Magazine of Civil Engineering. 2025. 18(7). Article No. 13908

Magazine of Civil Engineering

ISSN 2712-8172

journal homepage: http://engstroy.spbstu.ru/

Research article

UDC 69.07

DOI: 10.34910/MCE.139.8

Structural behavior of ultra-high performance concrete beams with different rebar and fiber reinforcement ratios

Y.Q.Y. Abuizeih , ***M.M. Tamov*** ✉

Kuban State Technological University, Krasnodar, Russian Federation

✉ *murat.tamov@gmail.com*

Keywords: ultra-high performance concrete, steel fibers, flexural behavior, crack control, hybrid reinforcement

Abstract. This experimental study comprehensively analyzes the flexural performance of ultra-high performance concrete (UHPC) beams with combined rebar and fiber reinforcement. The study examines the synergistic effects of longitudinal reinforcement ratio μ_s (varying from 0.31 to 5.13 %), steel fiber content (0–2 % by volume), and fiber geometry (comparing straight and wavy shapes) through testing of seventeen beam specimens under four-point bending conditions. Results demonstrate that steel fiber incorporation significantly enhances structural performance by improving crack control, with maximum crack widths remaining below 0.25 mm at service load levels (65–70 % of ultimate capacity). The benefits of fiber reinforcement show strong dependence on longitudinal rebar reinforcement ratio, with maximum strength improvements reaching 47 % for beams containing 2 % fibers at the lowest reinforcement ratio (0.31 %). Comparative analysis reveals the superior performance of wavy fibers, which provide up to 25 % greater strength enhancement compared to straight fibers in lightly reinforced specimens. The study identifies two distinct failure modes: abrupt failure after crack localization in lightly reinforced beams (μ_s ≤ ≤ 0.87 %) versus gradual strength gain at post-localization stage in highly reinforced specimens (μ_s ≥ ≥ 2.56 %). Fiber effectiveness diminishes significantly in highly reinforced beams due to rebar dominance and fiber distribution challenges in congested tensile zones. These findings provide quantitative evidence for optimizing fiber-rebar combinations in UHPC design, particularly highlighting the importance of fiber geometry selection and dispersion quality. The research establishes clear relationships between reinforcement parameters and structural performance, offering practical guidance for engineers while identifying key areas for future investigation, including advanced fiber dispersion techniques and hybrid reinforcement strategies for improved structural efficiency.

Citation: Abuizeih, Y.Q.Y., Tamov, M.M. Structural behavior of ultra-high performance concrete beams with different rebar and fiber reinforcement ratios. Magazine of Civil Engineering. 2025. 18(7). Article no. 13908. DOI: 10.34910/MCE.139.8

1. *Introduction*

Ultra-high-performance concrete (UHPC) is an advanced cementitious composite known for its exceptionally high strength, ductility, and durability [1]. The addition of steel fibers to the UHPC matrix further enhances its tensile properties and enables ductile behavior. Over the past two decades, UHPC has emerged as a significant innovation in concrete technology, offering outstanding mechanical performance and strong resistance to environmental deterioration [2]. To enable broader implementation, it is essential to thoroughly investigate and understand the structural performance of UHPC elements under various loading and environmental conditions.

The fibers bridge developing cracks in UHPC and limit their width, leading to the formation of numerous closely spaced, fine cracks, a phenomenon often referred to as multiple cracking [3, 4]. This behavior enhances stress redistribution across the beam, improves ductility, and contributes to greater overall durability by limiting the ingress of aggressive agents. As the applied load approaches the ultimate level, one or more cracks begin to open significantly more than the rest, marking the onset of crack localization [5, 6]. This occurs due to intensive fiber pull-out from the concrete matrix in the affected sections. At this stage, the longitudinal reinforcement typically yields at the locations where it intersects these dominant cracks. Thus, the reinforcement parameters are a key factor determining the behavior of UHPC beams under loading. Investigation of beam behavior under different combinations of bar and fiber reinforcement ratios is essential for developing more efficient and structurally reliable UHPC beam designs [7].

The influence of longitudinal reinforcement on the behavior of UHPC beams has been examined in several experimental studies [5, 8–15]. In the tests conducted by Li [8], the ductility index f_p / f_y as well as the strength and stiffness of UHPC beams, increased with the reinforcement ratio μ_s up to 5 %, which significantly exceeds the maximum permissible value specified by design codes. Somewhat different results were obtained by Chen et al. [13], who observed that, within a similar range of μ_s, ductility was highest in beams with intermediate reinforcement ratios. In the experiments by Zhang et al. [16], at a constant fiber volume fraction μ_{fv} = 2 %, the ductility of a beam with μ_s = 2.83 % was 27.6 % less than that of a beam with μ_s = 1.48 %.

The addition of steel fibers leads to a significant increase in the bearing capacity of UHPC beams. In the study by Yoo & Yoon [10], fiber reinforcement μ_{fv} = 2 % increased the beam strength by 27–54 % and reduced the ductility index by 13–73 %. Khalil & Tayfur [17] observed up to a 27 % increase in capacity for beams reinforced with crimped and hooked steel fibers at μ_{fv} = 2 %. The strength gain from fibers tends to be more pronounced in beams with a lower amount of longitudinal rebar reinforcement [18]. In the work of El-Din et al. [19], the inclusion of fibers at μ_{fv} = 3 % resulted in a 32.9 % increase of strength for beams with μ_s = 1.33 %, and only 8.1 % for beams with μ_s = 5.36 %.

