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Effects of fluidity and placing method of HPFRCC on tensile performance test results

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ABSTRACT: Tension tests were conducted on HPFRCC dumbbell-shaped specimens fabricated by shotcreting or casting to investigate the effects of their fluidity and placing method on the tension test results. Five HPFRCC mixtures with different fiber contents (2% and 1.7 % by volume) and fluidities were used. The differences of the placing methods and flow values scarcely affected the tensile strength. The ultimate tensile strain of a HPFRCC with a lower fiber content was more strongly affected by the fluidity and placing method, leading to a larger scatter.

1 INTRODUCTION

The tensile performance of a high performance fiber-reinforced cementitious composite (HPFRCC) is mostly evaluated in terms of the tensile stress-strain relationship and cracking properties. A higher ultimate tensile strain with a smaller scatter, as well as a smaller scatter of tensile strength, is desirable for a HPFRCC from the aspect of the durability and aesthetics of structures (JSCE 2007). A capability of dispersing fine cracks over the tension zone is also desirable.

Uniaxial tension testing on dumbbell-shaped specimens is mostly selected to measure the tensile performance of a HPFRCC. Its fluidity during placing is evaluated by flow values. It is mostly placed by shotcreting or normal placing (casting).

When applying a HPFRCC to actual structures, it is important to elucidate the effects of its fluidity and placing method (method of fabricating specimens) on its tension test results.

Tension tests were conducted in this study on HPFRCC dumbbell-shaped specimens with different fluidities fabricated by shotcreting or casting to experimentally investigate the effects of their fluidity and placing method on the tension test results.

2 OOTLINE OF EXPERIMENT

2.1 *Mix proportions and materials*

Five HPFRCC mixtures with different fiber contents (2% and 1.7 % by volume) and fluidities were used for the tests. Different fluidities were obtained by changing the dosage of a water-reducing admixture for 2% fiber mixtures ("A") and both the dosages of the water-reducing admixture and an air-entraining admixture for 1.7% fiber mixtures ("B"). Polymer cement mortar made by premixing normal portland cement and a polymer was used as the matrix for the HPFRCCs. Water-based acrylic and a redispersible powder-type vinyl acetate/vinyl versatate copolymer were used as polymers for "A " and "B" mixtures, respectively. While the water-binder ratio was kept constant at 34% for all mixtures, the binder content and unit water content for "A" mixtures were higher than for "B" mixtures. Short fibers were a blend of two types: high strength polyvinyl alcohol (PVA) fibers 12 mm in length and 40 μm in diameter and ultrahigh strength polyethylene (PE) fibers 9 mm in length and 12 μm in diameter.

2.2 *Methods of placing HPFRCC*

Dumbbell-shaped specimens were fabricated by two placing methods, shotcreting and casting, to investigate the effects of the fluidity and placing methods of HPFRCCs on their tensile performance. For specimens by shotcreting, the material conveyed by a squeeze pump was pneumatically (0.7 N/mm^2) shotcreted onto the molds. Pneumatic shotcreting expeled part of the air entrained in HPFRCCs, generally reducing the air content from the as-mixed value. For this reason, the material for casting was shotcreted onto a container before placing to equalize the air contents by both methods.

Table 2 gives the air content and flow value, which is an index to fluidity, after mixing and after

Table 1. Test conditions of 20 types of dumbbell-shaped specimens.

Specimen	Water-binder ratio(%)	Unit water content (W)	Fiber volume (%)	Water-reduced agent ratio	AE agent ratio	Placing methods	Shaping methods	Group name of specimen
AH	34%	336.3	2.0vol%	1.0(AH/AH)	None	Casting	Monolithic	AHN
							Cut-and-mold	AHNC
						Shotcreting	Monolithic	AHS
							Cut-and-mold	AHSC
AL	34%	336.3	2.0vol%	0.33(AL/AH)	None	Casting	Monolithic	ALN
							Cut-and-mold	ALNC
						Shotcreting	Monolithic	ALS
							Cut-and-mold	ALSC
BH	34%	301.5	1.7vol%	1.0(BH/BH)	1.0(BH/BH)	Casting	Monolithic	BHN
							Cut-and-mold	BHNC
						Shotcreting	Monolithic	BHS
							Cut-and-mold	BHSC
BM	34%	301.5	1.7vol%	0.5(BM/BH)	1.5(BM/BH)	Casting	Monolithic	BMN
							Cut-and-mold	BMNC
						Shotcreting	Monolithic	BMS
							Cut-and-mold	BMSC
BL	34%	301.5	1.7vol%	0.5(BL/BH)	1.0(BL/BH)	Casting	Monolithic	BLN
							Cut-and-mold	BLNC
						Shotcreting	Monolithic	BLS
							Cut-and-mold	BLSC

