Development of a Novel Shape Memory Alloy Actuated Soft Gripper

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ABSTRACT
Shape Memory Alloy (SMA) materials are often used as an activation source for bending actuators as they belong to the class of high power density materials. SMA based soft grippers have good performances in grabbing objects with non-uniform shapes in contrast to their counterpart rigid grippers but their performance is restricted by the small stroke of the SMA wire inside the polymeric matrix and it has also been described as having a low actuation speed, which is considered as a fundamental restriction to its use in a broader variety of applications. The heating and cooling time is the primary limiting cause for its low actuation speed[1]. In this research two types of actuators were developed, one of them was made in such a way that the cotton thread was inserted into the soft polymer and further connected to the SMA wire externally, and in the second type SMA wire, itself inserted into the soft polymer. After performance analysis of both actuators, a two-finger gripper was developed. The maximum bending angle of 44° at 4 sec recovery time was achieved using 160 mm SMA wire embedded in polymer matrix as free sliding wire and the gripper was demonstrated to be fit for grasping different types of objects weighing up to 5-grams

Keywords
Shape memory alloy, soft grippers, polymer, SMA actuator

1. INTRODUCTION
Traditional unbending body manipulators create high precision of developments along with kinematic links that have limited degrees of freedom (DOF) and are broadly utilized in well-characterized conditions. Unlike massive structure and sophisticated control of manipulators reported in past, recent advancements in soft robotics exploit the flexibility and compliance of materials to develop robotic actuators exhibiting soft and acceptable interactions with unpredictable environments [1, 2]. Robots using soft actuators [3] have an incredible potential to be connected to the working environment and individual robots, since they are characteristically protected, implying that they are not equipped for making damage to mankind even in unstructured situations [1]. Soft grippers with dexterous grasping performance had been produced which were based on various actuation methods such as soft pneumatic actuators [4] and other shape-memory materials. Meanwhile, SMA-based soft actuators with compact configurations have shown the advantages of being able to significantly reduce the size, weight, and system complexity, and are easy to fabricate by rapid manufacturing techniques [5].

1.1 Shape Memory Alloy
Some alloys of metals are found to display a certain kind of thermo-mechanical behavior known as the shape memory effect. This Shape memory effect is generally referred to as the capacity of an alloy to come back to its pre-set shape after the increase in temperature. Those alloys which display shape memory effect are called the shape memory alloys (SMAs). The very first-time shape memory alloys found was an alloy made up of Au-Cd reported in 1932. Then more importance was being given to this class of metal combinations after the discovery of NiTi in 1963. NiTi offered much better performance in functional and engineering properties as compared to its earlier rival and based on its performance it was immediately regarded as a better candidate for this type of work.

Today the known shape memory alloys can be classified into five classes according to their properties which include Cu-based, Fe-based, NiTi-based, and ferromagnetic based, and others. Actuator configuration is amongst the most vital part of the fabrication of delicate robots. For instance, actuator procedures for soft robots incorporate flattened air [6], SMA actuators, fluid [7,8], and ligaments [9,10]. SMA-based soft robotics actuators had been broadly investigated and generally utilized in various applications including robotics. Mao et al. created a polymeric auto-morphic starfish-like robot with several limbs with SMA springs connecting from the tip of each limb to the robot's central component [11,12]. In [13] Icardi utilized SMA contractile wires to assemble a vast twisting actuator. Wang et al. [14] additionally considered the control technique for the SMA dependent on self-detecting and hysteresis compensation. Wood [15] built up a two-directional SMA collapsing actuator applicable to macro-scale and micro-scale frameworks. Liu [16] contemplated tracking the standard of SMA actuators dependent on opposite hysteresis leveling and self-detecting response Zhang in [14] contemplated self-detecting properties for SMA impelled artificial muscle. Bergamasco [18] introduced delicate hands using SMA wires. Lee [19] built up a hand by utilizing SMA wire. SMA wires have very small length variation in a range of 3 to 7% of their actual length [20]. However, there are ways to transform these small variations into a large one by embedding them in the polymer [22]. Different types of elements can be embedded with SMA in the polymer to produce bending and twisting [23], and a number of multiple wires can be used to produce large deformation and bending in an actuator [24].

