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REVIEW ARTICLE

SHAPE MEMORY ALLOYS AND THEIR POTENTIAL APPLICATION: A REVIEW

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ABSTRACT

In the manufacturing world now we need some 'Intelligent' or Smart materials which can change their property according to our requirement. Smart materials are one of the unique material and the general characteristics of all these materials are common that is their behaviour or significant property can be altered, reversed or controlled under the influence of external impetus. Their smartness can be characterized by its self-adaptability, self-sensing and self-healing in response to any external stimuli. In the list of these kind of materials, we are about to brief studyof the application of Shape Memory Alloys. Shape memory alloys are the material that have property to regain its original shape when subjected to external stimulisuch as stress, temperature, electric field, magnetic field. Due to its unique and excellent mechanical properties these material has drawn a massive attention of the researchers and the scientists which brings it into a wide commercial use. In this review paper we have focused on the brief introduction and potential application of the shape memory alloys.

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INTRODUCTION

In the production world, the high technologies push towards the 'Smart' system in which we need some intelligent or smart material which can alter their properties according to our requirement. In simple words 'Smart Materials' may be defined as the material which react to its environment on its own ,the reaction may exhibit itself as a change in volume, color, viscosity, odour and this may occur in response to a change in temperature, stress, electric current, pH or magnetic field. Smart materials have a stupendous effect on variety of fields since its discovery to its present day and also its impact is visible in our day to day life through its application in smart infrastructure to smart sensors as well as smart gadgets and vehicles. Among these materials, the composites do not cease evolving towards new products which are,either theleast expensive possible, or the most powerful, or both at the same time (Dehart, 1990). This concept of "Smart materials" or intelligent materials are used to characterize the material those are able to answer in the suitable way to the surrounding and changes in it. Different types of Smart materials have been used in the new area of technologies (Sirlin, 1990 and Murotsu, 1990). These materials have the qualities to fit in the surrounding and in order to response the physical changes, they can modifytheir form, their dimensions or even their mechanical properties (Young modulus). In fact, a material able to answer to its environment presents a very interesting profile for industrial applications; and actually the materials the most frequently used because of their intrinsic remarkable properties, are the piezoelectric materials and memory shape alloys (Japan, 1991; Modi, 1991 and Miura, 1991). According to their properties smart materials have so many types such as (i) Piezoelectric materials, (ii) Shape memory alloys, (iii) Thermo chromic materials, (iv)Thermo responsive materials (v) Magneto restrictive materials (vi) PH-sensitive materials (vii) Polymer gels (viii) Photo mechanical properties. Distinction between Smart materials and smart system should be understand. A Smart structure is made up off some form of actuator and sensor with control hardware and software to form a system which reacts to its environment.

Shape Memory Alloy

Shape memory alloy (SMA) or ''smart alloy'' was first discovered by Arne Ölander in 1932 (Ölander, 1932), and the term ''shape-memory'' was first described by Vernon in 1941 (Vernon, 1941), for his polymeric dental material. Shape Memory Alloys are that type of smart alloys that has tendency to memorize its shape when subjected to external impetus, free from thermal and magnetic effect. This phenomena is known as *Shape memory effect*. Since the invention of SMA, the demand for SMAs for engineering and technical applications has been increasing in numerous commercial fields; such as in consumer products and industrial applications (Wu, 2000; Zider, 1998 and Hautcoeur, 1997), structures and composites

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(Furuya, 1996), automotive (Butera, 2007; Leo, 1998; Stoeckel, 1990), aerospace (Bil, 2013; Hartl, 2007; Humbeeck, 1999 and McDonald Schetky, 1991), mini actuators and micro-electromechanical systems (MEMS) (Humbeeck, 1999; Sun, 2012; Kohl, 2010; Kahny, 1998 and Fujita, 1998), robotics (Kheirikhah, 2011; Sreekumar, 2007 and Furuya, 1991) biomedical (Humbeeck, 1999; Sun, 2012; Petrini, 2011 and Duerig, 1999), and even in fashion (Langenhove, 2004). Although iron-based and copper-based SMAs, such as Fe–Mn–Si, Cu–Zn–Al and Cu–Al–Ni, are low-cost and commercially available, due to their instability, impracticability (e.g. brittleness) (Wilkes, 2000 Cederström, 1995 and Hodgson, 1990), and poor thermo-mechanic performance (Huang, 2002), NiTi-based SMAs are much more preferable for most applications.

