Critical Review On Shape Memory Alloy

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Abstract

This paper focuses on introducing shape memory alloy and their applications in past, present and in future. Shape memory alloy exhibits two specific properties such as super elasticity and shape memory effect. By using these properties of shape memory alloy provides wide range of applications. This paper revealed the concept and mechanism of shape memory materials for particular requirement.

1. Introduction

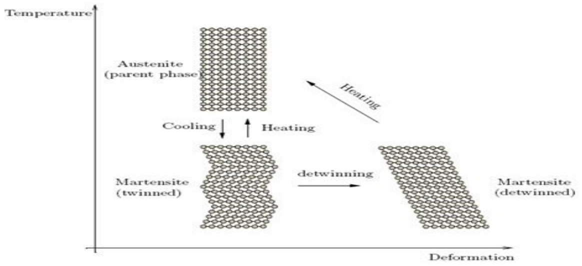
New materials are kept on being developed for enhanced the performance as per the need from engineering field. Out of them there is group of material which has properties to give a respond for a particular stimulus. Thermo response and magneto response materials.Thremoresponse material stimulates by providing heat which changes the physical and/or chemical properties of the material. For magneto responsive material stimulates by creating the magnetic field. Technically speaking, these materials are known as the stimulus-responsive materials which include shape memory alloys.[4]

Shape-memory alloys (SMAs) are a unique class of metallic alloys that exhibit two outstanding properties namely the shape-memory effect and superelasticity. These properties which make them different from the ordinary materials are based on the diffusionless transformation in solid. The shape-memory effect allows the material to recover its original geometry during heating, after being deformed. Superelasticity enables the material to withstand large cyclic deformations, without residual strains, while developing a hysteretic loop. The formation of this hysteretic loop translates into the ability of the material to dissipate energy. Due to these inherent wonderful properties, SMAs have been progressively introduced in new technological applications related with energy dissipation in civil engineering structural design and in vibration control devices.[4,8] Technological application built up of shape memory alloys are designed to take advantages of their characteristics properties like shape memory effect and super elasticity. The shape memory effect is a unique property of shape memory alloys that exhibit martensitic transformation, which enables the material to recover its original shape, after being deformed upon heating to a critical temperature. Super elasticity is associated with large non-linear recoverable strains during a mechanical cycle of loading and unloading. There are two types of shape memory alloy SMA (Shape Memory alloy), one way shape memory and two way shape memory alloy. In one way shape memory alloy the metal can be stretched or bend when that metal is in cold state. This will retain the similar shape till the heating level reaches the transition temperature. In two way shape memory type, the materials reflect one of its properties when it is in cold condition and reflects another property when it is heated.

2. Characteristics of shape memory alloys

1.1. Martensitic transformation

In near-equiatomic Ni-Ti alloys martensite forms on cooling from the body centered cubic high temperature phase, know as austenite, by a shear type of process. This martensitic phase is heavily twinned. The transformation which yields super elasticity and the shape-memory effect is diffusion less phase transformation in solids, called martensitic transformation. During this transformation, the atoms are cooperatively rearranged into a different crystalline structure with identical chemical composition, through a displacive distortion process. [19]



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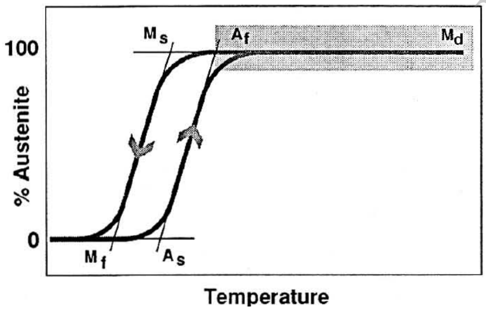
In SMAs, the martensitic transformation changes the material from the parent phase, a high-temperature (high-energy) phase called austenite, to a low-temperature phase (low-energy) called martensite shows in Figure.1. During the transformation from the high-temperature phase to the low-temperature phase, these martensitic variants are formed in a twinned pattern, in which the atoms achieve displacements with mirror symmetry. This occurs since the crystal lattice strives to achieve minimal potential energy states for a given temperature. If a deformed martensite is now heated, it reverts to austenite. The crystallographic restrictions are such that it transforms back to the initial orientation, thereby restoring the original shape. The transformation from austenite to martensite and the reverse transformation from martensite to austenite do not take place at the same temperature. A plot of the volume fraction of martensite as a function of temperatures shown in Figure.2 The complete transformation cycle is characterized by the following temperatures: austenite start temperature (A_s), austenite finish temperature (A_f), martensite start temperature (M_s) and martensite finish temperature (M_f)[18]



