CONSTRUCTION
e-ISSN: 2785-8731
VOL. 2, ISSUE 1, 136 – 143
DOI: https://doi.org/10.15282/cons.v2i1.7712

ORIGINAL ARTICLE

Flexural Strengthening of Normal Strength Plain Concrete Beams using Ultra-High Performance Fiber Reinforced Concrete Strips

S.A. Ashti[1], R. Serwan[2] and F.R Karim[3,*]

[1]MSc. Student, Civil Engineering Department, College of Engineering, University of Sulaimani. Iraq.
[2]Assistant Prof, Civil Engineering Department, College of Engineering, University of Sulaimani, Iraq.
[3]Lecture, Civil Engineering Department, College of Engineering, University of Sulaimani, Iraq.

ABSTRACT – In recent years, the strengthening of reinforced concrete elements in existing structures has become a very important interest topic because of the demand for development structures and extending their service life. Since the ultra-high-performance fiber-reinforced concrete properties in terms of durability and strength are fully exploited, it became early in the rehabilitation and strengthening field. This paper highlights the flexural behavior of small-scale plain normal strength concrete beam strengthened in flexure by ultra-high performance fiber reinforced concrete strips at the tensile surface by adhesive epoxy material to evaluate and quantify the effect on strength in flexure. Experimental results indicated that the ultra-high performance fiber reinforced concrete strengthening strips enhanced the flexural capacity and stiffness of the normal strength concrete substrate by 369%, 364%, and 168% at crack load and 364%, 232%, and 127% at ultimate load for concrete grades 20.8, 32.6 and 43.3 MPa respectively, delayed the crack development corresponding to apply load more than 0.37, 0.97 and 1.25 kN for strips thickness 10, 15 and 20 mm respectively in all grades of concrete beam and improved beams' ductility behavior. The main important point that affects the performance of flexural strengthening concrete beams using adhesive material is the quality of the interfacial transition bonded zone of the composite system produced between the strengthening material and the existing concrete substrate.

ARTICLE HISTORY
Received: 16th May 2022
Revised: 01st June 2022
Accepted: 10th June 2022

KEYWORDS
Flexure strength
Normal strength concrete
Strengthening strips
Ultra-high performance fiber reinforced concrete

INTRODUCTION

Reinforced concrete is one of the most widely used modern building materials globally. However, due to overcapacity, aging, and various destructive change in environmental conditions during many years of service life, RC structures going toward drop their carrying load capacity, stiffness, and durability; rather; in many cases, they are used for a different purpose than their initial design requirement. Therefore, strengthening the deterioration of RC structures becomes crucial to restore their functions and extend their life to avoid the community charges in terms of demolition and reconstruction [1]. Recently, there are several methods of rehabilitation and strengthening techniques using externally applied on structures elements as a part of strengthening or already damaged members, which have been currently explored in most literature., such as strengthening with fiber-reinforced polymers (FRP), which is a widespread method that is not time-consuming, nor a change in the geometry of the strengthened elements, and increases the load-carrying capacity of the strengthened structures element. FRPs have critical disadvantages with the concrete element where de-bonding is possible. Furthermore, the FRPs do not present ductility, and for the right application of the material, experienced and trained staff is required [2]. It is revealed that the bond act performance between the external strengthening stuff and old concrete of the structures is still a weak point in the strengthening mechanism of the structures and needs improvement for the durability of the strengthened structures.

