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Research Article

A REVIEW ON INITIATION, STRUCTURE AND ADVANCE UTILIZATION OF SHAPE MEMORY POLYMER

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ABSTRACT

Shape-memory polymers (SMPs) are stimuli-responsive shape-varying polymers. Now a days they become a great interest for fundamental research and technological innovation. Here a brief review of the recent trends in the arena of SMPs is presented with particular focus on their structure, shape-memory effects and practical application. A special attention is given to smart multi-responsive and multi-functional advanced SMP materials as they are of emerging technological class. Important applications of SMP in the field of biomedical engineering, polymer domain, and material replacement are explained in the applications part. Traditional shape memory polymers (SMPs) are those which are capable of memorizing a temporary shape and recovering to the initial shape upon heating. Though SMP is old concept initiated half a century ago but its applications in variety of fields is the topic where it's lagging. As such, the intent of the present paper isn't to supply an intensive review of the SMP analysis. Instead, the main focus is on light samples of recently emerged from memory phenomena, their thoughtful impact to the sector of SMP on each scientific and sensible fronts, and future outlook.

Keywords: *Shape Memory Polymer, smart multi responsive, shape-varying polymer.*

1. INTRODUCTION

Shape memory polymers (SMPs) represent an automatically necessary category of stimuli-responsive materials that the response lies within the form dynamical criteria. The traditional definition of associate degree SMP could be a compound which might be misshapen and afterwards fastened into a short lived form, which might stay stable unless it is exposed to external stimulation that triggers the compound to recover to its original form. This behavior of SMP is understood as compound form memory result. Though numerous kinds of external stimuli is also utilized because the recovery trigger, the foremost typical one is direct heating that results in a temperature increase [1, 2].

From the last decades the advancement of the SMP field has been comparatively related to its sensible potential. As such, the dearth of pleasure and analysis activities within the period of SMPs will be attributed to the restricted applications pictured for such materials. Today adapting SMP for numerous medicine uses represents a major portion of the SMP analysis. This intense specialize in the medicine applications of SMP is partly thanks to the associated high price that's unmatched by most non medicine application. A further drive lies presumptively within the comparatively giant funding allotted to medicine analysis. On the other hand recent progresses within the last five years within the SMP field have considerably challenged the traditional read of compound SME.

2. INITIATION OF SMP

In shape-memory polymers, alterations in shape are mostly induced by heating, and beyond a specific switching temperature, Tswitch. If polymers cannot be warmed up by heat transfer using a hot liquid or gaseous medium, non-contact triggering will be required [3].The viscoelastic property is the key factor that enables the polymer network to recuperate the primary shape on the application of a variety of physical and chemical stimuli. The permanent shape of a polymeric material depends on its maximum temperature. This temperature is often termed ''highest thermal transition temperature (Tperm).'' The region above this temperature is called ''processing zone'' wherein a polymer can be melted or molten and worked out by several processing techniques such as extrusion, molding, drawing, calendaring, etc. The other zone related to the temporary shape fixing is named ''forming zone.'' The modulation temperature is either glass transition temperature (Tg) or melting temperature (Tm); the Tm is preferred over the Tg since melting phenomenon is a sharper transition, comparatively. The polymer can undergo through a programming method between the modulation temperature and the Tperm to acquire a temporary shape that is fixed by cooling below this zone. The shape can be retrieved by reheating the material above the modulation temperature. The crystalline chains achieve the random coil conformation which results in the recovery of the original shape, macroscopically [4, 5].

2.1. Shape Memory Cycle

The shape memory cycle (SMC) as given in Fig. 1 shows the co-relation between the temperatures, stress and strain. One complete cycle describes the thermomechanical procedure, i.e., applying a programming technique to the sample to deform into a temporary shape and then redeeming its original shape. The illustration of a SMC is shown in Figure. The polymeric sample is heated above Tg inducing a maximum strain (em) and (stress rm). It is imperative here that the applied temperature should not be higher than, or increase, the highest transition temperature (Tperm); else the sample will start melting. The temperature of the sample is then brought down below Tg keeping the stress constant to achieve a temporary shape, and the load is then reduced to stress free point. To recover the original shape, the sample is reheated up to T_{high} maintaining zero stress until the original shape is recovered. The polymer chains are at rest below the glass transition temperature. The activation factor is the temperature that brings in a change from the glass transition phase to a rubbery elastic one. The thermodynamic studies reveal that a polymer chain shows the same energy potential for its all possible conformations. Hence, the ascent of the temperature will make the polymer chain to reassign into entropy favored spherical conformation. For a short time interval, there will be no movement orextrication of the chains, and material returns to itsoriginal shape upon releasing the stress. However, a prolonged exposure to the external stress makes the polymer to relax, which facilitates the extrication leading to the plastic deformation in the polymer [6].

