Use of steel microfibers, steel macrofibers, PVA fibers, and hybrid fibers in UHPC:
Experience from shear tests and bond strength tests of UHPC beams

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1. The presence of fibers disturbs UHPC's microstructure
2. Distribution of the steel microfibers is statistically more uniform when compared to other types of fibers.

=> In the last three decades, UHPC structural members have been mainly reinforced with steel microfibers.

- ACI Committee 544 considers the fiber diameter of 0.3 mm as the separating limit between microfibers and macrofibers.

Microfibers

Macrofibers

Fiber type	**Steel microfibers**	**PVA microfibers**	**Hooked end steel**	**Doubled hooked end steel**
Diameter	**0.22 mm**	**0.038 mm**	**0.38 mm**	**0.90 mm**
Length	**13 mm**	**8 mm**	**30 mm**	**60 mm**
Notation	**mF**	**mPVA**	**SF**	**LF**

Mixing UHPC with steel microfibers

Mixing UHPC with steel microfibers

Steel microfibers

- Uniform distribution of the fibers
- Slump > than 60 cm
- f'_c = 120~160 MPa when $V_f \geq 0.75\%$

Mixing UHPC reinforced with different types of fibers

Double hooked end macrofibers

Fiber balling

Mixing UHPC reinforced with different types of fibers

Hooked end steel macrofibers

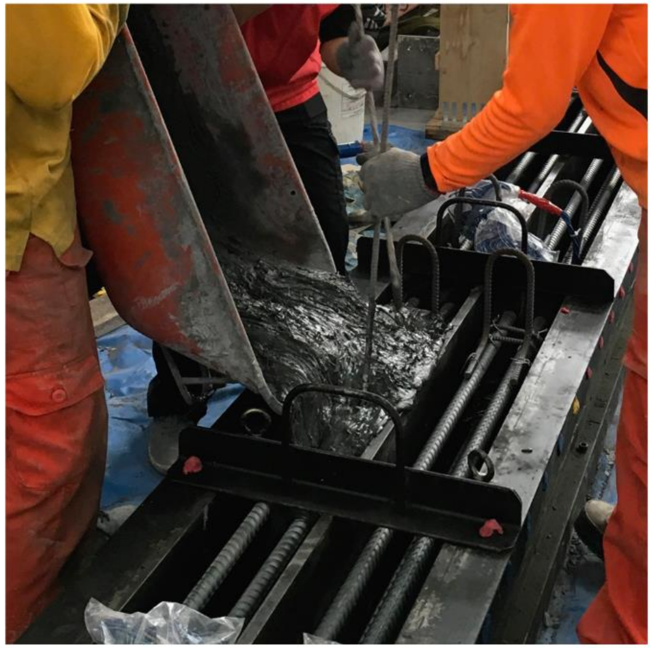
PVA fibers

UHPC reinforced with V_f = 2.25%LF

After adjusting the SP content

Slump = 35 ~ 40 cm

Good workability



UHPC reinforced with V_f = 2.25%PVA

Slump = 40 ~ 45 cm

UHPC reinforced with V_f = 0.75%SF + 0.75%LF

Reduction in the slump (25 ~ 30 cm)