Ultra-high-performance concrete (UHPC), as an original cement-built composite material, has been developed in different countries. These different particles of mixture composite are organized based on their gradient in a way to produce maximum packing density, with low water to binder ratio smaller than 0.2 by using a superplasticizer agent and adding steel fibers with volume content of 1-4% led to output concrete with high tensile strength greater than 7 MPa and compressive strength greater than 150 MPa, and high energy dissipation capacity with ductile failure due to fibers [3], [4]. Recent studies indicated that concrete combined with steel fibers subjected to cyclic loading displayed extra load-bearing capacities, cracking resistance, energy dissipation values, and deformation capability compared to the non-fibrous concrete [5]. Moreover, the strength of UHPFRC could be improved faster throughout the thermal treatment process, where shrinkage and creep coefficients are small in that curing process [6]. The mechanical properties of UHPFRC are superior to normal concrete reinforced with steel or fiber due to low air content and low water permeability that guarantees high durability, the water absorption coefficient of UHPC with water to binder ratio of 0.4 was 0.04 at 14 days. However, it decreased to 0.0025 at water to binder ratio of 0.17. In addition, the permeability coefficient of concrete before 28 days decreased with the prolongation of curing age. The corresponding value of UHPC after 98 days was 0.0005, which is one-third of conventional concrete [7]. Overall, due to these outstanding mechanical and physical performances, UHPFRC becomes a good alternative for strengthening deteriorated RC structures under flexure, which might enhance

***CORRESPONDING AUTHOR** | F.R Karim | ✉ ferhad.karim@univsul.edu.iq

the flexural capacity and ductility and improve the permeability and durability of the specific strengthened structure element; the test results from the conducted study revealed that the performance of the proposed composite system was successfully enhanced in both flexural and shear capacity [8].

Currently, many researchers focus on the flexural strengthening of RC structures using the UHPFRC layer [9]. Therefore, this research is now intensive on strengthening technique by UHPFRC due to combining the strength of elements, cost-effectiveness, ease, and speed of preparation and application, rather than the investigations indicating that the combined UHPFRC layer to RC elements enhanced the stiffness, resistance capacity, and durability. In this regard, two different interface techniques use for the strengthening, sandblasting RC substrate surfaces and then casting UHPFRC and prefabricated UHPFRC strips bonded to RC element using an epoxy adhesive [10]. Test results showed that both techniques guaranteed the RC and UHPFRC layers bond.

Bonding properties and quality between the ordinary concrete and the strengthening materials is one of the most important issues in strengthening processes. Many codes provide several tests to ensure a desirable strong bond, such as ASTM. Several researchers have conducted experimental work and found a perfect bond property between the substrate and adhesive materials, especially for fiber-reinforced cementitious materials used to strengthen and repair structural elements. In this framework, various tests were carried out, such as; the slant-shear test with the inclined bond interface at 55°, 60°, and 70°, pull off, and splitting tensile tests for two different bond methods epoxy-bonded (EP), and sandblasted (SB). The outputs present those normal concrete specimens with rough surfaces made by sandblasting present higher slant shear strength compared to epoxy-bonded ones.

Furthermore, the findings of splitting tensile strength reported a perfect bond between normal concrete and UHPFRC [9]. Similarly, split tensile strength, and slant-shear tests measured the bond strength between the host concrete and ultra-high performance fiber concrete UHPFRC. The results indicated that UHPRFC provides perfect bonding at the early strengthening age and works strongly together with the surface of the normal concrete [11]. Moreover, several experimental works were carried out and found excellent bonding between the host concrete and UHPFRC in different strengthening techniques. It was related to this concept, the outputs of the tensile splitting test highlight that the failure commonly happens in normal concrete samples. UHPFRC bonded very powerfully and efficiently with the normal concrete, where the wire brush and scabbing techniques behave almost monolithic [12].

OBJECTIVES OF THE STUDY

The aim of the present study are to evaluate the performance of strengthening different grades 21, 31, and 41 MPa of normal strength plain concrete beam substrate by different thicknesses 10, 15, and 20 mm of UHPFRC strips, jointed together with adhesive epoxy resin in the interface area. In addition, they are quantifying the effect of variations in thicknesses of UHPFRC strips used for strengthening normal strength plain concrete beam on the ultimate flexure load capacity of the substrate.

EXPERIMENTAL PROGRAM

This experimental research attempts to strengthen different grade NSC plain beams substrate by UHPFRC strips with various thicknesses through the adhesive epoxy resin in the interface area.

