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A Study of Bond of Structural Timber and Carbon Fiber Reinforced Polymer Plate

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The increase of well-being culture of problem related to environmental depletion of resource is not the growing interest in timber the natural material of construction markets. Also, the perception for historic preservation has been increased in respond to heightened interest. However, it is fairly difficult for architectural properties to maintain their durability because it was made by timber construction. Preventing traditional structure from damage and structural performance reduction is paramount in maintenance problem. A number of studies of reinforced method have been conducted in order to solve such a problem. In this paper, external bonded reinforcement and near-surface mounted was used as a way to reinforce timber structure’s durability. Bond strength for specimens with different bond length was investigated. As a result showed, maximum bond strength in bond length 300 mm from all method, was found to be not increased of bond strength over the certain bond length.

Keywords: bond, structural timber, carbon fiber reinforced polymer plate, external bonded reinforcement, near-surface mounted.

1. INTRODUCTION

Recently, life style quality improved for the well-being culture by problems of environmental pollution and resource depletion and there is an increasing attention in the housing sector on timber. Timber is construction material of the natural, it is distinguished from existing construction material of concrete [1]. As wooden construction uses dry construction method with short construction period, it has smaller demand for professional skills compared to wet construction method. Due to such advantage, awareness on timber housing is growing, and demand for timber houses is predicted to increase. Also, as importance and value for preservation of cultural heritage are increasing, there is an increasing awareness of preserve cultural heritage. Traditional timber buildings are based on the principle that maintains the original form of building while preventing reduction in structural performance and material loss [2]. However, as traditional timber structures with important values in preservation such as cultural heritages are being restored by replacing damaged members by new materials or complete demolition for reconstruction without sufficient review on accurate material characteristics, structural behavior and resistance, structural problems are deepening [3]. When timber structures are corroded or damaged by physical, chemical or biological means, they are primarily reinforced by replacing corroded structural members with new members. In the case of cultural heritages, each member has a value as cultural heritage. Therefore, causes difficulty in replacement. In order to resolve such problem, studies are being conducted on strengthening methods that do not involve replacement of existing timber. Among strengthening methods, the method using carbon fiber reinforced polymer (CFRP) plate was developed to be especially appropriate for strengthening of structures as CFRP plate has excellent corrosion resistance, chemical resistance, and fatigue resistance, as well as excellent performance in terms of constructability, workability, transportability, and light weight. There is an increasing use of CFRP plate at actual construction sites. There had been many studies on concrete member strengthening method based on Carbon Fiber Reinforced Polymer (hereinafter referred to as CFRP) since 1990s. Garden [4] and Wu et al. [5] studied CFRP plate and sheet post-tension strengthening system, and Baroos & Dias [6] performed an experiment on shear behavior of NSM beam and predicting shear strength of Near-Surface-Mounted beam by modifying the analysis model presented by Nanni et al. [7]. Many studies exist such as surface mounting of CFRP on the concrete bond strength according to surface bonding, and bond strength estimation equation for NSM CFRP plate on the concrete by Seo Su Yeon et al. Guenaneche et al. [8] and Krour et al. [9] were studied the numerical analysis for the FRP plate reinforced concrete beams. Studies on CFRP in timber are also being conducted actively. Giulia Fava et al. [10] carried out a study on bond strength with glulam according to fiber direction and thickness of CFRP and GFRP. L. F. P. Juvandes et al. [11] compared bond strength according to strengthening method of structural timber and FRP. Angelo D’Ambrisi et al. [12] performed an experiment on bending strength of NSM CFRP plate in timber. The study of Kwon Gi Hyeok et al. [13] was about bending strength of timber strengthened by NSM CFRP. However, there had not been basic research about bonding. Also, as timber materials are not uniform and have a difference among species, it is important to perform appropriate strengthening according to species. Therefore, the purpose of this study is recently used structural glulam with CFRP plate for comparison of bond strength according to external

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bonded reinforcement and near-surface mounted and to provide basic data about timber strengthening by use pine tree to mainly use in cultural heritages in the past.