UHPC reinforced with V_f = 0.75%SF + 1.50LF

Slump 35 ~ 40 cm

UHPC reinforced with V_f = 1.50%SF + 0.75%LF

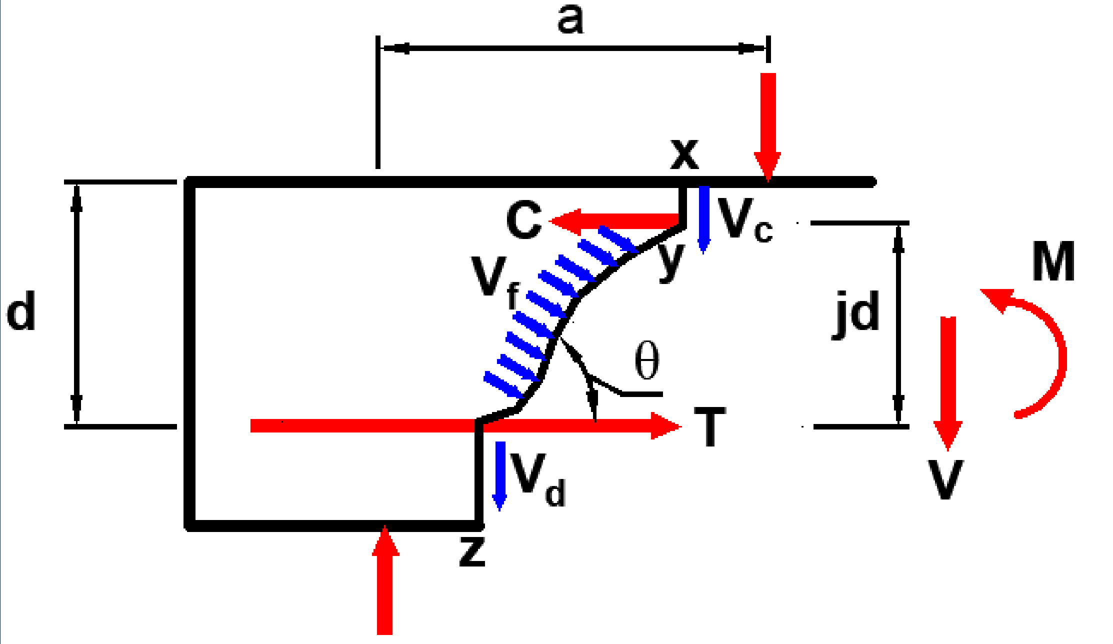
Slump 40 ~ 45 cm

Good workability

UHPC reinforced with V_f = 0.75%SF +

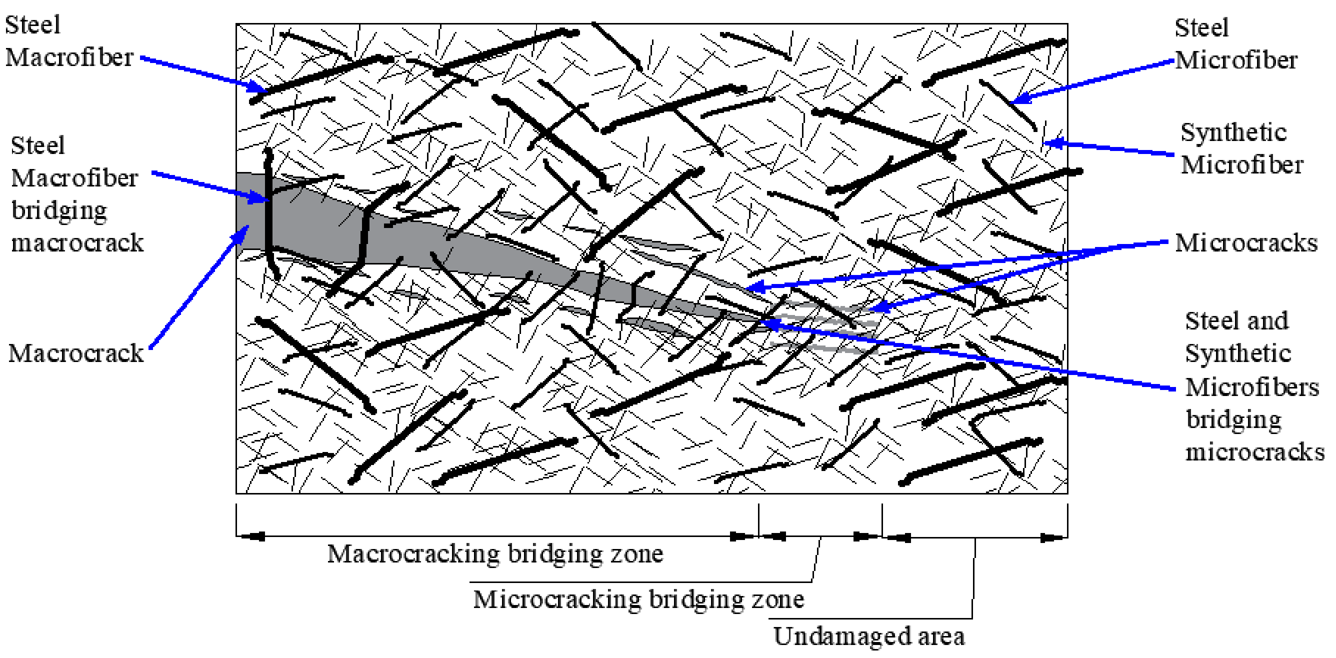
Slump 55 ~ 65 cm

Experience on Shear tests of UHPC beams



Shear Resisting Mechanisms of beams without stirrups

Effective net of fiber reinforcement



UHPC beams with (a/d = 1.5)