However, varying the fiber volume fraction μ_{fv} does not always have a significant effect on the strength of UHPC beams [20–22]. For example, in [16], when μ_{fv} was increased from 1.5 to 3.0 %, the maximum load increased by 11.87 % for the beams with the reinforcement ratio of 2.33 %. In the experiments by Feng et al. [23], an increase in μ_{fv} from 2 to 3 % had a noticeable positive effect on the strength of the beams only when μ_s = 1 и 2.9 %, whereas at μ_s = 4.8 and 7.1 %, the beams with different fiber contents failed under nearly identical loads. This is explained by the fact that the contribution of the fibers to the strength of the beam becomes insignificant compared to the contribution of the reinforcing bars [21]. In addition, in the case of beams with high μ_{fv}, it is likely that the researchers were unable to achieve uniform fiber distribution. From this, it can be concluded that using an effective fiber dispersion technology is a crucial condition for ensuring their contribution in the bending strength of UHPC beams. In addition, stirrups can prevent the proper fiber distribution during casting of beams [3].

Several studies have focused on evaluating the effectiveness of various fiber types used as dispersed reinforcement of UHPC beams. The study of Khalil et al. [17] showed that using twisted fibers and increasing the length of straight fibers had little effect on the strength and stiffness of the beams. In the experimental study of Yoo & Yoon [10], the variable parameter in the series of UHPC beams was the fiber length, while the fiber volume fraction was kept constant at μ_{fv} = 2 %. Strength, stiffness, and the energy absorption capacity of beams increased with fiber length up to 19.5 mm. Further increasing the fiber length to 30 mm reduced its effectiveness, which is attributed to the decreased number of fibers bridging the cracks. The authors [17, 10] note that neither the presence of fibers in the concrete mix nor their shape or concentration has a significant impact on the cracking load of beams or the corresponding deflections.

The experimental database of flexural tests on UHPC beams requires both qualitative and quantitative expansion. Currently, it does not allow for a clear understanding of the influence of fiber and rebar reinforcement parameters behavior of beams. Conclusions drawn by different researchers in this area are often contradictory. This is due to the complex nature of the stress-strain state in the tensile zone of

UHPC beams, as well as the variability in UHPC strength characteristics, which depend not only on the mix composition but also on the quality of fiber distribution. In most existing studies, UHPC beams were reinforced with straight fibers. Meanwhile, dispersed reinforcement of UHPC beams with wavy fibers – widely used in Russia and Belarus and known for significantly enhancing the tensile strength of UHPC [24, 25] – is of particular interest. In most studies, the effects of μ_{fv} and μ_s on beam performance are considered separately. However, in the few studies where both parameters were varied, it was clear that the influence of one depended on the value of the other [16, 22, 26]. Tests on beams with low μ_s are rare, yet it is precisely under low reinforcement conditions that the properties of UHPC have the most influence. The aim of this study was to experimentally assess the influence of bar and fiber reinforcement ratios varying in wide ranges, as well as fiber type, on the flexural behavior of UHPC beams.

2. Methods

According to the experimental plan, seventeen UHPC beams were tested, divided into four series based on the value of μ_s (Table 1). Within each series, μ_{fv} and fiber type were varied. Each series included specimens without fiber reinforcement (specimens F0-…). Beams in Group 4, with a high reinforcement ratio, were tested to investigate the behavior under load and failure characteristics of UHPC beams at μ_s values close to or exceeding the limits of balanced sections $\left(\xi \geq \xi_R\right)$.

Beams No. 1–15 had a rectangular cross-section of 100 × 200 mm (Fig. 1b). Beams No. 16 and 17 were designed with a flange in the tensile zone due to the need to enable placement of a large amount of longitudinal reinforcement (Fig. 1c).

The longitudinal reinforcement of the beams consisted of 2 to 6 bars of A500 reinforcement with diameters ranging from 6 to 14 mm (Fig. 1b, 1c). Dispersed reinforcement of UHPC beams in most of previous studies consisted of straight fibers (SFs), with hooked and twisted fibers used only in rare cases. At the same time, dispersed reinforcement of UHPC beams with wavy fibers (WFs), which have become widely used in Russia and Belarus, is of particular interest. Therefore, samples with WFs produced by JSC “BMZ” (Zhlobin, Belarus) were included in the experimental plan.

Table 1. The experimental program for flexural testing of UHPC beams

Group	Beam ID	μ_s (%)	μ_{fv} (%)	Fiber shape	R_b (MPa)	R_{fel} (MPa)	M_p (kNm)
1	F0-030	0.31	0	–	115	–	7.6
	SF1-030		1	SF	130.5	4.25	11
	SF2-030		2	SF	133.2	9.5	16.6
	WF1-030		1	WF	135	6.94	14
	WF 2-030		2	WF	140.4	12	20.1
2	Φ0-085	0.87	0	–	115	–	18.3
	SF1-085		1	SF	130.5	4.25	20.16
	SF2-085		2	SF	133.2	9.5	26.22
	WF1-085		1	WF	135	6.94	22.75
	WF2-085		2	WF	140.4	12	30.8
3	F0-250	2.56	0	–	115	–	41.1
	SF1-250		1	SF	130.5	4.25	46.4
	SF2-250		2	SF	133.2	9.5	45.9
	WF1-250		1	WF	135	6.94	47.4
	WF2-250		2	WF	140.4	12	50.14
4	F0-500	5.13	0	–	115	–	66.2
	WF1.5-500		1.5	WF	137	9.4	74.5

