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State of the Art of Bond Behavior of Lap Spliced Rebars in Ultra-High-Performance Concrete

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Abstract

Ultra-high performance concrete (UHPC) exhibits excellent mechanical proper-ties and superior bond performance with reinforcing bars compared with nor-mal concrete. Owing to its high bond strength, UHPC has attracted increasing attention in lap-spliced rebar connections. This paper reviews the bond behav-ior of lap-spliced rebars in UHPC. The main experimental methods and failure modes are first summarized. Then, the effects of key parameters, including steel fiber volume fraction, rebar diameter, lap length, clear spacing, cover thickness, and transverse reinforcement ratio, are discussed. In addition, the bond stress distribution along the lap length is reviewed. Existing studies indicate that the bond strength of lap-spliced rebars in UHPC increases with steel fiber content and cover thickness, while it generally decreases with increasing rebar diameter and lap length. Proper transverse reinforcement can restrain crack propagation and improve bond performance. The bond stress distribution also varies with lap length and exhibits different characteristics under different splice configura-tions. Finally, future research needs on the bond behavior of lap-spliced rebars in UHPC are briefly discussed.

Keywords

Ultra-high-performance concrete; Lap-spliced rebars; Bond behavior; Bond stress distribution; failure mode

1. Introduction

Precast concrete structures have the advantages of rapid construction, stable component quality, and reduced environmental impact, and have become an important form of industrialized concrete construction [1-5]. Among the various technical issues involved, the performance of structural connections directly affects both the global structural behavior and construction efficiency [6-8].

UHPC combines ultra-high strength, tensile strain-hardening behavior, and excellent durability [9-12]. The bond performance between reinforcing steel and UHPC is significantly better than that of normal concrete, and the anchorage length can be shortened by about 70% [13-15]. Therefore, using UHPC in lap-spliced rebar

connections can effectively shorten the splice length and simplify the connection details.

This paper reviews the bond behavior of lap-spliced rebars in UHPC. The main experimental methods and failure modes are first introduced. Then, the influences of major parameters on bond strength are summarized, including steel fiber content, rebar diameter, lap length, clear spacing, cover thickness, and transverse reinforcement ratio. The bond stress distribution along the lap length is also discussed. On this basis, the current research status is summarized and future research needs are highlighted.

2. Bond Behavior of Lap-Spliced Rebars in UHPC

The bond behavior of lap-spliced rebars in UHPC is a key issue in the design of precast concrete frame structures with UHPC-based connections. If the splice length is too short, a reliable connection cannot be achieved. If it is too long, transportation and erection of precast components become less convenient and construction efficiency is reduced.

2.1. Test Methods and Failure Modes

To investigate the bond behavior of lap-spliced rebars in UHPC, researchers have mainly used two experimental approaches, namely beam tests and direct tension tests [16].

Beam tests can reflect the stress state of lap-spliced bars in real structures with relatively high fidelity, but the test setup is comparatively complicated and the parameters are not easy to vary extensively. In beam tests, the dominant failure modes are cracking of the concrete at the beam bottom, followed by bond failure or yielding of the lap-spliced rebars [17-20].

Direct tension tests are simpler and more suitable for studying bond mechanisms. According to the number of rows of spliced bars, they can be divided into single-row and double-row direct tension tests. Because of eccentricity, single-row tests almost always fail by splitting [21-23]. In double-row tests, the failure modes can be classified into bar pullout, UHPC splitting, and bar fracture [16,24-27]. When UHPC splitting occurs, both Lagier et al. [24-27] and Hu et al. [16,28-29] observed an X-shaped crack pattern.

2.2. Major Factors Influencing Bond Strength

Existing tests [16-31] indicate that the bond strength of lap-spliced rebars in UHPC is mainly affected by steel fiber volume fraction, rebar diameter, splice length, clear spacing, cover thickness, and transverse reinforcement ratio.

2.2.1. Steel Fiber Volume Fraction

Lee [18] showed experimentally that adding steel fibers at a volume fraction of 2%

improved the ductility of ultra-high-strength concrete (UHSC) beams and significantly increased the bond strength of lap-spliced rebars. Hussein et al. [19] reported that the effect of steel fiber dosage on splice behavior in reactive powder concrete (RPC) was limited, and that increasing the fiber volume fraction from 0.75% to 1.5% increased bond strength by only 2.2%. Lagier et al. [25] found that when the steel fiber volume fraction increased from 1% to 2% and 4%, bond strength increased by 21.4% and 47.1%, respectively. Graybeal and co-workers [30-31] also reported a positive correlation between bond strength and steel fiber volume fraction, and recommended that the steel fiber volume fraction in UHPC should not be less than 2% to ensure effective lap splicing.

