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Applications of Shape Memory Alloys in Structural Engineering

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ABSTRACT

Shape Memory Alloys (SMA) are smart materials with the ability to" remember" their shape. Since its invention in1932, various properties of SMA have been exploited and applied in eclectic fields including aerospace, automotive, robotics and biomedical industries. The goal of this paper is to summarize applications of SMA in structural engineering applications.

KEYWORDS: Image Processing, Electronic invoicing, pdftotext, tesseract, tesseract4.

1. INTRODUCTION

The use of shape memory alloys (SMAs) has increasingly expanded in recent decades. Many researchers have intensively conducted activities aimed at exploring innovative devices and applications, making use of these smart materials. Shape memory alloys are unique alloys that have the ability to undergo large deformations, but can return to their undeformed shape by heating known as the shape memory effect[1] or through removal of the stress ~known as the superelastic effect. Recently, there has been increasing interest in using superelastic shape memory alloys for applications in seismic resistant design of structures. Binary nickel–titanium shape memory alloys are commonly referred to as Nitinol ~Nickel Titanium Naval Ordinance Laboratory.

The austenite phase (or parent phase) of a shape memory alloy (SMA) is a body-centered cubic structure occurring at high temperatures while the martensite phase, a non-equilibrium single phase structure, occurs at low temperatures (near-ambient) when rapidly cooled (most common) or subjected to stress related to temperature [2] [3]. The transformation occurs due to nucleation, which occurs when a tiny seed crystal begins crystallization in a polymorphous zone by overcoming a large energy barrier [4].

Phase transformation (austenite to martensite) occurs in 2 phases small layered dislocations while the lattice invariant shear / accomodation stage involves accomodating

the new structure by altering the surrounding austensite either by twinning (unable to accomodate volume changes) or slip (permanent and common) [5].

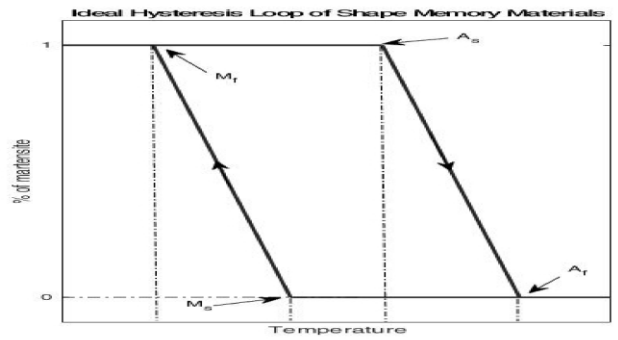

Fig: 1

Where,
Martensite Start Temperature Ms
Martensite Finish Temperature Mf
Austenite Start Temperature As
Austenite Finish Temperature Af
Deformation Induced Limit Temperature Md

If a SMA is cooled from above Afto below Mf, the SMA remains an austenite [5]. Now, when stress is applied,
the martensite is deformed by dislocation of twin boundaries, which are low energy mobile interfaces [2]. In order to get the martensite to the undeformed state, the temperature is increased from As to Af. Now, even if the temperature falls below Mf, the austenite will not deform, referred to as the one way effect [5]. ”Programming” the SMA involves [2]:

- Heat the alloy to a temperature much higher than Af.
- Store the material in its austenite shape for enough time.

The superelastic behavior also allows the use of austenite elements to provide full self-centering due to the ability of SMAs to regain their original shape after being deformed well beyond 6e8% strain. This shape recovery is the result of phase transformations that can be induced by either a stress or a temperature change. Several innovative systems and devices, mainly using NiTi and Cu-based SMAs, have been developed to absorb a part of the seismic energy and reduce the earthquake forces acting on a structure, for damping control, structural retrofit etc.
other excellent properties of SMAs such as good fatigue and corrosion resistance, large damping capacity, and a good versatility in terms of their many possible shapes and configurations. SMAs play a key role in the development and implementation of smart materials/devices, which can be integrated into structures to provide functions such as sensing, energy dissipation, actuation, monitoring, self-adapting, and healing of structures.

2. RELATED WORK

1. ENERGY DISSIPATION SYSTEMS: BRACED FRAMES

It is a passive device.

These structural systems are mainly composed of steel members in the form of wires, rods, and truss elements and are designed primarily to resist earthquake loads, being installed diagonally (or in other specific configurations) in the frame structures [6][7] (Fig 2).

