

Strengthening of RC beams using NSM rebars combined with and without ferrocement jacket

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Abstract

The present paper aims at evaluating the experimental flexural behaviour of reinforced concrete (RC) beam strengthened by Near Surface Mounted (NSM) rebars and combined with ferrocement jacket. RC beams of 150 mm width, 200 mm depth and 2100 mm length were made up with brick aggregate concrete. Different ratios of NSM rebars were installed in grooves of the RC beams by using epoxy resin and half of them were wrapped by expanded wire mesh with cement mortar. After curing properly and adequately, four-point bending tests were carried out upto failure on fourteen RC beams divided in two groups depending on their concrete strength. From each group, one beam was left un-strengthened to act as the control beam. Yield and ultimate strengths, failure behaviour of the beam, pre and post cracking behaviour of the beams and ductility were observed, reported and discussed based on the measured load and deflection. The test results show that flexural strength can be significantly increased along with achievement of excellent ductility by using NSM rebars with low cost and locally available technical and implementing manpower. For NSM rebars combined with Ferro-cement jacketing technique, strength is increased significantly but ductility is decreased compare with the NSM rebars technique.

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Keywords: Strengthening, flexural strength, NSM rebars, ferrocement jacket.

1. Introduction

In a structural frame system, beams are one of the most important load bearing elements. Beams may become unsafe due to detrimental environmental conditions, inferior construction, aging, lack of maintenance, increase load carrying demands, change of user pattern, inadequate design, damage of structure, and to accidental events such as earthquakes, cyclones. The under strength beams are required to increase the strength by strengthening. Strengthening RC beams has been performed by several methods. Now-a-days RC jacketing, FRP jacketing, ferrocement jacketing, externally bonded reinforcement (EBR), near surface mounted (NSM) CFRP, GFRP are very common methods which are used to strengthening of structures all over the world (Petrina 2009; Wuertz 2013; Rahal and Rumaih 2011; Asplund

1949; Garrity 2001; Lorenzis and Nanni 2002; Hosen et al. 2014). The NSM technique is one of the robust and inexpensive methods, which involves cutting a groove into the cover concrete on a beam and bonding reinforcement such as FRP, CFRP, GFRP, or steel rebar using epoxy resin (Petrina 2009). One of the advantages of NSM technique over the popular EBR technique is that the concrete cover and adhesive provide protection against vandalism and mechanical damage (Wuertz 2013). The technique can be used in the negative moment regions unlike the EBR method.

The NSM technique with steel bars to become a very suitable strengthening method due to easy availability of steel bars, economy, adequate ductility, durability, bond performance and strain compatibility with concrete (Rahal and Rumaih 2011), and acquaintance of the local people to work. However, durability of NSM technique may be questionable for corrosion of NSM rebars due to smallest covering. Ferrocement technique is another method for strengthening of structures, which is a type of thin wall reinforced concrete commonly constructed of hydraulic cement mortar, reinforced with closely spaced layers of continuous and relatively small diameter mesh (ACI Committee 2010). Many researches have been conducted to determine the effect of ferrocement jacketing technique on RC beams (Dadasaheb 2013; Andrews and Sharma 1998; Paramasivam et al. 1994; Dhanoa et al. 2016). All these studies showed that ferrocement improved the crack-resistance and ultimate capacity, and rigidity of beams.

However, ductility is reduced for ferrocement strengthening of beams. Failure mode of ferrocement jacketing is bond failure between the ferrocement jacketing and original beam (Dhanoa et al. 2016). The limitations of NSM rebars and ferrocement jacketing technique may be overcome by combined technique of them. In this paper the structural behaviour of RC beams strengthened with combined NSM rebars and ferrocement jacketing technique subjected to flexural loading is investigated. The beams under investigation to be used crushed bricks coarse aggregates which is used in Bangladesh as well as many other neighbouring countries (Akhtaruzzaman, and Hasnat 1983). The test variables are concrete strength, strengthening reinforcement ratio with and without ferrocement. Load and related deflection data are analysed to understand cracking behaviour, failure modes, strength and ductility of the tested beams.

