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REVIEW : SMA POTENTIAL AND LIMITATIONS IN CONSTRUCTION

[1] Pradeepa S, [1]Anitha J, [2] Dr. Shivanna S, [2] Dr. Ravi Kumar H

[1]Assistant Professor ,Department of Civil Engineering Sir. M. Visvesvaraya Institute of Technology, Hunasamaranahalli, Bangalore, India

[2]Associate Professor ,Department of Civil Engineering Sir. M. Visvesvaraya Institute of Technology, Hunasamaranahalli, Bangalore, India

Abstract : Shape Memory Alloy, smart material has made a significant impact in various fields especially in construction. Shape memory alloy (smart metal memory alloy) is a material which when deformed, regains its original shape. The most commonly used shape memory alloy (SMA) is nickel- titanium alloy, commonly known as Nitinol. These SMA are used presently in robotics and automotive, biomedical (fororthopedic surgery) and aerospace industries. SMA wires find numerous applications in civil engineering structures. Here, one such application of SMA in concrete members, for controlling of cracks developed or developing cracks is discussed. This review talks about intelligent reinforced concrete and its applications in civil engineering. SMA can be introduced, to reduce cracks in two ways, either externally or internally. SMA wires clubbed together as cables, is reinforced in concrete by the method of post tensioning. Thus, providing an efficient, rapid and convenient approach for repair and strengthening of damaged structures. It is only a matter of time and SMA will emerge as an essential material in construction industry. Thus, this review focuses on the potential and limitations of SMA in construction.

***IndexTerms* – Shape memory alloy, post tensioning, titanium alloy**

I. INTRODUCTION

Design of concrete structure must satisfy the requirement of strength and durability. A structural material characterized by low tensile strength is concrete, which is widely used. Reinforced concrete forms structural members in which cracks are unavoidable, having high effect on the durability and mechanical properties of the element. To overcome damages, cracks and for ensuring the durability of the structure, the introduction of new material is required for structure to improve in terms of safety. Hence, researches have been done in recent years for the development of smart concrete. In particular, a smart material Shape Memory Alloy (SMA) has been introduced. As SMA is highly expensive its usage is being limited, production and processing of SMA is being investigated to make it cost efficient. Because of its unique characteristics it has applications innumerous fields. One of the characteristic, Shape Memory Effect (SME) is a property of SMA to regain its initial shape by heating until they arrive at their phase conversion temperature. Another property of SMA is Super Elasticity (SE), which recovers comparatively large strain upon unloading. SMA is implanted in structural members to suppress the flexural damage. Crack healing by SMA in buildings and infrastructure are being reviewed in thispaper.

II . MATERIAL PHENOMENON AND MECHANISM

SMA can exists in two different phases as Martensite which is a low temperature phase and Austenite is a high temperature phase which are stable. The stability ofaustenite phase is due to its symmetric structure. Martensite occurs as a trapezoidalstructure where in austenite as a cubic crystalline structure. The memory metal in austenite phase "remembers" the shape it had, before the deformation. Temperature and stress are the only factor influencing thephase transformation and it is irrespective of time. At the low temperature in martensite phase SMA can be deformed into any shape and on application of heat it comes to austenite form (i.e. initial phase). Large elongation can be experienced by Martensite SMA during this process through recoverable plastic deformationsand absorbing energy.

Shape memory alloy is characterized by 4 distinct transformation temperatures in stress free state. Those are Martensite Start (M_s), Martensite finish (M_f), Austenite Start(A_s), Austenite finish (A_f) as shown in (figure 1). If temperature is less than M_f then it is in Martensite phase and when thetemperature is less than A_f then it is inAustenite phase. Both the phases together exist between the temperatures A_s & A_f andM_s & M_f during phase transformation.