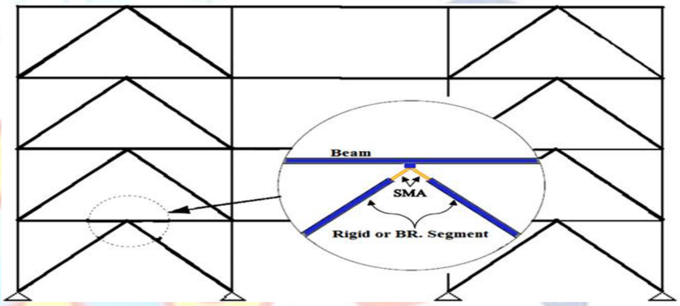

Fig: 2

The main energy-dissipating mechanism characterizing these elements is related to the work made by members in a braced frame under tension and compression loadings.
However, recent earthquakes have highlighted some weak points in the performance of ordinary steel-braced frames, including limited ductility and consequent low energy
dissipation capability due to brace buckling failure, asymmetric behavior in the tension and compression of the brace member, and failure of connection elements. To overcome these problems, buckling restrained braced frames (BRBFs) have been developed.

Clark et al. [8] conducted analytical studies on the use of SMA devices for control of multistory steel buildings. SMA devices, consisting of multiple loops of SMA wires, were integrated into eccentric bracing at each level. The resulting interstory drift decreased by almost 50% for each of the three levels of input, while the first-floor interstory drift was reduced even further.

Moreover, the energy absorbed by the frame was reduced to about 15%compared to the frame without the devices.

Han et al. [9] assessed the performance of eight damper devices made of the SMA wires and steel wires that were diagonally installed in a two-story steel-frame structure. Experimental comparisons showed a much faster decayof vibrations in the SMA-controlled frame than that of the uncontrolled frame. In addition, the largest displacement of the SMA controlled frame was only 15% of that of theuncontrolled case. Dynamic responses of frames with SMA braces showed energy dissipation capabilities comparable to the ones with BRBFs. Results suggested SMA hysteresis that takes place during loading cycles whileundergoing large deformations was able to reduce the maximum interstory drift (up to 60%), permanent deformation in the structure (exhibiting good recentering capability), and, consequently, the deformation demand on the column members at each floor level.

Key design parameters for SMA-based bracing members maximum force capacity, device length, residual displacement, and energy dissipating capability.

Asgarian and Moradi[10] reported that even though SMA can exhibit recentering properties for strain values in the 8-10% range, a conservative value of 6% strain should be adopted.

Miller et al.[11] proposed a hybrid device consisting of a typical BRBF component, which provided energy dissipation, and pretensioned superelasticNiTi SMA rods, which provided self-centering and additional energy dissipation (Fig. 3). The experimental program demonstrated that the developed high-performance earthquake-resistant brace was able to provide stable hysteretic response with appreciable energy dissipation, selfcentering ability, and large maximum and cumulative deformation capacities.

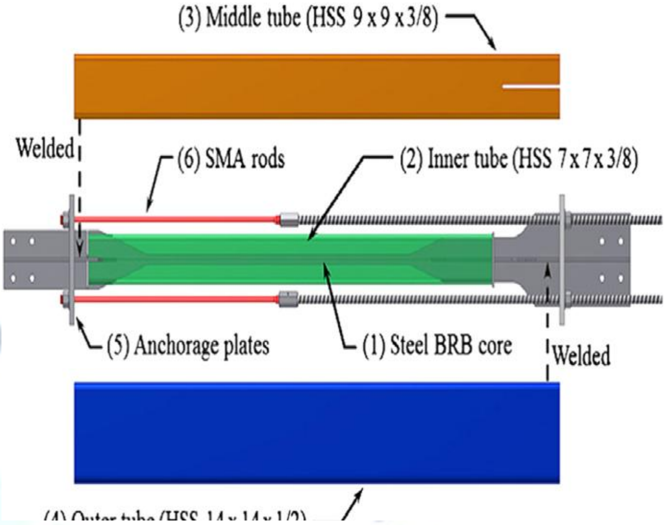

Fig: 3

2. ISOLATION SMA-BASED DEVICES

The fundamental mechanism of a base isolation device consists in decoupling the induced motion of the structure by means of a flexible interface element (i.e., bearing element) that isolates the base of the structure from the surrounding ground, allowing the structure to slide on a specific surface.