2. Materials and methods

2.1 Specimen details

In the experimental study, NSM rebar and NSM rebar with ferrocement jacketing techniques were used to strengthen of under reinforced beams. The beams were designed as per BNBC 2006. The dimensions of the beams were 150 mm x 200 mm x 2100 mm with an effective span of 1350 mm. The main flexural reinforcement was of 2-8 mm bars used at bottom and another 2-6 mm bars used at top as compression steel to help form the cages. 8 mm stirrups were spaced 75 mm center to center throughout the span to eliminate the possibility of shear failure. Fourteen RC beam specimens were tested in this study. The specimens were equally divided into two groups depending on their concrete mix ratio, Type-A and Type-B. The concrete mix ratios of type-A and type-B specimens were 1:1.5:3 and 1:2:4 respectively. Water cement ratio (w/c) was constant at 0.5 for both group of specimens.

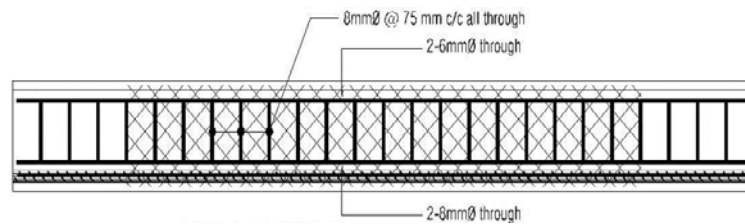
Each group contained a control beam to compare the effect of strengthening techniques. For strengthening the remaining beams, 1-8 mm, 1-10 mm and 2-8 mm NSM rebars combined with and without ferrocement jacket were used in each group. The NSM rebars bonded with epoxy resin and used full length of the beams. Experimental details matrix is shown in Table 1 and dimensions with the typical strengthening arrangements are shown in Figure 1.

2.2 Material properties

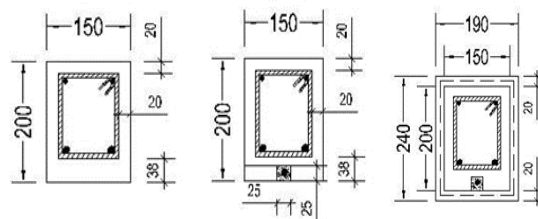
The materials of the present experimental program are concrete, reinforcing steel bars, wire mesh and epoxy adhesive. The concrete was prepared by using Portland Composite Cement (PCC), coarse sand (FM > 2.5) as fine aggregates and crushed brick chips (20mm downgraded) as coarse aggregate. Fresh tap water was used to hydrate the concrete mix during the casting and curing of the beams and cylinders. Each batch of concrete, three 100 mm x 200 mm concrete cylinders were taken for the test of concrete. The concrete cylinders were cured in water basin and tested in the laboratory. The average compressive strength of 28 day’s aged concrete of Type-A and Type-B were found 28.67 MPa and 22.08 MPa respectively. Tensile tests for both the longitudinal and transverse reinforcing steel bars were performed in the laboratory. The yield and ultimate strength of Ø8 mm and Ø10 mm reinforcing steel bars were 446, 432 MPa and 602, 568 MPa respectively. The modulus of elasticity for all bars was 200 GPa. Adesilex PG2 SP Epoxy was used for NSM rebars bonding. The mechanical properties of the epoxy have been provided by the manufactures and shown in Table 2. Expanded metal mesh of SWG (Standard wire gauge) 15 with 20 mm openings to contain the NSM rebar were used to strengthen the specimens.

