The 14th World Conference on Earthquake Engineering
October 12-17, 2008, Beijing, China

STUDY ON THE INFLUENCE OF THE FIBER ORIENTATION TO THE MECHANICAL PERFORMANCE OF HPFRCC

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ABSTRACT :

High Performance Fiber Reinforced Cementitious Composites, HPFRCC has been expected as new material because the ductility on bending, tension, and shear behavior would be improved largely than ordinary concrete. However, to give an expected performance, it is important to know how the fiber will be orientated and distributed in the matrix. There are many indistinct point how fiber is oriented. This paper aims to present the influence of fiber orientation to the mechanical performance of HPFRCC.

In this study, one large specimen of HPFRCC is prepared with polyvinyl alcohol (PVA) fiber. Then one large specimen is cut to small coupons and the mechanical performance of HPFRCC due to the influence of fiber is examined by using the bending test and observation of cross section by mercury lamp. From the test result, number of fiber is related to the mechanical performance closely when coupon is cut on axial direction. The number of fiber is increasing as close to the mold surface. As increased the number of fiber, the bending performance increases. On the other hand, bending performance of coupon that is cut on perpendicular direction is not related to the position of the coupons and number of fibers directly.

KEYWORDS: HPFRCC, PVA fiber, Coupon, Bending Moment-Curvature curve, Mercury Lamp

1. INTRODUCTION

Recently, as the substitute of reinforced concrete, the research of High Performance Fiber Reinforced Cementitious Composites, HPFRCC has been carried out. HPFRCC is the composite material with mixing fiber in mortar, and fibers bear the tension in substitution for reinforcing bar. For representative characteristic of HPFRCC, under the condition of uniaxial tensile stress or the bending stress, HPFRCC shows multiple cracks. Furthermore, it also shows that the stress increases after the first cracking, which is called as strain hardening or deflection hardening. Therefore, HPFRCC is expected as new materials, because the ductility of bending, tension, and shear behavior would be improved largely than ordinary reinforced concrete as the seismic members.

However, the distribution and orientation of fibers is an important factor in terms of mechanical performance of the composite. In other words, the large difference of mechanical performance is shown when fibers are oriented by axial and perpendicular direction of loading. In addition, it is difficult to confirm the distribution and orientation of fibers in the composite, there are many indistinct point how the fibers are oriented. In this study, the influence of the fiber orientation to the mechanical performance of HPFRCC is examined by using the bending test and observation of cross section by mercury lamp.

2. OUTLINE OF SPECIMEN

2.1. Mix Proportion

The mix proportion of HPFRCC is shown in Table 1.The length is 12mm, diameter is 40 μ m, tensile strength is 1600MPa, and elastic modulus is 40GPa of polyvinyl alcohol (PVA) fiber is used. The fiber volume fraction is 1.5%.

Table 1 The mix proportion of HPFRCC

	Unit quantity (kg/m^3)		Unit quantity (kg/m^3)
Water	380	Cement	576
Fine aggregate	484	Fly ash	291
Expansion agent	101.7	Shrinkage-reducing admixture	20
Thickening agent	1.91	High performance AE water reducing agent	5.78

2.2. Specimen

A large size specimen with 140mm in depth, 780mm in width and 1675mm in length and five prepared small specimens that cross section is 60mm x 60mm and length is 350mm were prepared as HPFRCC. The specimens were cured by stream at first day, and then mold are removed. After that the specimens left in atmospheric curing.

Overall view of cutting for a large specimen is shown in Figure 1. To compare the influence of the cast direction, a large specimen is cut to three parts such as A, B and C by using the diamond cuter. Then, to compare the influence of cast, mold and cutout surface, part A and C is cut to 14 coupons in each part. The detailed view of cutting in part A and C is shown in Figure 2. 4 coupons on axial direction (X-direction) and 3 coupons on perpendicular direction (Y-direction) are cut from both upper and lower section. Part B is cut to 9 coupons. The detailed view of cutting in part B is shown in Figure 3. 5 coupons on X-direction and 4 coupons on Y-direction are cut from middle section. The total number of coupons is 37. The size of coupons is same as five small prepared specimens that cross section is 60mm x 60mm and length is 350mm.