Shape memory alloy exhibits different shape memory effects. One way and Two way shape memory are the two common effects. In cold state in one way memory effect, the SMA can be bent in any shape and until heated above the transition temperature the shape remains same. WhenSMA is at high temperature and is cooled with one way effect, macroscopic shape change does not occur. To obtain low temperature shape a deformation is essential. Transformation starts at A_s and finishes at A_f on heating. A_s is determined by composition and type of alloy (figure 2).The effect of SMA to remember two different shapes (one at high temperature, one at low temperature) is two way memoryeffect. Two way shape memory is depictedby the material when it shows shape memory effect during both cooling and heating, which can also be obtained withoutapplying any external force (figure 3). A shape memory alloy "remembers" its low temperature shape, immediately it "forgets"the low temperature shape to recover the high temperature shape upon heating under normal conditions. One way shape memoryeffect after some processes such as cooling cycles, constrained heating, ageing and by heating it several times two way shape memory effect is generated.

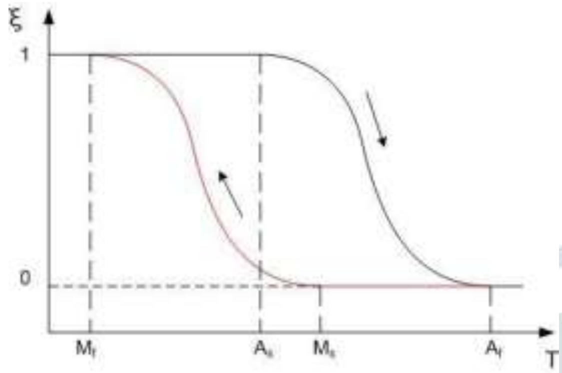

Figure: 1

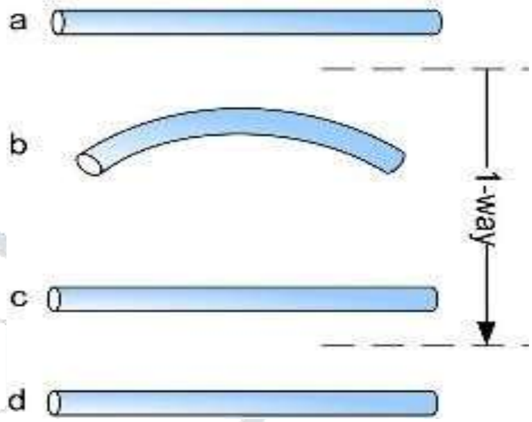

Figure: 2

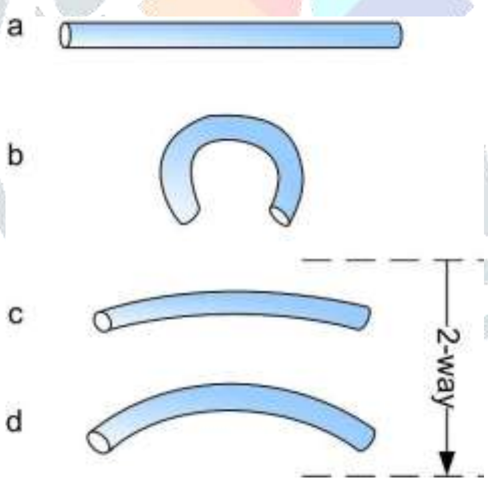

Figure: 3

There are mainly two types of SMA, copper–aluminium-nickel and nickel- titanium (NiTi). Because of its large strain,stability, practicability NiTi is moreappropriate in structural application in-spiteof being costly. But SMA's can also be created by alloying zinc, copper, gold and iron.

SMA can be used for crack healing as theycan create their own contractions and can close the cracks. Using SMA cables estimation of crack width can be carried out. By the method of post tensioning, martensite nitinol cables are reinforced in proposed concrete structures. The concretedamping property and ability to handle the cracks is highly increased by martensitenitinol.

III OUTCOMES

There have been many research and studies being done on the application of SMA in Civil Engineering. Structural passive control is being mainly focused. Thevarious researches and theory works arebeing discussed in this paper.

IV. REPAIR OF CRACKED REGION ON HIGHWAY BRIDGE OF MICHIGAN

The first field implementation using shape memory effect for post-tensioning of concrete structure was done in Michigan on Highway Bridge. It had suffered with cracks which were formed due to insufficient shear resistance. In order to strengthen the bridge girder, a harp likeiron-manganese-silicon-chromium shapememory alloy rods whose diameter was10.4mm were mounted crossing the both faces of the web. Each rod was being heatedto achieve 300^0C by passing electrical power of 1000 ampere current, resulted in crack width reduction by 40%.