METHODOLOGY

The current research investigates pioneering technique for the strengthening of concrete structures in flexure by using an unconventional material that is UHPFRC strips with different thicknesses bonded with different grades of NSC element through epoxy adhesive material,

The mixing design of normal strength concrete adopted in this study to ensures obtaining three grades of average compressive strength for specimens 21 MPa, 31 MPa, and 41 MPa at 28 days, producing specimen beams with dimensions of 100 mm width, 50 mm height, and 500 mm length to be used as a control specimen and substrate specimen height. Correspondingly mix design of UHPFC was adopted to produce strips for all grades of NSC specimens strengthening with the same dimensions except the thickness of strips which varies from 10 mm to 20 mm, for the best configuration evaluation of bonding strength.

In this study, the TYTAN FIX JET 20 adhesive, which was designed for bonding two pre-cast concrete surfaces used for bonding the surface of UHPFRC strips which were produced separately in molds having the dimensions corresponding to the full length and width of the NSC specimens were strengthened, surface for which it will be attached to, after curing procedure of both strips and NSC elements.

MATERIALS

Plain NSC beams specimens

Different grades of normal strength plain concrete were used in this study *i.e.* 21, 31, and 41 MPa for substrate plain beams. All mixes contain Type-I ordinary Portland cement, river sand with a fineness modulus of 2.4, coarse aggregate with a maximum size of 9.5mm, and different water-to-cement ratios according to the strength desired. The slump value of fresh concrete was between 150-180 mm. The mix proportion of the normal strength plain concrete substrate beams is displayed in Table 1. For each grade of concrete, consider two samples with dimensions of 50 mm depth, 100mm width, and 500 mm overall length for substrate beams and different concrete grade strengths. Slandered cylinders have been taken from NSC mixes for 28 days to ensure desired compression strength.

Table 1: Mix proportion of different normal strength concrete grades

Concrete type	Targeted strength, MPa	w/c	Mix proportion Cement: Fine aggregate: Coarse aggregate		
NSC	21	0.67	1	2.1	2.32
NSC	31	0.56	1	1.6	1.93
NSC	41	0.49	1	1.23	1.61

ULTRA-HIGH PERFORMANCE FIBER REINFORCED CONCRETE STRIPS

The mix design of UHPFRC strips strengthening objective, achieved by optimizing packing density of cementitious composite materials, with a very low water-binder ratio, contains Type-I ordinary Portland cement, densified silica fume, well-graded sieved and dried mining sand, copper-coated micro steel fibers and poly-carboxylate based superplasticizer. The straight copper-coated micro steel fibers used in the study have the properties shown in Table 2. A specific aspect ratio of 40 was selected to prevent micro-crack growth and interconnectivity by absorbing the tensile stresses based on mixed fiber content, which is 2 % by volume [3]. The standard cylinder has been taken from the UHPFRC mix to ensure mechanical properties at 28 days. The mix proportions of the UHPFRC strips as shown in Table 3.

Table 2: Straight coated copper micro steel fibers properties

Fiber type	Diameter mm	Length mm	Aspect ratio	Tensile Strength, MPa	Elastic Modulus, GPa
High strength coated copper micro steel fibers	0.20	8	40	≥2859	45-50

Table 3: Mix proportions for ultra-high performance fiber reinforced concrete

Concrete type	Target strength MPa	Mix proportion					
		w/b	Cement	Silica fume	Plasticizer	Silica sand	Micro-steel fiber % by volume
UHPFRC	≥150	0.24	1	0.25	0.0187	0.45	2

EPOXY ADHESIVE MATERIAL

The evidence regarding bond strength between a substrate's normal strength plain concrete beams to UHPFRC as strengthening material reported in the literature indicates that the important property ensuring the effectiveness of any concrete strengthening is the bond strength between the existing concrete substrate and the strengthening material [3]. Besides the degree of surface preparation roughness of the substrate, the bond strength is governed by the mechanical properties of the NSC substrate and strengthening material, especially the tensile strength that controls crack development at the interface [13].

To assess the bond quality of TYTAN FIX JET 20 requirements as adhesive. This epoxy is used for jointing normal strength concrete plain beams with UHPFRC strips. Pull-off test implements for checking the bond between two parts by preparing three NSC slab specimens for three different grades of concrete 21, 31, and 41 MPa with preparing of three sets of UHPFRC strips with different thicknesses of 10, 15, and 20 mm and the other dimensions like the NSC beam interface.

