ANALYTICAL INVESTIGATIONS ON RC BEAMS STRENGTHENED WITH NEAR SURFACE MOUNTED IRON BASED SHAPE MEMORY ALLOY STRIPS

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ABSTRACT

Structural member strengthening has been an essential requirement in construction industry. Iron based shape memory alloys got widespread attention as a strengthening material for RC beams. Shape memory alloys are that materials which remembers and return to its original shape when heated above certain temperature. When the return of the material to its initial position is restrained, it will produce some recovery stress and this stress can be transferred to connected concrete which act as prestress in the body. Extensive literature review was carried out to understand the state of art of RC beams strengthened with near surface mounted iron based shape memory alloys. Near surface mounting (NSM) technique was used to connect shape memory alloy strips to RC beam. This paper deals with finite element analysis of RC beams strengthened with near surface mounted iron based shape memory alloys.

KEY WORDS: RC beams; shape memory alloy; near surface mounted; strengthening; ANSYS WORKBENCH

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1. INTRODUCTION

RC structures should be strengthened during certain situations such as for increasing load capacity, for removing cracks, for modifying existing facilities etc. Strengthening of existing structures is always a challenge for engineers. Different strengthening techniques used are introducing extra supports to shorten span, applying internal or external prestressing, bonding external steel plates, using advanced composite materials etc. using of composite material as strengthening material has more advantages over other techniques and is used the most. Fiber reinforced polymer (FRP) is the most used composite material. FRP have certain problems such as its brittleness and problems in prestressing.

A lot of researches were going on in this field. A new material iron based shape memory was developed recently. Shape memory alloys are materials that return to its initial position when the material is heated. Initially there existed a shape memory alloy which was nickel titanium shape memory alloy (NiTi SMA). Its material cost was so high that it cannot be used widely in construction industry. But after invention of iron based shape memory alloy (FeSMA). Few experiments were conducted on RC beams strengthened with iron based shape memory alloys.

Moslem Shahverdi [18] established experimental program to investigate the flexural behavior of reinforced concrete (RC) beams that were strengthened and prestressed with Fe-SMA strips. total of six RC beams were experimentally examined under deflection control in a four-point bending loading rig. The experiments consisted of one beam strengthened by Fe-SMA strips but not prestressed, three beams strengthened by prestressed Fe-SMA strips, and one beam strengthened by one CFRP strip. Experimental results showed that the application of near surface mounted Fe-SMA strips worked well as prestressing elements in concrete beam.

HothifaRojob and Raafat El-Hacha [3] studied the behavior of reinforced concrete beams strengthened with near surface-mounted (NSM) iron-based shape memory alloy. The prestrained Fe-SMA bar was anchored inside a precut groove at the tension side of the RC beam (2000 x 305 x 150 mm [78.7 x 12.0 x 5.9 in.]). The bar was then activated through heating above 300ºC (572ºF), causing a prestressing force in the bar. The beam was then tested under four-point bending setup to failure. The results revealed a significant increase in the yielding and ultimate load capacities. Unlike the prestressed FRP strengthening techniques, the ductility of the beam was significantly improved due to the yielding nature of the Fe-SMA material.

Raafat El-Hacha and Hothifa Rojob [7] introduced a new anchorage system for fixing the FE-SMA bars to the tension side of a beam. And compared its behavior with normal anchorage systems. The anchorage mechanism maintained good contact at the anchor locations through the flexural test, where no failure or cracks were noticed at these anchorage locations.

Julien Michelsetal [10] presents the applications of Fe-SMA strips as an external end-anchored and Unbonded prestressing system for structural retrofitting. The strips were prestrained to 2%. The activation of the strips is performed by resistive heating up to a target temperature Results indicated that Fe-SMA strips are prestressed and the structure was under compression stress over its height. Static bending tests showed increased cracking loads compared to a reference beam as well as to a beam with a slag applied CFRP strip.

Hothifa Rojob, Raafat El-Hacha [3] investigated the long-term performance of RC beams strengthened with NSM Fe-SMA bars and exposed to severe freeze–thaw cycles and sustained loading. Beams were divided in to two groups with two beams in each group. The results revealed that the strengthened beam was superior in flexural performance compared to the un-strengthened beam, and there was minimal degradation compared to other beams tested at room temperature.