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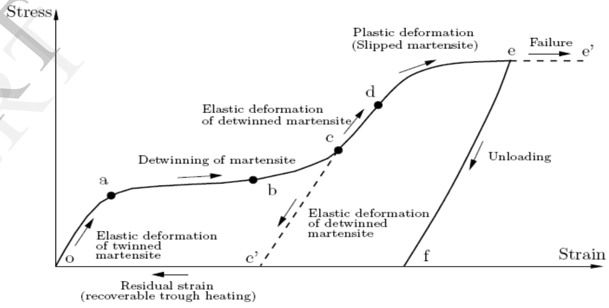
1.2. Shape memory effect

The other manifestation of the thermoelastic martensitic transformation in SMAs is the so called shape-memory effect. Whereas stressed induced martensite consists of a single preferential variant according to the applied stress, martensite produced by cooling consists of a random mixture of several variants (including twins). Twin boundaries can be relatively easily moved by the application of stress. When the twin boundaries of the crystal are moved due to application of the stress it will results in the change of the lattice orientation this phenomenon is known as detwinn. During the detwinning process of the martensitic crystal structure, when facing a unidirectional loading, the stress remains almost constant until the martensite is completely detwinned. Crystals favourably aligned to the load direction deform first, at a lower stress level, (o-a-b) in Figure.3 Less favourably aligned crystals deform later, at higher stresses (b-c). Further straining causes the elastic loading of the detwinned martensite (c-d). Unloading from any point in (o-d) initially results in elastic unloading of the detwinned material. The deformation recovered is much smaller than the one supplied by detwinning, giving the apparent impression of permanent deformation. This deformation can be recovered by raising the temperature above A_f, transforming the detwinned martensite back to austenite; see Figure.4. This shape is maintained during cooling below M_f, when the material re-transforms to twinned martensite. Straining further than point (d) will first cause the slipping of the martensite lattices and eventually lead the specimen to failure, corresponding to point (e). The force exerted by a specimen when it transforms from martensite to austenite is associated with a first-order phase transition, involving enthalpy of transformation. During this transition, the system absorbs an amount of energy, through heating. This force may be much higher than the force needed to deform the martensite specimen, causing it to detwinn.[20]



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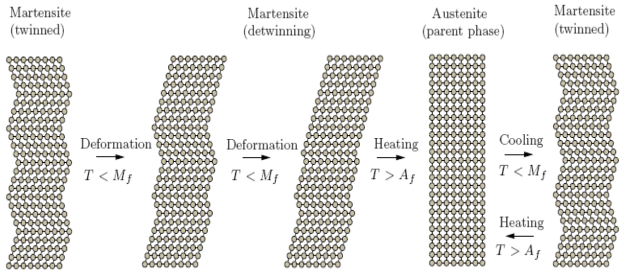

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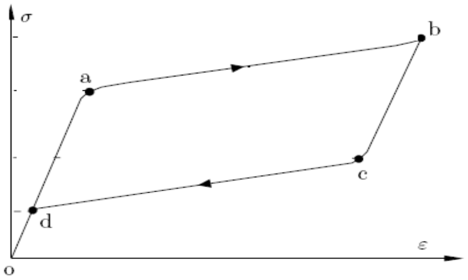
There are two categories of shape memory effect namely one way shape memory effect and two way shape memory effect. In one way memory effect material remembers its shape only in cold state where as in two way shape memory effect it will remembers their original shape in both cold and heat condition.

1.3 Super elasticity

When a unidirectional stress is applied to an austenitic specimen, within a temperature range between A_f and M_d ($M_d > A_f$), an elastic distortion of the austenitic lattice starts to occur (o-a). There is a critical value (a) whereupon austenite becomes unstable and a transformation from austenite to stress-induced martensite (SIM) takes place; see Figure 5 in which stress strain curve shows as the deformation proceeds the stress remains almost constant until the material is fully transformed (a-b). During this part of the response the two phases coexist. Upon stress removal, the elastic unloading of the detwinned martensite (b-c) takes place. Since martensite becomes unstable below a critical stress (c) a reverse transformation occurs as the unloading process continues. Detwinned martensite reverts back to austenite, at a lower stress plateau than during loading (c-d).



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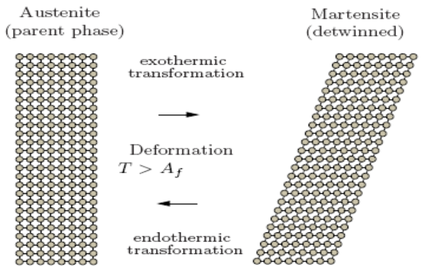
When the material is fully transformed to the parent phase (d) further unloading will follow the initial loading path, with full recovery of the deformation shows in Figure.6. A hysteretic effect is hence produced. If the temperature is greater than A_f, the strain attained during loading is completely recovered at the end of the unloading. This process is translated by an energy-absorption capacity with zero residual strain, called super elasticity.



