- Technical Paper -

EVALUATION ON BENDING LOAD BEARING BEHAVIOR OF REPAIRED COCNRETE MEMBER BY RESIN REPAIRING MATERIALS

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ABSTRACT
In order to grasp the interface behavior between concrete and resin repairing material with low elastic modulus and its generation and development process of internal cracks, the bending load bearing behavior of repaired concrete member by resin repairing materials with different thickness was studied and experimented. Moreover, the position orientation and formation mode of AE generation source corresponding to the cracks was conducted through the AE (Acoustic Emission) method. The results showed that the different repaired concrete members all can effectively ensure the interface integration, the detailed adhesion interface failure mechanism was defined. In addition, the importance of primer in interface integration was determined through comparative analysis.
Key words: AE method, bending load bearing, resin repairing material, shearing strength, thickness

1. INTRODUCTION

In recent years, along with the increase of sewer supply coverage ratio and the efficient treatment of foul water, the produced volume of sewage sludge is increasing. Therefore, the supply of reclamation disposal plants becomes very difficult to ensure and not adequate to the demand. In order to achieve the load reduction of disposal plants and the formation of a recycling-oriented society, the reduction of reclamation disposal amount of sewage sludge is proposed reasonably. On the one hand, as a new approach, the mixture of ash originating from sewage sludge incineration and repairing material using the resin is applied for repairing and reinforcing of manhole et.al. Regarding this construction method, although the elastic modulus is low, the cross-section repairing material with superior acid-resistance is coated to replace the deterioration member of concrete, the load bearing and corrosion protection can be ensured and improved. From the experiment results about the repairing and reinforcing in this construction method which takes deterioration part of piping facilities as research object, coating the resin repairing material mixed with incineration ash in concrete pipe of manhole can improve the breaking strength of concrete material. However, the interface behavior between the concrete and repairing material, the generation and development of internal micro cracks cannot be grasped until now. In addition, how to judge and ensure the interface integration of repaired concrete member, the research on bending load bearing behavior of adhesion interface between two kinds of materials become very important, but there is no unified evaluation method until now.

Based on the above background, the concrete and resin repairing material perform as composite material, so the adhesion performance was very important. And, bearing improvement mechanism is likely to be different from the reinforcing of high elastic modulus repairing material. Therefore, in this study, the bending load bearing behavior of cross-sectional repaired concrete member under the condition of different thickness of resin repairing material (0,5,10 and 20mm) was experimented, the bearing and bending strengths of different specimens were compared, with thickness as main factor. At the same time, the interface behavior and micro-cracks generation and development process of repaired concrete member was also analyzed from the microcosmic angle by AE method. In addition, aiming at the different construction conditions (for example, the existence of primer, adhesive and chipping), it was determined that the existenc of primer process was very important to shear strength and integration of adhesion interface of concrete by contrastive analysis in this study.

2. EXPERIMENT PROGRAMS

2.1 Manufacture of concrete specimen

An ordinary Portland cement, which met the requirements of Japanese Industrial Standard (JIS) R5210 :2003 “Portland Cement”, was used in this study. The mechanical properties of two kinds of sand (coarse and fine) and coarse aggregate were shown in **Table-1**. The resin premix type repaired material was used as repairing material in this study. The water reducing admixture and air entraining admixture in accordance with Japanese Industrial Standard for Chemical Admixtures for Concrete (JIS) A 6204 were used.

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Table-1 Experimental materials of concrete base material in this study

Cement	Coarse Aggregate G			Fine Aggregate (Coarse) S1			Fine Aggregate (Fine) S2		
Density	Density	Water absorption	Fineness modulus	Density	Water absorption	Fineness modulus	Density	Water absorption	Fineness Modulus
(g/cm^3)	(g/cm^3)	(%)	(F.M.)	(g/cm^3)	(%)	(F.M.)	(g/cm^3)	(%)	(F.M.)
3.16	2.61	1.81	6.67	2.57	2.22	2.76	2.65	2.89	1.58

Table-2 Mix proportion of concrete

G_{max} (mm)	Slump (cm)	Water/Cement (%)	Air content (%)	s/a (%)	Unit dosage (kg/m³)					
					W	C	S1	S2	G	Ad
20	8	60	4.5	46.0	165	275	669	167	991	C*0.4%