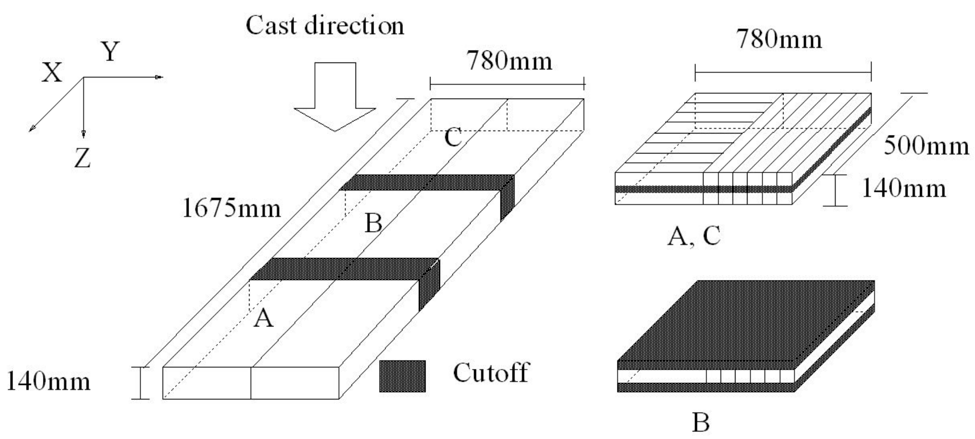
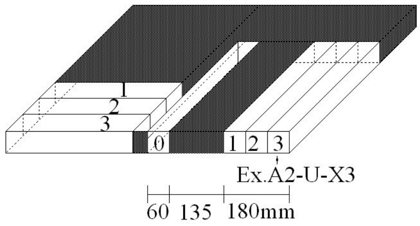


Figure 1 Overall view of cutting



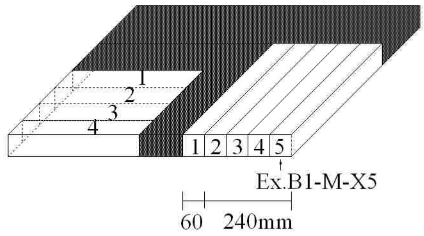


Figure 2 Detailed view of cutting in Part A and C   Figure 3 Detailed view of cutting in Part B

2.3. Specimen Identifications

The identification of coupon is shown in Figure 4. Cutting part is A, B and C that is shown in Figure 1. Cutting section is that upper section as U, middle section as M and lower section as L. Cutting direction is on X-direction and Y-direction from Figure 1. The position number is shown in Figure 2 and 3. In addition, the identification of five prepared specimens is as 1-1 to 1-5.

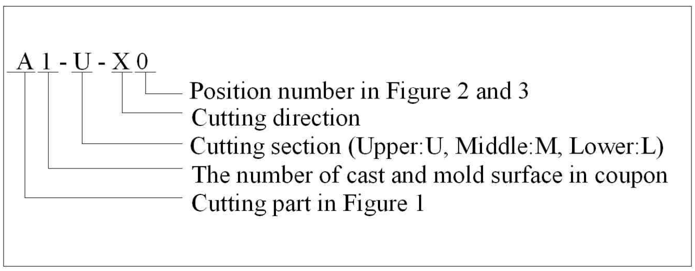


Figure 4 Identification of coupon

3. OUTLINE OF LOADING TEST

3.1. Four-point Bending Test

Four-point bending test based on Method of Test for Bending Moment-Curvature Curve of Fiber-Reinforced Cementitious Composites (JCI-S-003-2007) in Japan Concrete Institute (JCI) Standard is performed by using 2MN universal testing machine. However, specimen size is used as 60mm in depth, 60mm in width and 350mm in length instead of 100mm in depth, 100mm in width and 400mm in length. Outline of four-point bending test is shown in Figure 5. The bending moment and curvature is calculated by using the following equation (3.1) and (3.2) to obtain the bending moment-curvature curve.