The thermo-responsive SMPs show three basic mechanisms. The polymer is heated above its Tg, which takes the polymer into a chewy state and sets chains in motion. It is deformed by a programming skill, and is cooled back below Tg to maintain the interim shape since the molecularmotions are stopped or frozen. The reheating above Tg revives this motion and polymer returns to its original shape. Polymers like poly-methyl methacrylate and silicones show such mechanism. The other mechanism is observed in linear block copolymers such as based on polyurethane (PU), and ethyl vinyl acetate (EVA) which consist of two segments.[7-9]

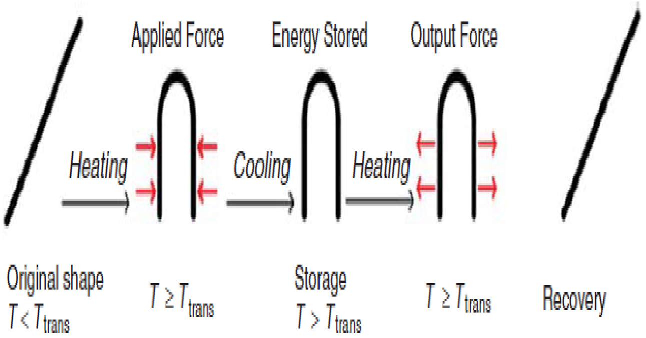

Fig. 1: Shape memory cycle [8]

One is elastic with the highest thermal transition (Tperm) acting as a physical cross-link, and maintaining the permanent shape. Above Tperm, the polymer starts melting and is then processed by extrusion, drawing, etc. The second part facilitates the attainment of the temporary shape whose transition temperature is either Tg or Tm (melting temperature). The material is formed by heating above the switching temperature; however, below Tperm, while the temporary shape is achieved by cooling below Tg. Heating the material again above Tg splinters the cross-links into switching phase, and the material returns to its original initial shape. The study has been advanced in recent years with the research on polymer blends of PU [10-13].

3. STRUCTURE OF SMP

SMPs can change their shape in numerous times either two times or three times or more than that. The structure of SMP with different transitions is shown in Fig. 2. The quantities of strain recovery rate and strain fixity rate generally describe the shape memory behaviors of getting changed to permanent shapes or getting deformed from their original state.

However the form change of SMPs may be triggered by an electrical or magnetic field, light or solution, SMPs additionally cowl a large property- range from stable to perishable, from soft to arduous and from elastic to rigid, betting on the structural units that represent the SMP. SMPs embody thermoplastic and thermosetting (covalent cross-linked) compound materials. SMPs are best –

known to able to store up to a few totally different shapes in memory [14-19].

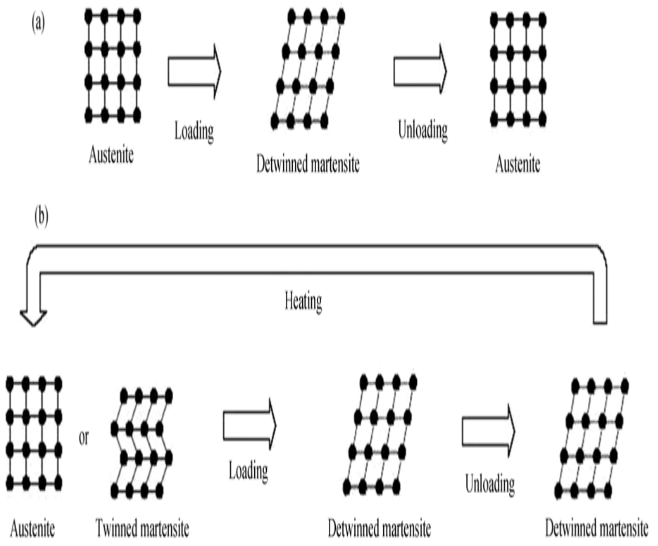

Fig. 2: Structure of SMP [15]

Two important quantities that are used to describe shape-memory effects are the strain recovery rate (R_r) and strain fixity rate (R_f) as shown in Fig. 3.The strain recovery rate describes the power of the fabric to study its permanent form, whereas the strain fixity rate describes the power of shift segments to repair the mechanical deformation.[14, 16]. The effect of stress and strain is shown in fig.3 as stress strain curve for SMP.

