EXPERIMENTAL STUDY OF SHAPE MEMORY ALLOY IN CONCRETE

N. Rajiv Gandhi
Associate Professor, Department of Civil Engineering,
Prince Venkateshwara Padmavathy Engineering College, Ponmar, Chennai - 600127,

Abstract

Shape-memory alloys (SMA) are a class of alloys that exhibit several unique characteristics, including Young's modulus-temperature relative, shape memory effects, and high damping characteristics. In most current applications, the temperature-induced phase change typical of shape-memory alloys is used. Shape Memory Alloy (SMA) materials are widely used in different corrections and it has considerable potential for civil engineering applications. For this demonstration concrete cube of M30 grade was modelled and compressive strength was evaluated. After that 'n' number of shape memory alloy wire were reinforced in the concrete cube of grade M30. The concrete cube with SMA reinforcement and concrete cube without SMA were tested to determine compressive strength. The SMA wires were added until the compressive strength of modelled concrete cube was shows no relative increment in compressive strength. This will give us a saturation limit for addition of SMA wire to concrete cube for increasing compressive strength.

Keywords: *Shape Memory Alloys (SMA), Nickel Titanium (Ni-Ti), Concrete Cube.*

1. Introduction

Shape memory alloys are a recover from large strains through the application of heat (known as the shape memory alloy effect) or removal of stress (known as the super elastic effect). This results Young's modulus-temperature relations for several unique characteristics, including, shape memory effects, super elastic effects, high damping characteristics, and recentering capabilities. Over the past 10 to 15 years, several studies have provided a better understanding of shape memory alloys, our main objective is to develop and implement our smart content in civil structures, this sensing, monitoring, enforcement and information processes, self-adapting and structures which therapies are used for tasks like can provide. Different kinds of memory alloys, smart materials rheological fluid and electro-rheological fluid magnet size electro-rheological fluids. Now-a-days size memory alloys because of the high energy density, solid state enforcement, and high efficiency, durability, fatigue resistance, shape memory damping effect elasticity and its unique properties like got your applications in many different areas. To reduce the damage caused by the earthquake SMA offer, passive and active components, integrated with the civil structure in half. Most of the research activities in the field of their application is implemented only a few and found it effective steps are still in the lab.

2. Types of alloys

There are mainly three groups of SMA represented in joining research and development Work.

(i) Ni-Ti alloys
(ii) Cu-Al alloys and
(iii) Fe-Mn alloys

Ni-Ti shape memory effect and their large better pseudo alloys elasticity due to dominate the commercial market (Bricknell, R.H, et al, 1979). They have flexibility, fatigue, corrosion resistance, biocompatibility and recovery with better properties of stress. Other alloys because of an increase in market interest may also be of interest in the future, especially high temperature alloys with step changes existing ones represent a complementary application of SMA to temperature range expands. Due to the current report the greatest attention of Ni-Ti alloys include most of the information.

3. Properties of Nitinol [1,2-3]:

3.1 Physical properties of Nitinol

(i) Density: 6.45gms/cc
(ii) Melting Temperature: 1240-1310° C

(iii) Resistivity (hi-temp state): 82 μohm-cm
(iv) Resistivity (lo-temp state): 76 μohm-cm
(v) Thermal Conductivity: 18 W/m K
(vi) Electrical Conductivity (hi-temp state): 1.219 x 10-6 S/m [21]
(vii) Heat Capacity: 450 J/Kg* K.
(viii) Latent Heat: 5.78 cal/gm; 24.2 J/gm
(ix) Magnetic Susceptibility (hi-temp): 3.8 μemu/gm
(x) Magnetic Susceptibility (lo-temp): 2.5 μemu/gm