2. DESIGN AND DEVELOPMENT
The basic design applied in this research is a soft gripper actuated by self-activated actuator possessing flexible-bending deformation. The diagram of the actuator and experimental setup is displayed in Fig.1. Different components of the test rig are described in the following

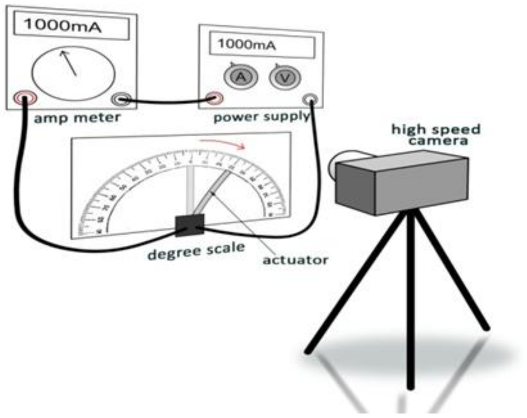

Figure 1: Experimental Setup

sections. Variable DC power supply was utilized to supply current to SMA wire. An ampere meter was used to measure the current flow in the SMA wire. High speed camera was used for recording the precise bending angle of the actuator at specific time for different currents, and a scale for angular measurement was used to identify the corresponding bend angle of the actuator.

2.1 Fabrication of Mold

The experimental procedure starts from the development of mold for actuators which were carried out in the following manner. An acrylic sheet of 1.5 mm thickness was taken and out of it, different sizes of stripes were cut to make a mold of 80 mm length, 15 mm width, and 5mm thickness as shown in Fig.2a. Then two wires of 1mm dia and 80mm in length were fixed in the mold as shown in Fig.2b. When the mold was ready then RTV-PDMS (Room temperature vulcanizing polydimethylsiloxane) is poured into the mold and cured for 24 hours at room temperature Fig.3c. After completely cured the mold was cut and discarded and copper wires were also carefully removed from the soft polymer which caused the soft polymer to hollow from inside

2.2 Development of Actuators

Two types of Actuators were developed for the experiment.

2.2.1 Type-1 (Thread Embedded in Actuator)

- A cotton thread was used to insert into the soft polymer slightly larger than the polymer length in a U-shape or loop.
- The SMA wire actuator was cut to a length of 160 mm with a pair of SMA-cutting pliers.
- SMA was crimped on both ends with a crimp tool.
- Ferrules of a crimp were used to tie the cotton thread with SMA as shown in Fig.3.

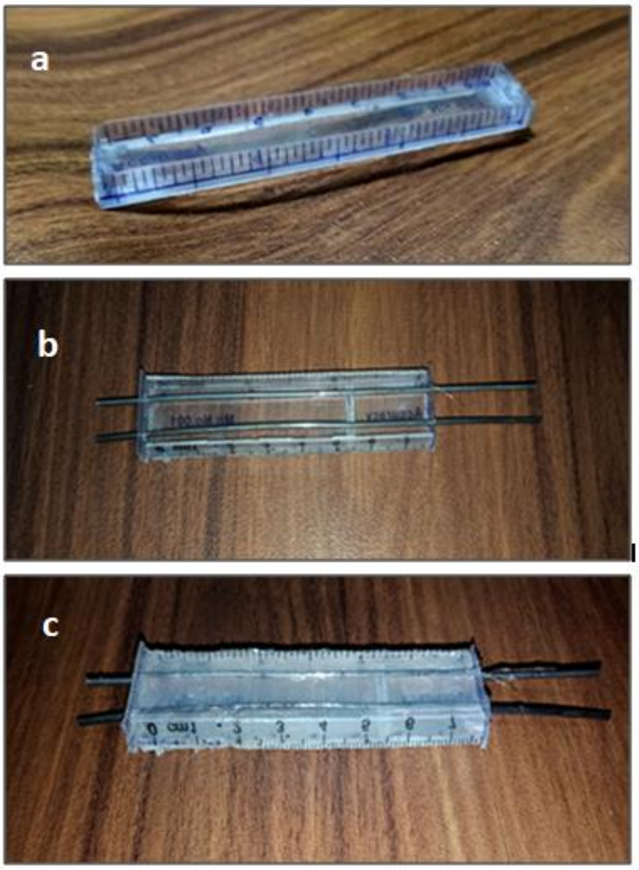

Figure 2: Fabrication of Mold

2.2.2 Type-2 (SMA Wire Embedded in Actuator)

- The SMA wire actuator was cut to a length of 160 mm using a pair of pliers suitable to cut SMA.
- The wire is then inserted into the soft polymer itself as shown in Fig.4.
- Both ends of the SMA wire were crimped using a crimp tool.

