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Shear Performance of Wood-Concrete Composite II*[1]

- Shear Performance with Different Anchorage Length of Steel Rebar in Concrete -

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ABSTRACT

Wood and concrete show significantly different physical properties, and it need to be firstly understood for using wood-concrete composite. This study is performed for compensating this and effective hybridization of wood and concrete. This research in planned for wood-concrete composite after previous research which deals the shear performance with different anchorage length of steel rebar in wood. Yield mode and reference design value (Z) were derived using EYM (European Yield Model). And the yield mode changed before and after anchorage length of 10～15 mm - I_s mode to IV mode. There was not increasing tendency of shear performance with increased anchorage length for over 20 mm of anchorage in concrete. And wood composite shows 65% and 93% on initial stiffness and yield load respectively compared with the wood-concrete composite. Wood-concrete composite showed brittle failure after yield point while wood-to-wood composite showed ductile failure.

Keywords : wood-concrete composite, shear performance, EYM, steel rebar, anchorage

1. INTRODUCTION

High composite action between members is one of the most important concern to design the wood-concrete hybrid system including the timber bridge (Yeah *et al*., 2011; Lee *et al*., 2012). Researches on the timber bridge have been widely conducted in European countries and Northern America. After 1930's, timber bridges started to be studied and to be constructed. Several experimental approaches which deal with the composite action between wood and concrete member have been performed. Ritter (1990) and Jutila and Salokangas (2010) pointed out that wood-concrete hybrid system can be effectively applied for the timber bridge even the fully-composite action is difficult to be achieved.

Additional researches for concerning high composite action have been tried after 1960's. They can be devided into three approaches - making notches at wooden part, inserting steel rebar or plate in wood and concrete and using the glue (An *et al*., 2008; Gutkowski *et al*., 2008; Balogh *et al*., 2010; Bathon and Bletz-Muhldorfer, 2010). The durability as well as the structural safety also have been studied (Nunes

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Table 1. Mix properties of concrete

Design strength (MPa)	Slump (mm)	W/C (%)	Mixture (kg/m^3)					
			C	W	S	G	Air (%)	Admix.
21	120	53.8	261	165	902	902	4.5 ± 1.5	2.92

Fig. 1. Wood-concrete composite.

Fig. 2. Compression test of concrete.

and Carlito, 2008). It was found out from these researches that the wood-concrete hybrid system can be effectively applied for the timber superstructure however the concept of the fully-composite action still remains main concern for using wood-concrete composites.

There is little approach for using wood-concrete composite system in Korea, moreover there is no wooden bridge for vehicle and written specifications and/or standard for constructing the wooden bridge. This makes it difficult to concern recent rising concern about structural usage of wood and wooden culture in Korea. Therefore, this study was planned for concerning the structural performance of wood-concrete composite. The shear performance with different anchorage length in wood (Lee *et al.*, 2012) was firstly studied and the shear performance with different anchorage length in concrete was tried to be studied in this paper. After the prediction with EYM (European Yield Model), comparison study was conducted between wood and concrete members.

2. MATERIALS and METHODS

2.1. Materials

The species of wood for manufacturing the wood-concrete composite was *pinus koraiensis* Sieb. and moisture content and oven-dried density were 13.5 ± 2.04% and 0.43 ± 0.04 g/cm^3 respectively. The shape and size of the wood-concrete composite (Fig. 1) were referred to previous research (Jurita and Salokangas, 2010;

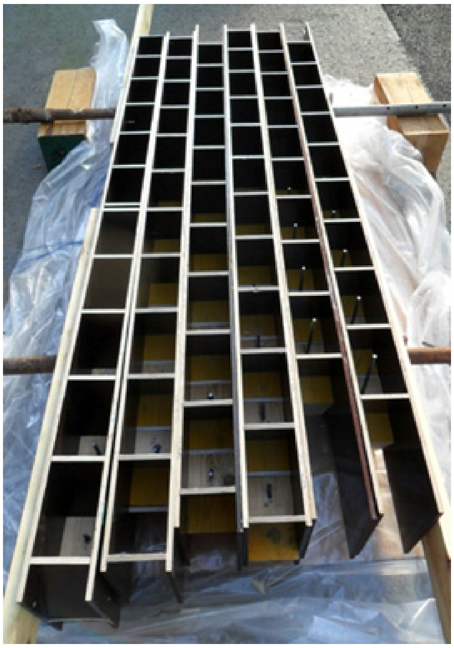


Fig. 3. Specimens after form work.