3.2 Mechanical properties of Nitinol:

(i) Ultimate Tensile Strength: 754 - 960 MPa or 110 -140 ksi
(ii) Typical Elongation to Fracture: 15.5 percent
(iii) Young's Modulus (austenite) = 75 - 83 GPa
(iv) Young's Modulus (martensite) = 28 – 41 GPa
(v) Typical Yield Strength (hi-temp): 560 MPa, 80 ksi
(vi) Typical Yield Strength (lo-temp): 100 MPa, 15 ksi
(vii) Approximate Elastic Modulus (hi-tem): 75 GPa,11 Mpsi
(viii) Approximate Elastic Modulus (lo-temp): 28 GPa,4 Mpsi
(ix) Poisson's Ratio: 0.33

3.3 Actuation:

(i) Energy Conversion Efficiency: 5%
(ii) Work Output: ~1 Joule/gram
(iii) Available Transformation Temperatures: -100 to +100° C

4. Shape Memory and Super Elastic Effect Memory:

When a shape memory alloy is in its martensitic form, it is easily deformed to a new shape. However, when the alloy is heated through its transformation temperatures, it reverts to austenite and recovers its previous shape with great force. This process is known as Shape Memory. The Shape Memory Alloy (SMA) occurs due to a temperature and stress dependent shift in the material's crystalline structure between two different phases, martensite (low temperature phase) and austenite (high temperature phase). The temperature, where the phase transformation occurs, is called the transformation temperature. Figure 1 is a simplified representation of material's crystalline arrangement during different phases.

In austenite phase, the structure of the material is symmetrical; each "grain" of material is a cube with right angles

a. When the alloy cools, it forms the martensite phase and collapses to a structure with different shape

b. If an external stress is applied, the alloy will yield and deform to an alternate state

c. Now, if the alloy is heated again above the transformation temperature, the austenite phase will be formed and the structure of the material returns to the original "cubic" form (a), generating force/stress

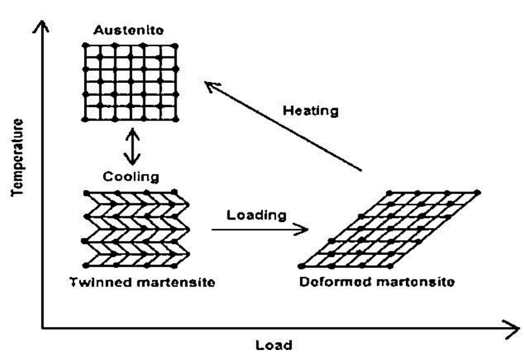


Figure 1: Crystalline arrangement of SMA in different phases (Debbarma, S. R , et al, 2012)

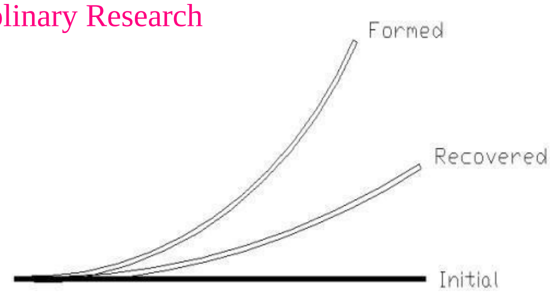


Figure 2: Demonstration of shape-memory effect

Super elasticity refers to the phenomenon that SMA can undergo a large amount of inelastic deformations and recovers their shape after unloading. On increasing the external stress without thermal actuation the phase transformation of SMA may occur from austenite to martensite which causes super elasticity or pseudo elasticity. A mechanical stress occurs in the material if this deformation recovery is restrained. This recovery stress can be used for introducing forces in concrete structures to improve its resistance towards growth of creep, shrinkage and thermal strains. Due to presence of super elasticity property the SMAs can be used in civil applications as a passive structural control, isolation device and energy dissipation devices.

