EVALUATION OF MICRO-REGIONS IN VARIOUS CONCRETE WITH NEWLY DEVELOPED MICRO-BENDING METHOD

Wanchai YODSUDJAI[*1], Nobuaki OTSUKI[*2], Takahiro NISHIDA[*3] and Ryousuke ONITSUKA[*4]

ABSTRACT: Although an evaluation of micro regions in concrete is highly important, no specific research has ever been mentioned quantitative measures of these regions. Therefore, this study is conducted to evaluate the micro-regions from various types of concrete by using the newly developed micro-bending method. In this study, three types of concrete: normal concrete, recycled aggregate concrete and concrete coated with CFRPS, are used to evaluate the strength properties of micro-regions. As a result, it can be concluded that the micro-regions in concrete can be successfully evaluated quantitatively by using the newly developed micro-bending method.
KEYWORDS: micro-bending method, micro-region, ITZ (Interfacial Transition Zone), surface layer

1.INTRODUCTION

Concrete is composed of various materials such as cement, aggregate, water and etc.; therefore, concrete is a highly heterogeneous and have complex structure. The need for a deeper understanding of concrete, particularly in the area of micro-regions has become urgent due to an increasing number of new problems such as the issue of durability. As advancements have been made in the field of material science, the study of micro-regions in concrete has captured the attention of many researcher, however, the micro-regions in concrete have not been evaluated quantitatively in term of strength properties. Therefore, this study provides a quantitative evaluation of the micro-regions strength properties in concrete particularly ITZ (Interfacial Transition Zone) and surface layer from various types of concrete by using the newly developed micro-bending method. From the quantitative evaluation of the micro-regions in concrete, the strength of the individual micro-regions as well as their interactions and relations to each other can be clearly understood. In this investigation, three types of concrete are considered: normal concrete, recycled aggregate concrete and concrete coated with CFRPS (Carbon Fiber Reinforce Plastics).

2.NEWLY DEVELOPED MICRO-BENDING METHOD

Micro-bending method is a testing method that originally developed by the authors. Fig. 1 shows a configuration of a testing device. The four points bending method is used as can be seen from the outline of a loading point shown in Fig. 2. For preparing a test piece, an outline is shown in Fig. 3. From the central part of a ϕ100 x 200 mm cylindrical specimen, a bar of 15 x 15 x 50 mm specimen is cut using diamond cutter. This bar is then cut crosswise by means of a Low Speed Saw (ISOMET™) set about 200 rpm into the 15 x 15 x 1 mm test piece. The 15 x 15 x 1 mm test piece is adhered to the glass plate by using the electron wax, and is subsequently polished by using a Grinder and Polisher

*1 Dept. of International Development Eng., Tokyo Institute of Technology, M.Eng., Member of JCI
*2 Dept. of International Development Eng., Tokyo Institute of Technology, D.Eng., Member of JCI
*3 Dept. of International Development Eng., Tokyo Institute of Technology, M.Eng., Member of JCI
*4 Dept of International Development Eng., Tokyo Institute of Technology, B.Eng.

(METASERV®2000) until the thickness of test piece become 0.5 mm. In order to obtain the final test piece, a 12 x 5 x 0.5 mm test piece is cut from the 15 x 15 x 0.5 mm test piece by selecting the position that contains ITZ between coarse aggregate and mortar matrix or only mortar matrix. In order to remove the test piece from the glass plate, heat is applied, and the electron wax adhered to test piece is released by using acetone. For preventing the drying condition, the test pieces are cured underwater until the loading process is performed. The bending strength calculation formula of micro region in concrete is shown as follow

$$\sigma = PL/bh^2 \qquad (1)$$

Where,
P: Load (N)
L: Distance Between Supporting Points (= 10 mm)
b: Width of Test Piece (= 5 mm)
h: Thickness of Test Piece (= 0.5 mm)

The accuracy of this test method was confirmed by the authors [1,3].

