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Combined EBR and NSMR for Flexural Strengthening of RC beams

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Abstract – *Repair and strengthening of damaged or vulnerable reinforced concrete structures is important in order to guarantee the safety of residents or users. Beams are important structural elements for withstanding loads, so finding the efficient repair and strengthening methods are necessary in terms of maintaining the safety of the structures. It is both environmentally and economically desirable to upgrade structures rather than rebuild them. There are many methods available for strengthening existing deficient structures, among which, Externally Bonded Reinforcement (EBR) method and Near Surface Mounted (NSM) techniques are the most popular. However, the presence of high interfacial shear stresses at the end of the externally bonded plate may reduce the resistance to failure of the strengthened structure. Also the application of NSM is limited due to the absence of sufficient width and clear cover of the existing unstrengthened deficit beam. This paper presents an experimental investigation on the behaviour of Reinforced Concrete Beams flexuraly strengthened with combined EBR and NSMR. Experimental investigation aims at finding the failure load, deflection and ductility of RC beams which uses steel plates and steel bars as strengthening tools.*

Key Words: **NSMR, EBR, debonding, steel, strengthening.**

1. INTRODUCTION

Rehabilitation and strengthening of reinforced concrete (RC) structures are some of the major challenges for structural engineers today. The strengthening of RC structures is a dynamically growing division of structural engineering and in recent years, there has been an increase in the application of new repair and strengthening systems for RC load-carrying structures. In most cases, it is an increase in dead and live loading that has to be safely carried by the structures, as well as their poor technical performance that necessitates the use of strengthening procedures. Therefore, new clever methods to strengthen and stiffen existing structures and to build new structures are necessary in the building industry. Structural strengthening allows existing underperforming structures to survive against additional service load requirement, design, structural deterioration due to age or the surrounding environment.

One technique commonly used to enhance the strength or serviceability of RC structures is Externally Bonded Reinforcement (EBR), where the steel or CFRP plates are glued to the outer surfaces of the structures. However, the development of high interfacial shear stresses at the plate ends could cause the premature debonding failure without utilizing the structure's full capacity. Many studies have been conducted to find solutions to this brittle debonding and to reduce the interfacial stresses between the RC substrate and the strengthening plate. One remedy was to change the thickness of the steel or FRP plate or the joint geometry by tapering the plate. Although the use of geometrical variations to the plate ends by tapering is a useful tool to reduce the stresses in adhesive joints, it is a complex, time consuming and costly process [12, 17].

More recently, near-surface mounted reinforcement (NSMR) has attracted an increasing amount of research as well as practical application because it is less prone to premature debonding. However, it has some limitations in application. Sometimes, the width of the beam may not be wide enough to provide necessary edge clearance and clear spacing between two adjacent NSM grooves. The ACI proposed a minimum edge clearance and clear spacing between two adjacent NSM grooves [7, 8, 6, 10, 2].

This work presents a hybridization of the above two strengthening methods. This hybridization combines the EBR with the NSM technique so that they complement each other and mutually reduce their limitations. Previous studies have shown that reduction in plate thickness decreases the magnitude of stress concentration at the plate extremities. Instead of tapering the plate, hybridization could make it possible to reduce the plate thickness by transferring a portion of the plate material from plate bonding to the NSM technique. Consequently, the size or number of NSM bars can also be reduced through shearing with plate bonding method and thus provide sufficient space for edge clearance and clear spacing of the groove [3, 4, 5, 11, 13, 15, 16].

The present study explores the use of steel bars in the NSM system and steel plates in EBR system and develops a new structural strengthening method that combines the conventional EBR with the NSM technique. Inorder to resist corrosion, the steel bars and steel plates are protected with anticorrosive coating paint. A number of RC beam specimens are strengthened using different configurations of steel bars and steel plates, which are then subjected to static loading. The beams are constantly monitored for loading and deflections till failure. The effect of different parameters such as grade of concrete and number of grooves is also investigated.