2. EXPERIMENTAL DESIGN

The most common technique for strengthening of structure members utilizing FRP is External Bonded Reinforcement (EBR) technique. Despite certain benefits of this technique such as simple and prompt installation, the main problem, which has greatly disrupted the use of EBR method, is premature debonding of FRP composite from member. This problem can cause a strength reduction of the retrofitted member. Accordingly, recently, Near-surface Mounted (NSM) method was developed. A study on bond capacities of EBR and NSM using GFRP was conducted. The bond strengths for specimens strengthened by two methods were compared. The key parameters for an experiment are retrofit method (EBR, NSM), timber species. The material properties of CFRP plate and epoxy are illustrated in Table 1.

Table 1. Material properties of CFRP-plate, epoxy resin and timber

CFRP-plate				
Measurement	Result, MPa	Method of examination		
Tensile strength	3.160	ASTM D 3039 [15]		
Modulus of elasticity	195.000			
Epoxy resin				
Measurement	Result, MPa	Method of examination		
Bond strength	3.1	KS F 4918 [16], ASTM C 882 [17]		
Compressive strength	77.8	KS F 2476 [18], ASTM C 579 [19], ASTM C 293 [20]		
Flexural strength	34.4			
Durometer	70.2	ASTM D 2240 [21]		
Timber				
Measurement	Species	Result	Grade	Method of examination
Compressive strength	Pine	44.1 MPa	1	KS F 2206 [22], ASTM D 198 [23]
	Glulam	54.9 MPa	1	
Moisture contents	Pine	11.5 %	1	KS F 2199 [24], ASTM D 4442 [25]
	Glulam	9.3 %	1	

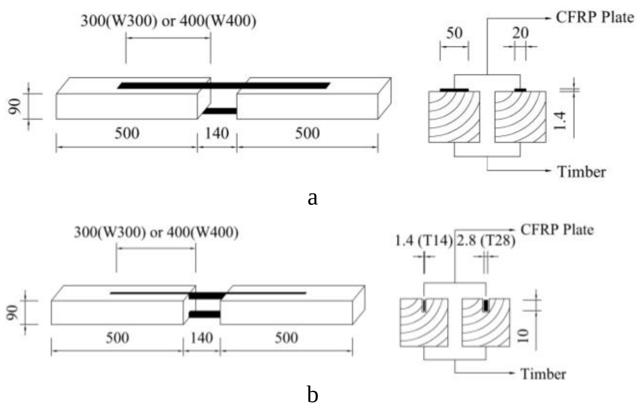


Fig. 1. Specimen configuration: a – EBR specimen; b – NSM specimen

Also, the result of measuring compressive strength and moisture content of timber according to the standard is shown in Table 1. According to KBC 200914, timbers used belong to structural timber grade 1. The relevant geometric information of specimens is displayed in Fig. 1 and summarized in Table 2.

Table 2. Specimen list

No	Specimen	Bond length, mm	Reinforcement form	CFRP plate Thickness, mm	CFRP plate Width, mm	Species
1	DS300W50	300	EBR	1.4	50	Pine
2	DS400W50	400				
3	DS300W20	300			20	
4	DS400W20	400				
5	LS300W50	300			50	Glulam
6	LS400W50	400				
7	LS300W20	300			20	
8	LS400W20	400				
9	DN300T14	300	NSM	1.4	10	Pine
10	DN400T14	400				
11	LN300T14	300				Glulam
12	LN400T14	400				
13	DN300T28	300		2.8		Pine
14	DN400T28	400				
15	LN300T28	300				Glulam
16	LN400T28	400				

CFRP plate with different width (20, 50 mm) and length (300, 400 mm) was used for the test of EBR method that one surface of it is bonded to the surface of timber (The timber specimens made by domestic pine and glulam were used in the test and size of timber is 90 × 90 × 500 mm.). As for NSM method, the GFRP plate is embedded into slit with width of 10 mm and depth of 1.4 and 2.8 mm.