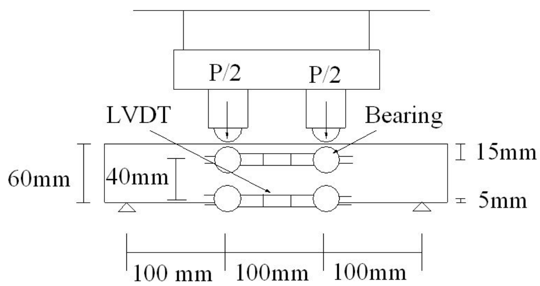


Figure 5 Four-point bending test

$$M = \frac{P}{2} \cdot \frac{l}{3} \tag{3.1}$$

$$\phi = \frac{\varepsilon_2 - \varepsilon_1}{d_0} \tag{3.2}$$

M:	Bending moment (kN・mm)
P:	Applied load (kN)
l:	Span (= 300mm)
ϕ :	Curvature (1/mm)
$\varepsilon_1, \varepsilon_2$:	Strains calculated by dividing the measured displacements of upper and lower LVDTs by contact length (mm) (elongation is defined as positive)
d_0:	Distance between two LVDTs (= 40mm)

3.2. Cross Section Observation

It is known that PVA fiber absorbs the ultraviolet radiation and emits fluorescence. [1] Based on this principle, mercury lamp is used to observe PVA fiber. Outline of the observation is shown in Figure 6.

The cross section is cut around close to the largest crack which occurred by four-point bending test, then the image of cross section's coupons is captured with a digital camera through a microscope by using mercury lamp. The yellow cellophane sheet is used with mercury lamp to let PVA fiber emphasize the emission of light more. The captured image of cross section is analyzed and mapped as two valued color that PVA fiber is to black dots and cement is to white color by using image analysis software. An example of analyzed and mapped cross section is shown in Figure 7. Finally, the black dots are counted as the number of fibers by using image analysis software.

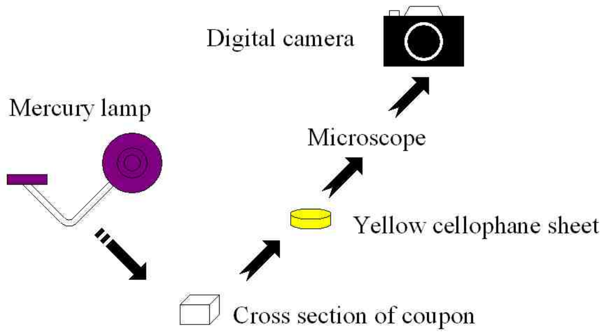


Figure 6 Outline of cross section observation

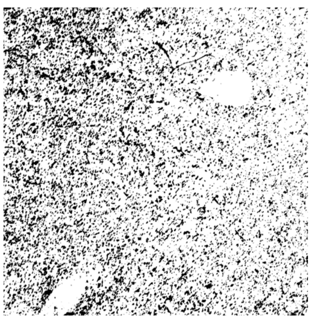


Figure7 An example of cross section (A1-U-X2)

4. Experimental Result

The list of test results is shown in Table 2. In this table, M_{max} is the maximum bending moment, ϕ_{max} is the curvature at the maximum bending moment and N_f is the number of PVA fiber by counted on black dots. The average of five prepared specimens' M_{max} and ϕ_{max} is defined as $M_{max,w}$ and $\phi_{max,w}$, respectively. In addition, the average of five prepared specimens' number of PVA fiber is defined as $N_{f,w}$.