Shape memory effect or Pseudoelasticity

Practically, SMAs can exist in two different phases with three different crystal structures (i.e. twinned martensite, detwinned martensite and austenite) and six possible transformations (Sun, 2009; Mihálcz, 2001) (see Fig. 1). The martensite structure is stable at low temperature and the austenite structure is stable at high temperature. When SMA is heated then there is phase change occurs from martensite to austenite. The starting temperature of austenite state is (A_s) and the finish temperature of austenite state is (A_f) at which this transformation completion will take place. When SMA is heated beyond (As) it begins to contract and transform into the austenite structure, i.e. to recover into its original form. This transformation is possible even under high applied loads, and therefore, results in high actuation energy densities (Mihálcz, 2001). During the cooling process, the transformation starts to revert to the martensite at martensite-start-temperature (Ms) and is complete when it reaches the martensite-finish-temperature (Mf) (Lagoudas, 2010) (see Fig. 2). The highest temperature at which martensite can no longer be stress induced is called Md, and above this temperature the SMA is permanently deformed like any ordinary metallic material (Duerig, 1994). These shape changes effect is known as Shape changes effect is known as Shape Memory Effect or Pseudoelastisity.

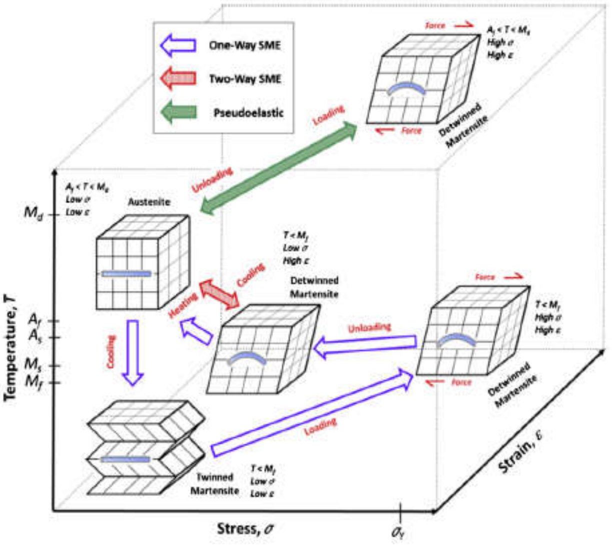

Fig. 1. SMA phase and crystal structures

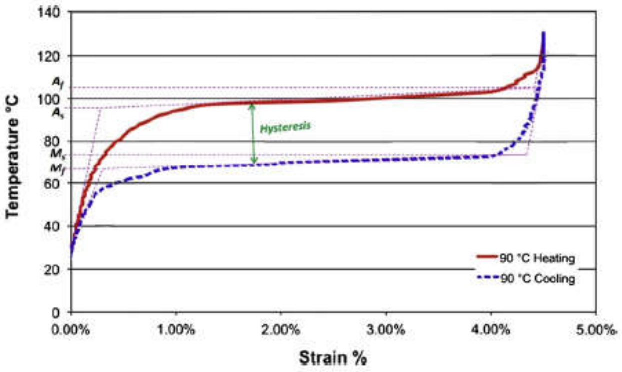

Fig. 2. Flexinol NiTi SMA (HT) phase transformation

On the basis of these effects Shape memory alloys can be categorized into three categories:

One-way shape memory effect (OWSME)

In this kind of shape memory effect, SMA regaina deformed state after the removal of an external force, and then recovers to its original shape upon heating.

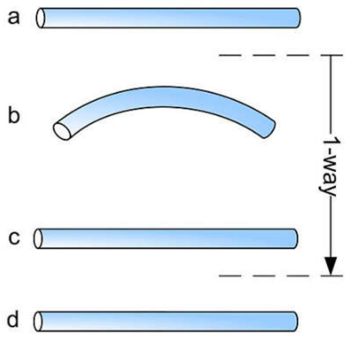

Fig. 3. One way shape memory alloy

Two-way shape memory effect (TWSME) or reversible SME: In two way shape memory effect, SMA remember their original shape at lower temperature as well as higher temperature.

