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Technical Analysis of Smart Material Structures and their Applications in Civil Engineering

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ABSTRACT

Due to the continuous development in the field of innovative materials, the smart material and structures can be used as a new tool in architectural industry. A conventional architectural structure is designed to function under pre-assumed forces and loads (pressure) and thus it can't develop itself an ability to control unexpected forces and loads.

The designs using smart materials are inspired with nature to mimic human i.e. a material with capability of sensing and responding with the change in environment .The aim of research in the field of smart material structures is to make a system to mimic living organism with actuators and sensors. These materials have numerous applications in the field of civil engineering e.g. SMA (shape memory alloys) with super elastic properties (inspired with the concept of elasticity),can provide a control over the shape of the structure with changing crystalline structure via a change in temperature.

1.Introduction:

A system having capability to sense and respond in a predetermined manner and in controlled fashion with some external stimuli in a short time and can revert to its original state as soon as the external stimuli removed.

A smart structural system is designed so that it can detect damages and can control the response from any external disturbance (seismic).During an earthquake, the damages often suffered by any multi-storey building, are usually shearing, bending, sliding and overturning damages that occur in concrete shear wall.

For the material and design research we consider three kinds of materials:

1.1. Smart Materials: Materials which are able to sense and respond to different situations; having one or more properties that can be significantly changed in a controlled fashion by external stimuli, such as moisture, electric, pressure, temperature, etc. (e.g. shape memory alloys SMAs, piezoelectric materials, temperature sensitive polymers, etc.).In totality, Smart Materials are able to change their shape, size or color in response to external stimuli.

1.2. Advanced Materials: Materials having superior properties such as advanced metals, alloys, ceramics, composites, plastics etc. covering the materials for advanced manufacturing, such as Electrorheological Fluids (ERFs) for haptic feedback and multi-material 3D printing

1.3. Environmentally Sensitive Materials: These are made up with environmentally sensitive substitutes derived from petroleum (e.g. materials made of waste, mycelium-based materials, natural fibre composites, bio-plastics, etc.).

Focusing on design, we try to investigate whether the developed smart structure is capable of holding all the necessary parameters required to be a smart design.

To create an adaptive structural system to environmental changes, we must be able to detect such changes through sensor technology based on the ability of materials to convert mechanical motion into electrical signals to some degree of correctness. These sensors can be piezoelectric accelerometers or a foil type strain transducers or an optical fiber sensor. When dealing with signal producing sensors, it is important to isolate and clean up signals for more accurate signal interpretations.

Traditionally, the Piezoelectric Materials are used in strain sensors, emitters and receptors of stress waves, actuators and pressure transducers. However the

Piezoelectric Materials and structures have been employed increasingly in vibration dampers and in controlling stationary or moving structures (in helicopter blades).When we apply Compressive and Tensile Stresses along the direction of polarization of material, it will generate an electric field (having opposite voltage polarity) and hence material will expand and contract with the applied fields as sown in the following figure.

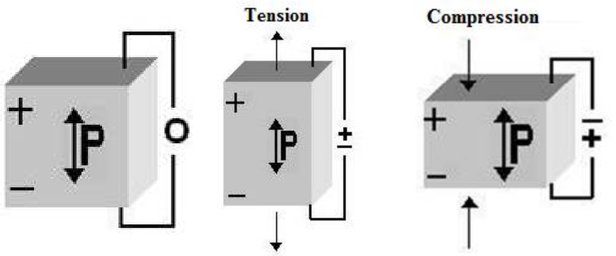


Fig.1(a) **Fig.1(b)** **Fig.1(c)**

The expansion and compression of the specimen under the application of the field is shown in following figure-

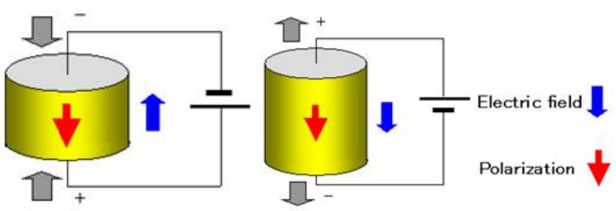
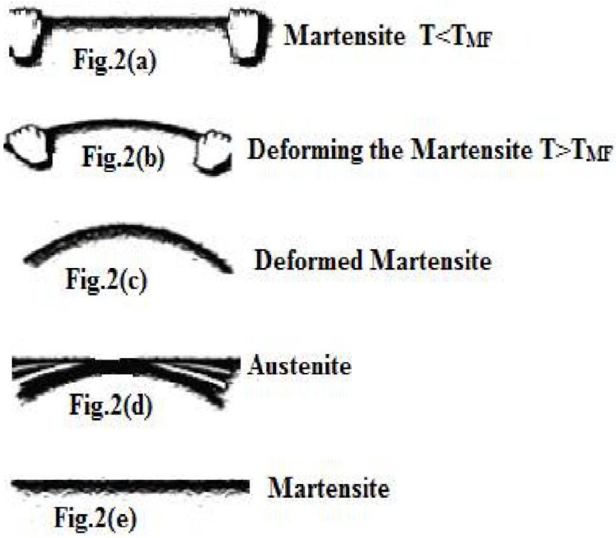


Fig.1(d) Shrinking **Fig.1(e) Expansion**

The shape memory alloys (SMAs) are basically metallic alloys that can be deformed and reformed to their original shapes when heated above their transformation temperature .They can recover their initial shape after the end of the deformation process e.g. NITINOL (the first developed SMA) an alloy of nickel and Titanium. Nowadays SMAs are produced by the combinations of Copper and Zinc. The Shape Memory Alloys are used in joint, screws for underwater construction (to avoid underwater welding).These materials can undergo large strains (8%-10% approx.) without any permanent deformation left in the material.

