A Review Paper on Shape Memory Alloy's Applications and Its Opportunities in Heat Recovery Systems

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Abstract— The Shape memory alloys (SMA's) are having the ability to remember the original shape and can retain to their previous shape or size when subjected to certain stimulus like thermo-mechanical variations. The researchers have been showing their attention and interest in this new alloy SMA from few years back. And has found this field has a broad range of commercial applications, because of their unique properties. This unique property of smart materials attracts researchers to do work on it and motivates them to find new innovations. Basically in this work author tries to describe various applications developed in the past researches and its associated limitations.

Key words: Shape Memory Alloy (SMA), Smart Materials, Actuators, Heat Recovery System

I. INTRODUCTION

Shape Memory Alloys (SMA's) , such as Au-Cd, Ni-Ti-Hf, Cu-Al-Ni/polyimide , Fe-Mn-Al-Ni, exhibits two useful characteristics , first the ability to recover its original geometry on heating and second pseudo elasticity [1][2][3].The SMA was first observed in sample of Au-Cd by are Olander . Later there were many other alloys has discovered like Ni-Ti by William Buehler and Frederick , which is also known as Nitinol ,since it was discovered in Naval Ordnance Laboratory[2][4].Further, more alloys and polymers Cu-Al-Ni / polyimide was investigated by K Akash et.al .[5] , where they have found several thermo-mechanical properties. Ji Xia et al.[6] Has investigated on characteristics of Fe-Mn-Al-Ni alloys. The SMA's exist in two different phases (Austenite and Martensite) with three crystal structures, i.e. Twinned Martensite, Detwinned Martensite, and Austenite. There are six transformations i.e., martensite start (M_s), martensite finish (Mf), austenite start (A_s) and austenite finish (A_f) temperatures.

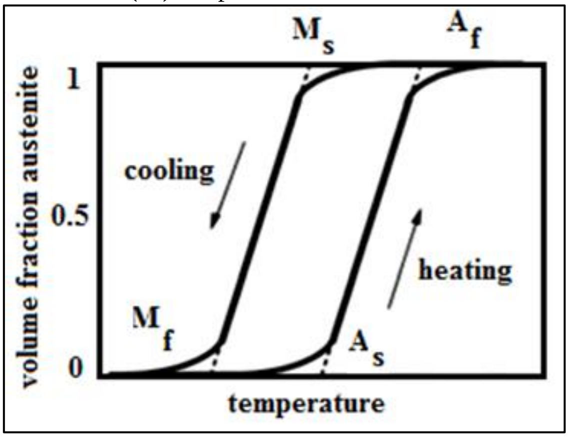


Fig. 1: Generic Graph For A Shape-Memory Material, Showing Transformation Temperatures on Heating and Cooling[7].

II. MECHANISM OF SMA

The characteristic of SMA during heating and cooling can be seen by phase transformation which is in the form of hysteretic curve as shown the figure (1). On cooling the process starts with M_s and finishes with M_f and during the application of heat , in heating process the curve starts with A_s and finishes with A_f .This shape changing are categorized into three types of shape memory effect as shown in the figure (2) and it is explained in following points [3]:

1) One way shape memory effect (OW-SME): The SMA object can be detwinned to deformed shape on the application of force and also can be twinned to its original shape on the application of heat.
2) Two way shape memory effect (TW-SME): The trained SMA during cooling which is austenite phase, martensite is formed, under no load condition. And during heating the SMA recovers to its original shape and it transformed to austenite [3].
3) Pseudo elasticity effect: When the SMA is external loading between the temperature A_f and M_d it can be able to recover original shape without any thermal activation, where M_d is the maximum temperature at which martensite can no longer be stress induced [8].

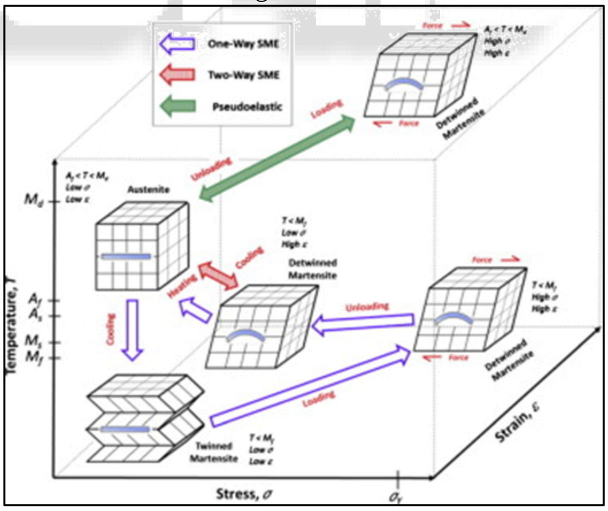


Fig. 2: Shape Memory Phases, Crystals and Effects [2].

