1.4.2 Aerospace applications: shape memorized polymer are frequently in used for aerospace's application because of low volume to weight ratio, especially when a devices are launching into orbit. Shape memorized polymer composites devises is also used in various parts of fighter planes and domestic aeroplanes. Some communally used applications are showing in Fig. 1.9.

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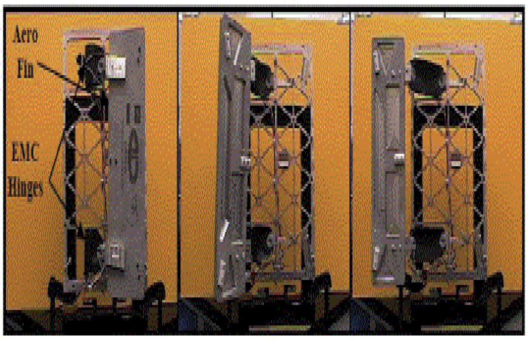
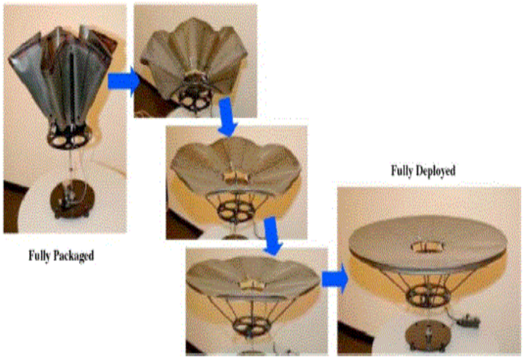
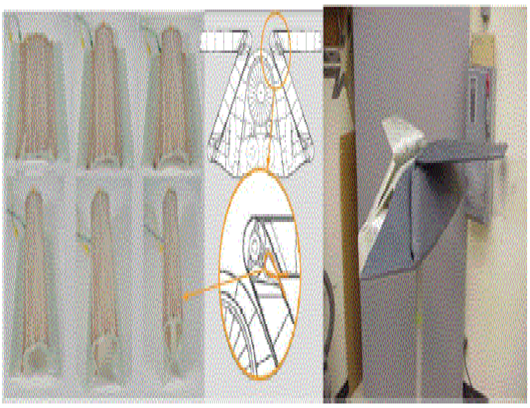


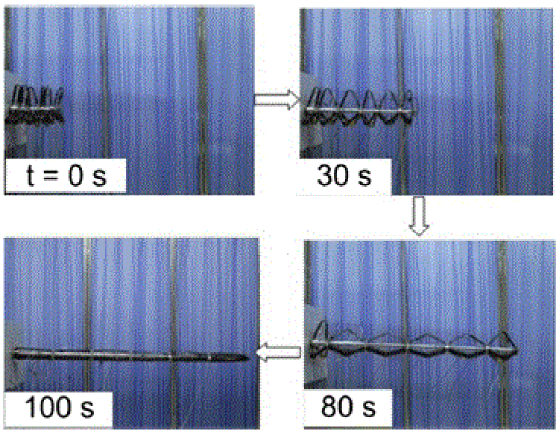
a) DINO sat of aero fin deployment from left to right side



b) Self exploring space anteena



c) Morphing vehicle wing design



d) Self deploying truss

Fig. 1.9 Showing various applications of SMPs in aerospace technology [1-6, 13]

1.4.3 Robotics, Sensor and actuator and Automobile applications: Now a days the use of shape memory smart materials in various automobile, sensor and actuators as well as robotics industries is growing widely since 1960. Intelligent material has ability to easily recovers its initial pre-deform shape under the various external stimuli are becoming gorgeous over conventional polymers [3-6, 22]. Some common uses of shape memory polymer components are shown in Fig. 1.10 and Fig. 1.11.