Fig. 5. Specimens on curing.

Fig. 4. Specimens after concrete pouring.

Lee *et al*., 2012). While anchorage length of steel rebar in wood fixed to 180 mm, anchorage length in concrete differed with eight steps (20, 40, ⋯, 160 mm). Eight wood-concrete composites were used for this study.

2 m^3 of ready-mixed concrete which was made by Korean standard (KSF 4009) was used for concrete material. Table 1 shows the mix properties of concrete which's design strength targeted to 21 MPa. The concrete was cured in shady place about 28 days and the compressive strength after the curing shows 20.1 MPa (Fig. 2).

2.2. Manufacture of the Wood-concrete Composites

After anchoring of steel rebar in wood with eight different length, form work for making concrete part was performed (Fig. 3). FIS V 360S chemical anchor (Fischer co., ltd., Germany)

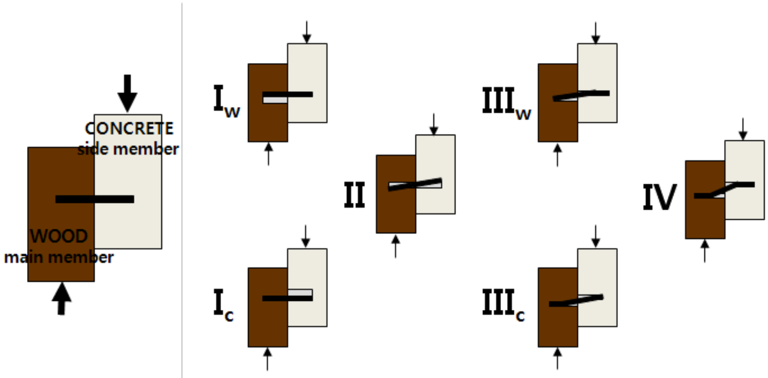


Fig. 6. EYM of wood-concrete composite.

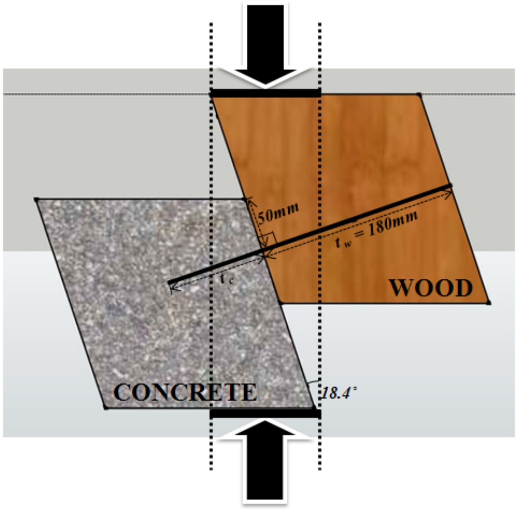


Fig. 7. Schematic View of Specimen on Shear Test.

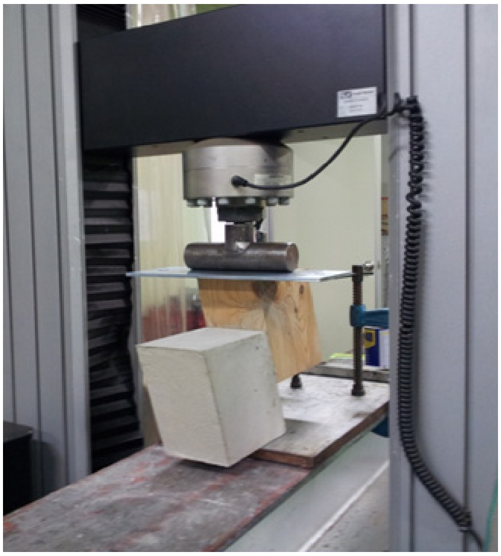


Fig. 8. Shear Test.

was used for anchoring steel rebar in wood and form work was done after two days of curing the chemical anchor. Fig. 4 shows the specimens after pouring ready-mixed concrete and concrete part was cured in shady place about three days. After removing the form, each specimens were additionally cured about twenty five days.