Table-3 Physical properties of concrete and resin repairing material

Concrete base material (28d)			Resin repairing material (7d)			Thickness (mm)	Elastic wave velocity (m/s)
Compressive strength (N/mm^2)	Tensile strength (N/mm^2)	Elasticity modulus (N/mm^2)	Compressive strength (N/mm^2)	Tensile strength (N/mm^2)	Elasticity modulus (N/mm^2)	0	4100
						5	3900
						10	4200
31.6	2.80	23.4	61.7	13.5	7.31	15	4200

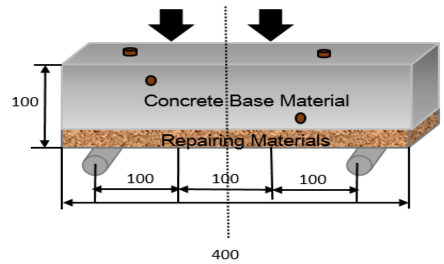


Fig.1 Schematic drawing of specimens

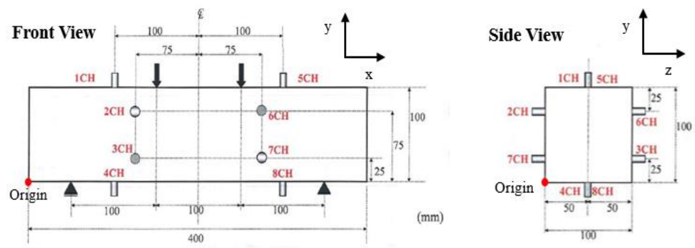


Fig.2 Installing position diagram of AE sensors

The mix proportion of concrete in this study was shown in **Table-2**. Regarding the manufacturing method of concrete specimen in this study, in order to research the interface behaviour and crack developing mechanism between the concrete base material and resin repairing materials with different thickness, the thickness of resin repairing material was set as 0, 5, 10 and 20mm, respectively. The 100×100×400mm steel mold was separated by the spacer of the corresponding thickness, the placing of concrete base material and resin repairing material was conducted separately. Three identical specimens were made for each specimen design. Firstly, the specimens of concrete base material were demoulded 24h later after placing, and then the specimens after demoulding were placed in a water bath at 20±1℃ to start the curing. At the curing age of 14 days, the specimens of concrete base material were put back into the corresponding steel mold and the remaining space was filled using the resin repairing material. After that, the repaired specimens of concrete were placed in the constant temperature and humidity environment of 20℃, 60% RH to keep curing until 28 days. At 28 days, the four-point bending experiment for repaired concrete member was conducted. For the treatment of the adhesion interface, the concrete base material was placed

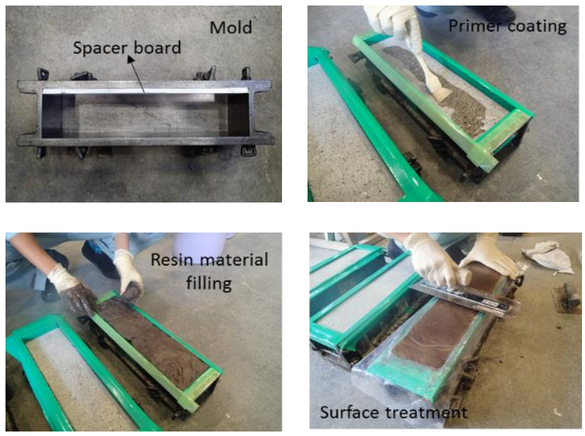


Fig.3 Manufacture of concrete specimen

in the steel mold adhibited with set retarding sheet, the uncongealed mortar was removed by flowing water and steel wire brush. Before repairing the concrete base material, the adhesion interface of concrete base material was smoothed by the floating apparatus for concrete, the primer and adhesive were coated in turn, and then the resin repair material was filled into the mold. Finally, the surface treatment of concrete member was conducted. The detailed manufacture order was shown in Fig.3.

