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RE-STRENGTHENING OF REINFORCED CONCRETE (RC) BEAM USING NEAR SURFACE MOUNTED (NSM) STEEL RE-BARS

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ABSTRACT

Strengthening of structures has become a highly sought after solution to improve inadequate, weakstructures. Strengthening of reinforced concrete (RC) members usingexternally bonded reinforcement (EBR)is a well established technology that is in widespread use. However, near surface mounted (NSM) reinforcement technique is a promising alternative due to several key advantages in terms of bonding and protection.This paper presents a study on the flexural behavoir of NSM steel strengthened RC beams made of brick aggregate concrete.Four-point bending tests were carried out up to failure on four rectangular RC beams, each of 150 mm width, 200 mm depth and 2100 mm length. One beam was left un-strengthened to act as the control beam. All other beams were strengthened with different ratios of steel reinforcements, of them two used epoxy adhesive as bonding material, while for the other two beams cement paste was used.Yield and ultimate strengths, flexural failure modes, effect of adhesives, cracking behavior and ductility are reported and discussed based on measured load and deflection. The test results show that flexural strength increased up to 102.4%, excellent ductility and dutile failure mode.

Keywords:*Retrofitting, flexural strengthening, RC, NSM, Steel, cement paste, epoxy, Brick chips.*

1. INTRODUCTION

Strengthening of existing structures or structural elements becomes a necessity due to ageing, environmentally induced degradation, poor initial design and/or construction, lack of maintenance, seismic upgrade and meeting new code requirements (*fib* Bulletin 14, 2001). In a frame structure, the chief load carrying members are beams and columns. That is why RC beam strengthening is an important issue of structural upgrading. Quite a few techniques have been developed over the years to strengthen or retrofitting of RC beams. One method, that is widely used to strengthen the deficient flexural strength of RC beams is Externally Bonded Reinforcement (EBR) technique. The technique originally pioneered simultaneously in South Africa and France in the 1960s (Fleming & King, 1967) requires adhering additional reinforcements like steel plates or fibre reinforced polymers (FRP) laminates. Although capable of achieving significantly higher capacity, EBR method has some major shortcomings. Firstly, the reinforcements are exposed which makes it vulnerable to rusting (in case of steel), fire, vandalism and other thermal, environmental and mechanical damage (Hosen*et al*, 2014). At the same time there is a high possibility of brittle failure like debonding and delamination. All these weaknesses adversely affect the durability and prevents achieving the full capacity of strengthening reinforcements (Brena*et al*,2001; Hawileh*et al*, 2014).

Another promising strengthening technique is Near Surface Mounting (NSM) reinforcement. The idea of NSM reinforcement started in Europe by using steel bars between 1940 and 1950 (Bournas & Traintafillou, 2008).The NSM technique involves cutting grooves into the concrete cover and bonding the bars into the grooves by using appropriate adhesive material such as epoxy resin or cement mortar (Petrina, 2009). The advantage of NSM over

EBR is that the concrete cover and adhesive provide protection against corrosion, fire, vandalism and mechanical damage (Wuertz, 2013).Another advantage of NSM technique is that it can be implemented in the negetive moment regions unlike the EBR method(El-Hacha& Rizkalla, 2004).Also, the NSM technique can delay the debonding of the reinforcement,compared to EBR method while retaining all the advantages the later offers.The use of FRP composites though very popular in enhancing the capacity to large extent(El-Hacha & Rizkalla, 2004; De Lorengis & Nanni, 2002), also suffer from certain disadvantages:low ductility, strain incompatibility with concrete, not readily available and extra large cost of both reinforcing and adhesive materials. Due to availability of steel bars combined with its economy, sufficient strength, excellent ductility, long-term durability, good bond performance and strain compatibility with concrete (Rahal &. Rumaih, 2011), also acquaintance of the local people to work with, NSM with steel bars has all the ingredients to become a very suitable proposition.NSM strengthening using steel bars has been used on masonry buildings and arch bridges (Garrity, 2001; Asplund, 1949). Crushed bricks are extensively used in Bangladesh for concrete making due to its economy and availability. Due to satisfactory performances of such concrete (Akhtaruzzaman & Hasnat, 1983), the beams under investigation will use crushed bricks as coarse aggregates.

