

# Study on Shape Memory Polymers and their Applications

R. B. Barjibhe

*Department of Mechanical Engineering  
SSGBCOET, Bhusawal, Maharashtra, India.*

Dr. Bimlesh Kumar

*Principal,  
J.T.Mahajan College of Engineering, Faizpur, Maharashtra, India*

**Abstract-** Shape-memory polymers are an emerging class of active polymers that have dual-shape capability. Shape-memory polymers (SMPs) undergo significant macroscopic deformation upon the application of an external stimulus (e.g., heat, electricity, light, magnetism, moisture and even a change in pH value). The applications of SMPs and their composites receive much interest, including deployable structures, morphing structures, biomaterials, SMP foams, automobile actuators and self-healing composite systems.

**Keywords – SMPs, Application of SMPs.**

## I. INTRODUCTION

The SMPs are stimuli-responsive smart materials with the ability to undergo a large recoverable deformation upon the application of an external stimulus. While the reversible martensitic transformation is the mechanism behind the shape-memory phenomenon in shape-memory alloys (SMAs), the shape-memory phenomenon in SMPs stems from a dual-segment system: cross-links to determine the permanent shape and switching segments with transition temperature to fix the temporary shape. Below, SMPs are stiff, while they will be relatively soft upon heating above and consequently they can be deformed into a desired temporary shape through applying an external force. When cooling and subsequently remove this external force, their temporary shape can be maintained for long. Upon re-heating, their temporary deformed shape will automatically recover the original permanent shape.

## II. NOVEL APPLICATIONS AND SHAPE-MEMORY POLYMERS

As a novel kind of smart materials, SMPs currently cover a broad range of application areas ranging from outer space to automobiles. Recently, they are being developed and qualified especially for deployable components and structures in aerospace. The applications include hinges, trusses, booms, antennas, optical reflectors and morphing skins. In addition, SMPs also present additional potential in the areas of biomedicine, smart textiles, self-healing composite systems and automobile actuators. Additionally, there are many patents in relation to SMPs applications, such as gripper, intravascular delivery system, hood/seat assembly and tunable automotive brackets in vehicles.

### A. Deployable Structures –

For the traditional aerospace deployable devices, the change of structural configuration in-orbit is accomplished through the use of a mechanical hinge, stored energy devices or motor driven tools. There are some intrinsic drawbacks for the traditional deployment devices, such as complex assembling process, massive mechanisms, large volumes and undesired effects during deployment. In contrast, the deployment devices fabricated using SMPs and their composites may overcome certain inherent disadvantages.

### B. Morphing Structure –

Flight vehicles are envisioned to be multi-functional so that they can perform more missions during a single flight, such as an efficient cruising and a high maneuverability mode. When the airplane moves towards other portions of the flight envelope, its performance and efficiency may deteriorate rapidly. To solve this problem, researchers have proposed to radically change the shape of the aircraft during flight. By applying this kind of technology, both the efficiency and flight envelope can be improved. This is because different shapes correspond to different trade-offs between beneficial characteristics, such as speed, low energy consumption and maneuverability. For instance, the

Defense Advanced Research Projects Agency (DARPA) is also developing morphing technology to demonstrate such radical shape changes.



Figure 1. Z-Shaped morphing wing

As illustrated in Fig. 1, Lockheed Martin is addressing technologies to achieve a z-shaped morphing change under the DARPA's program fund during the development of morphing aircraft, finding a proper skin under certain criteria is crucial. Generally, a wing skin is necessary, especially for the wing of a morphing aircraft. Researchers focus their works on investigating proper types of materials that are currently available to be used as a skin material for a morphing wing. In this case, the SMPs show more advantages for this application. It becomes flexible when heated to a certain degree, and then returns to a solid state when the stimulus is terminated. Since SMPs holds the ability to change its elastic modulus, they could potentially be used in the mentioned concept designs.