2.2 Experimental Method

The schematic drawing of specimens test was shown in Fig. 1. As for the load, the pressure testing machine with capacity of 2000kN was used, and the load speed was set to 0.0126kN/sec. The tests for 12 specimens in total of different concrete were conducted. The experiment results of physical properties of concrete base material and resin repairing material were shown in **Table-3**. The strength test for concrete was conducted at 28 days, while the test for resin repairing material was conducted at 7 days. The elastic wave velocity in **Table-3** refers to the propagation velocity of elastic wave in the test specimens containing concrete base material and resin repairing material. The elastic wave velocity was used for both concrete and resin material of the whole of concrete specimens at SIGMA parsing time. The excitated suspected AE was detected in the vicinity of each AE sensor showed in Fig.2, and the elastic wave velocity was used as the parameter to calibrate the position. The elastic wave velocity that the difference in distance of position calibration results and input points was within 5 meters is suitable for SIGMA analysis.[1] Regarding the measurement method of AE, the eight AE sensors with 150 kHz resonance frequency were used, which were attached on the surface of specimens by the electron wax. [2] The upper limit was 35dB, the AE signal was increased to 40dB by the preamplifier, and the 1024 amplitude value data was regarded as one wave form that was recorded at sampling frequency 1MHz. The installing position of AE sensor was shown in Fig.2. Therefore, according to the position orientation and formation mode of AE generation source corresponding to the cracks, the detailed interface failure mechanism could be defined.

3. RESULTS AND DISCUSSIONS

3.1 Bending strength and max load of concrete

Fig.4 showed that the relationship between the thickness of repairing material, max load and bending strength of concrete, it can be seen that both the bending strength and max load of concrete increased with the increase of the thickness of resin repairing materials, the bending strength and max load with 20mm thickness increased more than tripled compared to before repairing. Moreover, from Fig.5, it also showed the concrete using the resin repairing materials was tension and had good ductility, which can effectively improve the bending stiffness so that it can effectively barrage crack generating and developing. Therefore, this indicates that the resin repairing material has the superior bending resistance performance.

3.2 Strain variation of different concrete using resin repairing materials with load

The location where the strain gauge of concrete specimens without resin material was measured was from top to bottom was 0, 20, 65, 75, 85 and 100mm in proper order. The measured location of the strain gauge of concrete specimens with resin material of 5mm thickness was 0, 20, 65, 90, 97 and100mm; the measured

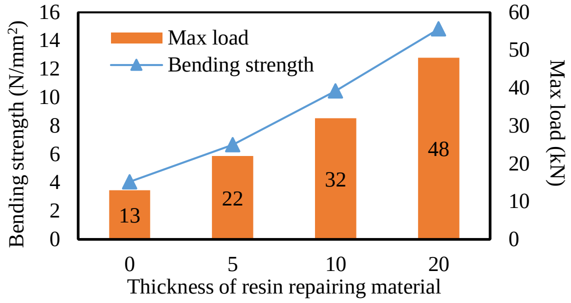
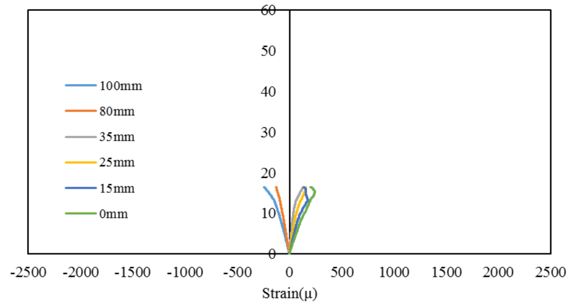
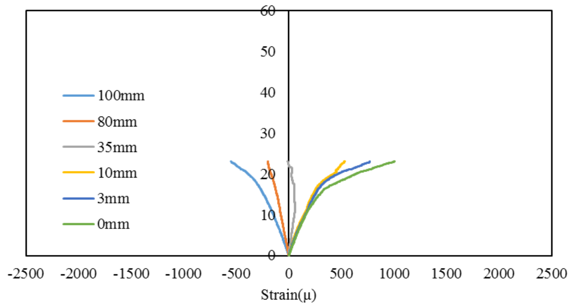


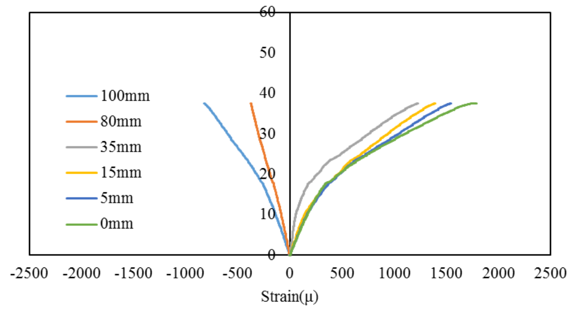
Fig.4 bending strength and max load of concrete