Ductilityis the ability of a material to undergo plastic (non-reversible) deformation before failure. Ductility is a essential property of a structure which gives ample warning before any impending failure thus catatrophic losses can be avoided.So, identifying the strengthening material which gives better ductility is important. Ductility is generally measured by the ratio of the ultimate deformation to that at the first yielding of steel reinforcement (strain = 0.002).

In this paper the structural behaviour of RC beams strengthened with NSM steel bars and exposed to flexural loading is investigated. The test variables are strengthening reinforcement ratio, adhesive materials and yield and ultimate strength. Load and deflection are analysed to understand cracking behaviour, failure modes and ductility of the tested beams.

2. EXPERIMENTAL PROGRAMME

2.1 Specimen Geometry and Reinforcement

The beams were designed as under reinforced beams to initiate failure in flexure, in accordance with the BNBC2006. The cross-sectional dimensions of the beams were 150 mm x 200 mm and the length of the beams was 2000 mm with 1350 mm as the effective span. The main flexural reinforcement consists of 2-8mm bars with 2-6mm bars used for compression steel and to help form the cages. The shear reinforcement consists of 8mm stirrups spaced 75mm center to center throughout the span. This excessive shear reinforcement was used to eliminate any possibility of Shear failure.

The materials of the present experimental program are concrete, steel reinforcing bars, epoxy adhesive. The mechanical properties of epoxy adhesive have been provided by the manufactures. Whereas, tensile tests for both the longitudinal and transverse steel reinforcement and compression tests for the concrete 100 mm x 200 mm cylinders were done in the laboratory.

2.2 Experimental Matrix

A total of five RC beam specimens were tested. The first beam specimen was the control beam with no strengthening and the remaining beam specimens were strengthened with steel bars of different diameters.

Table 1: Experimental Matrix

Beam ID	Strengthening Type	Bonding Material
CB-1 (control beam)	n/a	n/a
A-1	1-8 mm NSM steel bar	Epoxy adhesive
A-3	2-8 mm NSM steel bar	Epoxy adhesive
A-4	1-8 mm NSM steel bar	Cement mortar
A-5	2-8 mm NSM steel bar	Cement mortar