Table 2. Air content and flow values.

Mix proportions	Flow value (mm)				Air content (%)	
	Before shotcreting		After shotcreting		Before	After
	Before dropping	After 15 strokes	Before dropping	After 15 strokes	shotcreting	shotcreting
AH	147	170	135	169	19	3.2
AL	100	132	100	129	20	5.6
BH	110	153	121	152	18	4.1
BM	106	134	105	128	15	2.2
BL	101	120	100	118	5.6	2.6

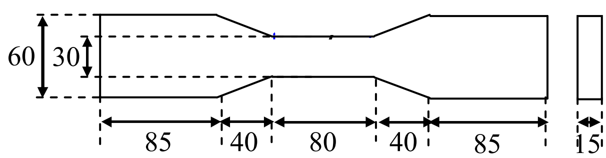

Figure 1. Dumbbell-shaped specimens.

shotcreting. The spread of mortar was measured immediately after lifting the flow cone (before jigging) and after 15 jigging strokes based on the mortar flow test method specified in JIS R 5201 to determine the flow values. The air content was measured using an air meter for mortar.

2.3 *Methods of shaping specimens*

Dumbbell-shaped specimens shown in Figure 1 were shaped by two methods: monolithic and cut-and-mold. Monolithic specimens were shaped by shotcreting the HPFRCC onto, or casting it in, dumbbell-shaped molds.

Cut-and-mold specimens (Rokugo 2007) were shaped into dumbbell-shaped specimens as follows: Prepare HPFRCC boards 300 by 330 by 15 mm by shotcreting and casting; cut out sticks 29.5 by 300 by 15 mm from the boards using a concrete cutter; place the cut sticks in dumbbell-shaped molds; and pour the HPFRCC in the enlarged parts to form shoulders (avoid the central control zones).

In the shotcreting process, the HPFRCC was applied, for both monolithic and cut-and-mold specimens, with a spray gun in passes in the direction of tensile forces to act during testing. As for casting, the HPFRCC was placed in the center of each specimen and allowed to flow in the direction of tensile forces to act during testing.

As given in Table 1, 20 types of dumbbell-shaped specimens were fabricated by combining five mixtures, two placing methods, and two shaping methods. The names of specimens were given in the column on the right side of the table.

2.4 *Tension test method*

Figure 2 shows the tension test setup. Upper and lower catches set in a steel frame (mass: approximately 30 kg, external size: 250 by 250 by 500 mm) held the shoulders of each dumbbell-shaped specimen to transfer the tensile forces.

A simple hydraulic loading apparatus (a hand-cranked BRI-type bond test apparatus) was fixed to

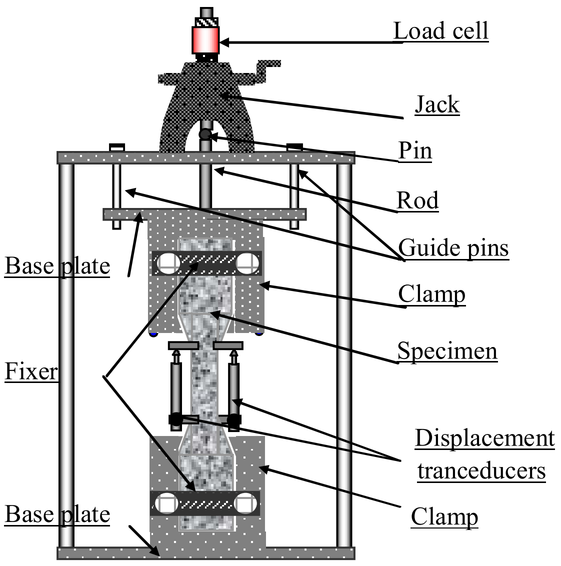

Figure 2. Tension test setup.

the top of the steel frame and pulled up the upper catch through a loading bar along two guide pins to apply the tensile forces to the specimen. The lower catch was fix-supported with the bottom of the steel frame, whereas the upper catch was pin-supported with a hinge provided in the loading bar. The displacement and load during tension testing were measured using displacement gauges directly set to the specimens and a load cell fixed on top of the loading apparatus.