The survey have been showing that form last decades the work on Shape Memory Alloy (SMA or Smart Materials) have been going on. And number of applications has developed on SMA. Now the research is going on, to enhance the thermo-mechanical characteristics of SMA and also to find alternative and new alloys that are showing such phenomenon.

On looking to SMA characteristics the researchers and industrialist have been developing many products using SMA such like actuators aerospace applications [9], micro valve, toys, robotics application such as gripper , smart fabrics and many more [10][11][2][12].

III. TWO WAY –SHAPE MEMORY ALLOY BI MORPH (TW-SMA BIMORPH)

As on its importance the researchers are now doing work to make the smart materials not limiting upto alloys but also moving to composites such as polymers. Akira, [3] has discussed the Ti-Ni-Cu/Polymide SMA and Akash et al. [5][13], has discussed the Cu-Al-Ni / polymode SMA.The polyimide bimorph has the ability to absorb heat which result in conduction of the polyimide samples and this results the decomposition temperature range assisted in relating the voltage required during the electrical actuation. To develop this Bimorph SMA they have used the phenomenon of thermal evaporation of metals such as (Cu-Al-Ni / Ti-Ni-Cu) under the system chamber of high vacuum during the evacuation process and allow the deposition carried on polyimide films (Kapton EN , H , HN) as shown in the figure (3).The polyimide film of varous thickness 50 µm and 75 µm[3], [5], [13].

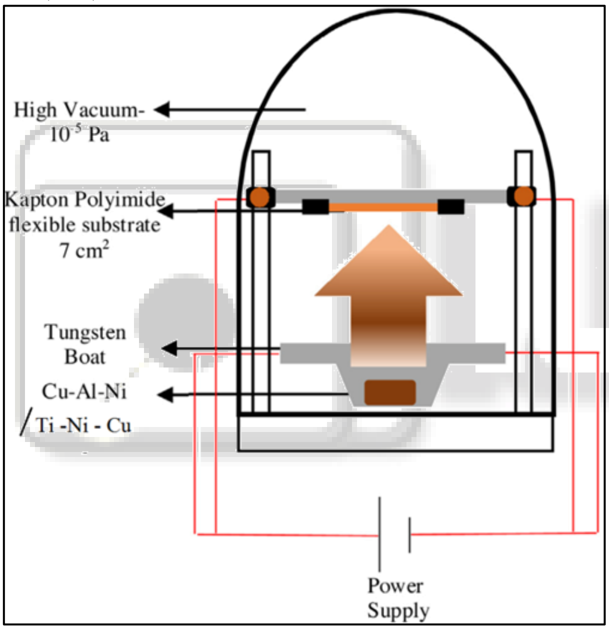


Fig. 3: Thermal Evaporation Setup [3], [5], [13]

The bimorph SMA after deposition looks like in the figure (4).During the deposition the polyimide sheets was clamped to substrate holder and the deposited material will be in twinned martensite state. It has stated by the author that on the application of heat the bimorph transforms from the detwinned martensite phase to austenite phase and can be able to identified with the help of X-Ray diffraction shows the crystalline diffraction on graphs .And during the actuation process the material will inclined towards the pre strained shape as in the clamped position during the deposition. And this process requires no training and can be repeated in cycle. The images showing the steps involved I the development of bi-morph in figure (5).

The author has identified that the polyimide of 75 µm thick sheet exhibited a higher recovery ratio of 1.30, whereas 50 µm thick sheet shows only 1.21 during the experiment. And during the test maximum displacement was observed during the actuation temperature range 230-250°C.

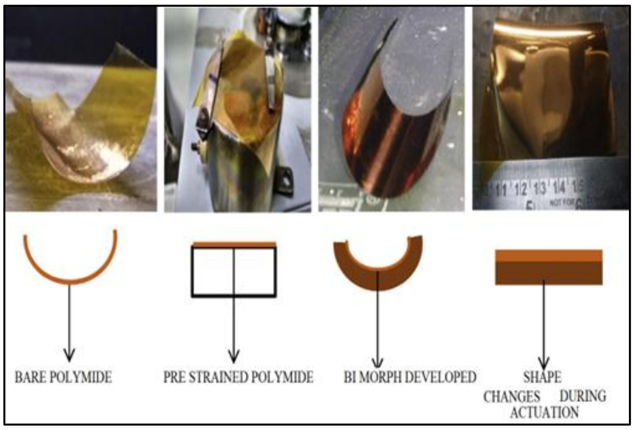


Fig. 4: Steps Involved In The Development of Bi-Morphs[5], [13].