2. EXPERIMENTAL PROGRAMME

2.1 Description of specimens and test setup

The specimens cast for this study were eight reinforced concrete beams with dimensions of 1000 x 140 x 120 mm simply supported having a clear span of 880 mm and subjected to four- point flexural loading up to failure as shown in Fig.1. The beams were designed as under reinforced beams to initiate failure in flexure. Of those beams, three were assigned as the control beam, denoted as CB and the remaining beams were strengthened using different configurations of steel bars and steel plates. Each beam designation (Table 1) indicates: 'H' for hybridized beam, diameter of NSM bar (D8, D16), thickness of EBR plate (T1), width of EBR plate (W25, W50), number of grooves (G1, G2), grade of concrete (M20, M25, M30). For example HD8T1G1M25W25 indicates a specimen strengthened with 8 mm diameter bar and 1.6 mm thick and 25 mm wide plate in single groove. M25 grade concrete was used for the specimen. Strengthening was done throughout the effective span by providing sufficient clear distance from the support points (860 mm).

The beams were reinforced with two numbers of 8 mm diameter steel bars in tension and two numbers of 6 mm diameter bars in compression. Enough shear reinforcement were provided in an amount calculated to ensure that the beams would fail in flexural (ie: 6mm diameter bar at 78 mm c/c spacing. A concrete cover of 25 mm was used. Fig.2 and Fig.3 shows the detailing of RC control specimen and strengthened specimen respectively.

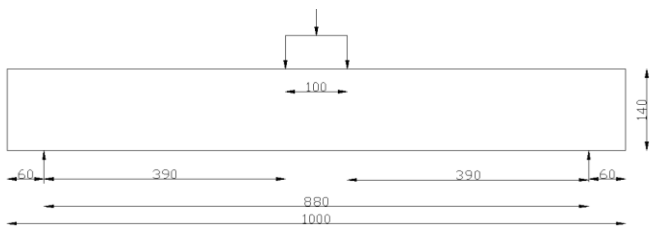


Fig -1: Test set-up

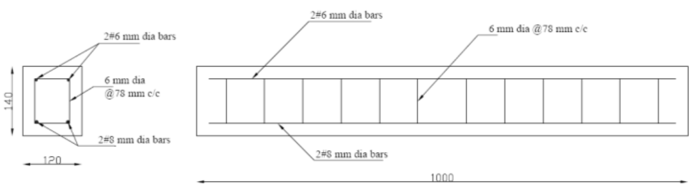


Fig -2: Detailing of Control Beam

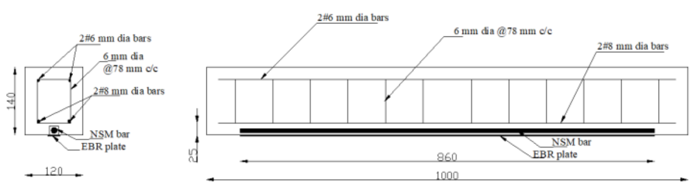


Fig -3: Detailing of Strengthened Beam

Table 1 Specification of RC Beam Specimens

Sl No	Notation	Number and size of bar (mm)	Dimension of steel plate [length x width x thickness] (each in mm)
1	CB-M20	-	-
2	CB-M25	-	-
3	CB-M30	-	-
4	HD8T1G1M20W25	1 no 8φ	860 x 25 x 1.6
5	HD8T1G1M25W25	1 no 8φ	860 x 25 x 1.6
6	HD8T1G1M30W25	1 no 8φ	860 x 25 x 1.6
7	HD8T1G2M25W25	2 no 8φ	860 x 25 x 1.6
8	HD16T1G1M25W50	1 no 16φ	860 x 50 x 1.6

2.2 Material used and its properties

For concrete mix design IS 10262:2009 and IS 456:2000 were employed inorder to achieve a 28th day compressive strength equal to 20 MPa, 25 MPa and 30 MPa. The mix proportion adopted is as shown in Table 2. For strengthening, steel bars of 8 mm and 16mm diameter having 500 MPa yield strength and steel plates of dimensions 1.6 x 25 mm and 1.6 x 50 mm having 250 MPa yield strength was used.