Specimens were tested in the Universal testing machine of 2000 kN capacity as shown in Fig. 2. End of specimen in joined by a gripping apparatus which are fixed to rotate and movement. The gripping apparatus are connected to the grip of the UTM. Tensile force was applied to the specimen at a constant rate of 0.5 mm/min in a displacement control mode. Two displacement transducers (LVDT) were set-up to measure the elongation of the specimens and two strain gauges were attached to the each surface (in the front and back) of specimen. The measured data was stored into the data logger at 1.0s intervals.

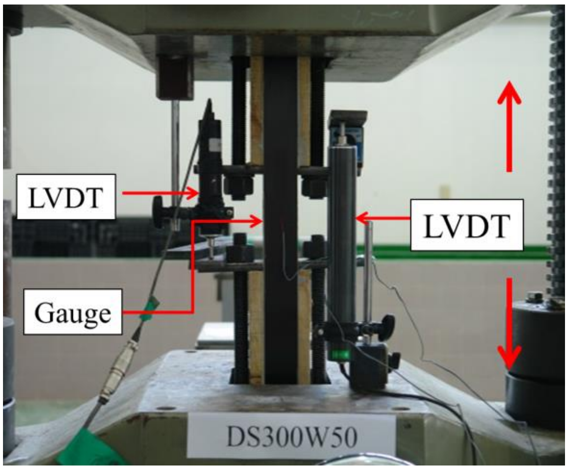


Fig. 2. Loading situation

3. EXPERIMENTAL RESULTS

3.1. Failure shape

Fig. 3 show presents the fracture mode of test results. Fracture mode can be divided into two groups depending on reinforced method. While EBR specimens failed in debonding failure (Fig. 3 a, b), NSM specimens showed the phenomenon of tensile fracture of epoxy (Fig. 3 c, d). In specimens in the same series (EBR, NSM), the failure pattern was same each other regardless of the bonded length, width and depth.

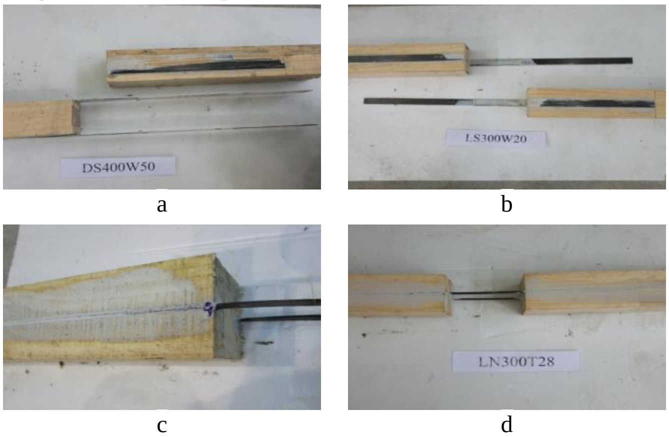


Fig. 3. Fracture shape: a – DS400W50 (EBR); b – LS300W20 (EBR); c – DN300T14 (NSM); d – LN300T28 (NSM)

3.2. Load-displacement curve

Table 3. Experimental results

No.	Specimen	Ultimate load, kN	Bond strength, MPa	Failure mode	Bond area, cm^2
1	DS300W50	41.99	7.00	B	600.0
2	DS400W50	64.75	8.09	B	800.0
3	DS300W20	28.45	11.85	B	240.0
4	DS400W20	29.43	9.20	B	320.0
5	LS300W50	75.64	12.61	B	600.0
6	LS400W50	67.40	8.43	B	800.0
7	LS300W20	40.91	17.05	B	240.0
8	LS400W20	18.74	5.86	B	320.0
9	DN300T14	7.95	3.10	T	256.8
10	DN400T14	13.73	4.01	T	342.4
11	LN300T14	30.90	12.03	T	256.8
12	LN400T14	35.22	10.29	T	342.4
13	DN300T28	23.45	6.43	T	273.6
14	DN400T28	16.48	6.02	T	364.8
15	LN300T28	34.43	12.58	T	273.6
16	LN400T28	36.49	10.00	T	364.8

