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The influence of SMA on reinforced concrete column

Mahmoud. Kamal*

Assistant Professor, Civil Engineering Department, Faculty of Engineering, Beni-Suef University, Egypt.

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ABSTRACT

In recent years, a novel concrete confinement technique employing shape-memory alloys (SMAs) has emerged. The new method employs active confinement, which has been shown to increase the strength and ductility of concrete more effectively than passive confinement. However, previous research on this technique has primarily focused on using external SMA spirals or ties to retrofit or repair existing concrete columns. Due to SMA's unique ability to recover substantial inelastic deformation upon unloading, seismic design can greatly benefit from it. Consequently, if shape memory alloy (SMA) is utilized at the location of plastic hinges with the proper design constraints, the structure will dissipate the demand energy and return to its original form when unloaded. Self-centering, SMA-reinforced concrete beam-column connections are a novel concept that can be improved for application in building. Utilizing SMA in numerous reinforcement applications: In addition to the material's super-elasticity, corrosion resistance, and fatigue resistance, the shape memory effect, which is the ability of SMA to return to its original shape after being heated and bent beyond its elastic limits, is SMA's defining characteristic. This transition's recuperated strain can replace hydraulic jacks in pre-stressing applications. Attaching pre-stressed SMA reinforcement to RC members and then heating them above the activation temperature enables the SMA to recover the inelastic strain, thereby subjecting the RC to a pre-stress.

1. Introduction

Our civil infrastructure is susceptible to a wide variety of natural and man-made disasters; consequently, it is crucial that we have effective and timely emergency measures in place to mitigate their severity. Keeping lifeline infrastructure as functional as possible in the face of such threats is a top priority for any emergency response strategy [1-3]. One way to achieve this is by developing efficient repair methods that can be quickly and easily implemented. Reinforced concrete (RC) columns are, from a structural standpoint, among the most important structural components, whose damage could significantly compromise the building's safety and functionality. When RC columns are severely damaged, the building is sometimes forced to be shut down permanently. If vital structures like lifeline bridges are damaged, emergency response teams may be delayed due to the potential for widespread traffic disruption. Therefore, there is an immediate need for effective methods of repairing severely damaged RC columns. [4-11].

To reinforce RC structures, we employ SMA rods. Once SMAs have been deformed beyond their elastic limit, they can be heated to regain their original shapes. Utilizing the shape memory effect (SME) of SMAs in structural

* Corresponding author. Mahmoud. Kamal, Assistant lecturer, Civil Engineering Department, Faculty of Engineering, Beni-Suef University, Beni-Suef, Egypt. Email: mahmoud .kamal@eng .bsu .edu .eg. Mobile no.+21067995993

applications causes the strain on the material to increase before it returns to its original shape. Traditional SMA composition (NiTi) is prohibitively costly, limiting its application. Recent research has determined that Fe-SMAs can effectively replace NiTi-SMAs because they share similar properties and behaviors. Notably, changing the temperature can alter the phases of Ni-Ti-SMA, but this may not always be the case for iron-based shape memory alloys. In order to improve the final characteristics and behavior of FE-SMAs, thermomechanical treatments, precipitation, grain size, and alloy composition are crucial factors. More research is necessary to fully comprehend the behavior of the materials. Rojob and El-Hacha compared the effects of strengthening RC beams with NSM Fe-SMA versus CFRP strips. [12-14].

The Fe-SMA-reinforced beam fractured ductilely, whereas the CFRP-reinforced beam fractured brittlely, as determined by the rupture of the CFRP strips. Increases in ultimate load bearing capacity and deflection were observed in beams reinforced with Fe-SMA [18] due to the yielding nature of the material. A further advantage of SMA pretensioning over other materials is its relative simplicity [18]. The prestressing of SMA rods is comparable to that of FRP rods. SMA is self-stretching; consequently, it can be heated to achieve prestressing without requiring ducts, anchor heads, oil hydraulic jacks, or duct injections [18]. Numerous studies have investigated the pretensioning and strengthening of RC with SMA. The recovery stress demonstrates that pretensioning the SMA rod, followed by heating the SMA with electrical resistance heating to form the (SME), results in the prestressing of SMA. [21].