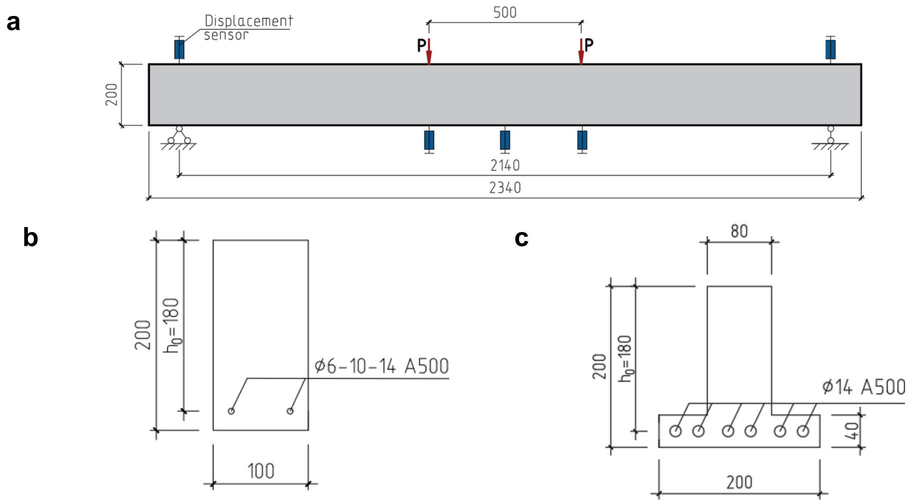

Figure 1. Side view of the beams, their loading scheme (a), cross-sections of rectangular (b), and T-shaped beams (c).

The UHPC mixtures included Portland cement 600-DO (CEM I 52.5 N), condensed silica fume MK-85, a blend of coarse (fineness modulus 2.56) and fine (fineness modulus 0.78) sand, and a polycarboxylate-based superplasticizer [24]. Steel brass-coated straight and WFs with a diameter of 0.4 mm and length of 14 mm, and a tensile strength of 2800 MPa were used as dispersed reinforcement. During casting of the beams, the concrete was placed sequentially along the length of the formwork and consolidated using mechanical vibration to ensure adequate compaction and a uniform distribution of the steel fibers throughout the cross-section. The compressive strength of UHPC was determined by testing cubes (70 × 70 × 70 mm) and prisms (100 × 100 × 400 mm). For UHPC containing fibers, the tensile strength values R_{Fel} were evaluated following the SP 360.13330 procedure through three-point bending tests on notched prisms with dimensions 150 × 150 × 550 mm. The obtained concrete strength characteristics of the beams are given in Table 1.

The beams were subjected to two point loads, spaced 500 mm apart and symmetrically positioned about the midpoint (Fig. 1a). The applied load was controlled by a gauge installed under one support of the beam. Deflections were measured using strain gauge displacement sensors positioned at five points – at the beam midpoint, at the load application points, and at the supports (Fig. 1a). Local concrete strains were measured with strain gauges, and average strains in the tensile zone were recorded using LVDT sensors (Fig. 2).

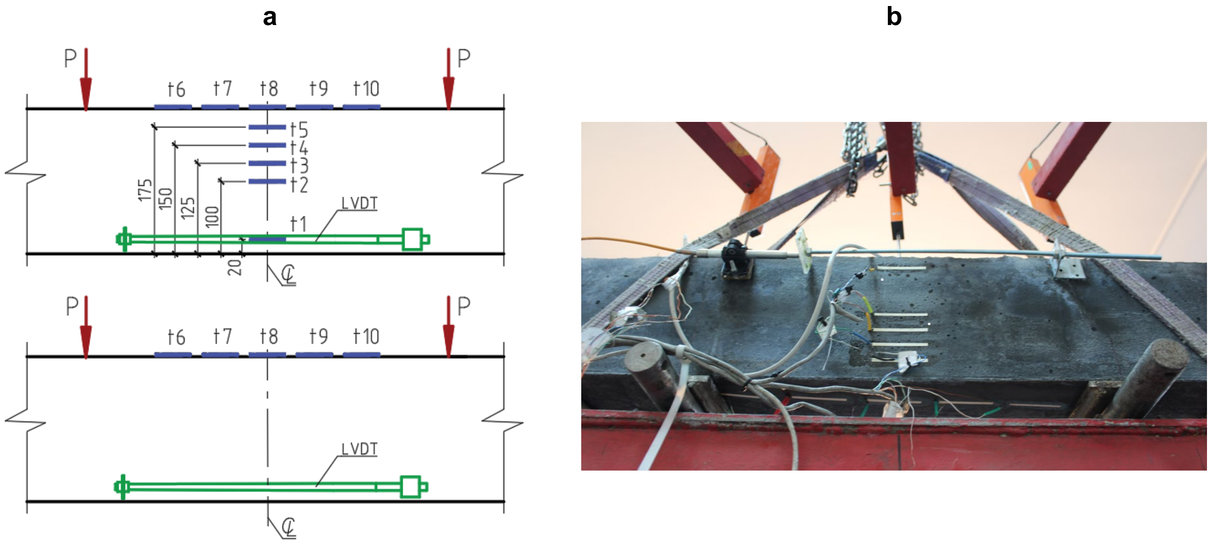

Figure 2. Investigated zone of pure bending (the test load is applied upwards): sensor layout diagram (a) and its actual implementation (b)