3 AIR CONTENT AND FLUIDITY TEST RESULTS

Table 2 gives the air content and flow, which was an index to fluidity, of five HPFRCC mixtures. All mixtures contain polymers. The "B" mixtures also contain an air-entraining admixture. The as-mixed air contents of all mixtures excepting BL were 15% or more. The reason for the low as-mixed air content of BL, as well as its small flow, was not clear. The air contents of all mixtures after shotcreting were2 to 6%, being lower than immediately after mixing, due to losses of air from the material during shotcreting.

The flow values after shotcreting did not appreciably differ from the as-mixed values, showing little effect of the reductions in the air content. The flow values of AH and BH having a high water-reducing admixture dosage (high water-reducing admixture ratio) were large.

4 TENSILE PERFORMANCE TEST RESULTS AND DISCUSSIONS

Figure 3 shows the stress-strain diagrams of dumbbell-shaped specimens (five specimens for each set of

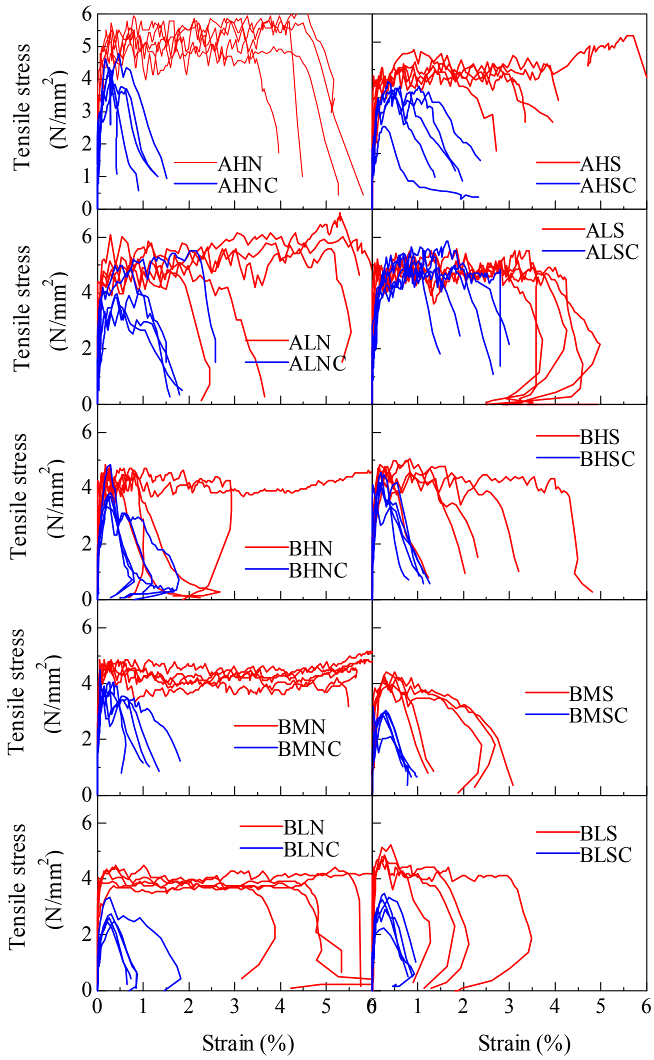

Figure 3. Stress-strain diagrams of dumbbell-shaped specimens.

test conditions) determined by tension tests. Table 3 gives their average tensile strength and average ultimate tensile strain. In this study, the maximum tensile stress on the tensile stress-strain diagram is defined as the tensile strength, and the tensile strain at the inflection point immediately before the tensile stress finally stops increasing is defined as the ultimate tensile strain. Therefore, the ultimate tensile strain was in most cases greater than the tensile strain at the point of tensile strength.