2.2.2. Rebar Diameter

Lagier et al. [25,27] found that when the rebar diameter increased from 25 mm to 35 mm, the bond strength of lap-spliced rebars in UHPC decreased by 8.6%-9.1%. In contrast, Hussein et al. [19] reported a 9% increase in bond strength when the rebar diameter increased from 12 mm to 16 mm. This discrepancy may be related to the limited number of diameter-related specimens in their study, which involved only two beams. Based on 20 double-row lap-splice tests, Hu et al. [29] showed that larger rebar diameters generally lead to lower bond strength in UHPC. For example, when the splice length was 4d, the bond strength of specimens with bar diameters of 20, 25, and 32 mm decreased by 14.8%, 27.6%, and 35.2%, respectively, compared with that of specimens with 10 mm bars. In general, because of the Poisson effect and shear lag effect, bond strength tends to decrease as rebar diameter increases.

2.2.3. Splice Length

Lagier et al. [24-27] reported that splice length in the range of 5d-12d had little influence on bond strength in UHPC. Fang et al. [21] found that, compared with specimens having a splice length of 5d (d = 20 mm), the bond strength of specimens with splice lengths of 7.5d and 10d decreased by about 5%. Based on 21 single-row direct tension tests, Ma et al. [22-23] found that specimens with a splice length of 12d (d = 25 mm) had bond strength 16.4% lower than that of specimens with a splice length of 8d. Hu et al. [16] showed that for 14 mm bars, the bond strength of specimens with splice lengths of 4d, 6d, and 8d was 30.9%, 40.6%, and 50.1% lower, respectively, than that of specimens with a splice length of 2d. For 25 mm bars, the bond strength of specimens with splice lengths of 4d and 6d was 14.5% and 18.5% lower, respectively, than that of specimens with a splice length of 2d. In general, a longer bond length results in a more nonuniform bond stress distribution and a lower average bond strength.

2.2.4. Clear Spacing of Lap Splices

Fang et al. [21] investigated the effect of clear spacing on the bond strength of rebars in RPC. Compared with specimens having a clear spacing of 1d, contact lap-splice specimens showed a 5% reduction in bond strength. Yuan and Graybeal [32] reported that the bond strength of contact lap-splice specimens was about 80% of that of noncontact lap-splice specimens with a clear spacing greater than 2d. Because contact lap splices contain inherent defects, UHPC design specifications in other countries generally require noncontact lap splices. For example, NF P18-710, Design of Concrete Structures: Specific Rules for Ultra-High Performance Fibre-Reinforced Concrete (UHPFRC), specifies that the clear spacing of lap-spliced rebars in UHPC should be greater than the maximum of the bar diameter, 1.5 times the steel fiber length, 20 mm, and the maximum aggregate size plus 5 mm.

2.2.5. Cover Thickness

Hussein et al. [19] found that when the cover thickness increased from 1.6d to 2.5d, the bond strength of lap-spliced rebars in RPC increased by 8%. Based on 12 beam tests, Ronanki et al. [20] showed that when the cover thickness was smaller than 4d, the bond strength of lap-spliced rebars in UHPC increased as the cover thickness increased. A larger cover thickness provides stronger confinement to the spliced rebars and therefore improves bond strength.

2.2.6. Transverse Reinforcement Ratio

Fang et al. [21] found that, compared with single-row direct tension specimens without stirrups, specimens with transverse reinforcement ratios of 0.34% and 0.75% showed a slight increase in bond strength, with the maximum increase approaching 10%. Ma et al. [22-23] further showed that providing stirrups can improve the bond strength of lap-spliced rebars in RPC. In addition, under the same transverse reinforcement ratio, spiral stirrups and rectangular stirrups had little difference in their influence on bond strength. Stirrups restrain crack propagation during RPC splitting failure and thus improve bond performance.

Overall, the bond strength of lap-spliced rebars in UHPC increases with steel fiber volume fraction in the range of 1%-4%, and decreases with increasing rebar diameter (10-32 mm) and splice length (2d-8d). When the cover thickness is smaller than 4d, increasing the cover thickness improves bond strength. Transverse reinforcement helps restrain crack development and thus enhances bond strength, whereas the stirrup configuration has little effect. Compared with contact lap splices, noncontact lap splices generally provide slightly higher bond strength.