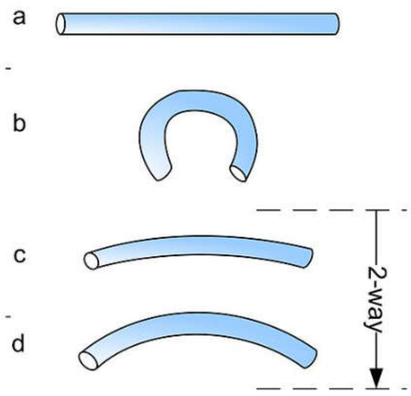

Fig. 4. two way shape memory alloy

However, TWSMA is less applied commercially due to the ‘training’ requirements and to the fact that it usually produces about half of the recovery strain provided by OWSMA for the same material (Huang, 2000; Perkins, 1990 and Schroeder, 1977), and it strain tends to deteriorate quickly, especially at high temperatures (Ma, 2010). Therefore, OWSMA provides more reliable and economical solution (Stöckel, 1995). Various training methods have been proposed (Schroeder, 1977; Huang, 1999 and Funakubo, 1987) and two of them are: Spontaneous and externalload-assisted induction (Brailovski, 2003).

Pseudoelasticity (PE) or Superelasticity (SE)

The tendency of SMA to regain its original shape after applying mechanical loading at temperatures between (Af) and (Md), without the need for any thermal activation.

Other type of shape memory Alloy

Other form of SMA has been explore due to some advantages and disadvantages, such as high manufacturing cost, limited recoverable deformation, limited operating temperature and low bandwidth.

High temperature Shape memory alloy

Extensive research for HTSMAs with other ternary additions to the NiTi SMA (e.g. Au, Hf, Pd, Pt and Zr) has been undertaken (Ma, 2010; Firstov, 2006; Beyer, 1994) due to the increasing demands for high temperature applications. Practically, HTSMAs are defined as SMAs that are operating at temperatures above 100 _C, and can be categorized into three groups based on their martensitic transformation ranges (Ma, 2010). But due to limited ductilityor poor fatigue resistance at room temperature, they are difficult to fabricate. Moreover their fabrication is very costly.

Magnetic Shape Memory Alloy

Magnetic shape memory alloy is also known as Ferromagnetic Shape memory Alloy. Because of martensite phase transformation, it exhibit large strains under the influence of an applied magnetic field. FSMA strain rate is quite comparable to magneto-strictive and piezoelectrics active elements, but at strains as large as SMAs (see Fig 5) (Ma, 2010). FSMA can also provide the same specific power as SMAs, but deliver it at higher frequencies (see Fig 5) (Ma, 2010).

Shape memory material thin film

SMM thin films evolved from the advancement of fabrication technology, where SMMs are deposited directly onto micro-machined materials or as stand-alone thin films to become micro- actuators (Winzek, 2004; Johnson, 2009; Fu, 2004; Miyazaki, 1999; Krulevitch, 1996 and Gabriel, 1989).

Shape Memory Polymers

Shape memory polymers can eaily manufactured and brings in the commercial application with the cost effectiveness comparatively to other type of shape memory alloys. SMPs are claimed to be a superior alternative to SMAs for their lower cost (at least 10% cheaper than SMAs), better efficiency, biodegradable and probably by far surpass SMAs in their mechanical properties (Voit, 2010; Ochonski, 2010; Liu, 2007; Witold, 2007 and Lendlein, 2002). SMPs can sustain two or more shape changes (Hu, 2012; Xie, 2010; Bellin, 2006), when triggered by thermal (heating (Huang, 2012) or cooling (Wang, 2012), Electricity (Liu, 2009), Magnetic field (Mohr, 2006), light (Mohr, 2006) or solutions (Mohr, 2005) (e.g. chemical (Lv, 2008) or water (Leng, 2005 and Huang, 2005) Generally, there are three categories of SMPs (Otsuka, 1998), and most of them are naturally either thermo- or chemo-responsive (Huang, 2012).

