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Side-Face Blowout Strengths of Headed Bars in Ultra-High-Performance Fiber-Reinforced Concrete (UHPFRC)

*Sungchul Chun[1)], Hye-Jung Sim[2)] and Sokhwan Choi[3)]

[1), 2)] *Div. of Arch. & Urban design, Incheon National University, Incheon, 22012, Korea*
[3)] *Dept. of Civil & Environmental Engineering, Kookmin University, Seoul, 02707, Korea*
[1)] *scchun@inu.ac.kr*

ABSTRACT

Ultra-High-Performance Fiber-Reinforced Concrete (UHPFRC) exhibits improved compressive and tensile strengths far superior to those of conventional concrete. The anchorage strengths of headed bars with $4d_b$ or $6d_b$ embedment length were evaluated by simulated exterior beam-column joint tests where the headed bars were used as beam bars and the joints were cast of 120 or 180 MPa UHPFRC. In all specimens, the actual yield strengths of the headed bars over 600 MPa were developed. Some headed bars were fractured due to the high anchorage capacity in UHPFRC. Therefore, the headed bar with only $4d_b$ embedment length in 120 MPa UHPFRC can develop a yield strength of 600 MPa.

1. INTRODUCTION

According to ACI 318-14(2014), the development length of headed bars is equal to 80 percent of that used for hooks, provided that headed bars meet the requirements of Class HA heads in ASTM A970-15(2015). In addition, the following conditions must be satisfied: the net bearing area of the head is at least four times the cross-sectional area of the bar; the smaller of the concrete cover to the surface of the bar and half the clear bar spacing is at least twice the bar diameter; the diameter of headed bars does not exceed 36 mm; the maximum yield strength f_y used to design l_{dt} is limited to 420 MPa; and f_c' is limited to a maximum of 42 MPa. The minimum limits on head size, clear cover, and clear spacing, and the restrictions on the upper limit of bar diameter, bar yield strength, and compressive strength of concrete are based on the available data from tests (Thompson et al. 2005, 2006a, and 2006b). Commentary R25.4.4.2 of ACI 318-14 states that because transverse reinforcement has been shown to be largely ineffective in improving the anchorage of headed deformed bars (Thompson et al. 2005,

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[1)] Associate Professor
[2)] Graduate Student
[3)] Professor

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2006a, and 2006b), additional reductions in development length are not used for headed bars.

The application of high-strength concrete over 42 MPa is not permitted because of the limited tests of headed bars in high-strength concrete. UHPFRC (ultra-high-performance fiber-reinforced concrete) (Hong et al. 2011; Karl et al. 2011; Park et al. 2012; Yang et al. 2012) developed by the KICT (Korea Institute of Construction Technology) is a relatively new type of concrete that exhibits mechanical properties that are far superior to those of conventional concrete and in some cases rival those of steel. The main characteristics that distinguish UHPFRC from conventional concrete are its improved compressive and tensile strengths. In addition, UHPFRC has enhanced displacement capacities as shown in Fig. 1 (Choi et al. 2012). These characteristics can significantly reduce the cross sectional area of the member but the steel congestion may become worse. The headed bar, as shown in Fig. 2, can be a viable option to alleviate the congestion, especially in joints. Moreover, the anchorage strengths of headed bars are expected to be improved because of the enhanced tensile strength of UHPFRC. However, the improved characteristics of UHPFRC cannot be utilized in designing headed bars because of the aforementioned limitations of the current code provisions for headed bars.

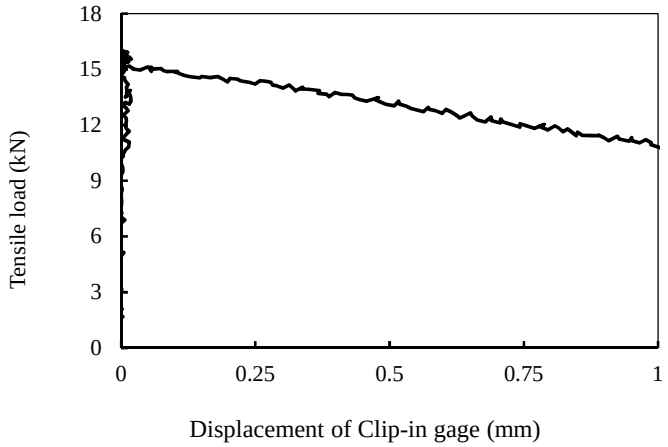

Fig. 1 Direct tensile load-displacement relationships of UHPFRC (Choi et al. 2012)

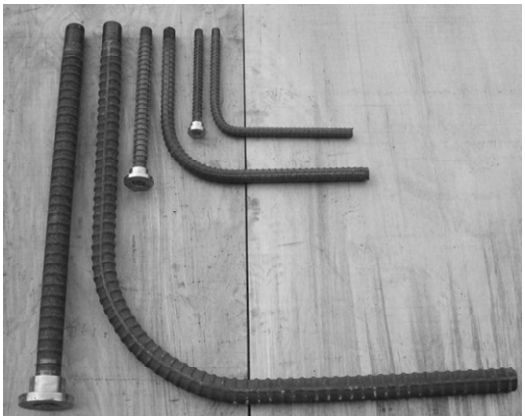

Fig. 2 Headed and hooked bars

A total of twenty tests, four with 180 MPa UHPFRC and sixteen with 120 MPa UHPFRC, were conducted to investigate behavior and strengths of headed bars in UHPFRC. The measured strengths were compared with the predictions by ACI 318-14 and Thompson's model (Thompson et al. 2006b). In addition, the effects of design parameters were investigated.

An exterior beam-column joint is an ideal application for headed bars due to the high level of reinforcement congestion. The ACI 318 provisions for hooked bars were developed based on joint tests (Marques and Jirsa 1975). In this study, simulated exterior beam-column joint tests were therefore conducted to evaluate the anchorage strength of headed bars.