3. Results and Discussion

Strain gauge readings recorded during the tests indicate that the failure of beams in Groups 1–3 occurred due to crushing of the concrete in the compressed zone after yielding of the longitudinal reinforcement. In fiber-reinforced UHPC beams from Groups 1 (μ_s = 0.31 %) and 2 (μ_s = 0.87 %), one or several of the flexural cracks began to open more intensively than the others at later loading stages – this marked the onset of the previously described strain localization in the tensile zone, caused by progressive fiber pull-out. Near failure, the critical crack in these beams extended to a depth of up to 0.9 *h*. In fiber-reinforced UHPC beams of Group 3 (μ_s = 2.56 %), failure also occurred in a sections with localized cracks; however, its depth did not exceed 0.7 *h*. In both beams from Group 4 (with and without fibers), as expected, the reinforcement did not reach yielding stress.

From the analysis of the moment–deflection curves (Fig. 3), the following conclusions can be drawn:

1. The presence of fiber reinforcement influences the performance of the beams for all the studied values of μ_s. A consistent effect observed across all four groups is that the addition of fibers increases both the strength and stiffness of the beams.
2. The most pronounced impact of fiber addition was observed in beams with a low μ_s (Group 1). The deflections of the fiber-reinforced concrete beams at the point of failure were approximately 3–4 times smaller than that of the beam F0-030 without fibers.
3. In Groups 1 (μ_s = 0.31 %) and 2 (μ_s = 0.85 %), increasing μ_{fv} and/or replacing straight fibers with wavy ones led to an upward shift of the curves – i.e., an increase in strength and stiffness. In contrast, in Group 3 (μ_s = 2.56 %), the deformation curves for beams reinforced with different quantities and types of fibers nearly coincided.
4. In Group 3 (μ_s = 2.56 %), beams with fibers exhibited continued growth in moment capacity beyond crack localization. In Group 2 (μ_s = 0.87 %), this post-cracking capacity gain was minimal, and in Group 1 (μ_s = 0.31 %), strength of beams dropped immediately after crack localization. Thus, for beams with μ_s = 0.31 % and 0.87 %, the load at which crack localization occurred was the failure load. In these beams, the tensile force carried by the fiber-reinforced concrete exceeded the capacity of the rebar reinforcement in its strain-hardening stage.

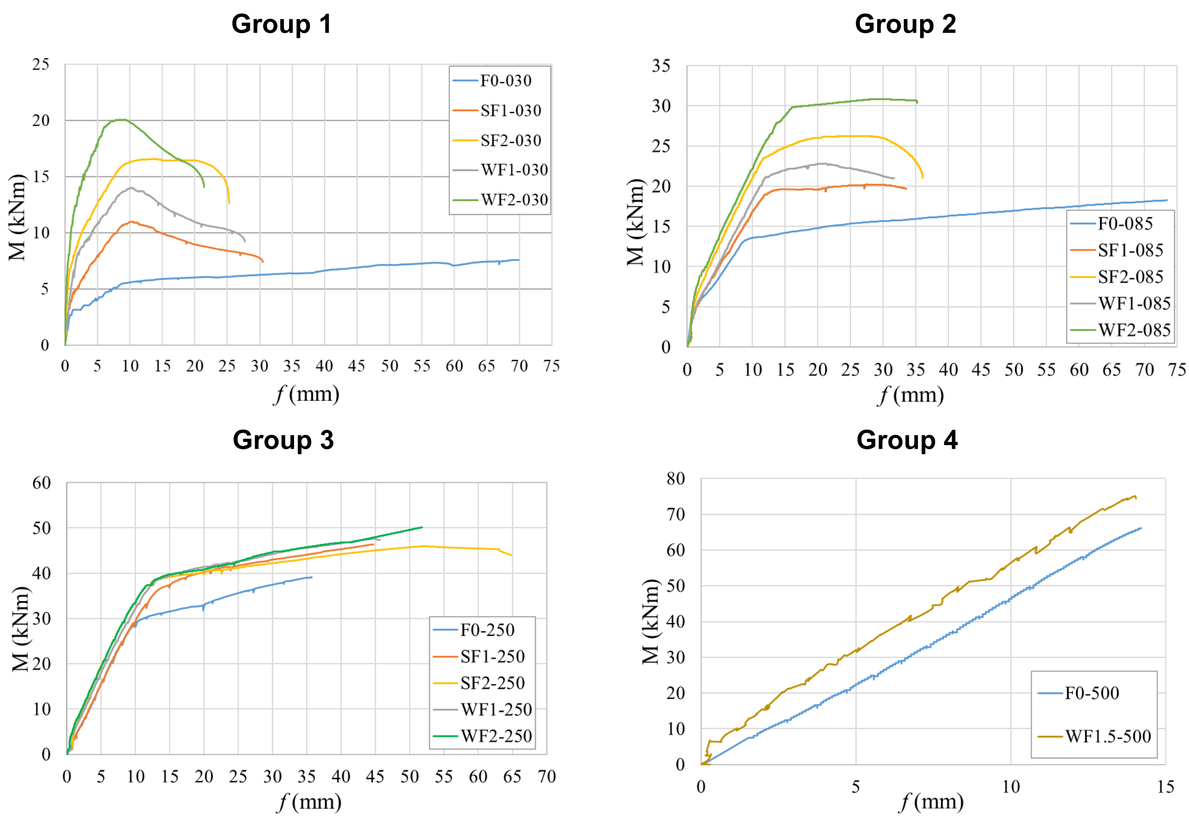

Figure 3. Moment-deflection diagram of beams.