All the materials stated above are readily available in the market and their main characteristics are presented in Table 1.

Table 1: SMA Characteristics

Sr no:	Parameter	Value
1	SMA martensitic start temperature (Ms)	52°C
2	SMA martensitic finish temperature (Mf)	42°C
3	SMA austenite start temperature (As)	68°C
4	SMA martensitic finish temperature (Af)	78°C
5	SMA diameter	0.25mm
6	SMA resistance per meter	18.5Ω

The behavior of the SMA wire is highly nonlinear and hysteric and the bending deformation depends on the heating and cooling time, therefore the characterization of SMA actuator plays a vital part in the advancement of SMA actuated systems. The information of actuation characteristics of an actuator is of crucial significance as this serves to produce a superior system.

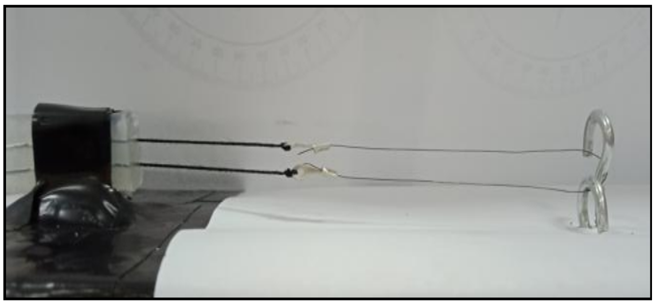

Figure 3: Thread Embedded in Actuator

Figure 4: SMA Wire Embedded in Actuator

2.3 Characterization of Bending Deformation

The bending deformation of the soft actuator can be accomplished by applying an electrical current to the two ends of the SMA wire. The maximum level of the current that causes the maximum deformation was determined by applying the different levels of currents for 1-second and 2-second actuation time.

The SMA actuators were tested in normal ambient temperature in which bending angle and time taken at specific angle was observed. However, the time required to restore last 0.5% strain is not included, as it is not considered by the manufacturer [25].

2.3.1 Type-1 (Thread Embedded in Actuator)

In the first type, the thread was inserted into the soft polymer and the ends of the thread were tied to the crimps which were connected to the SMA wire. For the bend test, different levels of currents were applied to the wire for one and two second actuation time.

2.3.1.1 1-Second Actuation Current

In order to determine the maximum bending angle of the actuator, electric currents ranging from 200mA to 1000mA with an increment of 200mA for one second actuation time were supplied to the actuator from the DC power supply. Results of different bending angles with different supplied currents are shown in Fig.5a.

It can be observed from the graph that at 200mA and 400mA current there was no deflection in the actuator, the heat produced on these currents was not enough to deflect the actuator, however, at 600mA, and 800mA currents maximum bend angle of 1-degree and 5-degree was observed. The maximum bend angle achieved was 10-degree at 1000mA current and the time taken to restore was 8 seconds.