After the end of 28 days curing process, each set of strips with thicknesses of 10, 15, and 20 mm combined with one of the different grades of concrete slabs by adhesion epoxy, as shown in Figure 1(a) and kept until the end of adhesion curing time. After implementation of the previous stage, execution of three cores on each combined slab-strip made to the depth on NSC slab specimen equal to the thickness of each strip above them, with 50 mm diameter in order to combine instrument dolly with the top surface of strips using the same adhesive material, as shown in Figure 1(b). The last stage is implanted after the adhesive curing period by applying direct tension force on the dolly to pull off the substance, as shown in Figure 1(c). The result shows that the adhesive agent is acceptable for the study since de-bonding does not occur in the adhesive layer despite detachment and separation from the surface of NSC slab specimens occur in all grades, which ensures that no de-bonding occurs in the testing process, as shown in Figure 1(d).

(a) Attached NSC substrate with UHPFRC strips (b) cores execution and attached instrument dolly

(c) pull-off by applying direct tension force on the dolly (d) Separation of the NSC surface without adhesive de-bonding

Figure 1: Pull-off test phases

SPECIMEN PREPARATION

The mold of normal strength plain concrete beams was prepared by plywood with dimensions of 100 mm × 50 mm × 500 mm for the three grades of concrete strength; for each grade, two specimens were prepared and denoted as A1 for concrete grade 21 MPa, B1 for grade 31 MPa, and C1for grade 41MPa.The fresh NSC mix was placed in the molds and left to set for 24 hours. After that, the NSC specimens were demoulded and cured for 28 days in a water curing tank at laboratory temperature. Then, after 28 days, the specimens were pulled out from the water tank, and their tension surface was prepared for jointing UHPFRC strengthening strips.

The strip's molds were prepared based on three thicknesses, 10 mm,15 mm, and 20 mm, with the same width and length of normal strength plain concrete beams. The fresh mix of UHPFRC was placed into the strip molds and left to set in its molds for 16 hours. After that, the UHPFRC strip specimens were demoulded and cured in the steam room for five days at a temperature of 55°C; then, they were moved from the steam room and cured in a water tank for 23 days [14]. Finally, at the end of 28 days, the specimens were pulled out from the water tank, and their surface was attached to the NSC beams tension face for strengthening was prepared.

Both NSC specimen beams and UHPFRC strips, after 28 days of curing time left, dried at laboratory temperature for one day with the cleaning by removing the debris and dust on the substrate contacting the surface of all specimens. For the next day, the bonding process started by applying one layer of adhesive epoxy "TYTAN JET FIX 20" on each surface of specimens and strips to be bonded together, and left for three days curing time for epoxy setting in temperature of between 25 - 31°C to be completed for testing.

TEST SET-UP

All simply-supported composite specimens were tested under three points loading for tooting under bending, as shown in Figure 3. The clear span of the slab was 450 mm. A concentrated two-point load was applied using a hydraulic jack at the top surface of the specimens. The loading rate was 0.1kN/s, and the deflection was measured by LVDT at the mid-span of specimens, as shown in Figure 2. The structural response of specimens was monitored during the test, including the load, crack development, vertical displacement, and interface slip.

Figure 2: Loading set-up composite plain concrete beam

RESULTS AND DISCUSSIONS

The three-point loading flexural test was conducted [15]. This test was conducted for all types of specimen composite beams. The twenty-one composite tested beams strengthened with three different thicknesses of 10 mm, 15 mm, and 20 mm were investigated in this study. The important variables are the concrete compressive strength, the thickness of the strip that was considered in this study, and the result displayed in Tables 4 - 6. The mechanical properties of the NSC and the UHPFRC strips obtained from 27 standard cylinder tests have been taken from mixes, as shown in Table 7.

All the control specimens without strengthening were reduced to failure by the typical flexural failure mode, where the flexural cracks occurred in the lower side of the middle area at regular intervals during the initial loading stage. These flexural cracks increased vertically toward the compression zone as the loading increased.