Table 1
Experimental details matrix

Specimen Type A		Specimen Type B	
Concrete mix ratio 1.0:1.5:3.0 with water cement ratio 0.5		Concrete mix ratio 1.0:2:4.0 with water cement ratio 0.5	
Beam ID	Strengthening Description	Beam ID	Strengthening Description
CB1	N/A, Control Beam	CB2	N/A, Control Beam
A1	1-8 mm NSM rebar	B1	1-8 mm NSM rebar
A2	1-10 mm NSM rebar	B2	1-10 mm NSM rebar
A3	2-8 mm NSM rebars	B3	2-8 mm NSM rebars
A6	1-8 mm NSM rebar with ferrocement wrapping	B6	1-8 mm NSM rebar with ferrocement wrapping
A7	1-10 mm NSM rebar with ferrocement wrapping	B7	1-10 mm NSM rebar with ferrocement wrapping
A8	2-8 mm NSM rebars with ferrocement wrapping	B8	2-8 mm NSM rebars with ferrocement wrapping



Long section of A6



Section of CB Section of A1 Section of A4

Fig. 1. Specimen dimensions with typical strengthening arrangements details.

2.3 Strengthening procedure

2.3.1 Surface preparation

For NSM technique, 25mm x 25mm wooden plunks of 2m length was placed to form a groove for the placement of NSM rebars in beams. A hammer and a hand chisel were used to chisel out the plunks and remove any remaining concrete lugs and to roughen the surface of the groove. The grooves were cleaned with a wire brush and water jet for installation of NSM rebars. After installation of NSM rebars by using epoxy, hammer and hand chisel were used to roughen the beam surface and cleaned with a wire brush and water jet for installation of wire mesh.

Table 2
Properties of Adesilex PG2 SP Epoxy

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

2.3.2 NSM rebars strengthening technique

To install the designated NSM rebars on the beams (A1-A3, B1-B3), the grooves were filled slightly more than one fourth depths by epoxy resin then the NSM rebars were pushed into the grooves so that the epoxy sufficiently bounded to the rebars. After that more epoxy was used to completely immerse the rebars into the adhesive paste. The epoxy was allowed to sit for 24 to 36 hours to ensure proper curing and bonding. Finally, cement mortar was used to fill the remaining portions of the grooves. The mortar was cured for seven days.

2.3.2 NSM rebars with ferrocement strengthening technique

Once the beams (A6-A8, B6-B8) were installed with NSM rebars by using epoxy and completed the surface preparation, designated specimens were wrapped with ferrocement overlay. Expanded wire mesh was wrapped around the beams with steel nails and washers driven by hammer at every 200 mm distance on all the four sides. After that, 20 mm thick cement mortar cover was applied on the wrapped beams from all sides. Mortar was prepared with PCC and coarse sand (FM>2.5) at a ratio of 1:2.5 using a water cement ratio of 0.5. To apply mortar, first cement slurry was applied on the surface of the beam, then cement mortar was placed by hand plastering which was forced through the mesh. Finally, the surface was finished using trowels and the dimensions were checked. The ferrocement process was carried out according to (BNBC 2006). The beams were cured for 15 days.

2.4 Experimental set-up and instrumentation

The flexural tests of the beams were performed in the material testing laboratory of Civil Engineering department of Dhaka University of Engineering and Technology, Gazipur. Four-point bending test method i.e., load is applied every one third point of the effective length 1350 mm. So, the distance of loading point is 450 mm apart from each other. A 125 kN-m servo-electro hydraulic beam flexural testing machine was used in this study. The loading jack was supported by two structural steel support columns and the columns were fastened to the laboratory RC strong floor. A 1000 kN TML 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 250 mm measureable linear variable differential transducer (LVDT) were placed at mid-span on the top of beams to measure deflection at mid-span shown in Figure 3. The beams were loaded at a rate of 2kN per minute. All the data from the instruments were recorded by using a data acquisition system called UCAM, a

sensor system developed by KYOWA Electric Instruments Company Limited. The data were recorded in every 2 seconds. At the start of each test, the data acquisition system was set to zero value for each instrument to ensure correct recording of data. At the end each test, the data were transferred from the data acquisition system to Microsoft Excel for analysis.

