Study on new strengthening method using a soft layer of polyurea and prefabricated CFRP plate for the prevention of peel off

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ABSTRACT: From the past research by the authors, the effectiveness of the construction method in improving bonding performance by using poly-urea resin with the prefabricated CFRP plate in the concrete structures have been confirmed by the shear bond test. This strengthening method has an advantage of labor saving in the construction sites. In this study, RC beam specimens were prepared by using high modulus or high tension type CFRP plate with parameters such as, conventional CFRP plate or prefabricated poly-urea resin CFRP plate, this adhesion method, and were evaluated by the bending test. The result indicate that, we could not confirm improvement of bending reinforcement effect by inserting poly-urea resin using high modulus CFRP plate specimen, but using high tension type poly-urea applied and conventional CFRP plate for RC beam specimen. The maximum load of the prefabrication specimen was about 1.6 times higher than that of the specimen without soft-layer. Therefore, the prefabrication specimen was also obtained sufficient reinforced effect.

1 INTRODUCTION

In recent years, Carbon Fiber Reinforced Polymer plate (CFRP plate) has been widely used in civil engineering and architectural field to strengthen the structures, due to advantages such as high tensile strength, excellent durability and light weight. CFRP plate external bonding method is easy to install in the construction site. From the past research by the authors, Bahsuan et al. (2016) and Sakurai et al. (2018), authors reported that traditional external bonding strengthening method by A.F Ashour et al. (2014), using CFRP plate is easy to de-bond without using the high tensile strength property of CFRP plate. In the above background, the authors confirmed the effectiveness of CFRP plate external bonding strengthening method using poly-urea soft-layer.It was confirmed that the peeling could be delayed by using a traditional epoxy resin adhesive and a poly-urea soft-layer having a low elastic modulus and high elongation as a bonding layer. As for the method of application order,poly-urethane primer, poly-urea putty paste (soft-layer), and putty paste adhesive of epoxy resin were applied respectively on the substrate concrete before finally bonding the CFRP plates. However, with this construction method, it needs longer time at the construction site due to application of multiple layers. Therefore, the objective of this study is to confirm the reinforcement effect by prefabricating the CFRP plates with the soft-layer of poly-urea in advance. The results were evaluated from the bending test of RC beam strengthened with the externally bonded CFRP plate, with/without poly-urea soft-layer as bonding material and type of plate bonding method as the test parameters.

2 FLEXURE TEST OF THE RC BEAM

2.1 Material Properties of CFRP plate and bonding agents

In this study, CFRP plates of high tension type (HT-plate) and high modulus type (HM-plate) were used. For the bonding agents, Epoxy/poly-urethane primer agents, poly-urea putty paste material and epoxy putty paste were used. Table 1 shows the mechanical properties of CFRP plate and bonding agents.

Table 1. Used materials properties of CFRP plate and bonding agents

	Type	Item	Unit	Test results	Test method
HT type CFRP plate	CFRP plut. Plate	Width	mm	50.6	Actual value
		Thickness	mm	1.1	Actual value
		Tensile strength	MPa	3229	JSCE-E-541
		Young's modulus	GPa	170	JSCE-E-541
HM type CFRPplate	CFRP plut. Plate	Width	mm	50.3	Actual value
		Thickness	mm	1.02	Actual value
		Tensile strength	MPa	1925	JSCE-E-541
		Young's modulus	GPa	412	JSCE-E-541
Epoxy primer	N.O.S epoxy primer	Specfic gravity	--	1.13	ISO 1183
		Viscosity	mPa/s	950	Btype
Poly urethene Primer	Poly urethene with organic solvent primer	Tg.	°C	135	DSC method
		Viscosity	mPa/s	480	Btype
Poly-urea putty paste	N.O.S poly-urea putty paste soft layer	Compressive strength	MPa	6.8	ISO 604
		Compressive modulus	MPa	20	ISO 604
		Tensile strength	MPa	12	ISO 178
		Tensile modulus	MPa	20	ISO 178
		Lap share strength	MPa	5.6	ISO 4587
Epoxy putty paste	N.O.S epoxy putty paste CFRP plate bonding agent	Compressive strength	MPa	96	ISO 604
		Compressive modulus	MPa	7230	ISO 604
		Tensile strength	MPa	37	ISO 178
		Tensile modulus	MPa	5300	ISO 178
		Lap share strength	MPa	16.6	ISO 4587

