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The effect of using SMA in reinforced concrete columns

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ABSTRACT: In the recent past, a novel concrete confinement method utilising shape memory alloys (SMAs) has evolved. Active confinement is used in the new method, which has been shown to increase concrete's strength and ductility more effectively than passive confinement. Previous studies on this method, however, have mostly concentrated on using external SMA spirals or ties to retrofit or repair existing concrete columns. Seismic design can benefit greatly from SMA due to its unique ability to recover significant inelastic deformation upon unloading. Therefore, if shape memory alloy (SMA) is utilised at the site of plastic hinges with appropriate design constraints, the structure will dissipate the demand energy and revert to its original form when unloaded. Self-centering concrete beam-column connections that are reinforced with SMA are a novel notion that can be improved for application in practical building. Incorporating SMA into several reinforcement applications: The shape memory effect, which is the capacity of the SMA to restore its original shape after being bent beyond the elastic limits by heating, is the primary characteristic of SMA, along with the material's super-elasticity, corrosion and fatigue resistance. Strain reclaimed through this transition can replace hydraulic jacks in pre-stressing applications. Attaching pre-stressed SMA reinforcement to the RC members and then heating them above the activation temperature allows the SMA to recover the inelastic strain, causing the RC to undergo a pre-stress.

KEY WORDS: SMAs, RC Columns, Ductility.

I. INTRODUCTION

Our civil infrastructure is vulnerable to a wide range of both natural and man-made disasters, therefore it's crucial that we have effective and timely emergency measures in place to lessen the severity of their effects. Keeping essential lifeline infrastructure as functional as possible in the face of such threats is a top priority for any emergency response strategy[1-5]. One means of accomplishing this is through creating efficient repair methods that can be quickly and readily put into practise. Reinforced concrete (RC) columns are, from a structural standpoint, among the most crucial structural parts, the damage to which might considerably compromise the safety and operation of the entire building. When RC columns are significantly damaged, it sometimes forces the building to be shut down permanently. Because of the potential for widespread traffic disruption, emergency response teams may be delayed if vital buildings like lifeline bridges are damaged. Therefore, there is an urgent requirement for efficient means of repairing severely compromised RC columns [3-12].

To reinforce RC buildings, we use SMA rods. After being distorted past their elastic limit, SMAs can be heated to return to their original forms. Structural applications of SMAs that take use of their shape memory effect (SME) see the strain placed on the material increase before it returns to its original shape. Traditional SMA composition (NiTi) is prohibitively expensive, restricting its use. Some recent research have found that Fe-SMAs can effectively replace NiTi-SMAs, as they exhibit similar characteristics and behaviour. Notably, the phases of Ni-Ti-SMA can be altered by altering the temperature, but this may not always be the case for iron-based shape memory alloys. Thermomechanical treatments, precipitation, grain size, and alloy composition are all important factors in improving the final characteristics and behaviour of FE-SMAs. More study is required to properly comprehend the materials' behaviour. Strengthening RC beams using NSM Fe-SMA vs. CFRP strips was studied by Rojob and El-Hacha [14].

The Fe-SMA-reinforced beam broke apart in a ductile manner, while the CFRP-reinforced beam broke apart in a brittle manner, as determined by the rupture of the CFRP strips. Increases in ultimate load bearing capacity and deflection were seen in Fe-SMA reinforced beams [17] due to the material's yielding nature. A further benefit of SMA prestressing over other materials is the relative simplicity of the process [17]. Prestressing SMA rods is similar to prestressing FRP rods.

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SMA is self-prestressing, therefore it may be heated to prestress it without the need of ducts, anchor heads, oil hydraulic jacks, or duct injections [18]. Prestressing and strengthening RC with SMA has been the subject of a number of research [6,14,15,17,19-22]. Pre-straining the SMA rod, then heating the SMA with electrical resistance heating to form the (SME), results in the prestressing of SMA, shown by the recovery stress [21].