HothifaRojob, Raafat El-Hacha [5] conducted an experimental programme to investigate the performance of large-scale reinforced concrete beams strengthened with near-surface-mounted iron-based shape-memory alloy strips.The results revealed the effectiveness of the strengthening technique in enhancing the flexural performance of the strengthened beams at service and ultimate load conditions.they compared the results with fibre reinforced polymer-strengthened beams and found out that strengthening using iron based shape memory alloys are better in maintaining the ductile behavior of the strengthened beams.

Kinam Hong etal [12] investigated the flexural behavior of the RC beam strengthened by the NSM technique with the Fe-SMA strip. A total of seven RC beams were tested by four-point bending tests under displacement control. The type of reinforcements, the quantity of Fe-SMA strips, and the pre-straining level of the Fe-SMA strips were considered as experimental variables. Cracking load, yielding load, and ultimate load increased, respectively, with larger quantities of Fe-SMA strip. The results show that the strengthening technique using the recovery stress of the Fe-SMA strip as the prestressing force solves the various problems of the existing prestressing strengthening systems, meaning that Fe-SMA can be used as a substitute for FRP strengthened beams.

HothifaRojob, Raafat El-Hacha [4] investigated experimentally the behavior of RC beams strengthened with self-prestressed NSM Iron-Based Shape Memory Alloy (Fe-SMA)bars under fatigue loading. Four beams were tested with two types of loading static and fatigue loadings, and beams were casted as strengthened with NSM Fe-SMA bars and un-strengthened beam. During fatigue loading, the beam strengthened with NSM Fe-SMA performs much better than the control beam at relatively low levels of fatigue loading.

Near surface mounted (NSM) technique is used for bonding the FeSMA to concrete. It includes cutting groove on the tension side of RC beam. FeSMA strips are inserted in this groove and connected to concrete through high strength cement mortar. For further investigations on RC beams strengthened with near surface mounted iron based shape memory alloys, finite element analysis can be done and it can reduce the cost and time required for experimental setup. This paper attempts to stimulate numerical analysis of RC beams strengthened with near surface mounted iron based shape memory alloys by modeling and validating the experimental work done by Kinam Hong etal, in ANSYS WORKBENCH

2. IRON BASED SHAPE MEMORY ALLOYS

Shape memory alloys are materials which return to its initial position when heated to certain temperature. There exist two crystallographic structures for thermally responsive SMA. They are high temperature high symmetric phase called Austenite (A) and low temperature low symmetric phase called Martensite. Phase transformation from one phase to other is called martensitic transformation. Recovery stresses are developed in the material if the material is restrained completely from returning to austenite phase on heating.

Iron based shape memory alloys offer huge applications in civil engineering field. Their high elastic stiffness and strength, wide range of transformation hysteresis and inexpensive for production made them capable as strengthening material. Recently iron based shape memory alloys with finely dispersed VC particles are developed which can produce large recovery stress when it's heated to just 130^{o} c. iron based shape memory alloys are based on Fe-Mn-Si alloy system.

3. MODELING OF BEAM

3.1 Introduction

Experimental setup by KINAM HONG Etal [12] is modeled as such in Workbench. The RC beam is of dimensions 3000X300X200 mm. four point loading is done. The beam is supported on roller supports. The finite element model of experimental setup is shown in figure 1.

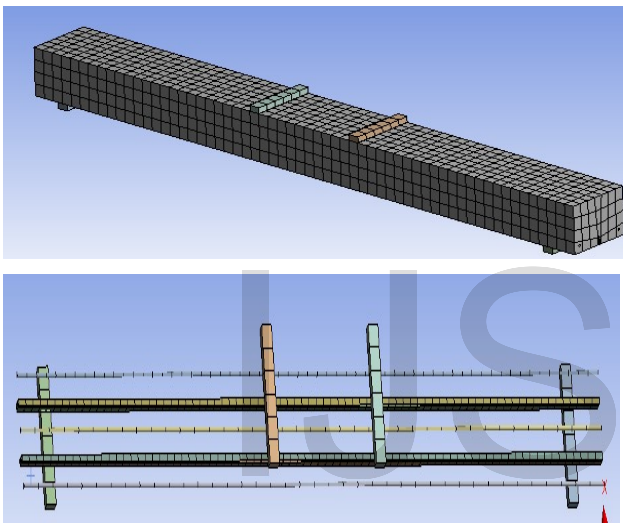

Fig 1 finite element model of test setup

Total of five beams were modeled and used for validation. One normal RC beam (control beam) and four beams strengthened with FeSMA at bottom by near surface mounted method. Of the four strengthened models, two different cross sectional areas for strengthening material are used. 30mm^2 and 60mm^2.30mm^2 strip was prestrained by 4% and 60mm^2 were prestrained by 0%,2% and4%.