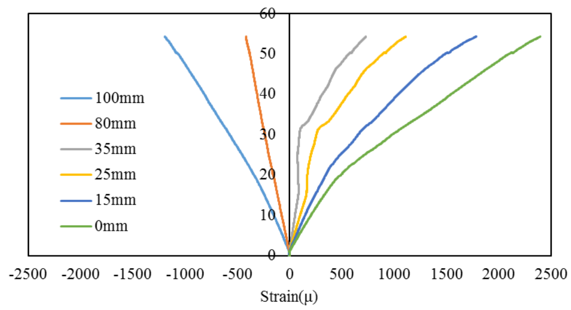
(a) Ordinary concrete



(b) Repairing material with 5mm thickness



(c) Repairing material with 10mm thickness



(d) Repairing material with 20mm thickness

Fig.5 Relationship between strain and load of different concrete

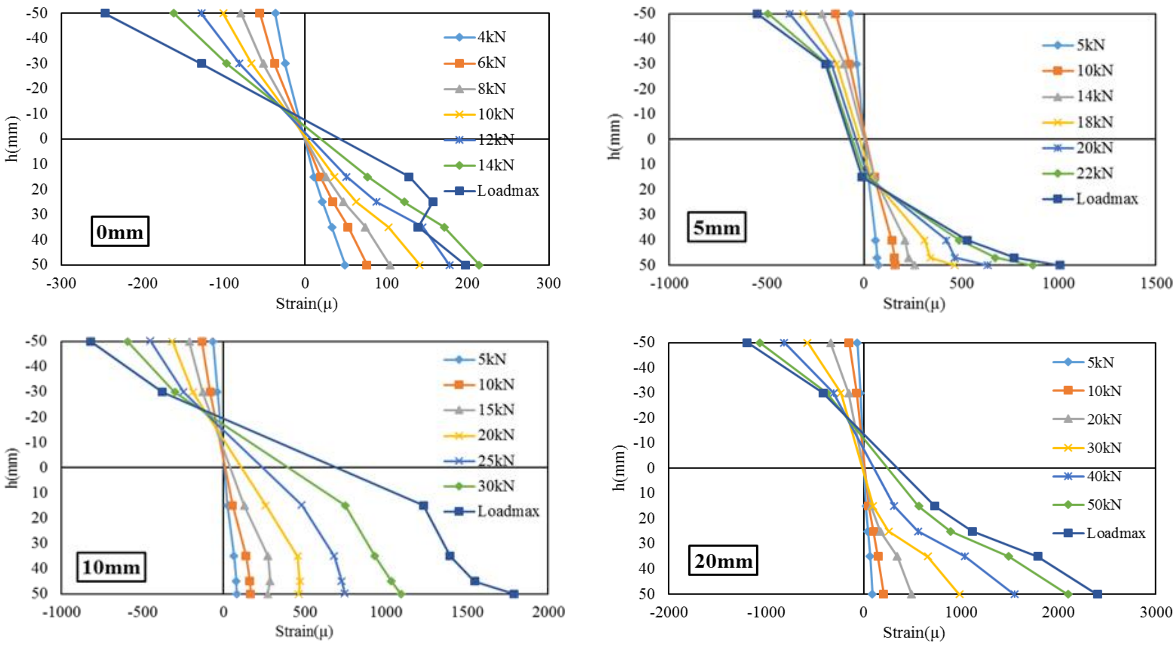


Fig.6 Strain variation of different concrete with load in the Y-axis direction

location of concrete specimens with resin material of 10mm thickness was 0, 20, 65, 85, 95 and 100mm; while the location of concrete specimens with resin material of 20mm thickness was 0, 20, 65 75, 85 and 100mm.

Fig.6 showed the variation of strain with the load of different concretes using the resin repairing material in the Y-axis direction. Compared with ordinary concrete, along with the increase of load, the strain of repaired concrete using resin repairing material increased toward the tension side. In the bending experiment, the resin coating with high strength takes charge of tensile stress pertaining to lower part of specimen, so as to enhance the tensile strength, so the strain increased towards the tensile side. The thicker the resin repairing material gets, the tensile strength of repaired concrete was higher. This also led to the improvement of bending strength which has a close relationship with tensile strength.