Within Groups 1 (μ_s = 0.31 %), 2 (μ_s = 0.87 %), and 4 (μ_s = 5.1 %), the cracking moment M_{crc} increased with the fiber volume fraction μ_{fv}. In Group 3, however, no such trend was observed based on the obtained M_{crc} values. It should be noted that the beams were inspected only during the constant-load holding phase, which may have led to inaccuracies in identifying the exact moment of crack initiation. The most significant influence of fibers on the cracking load was observed in Group 4 (over-reinforced beams), where the difference in M_{crc} values between beams with and without fibers reached a factor of four.

The width of critical (localized) cracks increased at the same rate as that of other cracks prior to the onset of rapid widening (see Fig. 4). In other words, until the ultimate stage was reached, the critical cracks did not stand out from the rest. In many cases, the formation of the critical crack occurred during the final stages of loading.

Up to the localization of critical cracks, i.e., practically until the ultimate load capacity was reached, crack openings remained small – no more than 0.25 mm. Thus, the results of our tests indicate that under service loads of about 65–70 % of the ultimate loads, the crack width in UHPC beams will not exceed the permissible limits of 0.3–0.4 mm adopted in design codes.

a **b**

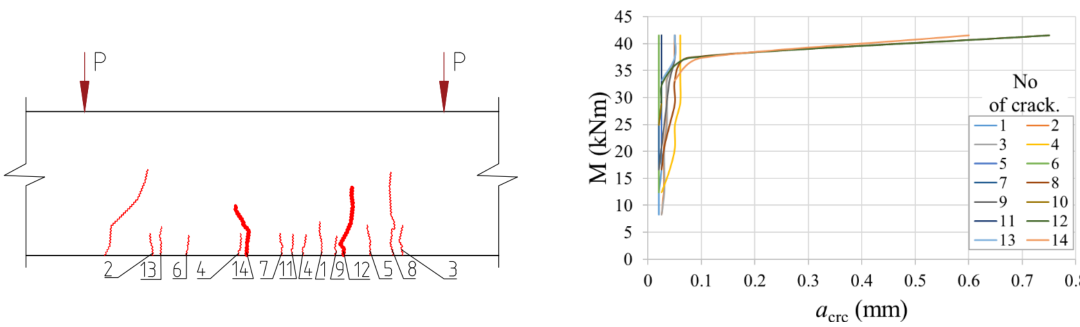

Figure 4. Crack pattern (a) and crack opening diagram (b) for beam SF2-250.

Concrete strains on the compressed side of the beams were measured at five points uniformly distributed within the pure bending zone over a distance of 300 mm. In beams from Groups 3 and 4, as well as in plain UHPC specimens from Groups 1 and 2, concrete strains at failure, $\varepsilon_{b,\max}^{ult}$ were about (260–370) 10^{-5} and mostly significantly exceeded the ultimate compressive strain ε_0 of UHPC determined from prism tests. Moreover, the difference between the average strain $\bar{\varepsilon}_b^{ult}$ and the maximum strain $\varepsilon_{b,\max}^{ult}$ did not exceed 20 %, which is consistent with results reported by other researchers for beams made of conventional normal strength concrete. In fiber-reinforced UHPC beams from Groups 1 and 2, which failed immediately after the formation and opening of a localized crack, the measured compression strains showed greater variability $\varepsilon_{b,\max}^{ult}$ ranged from (60–310)·10^{-5}, and the difference between $\bar{\varepsilon}_b^{ult}$ and $\varepsilon_{b,\max}^{ult}$ varied between 5 and 100 %. This scatter is due to the significant influence of the critical crack on the compressed concrete strain in the section. Higher strain values were recorded when the critical crack was located in the same section as the strain gauge (see Fig. 5). In other sections, compressive strains were significantly lower.

a **b**

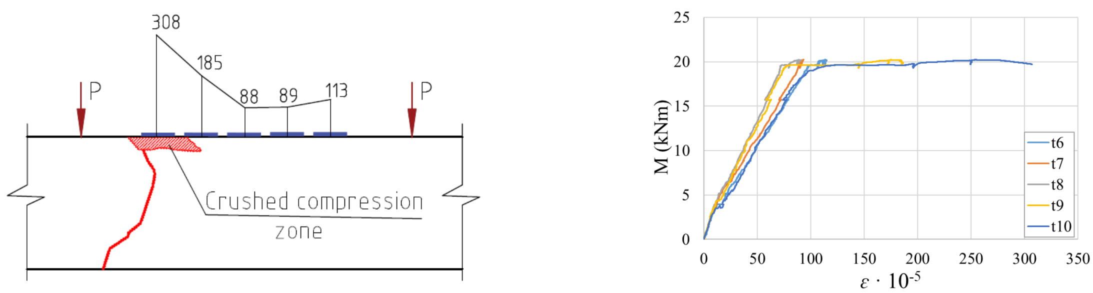

Figure 5. Ultimate values (a) and diagram of the strains on the compressed face (b) of beam SF1-085.