Czaderski et al. [20] looked at how pre-straining at 2% and 4% under 160 °C affected the material. For a pre-strain of 2%, the prestressing of ribbed SMA strips was between 298 and 304 MPa, while for 4%, the prestressing was 295 MPa (recovery stress). The Fe-SMA was similarly transformed from the detwinned martensite to the austenite phase and recovery stress (prestress) was generated by applying a 6% pre-strain and then heating the material to 315 °C [14]. The FE-SMA was tested to have an ultimate strain of 41% and a strength of 826 MPa. A prestressing value of 130 MPa was achieved at the applied temperature, which is the same as a 16% prestressing level. In addition, Shahverdi et al. looked at several prestraining parameters [15]. The results showed that the highest recovery stress was achieved with a 2% pre-strain and 160° C temperature. Recovering to 1000 MPa, Fe-SMA exhibited 40% of its ultimate strength. Studies on prestressed Fe-SMA have been conducted [14,15,17,19,20,22,23], but studies on different prestressing levels are still scarce [19,23]. Lee et al. [19] have tested two pre-straining levels (2 and 4%) at three different temperatures (50, 100, and 140 °C) to achieve different prestressing levels.

To reduce the temperature influence on the whole beam, the thermal expansion of SMA was minimal since the heating was applied in small, targeted areas using electrical resistance heating. It was discovered that a higher pre-straining level or heating temperature of SMA led to a greater recovery stress. Levels of 165, 290, and 317 MPa were attained after prestressing with a 2% pre-strain at temperatures of 50, 100, and 140 °C, respectively. In contrast, heating the SMA to 100 and 140 °C resulted in prestressing levels of 303 and 355 MPa with 4% pre-strain. In addition to the research on RC beams, tensile tests were conducted on Fe-SMA strips using coupons to see how different temperatures affected the recovery stress after being exposed to varying degrees of pre-straining. At the same heating temperature, it was discovered that the 2% pre-strain resulted in a larger recovery stress than the 4% pre-strain did [23].

II. PROPOSED REPAIR TECHNIQUE

To restore the injured section of the column's strength and ductility, the innovative repair method employs prestrained SMA spirals to provide substantial external active confinement pressure. The applied pressure is active because it is applied and sustained during the service life of the structure without axial loading of the column. Contrarily, the more prevalent kind of concrete confinement, known as "passive," depends mostly on the lateral expansion (dilation) of the concrete under axial pressures owing to Poisson's effect. When concrete expands, it creates confinement pressure by activating the jacket or spiral wrapped around the concrete.

The steps of the proposed repair method are as follows: (1) removing loose concrete, (2) straightening and/or coupling any buckled or fractured longitudinal reinforcement, (3) injecting epoxy into cracks in the concrete, (4) replacing the removed concrete with a quick-setting cement-based mortar, (5) wrapping the damaged region with the prestrained SMA wire in the form of a spiral, and heating the SMA spiral with a fire torch or by passing an electric current.

Using the significant recovery stress associated with the form recovery of prestrained martensite SMAs when heated is the core concept behind the use of SMAs in active confinement for concrete. Figure 2 shows how the hoop stress builds up in the spiral as the heated prestrained SMA tries to contract to its original length while being held in place by the column (prestress). Pressure for confinement will be applied perpendicular to the surface of the column due to this hoop tension.

Because of the specific nature of this application, the manufacturer will provide the SMA wires to the customer already stretched out by a strain of around 6% in the martensite phase. So long as the temperature of the spiral is below the austenite start temperature (As), the spiral will stay in its constrained state. It's worth noting that keeping the confinement pressure constant throughout a large range of ambient temperature is crucial for the effective implementation of this application. It is necessary to use an alloy with a large thermal hysteresis for this reason. The ternary NiTiNb alloy utilised here is a nice example of such a material. NiTiNb has a thermal hysteresis breadth of around 130 C and a martensite initiation temperature (Ms) of about 50 C, according to [9].