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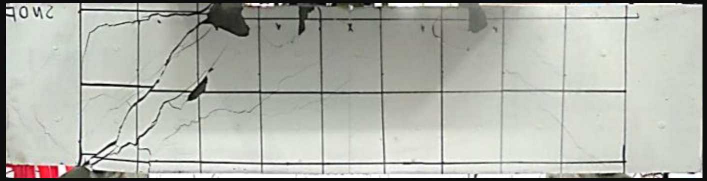
S – 0% F

At peak load

At failure



S – 2.25% LF

At peak load

At failure

S – 2.25% mPVA

At peak load

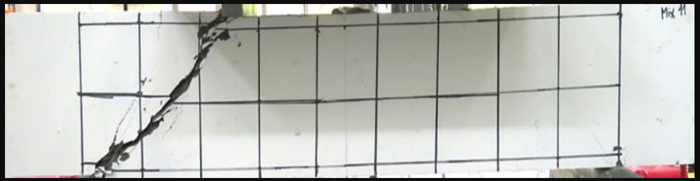
At failure

UHPC beams with hybrid fibers

S – 0.75%SF+1.50%LF

At peak load

At failure



S – 0.75SF+0.75LF+0.75mPVA

At peak load

At failure

UHPC beams with (a/d = 3.3)

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L – 0% F

At peak load

At failure

L – 2.25% LF

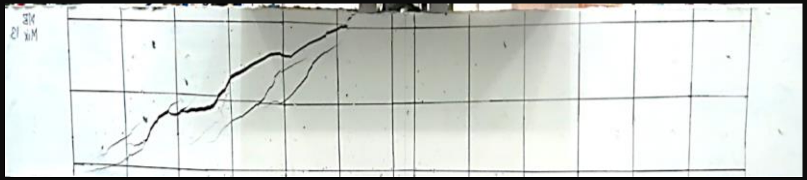
At peak load

At failure

L – 2.25% PVA

At peak load

At failure



L – 0.75%SF+1.50%LF

At peak load

At failure

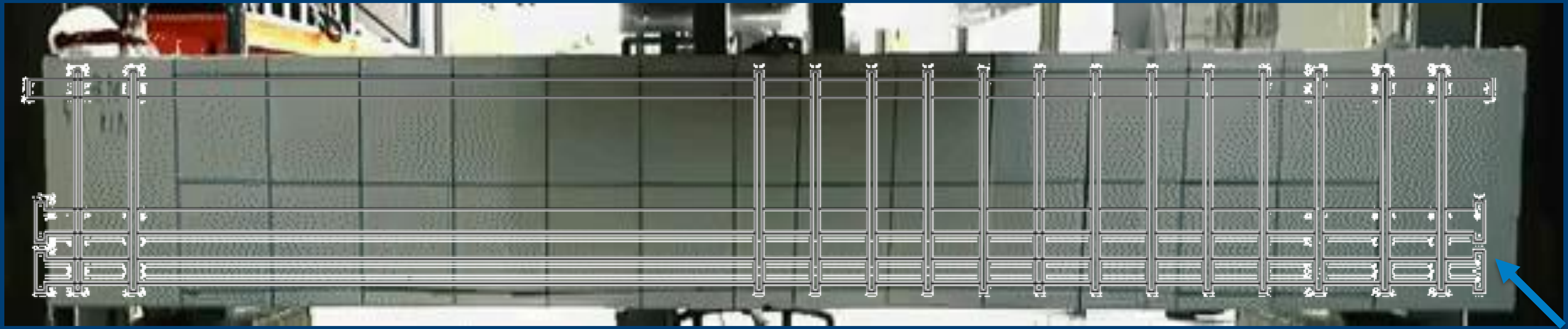
UHPC beams with hybrid fibers

L – 0.75SF+0.75LF+0.75mPVA

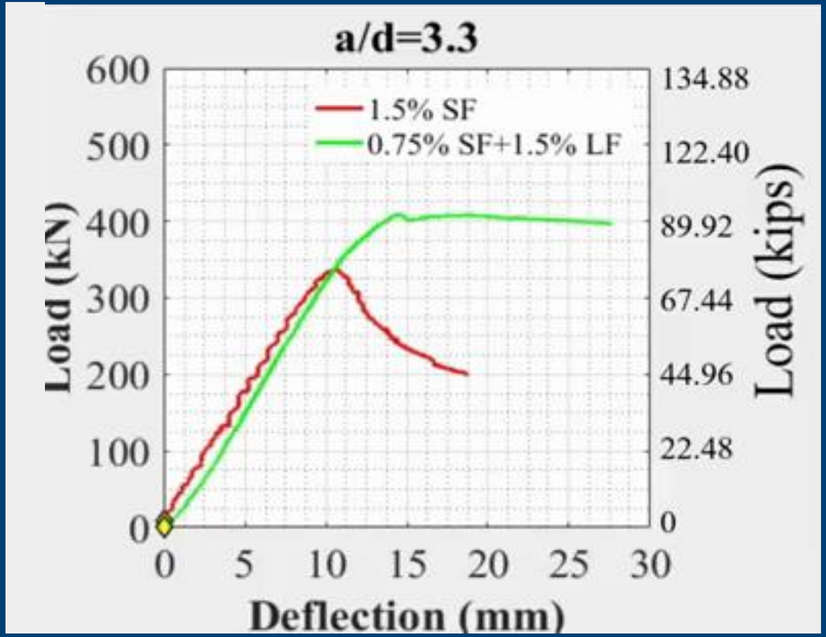