Fig. 6 shows examples of strain profiles of the cross-sections constructed for different loading stages based on readings from strain gauges and LVDT sensors. As can be seen, for beams from all groups, the strains correspond to the assumption of plane sections, including at the ultimate stage. During the test of beam SF1-030, the critical crack formed in the area covered by both LVDT sensors and strain gauges. This made it possible to obtain the strain profile in the section with the critical crack at all stages of the beam behavior. The strain profile at the maximum moment of 11 kNm (development of the critical crack) is shown by the gray line in Fig. 6 SF1-030, while the dashed blue line represents the strain profile at the moment of failure. As loading progresses, the depth of the compressed zone in all beams decreases, with a significantly higher rate observed after the reinforcement yields.

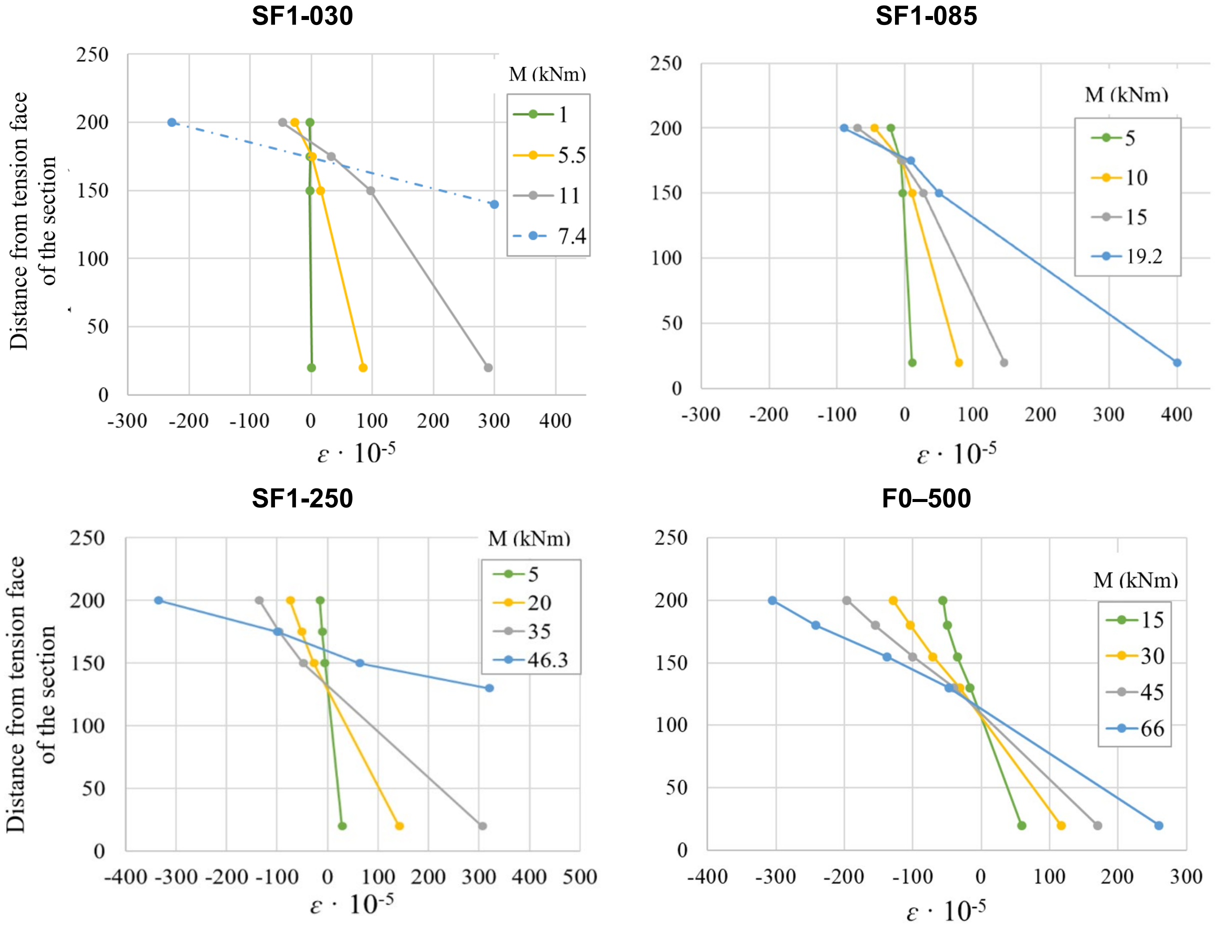

Figure 6. Strain profiles in cross-sections of the beams SF1-030, SF1-085, SF1-250, F0-500.

The beam flexural strength M_p is defined as the value of the bending moment corresponding to the peak point on the moment–deflection diagrams (Table 1, Fig. 3). For clarity, the beam strength values are presented in a summarized bar chart in Fig. 7.

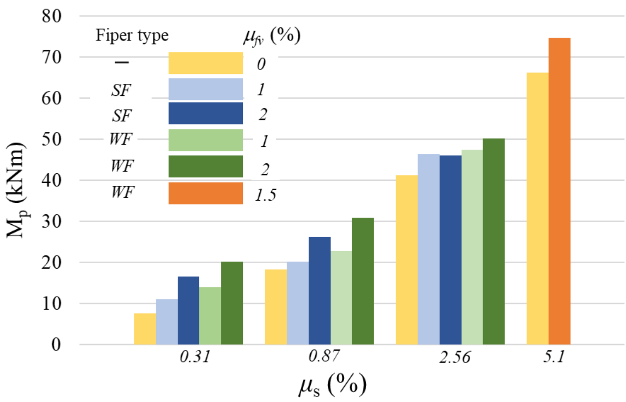

Figure 7. Relationship between beam flexural strength and fiber content and longitudinal reinforcement ratio.