Table 2 The list of test results

ID	M_{max} (kN・m)	ϕ_{max} (1/m)	N_f	M_{max} / $M_{max,w}$	ϕ_{max} / $\phi_{max,w}$	ID	M_{max} (kN・m)	ϕ_{max} (1/m)	N_f
1-1	0.327	0.390	6486	$M_{max,w}$ = 0.405 kN· m	$\phi_{max,w}$ = 0.245 1/m				
1-2	0.445	0.142	10345						
1-3	0.412	0.280	7721						
1-4	0.440	0.242	6293						
1-5	0.400	0.171	8855						
A1-U-X0	0.126	0.008	8388	0.311	0.033	A1-U-Y1	0.247	0.132	6747
A1-U-X1	0.159	0.011	6219	0.393	0.045	A1-U-Y2	0.276	0.124	6566
A1-U-X2	0.218	0.100	6824	0.539	0.408	A2-U-Y3	0.194	0.011	5827
A2-U-X3	0.391	0.288	10737	0.966	1.176				
A1-L-X0	0.250	0.126	7918	0.618	0.514	A1-L-Y1	0.112	0.040	5407
A1-L-X1	0.300	0.237	5801	0.741	0.967	A1-L-Y2	0.142	0.162	7045
A1-L-X2	0.347	0.228	10046	0.857	0.931	A2-L-Y3	0.245	0.045	4943
A2-L-X3	0.381	0.246	9463	0.941	1.004				
B0-M-X1	No Data		10992	—	—	B0-M-Y1	0.073	0.065	4352
B0-M-X2	0.221	0.089	7346	0.546	0.363	B0-M-Y2	0.083	0.004	5882
B0-M-X3	0.318	0.232	10057	0.786	0.947	B0-M-Y3	0.072	0.077	6622
B0-M-X4	0.378	0.166	11038	0.934	0.678	B0-M-Y4	0.062	0.096	4979
B1-M-X5	0.355	0.212	12784	0.877	0.865				
C1-U-X0	0.164	0.086	8427	0.405	0.351	C1-U-Y1	0.216	0.130	5795
C1-U-X1	0.110	0.007	6934	0.272	0.029	C1-U-Y2	0.084	0.027	6334
C1-U-X2	0.185	0.056	7088	0.457	0.229	C2-U-Y3	0.270	0.203	5975
C2-U-X3	0.258	0.083	9856	0.637	0.339				
C1-L-X0	0.272	0.245	9223	0.672	1.000	C1-L-Y1	0.299	0.180	6303
C1-L-X1	0.292	0.242	9699	0.721	0.988	C1-L-Y2	0.361	0.230	4823
C1-L-X2	0.319	0.151	11184	0.788	0.616	C2-L-Y3	0.284	0.079	3368
C2-L-X3	0.427	0.334	9348	1.055	1.363				

4.1. Prepared Specimens

The bending moment and curvature curve is shown in Figure 8. $M_{max,w}$ is 0.405 kN· m, and $\phi_{max,w}$ is 0.245 1/m. In addition, the standard deviation of M_{max} is 0.042 kN·m, standard deviation of ϕ_{max} is 0.088 1/m. From the Figure 8, the deflection hardening behavior is recognized.

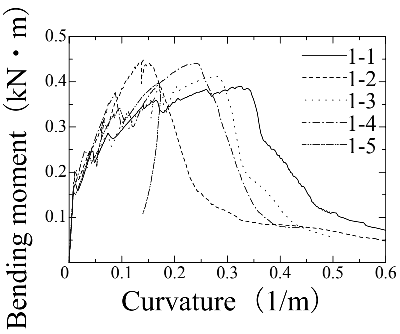


Figure 8 Bending moment – curvature curve of prepared specimens

4.2. Coupons on X-direction

4.2.1 Bending moment and curvature curve

The relationships between bending moment and curvature of coupon on X-direction in Part A and C are shown in Figure 9. From Figure 9, the deflection hardening behavior is observed well at lower section of Part A and C. However, the deflection hardening behavior is little observed at upper section of Part A and C and lower strength than lower section in both Part A and C is shown. Therefore, upper section of the maximum moment is lower than the maximum moment of lower section.