Lokfix S polyester resin anchor grout was used as the bonding agent between the strengthening materials and the tension surface of the concrete beams. It is a two component resin. Part A and Part B are mixed together in the ratio 1:2 by weight. The surfaces must be prepared before application. The properties provided by the manufacturer were Compressive strength of 70 MPa and Tensile strength of 11 MPa.

Table 2 Mix Proportion of Concrete

Grade	Mix Proportion				Compressive Strength (N/mm^2)	
	Cement (kg/m^3)	Fine aggregate (kg/m^3)	Coarse aggregate (kg/m^3)	w/c	7th day	28th day
M20	372.4	726.7	1180.1	0.45	11.55	25.11
M25	418.9	693.1	1174.2	0.40	19.11	34.04
M30	441.0	678.8	1169.6	0.38	32.44	40.44

2.3 Strengthening Procedure

All beams except control beams were strengthened using hybrid strengthening method. Strengthening requires careful observation and preparation of the beam. After the beam specimens were cured for 28 days they were ready for structural strengthening. The basic procedures carried out in strengthening the RC beam specimens is described below:

- The surfaces of both concrete and steel plates were prepared for proper bonding between the concrete and strengthening material is used.

- Grooves were first cut into the concrete cover (tension face) of an RC element using a special concrete saw (Fig.4). The groove dimensions were 1.5 times the diameter of NSM bar used. The length of groove and NSM steel bar is similar and equal to plate length.

(a) (b)

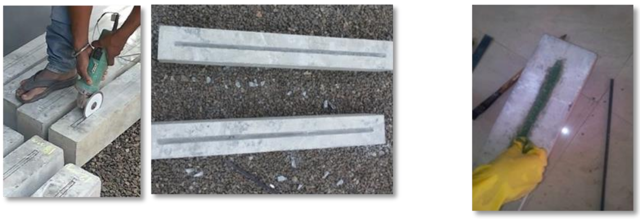
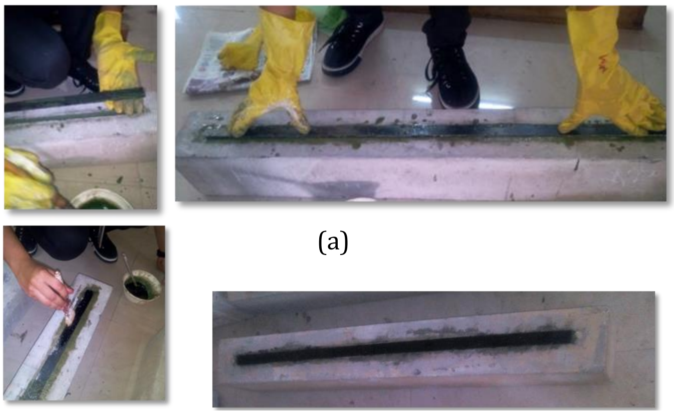


Fig -4: (a) Cutting of grooves and (b) filling of grooves with epoxy

- The properly mixed Lokfix was then spread over the bonding area of the concrete surface. The groove was half filled with epoxy and the steel bars were placed and pressed into the centre of the groove. Then, the remaining space in the groove was completely filled with epoxy. The epoxy was levelled with a spatula (Fig.4 and Fig.5). The epoxy was then applied to the bonding face of the strengthening plates. The plates were then placed on the prepared concrete beam surface. The properly placed plates were gently pressed using a rubber roller to remove the void in the interface area. After fixing the plates, the prepared beams were kept aside at least 7 days for proper curing.

- Inorder to protect the strengthening material from corrosion, the exposed surface of strengthening plate is coated with anticorrosive bituminous coating paint. Anticorrosive paint is not applied to steel bar because it is already well coated with epoxy adhesive which is a good corrosion resistant (Fig.5).