The addition of fibers to the UHPC mix increased the flexural strength of beams across all groups. However, the strength gain from increasing fiber content decreases as the longitudinal reinforcement ratio increases. In Group 1 (μ_s = 0.31 %), the difference in beam strength between fiber volume fractions μ_{fv} = 1 и 2 % was approximately 47 %. At μ_s = 0.87 %, increasing μ_{fv} led to a strength increase of up to 32 %, while at μ_s = 2.56 %, the effect was negligible. The lack of influence of μ_{fv} on the strength of beams with high reinforcement content has also been reported in several other studies. For example, in experiments by Feng et al. [23], increasing the content of straight fibers from 2 до 3 % did not result in any significant effect on beams with μ_s ≥ 2.9 %. Researchers attribute this to the possibility that at high reinforcement ratios, the uniform distribution of fibers in the tensile zone may be hindered due to congestion caused by the reinforcing bars.

WFs enhance the flexural strength of UHPC beams more effectively than SFs. In Groups 1 (μ_s = 0.31 %) and 2 (μ_s = 0.87 %), replacing SFs with WFs resulted in a 12–25 % increase in beam strength. In contrast, in Group 3 (μ_s = 2.56 %), the influence of fiber shape on beam strength was almost negligible. As with the effect of increasing μ_{fv} in this group, the potential gain due to using WFs might have been reduced by poor distribution in the tensile region, where the high reinforcement ratio limited available space.

4. Conclusions

This study experimentally evaluated the influence of longitudinal reinforcement ratio, fiber content, and fiber shape on the flexural performance of UHPC beams. Based on the results, the following conclusions can be drawn:

1. Crack localization was the governing failure mechanism in under-reinforced beams, while in over-reinforced beams, failure occurred by concrete crushing without yielding of steel rebars. Beams with low reinforcement ratios failed abruptly after crack localization, while highly reinforced beams exhibited post-localization strength gains.
2. Width of cracks in fiber-reinforced UHPC beams remained small (≤ 0.25 mm), ensuring serviceability under typical working loads (65–70 % of ultimate capacity).
3. The addition of steel fibers enhanced the flexural strength and stiffness of UHPC beams across all reinforcement levels. In beams with low reinforcement ratios, increasing fiber content from 1 to 2 % resulted in up to a 47 % strength increase. In highly- and over-reinforced beams, the contribution of fibers was reduced due to rebar dominance and potential non-uniform fiber distribution in congested tensile zones.
4. WFs outperform SFs in enhancing beam strength, especially at low reinforcement levels, with gains of up to 25 %.

The results highlight the need to optimize the balance between rebar and fiber reinforcement to achieve desired performance in UHPC beams. Future research should address fiber dispersion techniques and hybrid reinforcement strategies to maximize synergies between these components.

References

1. Khaleel, B.A., Dawood, E.T. Evolution of ultra high performance concrete using hybrid fibers: a review. Discover Concrete and Cement. 2025. 1. Article no. 2. DOI: 10.1007/s44416-025-00001-z
2. Graybeal, B.A. Behavior of Field-Cast Ultra-High Performance Concrete Bridge Deck Connections under Cyclic and Static Structural Loading. FHWA Report no. FHWAHRT-11-023. Washington, 2010. URL: https://rosap.ntl.bts.gov/view/ dot/957/dot_957_DS1.pdf (date of application: 21.01.2026).
3. Cai, Z., Duan, X., Liu, L., Lu, Z., Ye, J. Reinforced ultra-high performance concrete beam under flexure and shear: Experiment and theoretical model. Case Studies in Construction Materials. 2024. 20. Article no. e02647. DOI: 10.1016/j.cscm.2023.e02647
4. Zhu, Y., Zhang, Y., Yuan, X., Hou, C. An Adaptive Crack Width Prediction for Flexural Steel Reinforced UHPC Beams. I International Journal of Concrete Structures and Materials. 2023. 17. Article no. 73. DOI: 10.1186/s40069-023-00628-x
5. Shao, Y., Billington, S.L. Utilizing full UHPC compressive strength in steel reinforced UHPC beams. International Interactive Symposium on Ultra-High Performance Concrete Papers. 2019. 2(1). Pp. 1–9. DOI: 10.21838/uhpc.9699
6. Helou, R.G., Graybeal, B.A. Flexural Behavior and Design of Ultrahigh-Performance Concrete Beams. Journal of Structural Engineering. 2022. 148(4). Pp. 1–20. DOI: 10.1061/(ASCE)ST.1943541X.0003246
7. Tamov, M.M., Abuizeih, Y.Q.Y. The Effect of the Longitudinal Reinforcement Ratio on the Behavior of Ultra-High Performance Fibre-Reinforced Concrete Beams. Scientific Works of the Kuban State Technological University. 2025. 2. Pp. 56–71. DOI: 10.26297/2312-9409.2025.2.6