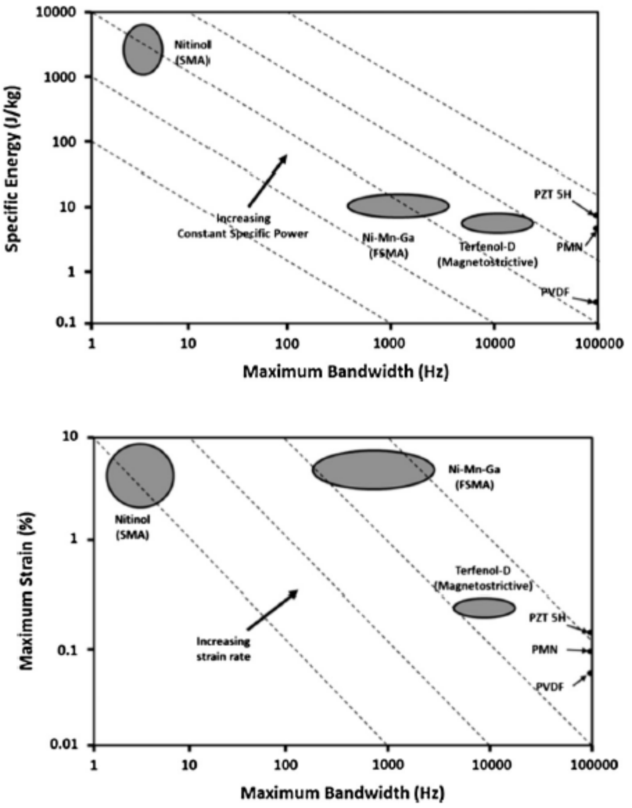

Fig. 5. Maximum strain and specific energy versus maximum bandwidth for different classes of active materials

Application of Shape Memory Alloys

The unique behavior of SMA has opened vast opportunity in aerospace, automotive, automation and control, appliance, energy, chemical processing, heating and ventilation, safety and security, and electronics (MEMS devices) industries. Some of these applications apply similar methods, concepts or techniques,\ which are also applicable for other areas; such as the Ni-Ti thermovariable rate (TVR) springs, which are used to control the opening door in the self-cleaning oven, is also used to offer smooth gear shifting for Mercedez-Benz automatic transmissions,for domestic safety devices to control the hot water flow (e.g. Memrysafe_ antiscald valves from Memry Corporation), and for industrial safety valves to prevent flammable and dangerous gasses from flowing (e.g. Firechek_ from Memry Corporation) (Stöckel, 1995; Duerig, 1990; Wu, 2000; Stoeckel, 1992) (see Fig 6). More interesting, these actuators can act as both a sensor and an actuator in these applications (Wu, 2000).

Automotive Industries

In Automotive industries SMA plays huge role. In modern vehicle there are massive use of actuators and sensors because of user's safety, comfortable and better performance. The emerging drive by-wire technology, offers a wide range of opportunities for SMA actuators as an alternative to electromagnetic actuators in automotive applications [9, 15, 80]. The existing and potential SMA applications for passenger vehicles are presented in fig 6, which categorizes them according to vehicle functional areas (Butera, 2008). Most of the selected components are occasionally functioning as linear actuators (e.g. rear-view mirror folding, climate control flaps adjustment and lock/latch controls) and as active thermal actuators (e.g. engine temperature control, carburetion and engine lubrication, and powertrain clutches) (Stoeckel, 1990 and Stoeckel, 1991). Although there are many application of SMA is suggested or mention in patent literature but in that there are just few are implemented because of their limitation such as lifetime, hysteresis width and stability.

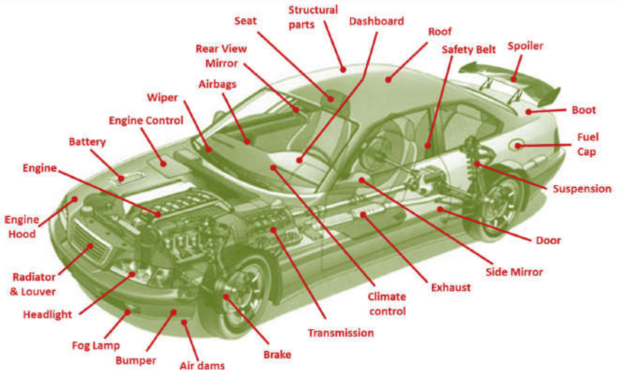

Fig. 6. Existing and potential SMA applications in the automotive domain

Aerospace industries

Since the success of the SMA coupling for hydraulic lines in the F-14 fighter jets in the 1970s (Melton, 1999), the unique properties of SMAs have gathered greater interest in aerospace applications (Humbeeck, 1999; McDonald Schetky, 1991; Godard, 2003; Singh, 2002), which are subjected to high dynamic loads and geometric space constraints. A few examples of these applications are actuators (Hartl, 2007 and Baumbick, 2000) structural connectors, vibration dampers, sealers, release or deployment mechanisms (Cleveland, 2008; Carpenter, 2001 Huettl, 2000; Long, 1998 and Lortz, 1998), inflatable structures (Fujun, 2005 and Roh, 2005), manipulators [93,94] and the pathfinder application (Melton, 1999 and Landis, 1997). Moreover there are many research going on in rotor technology. SMA is using from many years in the aircrafts for shock absorbers as well as for reducing vibration.