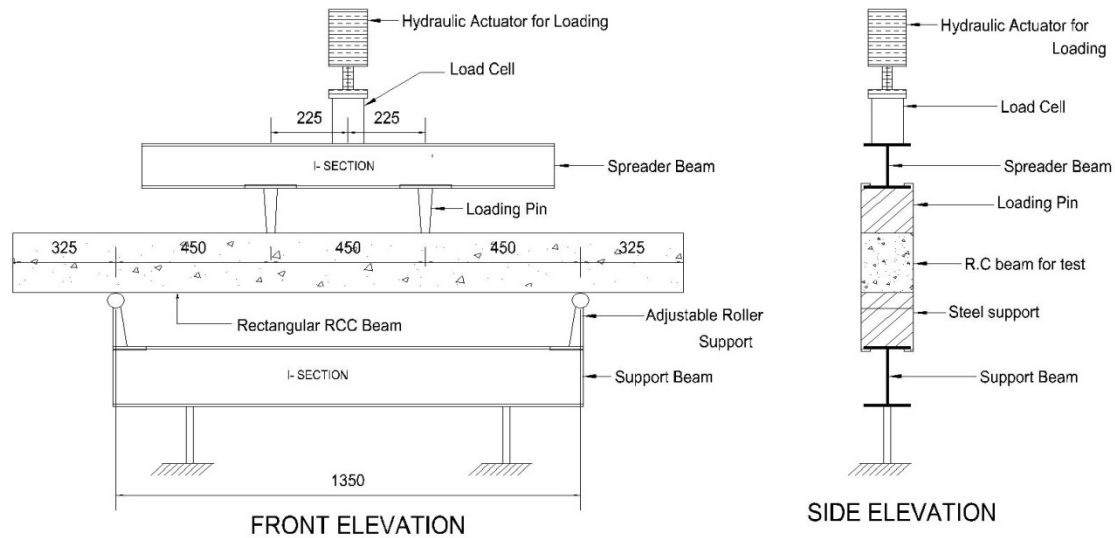


Fig. 2. Experimental test setup.



Fig. 3. Photography of the instruments with a test specimen.

3. Results and discussions

In the experimental investigation, six strengthened and a control RC beam specimens of each group were tested. From the investigation, flexural behaviour were observed and summarized in Table 3. The results are discussed in the subsequent subsections.

3.1 Load-deflection relationship

Load-deflection curves of the tested RC beams of type-A and type-B are shown in Figure 3. It is seen that the load on the beams are linearly increased with the increased of deflection up to the yield strength. After that, the slope is suddenly decreased and almost linear up to failure for NSM rebars strengthened beams but for the NSM rebars combined with ferrocement strengthened beams, the slope is gradually decreased up to failure. It is evident that load-deflection characteristics is improved at every deflection level i.e. the flexural strength as well as stiffness of the strengthened RC beams are higher than that of control beams. Higher flexural strength and stiffness and smaller deflection are observed for NSM rebars combined

with ferrocement strengthened beams compared with NSM rebars strengthened beams as well as the control beam. The strength and stiffness are increased due to the Ferro cement provided the addition strength and stiffness.

Table 3
Summary of experimental beams results

Beam ID	P_c (kN)	P_y (kN)	δ_y (mm)	P_u (kN)	δ_u (mm)	Failure mode	Beam ID	P_c (kN)	P_y (kN)	δ_y (mm)	P_u (kN)	δ_u (mm)	Failure mode
CB1	28.5	33.6	3.2	50.4	31.4	Ductile	CB2	31.7	36.0	2.7	46.8	29.2	Ductile
A1	48.1	56.0	3.7	82.0	41.4	Ductile	B1	47.2	55.6	2.5	72.8	32.5	Ductile
A2	47.5	60.0	3.6	90.0	38.4	Ductile	B2	50.5	63.2	3.3	88.4	33.0	Ductile
A3	43.6	73.6	3.7	102.0	45.4	Ductile	B3	63.3	70.4	3.5	94.0	54.6	Ductile
A6	79.5	92.4	3.3	118.0	17.5	Ductile	B6	67.0	87.6	2.7	105.0	23.2	Ductile
A7	65.0	102.4	5.4	128.0	16.8	Ductile	B7	77.0	102.2	3.7	125.0	14.2	Ductile
A8	98.0	116.4	4.2	142.4	20.2	Ductile	B7	92.0	108.0	5.9	136.0	18.8	Ductile

Notes: P_c = First cracking load; P_y = Yield load; P_u = Ultimate load;
 δ_y = yield deflection; δ_u = Maximum deflection.