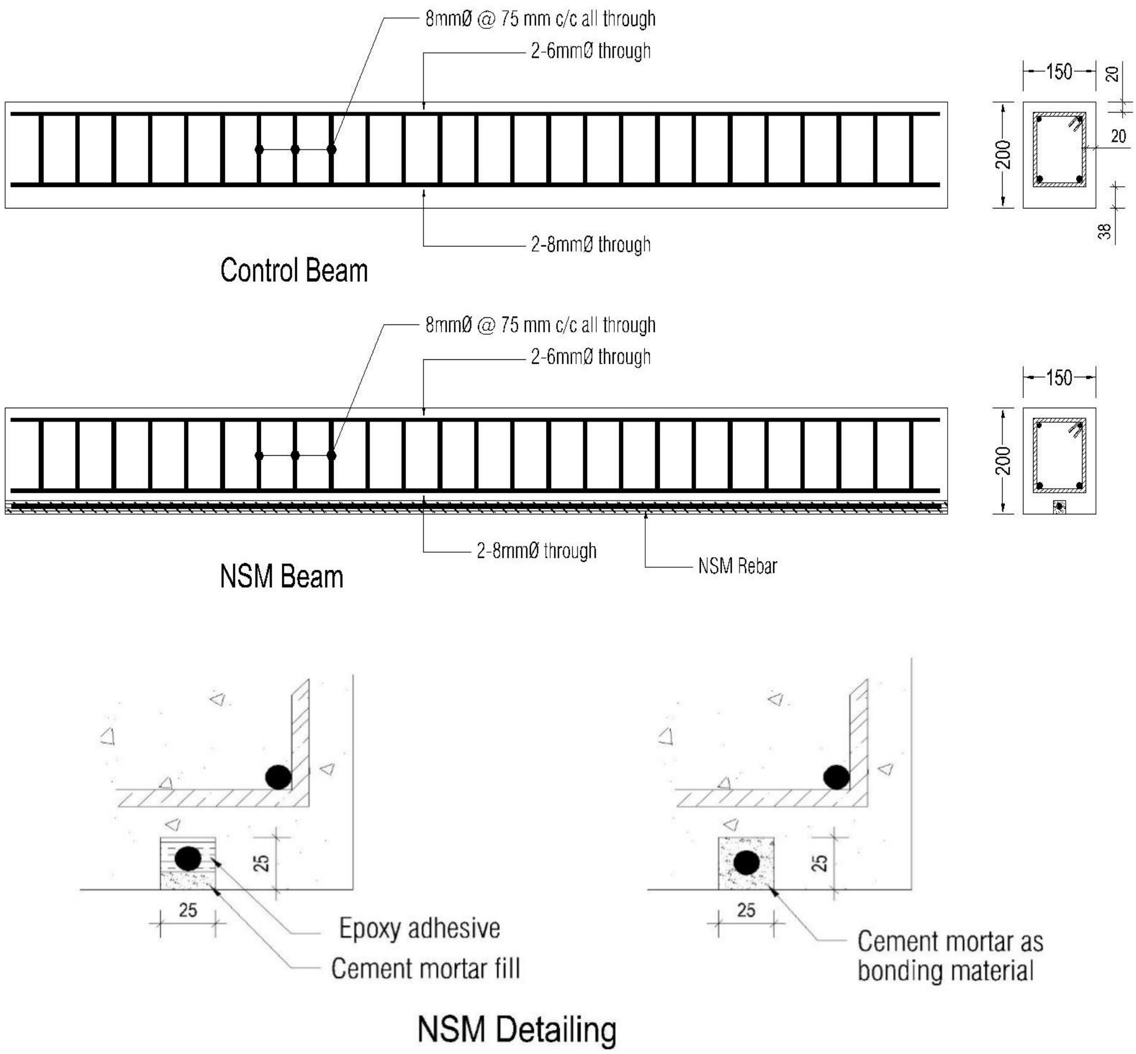

Figure 1: Details of Specimen

2.3 Material Properties

All the beam specimens were cast used normal concrete using Portland Composite Cement (PCC), coarse sand (FM > 2.5) as fine aggregates and crushed brick chips (20mm downgraded) as coarse aggregate. Fresh tap water was used to hydrate the concrete mix during the casting and curing of the beams, cubes, prisms and cylinders. The concrete mix ratio was 1:1.5:3 with a water/cement ratio (w/c) of0.50 which required 193 kg/m^3 of water, 654 kg/m^3 of fine aggregate, 1186 kg/m^3 of coarse aggregate and 386 kg/m^3 of PCC. The 28 day's average compressive strength of the concrete was 28.67 MPa based on tests of three 100 mm x 200 mm concrete cylinders. The yield and ultimate strength of φ8 mm steel bar was 446.76 MPa and 601.77 MPa respectively. The average yield and failure stress of the φ10mm bar were 432.54MPa and 568.44 MPa, respectively. The modulus of elasticity for all bars was 200 GPa.

A two-part epoxy named Adesilex PG2 SP was used to bond the NSM bars to the specified Beams. The mixing procedures were followed as specified by the manufacturer to ensure a good bond to the concrete surface.

Table 2: Properties of Adesilex PG2 SP Epoxy

Strength Type	**Strength (Mpa)**	**Final Hardening**
Compressive Strength	80	7 days
Tensile Strength	30	
Flexural Strength	40	

2.4Strengthening Procedure

In the NSM technique strengthening bars are placed into grooves cut into the concrete cover of the RC beams and bonded using epoxy adhesive groove filler. In this investigation, prior to the casting of experimental beams, 25mm x 25mm wooden rods of 2m length was placed to form grooves for NSM.A hammer and a hand chisel were used to chisel out the wooden rods and remove any remaining concrete lugs and to roughen the lower surface of the groove. The grooves were cleaned with a wire brush and water jet. The details of the grooves are shown in Figure 1.