Requirements

(1) adequate energy dissipation capability to reduce seismicdemand on piers,

(2) a good recentering mechanism to avoid excessive bearing deformations and instability, (3) no need for bearing replacement even after a strong earthquake (i.e., no residual deformation on the bearing after the excitation), and (4) high durability against cyclic loads.

Krumme et al. [12]investigated the performance of a sliding SMA device, where the resistance to sliding was achieved by opposing pairs of Nitinol tension elements. The performance of this device was analytically studied in a 1970s nonductile concrete frame building retrofit. The isolated structure exhibited noticeable improvement in terms of interstory drifts, and column rotational demands were reduced to acceptable levels.

A base isolation system made of superelastic SMA bars was investigated by Wilde et al [13]. SMA isolation system provided variable responses to excitation as well as a notable damping. The overall energy comparison indicated that the damage energy of the bridge with the SMA isolation device was smaller than with the conventional one.

Dolce et al. [14]reported a comprehensive study on testing and application of two full-scale isolation SMA prototype devices. The effective performance of SMA wires was demonstrated on a small building in Italy. Good recentering behavior was proven because, after only two oscillations, the building regained its original position
with no residual displacement.

3. DAMPING DEVICES FOR BRIDGE STRUCTURES

Civil infrastructures involve the use of structural cables, which are critical components of stay cable bridges, suspension bridges, and prestressed concrete bridges. Due to the environmental and functional exposure during bridge service life, these cables are prone to two main damage mechanisms:

- The corrosion phenomenon, related to an aggressive marine environment, rain and snow conditions, etc.
- The fatigue phenomenon, arising from cyclic traffic loads, meteorological actions (such as wind, storms etc.).cable vibrations induced by these actions are potentially responsible for cyclic stresses.

Torra et al. [15] reported that the oscillation amplitude of stay cable might be reduced by an appropriate SMA damper by a factor of more than 2, which would increase the useful life of the cable. They conducted realistic tests on stay cables that were approximately 50 m long and equipped with NiTi SMA damping systems.

Fig: 4

(a) Four cables of 45 m long and (b) NiTi SMA Dampers used in the Work of Torra et al. [15]

4. SMA-BASED STRUCTURAL CONNECTIONS

Structural connectors or beam-to-column connections are prone to damage during an earthquake. SMA connectors have been designed to provide damping properties to the structure.

4.1 Connections in Steel StructuresLeon et al. [16]who reported an experimental study on full-scale beam-column connections with and without the Nitinol tendon devices.

Ocel et al, [17]tested a partially restrained steel beamecolumn connection using martensite Ni-Ti SMA tendons under quasi-static and cyclic loading. The superelastic SMA-based connections wereable to recover 85% of their deformation after being cycled to 5% drift, enabling the concentration of all of the inelastic deformation into the tendons while keeping the other members in the elastic regime.

4.2 Connections in Reinforced Concrete Frames

Alam et al. [18]investigated the performance of concrete beam-column elements reinforced with regular reinforcing steel and superelasticNiTi SMA under cyclic displacement loading. The concrete beam-column element was reinforced with SMA rebars at the plastichinge region of the beam, along with regular steel in the remaining portion of the joint. Single barrel screw lock couplers were used for connecting steel and SMArebars. Although the steel-RC beam-column joint dissipated a relatively higher amount of energy due to its large hysteretic loops, it was reported that the SMA-reinforced joint performed better because of its capability in recovering postelastic strain. The study also focused on an analytical approach to determine the length of the plastic hinge, crack width, crack spacing, and bond-slip relationship for superelastic SMA RC elements.

3. FUTURE SCOPE AND CONCLUSION

It has been shown how SMAs can be successfully used for sensing, energy dissipation, actuation, monitoring, vibration control, self-adapting, and healing of structures. experimental and analytical studies have demonstrated that the use of SMAs can effectively improve the response of buildings and bridges subjected to seismic loadings.

SMAs are very sensitive to compositional variations: small changes to the constituents of an alloy may significantly modify the mechanical properties of the material, requiring quality control to ensure suitable properties. In addition, due to the thermomechanical sensitivity of the material, SMA properties are dependent on the ambient and in-service temperatures. Disadvantage is high cost of material and manufacturing.

Conflict of interest statement

Authors declare that they do not have any conflict of interest.

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