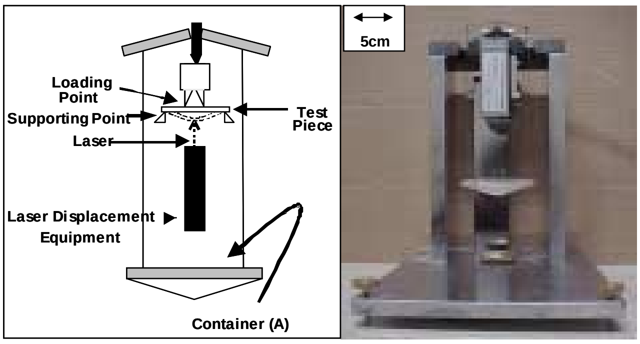


Fig.1 Micro-Bending Device

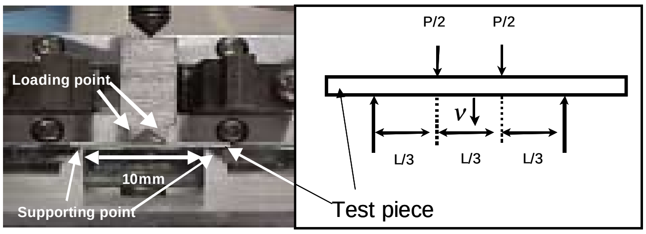


Fig.2 Loading Point

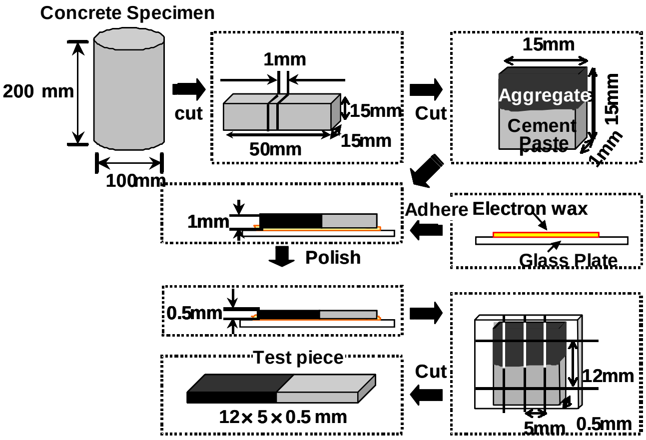


Fig. 3 Outline for Preparation of Test Piece

3. EXPERIMENTAL PROCEDURE

3.1 MATERIALS

Ordinary Portland cement is used. The chemical composition of these cement are shown in Table 1. Fine aggregate used is river sand and coarse aggregate used is crushed stone. For recycled aggregate, two types are used: the strong recycled aggregate (recycled aggregate A) and the weak recycled aggregate (recycled aggregate B). The physical properties of all aggregates are shown in Table 2. The chemical admixtures consist of high-range water-reducing agent with high condensation aromatic sulfonate for water-cement ratio of 0.3, and water-reducing agent and air-entraining agent with oxycarbonic acid and lignin sulfonic for water cement-ratio of 0.5 and 0.7.

3.2 EXPERIMENT CASES AND MIXING PROPORTIONS

As stated earlier, three types of concrete are considered: normal concrete, recycled aggregate concrete and concrete coated with CFRPS. In the case of normal concrete, parameter is water-cement ratio. For recycled aggregate concrete the parameter are water-cement ratio and recycled aggregate type. For the concrete coated with CFRPS, parameters are water-cement ratio, and curing condition. Table 3 shows mixing proportions. The same mixing proportion is applied to normal concrete, recycled aggregate concrete and concrete coated with CFRPS of the same water-cement ratio.

TABLE 1 Chemical Composition of Cement

Cement Type	SiO_2 (%)	Al_2O_3 (%)	CaO (%)	MgO (%)	SO_3 (%)	Na_2O (%)	Fe_2O_3 (%)
Ordinary	21.3	5.3	64.4	2.2	1.9	0.3	2.6

TABLE 2. Physical Properties of Aggregate

Aggregate Type	Specific Gravity	Water Absorption (%)	FM	Strength of Old Mortar* (MPa)
Fine Aggregate				
River Sand	2.62	1.9	2.51	-
Coarse Aggregate				
Crushed Stone	2.62	0.9	7	-
Recycled Aggregate A	2.47	4.4	6.61	68.5
Recycled Aggregate B	2.45	5.1	6.6	32.3