Table 4: Summary of flexural tests result of composite beams, grade 20.8 MPa

Composite specimen	Concrete strength MPa	UHPFRC strip thickness mm	Crack load kN	Ultimate load kN	Deflection at crack load mm	Deflection at ultimate load mm
A1 control 1	20.8	0	0.88	1.58	0.32	0.65
A1- thick 10-1	20.8	10	1.56	3.06	1.28	2.33
A1- thick 10-2	20.8	10	1.25	2.03	1.8	2.39
A1- thick 15-1	20.8	15	2.94	4.42	2.41	3.23
A1- thick 15-2	20.8	15	2.65	4.54	2.46	3.04
A1- thick 20-1	20.8	20	3.93	5.78	3.45	4.33
A1- thick 20-2	20.8	20	4.13	7.34	3.58	3.86

Table 5: Summary of flexure tests result of composite beams, grade 32.6 MPa

Composite specimen	Concrete strength MPa	UHPFRC strip thickness mm	Crack load kN	Ultimate load kN	Deflection at crack load mm	Deflection at ultimate load mm
B1 control 1	32.6	0	0.98	2.08	0.33	0.78
B1- thick 10-1	32.6	10	3.54	4.31	1.65	2.19
B1- thick 10-2	32.6	10	2.03	4.56	1.65	2.04
B1- thick 15-1	32.6	15	4.25	5.4	2.8	3.17
B1- thick 15-2	32.6	15	3.02	6.16	2.46	2.81
B1- thick 20-1	32.6	20	3.12	6.91	3.51	3.76
B1- thick 20-2	32.6	20	2.23	7.64	3.48	3.82

Table 6: Summary of flexure tests result of composite beams, grade 43.3 MPa

Composite specimen	Concrete strength MPa	UHPFRC strip thickness mm	Crack load kN	Ultimate load kN	Deflection at crack load mm	Deflection at ultimate load mm
C1 control 1	43.3	0	1.25	2.21	0.42	0.85
C1- thick 10-1	43.3	10	3.02	4.94	1.82	2.26
C1- thick 10-2	43.3	10	2.2	3.85	1.85	2.24
C1- thick 15-1	43.3	15	3.35	5.02	2.99	3.28

Table 6: Summary of flexure tests result of composite beams, grade 43.3 MPa (cont.)

Composite specimen	Concrete strength MPa	UHPFRC strip thickness mm	Crack load kN	Ultimate load kN	Deflection at crack load mm	Deflection at ultimate load mm
C1- thick 15-2	43.3	15	2.22	3.8	2.7	3.41
C1- thick 20-1	43.3	20	3.11	4.57	3.38	3.63
C1- thick 20-2	43.3	20	2.72	5.26	4.91	5.26

Table 7: Mechanical properties of NSC substrate specimen and UHPFRC strips

Specimen type	Type of concrete	Cylinder compressive strength, MPa	Splitting tensile strength, MPa	Flexural strength, MPa
A1	NSC	20.8	2.07	3.8
B1	NSC	32.6	2.31	4.35
C1	NSC	43.3	3.02	5.18
Strips	UHPFRC	170	13.47	13.4

CRACK AND ULTIMATE LOADS

Crack load

The outcomes of test results collected and displayed in Tables 4, Tables 5, and Table 6, clearly show a significant increase of cracks load for all grades of plain concrete beams strengthened compared to the control beam specimen; the cracks start forming first from NSC, after that growth and spread to UHPFRC strips, as shown in Figure 3. The results indicate an increasing crack load of 77%, 260%, and 141% for strips thickness 10 mm recorded for concrete grades 20.8, 32.6, and 43.3 MPa, respectively. Similarly, for strips thickness 15 mm 234%, 334%, 168%, and strips thicknesses of 20 mm 369%, 218%, and 149%, increasing crack load was recorded for concrete grades 20.8, 32.6, and 43.3 MPa, respectively, which means that the strengthening with UHPFRC strips enhances the capacity of beams in contrast to flexural load increasing before cracking.