(a)

(b)

Fig -5: (a) Placement of steel plate and (b) application of anticorrosive paint

3. RESULTS AND DISCUSSIONS

3.1 Load carrying capacity and Failure mode

Table 3 provides the results obtained from the experimental tests carried out on 3 control beams and 5 strengthened RC beams. The addition of the strengthening material to the RC beams caused superior load-carrying capacity, reduced ultimate deflection, and reduced the possibility of the debonding problem. The average increment of the ultimate load-carrying capacity was 82%, compared to that of the control beam. The corresponding yield load-carrying capacity of the beams significantly improved after strengthening. The yield point was determined by the stiffness variation in the load–deflection curve. This enhanced ultimate load-carrying capacity shows the superior performance of the strengthened beams compared with that of the control beam.

Table 3 Summary of test results

Sl No	Beam ID	P_u (kN)	Δ_u (mm)	% increase in ultimate load w.r.t CB-M25
1	CB-M20	30.0	27	-
2	CB-M25	31.0	25	-
3	CB-M30	33.0	23	6.45
4	HD8T1G1M20W25	49.2	16	58.71
5	HD8T1G1M25W25	50.0	18	61.29
6	HD8T1G1M30W25	51.2	21	65.16
7	HD8T1G2M25W25	68.2	15	120.00
8	HD16T1G1M25W50	64.5	17	108.03

The failure modes of all beams are shown in Figs 6-13. The behaviour of the control beams under loading was typical flexural and all failed due to concrete crushing after steel yield mechanism. The failure modes of all strengthened beams are found to be very close to each other. Debonding of externally bonded steel plate is the most commonly reported mode of failure. After the yielding of the internal reinforcement, a cracking noise was detected like those detected from other strengthened beams. At this stage, the steel plate was stretched under high tensile strain, which was the maximum at the mid-span. Numerous new micro-cracks developed at the interface of the plate and concrete cover, which expanded. At the maximum moment zone, the primary flexural crack widened and, at some point, the steel plate could not maintain its curvature with the beam. Afterwards, the plate lost its compatibility with the concrete surface and, with a bursting sound, the debonding initiated. The failure process was quick, and no sign of NSM failure was observed. Afterwards, the load was resisted only by the NSM reinforcement. A concrete crushing failure was marked at this stage, and the machine was stopped.

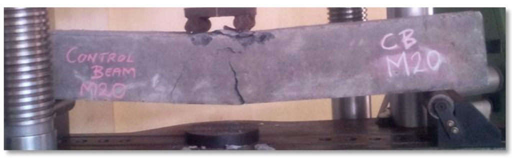


Fig -6: CB-M20

Fig -7: CB-M25

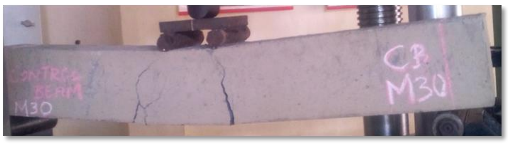


Fig -8: CB-M30

Fig -9: HD8T1G1M20W25

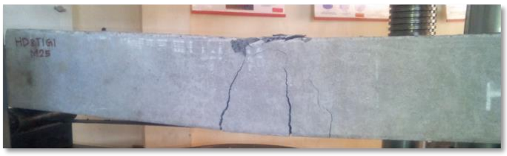


Fig -10: HD8T1G1M25W25

Fig -11: HD8T1G1M30W25

Fig -12: HD8T1G2M25W25

Fig -13: HD16T1G1M25W50

3.2 Effect of Strengthening on Stiffness

Stiffness is one of the dominant characteristics of RC structures. Change of its value with the applied load influences the deflection and curvature of any structure. Stiffness depends significantly on the cracking, the load level and thickness of bonded material and adhesive. Table 4 shows the deflection and reduction of deflection of the specimens due to strengthening by the hybrid technique at failure load of CB-M25 (31 kN) and ultimate failure load. It is observed that the deflection of the strengthened beams at this stage is less compared to that of control beam. This indicates that the strengthened specimens have good elastic stiffness when compared to control beams.

