Improving the Mechanical Properties of Low, Normal and High Strength Concretes

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Abstract Improvement the mechanical properties (compressive and flexural strength) of low, normal and high strength concrete (LSC, NSC and HSC) was investigated experimentally in this work by used CFRP sheets and steel fibers. The experimental program of this research was consisted of two parts, first part was aimed to evaluate the effect of confinement by CFRP sheets on the compressive strength on the cubes and cylinders, while the second part was investigated the effect of strengthening by CFRP sheets, adding steel fibers and use both on modulus of rupture. Comparison with unconfined specimens, results show that the confinement by CFRP was increased the cube compressive strength about 208, 47 and 27% for LSC, NSC and HSC, respectively, while the increasing in cylinder compressive strength was 216, 64 and 51%. On the other hand, increasing in modulus of rupture for LSC was 373.93, 84.83 and 506.6% for specimens with CFRP, steel fiber and both used of CFRP with steel fibers, respectively. While this increasing for HSC was 575, 128.2 and 725.64% for CFRP, steel fibers and both used of CFRP with steel fibers, respectively. However, for NSC, the percentage of increasing was 455.7, 73 and 605% for the same order.

Keywords Mechanical properties · CFRP · Steel fibers · High strength concrete · Low strength concrete

1 Introduction

As of late, the utilization of fiber fortified polymers (FRP) as a remotely wrapping have accomplished significant fame for the reinforcing and fixing of solid structures. The FRP composites have been utilized effectively for restoration and fortifying of insufficient and additionally redesigning fortified solid components.

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The potential market for such applications is gigantic since the evaluated yearly expense of fixing spans in the United States alone is 9.4 billion dollars [1].

One famous procedure of FRP fortifying is the wrapping of strengthened solid sections to expand their hub quality, shear quality, and seismic obstruction. In this application, the FRP sheets are commonly folded over the segments with fibers arranged principally in the circumferential (loop) heading.

The fibers limit the solid and increment the hub quality by making a triaxial stress condition. The FRP wraps additionally increment the shear opposition of sections and avert untimely disappointments when segments are exposed to parallel loadings run of the mill of those saw amid tremors [3].

2 Literature Review

Concrete is more grounded in managing compressive strength in contrast with the rigidity. Elasticity of cement is 3–5 $\sqrt{fc'}$, though Modulus of burst is 8–12 $\sqrt{fc'}$ With the advancement of the idea of admixtures and remote material in the solid for upgrading solid properties to the dimension that it can supplant steel, a few accomplishments have been made in this field. Among these accomplishments fiber support is a long ways ahead than some other substitutes in changing solid essential properties. Arrangements of trials were led to examine the viability of fiber consideration in the improvement of mechanical execution of cement with respect to solid sort and example measure [2]. Strands assume a significant job in achieving a distinct burden bearing limit after the grid crack, contingent upon allotment, introduction and implanted length [6]. FRP cylinder or sheet (coat) fortification has straight versatile conduct up to disappointment and applies a regularly expanding binding weight on the solid center. This conduct results in impressive improvement in quality and malleability of solid when stacked pivot ally. Such trial information have been accounted for cement encased in FRP tubes [4, 7, 9, 13], as well as for concrete confined by FRP jackets [5, 10, 15, 16]. Steel fiber fortified cement have the upgraded properties; progressively pliable, improved toughness, auxiliary quality, necessities for steel support diminishes, improvement in the effect and scraped spot obstruction. In the vast majority of the examinations in FRP restricted cement with pivotal compressive burden, shear cone disappointment of the solid was referenced on the grounds that no endeavor was made to lessen erosion between the solid and the steel bearing platen. Research has been led on the impact of grinding that is created between the example and the stacking platen on the variety of parallel strain [12]. In the examinations accessible, the cover length was considered with no computation or pretests for each extraordinary FRP material and cross-area [8, 11]. There is a variety in the setup of the overlap (in each layer or just in the external) that influences the control volumetric proportion of the cross—area and the outcomes got. Likewise there is a variety in the overlap length that is utilized. No diagnostic connection exists for the estimation of the best possible cover length. So pretests are important to maintain a strategic distance from the unwanted cover disappointment.