Czaderski et al. [20] examined the effect of pre-straining at 2% and 4% at 160 °C on the material. For a 2% pre-strain, the recovery stress of ribbed SMA strips was between 298 and 304 MPa, whereas for a 4% pre-strain, the recovery stress was 295 MPa. The Fe-SMA was similarly transformed from the detwinned martensite to the austenite phase by applying a 6% pre-strain and then heating the material to 315 °C [14]. The FE-SMA was tested with a 41% ultimate strain and 826 MPa strength. At the applied temperature, a prestressing value of 130 MPa was achieved, which corresponds to a 16% prestressing level. Moreover, Shahverdi et al. examined a number of constraining parameters [15]. The highest recovery stress was observed with a pre-strain of 2% and a temperature of 160° C. At 1000 MPa, Fe-SMA demonstrated 40% of its ultimate strength. There have been studies on prestressed Fe-SMA [14,15,17,19,20,22,23], but studies on various prestressing levels are scarce [19,23]. Lee et al. [19] evaluated two pre-straining levels (2 and 4%) at three different temperatures (50, 100, and 140 °C) in order to achieve varying prestressing levels.

To reduce the temperature's effect on the entire beam, the thermal expansion of SMA was kept to a minimum by applying electrical resistance heating in small, targeted areas. A higher pre-straining level or heating temperature of SMA was found to result in a greater recovery stress. At temperatures of 50, 100, and 140 °C, prestressing with a 2% pre-strain produced values of 165, 290, and 317 MPa, respectively. In contrast, heating the SMA to 100 and 140 °C produced prestressing levels of 303 and 355 MPa with a prestrain of 4%. In addition to the research on RC beams, coupons were used to conduct tensile tests on Fe-SMA strips to determine how different temperatures affected the recovery stress after being subjected to varying degrees of prestraining. At the same heating temperature, 2% pre-strain produced a higher recovery stress than 4% pre-strain [22].

2. Type of SMAs

Over the past seven decades, numerous other SMAs have been studied, beginning with early work on AuCd and AgCd alloys in the 1930s and continuing through the discovery of Nitinol in 1963 and current work on cutting-edge compositions. By incorporating new alloying elements into standard alloys, chemists have been able to create an extensive library of SMAs with a variety of desirable properties. With so many options, designers are able to fine-tune SMA characteristics to meet the needs of a diverse array of commercial applications. NiTi-Based Alloys, Copper-Based Alloys, Iron-Based Alloys, and Additional SMAs are classifications of shape memory alloys based on primary alloying components, actuation mode (magnetic, thermal), operating temperature, and intended behavior, among other factors.

3. Phase Transformation

There are three major types of NiTi alloys. Three types of martensite exist: twinned (Mt), detwinned (Md), and untwinned (A). The two types of martensite are linked to transformation at low temperatures, whereas austenite is linked to transformation at high temperatures. Different mechanical properties distinguish the various Ni and Ti configurations. Figure 1 depicts three distinct NiTi forms.