Table 4 Reduction in Deflection due to strengthening

Sl No	Beam ID	Deflection at 31 kN (mm)	Reduction (%) over CB-M25	Δ_u (mm)	Reduction (%) over CB-M25
1	CB-M20	-		27	
2	CB-M25	25.00	-	25	-
3	CB-M30	12.00	52.00	23	8
4	HD8T1G1M20W25	2.575	89.70	16	36
5	HD8T1G1M25W25	3.285	86.86	18	28
6	HD8T1G1M30W25	3.040	87.84	21	16
7	HD8T1G2M25W25	1.875	92.50	15	40
8	HD16T1G1M25W50	1.448	94.21	17	32

4.4 Effect of Strengthening on Ductility

Ductility of a member is defined as its ability to sustain large inelastic deformations prior to failure without substantial loss of strength. It is a desirable structural property because it allows stress distribution and provides warning of impending failure. These quantities are expressed as indices or factors, through relationship at two different stages, namely, at yielding of the tension steel and at ultimate load capacity.

Ductility is of two types; Deflection ductility and Energy ductility. Deflection ductility of beams is calculated as ratio of deflection at failure divided by the deflection at first steel yielding. Energy ductility of beams is calculated as ratio of energy absorbed till failure divided by the energy absorbed till first steel yielding. Ductility ratio is calculated as the percentage of ductility of the strengthened beam divided by that of the unstrengthened beam.

Table 5 and Table 6 shows the values of deflection ductility index and energy ductility index of all the tested specimen. In this study, it was observed that, during flexural strengthening of the beam using combined EBR and NSMR, there was an addition of tension reinforcement (NSMR and EBR) in the beams. So as the tension reinforcement increased, the section changed from an under reinforced section to an over reinforced section. This resulted in low ductility index values for the strengthened specimens and the failure of the specimens changed from ductile mode of failure into brittle mode of failure. Eventhough the beam failed in brittle manner, strengthening using this technique showed higher load carrying capacity and high elastic stiffness and hence the method can be recommended for retrofitting of RC beams.

Table 5 Deflection Ductility Index of Beams

Specimen	Ultimate Load (kN)	Δ_u (mm)	Yield Load (kN)	Δ_y (mm)	μ_Δ	Ductility ratio (%)
CB-M20	30.0	27	20	2.35	11.49	-
CB-M25	31.0	25	17.5	1.70	14.71	-
CB-M30	33.0	23	14	1.40	16.43	-
HD8T1G1M20W25	49.2	16	38	3.30	4.85	32.96
HD8T1G1M25W25	50.0	18	38	4.14	4.35	29.56
HD8T1G1M30W25	51.2	21	42	4.6	4.57	31.03
HD8T1G2M25W25	68.2	15	62	6.0	2.5	17.00
HD16T1G1M25W50	64.5	17	55	3.15	5.40	36.69

Table 6 Energy Ductility Index of Beams						
Specimen	Ultimate Load (kN)	E_u (Kn-mm)	Yield Load (kN)	E_y (kN-mm)	μ_E	Ductility ratio (%)
CB-M20	30.0	617.6	20	35.7	17.29	-
CB-M25	31.0	637.8	17.5	25.2	25.24	-
CB-M30	33.0	720.9	14.0	16.1	44.75	-
HD8T1G1M20W25	49.2	653.0	38	78.0	8.37	33.15
HD8T1G1M25W25	50.0	703.1	38	80.9	8.68	34.40
HD8T1G1M30W25	51.2	895.8	42	164.1	5.46	21.62
HD8T1G2M25W25	68.2	830.3	62	260.3	3.19	12.64
HD16T1G1M25W50	64.5	954.7	55	117.5	8.12	32.19

4. PARAMETRIC STUDY

The effect of bar diameter, plate thickness and bond length has been studied by various researchers [15]. Here the effect of grade of concrete and the effect of number of grooves is studied.