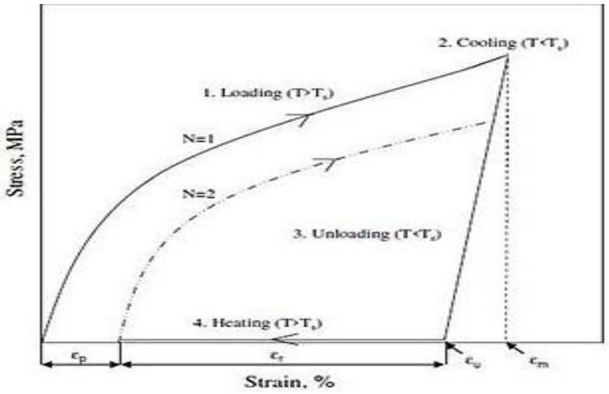

Fig. 3: Stress-strain curve for SMP

$$R_r(N) = \frac{\varepsilon_m - \varepsilon_p(N)}{\varepsilon_m - \varepsilon_p(N-1)}$$

Where N is the cycle number, ε_m is the maximum strain imposed on the material, and $\varepsilon_p(N)$ and $\varepsilon_p(N\text{-}1)$ are the strains of the sample in two successive cycles in the stress-free state before yield stress is applied.

Shape-memory effect can be described briefly as the following mathematical model:

$$R_f(N) = 1 - \frac{E_f}{E_g}$$

$$R_r(N) = 1 - \frac{f_{IR}}{f_\alpha\left(1 - \frac{E_f}{E_g}\right)}$$

Where E_g is the glassy modulus, E_r is the rubbery modulus, f_{IR} is viscous flow strain and f_α is strain for $t >> t_r$.

4. PROCEDURES TO INITIATES MP

4.1. Thermo responsive shape memory polymers

The normally available shape memory polymers are those which change in shape with the change in temperature & these are thermo responsive shape memory polymers. [20-27].

4.2. Electrical heating induced shape memory effect

The shape memory polymers are generally non-conducting by nature. So they are made conductive by blending with carbon Nano powders. The electric current is converted into heat. The property of recovering original state when electric current is passed through it is known as electrical heating induced shaped memory effect. [20-24, 28-30].

4.3. Light induced shape memory polymers

The shape memory polymers are stretched and illuminated by a light of wavelength greater than a fixed wavelength and the photo sensitive group's form cross links .The polymer is locked in the new shape and retains the temporary shape even when the stress is released. When this is illuminated by a light of lower frequency, the cross linking cleaves allowing the material to go back to its original state. [20-24, 31].

4.4. Magnetically induced shape memory effect

Some special properties changes occur when magnetic particles are induced in SMPs such are known as magnetically induced shape memory effect as shown in Fig. 4. Magnetic nano-particles having an iron (III) oxide core in silica matrix could be taken into consideration in the shape- memory polymers. [20-24, 31].

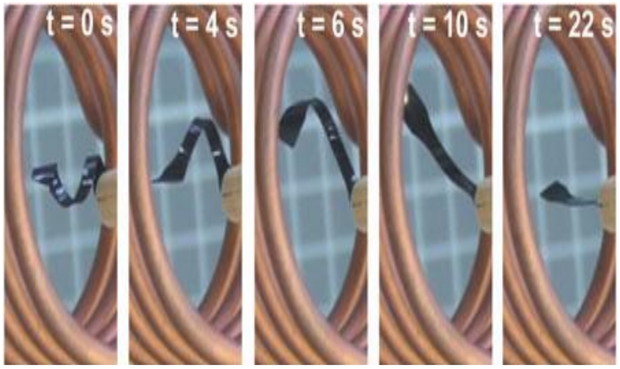

Fig. 4: Change of permanent shape of SMP (black strip) in the presence of an alternating magnetic field [11]

4.5. Water activated shape memory effect

The Actuation of the polymer can be achieved by immersion in water:

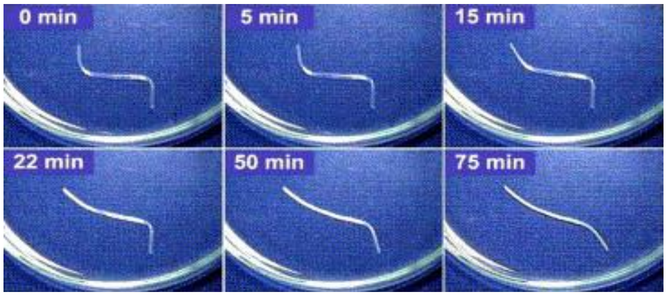

Fig. 5: Recovery of functionally gradient SMP actuated by water in a sequence [21]

A shape memory polymer which is a straight rod as the permanent shape is programmed into a Z shape. The left part of the polymer as Fig. 5 is dipped into water and the right part is not immersed. There is a reduction of the glass transition temperature for the left part and it gets actuated i.e. gets back to its original form with the help of the room temperature water itself [21, 24, 32-34].

5. ADVANTAGES/DISADVANTAGES OF SMP COMPARED TO SMA

The majority of advantages and disadvantages of these classes of shape memory materials are:

The density factor helps them to have an added advantage of volume occupancy. The inhibited force that can be generated from SMPs is a fraction of the constrained force that can be generated by SMAs, while the recovery strains are orders of magnitude higher. That is, there is a monotonic relationship between temperature and elastic modulus. This is not observed for SMAs. SMPs are cost effective and easily moldable when compared to SMA.

The thermal conductivity of SMPs is much lower than the thermal conductivity of SMAs [16].

This can be seen as an advantage or a limitation. Low thermal conductivity is desirable if the thermal insulation is required. It is a limitation if an SMP is used in an application where heat flows into or out of the polymer in a short period of time. One approach to overcome the low thermal conductivity of SMPs is to use SMP foams. The high permeability of foams allows them to be heated and cooled quickly compared to solid polymeric materials [16].

6. APPLICATIONS

One of the most common applications of the shape memory effect is in heat shrink tubing. The tubing is deformed (stretched) at high temperature, cooled while the deformation ismaintained, and after heating returns to its pre-stretched shape (shrinks) [35-37].

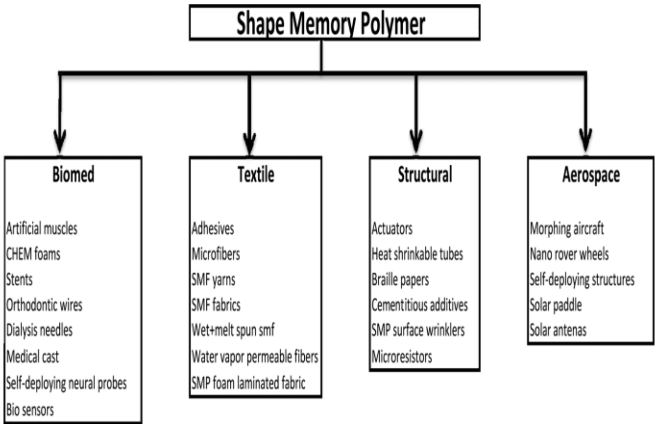

Fig.6: Different applications of SMP [10]

It was noted in 1997 that applications of SMPs were limited. However, the literature indicates that applications/potential applications of intelligent or adaptive polymeric materials, such as SMPs, are abound. Applications include use in clothing materials, in medical devices, for damping and active vibration control, for pipe joining, for sealing, and for load bearing and non-load bearing structural materials. Polymers with shape memory capability have other properties, such as moisture permeability, specific volume, refractive index and loss factor that change significantly at the glass transition temperature. As such these materials can be referred to as intelligent or adaptive materials, one aspect of which is the shape memory effect. Some of the applications reviewed in the following paragraphs depend not only on the shape memory effect, but also on material properties changes in the glass transition region [35, 38, 39, 16].

6.1. Clothing Materials

The water vapor permeability of polymers with shape memory capability changes in the vicinity of the glass or melting point transitions. This property has been used to design 'breathable' clothing, including rainwear, inner soles and boot coverings. For instance, polyurethane coatings that impart water resistance have been incorporated into rainwear. The water vapour permeability of these coatings increases substantially as they are heated through the phase transition temperature. This imparts increased breathability at higher temperatures and improves the comfort associated with wearing these garments. [35, 38-41].