The main feature of the SMA is the shape memory effect when the material is in martensite form (a hard and very brittle solid solution of carbon in iron which is the main constituent of hardened steel) as figured below-

Shape Memory Effects



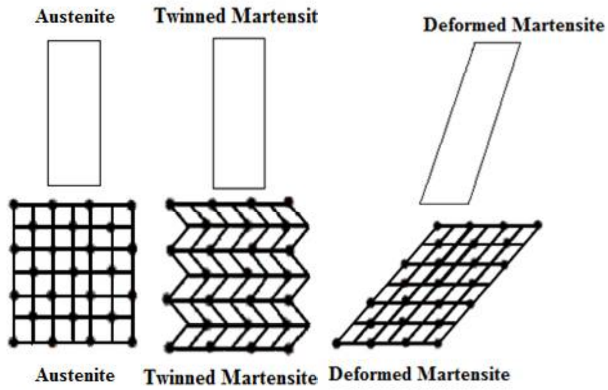


Fig.3(a) Fig.3(b) Fig.3(c)

2. Effect of Temperature in Austenite and Martensite state:

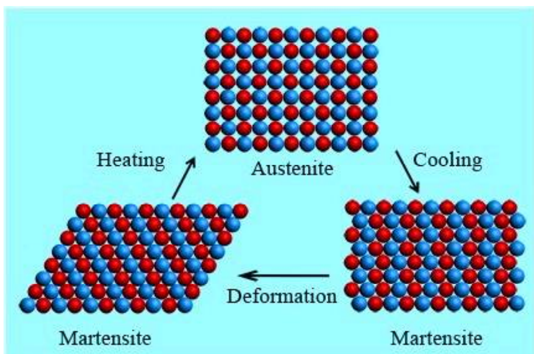


Fig.(4)

3.Transformation Temperatures of NITINOL (a Shape Memory Alloy): We have to consider following four types of transformation temperatures-

3.1._Martensite Start Temperature (Ms): It is the temperature at which a transformation from austenite state to martensite state begins on cooling.

3.2. Martensite finish temperature (Mf): It is the temperature at which the transformation from austenite state to martensite state finishes on cooling.

3.3. Austenite start temperature (As): It is the temperature at which the transformation from martensite state to austenite state begins on heating.

3.4. Austenite finish temperature (Af): It is the temperature at which the transformation from martensite state to austenite state finishes on heating.

All these transformation temperatures are plotted the following graph in fig.5.

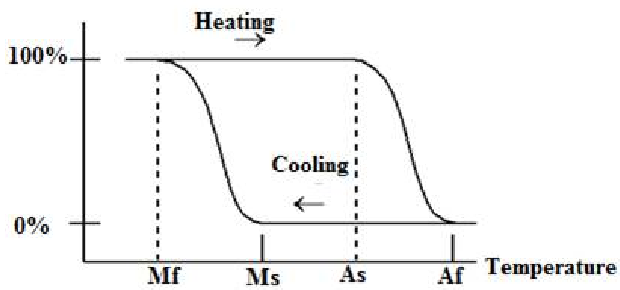


Fig.5

4.Measurement of Transformation Temperatures:

To determine the transformation temperatures for NITINOL shape memory alloy, Differential Scanning Calorimetry (DSC) is done by measuring the heat flow between environment and the NITINOL, as a function of temperature.

To trace the shape recovery of the specimen as a function of temperature (i.e. for the measurement of active transformation temperatures), BFR (Bend and Free Recovery) test can be done.

The transformation temperatures for fastener or actuator applications are measured by performing Constant Load Dilatometry (CLD) process that evaluate the effects of applied stress on the transformation.

5. Factors influencing the transformation temperatures:

The transformation temperatures and the material's mechanical characteristics together depend upon the composition of the material and the amount of heat and cold-work performed with external stress parameters. In fully annealed condition, the intrinsic alloy transformation temperature depict the transformation temperature of the specimen i.e. it characterizes the transformation of the specimen at the final product level.

6. Proposed Analytical Models of Shear Walls (SMAs):

In following figures, we are going to illustrate the seismic performance of two concrete wall (shear) structures with super elastic SMA.