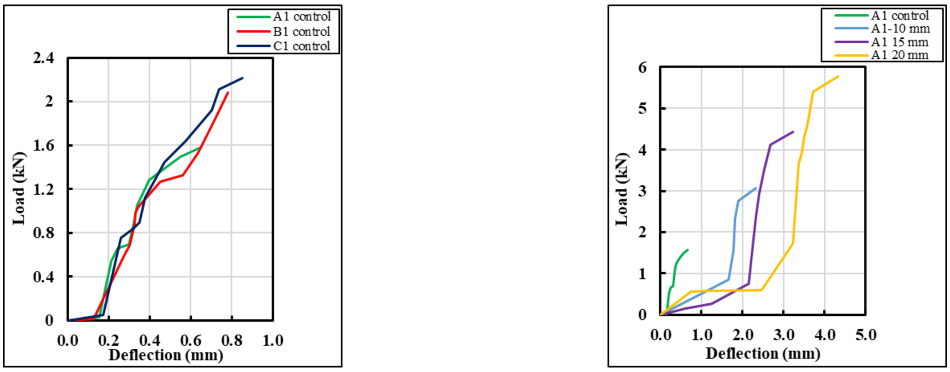
Figure 3: First crack start and failure crack width development of composite plain beam under flexural test

Ultimate flexural load

The ultimate loads of control beam specimens corresponding to the ultimate load of the specimens strengthened with UHPFRC strips generate a lower ultimate failure load. The ultimate strength of plain beams at failure was improved compared to the non-strengthened specimens due to increased sectional depth after strengthened UHPFRC strips. The ultimate load improved by 93%, 107%, and 123% for strips thickness 10 mm recorded for concrete grades 20.8, 32.6, 43.3 MPa, respectively, and similarly, the growth of ultimate load occurs for other grades of concrete beams strengthened by strips thickness 15 mm where, 198%, 160%, 127% and by strips thicknesses 20 mm, 364%, 232%, 107% enhancing of ultimate load recorded for concrete grades 32.6, 43.3 MPa, respectively. At the ultimate load, the same scenario of crack load conforms by the strengthened specimens due to presenting more ductility behavior lead to significant growth in ultimate strength at the failure of all different grades of concrete strength.

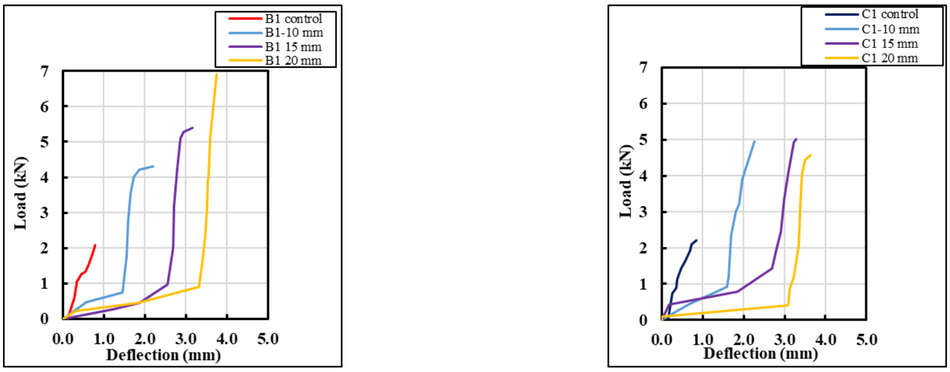
DEFLECTION OF THE STRENGTHENED BEAMS

Load-deflection relationship of the control NSC specimens without strengthening has brittle behavior due to its concrete nature without flexure reinforcement. In contrast, the specimens strengthened with UHPFRC strips have ductal behavior due to the high tensile strength capacity of steel fibers content in UHPFRC strips; the fibers are slowly pulled out, accompanied by multi-cracking in the UHPFRC strips after cracking of NSC specimens, which results in a slow load transfer from the UHPFRC strips to inside fiber reinforcements. After the load reached the crack stage, the deflection entered into the nonlinear development relationship up to failure load due to the slip between the NSC specimens and UHPFRC strips with different behavior and nature of both kinds of concrete in contrast to applying loads. Different increasing quantities of deflection were noted at the crack, and the ultimate load based on strips thicknesses and various grades of beams plain concrete where extra deflection than the control specimen over 1.26, 1.39, and 2.78 mm recorded for specimens strengthened by strips thickness 10, 15 and 20 mm respectively, as shown in Figure 4.