3.3 Failure process discussion of specimen based on AE-SIGMA analysis

Regarding the SIGMA analysis, from the arrival time and elastic wave velocity of the detected AE signal, the position orientation of AE generation source was conducted. The formation mode of AE generation source can be obtained by the initial motion amplitude value of AE wave, the AE phenomenon identified by the position of AE generation source and formation mode was called AE event. [3] Fig.7 concluded the relationship of loading time, load and number of AE hits. For the cases of 5 and 10mm thickness, similar to ordinary concrete, the number of AE hits of concrete both gradually increased with loading time, which failed in flexure ultimately. In contrast, for the case of 20mm thickness, because the elastic modulus of resin materials was lower than ordinary concrete, the apparent thickness of concrete decreased, leading to the first AE hits peak in 252s. After that, because the resin materials carried the tensile stress more and thus the number of AE hits changed little and stabilized with loading time before failing in shear. In

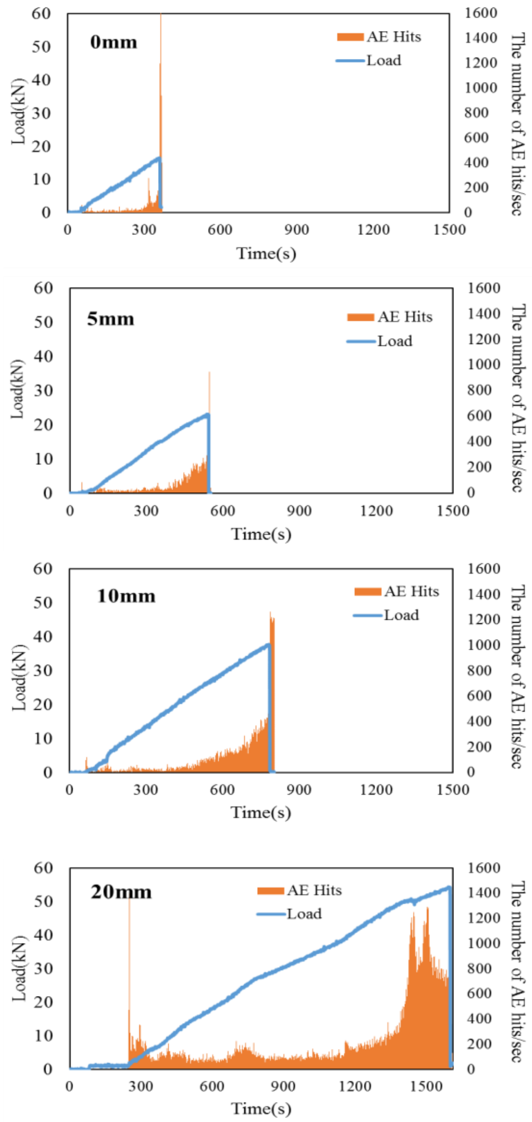


Fig.7 Relationship of load, loading time and the number of AE hits

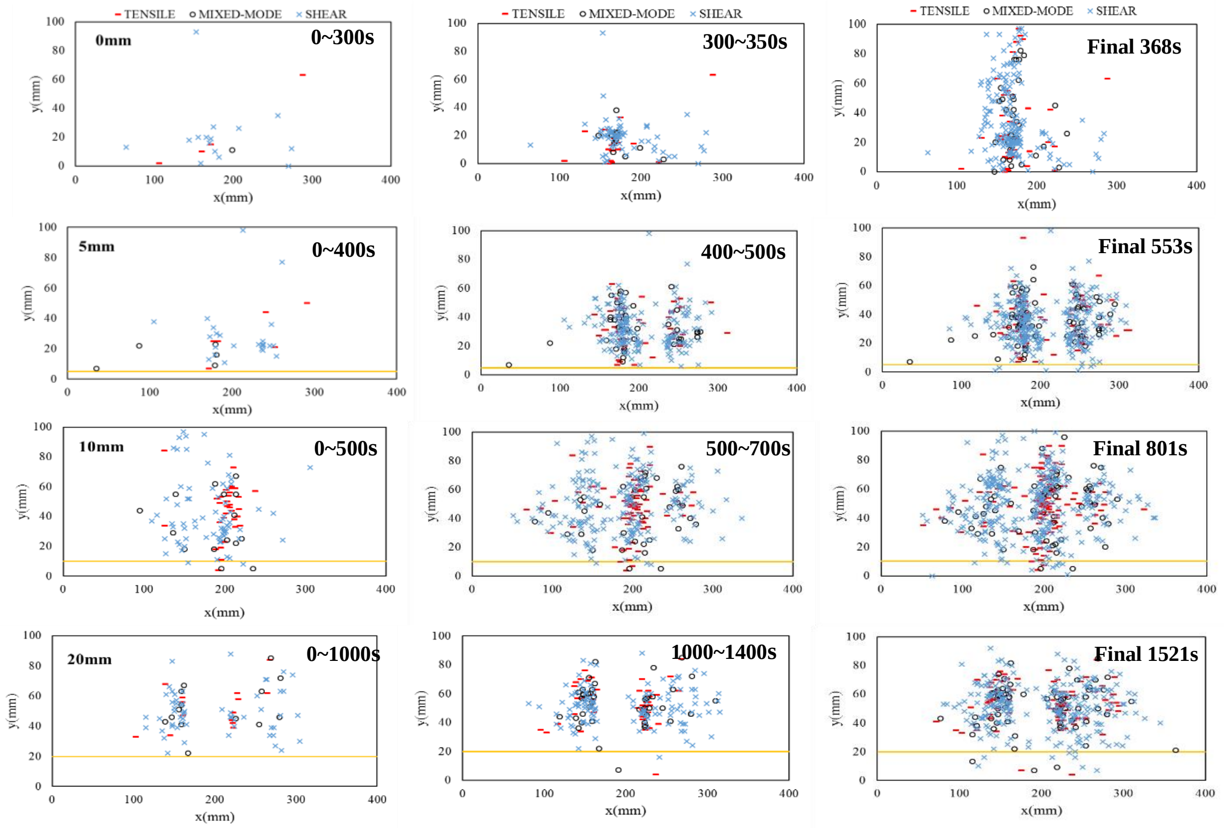


Fig.8 the AE-SIGMA analysis results of different concrete with loading time

addition, in the case of 20mm thickness resin material, the load still had an obvious increase between 1300~1500s after showing the shear failure, which indicated the concrete specimens with 20mm thickness resin material had a good ductility. Moreover, besides the friction between the loading device and specimens, the friction between the concrete and resin material was also a reason for the increase in the number of AE hits.

Based on the AE-SIGMA analysis results in Fig.8, compared with ordinary concrete, the initial cracks of different repaired concrete member using resin material all generated on the interface between concrete base material and resin material, and then diffused and moved to upper part of concrete member with the loading time, the tension failure and shear failure of resin repairing material was caused until ultimate load. The specimens with the resin material of 20mm thickness showed the shear failure, while the tensile failure for concrete using the resin materials of 5 and 10mm thickness. The failure mode was different depend on the tensile resistance of resin material. Moreover, until it reached the maximum bearing force, the position orientation number of AE event in concrete base material of repaired concrete member was very large and concentrated, while the number in the resin repairing material and interface was very small and decentralized, which can sufficiently prove and ensure the interface integration of concrete and resin repairing material. In addition, in the case of repairing material with 20mm thickness, because the load bearing of resin repairing material was high than concrete, the concrete base material was destroyed first before reaching the bearing strength of repairing material. Fig.9 showed the cracking photos of different concrete specimens after the tests.