At peak load

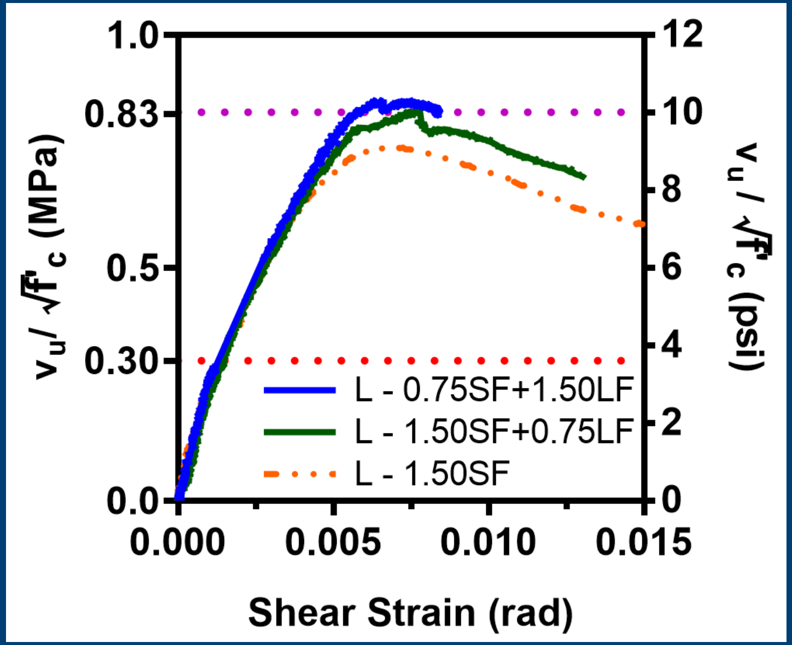
At failure

Slender UHPC beam with 0.75%SF+1.50%LF



$\rho_l = 7.6\%$



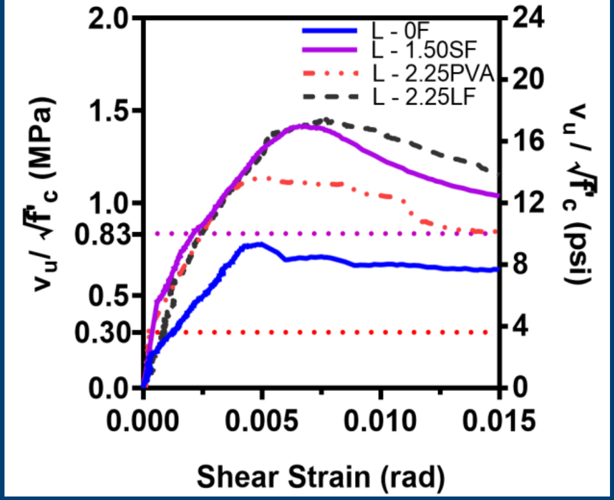


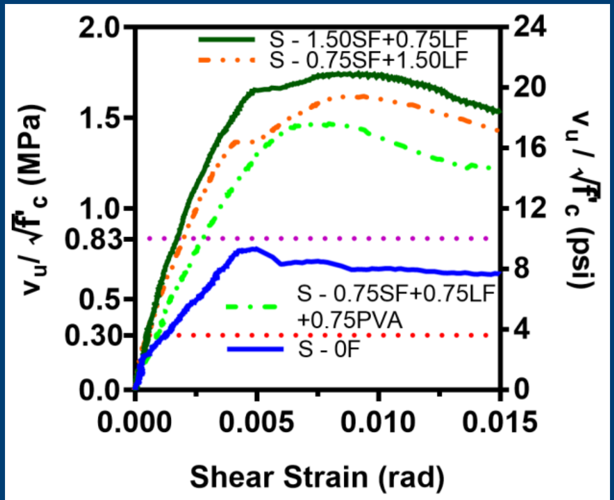
Can we use other types of fibers as shear reinforcement?

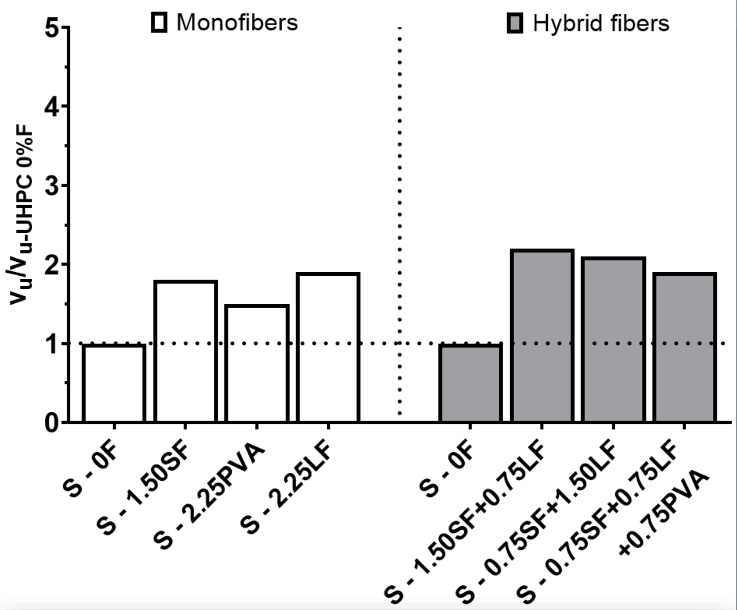
Monofibers

Hybrid fibers

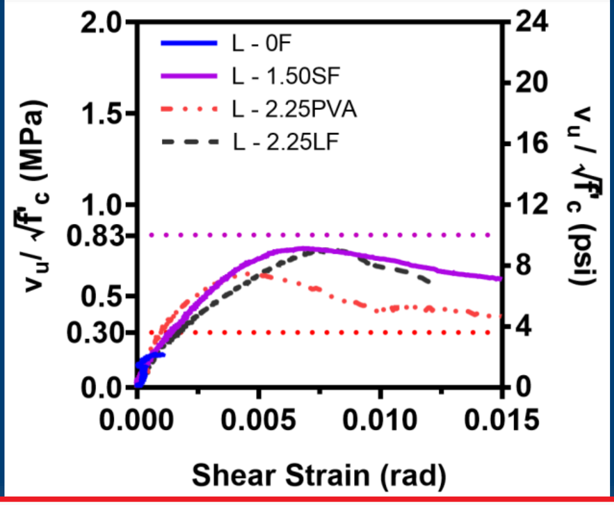
(a/d =1.5)