** Strength of Old Mortar: The concrete was mixed with the original mixing proportion. Wet screening separated the mortar and coarse aggregate, and mortar strength was measured at 10 months age.*

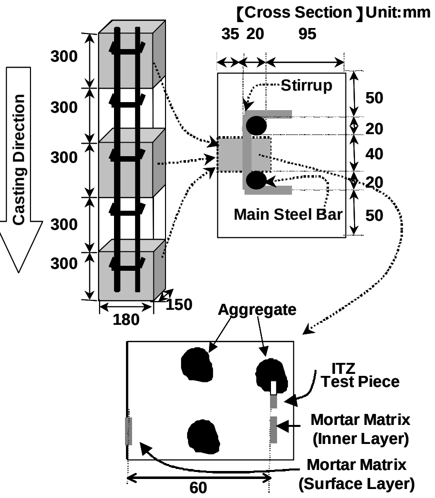


Fig. 4 Normal Concrete Specimen and Position of Test Pieces

TABLE 3. Mixing Proportions

Cement Type	W/C	s/a (%)	Unit Weight (kg/m^3)				Chemical Admixture (C x %)		
			W	C	S	G	Water-Reducing Agent	AE Agent	High-Range Water-Reducing Agent
Ordinary*,**	0.3	45	175	583	698	870	-	-	0.01
Ordinary*,**	0.5	45	175	350	785	979	0.01	0.02	-
Ordinary**	0.7	45	175	250	821	1024	0.01	0.02	-

* Mixing Proportion For Recycled Aggregate Concrete

** Mixing Proportion For Concrete Coated With CFRPS

3.3 SPECIMENS CONFIGURATION

Fig. 4 shows a configuration of normal concrete specimen and a position of test pieces. Two types of test pieces are investigated: the test pieces containing ITZ between mortar matrix and aggregate; and the test pieces containing only mortar matrix. For the mortar matrix, the test pieces are classified into two types: surface layer (0 mm distance from concrete surface) and inner layer (60 mm distance from concrete surface). For recycled aggregate concrete, a ϕ100 x 200 mm cylindrical specimens is used. As can be seen in Fig. 5, there are four types of the test pieces for micro-bending testing: the test pieces containing ITZ (old ITZ) between original aggregate and old mortar matrix, the test pieces containing ITZ (new ITZ) between old mortar and new mortar matrix, the test pieces containing only old mortar matrix and lastly the test pieces containing only new mortar matrix. For concrete coated with CFRPS, the specimen configuration is shown in Fig. 6. The concrete beam specimens of 150 x 180 x 1500 mm are used. After 28 days underwater curing, 1 mm thickness of concrete surface is removed from a 180 x 1500 mm plane. Then, the primer (250 g/m^2) and the putty (400 g/m^2) are coated respectively. After curing under dry condition of 20 °C for 1 day, the resin (400 g/m^2) is coated, and the CFRPS are subsequently adhered. Lastly, the resin (200 g/m^2) is coated on the CFRPS again. The specimens are cured under dry condition of 20 °C for 7 days. The test pieces for micro-bending method are taken from the surface layer as can be seen in Fig. 6. Six test pieces are used in each case of the experiment.

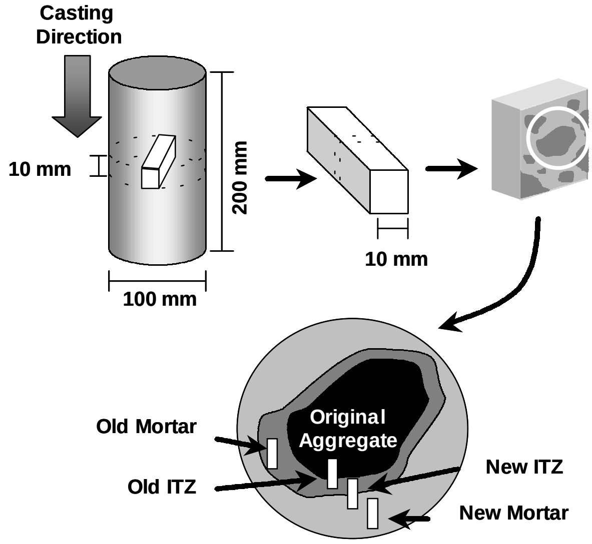
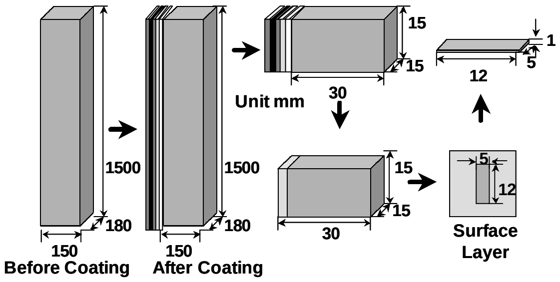