The martensitic transformation possesses well defined characteristics that distinguish it among other solid-state transformations

a. It is associated with an inelastic deformation of the crystal lattice with no diffusive process involved. The phase transformation results from cooperative and collective motion of atoms over distances smaller than the lattice parameters. The absence of diffusion makes the martensitic transformation almost instantaneous.
b. Parent and product phases coexist during the phase transformation, since it is a first order transition, and as a result there exists an invariant plane, which separates the parent and product phases.
c. Transformation of a unit cell element produces a volumetric and a shear strain along well defined planes. The shear strain can be many times larger than the elastic strain of the unit cell. This transformation is crystallographic ally reversible.
d. The martensitic phase has lower symmetry than that of the parent austenitic phase; several variants of martensite can be formed from the same parent phase crystal.
e. Stress and temperature have a large influence on the martensitic transformation. Transformation takes place when the free energy difference between the two phases reaches a critical value.

5. Phase Transformations

The structure of the SMA to a certain temperature depends on the level of internal energy; Crystal structure to accommodate the minimum energy State. Driven by external force, two crystal phases can be changes. The driving force for two steps step change, which either temperature gradient or mechanical loading can be provided by the Gibbs free energy is the difference between. Thermo mechanical point of view, the same temperature and external stress change mechanisms come into play. There are two different types of martensite changes:

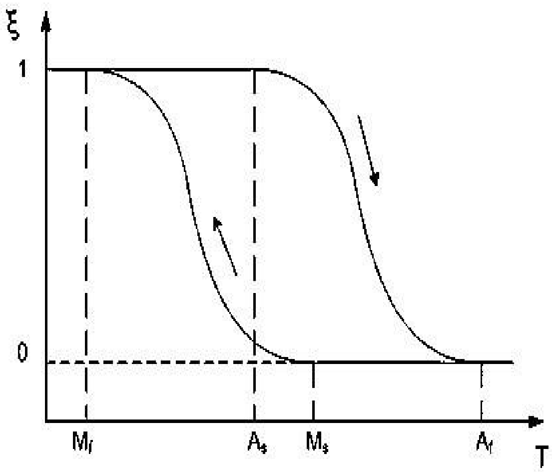
a. Temperature-induced transformations which causes the shape memory effect
b. Stress – induced transformations which results in the super elasticity

A typical stress-free temperature-induced martensitic transformation and its inverse transformation is shown in figure1 under temperature excitation cycle. It has four different transition temperatures that characterize the transformation loop:

a. Martensite start temperature (Ms)
b. Martensite finish temperature (M_f)
c. Austenite start temperature (As)

Unlike many SMA material models, the stress values where the martensite and austenite start and finish their respective phase transformations are not directly specified. Rather, they are evaluated on the stress-temperature diagram on a per temperature basis.

Table 1: Table of properties for the SMA material model (Porter, David A, et al,



A	70 GPa
Elastic stiffness of martensite E^M	30 GPa
Poisson's ratio υ	0.33
Coefficient of thermal expansion for austenite α^A	22 x 10^{-6} K^{-1}
Coefficient of thermal expansion for martensite α^M	22 x 10^{-6} K^{-1}
Martensitic start temperature M^{0s}	291 K
Martensitic finish temperature M^{0f}	271 K
Austenitic start temperature A^{0s}	295 K
Austenitic finish temperature A^{0f}	315 K
Maximum transformation strain H	0.05
Stress influence coefficient for austenite $\rho\Delta s^A$	
Stress influence coefficient for martensite $\rho\Delta s^M$	-0.35 MPa K^-

7. Use of SMA (annealing) for application in concrete

Use of shape memory alloy in concrete structure is for the following applications-

- **a.** Passive vibration damping and energy dissipation system
- **b.** Active vibration control system
- **c.** Actuator applications
- **d.** shape memory effect for tensioning applications
- **e.** Hybrid Composites of shape memory alloys and plastics
- **f.** Sensors

In these applications use of SMA is playing important role as tensioning memberwhen used in concrete. Over annealing causes the Oxidization of thickness of these wires. In such condition use of SMA as tension taking member will not significant effective.

8. Compressive strength without SMA wire

The dimensions of the specimen were 150 mm x 150 mm x 150 mm. The compressive strength of normal concrete was found to be 31.9 MPa without SMA wire. The Figure.4 shows COMSOL model of the cube specimen.