4.1 Effect of Grade of Concrete

The effect of grade of concrete on the strengthened specimens is shown in Fig. 14. As expected, this method with steel bars and steel plates is more helpful in increasing the failure load of the strengthened beam with low concrete strength. The percentage increase in ultimate load with respect to control beam is higher for the specimen with concrete strength of 20 MPa .Ductility index of the specimen with M20 grade was higher compared to the specimens with M30 and M25 grade concrete.

Fig 15 shows the percentage increase in ultimate load of the strengthened specimens HD8T1G1M25W20, HD8T1G1M25W25 and HD8T1G1M30W25 with respect to the control specimens CB-M20, CB-M25 and CB-M30 respectively. From the figure it is observed that higher percentage increase is shown by the specimen of less concrete strength. So it can be concluded that this strengthening scheme is more effective in specimens with less mix ratios.

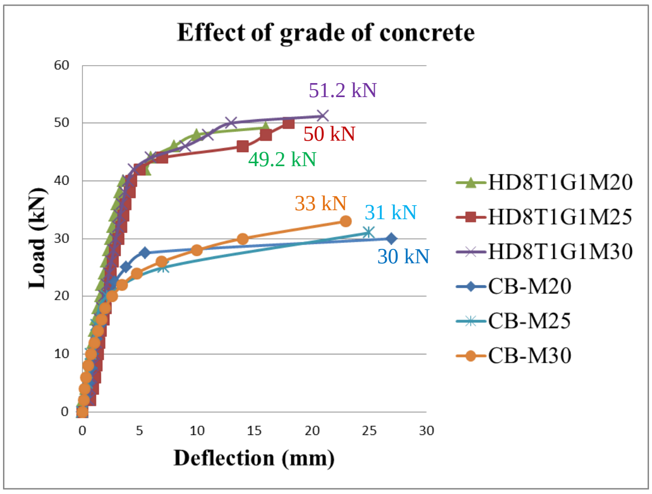


Fig -14: Effect of Grade of Concrete

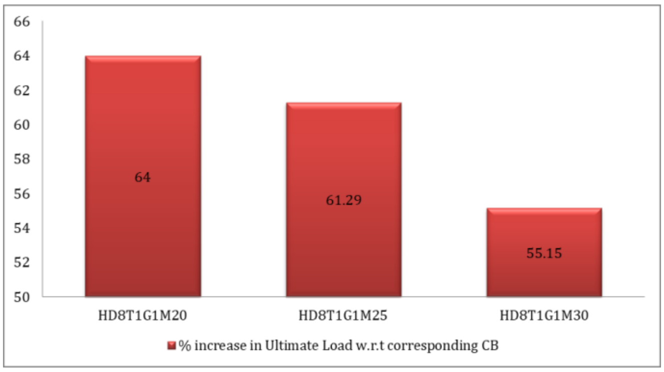


Fig -15: Percentage increase in ultimate load

4.2 Effect of Number of Grooves

To study the effect of number of grooves on hybrid strengthening method, same percentage of reinforcement is provided in single groove and two grooves. The experimental data of HD8T1G2M25W25 and HD16T1G1M25W50 were used to investigate this effect. Fig. 16 and 17 shows the effect of number of grooves on the performance of hybrid strengthening method. It was observed that an increase in the number of grooves provides increase in load carrying capacity, but it decreases both the edge clearance and clear spacing of two adjacent grooves. Consequently the possibility of edge breaking is increased. The beam specimen used in this study lack enough width to place two bars as per ACI 440.2R-08. Also, when compared to control beam (CB-M25), increasing the number of bars of same diameter showed an increase in load carrying capacity by 120% (ie: twice the % increase in load observed for specimen with one bar of same diameter). HD8T1G2M25W25 showed less ductility when compared to HD16T1G1M25W50.