4.1 *Tensile performance of monolithic specimens*

4.1.1 *Tensile strength and ultimate tensile strain*

The average tensile strength of "A" specimens containing 2.0% fibers was 5.5 N/mm^2, being higher by around 20% than those of "B" specimens (4 to 5 N/mm^2) containing 1.7% fibers. The differences of the placing methods and flow values scarcely affected the average tensile strength.

In regard to "A" specimens, the average ultimate tensile strain was 3.5% to 4%, with the value of deposited specimens being greater than that of shot-

Table 3. Tensile strength and ultimate tensile strain.

Specimen	Placing methods	① Monolithic specimen Tensile strength (N/mm2)	① Ultimate strain (%)	② Cut-and-mold specimen Tensile strength (N/mm2)	② Ultimate strain (%)	②/① Tensile strength rario	②/① Ultimate strain ratio
AH	Casting	5.72	4.13	4.34	0.48	0.76	0.12
	Shotcreting	5.54	3.42	3.96	0.80	0.72	0.24
AL	Casting	5.78	3.92	4.34	1.09	0.75	0.28
	Shotcreting	5.30	3.54	5.30	1.84	1.00	0.52
BH	Casting	4.78	2.23	3.82	0.47	0.80	0.21
	Shotcreting	4.86	1.89	4.13	0.31	0.85	0.17
BM	Casting	4.96	5.88	3.99	0.61	0.80	0.10
	Shotcreting	4.21	1.05	2.99	0.23	0.71	0.22
BL	Casting	4.21	4.55	2.72	0.41	0.65	0.09
	Shotcreting	4.78	1.20	3.06	0.32	0.64	0.26

creted specimens by around 10%. As was evident from the results of AH and AL, the average ultimate tensile strain was scarcely affected by the flow value.

In regard to "B" specimens, the average ultimate tensile strain was in the range of 1% to 6%, with the value of deposited specimens being greater than that of shotcreted specimens. Among deposited specimens, the average ultimate strain of those with relatively low fluidity of 130 mm or less (BM and BL) was approximately 5%, whereas that of specimens with high fluidity (BH) was as low as around 2%. Among shotcreted specimens, however, the average ultimate strain of relatively high fluidity specimens (BH) was greater (around 2%) than those of relatively low fluidity specimens (BM and BL, around 1%).

Figure 3 reveals that the scatters of the ultimate tensile strain of "B" specimens tend to be higher than those of "A" specimens. Among "A" specimens, the scatter of the ultimate tensile strain of deposited specimens with a large flow (AHN) was smallest. Among "B" specimen, the scatter of deposited specimens with a small flow (BMN) was smallest, while that of deposited specimens with a large flow (BHN) was largest.

As stated above, higher ultimate tensile strains with a smaller scatter were desirable as a tensile performance of HPFRCCs. Comparison between the results of "A" and "B" specimens with a fiber content of 1.7% and 2.0 % by volume demonstrated that the ultimate tensile strain of a HPFRCC with a lower fiber content was more strongly affected by the fluidity (flow value) and placing method (execution method), leading to a larger scatter. In regard to the "A" mixtures with a fiber content of 2%, AH with a high fluidity (a flow value of around 170 mm) among deposited specimens and AL with a low fluidity (around 130 mm) among shotcreted specimens achieved stable average ultimate strains with small scatters. In regard to "B" mixtures with 1.7% fibers, deposited specimens with a low fluidity (BM and BL) achieved high ultimate tensile strains with small scatters.

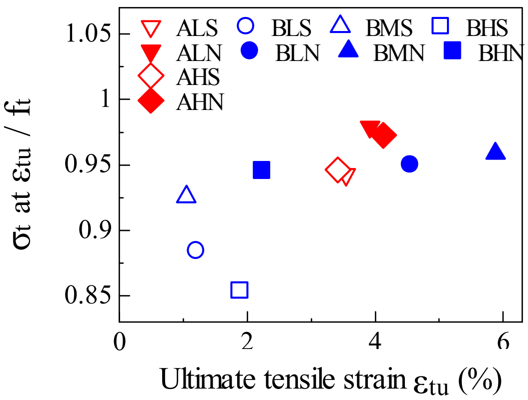

Figure 4. Ratio of tensile stress at point of ultimate tensile strain to tensile strength.