Figure 1 shows a schematic of a SMA with a large hysteresis for the typical temperature range. Since the projected range of ambient temperatures is higher than Ms, the alloy should remain in the austenite phase when the ambient temperature decreases. Figure 2 [10] shows some of the results from the authors' previous work in which they performed thermomechanical testing on NiTiNb wires with a diameter of 2 mm. A time-temperature plot of the recovery stress is presented in the figure. The recovery stresses of the NiTiNb wire rose with temperature up to a high of 565.4 MPa at 108 C, whereafter they declined somewhat to settle at a value of 459.9 MPa. The wires' recovery stress remained constant

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even at normal room temperature (16 C). In this research, the stable recovery stress was utilised to impart significant and continuous external confinement pressure on the injured area of the columns, restoring their strength and flexural ductility.

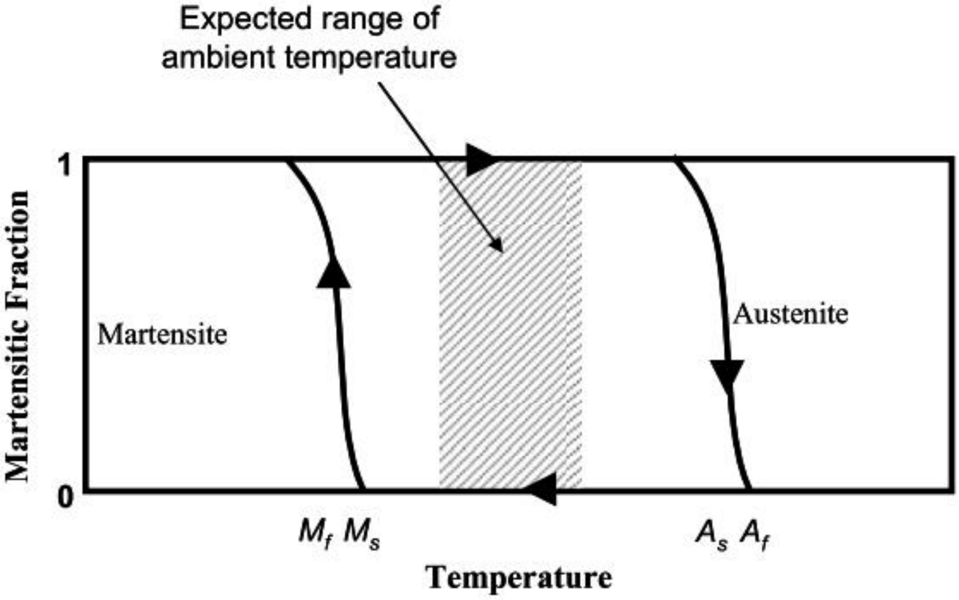

Figure 1 Temperature dependence of the martensitic component in a SMA with high thermal hysteresis.