Fiber support tends to the deficiency of the ordinary cement for example Low rigidity, Brittleness, low post splitting limit. Fibers make the solid holding more grounded by expanding the interlocking quality.

3 Research Significance

This research aims to investigate the effect of confinement by CFRP fabrics on the compressive strength of plain concrete, in the other hand the second part of this paper conducted to find the effect of CFRP fabrics and steel fibers on the flexural strength of plain concrete, also.

4 Experimental Work

4.1 Materials Properties

4.1.1 Concrete Mix Proportions

Three types of concrete were used in this work; low, normal and high strength concrete, Table 1 show mix proportions for these types.

4.1.2 CFRP Sheets and Resin

The carbon fiber sheets used in this study were the SikaWrap-230C product, a unidirectional wrap. The manufacturer's guaranteed tensile strength for this carbon fiber is 4300 MPa, with a tensile modulus of 238 GPa, ultimate elongation of 18%, and a sheet thickness of 0.13 mm. The resin system that was used to bond the carbon fabrics over the cylinders in this work was the epoxy resin made of two-parts, resin and hardener. The mixing ratio of the two components by weight was 4: 1. SikaWrap-230C was field laminated using Sikadur-330 epoxy to form a CFRP wrap used to strengthen the concrete specimens.

Table 1 Concrete mix proportions

Concrete type	Cement (Kg/m^3)	Sand (Kg/m^3)	Gravel (Kg/m^3)	w/c	Superplasticizer (%)	Steel fibers (%)
NSC	410	672	1050	0.45	0	1
LSC	342	730	1050	0.6	0	1
HSC	540	564	1050	0.35	1	1

Table 2 Details of testing specimens

Concrete type	Type of enhancement	No. of cylinders	No. of cubes	No. of prisms
LSC (L)	Unconfined (U)	3	3	3
	Confined (C)	3	3	3
	Steel fiber (S)	3	3	3
	CFRP + Steel fiber (CS)	3	3	3
NSC (N)	Unconfined (U)	3	3	3
	Confined (C)	3	3	3
	Steel fiber (S)	3	3	3
	CFRP + Steel fiber (CS)	3	3	3
HSC (H)	Unconfined (U)	3	3	3
	Confined (C)	3	3	3
	Steel fiber (S)	3	3	3
	CFRP + Steel fiber (CS)	3	3	3

4.2 Experimental Program

A total of 36 cylinders of 100 mm diameter and 200 mm height and 36 cubes of 150 mm side length were tested under axial compression loading. Also a total of 36 prisms of 100 × 100 × 500 mm were tested under tow point loading. Three types of specimens; cubes, cylinders and prisms denoted by C, Y and P, respectively, three mixtures of concrete cylinders LSC, NSC and HSC labeled with L, N and H, respectively, were investigated in the present work. Four types of concrete enhancement were used in this study; unconfined, confined by CFRP, addition of steel fibers and confined by CFRP with addition of steel fibers denoted by U, C, S and CS. For each group of testing parameters, three identical specimens were examined and labeled with A, B and C. For example, the specimen CN-CB is the second cubes (C) specimen (B) of Normal concrete (N) confined with CFRP materials (C). Table 2 collects the experimental parameters investigated in this study.

4.3 FRP Wrapping and Testing Procedure

Following 28 days of relieving, the solid examples were cleaned and completely dried. For each layer of FRP wrap, two employs of epoxy, one on the example surface and the other on the outside of the introduced wrap, were connected utilizing paintbrushes to completely soak the layers with epoxy. In light of the presumption of [14, 17, 18] which demonstrated that the FRP layer was folded over the examples with a cover of 1/4 the border to counteract slipping or separation fiber amid testing and guarantee the advancement of the full composite quality. Examples were examined under a monotonic hub pressure load (for cubes and cylinders) and flexural load (for prisms) up to collapse.

5 Experimental Results

The mechanical properties of the tested specimens (mean-values) are listed in Table 3. From this table, it can be seen that carbon fiber composite confinement can significantly enhance the ultimate strengths and strains of plain concrete. The mean value for three specimens.