(a) Load-deflection relationship of tested control specimens

(a) Load-deflection relationship of tested strengthened specimens grade 20.8 MPa



(a) Load-deflection relationship of tested strengthened specimens grade 32.6 MPa

(a) Load-deflection relationship of tested strengthened specimens grade 43.3 MPa

Figure 4: Load- deflection relationships of composite beams under flexural test

EVALUATION OF BOND AND DUCTILITY BEHAVIOR

Besides, the thickness of UHPFRC strips enhances the ultimate load of tested specimens by the successful, effective bond between composite beams compared with the control specimen. The results in Tables 4-6 and the visible appearance of tested specimens, such as shown in Figure 3, clarify that no adhesive bond failure occurred between the normal strength plain concrete beams and UHPFRC strips even though the changes were made to the strength of concrete beams. From observation of the final pattern failure of the composite beam, it could be considered that the bonding between the NSC and the strengthening strips is classified as a very good to excellent bond regardless of the type of the surface preparation [14].

Ductility behavior is the response of members to stress without fracturing; based on the classical beam theory, when a two composite beam is subjected to a bending moment, the maximum tensile and normal compressive stresses are at the bottom and top edge of the beam, respectively, while the maximum shear stress is at the neutral axis of the beam. The neutral axis position is not located at the centroid of the whole cross-section. Thus, the maximum shear stress is right at the bond line of the composite beam, which leads to expected because of shear failure at the bond line due to the transformation of the shear stress; during the test, the procedure was increasing in load occurred, at the same time similarly increasing in shear stress occur at the bond line, then the cracks start formed first from NSC substrate specimens and after that near ultimate load transforms to UHPFRC strips through the bond line without de-bonding of adhesive epoxy that's mean the adhesive bond role is strong and adequate for strengthening purpose.

After normal strength concrete of beams cracks, the stiffness might be reduced suddenly due to the cracked section of specimens [16]. The force carried by cracked concrete gradually transfers to the existence of UHPFRC strips, the NSC specimen was restrained, and the stress in the NSC specimen was also reduced. Therefore, crack development in the UHPFRC strips was delayed. Then, the cracks in the UHPFRC strips were extensively developed and propagated. As a result, the strengthened slab exhibited a higher ductility behavior after cracking the UHPFRC strips. The interfacial connection type affected this ductility behavior improvement after concrete cracking.

The load-deflection curves define elastic stiffness as a slope between the original and cracking points. The stiffness after concrete cracking is defined as the slope of the line between the point at which the NSC specimen cracks and the point at which the UHPFRC strips start to fail. This is because the UHPFRC strips effectively restrained and delayed the development of the flexural crack. In addition, the thickness of UHPFRC strips increased the section moment of inertia. However, it increases the stiffness of the strengthened specimens and decreases the deflection at the mid-span.

CONCLUSIONS

This research conducted three-point flexure tests on the NSC beams strengthened by UHPFRC strips. The flexural behavior of the strengthened beams was analyzed based on research variables. The summary of the results derived through this research is as follows:

a) The results of the test and the mode of failure displayed in the study show that the bond strength was very strong and tough enough for these grades of normal strength concrete since the cracks occurred in the NSC substrate first and the interface failure occurred after the damage in the NSC specimen's substrate and UHPFRC strips without separation between them which indicates that superior bond behavior.

b) The outcome data from the tested specimens clarify that the changes in concrete grade have a relatively slight effect on the strengthening performance of NSC beams strengthened with UHPFRC strips compared to the UHPFRC strip's thickness, where a great amount of the ultimate load and deflection obtained when the thickness of strips change from 10 mm to 15 mm and 20 mm.

c) The effect of UHPFRC strips thickness on the strengthening performance was great due to this concrete type's worthy and strong mechanical properties. In addition, the strip's thickness enhances the effect of the section geometry on the bending capacity of the concrete specimens. In addition, UHPFRC strengthening strips improve the cracking and ultimate flexure loads of NSC beams, where the cracking and ultimate loads of beams increased about (112.6% to 97.9%) respectively, for all grades of concretes compared to the control beams.

d) The ductility behavior of the strengthened beams with the UHPFRC strips increases significantly compared to the NSC non strengthened beams specimens since composite beams failure transforms from brittle to ductal mode.