To install the NSM bars on the beams using epoxy, the grooves were filled slightly more than one fourth depths, and then the bars were pushed into the grooves so that they were sufficiently surrounded by epoxy. More epoxy was then used to completely drown the bars into the adhesive paste. After that, the epoxy was allowed to sit for 24 to 36 hours to ensure proper curing and bonding. Finally, the remaining portions of the grooves were filled with cement mortar scraped off using trowel until flushed with the soffit of the beam. The mortar was cured for seven days.

For the beams in which cement is to be used as bonding material for NSM rebars, cement paste was made by mixing cement and water. The grooves were filled slightly more than halfway full, and then the bars were pushed into the grooves so that they were sufficiently surrounded by the cement paste. Excess paste was then used until it was flushed using trowel with the soffit of the beam. Once finished, the cement paste was cured for seven days to ensure proper bonding.

2.5Experimental Set-up& Procedures

The flexural tests were performed in the material testing laboratory at DUET. The beams were loaded in four-point bending using a spreader beam of 450mm long effective span and a 250 KN beam testing machine. The loading jack was supported by two structural steel support columns and the columns were fastened to the laboratory RC strong floor. The actuator is controlled by a servo-electro hydraulic system operated by the technical stuff. A load cell was placed under the centre of main loading point and at the top of spreader beam to measure the applied loads. Figure 2 shows the experimental test setup.

Two ten inches long linear variable differential transducer (LVDT) sensors were placed at mid-span on the top of the beams to measure deflection at mid-span. All of the instrumentation was wired into a channel data acquisition system called Megadac 200, a system developed by MTS. The data was recorded every 2 seconds. Before each test, the data acquisition system was reshuffled to zero value to ensure that is recording data and recording it correctly. The beams were loaded at a rate of 2kN per minute. After completing each test, the data was transferred from the data acquisition system to Microsoft Excel for analysis.