The tensile modulus of the HM plate is 2.42 times higher than that of the HT plate, but the tensile strength is 0.59 times of the HT plate. The Young's modulus of the poly-urea putty paste was only seven percent than that of epoxy putty paste bonding agent.

2.2 Material Properties of used materials in the RC beam

The mechanical properties of materials used in the RC beam is listed Table 2.

RC beam specimen used three types of deformed shaped steel rebar (SS-400 type). Concrete mixture design for target compressive strength of 35MPa was used with maximum coarse aggregate size of 25mm, fine aggregate, OPC cement and AE water reducing agent. The compressive strength at the time of the test was 43.7MPa.

Table 2. Used materials property of steel rebar and concrete

	Type	Item	Unit	Test results	Test method
Steel rebar	Deformed type 10 phi	Yield strength	MPa	387	ISO 6935-2
		Tensile strength	MPa	553	
	Deformed type 13 phi	Yield strength	MPa	387	
		Tensile strength	MPa	553	
	Deformed type 16 phi	Yield strength	MPa	405	
		Tensile strength	MPa	577	
Concrete		Compressive strength	MPa	43.7	ISO 6784
		Compressive modulus	GPa	27.5	ISO 6784

2.3 Experimental program

2.3.1 Bonding layer details

This study includes three types of specimen with different layers. Type-T is a conventional strengthening method in which all the layers are applied at the construction site. All the layers in TypeN-1 is also applied at construction site before installing the CFRP plate but includes soft layer of poly-urea. Type-N-2 is the pre-fabricated type of CFRP reinforcement using soft layer of poly-urea. This specimen type is separated prefabricated CFRP plate and onsite application layer. Type N-2 specimen has similar installation procedure on site as Type-T. The details of the layer and its thickness are shows in Figure 1.

CFRP plate	1.0mm
Putty paste Epoxy bonding agent	1.0mm
Epoxy primer	0.18mm
Concrete substrates	
Type T layer	

CFRP plate	1.0mm
Putty paste Epoxy bonding agent	1.0mm
Poly-urea soft layer	0.8mm
poly urethane primer	0.03mm
Concrete substrates	
Type N-1 layer	

CFRP plate	1.0mm	Pre fablicated layers
Epoxy primer	0.18mm	
poly urethane primer	0.03mm	
Poly-urea soft layer	0.8mm	
Bonding in construction site		
Putty paste Epoxy bonding agent	1.0mm	Onsite applied Layer
poly urethane primer	0.03mm	
Concrete substrates		
Type N-2 layer		

Figure 1. CFRP bonding layers and its details

2.3.2 RC beam specimen

The details of the RC beam specimen are shown in Figure 2. Three different dimensions of the deformed steel re-bars were used. RC beams of dimension 150 x 250 x 2700mm were prepared. CFRP plate of 2200mm x 50mm dimension was bonded underneath the beam as shown in the figure. During the experiment, deflection measurement instrument was placed at the center of the RC beam. The support condition on the left side is set as hinge and the right side is set as roller condition. This RC beam was designed to fail in bending by taking the shear reinforcement.