REFERENCES

[1] G. Martinola, A. Meda, G. A. Plizzari, and Z. Rinaldi, "Strengthening and repair of RC beams with fibre reinforced concrete," *Cem. Concr. Compos.*, vol. 32, no. 9, pp. 731–739, 2010.

[2] T. C. Triantafillou, "Upgrading concrete structures using advanced polymer composites," in *Advanced Polymer Composites for Structural Applications in Construction*, Elsevier, 2004, pp. 89–100.

[3] K. Wille, D. J. Kim, and A. E. Naaman, "Strain-hardening UHP-FRC with low fibre contents," *Mater. Struct.*, vol. 44, no. 3, pp. 583–598, 2011.

[4] M.-G. Lee, Y.-C. Wang, and C.-T. Chiu, "A preliminary study of reactive powder concrete as a new repair material," *Constr. Build. Mater.*, vol. 21, no. 1, pp. 182–189, 2007.

[5] C. E. Chalioris, P.-M. K. Kosmidou, and C. G. Karayannis, "Cyclic response of steel fibre reinforced concrete slender beams: An experimental study," *Materials*, vol. 12, no. 9, p. 1398, 2019.

[6] E. Fehling, M. Schmidt, and S. Stürwald, *Ultra-High-Performance Concrete:(UHPC); Proceedings of the Second International Symposium on Ultra-High-Performance Concrete, Kassel, Germany, March 05-07, 2008*, vol. 10. kassel university press GmbH, 2008.

[7] J.-P. Charron, E. Denarié, and E. Brühwiler, "Transport properties of water and glycol in an ultra-high performance fibre reinforced concrete (UHPFRC) under high tensile deformation," *Cem. Concr. Res.*, vol. 38, no. 5, pp. 689–698, 2008.

[8] J. Li, Z. Wu, C. Shi, Q. Yuan, and Z. Zhang, "Durability of ultra-high performance concrete – A review," *Constr. Build. Mater.*, vol. 255, p. 119296, Sep. 2020, DOI: 10.1016/j.conbuildmat.2020.119296.

[9] H. Wibowo and S. Sritharan, "Use of ultra-high-performance concrete for bridge deck overlays," 2018.

[10] M. A. Al-Osta, M. N. Isa, M. H. Baluch, and M. K. Rahman, "Flexural behaviour of reinforced concrete beams strengthened with ultra-high performance fibre reinforced concrete," *Constr. Build. Mater.*, vol. 134, pp. 279–296, 2017.

[11] B. A. Tayeh, B. A. Bakar, M. M. Johari, and Y. L. Voo, "Utilization of ultra-high performance fibre concrete (UHPFC) for rehabilitation–a review," *Procedia Eng.*, vol. 54, pp. 525–538, 2013.

[12] A. AL Hallaq, B. A. Tayeh, and S. Shihada, "Investigation of the bond strength between existing concrete substrate and UHPC as a repair material," *Int. J. Eng. Adv. Technol. IJEAT*, vol. 6, no. 3, 2017.

[13] K. Neshvadian Bakhsh, "Evaluation of bond strength between overlay and substrate in concrete repairs." 2010.

[14] F. R. Karim, "Behaviour of Under-Reinforced Shallow Fibrous Concrete Beams Subjected To Pure Torsion," Ph.D., University Sains Malaysia, 2016. Accessed: Feb. 28, 2022. [Online]. Available: http://eprints.usm.my/45959/

[15] ASTM, "Standard test method for flexural performance of fiber-reinforced concrete (using beam with third-point loading)," *ASTM-C1609*, 2012.

[16] R. I. Gilbert, "Time-dependent stiffness of cracked reinforced and composite concrete slabs," *Procedia Eng.*, vol. 57, pp. 19–34, 2013.