Based on the authors' field experience, fibers in a HPFRCC immediately after being sprayed into the air appeared to be surrounded by the matrix (the binder and sand) but segregated from it. It is therefore desirable that the mixture has sufficient fluidity (softness) to integrate fibers in the matrix on the shotcreted surface.

4.1.2 *Shape of stress-strain diagram*

As stated above, the ultimate tensile strain defined in this study was in most cases larger than the strain at the point of tensile strength, and the tensile stress at the point of the ultimate tensile strain was in most cases lower than the tensile strength. Therefore, the ratio of the tensile stress at the point of the ultimate tensile strain to the tensile strength was determined as shown in Figure 4. When the ultimate tensile strain exceeds 2%, this ratio was 0.94 or higher, demonstrating that a large tensile stress was retained to a large strain level. The ratios of shotcreted specimens with 1.7% fibers (BHS, BMS, and BLS) were low.

4.1.3 *State of cracking*

Figure 5 shows the state of cracking in monolithic dumbbell-shaped specimens along with the average ultimate tensile strain values. Specimens having large average ultimate strain show a large number of

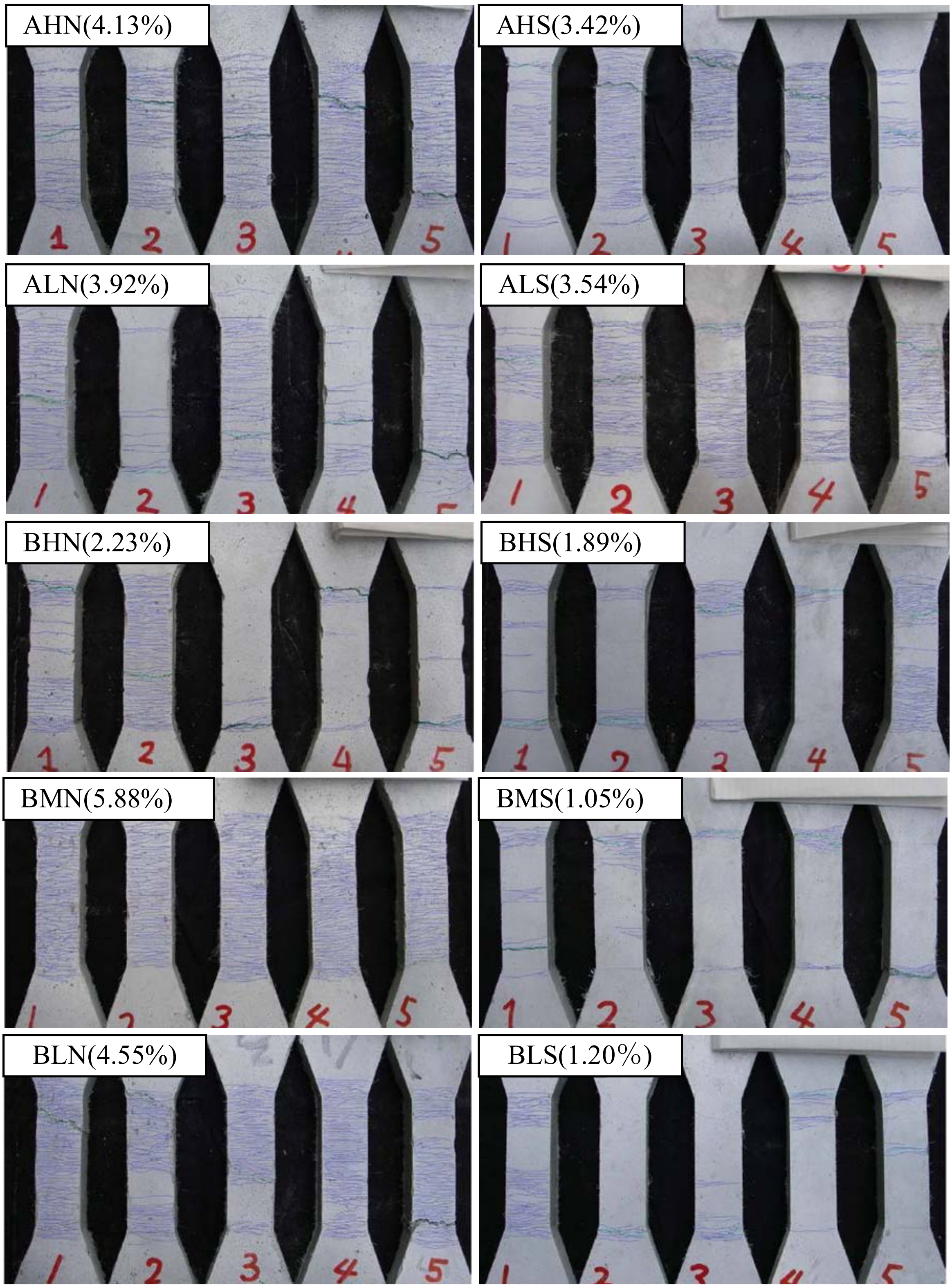

Figure 5. Cracking in monolithic dumbbell-shaped specimens.

cracks dispersed over a wide area. Mixtures that showed a large scatter of the ultimate tensile strain values in Figure 3 showed large differences among specimens in the number of cracks and cracking area in this photograph. When the average ultimate strain exceeded 3%, cracks were found in areas outside of the control zones of specimens. In contrast, cracks were localized in specimens with an average ultimate strain of around 1%.