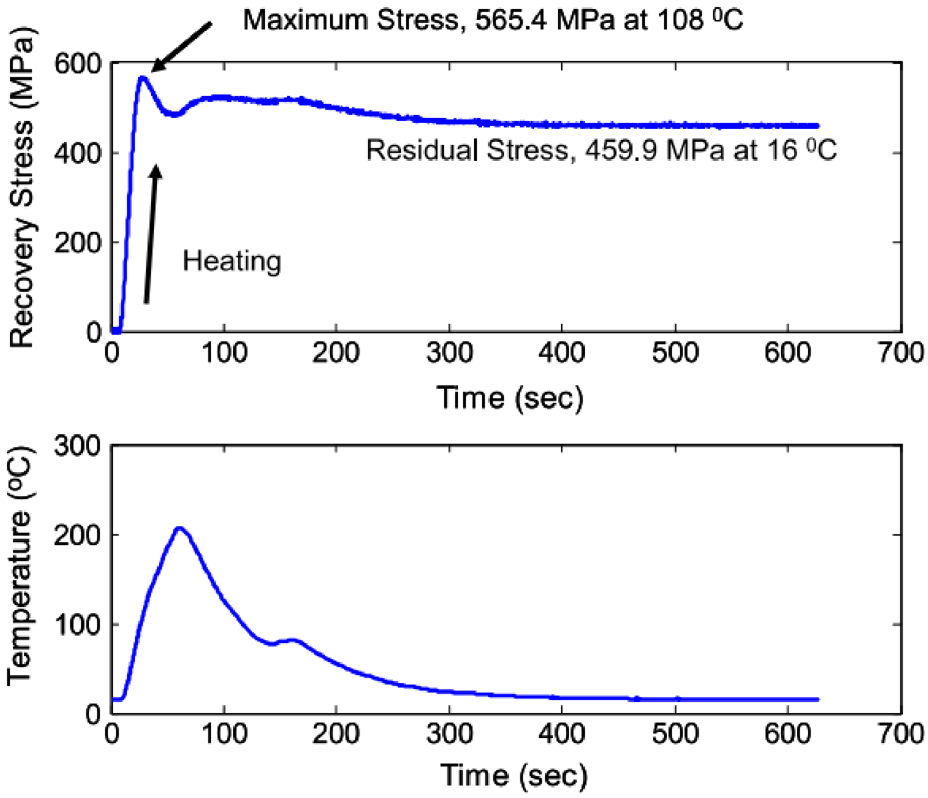

Figure 2 NiTiNb wires were subjected to thermomechanical testing, which involved a time-dependent increase in stress after recovery. Printed with Elsevier's kind permission from [10], copyright 2010.

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III. Type of SMAs

Many other SMAs have been studied over the past seven decades, from early work on AuCd and AgCd alloys in the 1930s 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 a library of SMAs with a wide range of desirable characteristics. With so many options, designers may fine-tune SMA characteristics to meet the requirements of any number of commercial uses. Primary alloying components, actuation mode (magnetic, thermal), operating temperature, and intended behaviour are only some of the many ways in which shape memory alloys may be categorised as: NiTi-Based Alloys, Copper-Based Alloys, Iron-Based Alloys, and Additional SMAs.

IV. Phase Transformation

There are three primary categories of NiTi alloys. There are 3 varieties of martensite: twinned (Mt), detwinned (Md), and untwinned (A). The two martensite types are associated with transformation at low temperatures, whereas austenite is associated with transformation at high temperatures. The mechanical properties of the various Ni and Ti configurations are different. Figure 3 shows three distinct forms of NiTi.

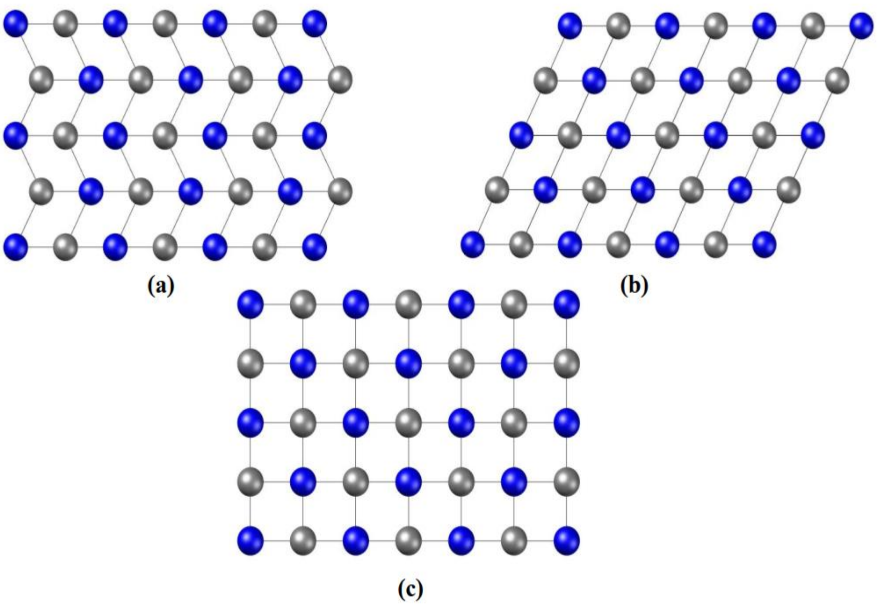

Figure 3: NiTi (SMA) Transformation Forms: (a) Twinned Martensite, (b) Detwinned Martensite, (c) Austenite.