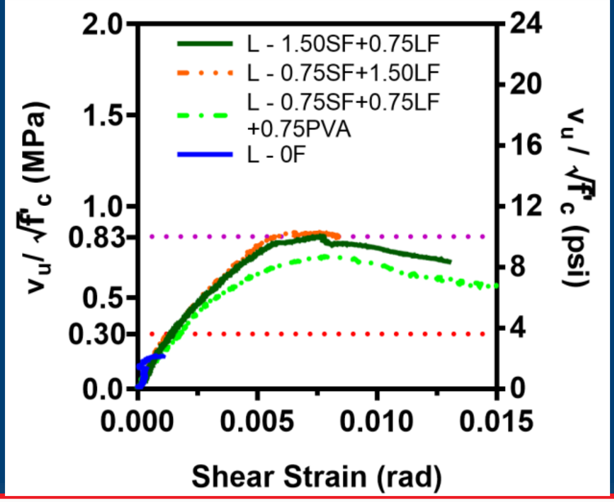


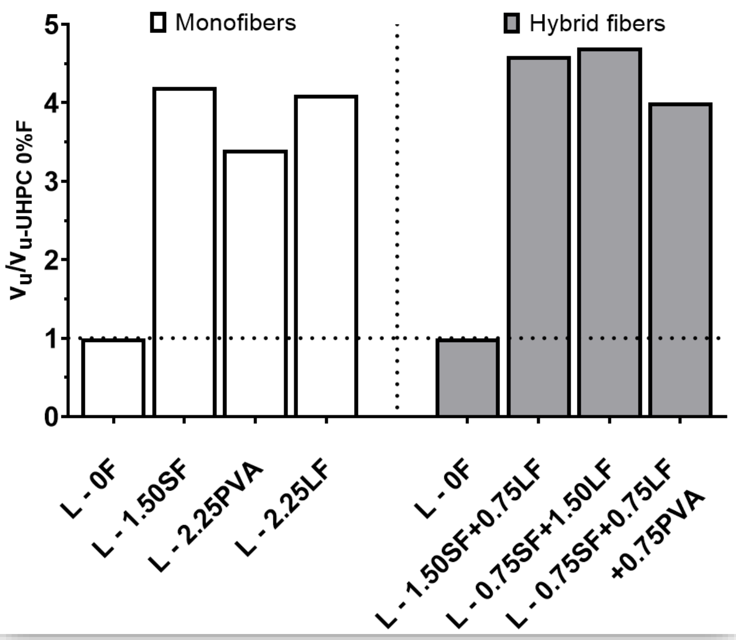




(a/d =3.3)







Experience in bond strength and splicing length of rebars in UHPC

- The development of reinforcement stipulated by ACI 318 (2019) in section 25.4 has an upper limit of compressive strength up to 70 MPa.
- This limit is too conservative when considering the outstanding mechanical properties exhibited by UHPC.

$$l_{d,318-19} = \left(\frac{f_y}{1.1\lambda\sqrt{f_c'}} \frac{\psi_t\psi_e\psi_s\psi_g}{(\frac{c_b + k_{tr}}{d_b})} \right) d_b$$

Development length
(ACI 318-2019)

$$u_{318-19} = \frac{A_b f_s}{\pi d_b (1.3 l_s)} = \frac{\frac{\pi d_b^2}{4} f_s}{\pi d_b 1.3 \left(\frac{f_s}{1.1\lambda\sqrt{f_c'}} \frac{\psi_t\psi_e\psi_s\psi_g}{(\frac{c_b + k_{tr}}{d_b})} \right) d_b} = \frac{\lambda(\frac{c_b + k_{tr}}{d_b})}{4.68\psi_t\psi_e\psi_s\psi_g} \sqrt{f_c'}$$

Bond strength
(ACI 318-2019)