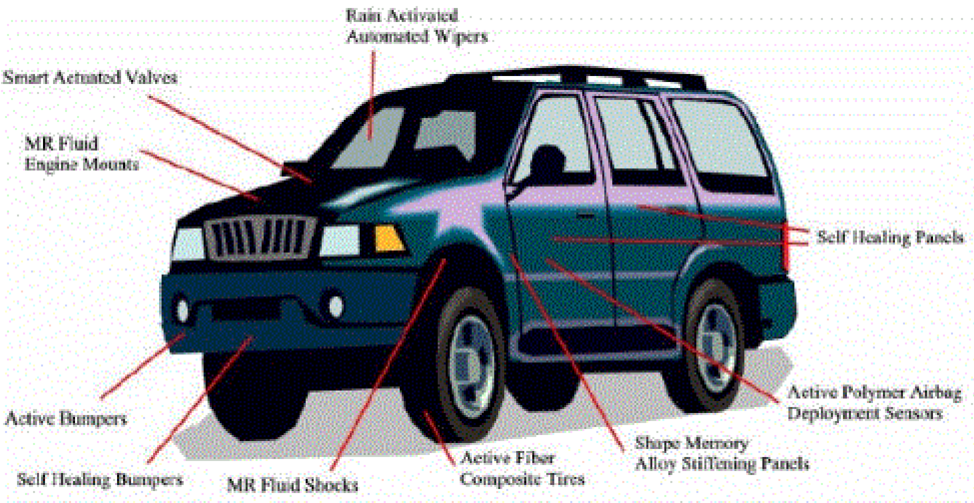


Fig. 1.10 Applications of SMPs in various part of automobile [4]

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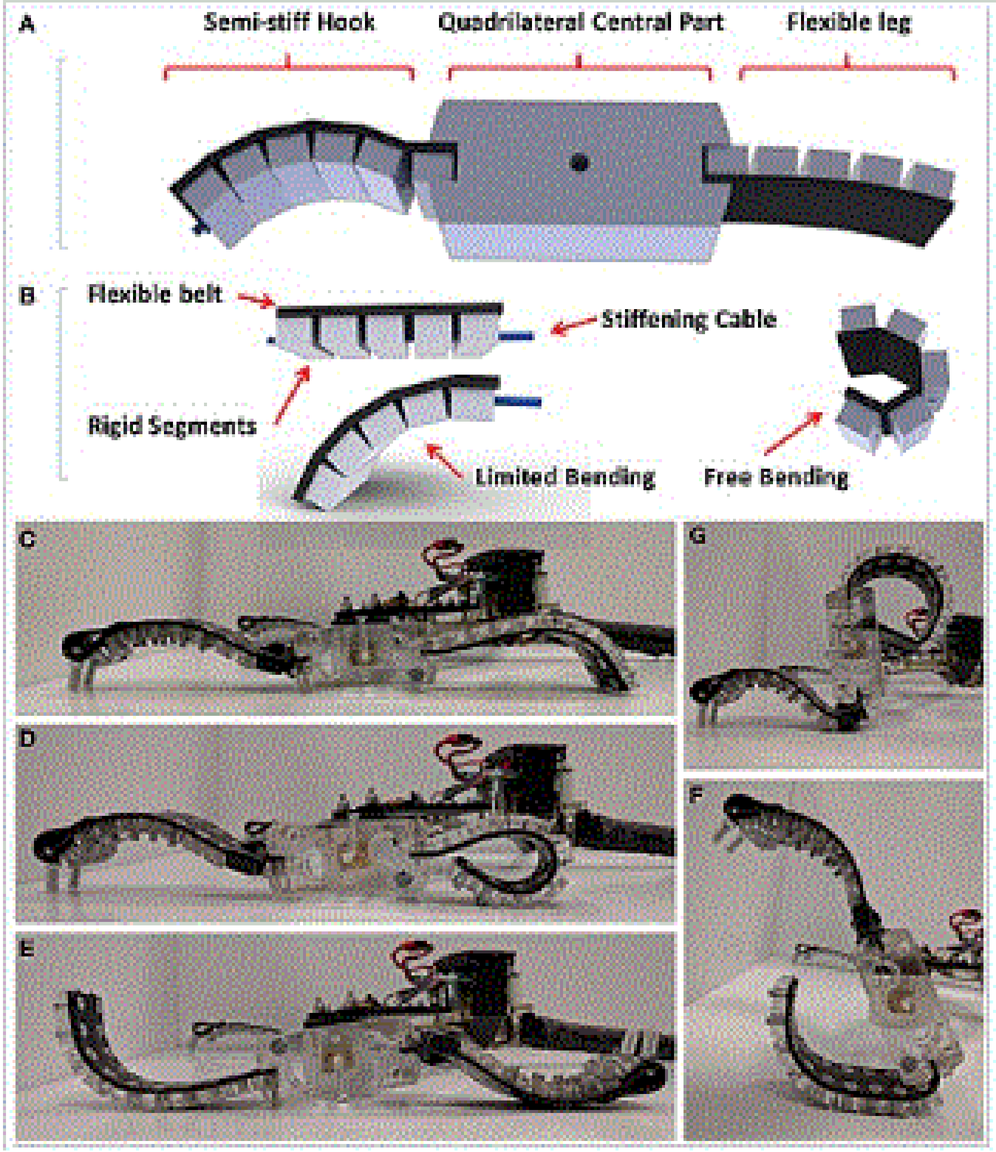