2.3. Evaluation of the Shear Performance

2.3.1. Prediction of Shear Performance with EYM

EYM was applied for prediction of shear performance of wood-concrete composite. Reference design value(Z)s were derived from each

Table 2. Results of EYM due to anchorage length of steel rebar in concrete (Unit : N)

Anchorage Length in Concrete (mm)	Yield Mode				Determined Yield Mode	Reference Design Value (Z)
	I_s	II	III_s	IV		
5	**2,100**	38,477	11,708	5,945	I_s	2,100
10	**4,200**	39,544	16,246	5,945	I_s	4,200
15	6,300	40,685	19,630	**5,945**	IV	5,945
20	8,400	41,897	22,429	**5,945**	IV	5,945
40	16,800	47,402	30,841	**5,945**	IV	5,945
60	25,200	53,838	37,145	**5,945**	IV	5,945
80	33,600	61,053	42,425	**5,945**	IV	5,945

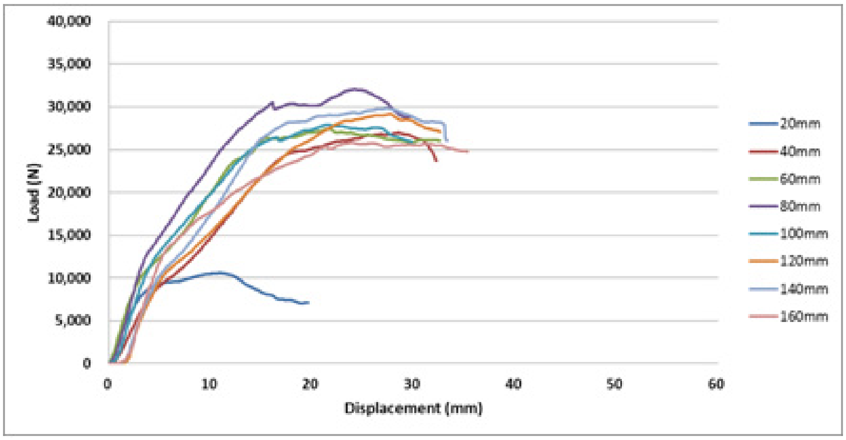


Fig. 9. Load-displacement curves.

determined yield mode.

As the material properties, the embedding strength of wood and concrete materials (Few, Fec) was determined to 31.6 MPa and 42 MPa (KBC Wood Design Manual, 2008) and the yield strength of steel rebar (F_{yb}) was determined to 294 MPa as the property of SD30A steel rebar. Wooden part was assumed as the main member and concrete part was assumed as the side member. While the anchorage length of steel rebar in wood (t_w) was fixed to 180 mm, EYM results were derived with seven steps of anchorage length (t_c) in concrete.

2.3.2. Shear Test

Universal Testing Machine (UTM) (Instron, co., ltd, USA) was used for shear test (Figs. 7, 8). The testing procedure was referred to previous research (Lee *et. al*., 2012).

3. RESULTS and DISCUSSIONS

3.1. Prediction of Yield Mode and Reference Design Value(Z)

Table 2 shows results of EYM due to anchorage length of steel rebar in concrete member.

Table 3. Shear performance of wood-concrete composites due to anchorage length in concrete

Anchorage Length in Concrete (mm)	Initial Stiffness (kN/mm)	Yield Load (N)	Maximum Load (N)
20	2.5	7,527	10,602
40	2.7	7,956	26,985
60	3.2	9,652	27,403
80	2.9	11,728	32,055
100	2.6	10,558	27,869
120	2.0	9,808	29,148
140	2.0	10,144	29,802
160	2.4	11,956	25,807

Below 10 mm of anchorage, minimum yield loads were calculated at I_s mode which makes bearing failure at concrete. And the reference design values at anchorage length of 5 mm and 10 mm derived 2,100 N and 4,200 N respectively. IV mode which makes plastic hinge at shear plane was derived over 15 mm of anchorage. And the reference design value was calculated to 5,945 N.

Results show similar tendency with previous research (Lee *et. al.*, 2012) which applies the wood-to-wood composite. Yield mode was changed from I_s mode to IV mode at 15～20 mm and 10～15 mm of anchorage length for wood and concrete side member respectively. At IV yield mode, reference design values show 5,565 N and 5,945 N respectively for wood-to-wood and wood-to-concrete composites. Reference design value at IV mode of wood-to-wood composite shows about 94% of wood-to-concrete composite even the embedding strength of wood (31.6 MPa) is about 75% of concrete (42 MPa).