f'_c limited to 70 MPa

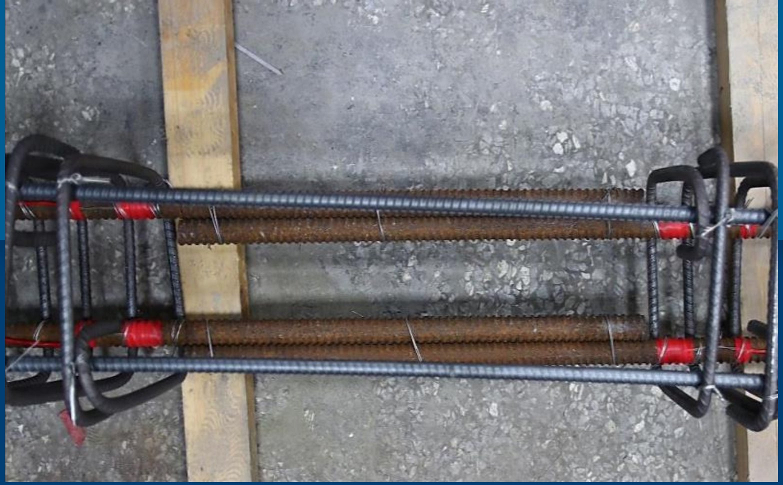
High Strength Steel Reinforcing Bars

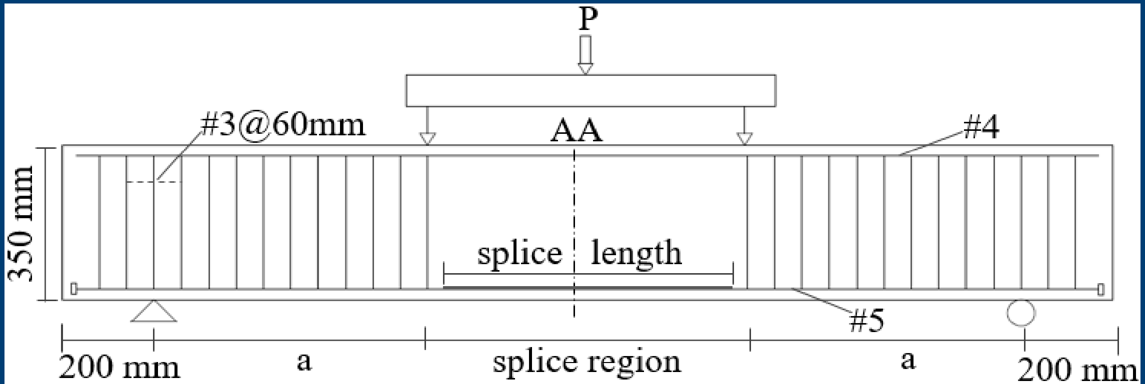
Bar size	Face 1	Face 2
(D16) SD785 #5, Grade 120		
(D25) SD685 #8, Grade 100		

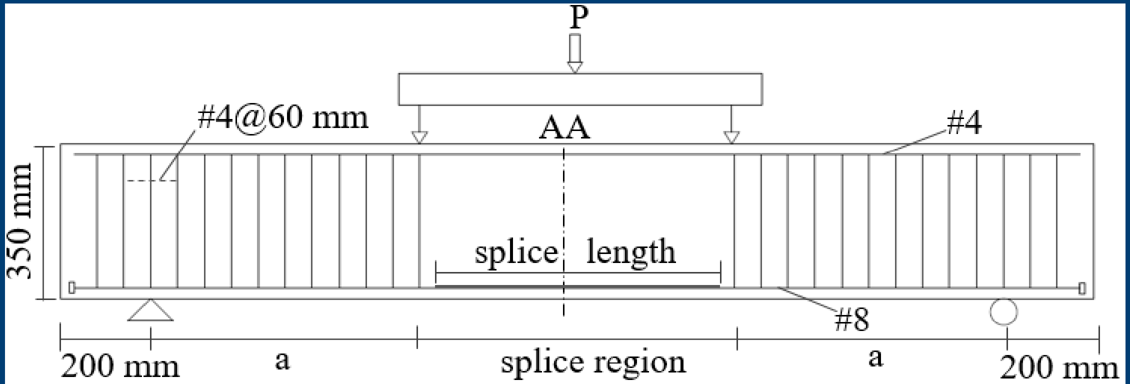
Bar type	Nominal area (mm^2)	Depth of each rib h_r(mm)	Width of each rib w_r (mm)	Spacing between ribs S_r (mm)	Area of ribs A_r (mm^2)	Relative area of ribs R_r
#5(D16) SD785	198.5	0.72	2.7	6.5	32	0.096
#8(D25) SD685	490.7	2	3	10	148	0.184

Bar Type	Yield Strength (MPa)	Ultimate Strength (MPa)
SD785-#5(D16)	800	993
	840	1025
	821	1022
Average	**820**	**1013**
SD685-#8(D25)	702	901
	707	902
	710	905
Average	**707**	**902**