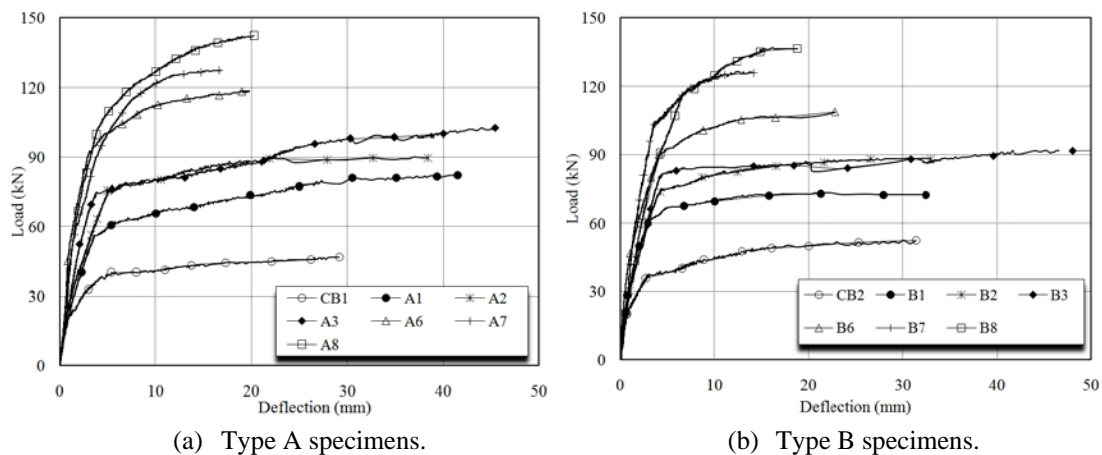


Fig. 4. Load-deflection curves of the tested RC beams.

3.2 Crack pattern and mode of failure

At the experiment time of the beams, crack pattern and failure mode were observed. The control beams CB1 and CB2 were observed to fail in ductile mode in which steel was observed to yield first followed by crushing of the concrete. The failure modes of all other beams were the same pattern shown in Table 3. The cracking pattern of the beams are shown in Figure 5. At first, a fine flexural crack developed under one of the two loading pins initiating at the bottom of the beam. The second crack typically appeared at or very close to the mid span within the constant moment region. As the external load increases, additional cracks developed up to neutral axis even further beyond the neutral axis, with a notable increase in the deflection of the beam. The first cracking load was 28.5 kN for the control beam CB1 and 31.7 kN for the control beam CB2 shown in Table 3. The first cracking load was notable increased of the strengthened beams with respect to the respective control beam. The first cracking strength ratios of the strengthened beams to the respective control beam are shown in Figure 6. From the figure, it is seen that the strength is increased about 1.53 times to 3.44 times for the strengthened beams group type A and about 1.49 times to 2.90 times for the strengthened beams group type B. The first cracking strength was increased higher for the beams strengthened by NSM rebars with ferrocement jacketing. It is increased about 128-

244% for type-A and 111-190% for type-B while the first cracking strength for the beams with NSM rebars was increased about 53-69% for type-A and 49-100% for type-B over the respective control beams.