Fig.5 Recycled Aggregate Concrete Specimen and Position of Test Piece



		g/m²	Curing Period (days)
	primer	250	1
	putty	400	1
	resin	400	7
	CFRPS	–	
	resin	200	

Fig.6 Concrete Coated with CFRPS Specimen and Position of Test Piece

4.RESULTS AND DISCUSSIONS

4.1 NORMAL CONCRETE

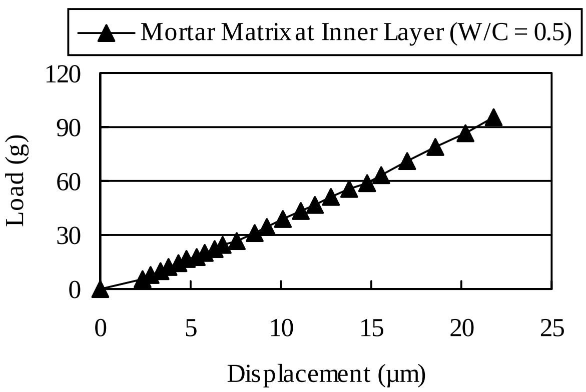


Fig. 7 Typical Load-Displacement

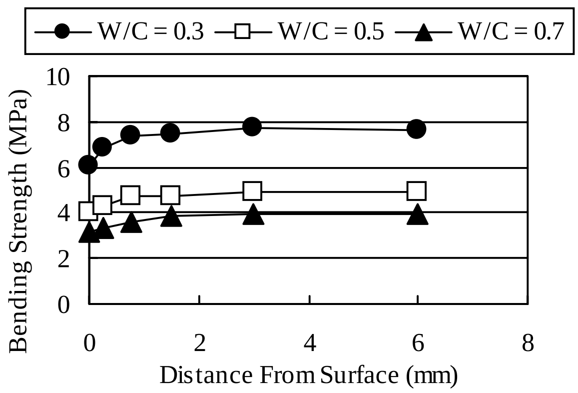


Fig.8 Bending Strength of Mortar Matrix

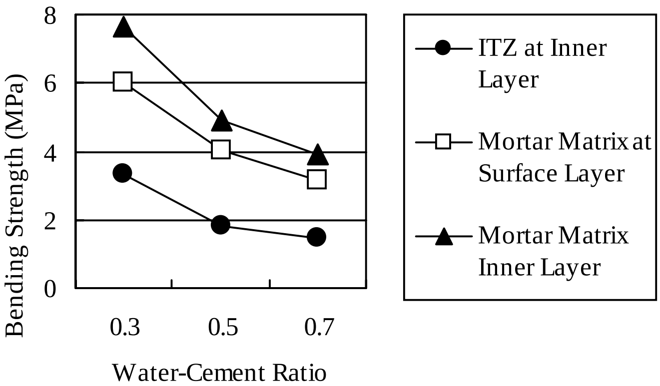


Fig. 9 Bending Strength of Micro-Regions in Concrete

Fig. 7 shows a typical load-displacement curve obtained from the mortar matrix test piece that is measured by micro-bending method. In addition, it is found that the coefficient of variation in bending strength varies from 2.05% to 7.10% in the case of ITZ test pieces and from 3.26% to 8.45% in the case of mortar matrix test pieces. Fig. 8 shows the bending strength of mortar matrix. It can be seen that the bending strength of the mortar matrix at near surface of concrete is smaller than that of far from the surface of concrete. It can also be seen in Fig. 9 that, the bending of mortar matrix at surface layer is smaller than that of mortar matrix at inner layer for all cases of water-cement ratio. Moreover, the bending strength of ITZ is smaller than that of mortar matrix at both surface and inner layers. There is no doubt that the strength properties of ITZ are worse than that of mortar matrix, and it was the first time to prove this quantitatively in this study by using the micro-bending method. When test pieces with ITZ are loaded, stress concentration may appear to occur at the ITZ location because of the stiffness difference between mortar matrix and aggregate. However, the effect of stress concentration in this paper was not covered. The authors suggest that further study should be made.