In most of the specimens, increase of displacement is higher than the increase of load during an early stage. Such phenomenon is probably caused by indentation, which occurs by pressure that occurs at the point of force upon initial application of load, according to material characteristics of timber, creating displacement as large as depth of indentation. Fig. 4 a and b represent the load-displacement curve of EBR specimens with width of 20 and 50 mm. For specimens in DS series made from pine, the longer bond length lead to an increase of strength. For example, DS300W50 with bond length of 300 mm has an ultimate load of 41.99 kN (Table 3) and much larger value than those of DS400W50 with bond length of 400 mm (ultimate load = 64.75 kN in Table 3). However, the strength of specimens in LS series has reduced by increase of bond length. As for the NSM specimens, except for some specimens in DN series with depth of 2.8 mm, the strength of specimens increased as increase of the bond length.

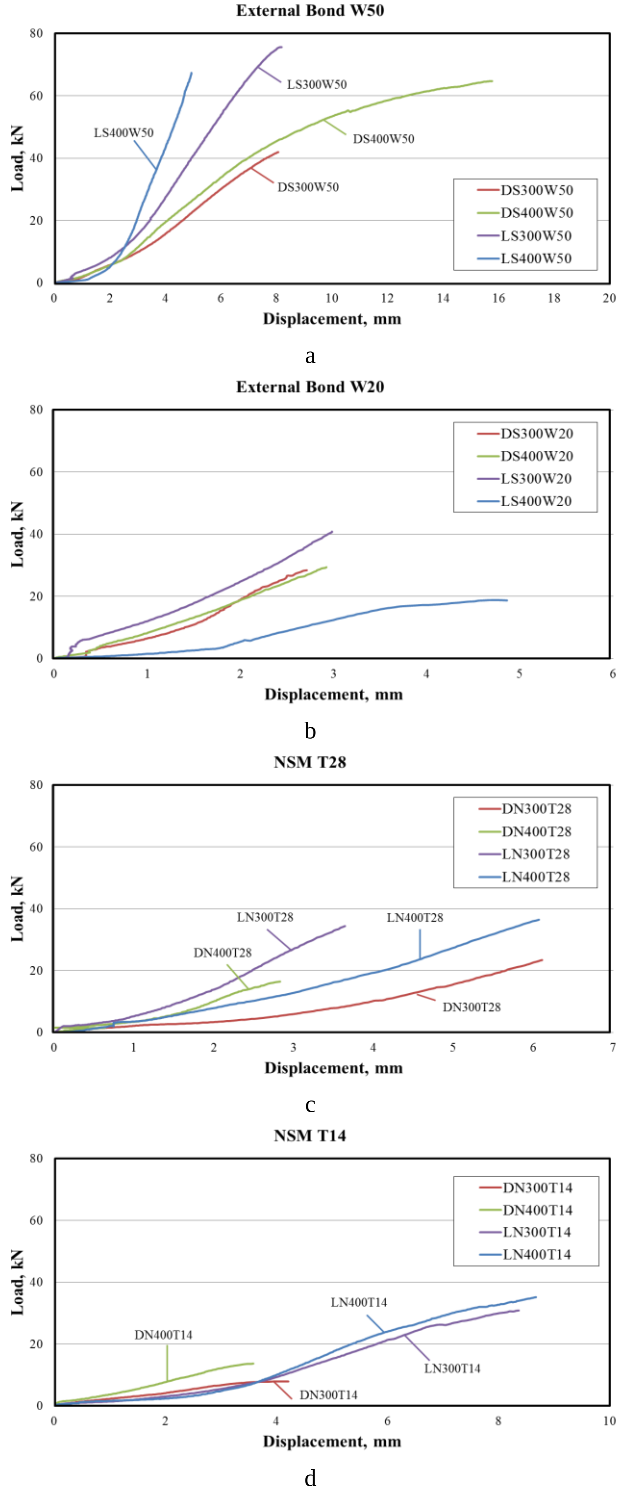
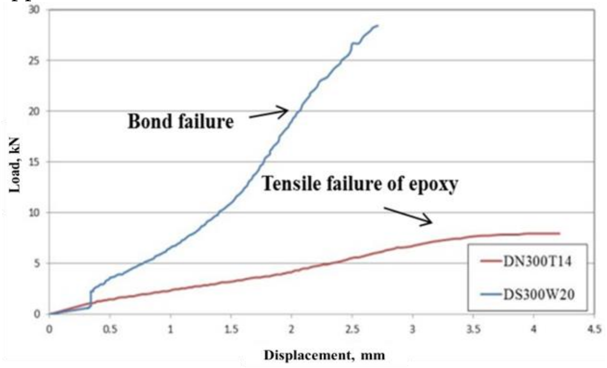