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3. Trends in shape memory alloy materials in practicals

BenMekki *et al.* have investigated the performance of a passive control device for stay cable in cable-stayed bridges made with shape-memory alloys (SMA).The super elasticity property of SMA was sought in this study to develop a supplementary energy dissipation device for stay cable.[1] Kin-tak Lau has estimated the natural frequency of the structures with and without embedded shape memory alloy wires. Further experimental were carried out with pre-strain SMA wire. He was found that the natural frequencies changed slightly at a temperature above the austenite finish temperature of composite beams with embedded non-pre strained SMA wires. However, the increases of the natural frequencies of the beams with embedded prestrained SMA wires were found in both the theoretical prediction and experimental measurements. The damping ratios of SMA composite beams increased with increasing the temperature of the embedded wires with and without being pre-strained. In the experimental observations, it was found that the embedded SMA wires could modulate the natural frequency of the beams in certain levels. The natural frequencies of the composite beam embedded with the SMA wires were dependent on the number, size, transformation temperature and constitution of embedded wires and the constraints of structures.[2].

Reza Mirzaeifar *et al.* have studied the super elasticity of shape memory alloy (SMA) helical springs under axial force. Firstly he did the experiment without considering the curvature effect of the helical spring. In the next step, the curvature effect was included and the SMA helical spring was analyzed using the exact solution presented for torsion of curved SMA bars. All the results were compared with experimental data for a Nitinol helical spring. Finally, some practical recommendations were given for improving the performance of SMA helical springs used as energy dissipating devices.[3] Songa *et al.* have presented a review of applications of the SMA materials for passive, active, and semi-active controls of civil structures. The shape memory effect (SME) and pseudo elasticity, two major properties of SMA associated with the thermal-induced or stress-induced reversible hysteretic phase transformation between austenite and marten site, were reviewed. Those unique properties enable SMA to be used as actuators, passive energy dissipaters, and dampers for civil structure control.[4] Lexcellent *et al.* have presented a macroscopic description for the simulation of the two ways shape memory effect (TWSME) of shape memory alloys (SMA), the model was set in the framework of the thermodynamics of irreversible processes. Two internal variables were taken into account: the volume fraction of self-accommodating (pure thermal effect) and oriented (stress-induced) product phase. This termed, depends on the thermo mechanical procedure of training submitted to the sample. In the proposed techniques the accounts for the stress tensor applied during thermal cycling.[5].

Farzad Ebrahimi *et al.* have used a macro-scale, phenomenological constitutive model for shape memory alloy (SMA) in conjunction with energy balance equations to study the evolution of temperature and deformation profiles seen in SMA wires. The general fully-coupled thermo mechanical formula for resistive heating of an SMA wire-initial detwined martensite, leading to strain recovery on heating, was used and numerical results were obtained with use of "Meshless" methods which were rather new computational techniques that do not require the use of any connectivity concept, such as those used in finite element method (FEM). A good agreement was obtained between the achieved results and the literature. The proposed model could accurately predict the pseudo elastic behaviour of SMA materials. [6] U. Icardi *et al.* have represented preliminary design study aimed to verify the feasibility of an adaptive wing for a small unmanned aircraft (UA), which is entirely actuated by shape memory alloy devices (SMA). The capability of the wing to bear the aerodynamic loads, the power required by the actuators and their force and torque during flight is assessed by finite element simulations.[7]

Alaa M. Sharabash et al. have investigated the performance of a new passive seismic control device for cable-stayed bridges made with shape memory alloys (SMAs). The super elasticity and damping capability of SMAs is sought in this study to develop a supplementary re centering and energy dissipation device for cable-stayed bridges. The effectiveness of the SMA dampers in controlling the deck displacement and limiting the shear and bending moment demands on the bridge towers is assessed. The results also show that the variation in the SMAs' strain hardening during phase transformation has a small effect on the bridge response compared to the variation in the unloading stress during reverse phase transformation.[8] Ottavia Corbi has represented the benefits about the SMA and its behaviour can introduce in the dynamical response of a structural system. The influence of SMA tendons contributing to the overall strength of a simple elastic– plastic structural model undergoing horizontal shaking and subject to vertical loads.[9] Victor Birman has discussed about different approach to passive vibration control of shear deformable and thin plates. The first of two methods of vibration control employs pre stressed shape memory alloy (SMA) wires embedded in sleeves attached to the surface of the plate.[10] Yutaka Toi *et al*. have addressed Brinson’s one-dimensional constitutive modelling for shape memory alloy (SMA) is extended to consider the asymmetric tensile and compressive behaviour as well as the torsional behaviour. The incremental finite element method using linear Timoshenko beam elements is formulated by the total Lagrangian approach for the superelastic, large deformation analysis of SMA helical springs.[11].