### III. SMPs IN BIOMEDICINE AND BIOINSPIRATION

SMPs show extensive interest in used for biomaterials and bioinspiration. For instant, polyurethane SMP performs excellent biocompatibility, and it can be used for the deployment of different clinical devices when contacted or implanted in the human body. Recently,

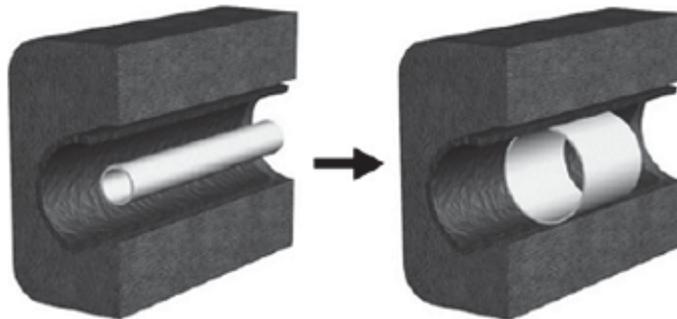


Figure 2. Schematic of the shape-memory effect prior to application (left) and right after reset (right)

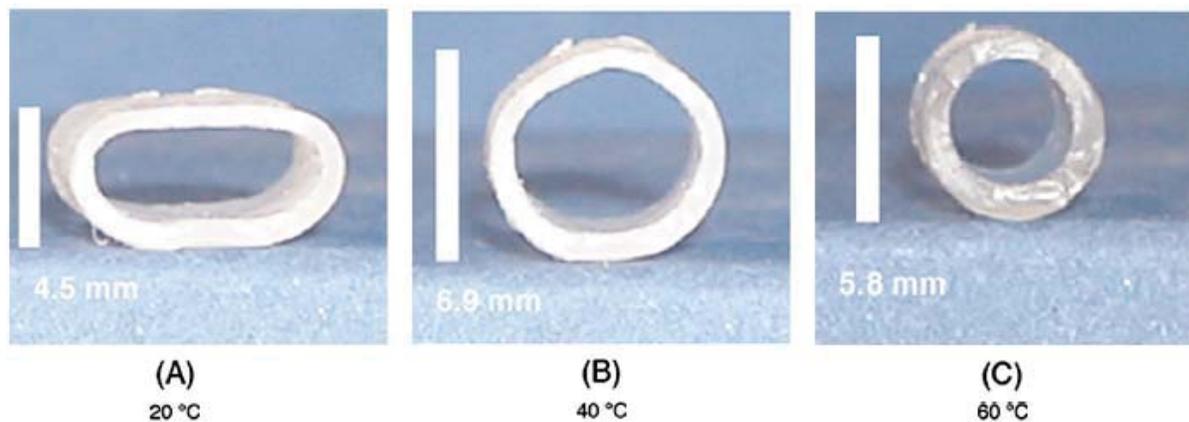


Figure 3. Through increasing the temperature from 20°C (A) to 40°C (B) an initial shape change was induced followed by a second shape change through increasing the temperature to 60°C

The field of applications of this polymer stent was demonstrated in pre-trials. The use of the SMP stent as a drug delivery system leads to significant reduction of rest enosis and thrombosis. An improved biological tolerance in general is expected when using biocompatible SMP materials. The exciting SMPs can move from one shape to another in response to a stimulus. Thus, SMPs are dual-shape materials. As shown in Fig. 3, the SMP is able to change from an initial shape (A) to a second shape (B) and finally deform to a third shape (C). It may be inserted into the body, expanded at a target site, and be removed at a later point in time which may be necessary even with degradable materials. The thermo/moisture-responsive polyurethane SMP sheds light for the possibility to fabricate micro/nano devices for surgery/operation at the cellular level. Many researchers have developed many polymer micro-machines, which are similar to the size of cells or even smaller and can be triggered for operation by a laser beam outside the cell. However, there are tremendous difficulties to deliver such machines into cells. The thermo/moisture-responsive polyurethane SMP offers a possible solution.