2.3. Distribution of Bond Stress

The bond stress distribution along the splice length is important for understanding bond mechanisms in UHPC. Existing studies have mainly used two measurement methods, namely externally bonded strain gauges on the rebar surface and

internally mounted strain gauges embedded in grooves cut into the rebar. The latter method can avoid the influence of surface damage to the bar on the measured stress distribution.

Using externally bonded strain gauges on the rebar surface, Ronanki et al. [20] showed that when the splice length was 8d (d = 13 mm), the bond stress along the splice length was nonuniform, and the bond stress within 2d of the free end accounted for about 60% of the maximum stress in the bar. In that study, however, only four measurement points were arranged along the splice length, which may have introduced some uncertainty into the test results.

Lagier et al. [26] used internally mounted strain gauges in rebar grooves and arranged 8-13 measurement points along the splice length. Their results showed that when the splice length was 5d or 10d (d = 25 mm), the bond stress exhibited two local peaks near the free end and loading end, while the bond stress between the two peaks could be approximately regarded as uniformly distributed.

Using the same internally mounted strain-gauge method, Hu et al. [16,28-29] further investigated the effects of splice length and rebar diameter on bond stress distribution. Eleven measurement points were arranged along the splice length, and a third-order polynomial distribution function of bond stress along the splice length was established. The results showed that when the splice length was 2d, the bond stress was approximately uniformly distributed along the splice length. When the splice length was 4d, the bond stress showed a double-peak distribution. When the splice length was 6d or 8d, the bond stress exhibited a single-peak distribution.

3. Conclusions

(1) The bond performance of lap-spliced rebars in UHPC is significantly better than that in normal concrete. Owing to the high tensile strength and crack resistance of UHPC, reliable force transfer can be achieved within a relatively short lap length.

(2) The bond strength of lap-spliced rebars in UHPC is mainly influenced by steel fiber volume fraction, rebar diameter, lap length, clear spacing, cover thickness, and transverse reinforcement ratio. In general, higher steel fiber content and larger cover thickness improve bond performance, whereas larger rebar diameter and longer lap length tend to reduce the average bond strength.

(3) The bond stress distribution along the lap length is non-uniform and is closely related to the lap length and splice configuration. Different lap lengths may result in nearly uniform, double-peak, or single-peak bond stress distributions.

(4) Although substantial progress has been made, further studies are still needed on the bond mechanism under cyclic loading, the influence of more complex stress states, and the establishment of unified evaluation approaches for lap-spliced rebars in UHPC.

References

[1] Bachmann, H. and Steinle, A. (2012) Precast Concrete Structures. Wiley, Berlin.

[2] Xue, W. (2002) Progress of studies and applications of precast concrete frame structure systems. Industrial Construction, 32(11), 47-50.

[3] Xue, W. and Hu, X. (2018) Overview of research progress on precast concrete building structure systems. Construction Technology, 47(12), 1-5, 43.

[4] Xue, W. and Hu, X. (2019) State of the art of studies on precast concrete shear wall structures. Journal of Building Structures, 40(2), 44-55.

[5] Xue, W. and Hu, X. (2020) Research progress on precast concrete frame structures. Journal of Tongji University (Natural Science), 48(9), 1241-1255.

[6] Xue, W., Hu, X., Ren, D., et al. (2021) Hysteretic performance of precast beam-column connections fabricated with high-strength materials. Structures, 33, 4568-4578.

[7] Xue, W., Bai, H., Dai, L., et al. (2021) Seismic behavior of precast concrete beam-column connections with bolt connectors in columns. Structural Concrete, 22(3), 1297-1314.

[8] Xue, W., Hu, X., Dai, L., et al. (2022) Cyclic behavior of semi-rigid precast concrete beam-to-column subassemblages with rapid assembly connections. Journal of Building Engineering, 46, 103671.

[9] de Larrard, F. and Sedran, T. (1994) Optimization of ultra-high-performance concrete by the use of a packing model. Cement and Concrete Research, 24(6), 997-1009.

[10] AFGC/SETRA. (2013) Ultra High Performance Fibre-Reinforced Concretes. French Civil Engineering Association, Bagneux.

[11] Haber, Z.B., de la Varga, I., Graybeal, B., et al. (2018) Properties and Behavior of UHPC-Class Materials, FHWA-HRT-18-036. Federal Highway Administration, Virginia.