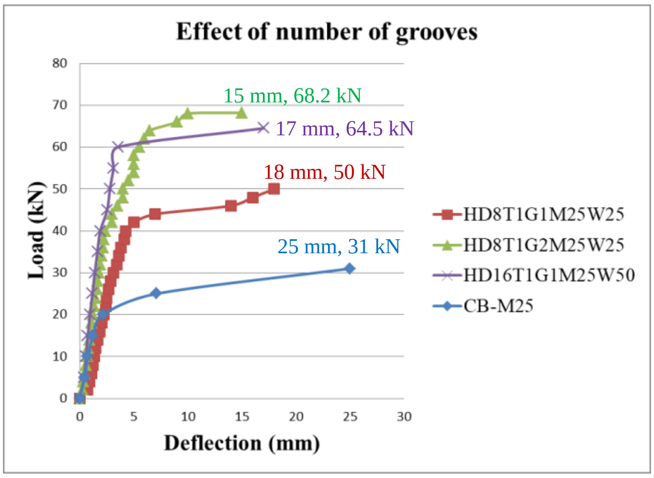


Fig -16: Effect of Number of Grooves

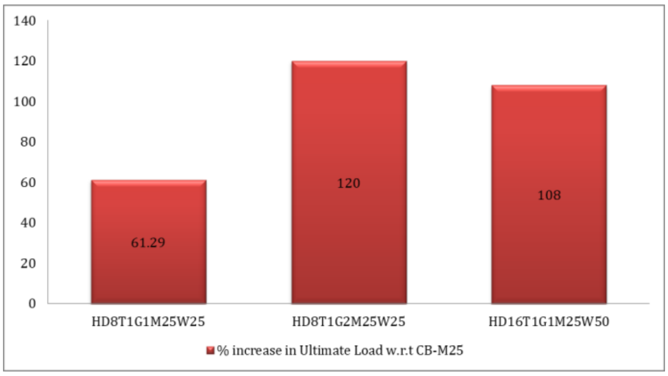


Fig -17: Percentage increase in ultimate load

5. CONCLUSIONS

- In the present study, the flexural strengthening effectiveness of beams reinforced with NSM steel bars and EBR steel plates was investigated by a series of experiments. To do so, a total of 5 beams were strengthened with steel bars and steel plates with different configurations so as to study the effect of grade of concrete and number of grooves.

- The test results of strengthened specimens and control specimens yielded promising results, which encourage using the proposed method in field applications for repair and maintenance of existing RC structures. Flexural strengthening using combined NSMR and EBR significantly enhanced flexural capacity, stiffness and ductility of existing RC members.

- The increase in ultimate load ranged from 58% to 120% in comparison to non-strengthened reference beams. The ultimate deflection values of the strengthened beams decreased by an average of 30% when compared with the ultimate deflection value of control beam. Failure of strengthened beams occurred by debonding of externally bonded steel plate after the flexural cracks widened. No sign of NSM failure was observed.

- Strengthening of RC beams with combined EBR and NSMR method significantly increased the load carrying capacity of beams having low concrete strength. Hence it was found to be effective in specimens made of concrete with less mix ratios.

- As the number of grooves increased, the percentage of reinforcement increased and there was a significant increase in the load carrying capacity of the specimen. But higher ductility and stiffness was observed for specimens with same percentage of reinforcement provided in single groove due to the use of higher diameter NSMR.

REFERENCES

[1] Ahmed H.Al-Abdwais and Riadh S.Al-Mahaidi (2017),"Bond properties between carbon fibre reinforced polymer (CFRP textile) and concrete using modified cement based adhesive", Construction and Building Materials, Elsevier, Vol 154, pp 983-992.

[2] B.Yu and V.K.R Kodur (2014), "Effect of high temperature on bond strength of near-surface mounted FRP reinforcement", Composite Structures, Elsevier, Vol 110, pp 88-97.

[3] D. H. Lim (2009), "Combinations of NSM and EB CFRP strips for flexural strengthening of concrete structures", Magazine of Concrete Research, www.concrete-research.com Vol 61, pp 633-643.