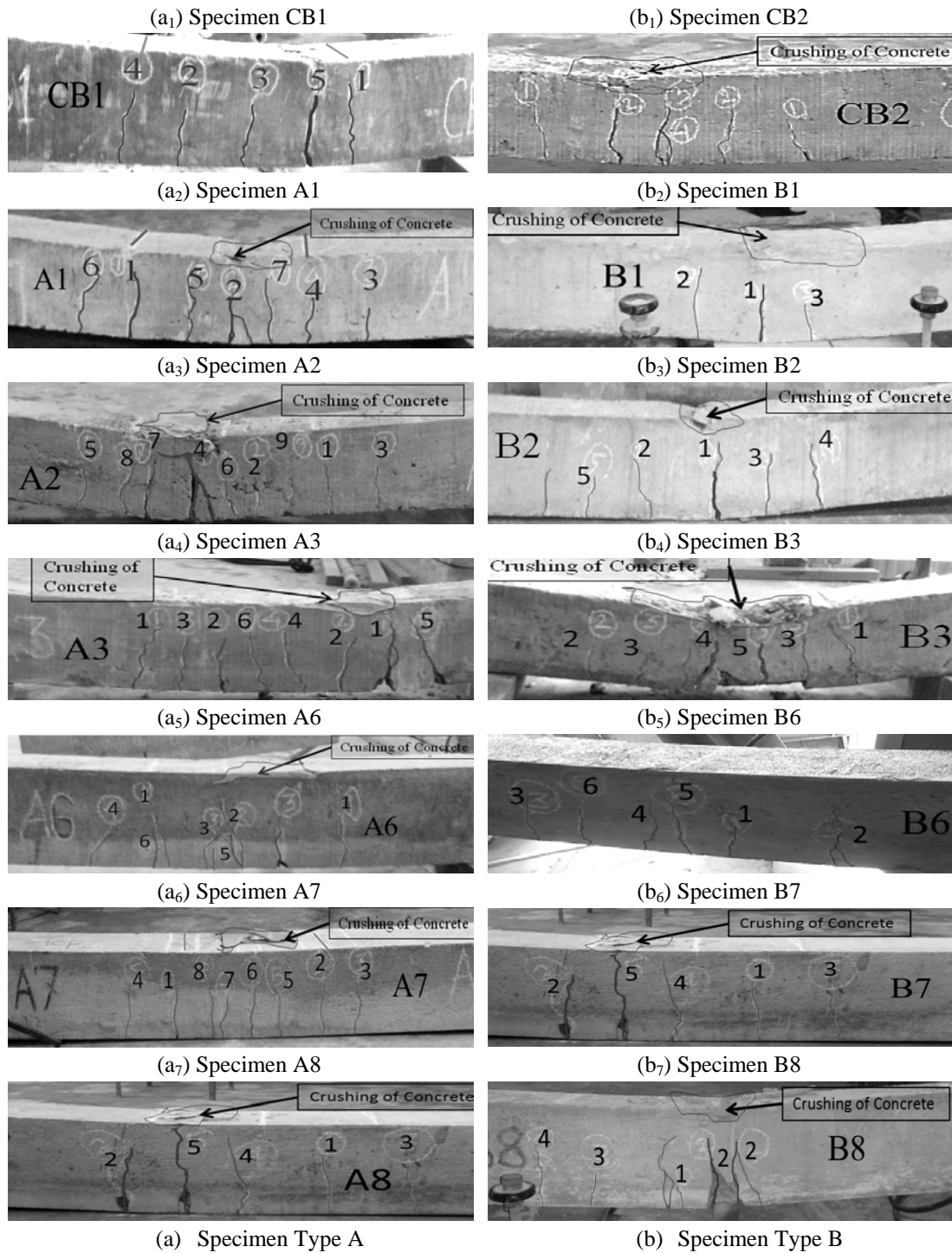


Fig. 5. Crack patterns of the tested beams.

3.3 Flexural strength

The yield and ultimate flexural strength of experimental beams are shown in Table 3. The yield and ultimate flexural strength were 33.6 kN, 50.4 kN for the control beam CB1 and 36.0

kN, 46.8 kN for the control beam CB2. The yield and ultimate flexural strength were notable increased of the strengthened beams with respect to the respective control beam. The yield and ultimate flexural strength ratios of the strengthened beams to the respective control beam are shown in Figure 7. From the figure, it is seen that the yield and ultimate strength were increased about 1.67 times to 3.46 times and about 1.63 times to 2.74 times respectively for the strengthened beams group type A and about 1.54 times to 3.00 times and about 1.56 times to 2.91 times respectively for the strengthened beams group type B.