Different types of phase changes characterise the three NiTi shape memory alloys. The first step occurs when twinned martensite transforms into detwined martensite in response to an external stimulus. Detwinning is the process that permits long plastic strains in the SMA and goes by that name. As a result of being heated past its high transition temperature, detwinned martensite undergoes a second transformation, becoming austenite. The third is when austenite is cooled to its low transition temperature and undergoes a phase change into twinned martensite. The final phase is the transformation of austenite into detwinned martensite. For this transition, strong stress is applied while the material is still above the high transformation temperature. There are four temperatures that may be used to characterise the phase transitions in a SMA material. The austenite-to-martensite phase transition occurs between these temperatures. When SMA is heated to these temperatures, the transformation from ferrite to austenite occurs

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at the austenite start temperature (As) and ends at the austenite finish temperature (Af). The transformation from austenite to martensite occurs in reverse at the martensite start temperature (Ms) and the martensite finish temperature (Mf) in SMA material. No two changes, forward or backward, follow the same path. Cooling causes the transition to occur in reverse, demonstrating hysteresis. While austenite transforms forward at higher temperatures, martensitic materials transition backward at lower temperatures, preserving the stresses introduced at higher temperatures. Thermal strain (T) is the strain attained using the forward shape memory effect. This change in opposite directions is seen in Figure 4.

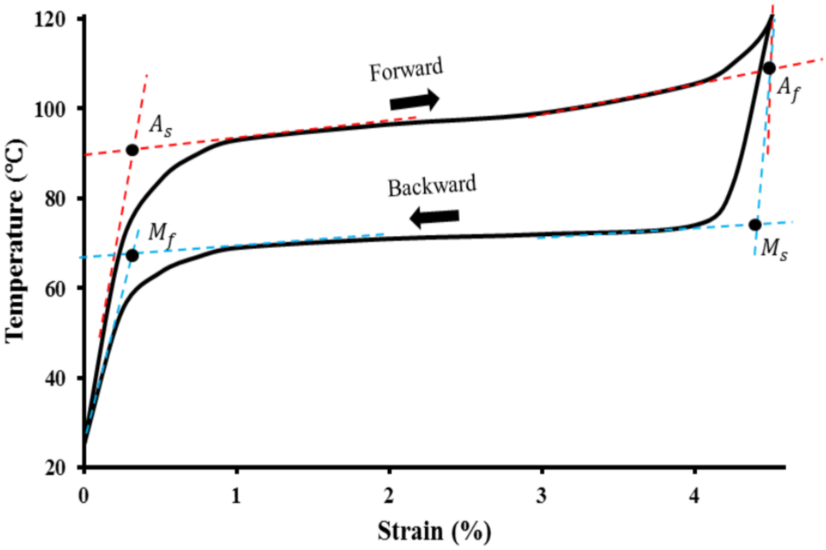

Figure 4: Forward and backward transformations of the shape memory effect

V. CONCLUSION

Using SMA in reinforced concrete columns was previously reviewed briefly to assess its impact.

- This study provides a brief overview of the fundamental characteristics of Nitinol shape memory alloys (SMA) and their uses in passive, active, and semi-active management of civil constructions. Thanks to the shape memory effect (SME), martensite Nitinol materials may be utilised as actuators, with potential further applications in active and semi-active controls of civil constructions. Active structural control may be shown in the self-repair of reinforced martensite SMAs. An example of semi-active control is the use of martensite SMA wires to actively tune the structural natural frequency, which dampens vibrations in civil engineering. Stress-strain curves for loading-unloading cycles reveal significant hysteretic effects in both martensite and superelastic SMAs, indicating energy dissipation. Using martensite and superelastic SMAs, this paves the way for the creation of passive structural damping devices. As a passive structural controller, SMA is most useful in two mechanisms: isolation and energy dissipation. The study compares the two by providing several real-world and academic instances of each. These cases also showed that passive SMA devices may be useful and practical. There has been a shift toward combining the benefits of martensite and austenite SMAs for superior structural control performance.

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