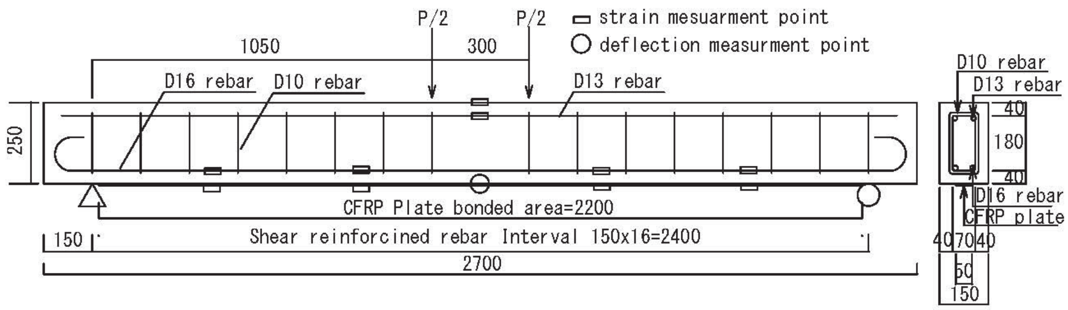

Figure 2. The overview of the RC beam specimen (unit: mm)

The details of the experimental RC beam specimens are listed in Table 3. Only 1-specimen was used for each condition for comparison of the results. The load was increase by the hydraulic jack and measurements such as load, mid-span deflection, stains in re-bar, CFRP and concrete were measured by the data logger.

As for the procedure of specimen preparation, first the bottom surface of the RC beams was disk grinded. Then, the CFRP plates were bonded on the bottom of the RC beams using the adhesive order shown in Table 3 and Figure 1.

The naming of the specimen is performed as 1: CFRP thickness, HT: High tension type CFRP, HM: High modulus type CFRP, N: without poly-urea layer, S: with poly-urea layer, P: Pre-fabricated CFRP.

Table 3. RC beam specimen specification

Specimen Name	CFRP type	CFRP thickness (mm)	layer type	Method
1HTN	High tension	1	T	Traditional
1HTS	High tension	1	N-1	poly-urea
1HTS-P	High tension	1	N-2	Pre-fabric poly-urea
1HMN	High modulus	1	T	Traditional
1HMS	High modulus	1	N-1	poly-urea

3 RESULTS AND DISCUSSION

There was a considerable increase in the load carrying capacity of the RC beams after strengthening. The effects of various test variables are discussed as following.

3.1 Effect of strengthened RC beam

3.1.1 Comparison between the calculated and experimental load

The maximum load and failure mode results are listed in Table 4. The control specimen represents the un-strengthened case which was used as a reference for comparison after the strengthening. CFRP plate de-bonding failure occurred in 1HTN specimen while 1HTS and 1HTS-P specimens failed by concrete compressive failure at upper side of the RC beam. Whereas, 1HMN and 1HMS specimen failed by the rupture of the CFRP. The specimen 1HTN failed at 85kN which was comparatively lower than the 1HTS (97kN) and 1HTS-P (95kN) specimens. This increase in the maximum load is considered due to the greater peel-off resistance provided by the addition of soft poly-urea layer changing the ultimate failure mode to the concrete compression failure. The specimens 1HMN and 1HMS which used HM type CFRP plate ended with rupture of the CFRP plate as the failure strain of the HM type CFRP plate is lower compared to the HT type CFRP plate. The calculated maximum load of the HM series specimens was determined by the CFRP rupture in the case of with/without the poly-urea soft layer. The test results also indicate no difference between 1HTS (97kN) and 1HTS-P (95kN) in the maximum load. It indicates that the similar strengthening effect could be obtained by using the prefabrication method which had a greater advantage in the construction speed at the site.

In this study, the load was calculated for 1HTS by considering compressive failure of concrete, while 1HMN and 1HMS specimens by rupture of CFRP.