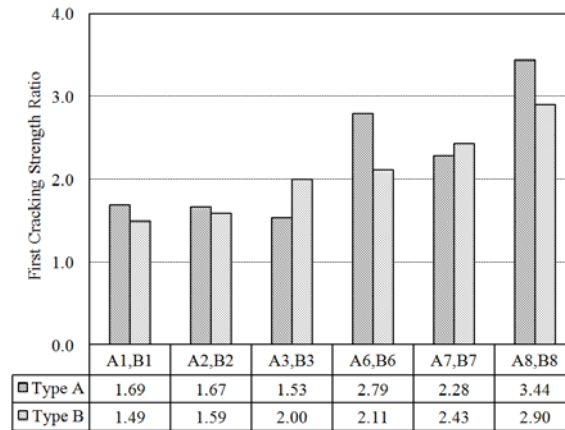


Fig. 6. First cracking strength ratio with respect to the respective control beam.

The yield and ultimate strength was increased higher for the beams strengthened by NSM rebars with ferrocement jacketing. It is increased about 175-246% yield strength and 134-174% ultimate strength for type-A and about 102-200% yield strength and 124-191% ultimate strength for type-B while the yield and ultimate strength for the beams with NSM rebars were increased about 67-119% yield strength and 63-102% ultimate strength for type-A and about 54-96% yield strength and 56-101% ultimate strength for type-B over the respective control beams.

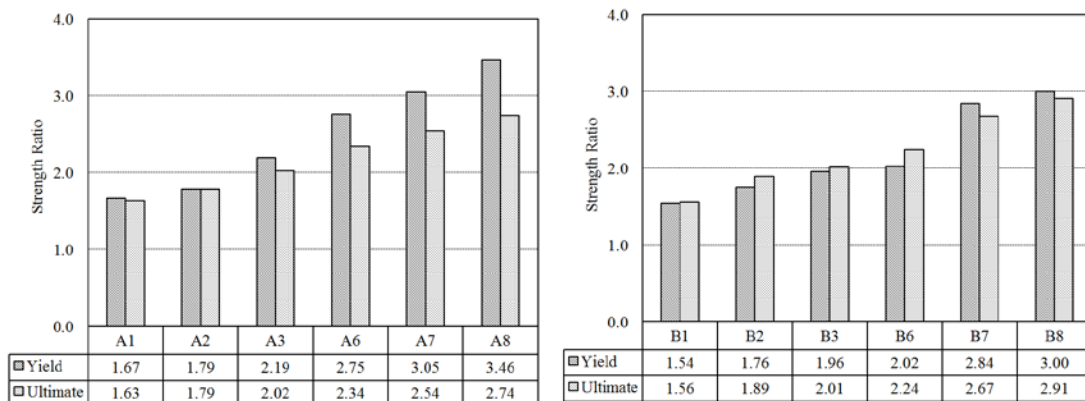


Fig. 7. Yield and ultimate strength ratio the strengthened beam to the respective control beam.

3.4 Ductility

In the present study, yield and ultimate deflection at the mid-span of beams were measured and presented in Table 3. Using the yield and ultimate deflection, deflection ductility index was calculated and shown in Figure 8. The deflection ductility index is expressed as the ratio of ultimate deflection (δ_u) for the ultimate strength to the yield deflection (δ_y) for the yield

strength. The deflection ductility index was about 9.8 for the control beam CB1 and about 10.6 for the control beam CB2. The deflection ductility index for the control beam and the beams strengthened with NSM rebars was about 11.0 to 12.1 and 10.0 to 12.9 for type A and type B respectively while the deflection ductility index for the beams strengthened NSM rebars with ferrocement jacketing was low and it is about 3.1 to 5.3 and 3.2 to 7.4 for type A and type B respectively. The deflection ductility index ratio was also calculated and shown in Figure 9. The deflection ductility index ratio is defined as the ratio of strengthened beams ductility index to the control beam ductility index. From the figure, it is observed that the ductility can be increased for the strengthened beams with NSM rebars and it is about 1.07 times to 1.23 times for type A and about 1.22 times to 1.45 times for type B though ductility of beam B2 was reduced about 6%. It is also observed that the ductility of the beams strengthened NSM rebars with ferrocement jacketing was significantly decreased and it is about 0.32 times to 0.54 times for type A and about 0.30 times to 0.70 times for type B over the respective control beams.