UHPC reinforced with 2% of steel microfiber



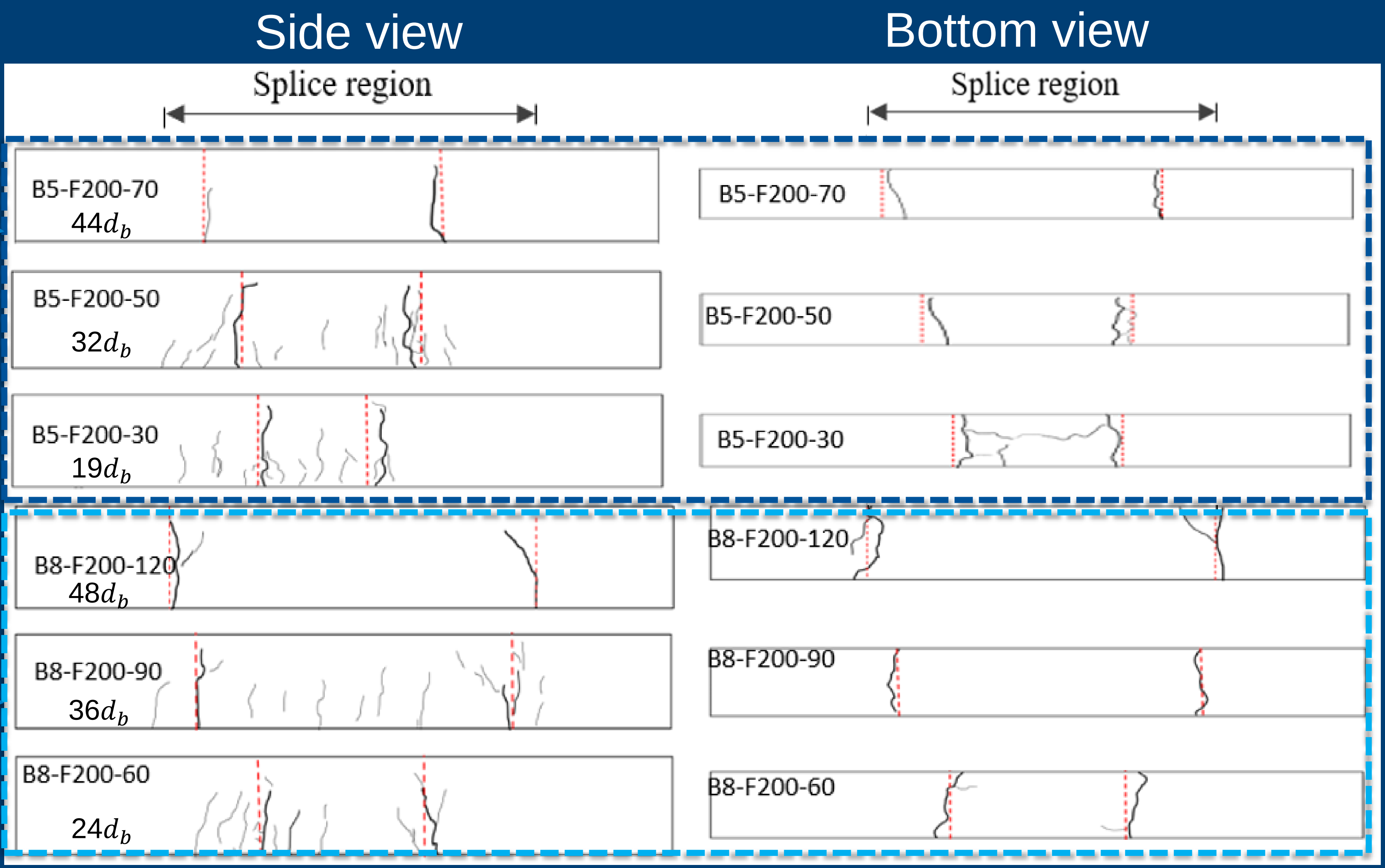




	Bar #5 (D16)	**Bar #8 (D25)**
	<u>Splicing lengths</u>	<u>Splicing lengths</u>
	$44d_b$ / 32 d_b / 19 d_b	$48d_b$ / 36 d_b / 24 d_b
$l_{d-ACI\ 318}$ f'_c = 70 MPa	74% / 53% / 32%	73% / 55% / 36%
$l_{d-ACI\ 318}$ using real f'_c	106% / 71% / 44%	107% / 77% / 51%

(D16) SD785
#5, Grade 120

(D25) SD685
#8, Grade 100



- In some lap-splice beams, we failed to allow the UHPC beams to fail in bond failure because the very high bond strength of UHPC: UHPC beams with either bar #5(D16) or #8(D25) had only flexural cracks with no splitting cracks and tension reinforcement yielding before failure.

- The superior performance of UHPC can also represent an obstacle in trying to investigate the design parameters such as the bond strength and shear strength.

- It was found that in UHPC beam tests that had the splice length of only 40% of the required length per ACI 318 for normal concrete, flexural capacity developed by the reinforcing bars prevented bond failure.

Thank you!

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