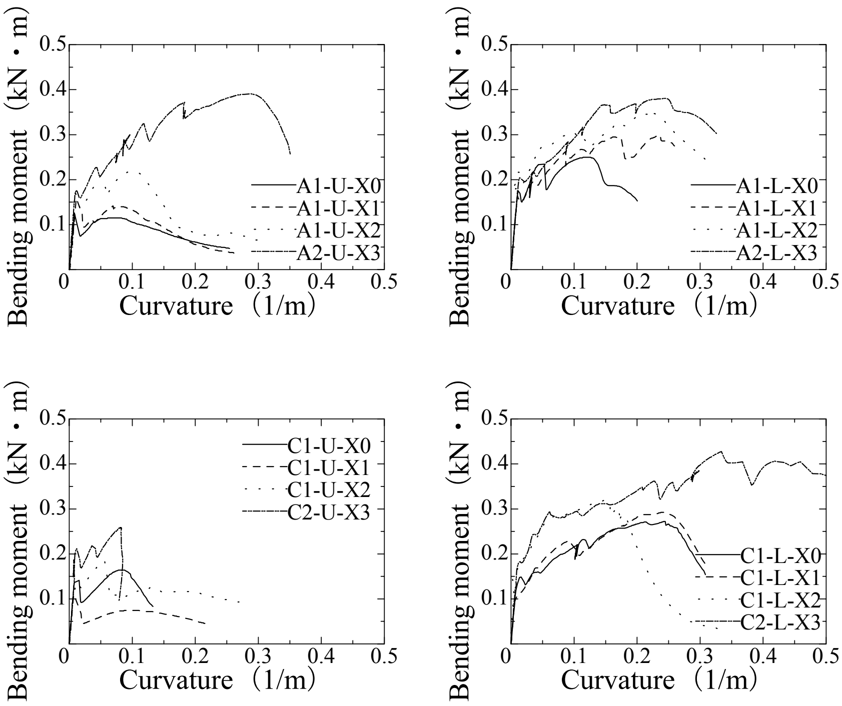


Figure 9 Bending moment-curvature curve of coupons on X-direction

4.2.2 Influence of mold surface

The distance from mold surface to the center of each coupon and maximum moment (M_{max}) relationship in Part A, B and C is shown in Figure 10. The distance from mold surface to center is calculated from each center of coupons. The maximum moment of coupon decreases with increases the distance from the mold surface to center of each coupon at Part A and C. However, in part B, the maximum moment of coupon increases around 100mm from mold surface once, and then decreases with increases the distance.

The distance from mold surface to center of each coupon and number of PVA fiber (N_f) relationship in Part A, B and C is shown in Figure 11. The number of PVA fiber decreases with increases the distance from mold surface. This result has same tendency described in Figure 10. Especially in Part C, the maximum moment increases after the distance from mold surface is around150mm, as same as number of PVA fiber in Figure 11. Therefore, it can be recognized that the number of PVA fiber is related closely with the maximum moment for each coupon.

Moreover, the reason why maximum moment increases as the mold surface comes to a close can be recognized that PVA fiber would be concentrated around mold surface and orientated as parallel to mold surface.