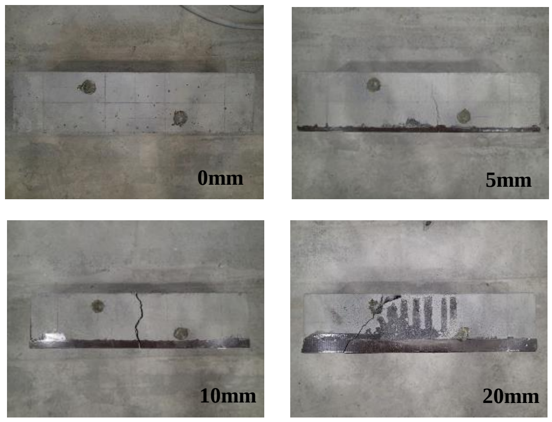


Fig.9 cracking photos of concrete specimens

From the results of repaired concrete member with 20mm thickness, the shear stress of adhesion interface can be calculated to more than 3.6Mpa, which was very close to the maximum value (4.0Mpa) of average shear stress for concrete with 30N/mm^2 depend on the “Specification for Highway Bridges”. According to different construction conditions, aiming at the existence of primer, adhesive and chipping, the calculation of reasonable thickness of repairing material need to be considered. Kurohara. et al. researched the evaluation of shear strength of different repaired concrete member with average roughness [4]. From Fig.10, under the condition of different strength of repairing material, the shear strength and the average roughness had a liner correlationship. In which, Hs represented the repairing material with high strength (58.6N/mm^2 at 28days), Ms represented the repairing material with middle strength (46.2N/mm^2), Ls represented the repairing material with

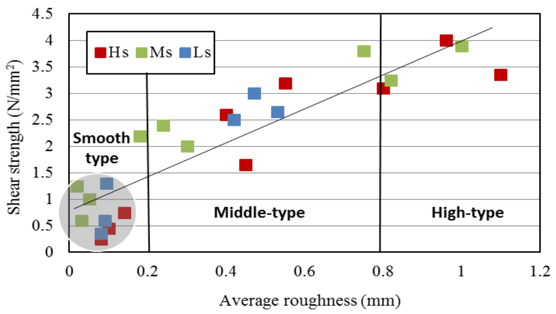


Fig.10 Relationship between shear strength and average roughness of concrete [4]

low strength (40N/mm^2). In general, the types of roughness index can be divided into three types, which are High-type (＞0.8mm), Middle-type (0.2~0.8mm) and Smooth-type (＜0.2mm). In this study, the adhesion interface was smooth because of primer and adhesive process and its roughness index can be considered as Smooth-type. Based on the results of repaired concrete member with 20mm thickness, the shear strength of adhesion interface was calculated to more than 3.6Mpa. In contrast, under the condition of repaired concrete member without primer and adhesive process, the shear strength of Smooth-type (＜0.2mm) adhesion interface of repaired concrete member was less than 1.5Mpa and far lower than 3.6Mpa. In other words, the shear strength of Smooth-type interface of repaired concrete member with primer process can reach the same value as that of High-type (1.0 mm) interface of repaired concrete member without primer process. For example, without the primer process, it is assumed that the shear strength (T_{max}) was 1.0Mpa, the max load value can be calculated to 13.4 kN based on following equation (1), the same level as ordinary concrete, far lower than concrete with resin repairing material of 20mm thickness in this study (48kN). This results indicated that the roughness index and primer process was very important to the interface integration of concrete.

$$W=(2\times A\times T_{max})/k \quad (1)$$

Where W: The calculated max load value (kN)

A: Area of cross-section (mm^2)

T_{max}: Max shear stress (N/mm^2)

k: shape coefficient—1.5

In addition, Trun Dung .etc. [5] also showed that the shear strength (4.69N/mm^2) of adhesion interface of repaired concrete member with epoxy primer was higher than that (3.9N/mm^2) of concrete member without epoxy primer. In future, the optimum thickness of resin repairing material could be deduced by the calculation of superior margin stress and repairing material stress of concrete.

4. CONCLUSIONS

Through a comprehensive analysis, the following results were obtained in this study:

(1) The bending strength and max load of concrete member increased with the thickness of resin repairing material, the resin repair material has a superior bending resistance performance, which can restrain the occurrence and development of crack. Moreover, the strain of repaired concrete member increased to tensile side with the load. The concrete members with the resin repairing material of 20mm thickness showed shear failure, while tensile failure for the cases of 5 and 10mm thickness.

(2) Compared with ordinary concrete, the initial cracks of different repaired concrete member by resin repairing material all generated on the interface between concrete base material and repairing material, and then diffused and moved to upper part of concrete member with the loading, the tension and shear fracture of resin repairing material was caused until the ultimate load.

(3) The position orientation number of AE event in concrete base material was very large and concentrated, while the number in the repairing material and interface was very small, which can prove and ensure the interface integration of concrete base material and resin repairing material.

(4) Based on the results of 20mm thickness repaired concrete member, the shear strength of adhesion interface was calculated to more than 3.6Mpa, which was far higher than that of repaired concrete member without primer process under the condition of same roughness index, which indicated existence of the primer process was very important to the interface integration of repaired concrete member.

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