4.2 RECYCLED AGGREGATE CONCRETE

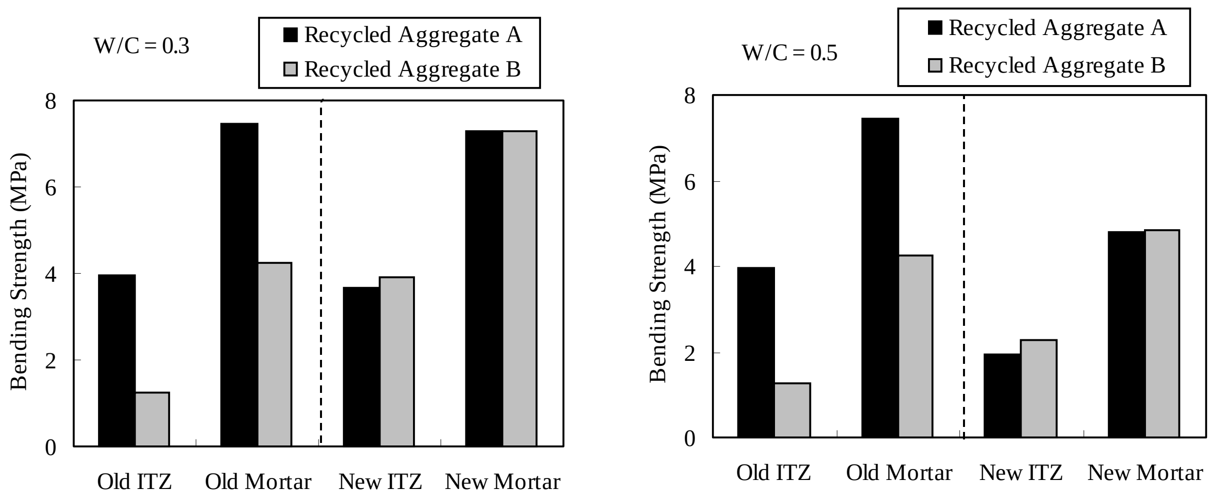


Fig. 10 Bending Strength of Micro-Regions in Recycled Aggregate Concrete

Fig. 10 shows the bending strength of micro-regions in the recycled aggregate concrete. As a result, it can be confirmed that the bending strength of both old and new ITZs are smaller than that of mortar matrix in all cases. Additionally, it can be seen that the bending strength of the old ITZ depends on the bending strength of old mortar matrix. For instance in the case of 0.3 water-cement ratio, when strong recycled aggregate (recycled aggregate A) is used, the bending of old ITZ is strong (around 4 MPa). In other words, when weak recycled aggregate (recycled aggregate B) is used, the bending strength of old ITZ is also weak (around 1 MPa). For new ITZ, even different types of recycled aggregate are used the bending strength of the new mortar is not different (around 7 MPa), and subsequently, the bending strength of the new ITZs of concrete using recycled aggregate A and B are similar (around 4 MPa). The same trend can be found in the case of 0.5 water-cement ratio. Therefore, it follows that the bending strength of ITZ depends on the bending strength of mortar matrix around it. And it is also possible to conclude that this newly developed method can be successfully applied to measuring the bending strength of the micro-regions in recycled aggregate concrete as well.