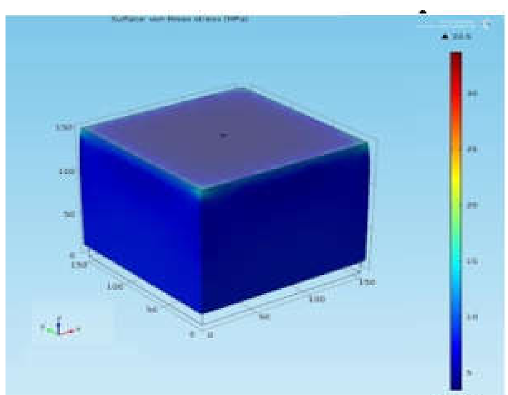


Figure 5: Compressive strength with One SMA rope.

Figure 5 shows one specimen with each rope having seven wires of 0.102 mm diameter. SMA wires with 90^0C transformation temperature were done. Only one SMA rope was installed at the centre of the Cube to increase the compressive Strength which amounted to 33.6 MPa which was greater than the compressive strength of the normal concrete specimen.

9. Optimisation of SMA rope

The compressive strength of the cube specimen increased with the increase in the number of SMA ropes till three ropes after which the compressive does not increased further. Table 2 shows the details of the testing of the cube specimens. The force applied was kept same throughout the testing

Table.2 Optimisation of SMA rope

S .NO.	Force (KN)	No of SMA rope 1 rope = 7 SMA wire	Compressive strength (MPA)
1	680	No rope	31.90
2	680	1	33.60
3	680	2	36.40
4	680	3	38.20
5	680	4	38.20
6	680	5	38.15

10. Relation between Compressive Strength and No of SMA wire

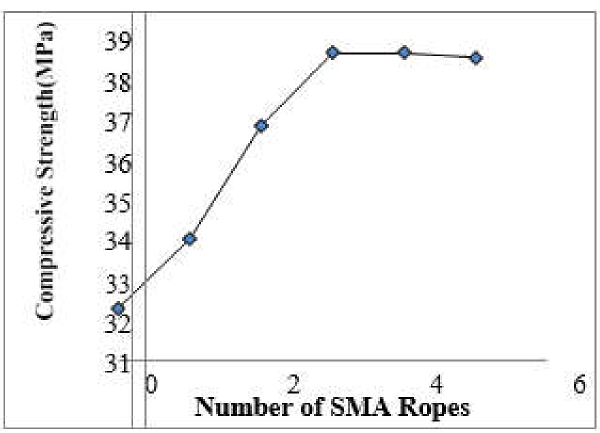


Figure 9: Relation between Compressive Strength and No of SMA wire Figure.9 shows the graphical representation of increase in the compressive strength of cube specimen with the increase in the number of SMA ropes which becomes constant at four numbers of SMA ropes.

11. Conclusion

In this current work application of Shape Memory alloy for the strengthening of concrete cube is demonstrated. For this demonstration concrete cube of M30 grade was modelled and compressive strength was evaluated. After that 'n' number of shape memory alloy wire were reinforced in the concrete cube of grade M30. The concrete cube with SMA reinforcement and concrete cube without SMA were tested to determine compressive strength. These compressive strengths were compared on the basis of number of wire ropes in the cube. The compressive strength of SMA reinforced concrete cube was found greater than of M30 normal concrete cube. The SMA wires were added until the compressive strength of prepared concrete cube was shows no relative increment in compressive strength. After the application of the 3 SMA wires it was observed that the compressive strength of the Cube was became stagnant. Application of 5 the SMA wire was resulted in terms of the minor decreases in compressive strength. It is observed from that after the certain limit SMA is not contributing in the compressive strength. This is due to that it can accommodate 10 % to 25 % of load. In this Experimental condition it is about 16 % of the original compressive strength. This is due to limit of the condition of the 'plateau region' of the SMA. This will give us a saturation limit for addition of SMA wire to concrete cube for increasing compressive strength.

References

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