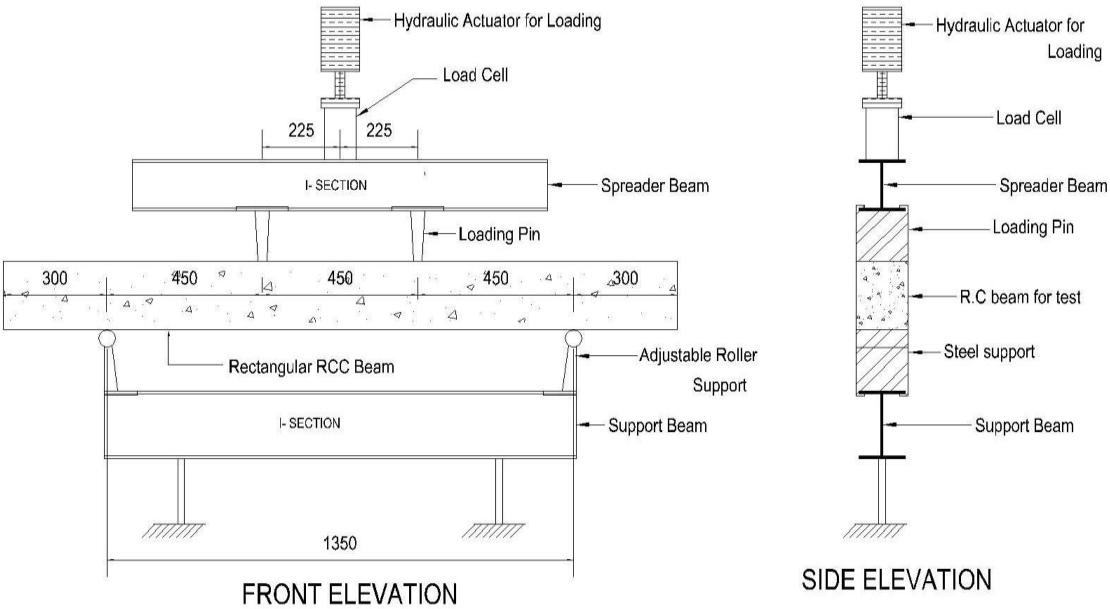

Figure 2: Experimental test setup

Figure 3: Typical loading arrangement

3. RESULTS & DISCUSSIONS

3.1 Mode of Failure:

The control beam CB1 failed in a ductile concrete crushing failure mode, which is steel yielding first followed by crushing of the concrete. The failure modes of all the other beams i.e. A1, A3, A4 and A5 followed the same pattern. The cracking pattern was similar for all the beams. At first, a fine flexural crack developed under one of the two loading pins originating at the bottom of the beam. As the external load increased, additional cracks developed at the neutral axis or beyond the neutral axis, with a notable increase in the deflection of the beam.

3.2 Load & Deflection

Control Beam (CB-1):
The test results show that the beam achieved a maximum load of 50.4 kN with a maximum deflection of 31.4 mm. The beam reached yielded at 33.6 kN with 3.22 mm deflection. Figure 4 shows the beam after testing and the concrete crushing that occurred at failure.

Figure-4: CB-1 after testing

Beams with NSM Bars using Epoxy adhesive (A1 & A3):
The test result showed that the beam A1 yielded at 56 kN having a deflection of 3.76 mm and failed at a maximum load of 82 kN which corresponds to a maximum deflection of 41.4 mm. Beam A3 yielded at 73.6 kN and failed at 102 kN with corresponding deflections of 3.76 mm and 45.42 mm, respectively.

Figure-5: A-1 after testing

Figure-6: A-3 after testing

Beams with NSM Bars using cement paste (A4& A5): The beam A4 yielded at 54.4 kN having a deflection of 4.06 mm and failed at a maximum load of 70.8 kN which corresponds to a maximum deflection of 42 mm. Beam A5 yielded at 70.4 kN and failed at 96.4 kN with corresponding deflections of 3.66 mm and 36.7 mm, respectively.