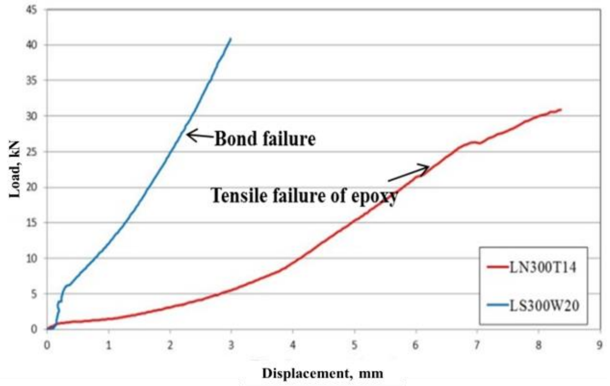
Fig. 4. Load-deformation curve: a – EBR – W50; b – EBR – W20; c – NSM – T28; d – NSM – T14

3.3. Bond strength

In the experimental data of Giulia Fava et al. [10], it can be seen that the adhesive strength increases as the bonding area is not increased. Therefore, determination of e the proper bond area at the time of reinforced design appears to be economical.



a



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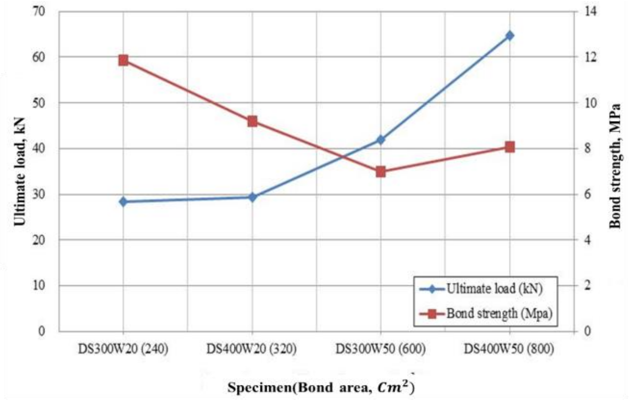

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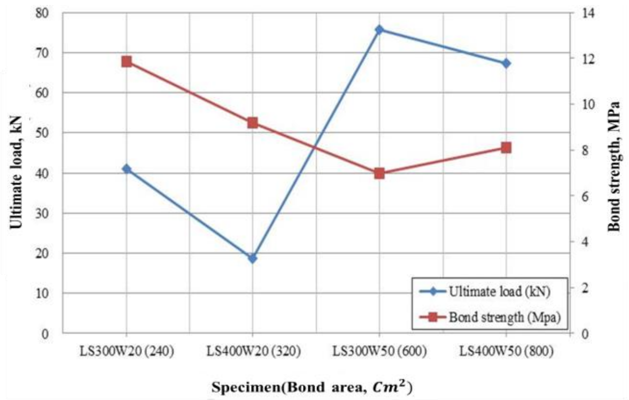

d

Fig. 5. Load-displacement curves of the EBR and NSM specimens and Ultimate load and bond strength of EBR specimens: a – EBR specimens; b – NSM specimens; c – DS series; d – LS series