The sheet of 75 µm thickness showed the no signs of fatigue and steady displacement during the test of electrical heating to bimorph at different voltages from 2V – 3V [5].

During the experiment, Akash et al.[4] has identified during the test with help of Differential Scanning Calorimeter (DSC) at varying growth substrate temperature of 100 ^{0}C, 150 ^{0}C and 200 ^{0}C, found that 150 ^{0}C is the best suited to develop Cu-Al-Ni / polyimide bi morphs, beyond which different phase coexist which will hinder the stability of SME, and concluded that thermo-mechanical behavior can be varied by changing substrate temperature [5][14].Similarly Ji Xia et al. [6], has found that Fe-Mn-Al-Ni SMA was showing super elasticity behavior between 10 K – 100 K during compression test and also states that at cryogenic temperature , transformation hysteresis is less sensitive.

T. W. Duerig, [15]states that it is require one to construct an effective Clausius Clapeyron ratio that hinges upon the triple point of the phase diagram, and also that by moving the triple point to higher temperatures, one can reduce the transformation temperature to and from martensite. As per the application of SMA's in different places geographical and working conditions and temperatures like automotive, power plants, toys , etc. So SMA's are distinguished into three categories with respect to martensite transformation temperatures which are as follows [16]:

1) Group1: transformation temperatures from 100-400 ^{0}C.
2) Group2: transformation temperatures from 400-700 ^{0}C.
3) Group3: transformation temperatures above 700 ^{0}C.

Such types of SMA are called as high temperature shape memory alloys (HTSMAs) , it must also exhibit acceptable recoverable transformation strain levels, long term stability, resistance to plastic deformation and creep, and adequate environmental resistance. To satisfy these criteria use of Palladium (Pd) or Platinum (Pt) has to involve such like Ti-Ni-Pd and Ti-Ni-Pt because of their high operating temperatures, otherwise it is difficult to satisfy above said criteria due to greater involvement of thermally activated mechanisms in their thermo mechanical responses[16][17].

IV. USE OF SMA FOR HEAT RECOVERY

There are many work has done in this field, where heat recovery system has built for the application like heat rejected from air conditioners/ refrigerator compressor utilized for water heating device, Steam super heaters, Economizers, air preheater, use of heat from automotive for battery charging[18], [19]. Therefore to take advantage of the abundant thermal energy around us, its required to convert it and utilize it in the form of production of sufficient electrical power to supply a device. The author has developed a mechanism which having the combination of shape memory alloys (SMA) and piezo- electric materials (PM)[20]. The propsed designed shown in the figure (6), the SMA layer is as top layer on the cantilever beam and bottom layer is of piezoelectric layer, having thickness h_1 and h_2 respectively. There are certain assumptions made as Euler's Bernoulli's assumptions like during the bending both layer will have same radius of bending and height "h" is very less as compared with width "w" of the composite beam.

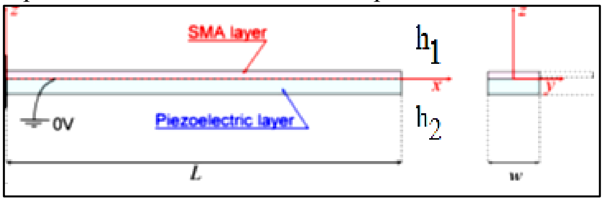
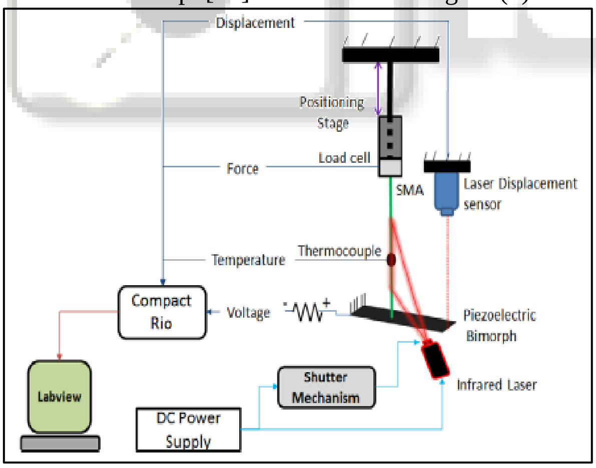
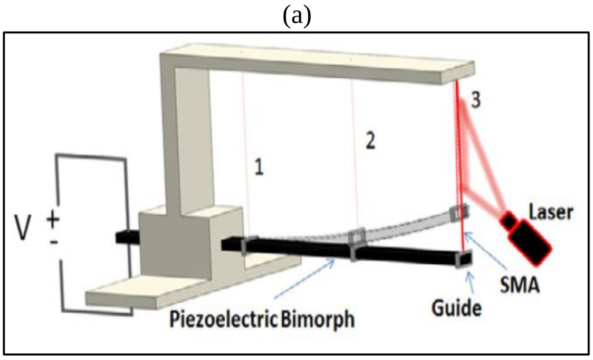