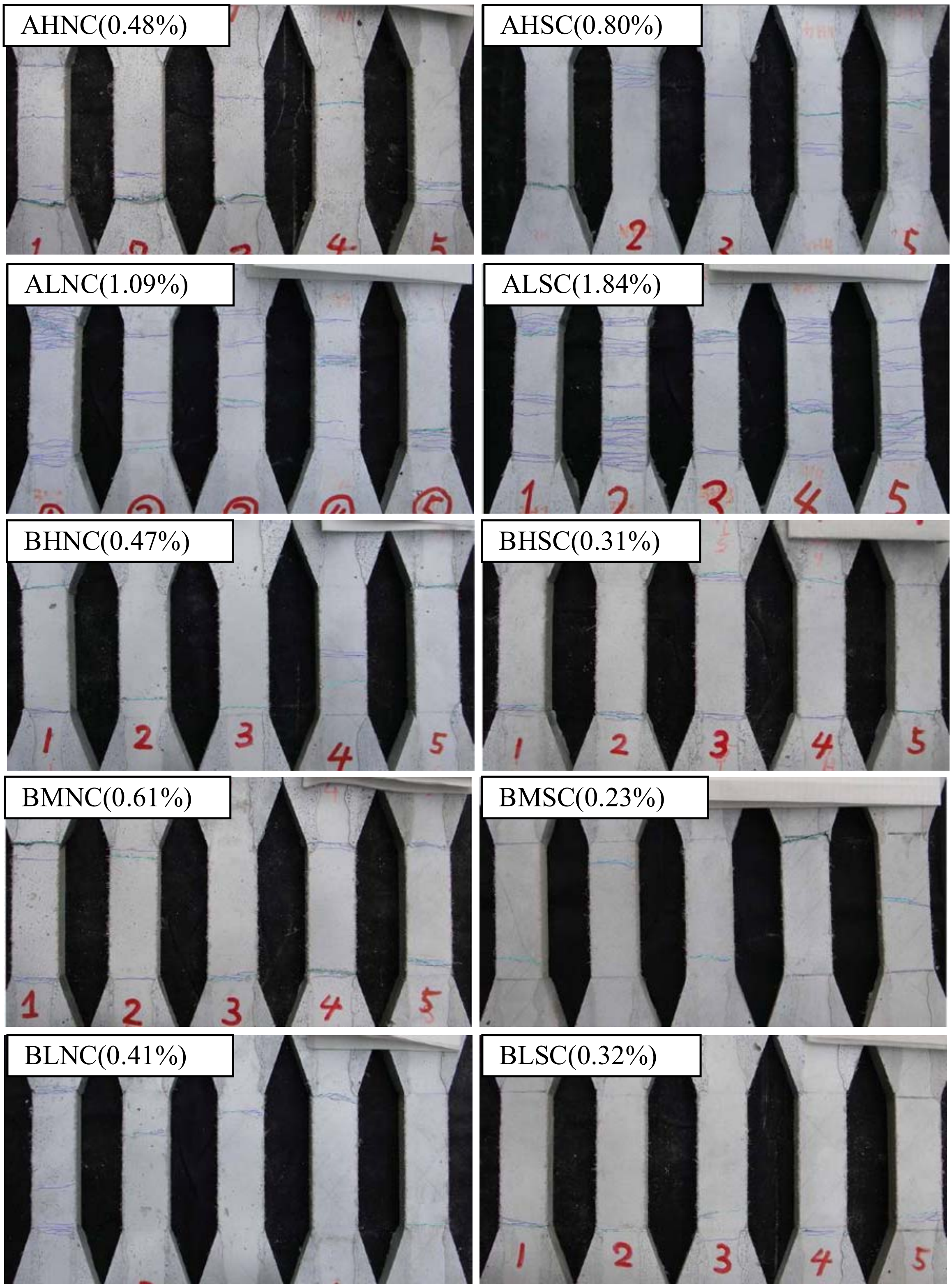

Figure 6. Cracking in cut-and-mold dumbbell-shaped specimens.

4.2 *Tensile performance of cut-and-mold specimens*

4.2.1 *Fiber content and tensile performance*

As shown in Figure 3 and Table 3, the average tensile strengths of all cut-and-mold specimens excepting ALSC, which was made of AL by shotcreting, were lower than those of monolithic specimens by 15% to 35%, with their average ultimate tensile strain being also smaller by more than 70%. The tensile strength and ultimate tensile strain of “A” specimens were slightly greater than those of “B” specimens. Those of “A” specimens with a smaller flo-w tended to be greater. The ultimate tensile strain of ALSC, which was made by shotcreting mixture AL with a fiber content of 2% by volume, was 1.8%, being the largest among cut-and-mold specimens.

The tensile performance of monolithic specimens was high, because fibers were oriented along the molded surfaces in the control zone in the center of each specimen. On the other hand, the tensile performance of cut-and-mold specimens was low, presumably because fibers crossing the sawed surfaces in the control zones were cut off by a concrete cutter. It is inferred that actual slab-shaped HPFRCC members will demonstrate an intermediate tensile performance between those of monolithic and cut-and-mold specimens.

4.2.2 *Shape of stress-strain diagram*

Figure 6 shows the state of cracking in cut-and-mold dumbbell-shaped specimens along with the average ultimate tensile strain values. Though cracks in ALSC specimens with an ultimate tensile strain of 1.84% spread over a wide range, cracks in the other specimens with an ultimate tensile strain of less than 1% were localized to at most two locations.

5 CONCLUSIONS

Tension tests were conducted on HPFRCC dumbbell-shaped specimens fabricated by shotcreting or casting to experimentally investigate the effects of their fluidity and placing method on the tension test results. Five HPFRCC mixtures with different fiber contents (2% and 1.7 % by volume) and fluidities were used. Polymer cement mortar was used as the matrix. The material for casting was shotcreted onto a container before casting to equalize the air contents by both methods.

The flow values after shotcreting did not appreciably differ from the as-mixed values, showing little effect of the reductions in the air content. The differences of the placing methods and flow values scarcely affected the average tensile strength.

The average ultimate tensile strain was 3.5% to 4% for “A” specimens containing 2.0% fibers, and was in the range of 1% to 6% for “B” specimens containing 1.7% fibers. The scatters of the ultimate tensile strain of “B” specimens tended to be higher than those of “A” specimens. The ultimate tensile strain of a HPFRCC with a lower fiber content was more strongly affected by the fluidity and placing method, leading to a larger scatter. Specimens having large average ultimate strain showed a large number of cracks dispersed over a wide area.

The average tensile strengths of most of cut-and-mold specimens were lower than those of monolithic specimens by 15% to 35%, with their average ultimate tensile strain being also smaller by more than 70%.

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