6.2. Medical

SMPs have been proposed for a number of medical applications including catheters, bonecasts, stents, and endotracheal devices, surgical staples, intra-arterial catheters, orthopedic braces and splints, and contact lens. Poly (urethane) based SMPs have good biocompatibility and anti-thrombus properties. These properties make them candidates for applications such as catheters, artificial blood vessels, muscle, and contact lens. The SMP would be designed to have a Tg below body temperature [35, 38, 39].

For an intra-arterial catheter application, the SMP would be inserted into the patient in the glassy state. In the body the catheter would be warmed above the Tg and soften, minimizing the chance of damaging the arterial wall. A contact lens would be designed in the same way.

That is, it would be in glassy state at room temperature allowing ease of handling but have aTg less than body temperature and therefore soften once placed onto the eye [35].

The use of SMP for surgical staples has been investigated. The proposed material has a Tg of37oC, and a modulus of ~750 MPa at 24oC and ~430 MPa at 37°C. The staple material is formed in the closed (permanent) shape, then heated above its transition temperature and formed into the temporary (open) shape and cooled. When placed in the body it is heated and reverts to its permanent (closed) shape [35].

SMPs are also being investigated for use in fracture fixation. The fracture fixation device is flat as received. It is heated and shaped to the patient, and then cooled to fix its shape. The original flat shape can be recovered by heating the device above the Tg [35].

6.3. Damping

SMPs have been investigated for use as constrained layer damping materials in fiber reinforced composites [40]. By controlling the temperature of the SMP in the fiber reinforced composite, the damping resulting from the incorporated SMP can be varied. In the system investigated, a poly (urethane) based SMP (Tg ~ 45^{o}C) was incorporated into a glass/carbon fiber composite. The carbon fiber was used to heat the SMP and alter/control the damping characteristics of the composite [35].

Composites of SMPs with high performance reinforcing fibers have the potential to be used as adaptive structural materials for active vibration and acoustic control and/or active shape control. SMP composites have higher in plane strength and modulus while maintaining shape and elastic memory properties of the polymeric component [38].

The temperature dependent acoustic properties of SMPs vary in the vicinity of Tg. Tests carried out on SMP polymer foams in a number of thicknesses revealed a shift in resonance of several hundred Hertz (Hz) at a nominal frequency of 2.5 kHz. This indicates SMP polymer foam resonance frequencies can be 'tuned' by changing temperature [35].

6.4. Defense Applications

SMP can be used effectively in the perspective of defense. Shape memory foams can be used to fabricate parts that are light weight and compact thus easily transported. These aspects of SMPs, low mass and volume, also make them attractive materials for space applications. Parts can be fabricated, their shape modified (in general compacted), and then changed back once in space. Thermoplastic and thermoset SMPs fiber composites have been investigated for space applications. As mentioned earlier, SMPs have also been investigated for medical applications such as splints, surgical staples, and intra-arterial catheters. Each of these applications has the potential to improve first line medical care of the soldier in the field. SMPs and SMP fiber composites have been investigated for vibration and acoustic control and/or shape control. These materials would reduce noise generated by defense platforms. For instance, noise abatement on ships would not only decrease probability of detection but also improve working conditions for ships staff [35, 42, 43].

6.5. Biodegradable SMP's in Biomedical Application

In this field of biomedical SMP finds its vivid application where tissue repairs will be done in a painless and effective with long lasting approach. When this comes into action the day is not far when tissue repairs and ligaments replacement will be done in no time with less pain or practically no pain at all [7,44].

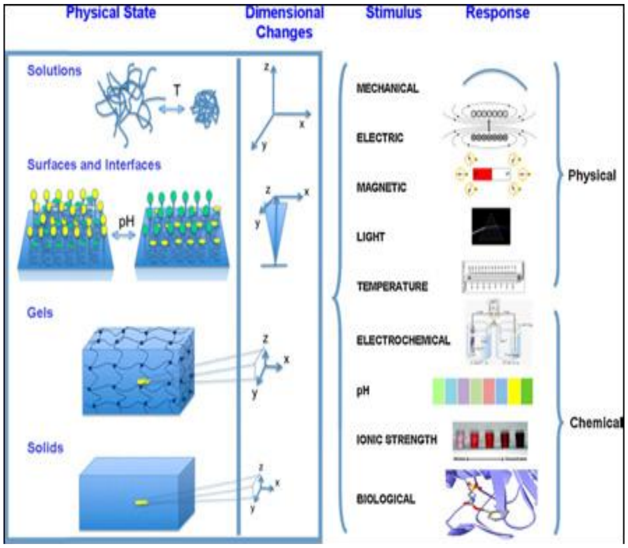

Fig. 7: Schematic representation of dimensional changes of polymeric systems upon different stimuli and their resulting response [7]