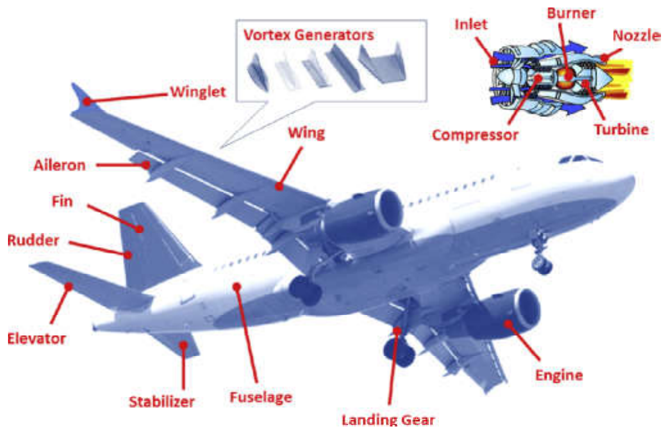

Fig. 7. Existing and potential SMA applications in the aerospace domain

Fig. 8. Festo Bionic Opter – inspiration dragonfly flight

In the field of robotics

Due to tremendous properties of SMA it has been using in the field of robotics since many years especially as micro-actuators and artificial muscles. In present time researchers and scientists are trying to make them more biological but the main problem which are coming in this field: to increase their artificial intelligence as well as to increase their performance. To increase the efficiency of these kind of machinewe need more developed SMA to solve the problems. Moreover many flying robots have been developed with the help of SMA and smart system (actuators and sensors): such as the BATMAVand Bat Robot.

Fig. 8. Existing and potential SMA applications in the robotics domain

In the field of biomedical

After the invention of SMA in nitinol by Buehler et al. in 1962, he suggested to use SMA to implant in Dentistry. After this first superelastic braces introduce by Andreasen in 1971. SMA made a significant breakthrough into biomedical domain after its introduction in minimally invasive surgery (MIS) (Song, 2010). And more biomedical application are developed. Moreover SMA possess excellent physical properties which replicate those of human tissues and bones (Morgan, 2004) (Morgan, 2004) (see Fig 7), and can be manufactured to respond and change at the temperature of the human body (Machado, 2003).

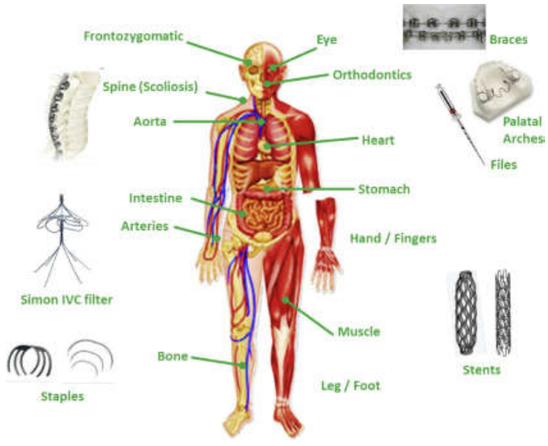

Fig. 9. Existing and potential SMA applications in the biomedical domain

Conclusion

Many potential area of researches and application has been proposed throughout the discovery of SMA. All of these researches has been focused on metallurgical properties and lesser on the design perspective. Thus to increase the potential application of SMA's researchers and scientists has to focus on the design properties. Besides this they also need to focus on to increase its commercial application in every fields which are just proposed in the patent literatures and make it more feasible and cost effective for human being. In a present scenario SMA just have limited application focused on some particular fields such as aerospace industries, automotive, robotics and in biomedical. Basically we are not lacking by ideas we are just lacking by to make its more suitable for commercials and to make it more commercials we will have to make Smart strategies.

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