Fig. 1.11 Applications of SMPs in self actuating bending arms from (a) to (g) [4, 22]

1.4.4 Textile and other applications of SMP: Textile industries are using shape memory polymers for various toys, cloths, jacket, gun, and domestic products and so on for more comfort, more attractive and easy assembly/disassembly etc [13-15]. Fig. 1.12 shows various textile applications of SMPs and Fig. 1.13 (a) and (b) show self straight and bending tower (from right to left) of SMPs and opening of bolt with SMP actuator respectively.

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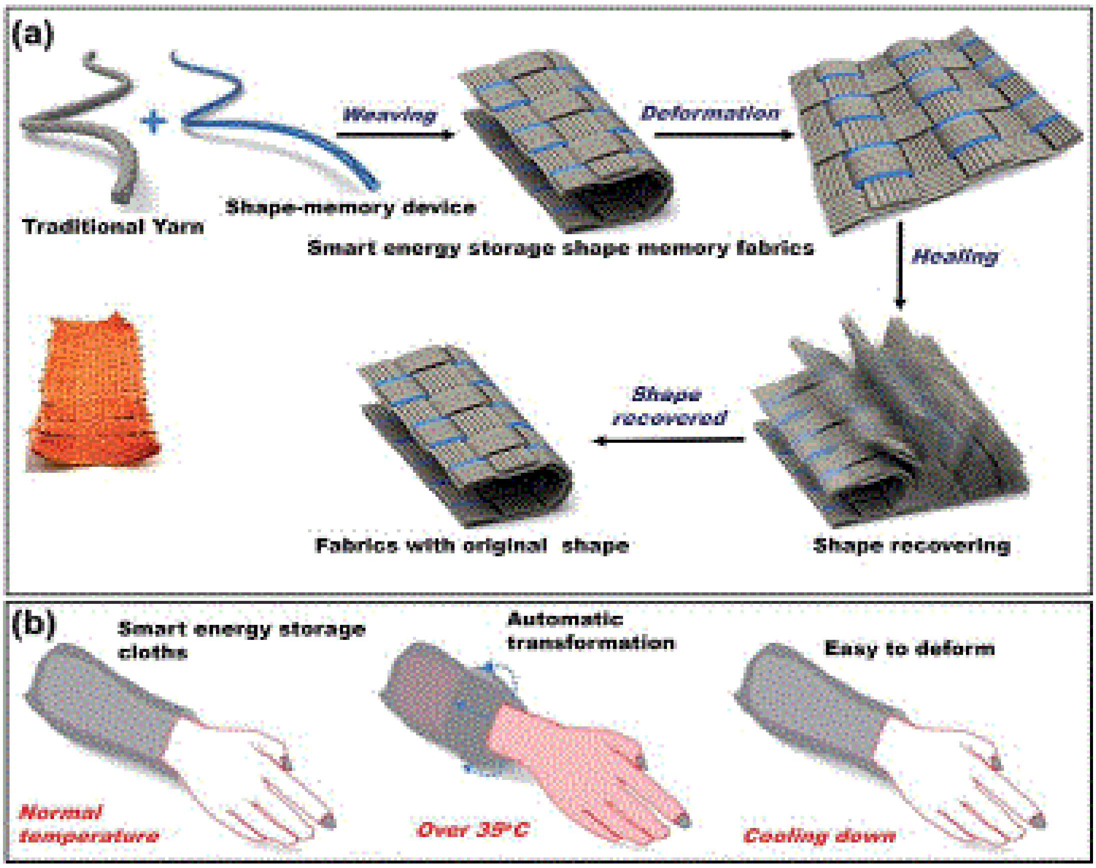
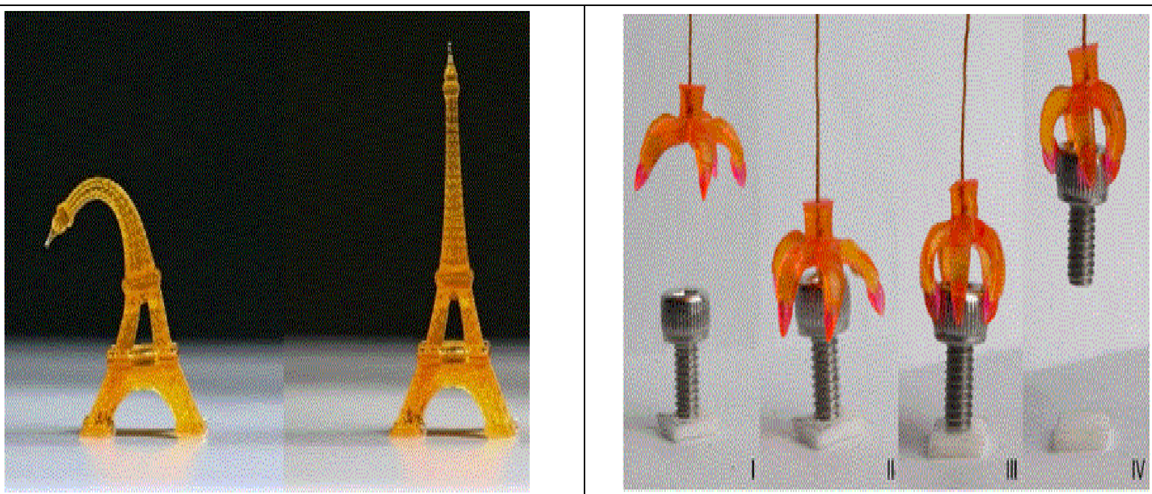


Fig. 1.12 showing various textile applications of SMPs [1-4, 13]



(a) (b)

Fig. 1.13 showing a) self straight and bending tower (from right to left) of SMPs, b) opening of bolt with SMP actuator [6, 9]

II. CONCLUSION

Shape memorized (memory) material is smart shape recovery materials which are responsible for various stimuli like skin touch, vibration, temperature, water, electrical, magnetic, electromagnetic, microwaves, ph, and solutions, etc. The idea has got from natural Chui Mui (Mimosa Pudica) plant. Chui Mui plant leaf is natural example of shape memory, smart, self-actuating material. The leaf of Chui Mui gets shrink (contract) to each other when the leaf of Chui Mui touch by hand or shake the plant. An exciting feature of Chi Mui plat is sensitive to skin, vibration, light, and thermal may open the door for scientists and researchers for further research in various self-actuating smart shape-memory materials.

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