The application of biodegradable polymers with shape memory effect may usher in an era of simple, low cost biocompatible smart materials that expands the scope and clinical utility of these materials as shown in Fig. 6 and 7. The majority of applications were in pilot developmental stages and hence these degradable biocompatible materials with dynamic properties will be explored more in future that may help in diverse application in this material world [7].

6.6. Self-centering pseudo-rubber

A very effect of fascinating shocks causes a motivating modification throughout earthquakes and ship collisions because of SMPs damper. Shock absorber devices (SAD) typically accustomed connects the separation gap to scale back the pounding force. A unique energy fascinating material with residual deformation self- recovery ability, martensitic nickel metal (NiTi) form memory alloy pseudo-rubber is invented victimization 3 ways during this study assented in Fig. 8 [45].

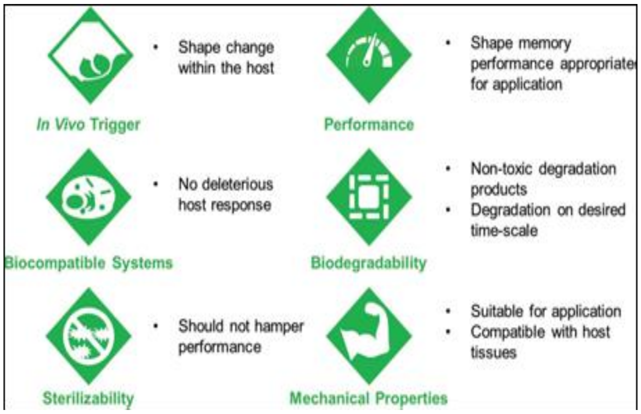

Fig. 8: Schematic representation of the basic design consideration in biomedical field [7]

6.7. A Kirigami shape memory polymer honeycomb concept for deployment

With certain special characteristics developed this SMP with honeycomb and shape changing property is used to design the honeycombs displayed in Fig. 9. The following figure shows the different steps of designing the honeycomb structure after preparation of a bond. It includes the following steps of cutting, corrugating, folding & bonding structure finally which develops the honeycomb mesh.

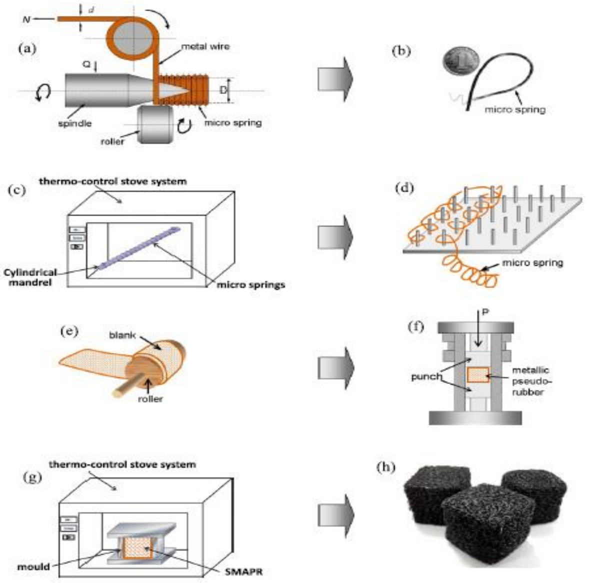

Fig. 9: General fabrication process of the SMAPR [45]

As described in this work the cellular structure has styrene SMP hinges that create the shape change and the deployment actuation. For obtaining a large volumetric deployment, the Kirigami open honeycomb configuration has been designed by setting an initial three-dimensional re-entrant axenic (negative Poisson's ratio) configuration, while the final honeycomb shape assume a convex (positive Poisson's ratio) layout [46].