Material properties are as follows

Concrete

Compressive strength	30 MPa
Young's modulus E	27386 MPa
Poisons ratio	.18

Steel

Modulus of elasticity	210000 MPa
Poisons ratio	0.3
Yield strength	480 MPa

Iron based shape memory alloy

Young's modulus	133000 MPa
Poisons ratio	0.33
Tensile yield strength	463 MPa
Ultimate yield strength	863 MPa

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4. ANALYSIS RESULTS

Model details are given below

Table 1 model details

Sl no	Name	Cross section area of strengthening material mm^2	Amount of prestrain %
1	SL-STRL	_	_
2	SL-30S-4	30	4
3	SL-60S-0	60	0
4	SL-60S-2	60	2
5	SL-60S-4	60	4

4.1 RESULTS

4.1.1 SL-CTRL

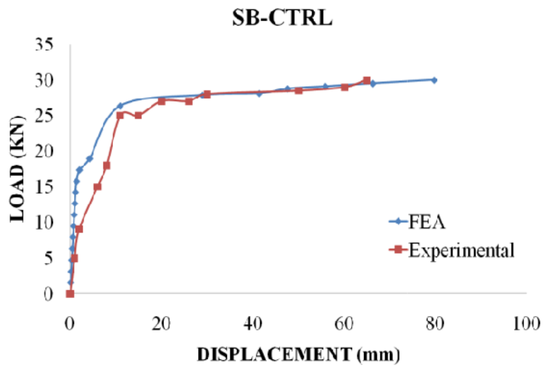

Fig 2 load displacement graph of model 1

4.1.2 SL-30S-4

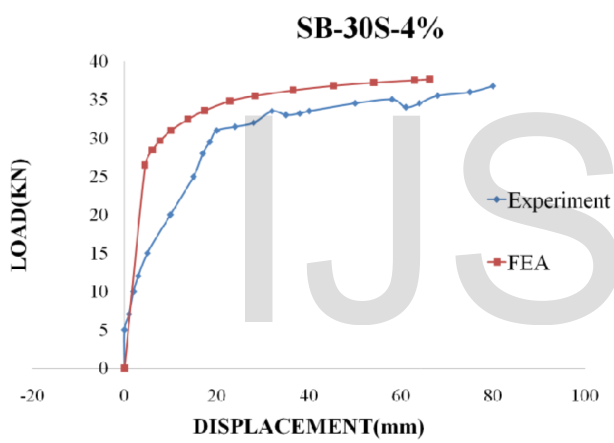

Fig 3 load displacement graph of model 2

4.1.3 SL-60S-0

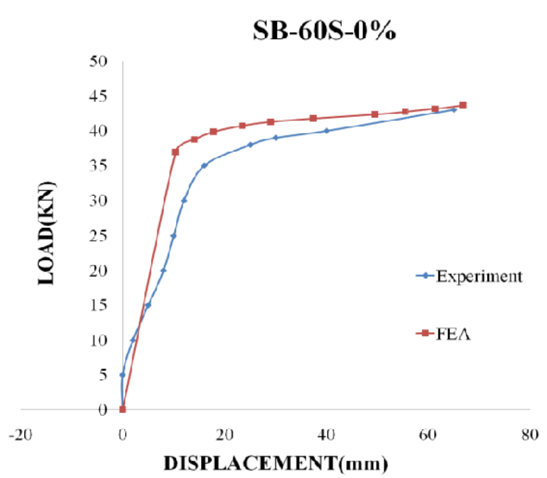

Fig 4 load displacement graph of model 3

4.1.4 SL-60S-2

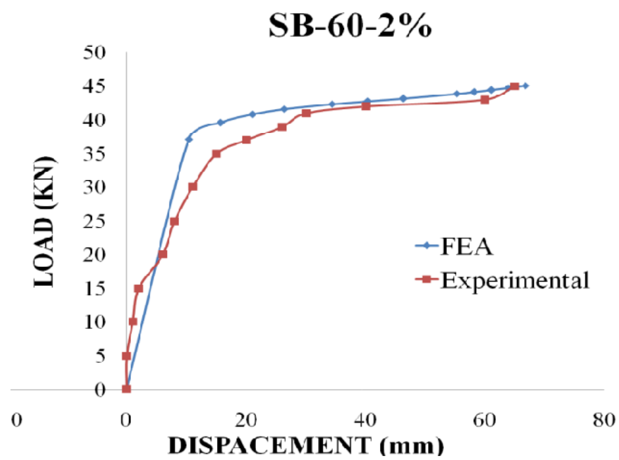

Fig 5 load displacement graph of model 4

4.1.5 SL-60S-4

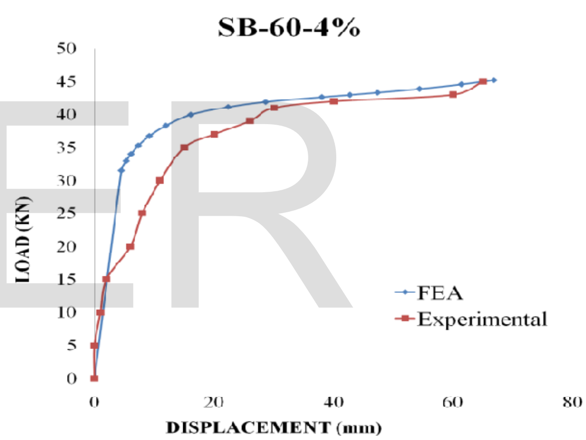

Fig 6 load displacement graph of model 5

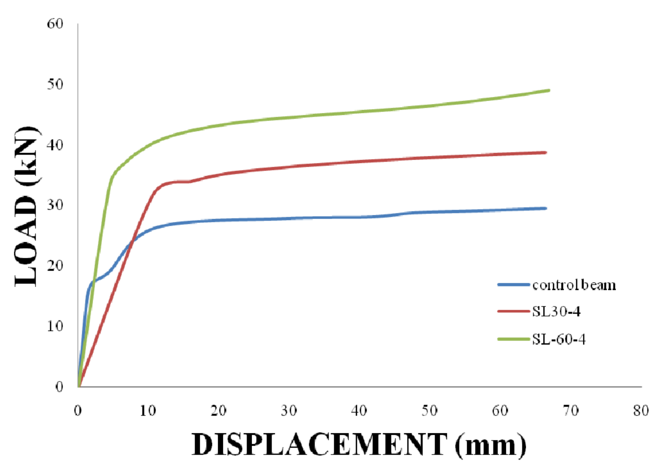

Fig 7 comparison of SL-CTRL, SL-30-4, SL-60-4

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Table 2 yield load comparison