Figure-7: A-4 after test

Figure-8: A-5 after test

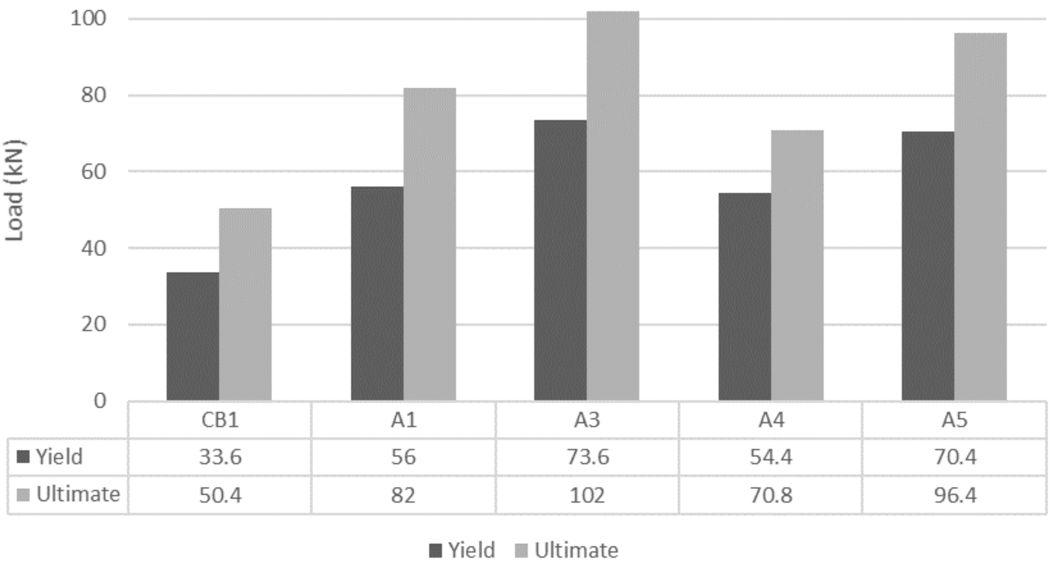

Figure-9: Yield and Ultimate load of beams

Table-3: Capacity of test specimens

Beam ID	Yield Load (KN)	Ultimate Load (KN)	Increase in Capacity (%)	Failure mode
CB1	33.6	50.4	0.00	Ductile
A1	56	82	62.7	Ductile
A3	73.6	102	102.4	Ductile
A4	54.4	70.8	40.47	Ductile
A5	70.4	96.4	91.27	Ductile

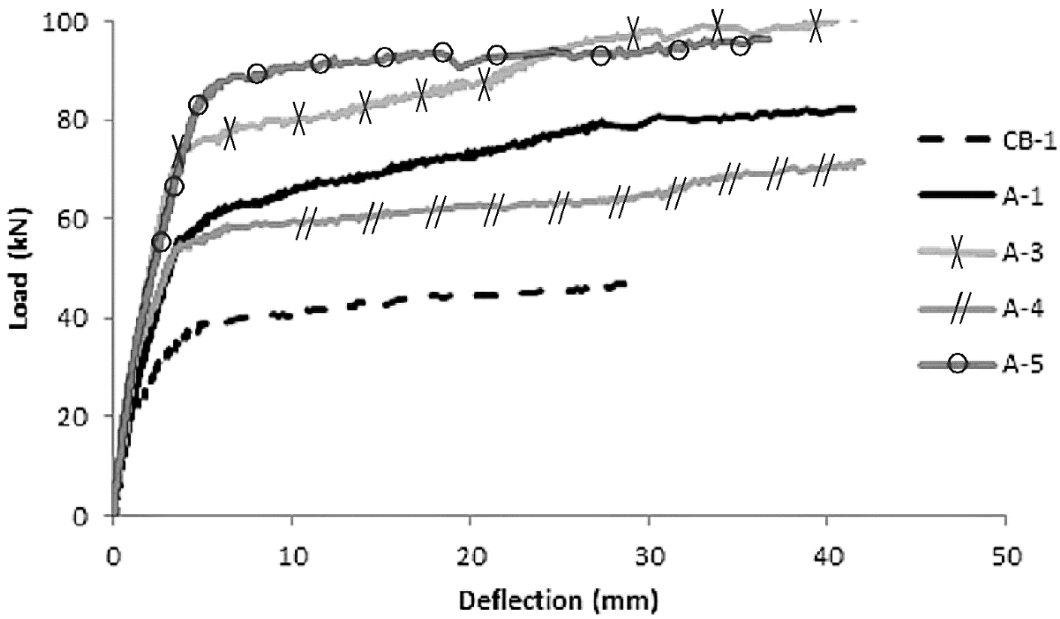

Figure-10: Load- Midspan Deflection of Beams

3.3 Ductility:

Table-4: Ductility of tested beams

Beam ID	∆y (mm)	∆u (mm)	Ductility, µ	Ductility increase, ∆µ
CB-1	3.22	31.4	9.75	0
A-1	3.76	41.4	11.01	1.26
A-3	3.76	45.42	12.08	2.33
A-4	4.06	42	10.34	0.59
A-5	3.66	36.7	10.03	0.28

In this study deflection ductility, was examined and are presented in Table 4. The deflection ductility index is expressed as the ratio between the deflection at ultimate load (∆u is the mid-span deflection at ultimate load) and the yield load (∆y is the midspan deflection at yield load). The deflection ductility index was increased by 12.93%, 23.9%, 6.05% and 2.87% for A-1, A-3, A-4 and A-5 respectively over the control beam. Overall, all the strengthened beams showed very good ductility.