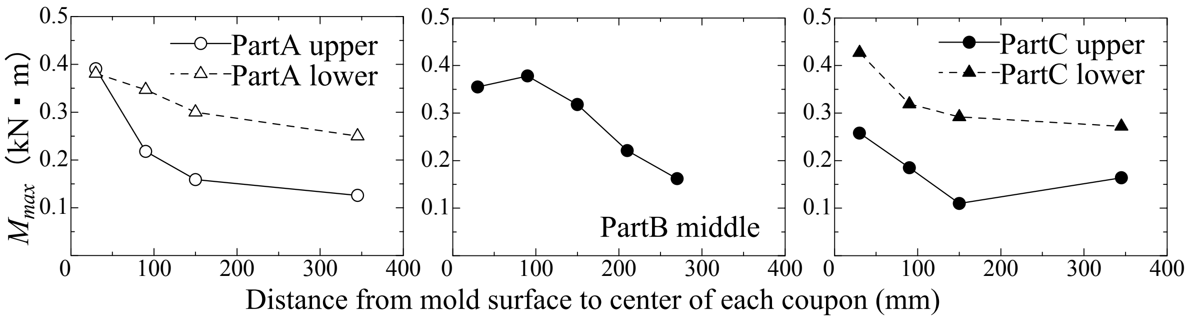


Figure 10 Maximum moment (M_{max}) and distance from mold surface relationships

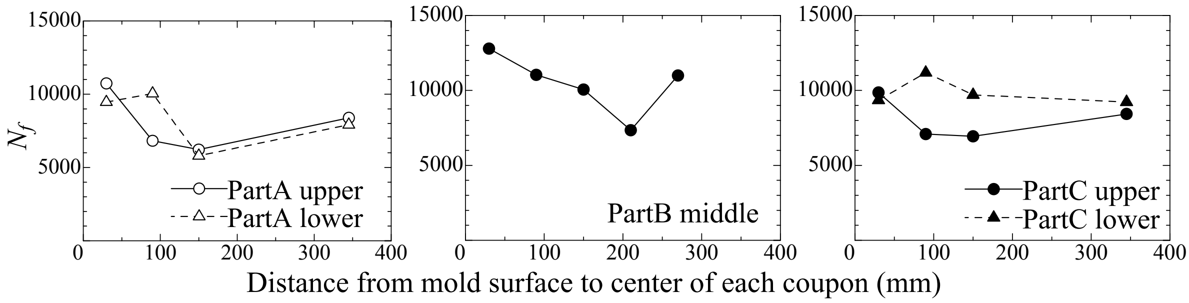
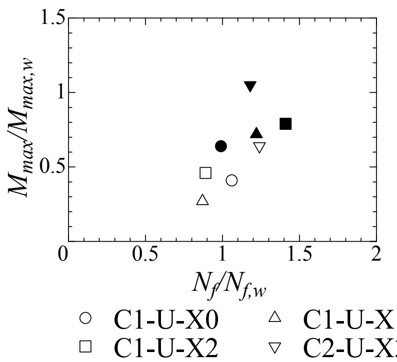


Figure 11 Number of PVA fiber (N_f) and distance from mold surface relationships

4.2.3 Maximum moment and number of PVA fiber relationship

The ratio of maximum moment ($M_{max}/M_{max,w}$) and the ratio of number of PVA fiber ($N_f/N_{f,w}$) in Part C is shown in Figure 12 and the ratio of curvature ($\phi_{max}/\phi_{max,w}$) and the ratio of number of fiber ($N_f/N_{f,w}$) in Part C is shown in Figure 13. $N_{f,w}$ is 7940. The ratio is defined as that the maximum moment or curvature of each coupon is standardized by $M_{max,w}$ or $\phi_{max,w}$. The ratio of number of PVA fiber is same calculation as the ratio of maximum moment or curvature. From Figure 12 and 13, higher ratio of maximum moment or curvature has higher ratio of number of PVA fiber basically. However, some results show that even if higher ratio of number of PVA fiber, the ratio of maximum moment or curvature has lower ratio at upper section in Part C. This result can be recognized that the influence of polishing and cleaning on cast surface is very large.