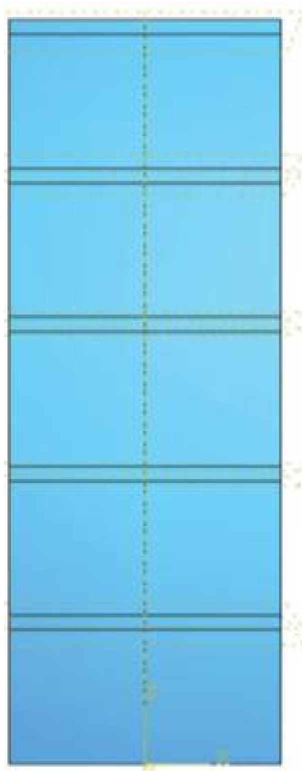


Fig.6.(a) Ordinary Shear wall without openings

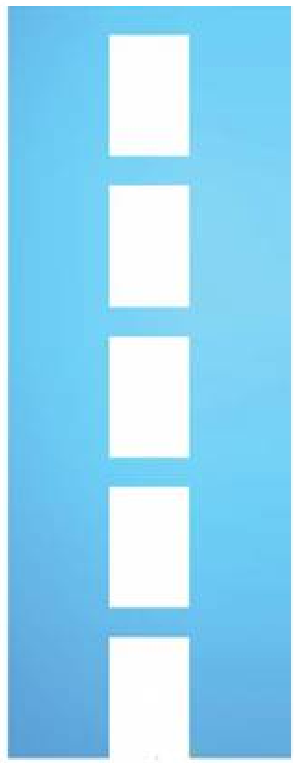


Fig.6.(b) Model for the coupled shear wall

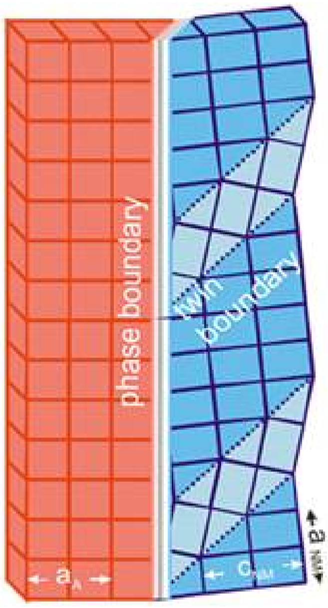


Fig. 7(a)

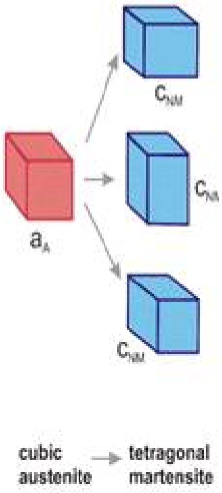


Fig. 7(b)

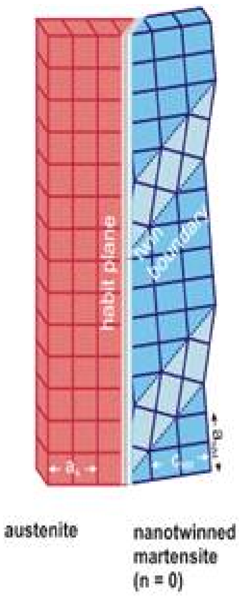


Fig. 7(c)

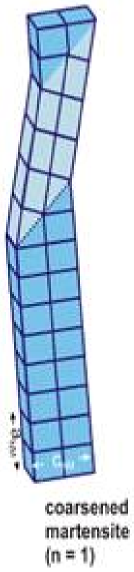


Fig. 7(d)

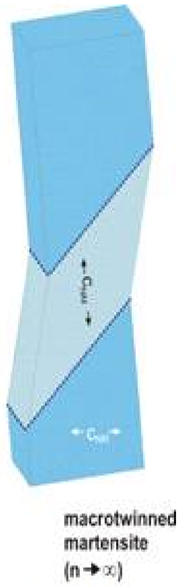


Fig. 7(e)

To understand the dynamic behavior of these shear walls, have a look on the following figure.7.

SMAs have been also employed for constructing seismic isolation cable stayed bridges (Fig.8.) as shown as follow-

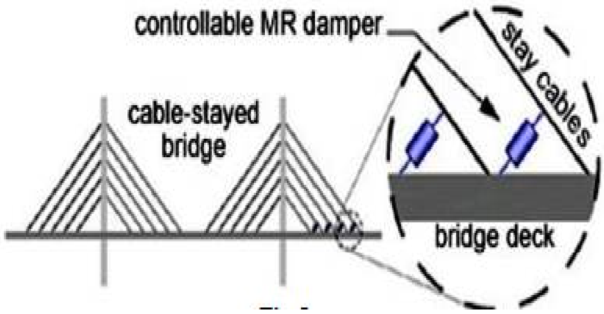


Fig. 8

7. Conclusion:

In this paper an analytical study is done to evaluate the effectiveness of smart materials (SMAs and Piezoelectric) in civil engineering structures namely seismic isolated concrete shear walls .Using computer modeled reference ABAQUS, two types of walls , one is ordinary and other is coupled shear wall , are introduced. Also the dynamic response in case of earthquake excitations is investigated. Instead of steel bars, the super elastic SMA materials have caused a remarkable reduction in reduction in residual displacement. Different SMA combination with steel reinforcement is modeled in both reference structures.

8._References:

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