Fig. 5: Schematic View of the SMA-PM Bimorph [20].

So as per the concept given by the author that during the action of thermal load, this TW-SMA (two way shape memory alloy) bi morph , will undergoes phase transformation that induced transformation strains , and since it is bonded to piezo electric material in the bottom layer it also gets deform and generates electric potential [20] .Similarly in one of the work the author has described that SMA can be heated remotely by laser and the resulting deformation can be converted into electricity through a piezoelectric bimorph[21] as shown in the figure (7).



(a)



(b)

Fig. 6: (a). Experiment Setup , (b) SMA –PM System[21].

Here also during the movement of SMA the piezoelectric material will gets deform and generates electric potential. The same phenomenon was also mentioned during the cylindrical bending of composites plates with PM and SMA layers[22][23].

This TW-SMA Bimorph heat recovery system can be used with various application like in automobiles, home appliances such as refrigerators / air conditioners compressors, industrial equipment's, wherever the loss or wastages are heat loss. From this it is possible to save lot of un-used energy.

V. Spring Based Actuators

The proposed design for the SMA based actuators is shown in the following figure:

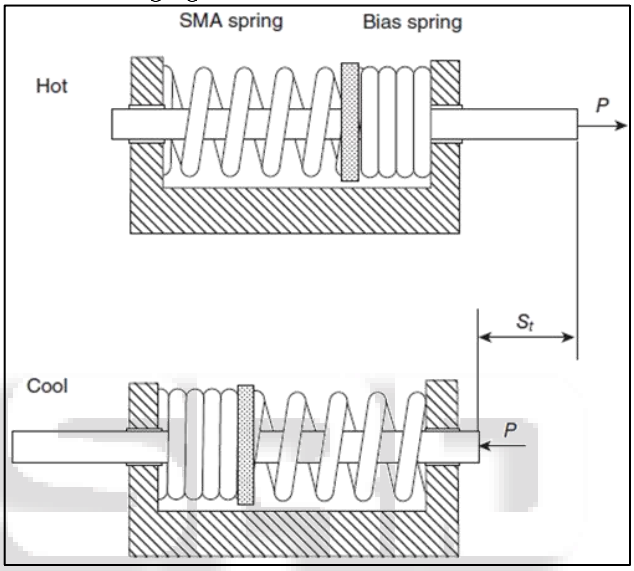


Fig. 7: Show the Proposed Design of SMA Actuator.

Conventional SMA springs reveal the one-way shape memory effect. Therefore, in order to operate repeatedly, the bias stress is required. Figure8 shows an example of two-way SMA actuator combined with a bias spring where an SMA spring and a bias spring are set so as to oppose each other. When the SMA spring is heated above the reverse transformation temperature, the axis moves to the right since the recovery force of the SMA spring overcomes the force exerted on the bias spring. The axis returns to original position when the SMA spring cooled below the martensitic transformation temperature. As a result, the SMA spring with a bias spring actuates by heating and cooling. The two-way motion generates a stroke of St. As the concept has identified from the literatures, the piezoelectric material can also be combine with the spring so that this composite can develop electric potential[20], [22].

VI. Conclusions:

The past research shows that there are much potential in this field and it is possible to develop many useful mechanisms such as actuators. And it is possible to replace the heavy, robust available one and can be able to save connecting resources. Also it is possible to develop much useful mechanism such as heat recovery systems. It's possible to develop aerospace applications so that light mechanism can be able to save much fuel. With the help of finite element software and proper computer aided systems one can be able to design and develop many useful systems for various commercials applications.

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