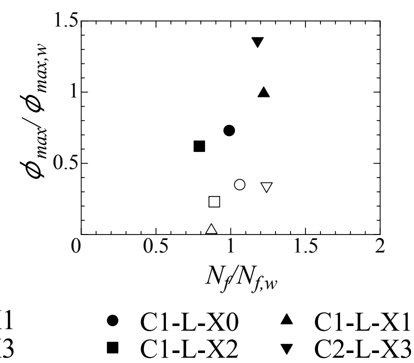


Figure 12 The ratio of M_{max} and N_f Figure 13 The ratio of ϕ_{max} and N_f

4.3. Coupons on Y-direction

The bending moment and curvature curve of coupon in Part A and C on Y-direction is shown in Figure 14. The maximum moment and curvature at the maximum moment on coupon in upper section is lower than those in lower section by compared at same position number. This result shows same trend as the result of coupon on X-direction. From Table 2, the result of curvature at maximum moment of coupon on Y-direction is smaller than those on X-direction in general. In addition, position number is not related as the result of the maximum moment or curvature. The result of coupon on Y-direction is varying widely. The reason can be recognized that PVA fiber has tendency to be orientated as parallel at the cross section of coupon on Y-direction. PVA fiber of the coupon on X-direction is not related to mechanical performance for Y-direction coupons directly. Moreover, number of PVA fiber of the coupon in Y-direction is also not related to the test result such as maximum moment or curvature directly.

In addition, the number of PVA fiber of coupon on Y-direction is almost 2/3 of the average number of PVA fiber of coupon on X-direction in general.

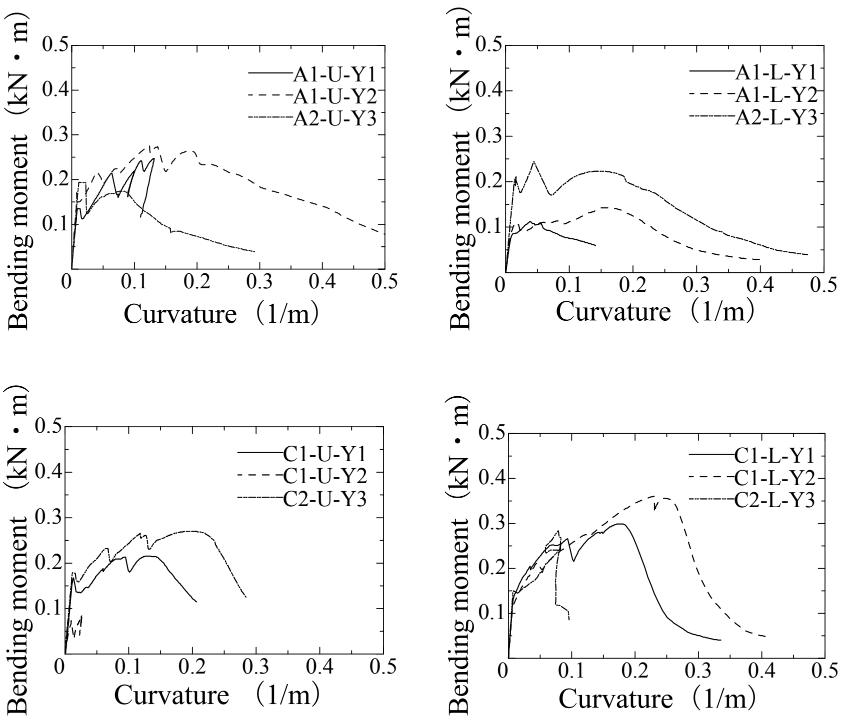


Figure 14 Bending moment-curvature relationships on Y-direction

5. CONCLUSION

In this study, five prepared specimens and 37 coupons are subjected to four-point bending test and observation of cross section using mercury lamp are carried out. The main parameters for coupons are cutting part, direction and position from the mold surface. From the test result, the followings are summarized.

(1) It is confirmed that the maximum moment increases with close to mold surface on coupon in X-direction. However, the result of coupon in Y-direction does not show same tendency as in X-direction.
(2) The number of PVA fiber is related to mechanical performance of coupon closely in X-direction.
(3) In upper section of casting direction, some coupon has lower rate of maximum moment or curvature at the maximum moment even if they have higher number of PVA fiber.

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