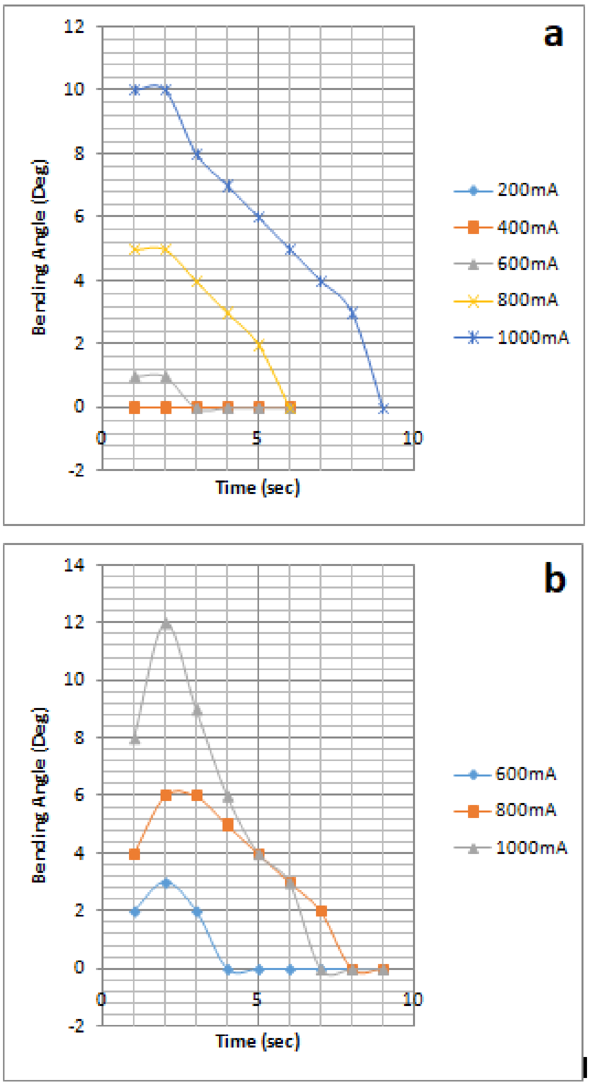

Figure 5: Actuator Characterization

2.3.1.2 2-Second Actuation Current

As we observed in the previous experiment that current up to 400mA was not producing any deflection so currents ranging from 800mA to 1000mA with an increment of 200mA for two second actuation time were supplied to the actuator from the DC power supply. Response of different currents supplied to the actuator is shown in Fig.5b.

It tends to be seen from the diagram that at 600mA current 2-degree deflection at 1-second and 3-degree deflection at 2-second occur. Similarly, 4 and 6-degree deflection at 1 and 2-second times occur with a supplied current of 800mA. The maximum bend angle accomplished was 12-degree at 1000mA current and the time taken to restore was 5 seconds.

2.3.2 Type-2 (SMA Wire Embedded in Actuator)

In the second type SMA wire, itself was inserted into the soft polymer and the ends of the wire were tied to the crimps. For the bend test, different levels of currents were applied to the wire for one and two second actuation time respectively.

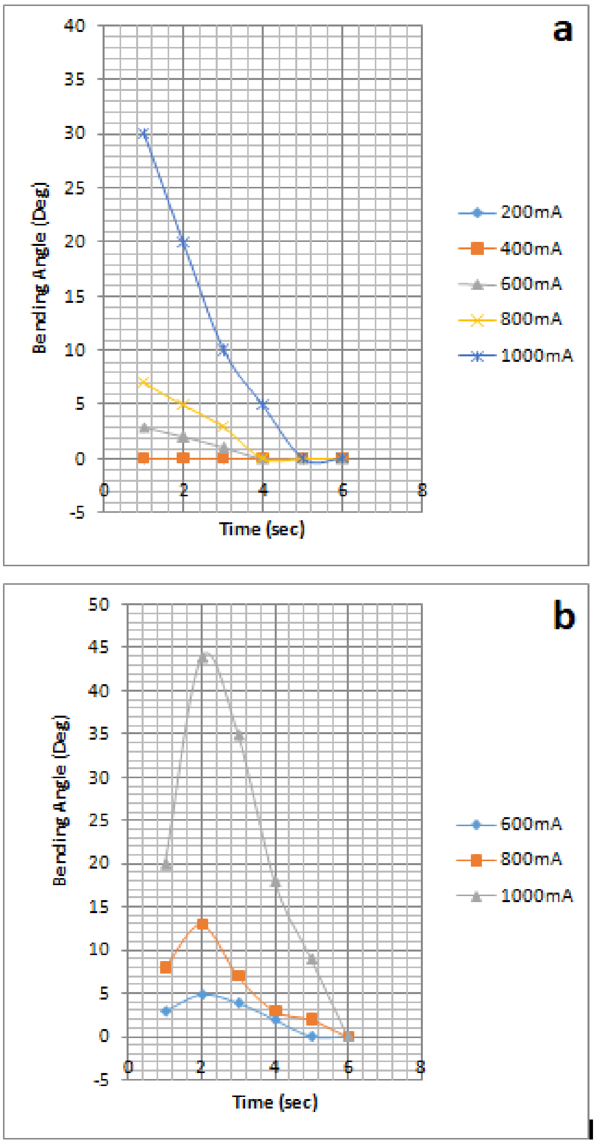

Figure 6: Actuator Characterization

2.3.2.1 1-Second Actuation Current

To determine the maximum bending angle of the actuator, electric currents ranging from 200mA to 1000mA with an increment of 200mA for one second were supplied to the actuator from the DC power supply. Results of different bending angles with different supplied currents are shown in Fig.6a.

It has been seen from the graph that at 200mA and 400mA current there was no deflection in the actuator, the hotness created on these currents was adequately not to divert the actuator, but at 600mA and 800mA currents, maximum bend angle of 3-degree and 7-degree was observed. The maximum bend angle achieved was 30-degree at 1000mA current and the time taken to restore was 4 seconds.