Table 4. Test results

Name	P_{yex}(kN)	P_{yca}(kN)	P_{yex}/P_{yca}	P_{max}(kN)	P_{uca}(kN)	P_{max}/P_{uca}	Failure mode
Control		57			60		
1HTN	64	66	0.96	85	105	0.81	Debonding failure
1HTS	65	66	0.98	97	105	0.92	Compresive failure
1HTS-P	67	66	1.02	95	105	0.90	Compresive failure
1HMN	82	79	1.03	90	89	1.01	CFRP rupture
1HMS	75	79	0.95	88	90	0.98	CFRP rupture

Pyex：Rebar yielded load (Exp.), Pyca：Rebar yielded load (Cal.), Pmax：Maximum load (Exp.), Puca：Maximum load (Cal.)

3.1.2 Load and deflection results

The results showing the relationship between load and displacement is presented in Figure 5.

In HT type specimens, regardless of the presence of the poly-urea resin, it was confirmed that all specimens has similar bending rigidity which changed at around 70kN after the yielding of the steel reinforcement. This decrease in rigidity is due the yielding of the tensile reinforcement. The ultimate failure of the specimens 1HTN, 1HTS and 1HTS-P occurred at 85kN, 97kN and 95kN respectively. Also, for 1 HTS, the bending rigidity changed around 95kN which is considered due to concrete compression failure at the upper side of the RC beam. Therefore, in the HT type CFRP

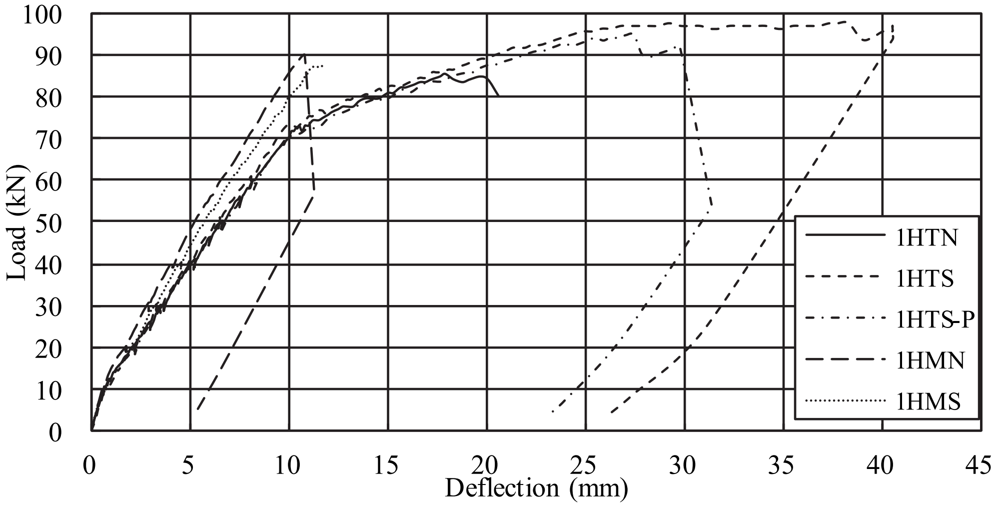

Figure 3. Relationship between load and deflection results

plate bonded specimens, from the relationship between load and deflection, it was not possible to confirm any difference with/without poly-urea soft layer in the bending rigidity.

4 CONCLUSION

All the CFRP plate strengthened RC beams showed increase in the maximum load both in experimental and calculated values when compared to the control specimen. Also, all the HM type CFRP plate strengthened RC beams showed increase in the flexural rigidity increased due to use of higher modulus CFRP plate.

Comparing the results of 1HTS and 1HTS-P specimens, it was confirmed that there was almost no difference in the maximum load while using soft poly-urea layer.

By comparing the experimental and calculated values of the 1HTS specimen, it could be stated that the calculation is possible with the theory of RC structure with only minimal error.

Finally, in case of manufacturing CFRP plates at the plant, if a soft poly-urea layer is applied in advance by the prefabricated method, higher strengthening effect can be obtained than the conventional external bonding method using CFRP plate. Thus the authors propose prefabricated CFRP plate strengthening method using the poly-urea soft-layer considering the practicality of the construction at site.

5 REFERENCES

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