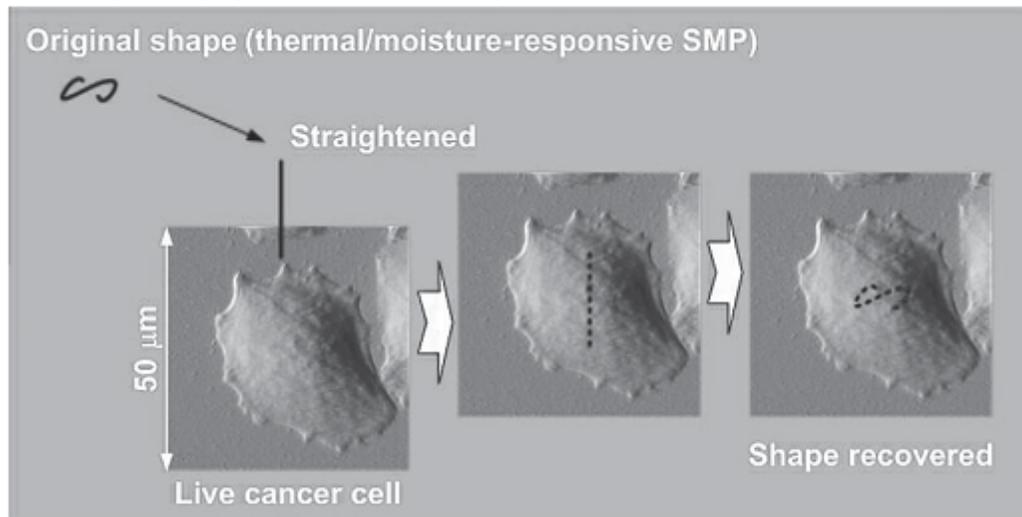


Figure 4. Concept of delivery of micro/nano device into a living cell for cell-level surgery/operation using thermo/moisture responsive SMP.

As illustrated in Fig. 4, a piece of original curved SMP is straightened and then inserted into a living cell. Upon absorbing moisture inside the cell, the SMP recovers its original shape. As the recovery strain in solid or porous SMPs is on an order of hundred percent, it becomes possible to make cell or sub-cell sized machines using the thermo/moisture-responsive SMP and then deliver the machines into living cells for operation controlled by an outside laser beam.

An attractive application area for shape-memory polymers is their use in active medical devices. First examples include a laser-activated device for the mechanical removal of blood clots Fig.5. The device is inserted by minimally invasive surgery into the blood vessel and, upon laser activation, the shape-memory material coils into its permanent shape, enabling the mechanical removal of the thrombus (blood clot). Another example of a medical challenge to be addressed is obesity, which is one of the major health problems in developed countries. In most cases, overeating is the key problem, which can be circumvented by methods for curbing appetite. One solution may be biodegradable intragastric implants that inflate after an approximate predetermined time and provide the patient with a feeling of satiety after only a small amount of food has been eaten.

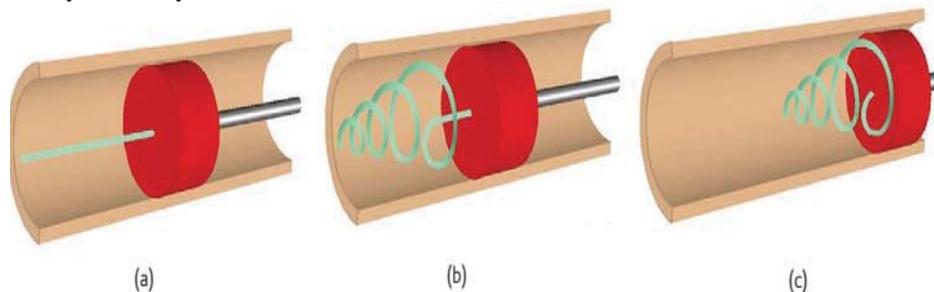


Figure 5. Depiction of removal of a clot in a blood vessel using the laser-activated shape-memory polymer micro actuator coupled to an optical fiber. (a) In its temporary straight rod form, the micro actuator is delivered through a catheter distal to the blood clot. (b) The micro actuator is then transformed into its permanent corkscrew form by laser heating. (c) The deployed micro actuator is retracted to capture the thrombus.

Biodegradable SMPs may be used in medical devices. The usefulness of SMPs in wound closure has been recently investigated and a design of smart surgical sutures has been examined, where a temporary shape is obtained by elongating the fiber under controlled stress his suture can be applied loosely in its temporary shape under elongated stress. When the temperature is raised above  $T_g$ , the suture will shrink and then tighten the knot, in which case it will apply an optimal force. The biocompatibility and degradation products should be considered.

#### IV. SHAPE MEMORY POLYMER FOAMS AND APPLICATIONS

A technology called “cold hibernated elastic memory” (CHEM) based on SMPs received much attention in recent years. This CHEM material utilizes SMPs foam structure or sandwich structures made of SMP foam cores and polymeric composite skins. This SMP foam was proposed for space-bound structural applications. This SMP foam exhibits micron-size cells that are uniformly and evenly distributed within the cellular structure and, therefore, it is suitable for ultra-lightweight porous membrane or thin film space applications. A study on the influence of long-term storage in cold hibernation on the recovery strain–stress of polyurethane SMP foam revealed its excellent stability.