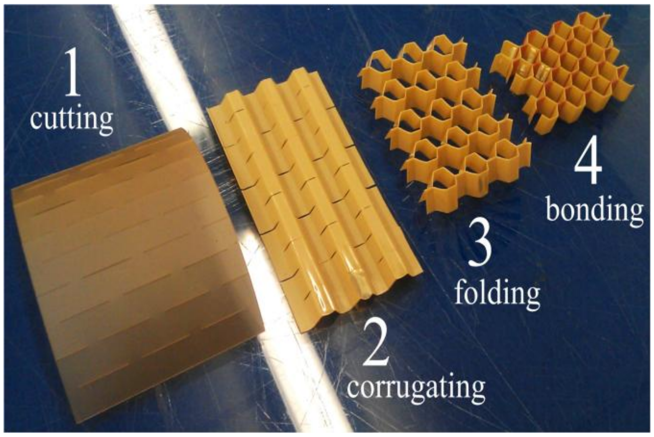

Fig. 10: The Kirigami honeycomb manufacturing process [46]

6.8. Switch spring

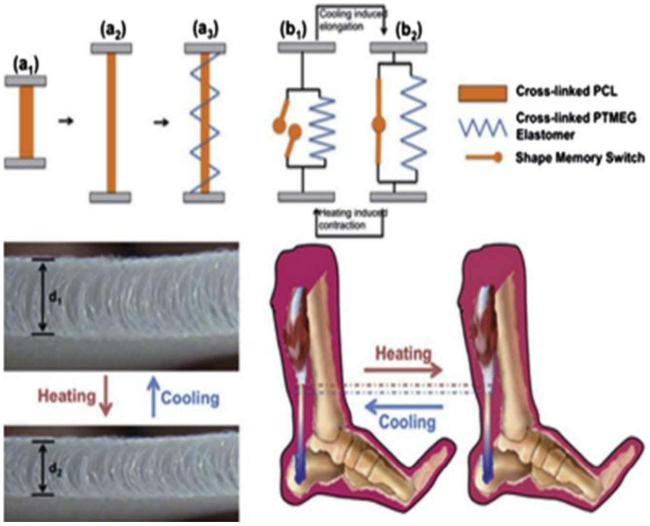

Fig.11: Total function of switch spring with its application [1]

The spring is a compound of Tetra methylene ether glycol (PTMEG). This is a 2-way-shape-memory system and shows a great advantage to use and in compare with price also. Its free-loading preparation is very easy. It uses a concept of IPN which require a pre-programming process. Raw materials, including modified macromonomers and cross-linkers, were dissolved in dimethylformamide. Pre-IPN was come by photo cross-linked of acrylate-PCL. The final IPN was achieved after the obtained gel like structure is stretched and respectively by curing the PTMEG at ≥80°C, followed by cooling for the formation of the elastomeric network. Afterwards, by reheating the sample, PCL melted ''opening of the switch" and the PTMEG undergone a compression movement. As a consequence, PTMEG pushed the PCL segment to crystallize following ''spring direction" when the system was cooled again. Such new tension-free permanent 2-way-SMP could be employed as artificial muscles or tendon as given in Fig. 10 [1].

7. CONCLUSION

In the era of rapid development and extensive changes SMPs may bring a revolutionary change in the world as we see now. The applications are very diverse ranging from individual biomedical application to very vast defense sector making it a great scope for researchers to work on. Here the paper is concentrated on few basic principles of SMPs& its effects concentrated on application based effects.

Use of SMP in manufacturing and in industrial application will lead the production system to a different level where people can get the product as their desire and a multifunctional material will help to minimize the cost, effective use of material and great saving of time.

Hence to conclude with, SMPs will offer a revolutionary change in the field of biomedical engineering & others when properly streamlined and applied to its applications. When it will be ready we would see the world in a different perspective the SMP s approach where the clothes which we wear the materials which we use, the physical building of our body & weapons to be used in defense everything precisely everything would change in a manner different and more modern way than we see today . Instead of all these application now Shape Memory polymer has gone beyond the regular manufacturing process. How it has given a great performance in the field of medical, bio medical, and aerospace and in many more like that it can also be used in the manufacturing to modify the process. Recent requirement gives a path to use the Shape memory polymer in different shape making, tool design, tool life increment and can also be used as a cutting tool. If the experiments and researches on SMP as to be used as tool in machining process or as a catalyst to increase the tool life then it will be a great revolution in the field of manufacturing.

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