Lesson learnt from this was that thebehavior of the shape memory alloy is to beexamined under different working temperatures and if the purpose is to close the cracks in the structure by applying force conventional hydraulic jacks can be used insite for completing work easily. [1, 2]

V. FIBRE REINFORCED CONCRETE BASED MATERIAL

In the study done by Bergamini A, Moser K, Christen R and Czaderski C, shape memory alloy wires which been shaped by inelastic elongations as loops and star shaped fibers as they show the feasibility of pre-stressed fiber reinforced concrete are embedded in mortar. To optimize the scaleproduction process and to reduce the loss inpre-stressing due to fiber anchorage length, the shape of fibers are chosen when the mortar gets hardened, to activate the tensilestresses in the fibers, the specimens were heated up there by causing a pre-stress of the surrounding mortar. The effect was monitored by the length measurement bothon specimens with and without fibers. Compressive strengths were estimated and around 6Mpa was reached in experiment. Finally concluded that in practical application development of efficient methods of production of fiber mortars of shape memory alloy mostly based on iron having suitable temperature domains of austenitic and martensitic phase transformations is required. The practical application of such internally pre-stressed cement based material is visualized in repairing mortars, in which shrinking induced cracks are formed due to difference in hygro thermal histories of freshly applied mortar layer and pre-existing under layer. This problem can be overcome by application of compressive stress to the matrix. This approach will lead to meet theneed for crack free rebar cover to the rehabilitation of reinforced concrete structures. [2]

VI. THREE POINT BENDING TEST

It's been carried out by Daghia et al. to study the behavior of SMA when subjectedto three point bending test. There are three phases in this experiment. In 1st phase loading is done till cracks are observed on the beam. Beam is unloaded in 2nd phase. By Joule Effect SMA actuators are heated up in 3rd phase. At this phase cracks closureand reduction of residual beam deflections are observed. [3,]

VII APPLICATIONS OF SMA IN CIVILENGINEERING

Passive control of structures using SMA mainly concentrates on the application of various dampers. For the improvement of the quality of the structure some researchesare being done using Super Elastic propertyof SMA. Due to which structure is made highly resistive to the external load and has the self-repairing capability. KuangYachuan Ou Jinping developed a smart concrete beam which has self-damagerepair function, which minimizes the effect of typhoon, earthquake and ensure safety using Super-elastic characteristics of SMA resulting in closure of cracks, quick recovery when external force is removed.

For self-sensing and repairing bolted joints,Park et al. used piezoelectric and SMA elements. Lost torque can automatically regained by SMA washers when there is a damage. Thus allowing the operation to be continued by the structure. In bolted joints, clamping force actuators made up of compressed SMA rings are used by Hesse et al. In case of any cracks, rings are heated between A_s and A_f temperatures to close the cracks by increasing rings axial dimension.

VIII LIMITATIONS OF SMA

Due to high cost, difficulty in production and processing technology of SMA its use limited. Because of these problems SMA elements of small size are used for most of the research works so far. Welding of SMA with dissimilar materials hinders the development of SMA. Machining of SMA is difficult and processing technology is notup to mark resulting in limited usage of SMA. Scope of work of SMA is limited dueto special nature of temperature and power supply required for SME

XI CONCLUSION

This paper presents the review of basic properties of Shape Memory Alloy, mechanism and their applications in civil engineering field. Outcomes of several experiments were been reviewed. Because of aging and decay the civil engineering

Structures need monitoring and repairingregularly. So infrastructure management became common crisis. If the structure can adapt to variation in loading conditions andis good enough to detect its own damages, many difficulties can be reduced. So SMA can be introduced in construction to greaterextent. In present scenario, society is readyto spend money on structures which are safe irrespective of cost. So by implementing SMA in construction, safety factor of structure can be increased to an extent which society might accept.

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