Table 4, lists the relevant geometric dimensions and test results as ultimate load, bond strength, bond area and failure mode. When comparing of bond strength between two methods (EBR, NSM), the specimens reinforced by NSM showed lower bond capacity relatively because their bond strength was decided by tensile failure of epoxy, unlike specimens of EBR that failed in bond failure as shown in Fig. 5 a and b. Fig. 5 c and d, shows ultimate load and bond strength pattern by increase of bond area. As for bond strength according to increase of bond area, except for LS400W20, the ultimate load of specimens has increased with increase of bond area regardless of timber material. However, bond strength has a tendency to decrease despite to increase of bond area. Based on the test results, it can be deduced that the load doesn't transfer whole area of the member.

Table 4. Comparison of test results between EBR and NSM

NSM					Bond strength ratio P_{EBR} / P_{NSM}
Specimen	Ultimate load, kN	Bond strength P_{NSM}, MPa	Failure mode	Bond area, cm^2	
DN300T14	7.95	3.10	T	256.8	
LN300T14	30.90	12.03	T	256.8	
EBR					
Specimen	Ultimate load, kN	Bond strength P_{EBR}, MPa	Failure mode	Bond area, cm^2	
DS300W20	28.45	11.85	B	240	3.82
LS300W20	40.91	17.05	B	240	1.42

4. CONCLUSIONS

In this study, CFRP plate was used for strengthening of timber structure using EBR and NSM methods, bond length, and thickness and width of CFRP plate as variables. The results of the experiment on bond strength for pine and glulam species are as follows.

1. When the two species were compared in EBR method, maximum resistance of pine was 64.75 kN in specimen no. 2 with largest bond area, and maximum resistance of glulam was 75.64 kN in specimen no. 5.
2. As a result of comparing bond strength of EBR and NSM methods according to species, mean bond strength was 9.04 MPa for EBR pine, 10.99 MPa for EBR glulam, 4.89 MPa for NSM pine and 11.23 MPa for NSM glulam. Compared to pine, glulam showed higher bond strength for both methods, respectively by 17.8 and 56.4 %.
3. In EBR method, both pine and glulam showed maximum bond strength of 11.85 and 17.05 MPa respectively at bond length of 300 mm and width of 20 mm. As for NSM method, maximum bond strength was respectively 6.43 and 12.58 MPa at bond length of 300 mm and thickness of 2.8 mm. Strength was found to reduce above certain bonding area.
4. As a result of the comparison on bond area ratio of the two methods, both species showed high strength in 300W20 series of NSM method compared to low bond area, verifying higher efficiency of NSM method compared to an area.