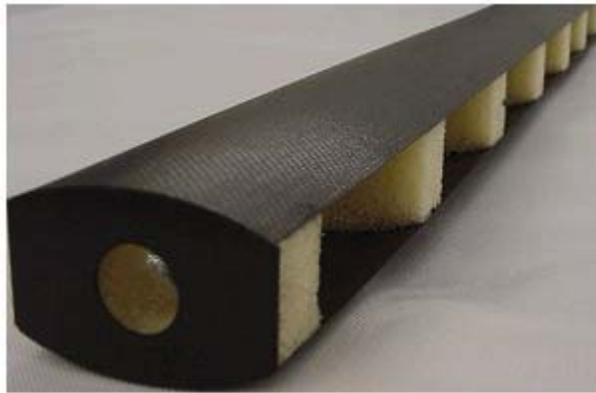


Figure 6. Shape memory polymer Foam Truss element

As one of these applications, a spring-lock truss-element concept for large boom structures was proposed. It involved a unique hybrid design of SMP foams and normal polymer composites. As shown in Fig.6, the truss-element consists of two carbon-fiber-reinforced polymer laminates separated by the SMP foams. In this way, the two material systems allow the truss-element to be stowed in a small volume and then deployed without the use of complex mechanisms.

#### V. SHAPE MEMORY POLYMER FOAMS AND APPLICATIONS

SMPs have been used in automobile engineering, and many interesting products have been developed. Some interesting applications of SMPs include seat assemblies, reconfigurable storage bins, energy absorbing assemblies, tunable vehicle structures, hood assemblies, releasable fastener systems, airflow control devices, adaptive lens assemblies and morph able automotive body molding. The reasons for using SMPs are due to their excellent advantages such as shape-memory behavior, easy manufacturing, high deformed strain and low cost. That is why they have attracted a lot of attention in automobile engineering and have even been used to replace the traditional structural materials, actuators or sensors. As a typical example, SMPs are proposed to be used for the reversible attachments [298] in this embodiment; one of the two surfaces to be engaged contains smart hooks, at least one portion of which is made from SMP materials. By actuating the hook and/or the loop, the on-demand remote engagement and disengagement of joints/attachments can be realized. With a “memorized” hook shape, the release is effective and the pull-off force can be dramatically reduced by heating above the  $T_g$ . It can be used for a reversible lockdown system in the lockdown regions between the vehicle body and closure.

SMPs can also be used in an airflow control system to solve a long-time problem for automobiles. As we know, airflow over, under, around, and/or through a vehicle can affect many aspects of vehicle. As we know, airflow over, under, around, and/or through a vehicle can affect many aspects of vehicle performance, including vehicle drag, vehicle lift and down force, and cooling/heating exchange. Reduction to vehicle drag reduces the consumption of fuel. A vehicle airflow control system, which comprises an activation device made of SMP material, actively responds to

the external activation signal and alters the deflection angle accordingly. Thus, the airflow is under control based on the environmental changes. The performance including vehicle drag, vehicle lifts and down force, and cooling/heating exchange. Reduction to vehicle drag reduces the consumption of fuel. A vehicle airflow control system, which comprises an activation device made of SMP material, actively responds to the external activation signal and alters the deflection angle accordingly. Thus, the airflow is under control based on the environmental changes. Self-healing composite system a healable composite system for use as primary load-bearing aircraft components has been developed by Cornerstone Research Group (CRG). The composite system consists of piezoelectric structural health monitoring system and thermal activation systems based on SMPs. Upon damaging, the monitoring system will sense the location and magnitude of damage, send the corresponding signals to the controlling system, resistively heat the SMPs at the location of damage, and finally the induced shape recovery of SMPs will heal the damage.

#### VI. OTHER APPLICATION

1. SMPs toys: toys that take the advantage of simple reversible compaction, deployment cycle: decoys with high fidelity features.
2. Recreation/sport products: tents and camping equipment; life jacket, floating wheels; water and snow skis; surf and snow boards.
3. Deployable structures: thermally insulated deployable shelters, hubs; prefabricated walls/slabs; access denial barriers/walls; automatic disassembly of electronic products reusable shape-memory polymer mandrel.
4. SMPs packaging: packaging of thermal sensitive products; sensors/drug/food air delivery systems.
5. SMPs food equipment: dishes and meal containers; plates and coffee cups: hot/cold storage for food.

#### VII. CONCLUSION

The field of actively moving polymers that are able to perform movements by themselves is progressing rapidly. The advantages of SMPs include lower density, lower cost, easier processing, larger recoverable strains, etc. and hence, shape memory polymers play a key role within deployable structures, morphing structures, biomaterials, SMP foams, automobile actuators and self-healing composite systems

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