[12] Xue, W., Hu, X. and Xue, W. (2022) Calculation method of flexural capacity of ultra-high-performance concrete beams reinforced with FRP rebars. Acta Materiae Compositae Sinica, 39(11), 5109-5121.

[13] Deng, Z. and Yuan, C. (2014) Experimental study on bond capability between high-strength rebar and reactive powder concrete. China Civil Engineering Journal, 47(3), 69-78.

[14] Yuan, J. and Graybeal, B. (2015) Bond of reinforcement in ultra-high-performance concrete. ACI Structural Journal, 112(6), 851-860.

[15] Yoo, D.Y. and Shin, H.O. (2018) Bond performance of steel rebar embedded in 80-180 MPa ultra-high-strength concrete. Cement and Concrete Composites, 93, 206-217.

[16] Hu, X., Xue, W., Lv, Y., et al. (2023) Experimental investigations of bond behavior of double-row spliced rebars in ultra-high-performance concrete (UHPC). Engineering Structures, 284, 115929.

[17] Dagenais, M.A. and Massicotte, B. (2015) Tension lap splices strengthened with ultrahigh-performance fiber-reinforced concrete. Journal of Materials in Civil Engineering, 27(7), 04014206.

[18] Lee, J.K. (2016) Bonding behavior of lap-spliced reinforcing bars embedded in ultra-high-strength concrete with steel fibers. KSCE Journal of Civil Engineering, 20(1), 273-281.

[19] Al-Quraishi, H., Al-Farttoosi, M. and Abdulkhudhur, R. (2019) Tension lap splice length of reinforcing bars embedded in reactive powder concrete (RPC). Structures, 19, 362-368.

[20] Ronanki, V.S., Aaleti, S. and Valentim, D.B. (2018) Experimental investigation of bond behavior of mild steel reinforcement in UHPC. Engineering Structures, 176, 707-718.

[21] Fang, Z., Chen, X., Zhang, M., et al. (2019) Experimental study on performance of lap-spliced ribbed steel bars in reactive powder concrete. China Civil Engineering Journal, 52(3), 20-28, 49.

[22] Ma, F., Deng, M., Fan, H., et al. (2020) Study on the lap-splice behavior of post-yield deformed steel bars in ultra-high-performance concrete. Construction and Building Materials, 262, 120611.

[23] Ma, F., Deng, M., Ma, Y., et al. (2021) Experimental study on interior precast concrete beam-column connections with lap-spliced steel bars in field-cast RPC. Engineering Structures, 228, 111481.

[24] Lagier, F., Massicotte, B. and Charron, J.P. (2012) Bond splitting strength of lap splice embedded in ultra-high-performance fibre-reinforced concrete under direct tension. Bond in Concrete, 351-358.

[25] Lagier, F., Massicotte, B. and Charron, J.P. (2015) Bond strength of tension lap splice specimens in UHPFRC. Construction and Building Materials, 93, 84-94.

[26] Lagier, F., Massicotte, B. and Charron, J.P. (2016) Experimental investigation of bond stress distribution and bond strength in unconfined UHPFRC lap splices under direct tension. Cement and Concrete Composites, 74, 26-38.

[27] Lagier, F., Massicotte, B. and Charron, J.P. (2016) Behaviour of tension lap splice specimens in UHPFRC. Proceedings of the 9th RILEM International Symposium on Fiber Reinforced Concrete (BEFIB), Vancouver, 2016.

[28] Xue, W., Hu, X. and Lyu, Y. (2023) Experimental Study on Lap-Spliced Properties of Rebar in UHPC. Research Report, College of Civil Engineering, Tongji University, Shanghai, 35-71.

[29] Hu, X., Xue, W. and Lyu, Y. (2023) Bond properties between lapped steel rebars and UHPC under direct tension. Construction and Building Materials, 408, 133761.

[30] Graybeal, B. (2014) Design and Construction of Field-Cast UHPC Connections, FHWA-HRT-14-084. Federal Highway Administration, Virginia.

[31] Haber, Z.B. and Graybeal, B.A. (2018) Lap-spliced rebar connections with UHPC closures. Journal of Bridge Engineering, 23(6), 04018028.

[32] Yuan, J. and Graybeal, B.A. (2014) Bond Behavior of Reinforcing Steel in Ultra-High Performance Concrete, FHWA-HRT-14-090. Federal Highway Administration, Virginia..