Model	Comparison of yield load kN		
	KINAM HONG [12]	FEA	% variation
SL-STRL	23.79	24	0.9
SL-30S-4	28.48	29.478	3.5
SL-60S-0	32.09	36.94	15.1
SL-60S-2	33.12	37.04	11.83
SL-60S-4	34.02	35.419	4.11

Table 3 ultimate load comparison

Model	Comparison of ultimate load kN		
	KINAM HONG [12]	FEA	% variation
SL-STRL	29.56	30	1.4885
SL-30S-4	36.78	37.67	2.41979
SL-60S-0	45.22	43.681	3.403361
SL-60S-2	44.23	45.019	1.78386
SL-60S-4	46.64	45.19	3.108919

5. INFERENCES

- Increase in stiffness and yield strength might be due to error occurring during experiment procedure or during casting. It can also be due to assumptions such as considering concrete as homogeneous material in FEA
- Increase of yield load for RC beams strengthened with FeSMA in finite element model might be due to loss of prestress in practical case.

6. CONCLUSIONS

- RC beams strengthened with near surface mounted iron based shape memory alloys can be successfully modeled and analyzed using finite element method to get accurate results
- Ultimate load increased by 25% when 30 mm^2 cross section area of strengthening material was used compared to control beam
- Ultimate load increased by 50% when 60mm^2 cross section area of strengthening material was used compared to control beam

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