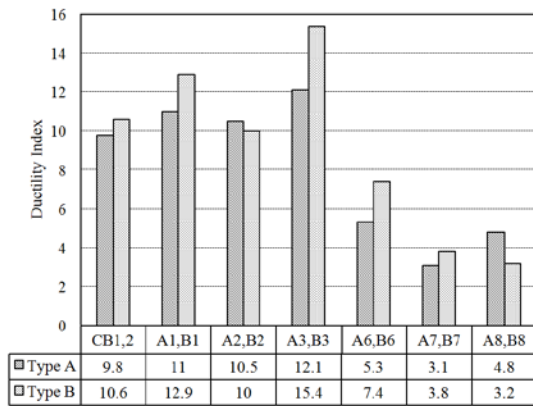


Fig. 8. Ductility index for the tested beams.

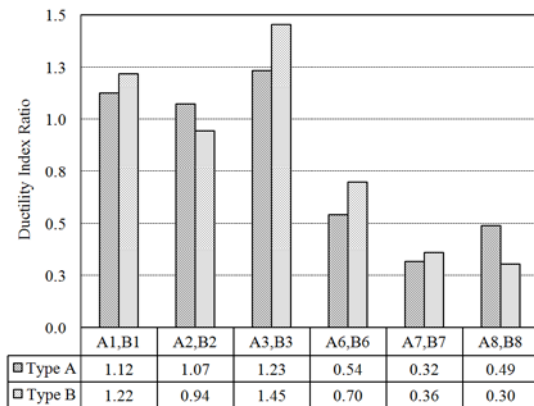


Fig. 9. Ductility index ratio the beams with respect to control beam.

3.5 Effect of concrete strength

The use of differing strength of concrete in Type-A ($f_c'=28.67$ MPa) and Type-B ($f_c'=22.08$ MPa) did not translate to any notable difference. In general, when comparing identically strengthened beams, the yield load was almost the same for both types. In terms of ultimate load, similarly configured Type-A beams showed somewhat higher capacity than their counterparts in Type-B (up to 12.6%). Hence, strength of concrete showed very limited influence in flexural behaviour.

4. Conclusion

In this paper, flexural behaviour of RC beams strengthened using NSM rebars has been studied and compared with a control beam. In addition, flexural performance of the NSM strengthened beams jacketed with ferrocement overlay was investigated. The following conclusions can be derived from the experimental results:

Application of both NSM rebars strengthening and NSM rebars with ferrocement jacket strengthening proved to be a success due to their ductile failure mode, in which the steel yielded first followed by crushing of the concrete in the constant moment region. This occurred due to the beams reaching the full flexural capacity of the concrete after the steel yielded in the NSM rebars and internal reinforcement ensuring the capacity of strengthening material was exploited to full extent. Increasing the amount of steel reinforcement by 50.26 mm²-100.52 mm² following NSM method increased the yield load by 54.4%-118% and

ultimate load by 53.8% -102.4% over the control beams. The use of ferrocement wrapping on NSM rebars strengthened made notable improvement in yield (53.4-70%) and ultimate load (40-45%) over original NSM rebars only strengthened beams due to their better confinement and enlarged section. The NSM rebars 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. Use of ferrocement wrapping brought marked improvement in stiffness over the similar NSM only strengthened beams reflected in the load-deflection curve. NSM rebars strengthened specimens showed good ductility, better than or approaching the ductility index of control beams. However, application of ferrocement laminates on NSM rebars strengthened beams lowered the ductility significantly. Strength of concrete has minimal effect on flexural behaviour of the specimens. The use of NSM rebars with or without ferrocement wrapping is a very effective strengthening technique.

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