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REFERENCES

1. **Kang, M.H., Joo, S.J.** A Study on the Elements Affecting the Demand of Wooden House *Journal of AIK* 23 (1) 2007: pp. 21 – 27.
2. KBC, "KBC Wood Design Manual", 2008.
3. **An, J.H.** Flexural Strengthening Effect of Deteriorated through Crack Timber Beam Strengthened by Various Methods Using Synthetic Resin *Journal of AIK* 14 (3) 2012: pp. 221 – 227.
4. **Garden, H.N., Hollaway, L.C.** An Experimental Study of the Failure Modes of Reinforced Concrete Beams Strengthened with Pre-Stressed Carbon Composite Plates *Composites Part B* 1998: pp. 411 – 424. http://dx.doi.org/10.1016/S1359-8368(97)00043-7
5. **Wu, Z., Matsuzaki, T., Yokoyama, K., Kanda, T.** Retrofitting Method for Reinforced Concrete Structures With Externally Prestressed Carbon Fiber Sheets *Procceedings of 4th International Symposium on Fiber Reinforced Polymer Reinforcement for Reinforced Concrete Structures* 1999: pp.751 – 765.
6. **Barros, J.A.O., Dias, S.J.E.** Surface Mounted CFRP Laminates for Shear Strengthening of Concrete Beams *Cement & Concrete Composites* 28 2006: pp. 276 – 292.
7. **Nanni, A., Di Ludovico, M., Parretti, R.** Shear Strengthening of PC Bridge with NSM CFRP Rectangular Bars *Advanced Structure Engineering* 7 (4) 2004: pp. 97 – 109. http://dx.doi.org/10.1260/1369433041653570
8. **Guenaneche, B., Tounsi, A., Bedia, E.A.A.** Effect of Shear Deformation on Interfacial Stress Analysis in Plated Beams Under Arbitrary Loading *International Journal of Adhesion and Adhesives* 48 2014: pp.1 – 13.
9. **Kror, B., Bernard, F., Tounsi, A.** Fibers Orientation Optimization for Concrete Beam Strengthened with a CFRP Bonded Plate: A Coupled Analytical–Numerical Investigation *Engineering Structures* 56 2013: pp.218 – 227.
10. **Fava, G., Carvelli, V., Poggi, C.** Pull-out Strength of Glued-In FRP Plates Bonded in Glulam *Construction and Building Materials* 43 2013: pp. 362 – 371. http://dx.doi.org/10.1016/j.conbuildmat.2013.02.035
11. **Juvandes, L.F.P., Barbosa, R.M.T.,** Bond Analysis of Timber Structures Strengthened with FRP Systems *STRAIN an International Journal for Experimental Mechanics* 48 2012: pp. 124 – 135.
12. **D'Ambrisi, A., Focacci, F., Luciano, R.** Experimental Investigation on Flexural Behaviour of Timber Beams Repaired with CFRP Plates *Composite Structures* 108 2014: pp. 720 – 728. http://dx.doi.org/10.1016/j.compstruct.2013.10.005
13. **Kwon, K.H., Yu, H.R., Lee, J.H., Choi, M.S.** A Study on the Flexural Capacity of Reinforced Timber Beams with the Inserting Method of CFRP Plates *Journal of the Korean Society of Hazard Mitigation* 8 (1) 2008 pp. 1 – 7.
14. KBC "Korea Building Code – Structural" 2009.
15. ASTM International, "Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials". ASTM D 3039.
16. Korean Agency for Technology and Standards, "Cement mixed siliceous power waterproof coatings", KS F 4918: 2008.
17. ASTM International "Standard Test Method for Bond Strength of Epoxy-Resin Systems Used with Concrete by Slant Shear" ASTM C 882: 2013.
18. Korean Agency for Technology and Standards, "Test method for polymer-modified mortar", KS F 2476: 2007.
19. ASTM International, "Standard Test Methods for Compressive Strength of Chemical-Resistant Mortars, Grouts, Monolithic Surfacings, and Polymer Concretes", ASTM C 579: 2012.
20. ASTM International, "Standard Test Method for Flexural Strength of Concrete (Using Simple Beam with Center-Point Loading)", ASTM C 293: 2010.
21. ASTM International, "Standard Test Method for Rubber Property—Durometer Hardness", ASTM D 2240: 2010.
22. Korean Agency for Technology and Standards, "Method of compression test for wood", KS F 2206: 2004.
23. ASTM International, "Standard Test Methods of Static Tests of Lumber in Structural Sizes", ASTM D 198: 2013.
24. Korean Agency for Technology and Standards, "Determination of moisture content of wood", KS F 2199: 2001.
25. ASTM International, "Standard Test Methods for Direct Moisture Content Measurement of Wood and Wood-Base Materials", ASTM D 4442: 2007.
26. **Park, S.M., Lee, J.K.,** A Study on the Flexural Capacity of Deteriorated Circular Section Wood using Synthetic Resins *Journal of AIK* 26 (8) 2010: pp.47 – 54.