[4] Davood Mostofinejad , Amirreza Moghaddas (2014), "Bond efficiency of EBR and EBROG methods in different flexural failure mechanisms of FRP strengthened RC beams", Construction and Building Materials, Elsevier, Vol 54, pp 605-614.

[5] Davood Mostofinejad, Seyed Masoud Shameli (2013),"Externally bonded reinforcement in grooves (EBRIG) technique to postpone debonding of FRP sheets in strengthened concrete beams", Construction and Building Materials, Elsevier, Vol 38, pp 751-758.

[6] Firas Al-Mahmoud, Arnaud Castel , Raoul François (2012), "Failure modes and failure mechanisms of RC members strengthened by NSM CFRP composites-Analysis of pull-out failure mode", Composites: Part B, Elsevier, Vol 43, pp 1893-1901.

[7] Firas Al-Mahmoud, Arnaud Castel, Raoul François , Christian Tourneur (2009), "Strengthening of RC members with near-surface mounted CFRP rods" , Composite Structures, Elsevier, Vol 91, pp 138-147.

[8] Francesca Ceroni, Marisa Pecce, Antonio Bilotta, Emidio Nigro (2012), "Bond behaviour of FRP NSM systems in concrete elements", Composites: Part B, Elsevier, Vol 43, 99-109

[9] G Al-Bayati, R Al-Mahaidi (2014) "Effective bond length of modified cement-based adhesive for FRP-NSM strengthening system", 23rd Australasian Conference on the Mechanics of Structures and Materials, pp 389-396.

[10] Haixia Zhang, Luyuan He, Guochang Li (2015), "Bond failure performances between near-surface mounted FRP bars and concrete for flexural strengthening concrete structures", Engineering Failure Analysis, Elsevier, pp 1-12.

[11] Hayder A. Rasheed, Richard R. Harrison, Robert J. Peterman, Tarek Alkhrdaji (2010), "Ductile strengthening using externally bonded and near surface mounted composite systems", Composite Structures, Elsevier, Vol 92, pp 2379-2390.

[12] Ismail M.I. Qeshta a,b, Payam ShaFig.h c, Mohd Zamin Jumaat (2016), "Research progress on the flexural behaviour of externally bonded RC beams" , Archives Of Civil And Mechanical Engineering, Elsevier, Vol 16, pp 982-1003.

[13] Kh Mahfuz ud Darain, Mohd Zamin Jumaat, Ahmad Azim Shukri, M. Obaydullah, Md. Nazmul Huda, Md. Akter Hosen and Nusrat Hoque (2016), "Strengthening of RC Beams Using Externally Bonded Reinforcement Combined with Near-Surface Mounted Technique" , Polymers, www.mdpi.com, Vol 261, pp 1-23.

[14] Md. Moshiur Rahman, Mohd Zamin Jumat, Md. Akter Hosen, and A. B. M. Saiful Islam (2016) Effect of adhesive replacement with cement mortar on NSM strengthened RC Beam, University of Malaya, ResearchGate, pp 61-72

[15] Md. Moshiur Rahman, Mohd Zamin Jumaat, Muhammad Ashiqur Rahman, Ismail M.I. Qeshta (2015), "Innovative hybrid bonding method for strengthening reinforced concrete beam in flexure", Construction and Building Materials, Elsevier, Vol 79, pp 370-378.

[16] Renata Kotynia and Szymon Cholostiakow (2015), "New Proposal for Flexural Strengthening of Reinforced Concrete Beams Using CFRP T-shaped Profiles", Polymers, www.mdpi.com, Vol 7, pp 2461-2477.

[17] Thomas H.-K. Kang, Joe Howell, Sanghee Kim and Dong Joo Lee (2012), "A State-of-the-Art Review on Debonding Failures of FRP Laminates Externally Adhered to Concrete", International Journal of Concrete Structures and Materials, Springer, Vol 6 , pp 123-134.

[18] Harjinder Singh and Shikha Bansal (2015), "Effect of Silica Fume on the Strength of Cement Mortar", International Journal of Research in Engineering and Technology, Vol 4 , pp 623-627.