2.3.2.2 2-Second Actuation Current

As we saw in the previous experiment that current up to 400mA was not producing any deflection so currents ranging from 800mA to 1000mA with an increment of 200mA for two second actuation time were supplied to the actuator from the DC power supply. Response of different currents supplied to the actuator is shown in Fig.6b.

It was observed from the experiment that at 600mA current 3-degree deflection at 1-second and 5-degree deflection at the 2-second time occur. Similarly, 8 and 13-degree deflection at 1 and 2-second times occur with a supplied current of 800mA. The maximum bend angle accomplished was 44-degree at 1000mA current and the time taken to restore was 4 seconds.

2.4 Robotic Gripper

The main task of the soft manipulator is to grasp lightweight and deformable objects. To accomplish this objective we developed a two-finger soft gripper by using the second type of actuator, as the experiment proved it is more efficient than the first type in terms of bending. The size of the single finger was the same as demonstrated above and the distance between both fingers was 60 mm as shown in Fig.7. In order to determine the maximum weight lifting capability of the gripper, series of the experiment were conducted in which different sizes of springs were used as shown in Fig.8. In addition to this, a delicate thermocol cylinder was also lifted by the gripper to observe the delicacy of the gripper. The maximum weight a gripper could lift was observed to be 5grams.

2.5 Comparison

In comparison with other SMA-based soft grippers, the robotic hand with an embedded sensor in [26] was capable of lifting 412g weight but the response time was 11 seconds at the input current of 1-Amp to achieve complete bend. In [27] soft planar gripper was achieving 80-degree bend at 0.6-Amp input current and took 4-seconds in actuation and 4-seconds in restoration, a robotic griper with variable stiffness in [28] was taking 70-seconds to achieve its low stiffness state and 380-seconds to achieve its high stiffness state and the pulling force observed were 3.28N and 8.73N at both state respectively A 150 g cylindrical object was steadily grasped, effectively lifted, concretely held, and then placed back to the original position within 20 seconds in [29]. All the soft grippers mentioned were complex in structure and made up of multiple materials. In contrast to them in this research, a simple actuator made up of only two materials proposed, which can achieve a 44-degree bend in 2-seconds and with 4 seconds restoration time.

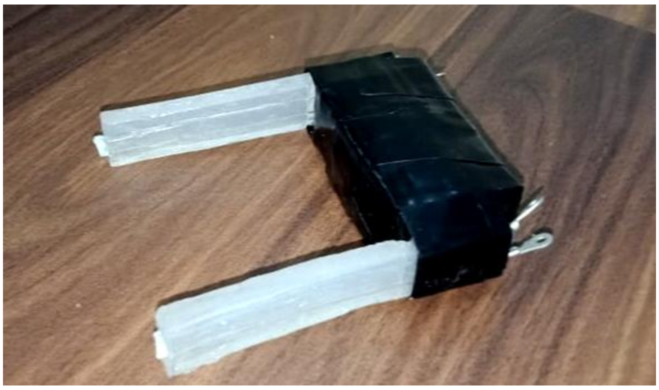

Figure 7: Two Finger Gripper

Figure 8: Grasping Performance of the Gripper

3. CONCLUSIONS

This research demonstrates the technique of utilization of SMA wires themselves as free-sliding material to drive a polymeric matrix which permits the SMA length and the design of the polymeric matrix to be decoupled, this method also minimizes the recovery time of SMA based soft actuators, The maximum bend angle observed was 44 degrees at 2-sec actuation current and the restoration time was 4-sec. A two-finger soft gripper was also developed in this research which was capable of grasping delicate objects. The maximum weight a gripper could lift was observed to be 5grams.

It is to be believed that the flexible SMA actuator concept has shown a design area that has to be further investigated to solve some of the limiting factors of SMA actuators still present in the existing design. The parallel mechanical arrangement of thinner wires in multiple loops in an actuator could significantly reduce the cooling time.

4. FUTURE WORKS

The suggested approach is simple to implement in a range of SMA actuator applications, particularly in robotics and biomedical applications in which compactness is required. However, additional work needs to be done to address this problem and create faster cooling techniques for SMA actuators so that their frequency can be increased.

According to the datasheet, the maximum stroke of the SMA wire is 3 to 5% of the total length so the technique used in this research shall allow researchers to use longer wire in multiple loops and along with this, a better structure model could be used in future works which would produce larger bend angle.

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