8. Li, H.S. Tension stiffening behavior and structural flexural behavior of steel reinforced UHPFRC members. Master thesis. National Cheng Kung Univ. Dept. of Civil Engineering, 2016.
9. Yang, I.H., Joh, C., Kim, B.S. Structural behavior of ultra high performance concrete beams subjected to bending. Engineering Structures. 2010. 32(11). Pp. 3478–3487. DOI: 10.1016/j.engstruct.2010.07.017
10. Yoo, D.Y., Yoon, Y.S. Structural performance of ultra-high performance concrete beams with different steel fibers. Engineering Structures. 2015. 102. Pp. 409–423. DOI: 10.1016/j.engstruct.2015.08.029
11. Yoo, D.Y., Kang, S.T., Yoon, Y.S. Enhancing the flexural performance of ultra-high-performance concrete using long steel fibers. Composite Structures. 2016. 147. Pp. 220–230. DOI: 10.1016/j.compstruct.2016.03.032
12. Hung, C.C., Chueh, C.Y. Cyclic behavior of UHPFRC flexural members reinforced with high-strength steel rebar. Engineering Structures. 2016. 122(6). Pp. 108–120. DOI: 10.1016/j.engstruct.2016.05.008
13. Chen, S., Zhang, R., Jia, L.J., Wang, J.Y. Flexural behaviour of rebar-reinforced ultra-high-performance concrete beams. Magazine of Concrete Research. 2017. 70(19). Pp. 997–1015. DOI: 10.1680/jmacr.17.00283
14. Hasgul, U., Turker, K., Birol, T., Yavas, A. Flexural behavior of ultra-high-performance fiber reinforced concrete beams with low andhigh reinforcement ratios. Structural Concrete. 2018. 19(6). Pp. 1577–1590. DOI: 10.1002/suco.201700089
15. Turker, K., Hasgul, U., Birol, T., Yavas, A., Yazici, H. Hybrid fiber use on flexural behavior of ultra high performance fiber reinforced concrete beams. Composite Structures. 2019. 229. Article no. 111400. DOI: 10.1016/j.compstruct.2019.111400
16. Zhang, Y., Zhu, Y., Qiu, J., Hou, C., Huang, J. Impact of reinforcing ratio and fiber volume on flexural hardening behavior of steel reinforced UHPC beams. Engineering Structures. 2023. 285. Article no. 116067. DOI: 10.1016/j.engstruct.2023.116067
17. Khalil, W.I., Tayfur, Y.R. Flexural strength of fibrous ultra high performance reinforced concrete beams. ARPN Journal of Engineering and Applied Sciences. 2013. 8(3). Pp. 200–214. URL: https://www.researchgate.net/publication/287399660 (date of application: 21.01.2026).
18. Kodsy, A., Morcous, G. Flexural strength prediction models of non-prestressed Ultra-High Performance Concrete (UHPC) components. Structures. 2021. 34. Pp. 4532–4547. DOI: 10.1016/j.istruc.2021.10.047
19. El-Din, H.S., Husain, M., Khater, M. Effect of steel fibers on flexural behavior of ultra high performance r.c. beams. Egyptian Journal for Engineering Sciences and Technology. 2013. 16(1). Pp. 35–45. DOI: 10.21608/eijest.2013.96788
20. Kahanji, C., Ali, F., Nadjai, A. Structural Performance of Ultra-High Performance Fibre Reinforced Concrete Beams. Structural Concrete. 2017. 18(2). Pp. 249–258. DOI: 10.1002/suco.201600006
21. Randl, N., Meszoly, T. The effect of fibres in UHPFRC beams with longitudinal steel reinforcement. fib Bulletin 79. Fibre-reinforced concrete: From design to structural applications – FRC 2014: ACI-fib International Workshop. 2016. Pp. 181–192. DOI: 10.35789/fib.BULL.0079.Ch18
22. Yang, I.H., Park, J., Bui, T.Q., Kim, K.C., Joh, C., Lee, H. An Experimental Study on the Ductility and Flexural Toughness of Ultrahigh-Performance Concrete Beams Subjected to Bending. Materials. 2020. 13(10). Article no. 2225. DOI: 10.3390/ma13102225
23. Feng, Z., Li, C., Yoo, D., Pan, R., He, J., Ke, L. Flexural and cracking behaviors of reinforced UHPC beams with various reinforcement ratios and fiber contents. Engineering Structures. 2021. 248. Article no. 113266. DOI: 10.1016/j.engstruct.2021.113266
24. Tamov M.M., Salib M.I.F., Abuizeh Y.Q.Y., Sofianikov O.D. Mix design and study of strength properties of self-compacting ultra high-performance fiber-reinforced concrete. News of Higher Educational Institutions. Construction. 2022. 4(760). Pp. 25–39. DOI: 10.32683/0536-1052-2022-760-4-25-39
25. Solhmirzaei, R., Kodur, V.K.R. Modeling the response of ultra high performance fiber reinforced concrete beams. Procedia Engineering. 2017. 210. Pp. 211–219. DOI: 10.1016/j.proeng.2017.11.068
26. Alsomiri, M., Liu, Z. Experimental Study on the Structural Ductility of UHPC Beams under Flexure. International Interactive Symposium on Ultra-High Performance Concrete Papers. 2023. 3(1). Pp. 1–8. DOI: 10.21838/uhpc.16653

Contacts:

Yousef Abuizeih*,*
ORCID: https://orcid.org/0009-0000-0813-8133
E-mail: yousef.qasem1993@gmail.com

Murat Tamov*, PhD in Technical Sciences*
ORCID: https://orcid.org/0000-0001-8235-2314
E-mail: murat.tamov@gmail.com

Received 01.08.2025. Approved after reviewing 13.10.2025. Accepted 17.10.2025.