D.S. Burton *et al.* have discussed a self-healing; metal matrix composite reinforced by shape memory alloy wires is simulated using finite element analysis. A one-dimensional constitutive model for SMA behaviour is implemented as a user-defined truss element in ABAQUS. The matrix is brittle and a mode I crack is allowed to propagate through the specimen upon loading. During the loading process the wires undergo a martensitic phase transformation, bridging the crack. To heal the composite, simple heating is required which reverse transforms the wires and brings the crack faces back into contact.[12] S.M.T. Hashemi *et al.* have explained that shape memory alloys have a high potential for passive isolation of vibrations as well as capability of being used as an active vibration isolation system for their shape memory behaviour, i.e. having hysteresis along with superelastic behaviour. Study of this behaviour necessitates recognition of distinct specifications of this alloy and also presentation of a suitable and simple mathematical model. In this paper, a mathematical model based on Auricchio model, considering asymmetry in tension and compression and also temperature effects on hysteresis at superelastic conditions has been presented. Finally, dynamical behaviour of a NiTi beam under free vibration as well as application of sinusoidal and impulse loads upon free–clamped and also simply supported conditions have been analysed [13]. J.M. McNaney *et al.* have represented constitutive laws for shape-memory alloys subjected to multiaxial loading, which are based on direct experimental observations, are generally not available in the literature. Accordingly, in the present work, tension–torsion tests are conducted on thin-walled tubes (thickness/radius ratio of 1:10) of the polycrystalline superelastic/shape-memory alloy Nitinol using various loading/unloading paths under isothermal conditions.

The experimental results show significant variations in the mechanical response along the two loading axes. These are attributed to changes in the martensitic variants nucleated in response to the directionality of the applied loading, as well as to microstructural texture present in the parent material. Numerical simulations suggest that the characterization and modeling of the microstructure is of paramount importance in understanding the phenomenology of shape-memory alloys.[14] Mauro Dolce *et al.* have explained about two families of passive seismic control devices exploiting the peculiar properties of shape memory alloy (SMA) kernel components have been implemented and tested within the MANSIDE project (Memory Alloys for New Seismic Isolation and Energy Dissipation Devices). They are special braces for framed structures and isolation devices for buildings and bridges. Their most important feature is their extreme versatility, i.e. the possibility to obtain a wide range of cyclic behaviour from supplemental and fully re-centering to highly dissipating by simply varying the number and/or the characteristics of the SMA components. Other remarkable properties are their extraordinary fatigue resistance under large strain cycles and their great durability and reliability in the long run. In this paper, the working mechanisms of the SMA based devices are outlined and the experimental tests carried out to verify the above-mentioned properties are extensively described.[15]

Yu-Lin Han1 *et al.* have developed damper device based on shape memory alloy (SMA) wires. The design procedures of the SMA damper are presented. As a case study, eight such SMA dampers are installed in a frame structure to verify the effectiveness of the damper devices. Experimental results show that vibration decay of the SMA damper controlled frame is much faster than that of the uncontrolled frame. The finite-element method is adopted to conduct the free and forced vibration analysis of the controlled and uncontrolled frame. The experimental and numerical results illustrate that the developed SMA dampers are very effective in reducing structural response and have great potential for use as efficient energy dissipation devices with the advantages of good control of force and no lifetime limits.[16]

Dimitris C. Lagoudas *et al.* have studied the effect of Shape Memory Alloy pseudo elasticity on the behavior of vibrating systems. A physically based model for Shape Memory Alloy pseudoelastic response is modified to predict the component level response of Shape Memory Alloy springs and is integrated into a numerical solution of the non-linear dynamic system that results from the inclusion of Shape Memory Alloy components in a dynamic structural system. Promising results from these investigations and the application of these studies to experimental work in progress by the authors are briefly discussed [17] J. Raghavan *et al.* have described the potential of superelastic shape memory alloy (SMA) fibers to enhance the damping capacity and toughness of a thermo set polymer matrix was evaluated.[18]

4. Conclusions

In this paper, in addition to introducing some new features and phenomena developed in shape memory alloy in recent years, we present a number of interesting applications of shape memory alloy, in particular in these emerging technologies. This shows the potential of shape memory materials to use in new applications like rolling car, energy conversion using SMA springs and also in the vibration controlling and in earthquake resisting devices by using the super elasticity properties of the SMA.

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