4.3 CONCRETE COATED WITH CFRPS

Fig. 9 shows the bending strength and an increasing ratio of bending strength of mortar matrix at the surface layer before and after coated with CFRPS. It can be seen that the bending strength of mortar matrix at the surface layer decreases as water-cement ratio increases and curing humidity decreases. Also, the bending strength of mortar matrix at the surface layer after coating with CFRPS is higher than before coating. It is considered due to the influence of the permeation of a coated resin into the concrete surface.

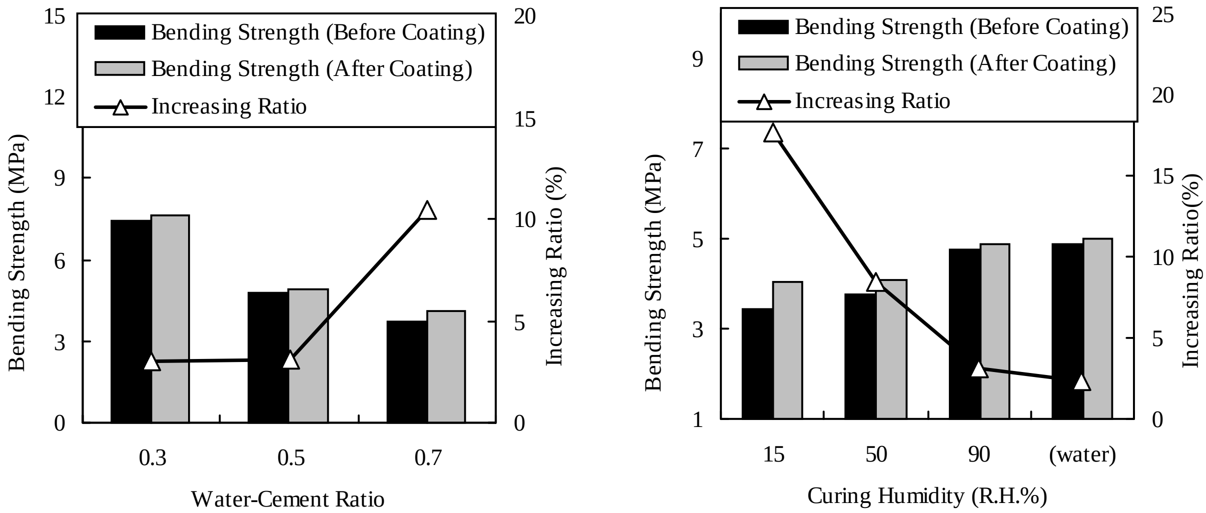


Fig.11 Bending Strength and Increasing Ratio of Bending Strength of Micro-Regions in Concrete Coated with CFRPS

Moreover, it can be seen that the increasing ratio of bending strength increases as water-cement ratio increases and curing humidity decreases. Therefore, it can be concluded that the effectiveness of the CFRPS coating can be clearly seen when concrete has a weak surface layer.

5. CONCLUSIONS

1. The strength properties of micro-regions in various types of concrete can be successfully evaluated quantitatively by using the newly developed micro-bending method.
2. For normal concrete, the bending strength of ITZ (inner layer) is smaller than that of mortar matrix, and the bending strength of mortar matrix at the surface layer is smaller than that of mortar matrix at the inner layer.
3. The bending strength of ITZs in recycled aggregate concrete depends on the bending strength of mortar matrix around it.
4. The bending strength of mortar matrix at the surface layer after coated with CFRPS is higher than before coated with CFRPS, furthermore, the increasing ratio of bending strength increases as water-cement ratio increases and curing humidity decreases.

REFERENCES

1.Nishida, T. et al., “Development of a Measuring Method for Bending Strength and Elastic Modulus of Micro Region in Concrete”, 26th Conference on Our World in Concrete & Structure, 2001, Singapore, pp.497-504

2.Noboru, Y., “The Surface Layer Concrete” (in Japanese), Cement and Concrete, No. 621, pp.44-50

3.Yodsudjai, W., Otsuki, N., Miyazato, S. and Onitsuka, R., “Development of a Test Method for Measuring Bending Strength and Elastic Modulus of Micro Region in Concrete”, Proceeding of the Third International Summer Symposium, 2001, pp.253-256, Tokyo, Japan