5.1 Compressive Strength and Observed Failure Modes

5.1.1 Effect of CFRP Confinement

The results show that CFRP confinement can significantly enhance the ultimate strength and strain of concrete cubes and cylinders. In comparison with unconfined concrete, for CFRP confined concrete, the cubes compressive strength exhibited an average gain of 208%, 47% and 27% for LSC, NSC and HSC, respectively. Also, for cylinders of CFRP confined concrete, the average gain was 216%, 64% and 51% for LSC, NSC and HSC, respectively. While the effect of steel fibers was slightly on the compressive strength as shown in Table 3.

Table 2 Details of testing specimens

Concrete type	Type of enhancement	No. of cylinders	No. of cubes	No. of prisms
LSC (L)	Unconfined (U)	3	3	3
	Confined (C)	3	3	3
	Steel fiber (S)	3	3	3
	CFRP + Steel fiber (CS)	3	3	3
NSC (N)	Unconfined (U)	3	3	3
	Confined (C)	3	3	3
	Steel fiber (S)	3	3	3
	CFRP + Steel fiber (CS)	3	3	3
HSC (H)	Unconfined (U)	3	3	3
	Confined (C)	3	3	3
	Steel fiber (S)	3	3	3
	CFRP + Steel fiber (CS)	3	3	3

The ultimate strength of CFRP confined concrete cylinders was increased with the amount of composite wrapping. All the FRP confined concrete specimens failed by the rupture of CFRP jacket as a result of hoop tension. During the loading state, crack sounds in the CFRP jacket started at approximately 60% of the ultimate compressive stress. The failure was gradual, and finished with a sudden and explosive noise. The rupture of the CFRP confined concrete cylinders can be divided into two modes, ringed rupture and localized FRP rupture at the lower, mid and top sections, but the confined concrete cubes was circumferential. Figure 1 shows examples of both of these failure modes.

5.1.2 Effect of Steel Fibers

The effect of steel fibers on the compressive strength was slightly compared with CFRP confinement. Comparison with specimens without steel fibers, for concrete cubes specimens with steel fibers was increased the compressive strength by 33%, 14% and 10% for LSC, NSC and HSC, respectively. While for concrete cylinders was 36, 24 and 14% for the same order.

5.1.3 Combined Effect of CFRP and Steel Fibers

The effect of CFRP confinement for fiber concrete was very close to CFRP confinement for plain concrete, the increase in compressive strength for concrete cubes specimen was 253%, 54% and 31% for LSC, NSC and HSC, respectively. While for concrete cylinders was 258, 82 and 62% for the same order. The inclusion of steel fibers in cubes and cylinders resulted in a significantly enhanced ductility which made the specimens fail gradually in a ductile manner, unlike non-fibrous specimens which showed lesser ductility at failure.

5.2 Flexural Strength

Strengthening by CFRP sheets plays the main role in increasing the flexural strength of plain concrete prisms; the increasing ratio was 305%, 352% and 430% for LSC, NSC and HSC, respectively. On the other hand the addition of steel fibers to concrete had little effect than CFRP on the flexural strength; the increasing ratio was 43%, 59% and 114% for LSC, NSC and HSC, respectively. The strengthening by CFRP sheets for fiber concrete made the highest difference in the flexural strength; the increasing ratio was 400%, 472% and 660% for LSC, NSC and HSC, respectively.

Unconfined Cylinder Confined Cylinder

Unconfined Cube Confined Cubes

Fig. 1 Typical failure of CFRP wrapped specimens

6 Conclusions

1. The compressive strength capacities of the specimens wrapped with CFRP sheets are greatly improved compared to the unconfined concrete specimens.

2. Failure of all confined concrete specimens is marked by the rupture of FRP materials, it occurs prematurely.
3. The confinement effectiveness increases with the decrease of unconfined concrete strength, the confinement for concrete cylinders led to an increase of compressive strength by about 216%, 64% and 51%, respectively for LSC, NSC and HSC of unconfined cylinders strength.
4. The confinement by CFRP sheets was more effective for concrete cylinders than cubes due to the shape effect and concentration of stresses in the corners of the concrete cubes.
5. The effect of steel fibers on the compressive strength was slightly compared with CFRP confinement, but the inclusion of steel fibers in cubes and cylinders resulted in a significantly enhanced ductility which made the specimens fail gradually in a ductile manner, unlike non-fibrous specimens which showed lower ductility at failure.
6. Strengthening by CFRP sheets for concrete prisms showed great effect in increasing the flexural strength; the increasing ratio was 305%, 352% and 430% for LSC, NSC and HSC, respectively.