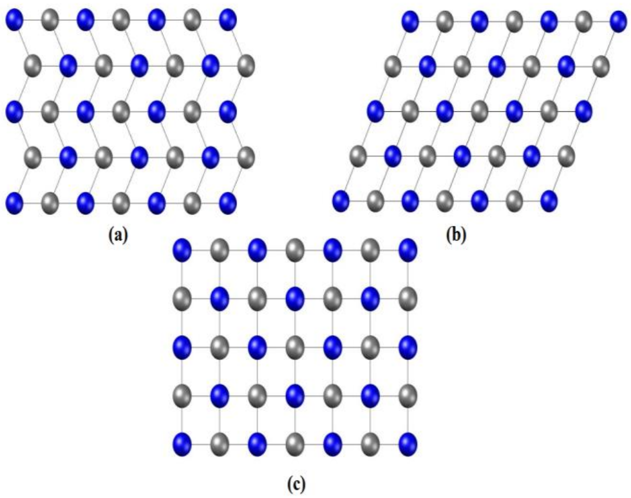

Figure 1. NiTi (SMA) Transformation Forms: (a) Twinned Martensite, (b) Detwinned Martensite, (c) Austenite.

The three NiTi shape memory alloys are distinguished by their diverse phase changes. In response to an external stimulus, the first step occurs when twinned martensite transforms into detwined martensite. Detwinning is the process that enables long plastic strains in the SMA and is referred to by this name. By exceeding its high transition temperature, detwinned martensite undergoes a second transformation into austenite. When austenite is cooled to its low transition temperature and undergoes a phase change into twinned martensite, this is the third stage. Austenite is transformed into detwinned martensite during the final phase. For this transition, the material is subjected to intense stress while still above its high transformation temperature. Four temperatures can be used to characterize phase transitions in a SMA material. These temperatures correspond to the austenite-to-martensite phase transition. The transformation from ferrite to austenite begins at the austenite start temperature (As) and ends at the austenite finish temperature (Af) when SMA is heated to these temperatures. At the martensite start temperature (Ms) and the martensite finish temperature (Mf) in SMA material, austenite is transformed into martensite. No two forward or reverse changes follow the same path. The transition is reversed as a result of cooling, demonstrating hysteresis. In contrast to austenite, which transforms forward at higher temperatures, martensitic materials transform backward at lower temperatures, thereby retaining the stresses introduced at higher temperatures. Thermal strain (T) is the strain attained via the shape memory effect in the forward direction. Figure 2 illustrates this shift in opposite directions.

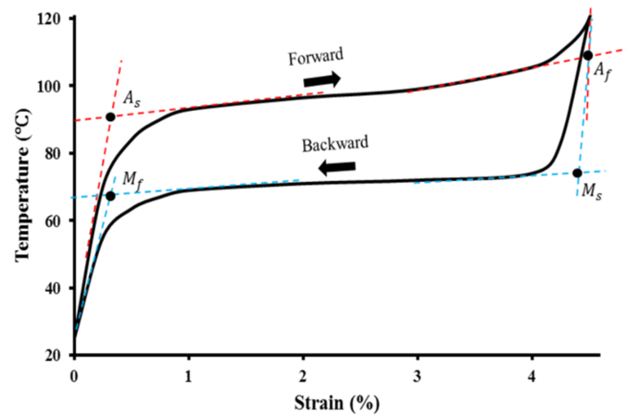

Figure 2. Forward and backward transformations of the shape memory effect.

4. CONCLUSION

This study provides an overview of the fundamental properties of Nitinol shape memory alloys (SMA) and their applications in passive, active, and semi-active civil construction management. Due to the shape memory effect (SME), martensite Nitinol materials may be used as actuators, with additional applications in active and semi-active controls of civil constructions. Self-healing reinforced martensite SMAs may exhibit active structural control. The use of martensite SMA wires to actively tune the structural natural frequency, which dampens vibrations in civil engineering, is an example of semi-active control. Stress-strain curves for loading-unloading cycles reveal significant hysteretic effects in both martensite and superelastic SMAs, which indicates energy loss. This paves the way for the development of passive structural damping devices by utilizing martensite and superelastic SMAs. SMA is most useful as a passive structural controller for two mechanisms: isolation and energy dissipation. The study compares the two by providing several examples of each from the real world and academic literature. These cases also demonstrated that passive SMA devices can be practical and useful. For superior structural control performance, there has been a shift towards combining the advantages of martensite and austenite SMAs.

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