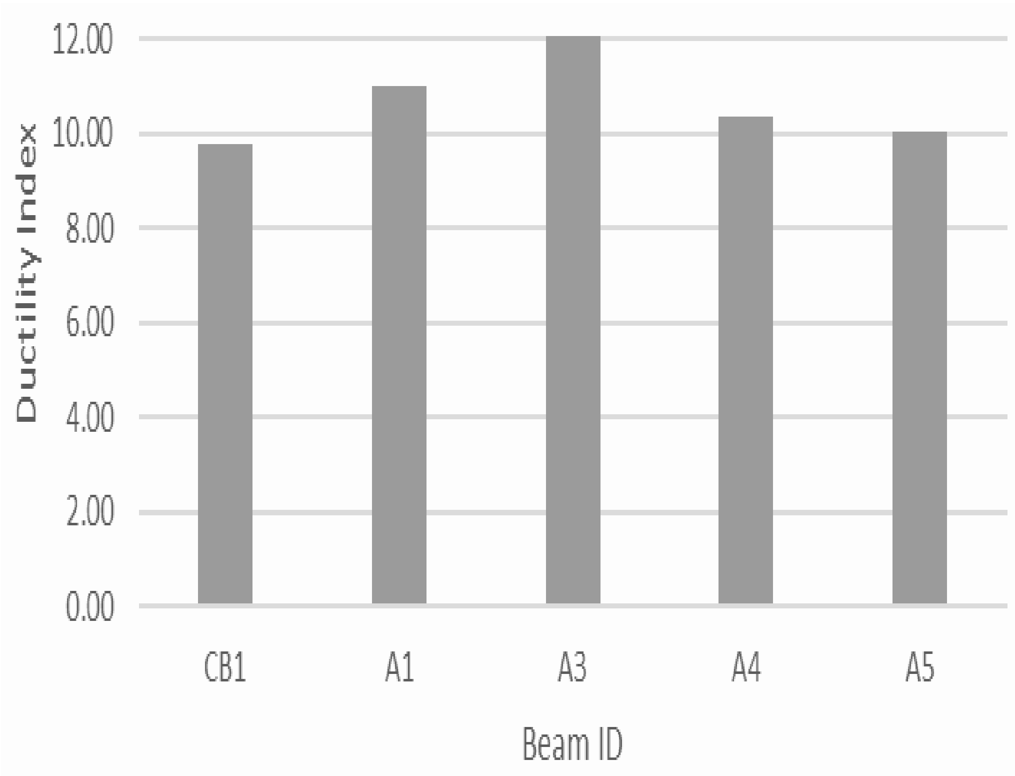

Figure-11: Ductility of Beams

3.3 Comparison of adhesives:

In terms of yield load epoxy does not show any advantage over cement as adhesive material. However, the epoxy used beams (A-1 and A-3) showed higher ultimate load than similarly configured beams which used cement paste as bonding material (A-4 and A-5). Also, when the adhesive changes from epoxy to cement paste, the beam shows lower ductility.These behaviours are expected due to the fact that epoxy possesses much higher strength than the cement paste.

4. CONCLUSION

The investigation carried out in this paper on RC beams strengthened by NSM steel reinforcement either with epoxy adhesive or cement paste has shown that this is a very effective strengthening technique. The following conclusions can be derived from the experimental results: -

- The mode of failure observed in all strengthened beams was ductile concrete crushing.
- Increasing the amount of NSM steel reinforcement from 50.26 mm^2 to 100.53 mm^2 increased the ultimate load capacity from 62.7% to 102.4% over control beam.
- Beams strengthened with NSM steel reinforcement have significantly increased yield and ultimate capacities with very good ductility.
- The use of cement paste as an alternative to epoxy adhesive shows adequte strength and ductility, hugely reduces the cost with slight reduction of performance.
- The NSM steel reinforcement enhances the load-deflection response of the RC beams. At any load level, the deflections of the strengthened beams were less than that of the control beam.
- The NSM strengthening technique using steel reinforcement and cement paste offers a very cheap but effective solution compared to any other strengthening technique.

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