References

1. ASCE (2005) Report card for America's infrastructure. Available from http://www.asce.org/reportcard/2005/. Accessed 23 Jan 2005
2. Balendran RV, Zhou FP, Nadeem A, Leung AYT (2002) Influence of steel fibres on strength and ductility of normal and lightweight high strength concrete. Build Environ 37(12): 1361–1367
3. Green MF, Bisby LA, Fam AZ, Kodur VKR (2006) FRP confined concrete columns: behaviour under extreme conditions. Cement Concr Compos 28(10):928–937
4. Harmon T, Slattery K, Ramakrishnan S (1995) The effect of confinement stiffness on confined concrete. In: Proceedings of the second international RILEM symposium (FRPRCS-2) on non-metallic (FRP) reinforcement for concrete structures, Ghent, 23–25 Aug 1995, pp 584–592
5. Harries K A, Kestner J, Pessiki S, Sause R, Ricles J (1998) Axial behavior of reinforced concrete columns retrofit with FRPC jackets. In: Proceedings of the 2nd international conference on composites in infrastructure ICCI'98, Tucson, Arizona, pp 411–425
6. Holschemacher K, Mueller T, Ribakov Y (2010) Effect of steel fibers on mechanical properties of high-strength concrete. ELSEVIER Materi Des 31:2604–2615
7. Irmiran A, Shahawy M (1997) Behavior of concrete columns confined by fiber compo-sites. ASCE J Struct Eng 123(5):583–590
8. Kono S, Inazumi M, Kaku T (1998) Evaluation of confining effects of CFRP sheets on reinforced concrete members. In: Proceedings of the 2nd international conference on composites in infrastructure ICCI'98, Tucson, Arizona, pp 343–355
9. Li P, Sui L, Xing F, Zhou Y (2019) Static and cyclic response of low-strength recycled aggregate concrete strengthened using fiber-reinforced polymer. Compos Part B: Eng 160: 37–49
10. Matthys S, Taerwe L, Audenaert K (1999) Tests on axially loaded concrete columns confined by fiber reinforced polymer sheet wrapping. In: 4th international symposium on fiber reinforced polymer reinforcement for reinforced concrete structures, pp 217–228

11. Miyauchi K, Nishibayashi S, Inoue S (1997) Estimation of strengthening effects with carbon fiber sheet for concrete column. In: Proceedings of the third international symposium (FRPRCS-3) on non-metallic (FRP) reinforcement for concrete structures 1, Saporo, Japan, pp 217–224
12. Rochette P, Labossiére P (2000) Axial testing of rectangular column models confined with composites. ASCE J Compos Constr 4(3):129–136
13. Samaan M, Mirmiram A, Shahawy M (1998) Model of concrete confined by fiber composites. ASCE J Struct Eng 124(9):1025–1031
14. Shahawya M, Mirmiranb T, Beitelman T (2000) Tests and modeling of carbon wrapped concrete columns. Compos Part B: Eng 31:471–480
15. Toutanji H (1999) Stress-strain characteristics of concrete columns externally confined with advanced fiber composite sheets. ACI Mater J 96(3):397–404
16. Wang YC, Restrepo JI, Park R (2000) Retrofit of reinforced concrete members using advanced composite materials. University of Canterbury, Civil Engineering, Research Report 2000-3. Christchurch, New Zealand, Feb 2000
17. Youxi Y, Shengning L, Qiongming J, Leilei Z, Yingna H (2019) A review on concrete structures strengthened with CFRP sheets bonded with organic and inorganic cementation materials. Adv Civil Eng 8(1):1
18. Zhou Y, Zheng Y, Sui L, Xing F, Hu J, Li P (2019) Behavior and modeling of FRP-confined ultra-lightweight cement composites under monotonic axial compression. Compos Part B: Eng 162:289–302