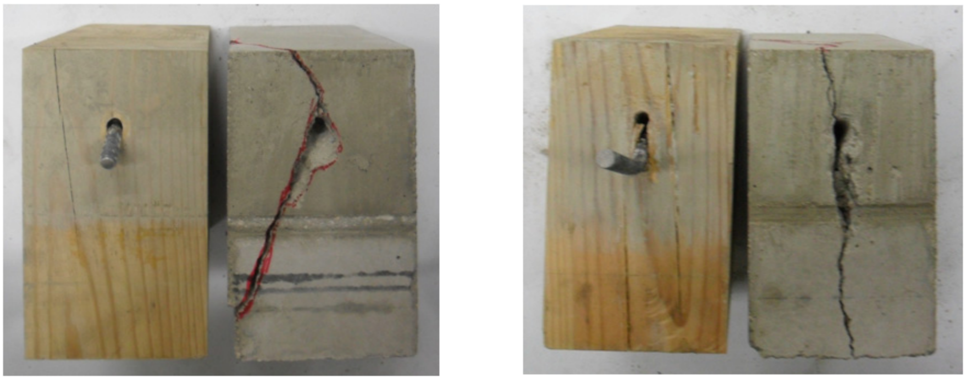
3.2. Shear Performance

Fig. 9 shows the load-displacement curves for tested wood-concrete composite and table 3 shows derived shear performance with initial stiffness, yield load and maximum load. Initial stiffness and yield load show 2.54 ± 0.42 kN/mm and 7,932 ± 1,266 N respectively for the eight tested wood-concrete composites. Results at 20 mm and 40 mm of anchorage show a little bit smaller values, however there was not increasing tendency with increment of the anchorage length. It is considered that all specimens yield samely in IV mode as predicted with EYM. In the case of maximum load, there was no increasing tendency with increment of the anchorage length except composite with anchorage of 20 mm which shows pullout failure of inserted steel rebar.

Table 4. Comparison of shear performance between wood-to-wood and wood-to-concrete composites

	Initial Stiffness (kN/mm)	Yield Load (N)
Wood-to-wood composite (Lee *et. al.*, 2012)	1.63 ± 0.19	7,527 ± 778
Wood-to-concrete composite	2.54 ± 0.42	7,956 ± 1,266

Table 4 shows comparison of shear performance with initial stiffness and yield load between wood-to-wood and wood-to-concrete composites. Results of wood-to-wood composite re



(a) 20 mm anchorage (b) 100 mm anchorage

Fig. 10. Photographs after shear failure of wood-concrete composites.

fers to previous work (Lee *et. al.*, 2012). Same with the result of wood-concrete composite, there was no increasing tendency of initial stiffness and yield load with increment of anchorage length of steel rebar in wood-to-wood composite. Average initial stiffness and yield load of wood-to-wood composite shows about 65% and 93% than those of wood-concrete composite. Reference design values of wood-to-wood and wood-to-concrete composites calculated to 5,565 N and 5,945 N respectively, and actual yield loads showed about 130% of there values.

3.3. Shear Failure

Fig. 10 shows photographs after failure of tested wood-concrete composites at 20 mm and 100 mm of anchorage. After the yield load, local part around steel rebar at concrete part pulled out with steel rebar in the case of 20 mm of anchorage (Fig. 10(a)). However, there was not pull out failure over 40 mm of anchorage and brittle failure of concrete occurred different from the wood-to-wood composite (Lee *et. al.*, 2012). Concrete cracked along the loading direction as confirmed from Fig. 10(b). And bending of steel rebar also can be confirmed which indicates the plastic hinge at the shear plane.

4. CONCLUSIONS

This study was performed for evaluation of wood-concrete composite with different anchorage length of inserted steel rebar. Results were compared with previous work (Lee *et. al.*, 2012) which dealt with the wood-to-wood composite. EYM was applied as the preliminary prediction and mode conversion from I_s mode to IV mode occurred before and after anchorage length of 10～15 mm which is about 5 mm shorter anchorage length then the wood-to-wood composite.

There was not increasing tendency of shear performance with increment of anchorage length from 20 to 160 mm in concrete. Initial stiffness and yield load show 2.54 ± 0.42 kN/mm and 7,932 ± 1,266 N respectively and those of wood-to-composite were about 65% and 93%. Actual yield loads derived from shear test showed around 130% of reference design value(Z)s from EYM for wood-to-wood and wood-to-concrete composites. Wood-concrete composite showed brittle failure after the yield point while wood-to-wood composite showed ductile failure.

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