東京理科大学「火災安全科学研究拠点」

Tokyo University of Science “Research Center for Fire Safety Science”

■研究成果概要報告書 / Report for Outline of Research Results

研 究 課 題 Research Topic		Basic Research and Development of Fire-Resistive Hybrid Beams (T-CS Beam)	実 施 年 度 平成 26 年度
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１．研究の背景および目的 / Background and Aim of Research

Sawn-Timber, Glulam and CLT are among of the most important industrial products in Austria. In recent years, several multi-story buildings up to 10-stories have been built in EU and Oceania by timber panels supplied from Austria. These timber products are considered as highly sustainable material and can be used for large urban buildings. Nevertheless, it is difficult to use timber structures in city center of our own country because of expensiveness of material and cost for coverings to fulfill strict fire regulation. We intend to develop Hybrid T-CS post and beam structure (incl. CLT floor) from the viewpoints of efficient material combination both for structural and fire behavior with reasonable cost. T-CS beam is composed by glulam and 3 to 4 mm thin cold-formed-steel. For load transmission, timber and steel parts work together, and even after timber parts fails under the tension, they prevent buckling of the steel parts. In case of fire, timber elements protect steel parts from over heating.

This T-CS beam is in the experimental stage had been tested under short- and long-term loads. For the next step, we want to optimize the profile combination to obtain less deformation, and better performance under fire than pure timber or steel beams. Therefore we need to have basic experiments on fire resistiveness of components and their combination.

２．利用施設及び利用日 / Facility and Schedule

・ Middle-sized furnace (26th to 31st March 2015)

３．実験方法・研究成果、および考察（申請時の計画に対する達成度合いも含む）
※継続課題の場合は，前年度との関係性，進展度合いについても記載すること。
/ Method, results, and conclusions (degree of achievement compare to application)

3.1 Specimens

Three types of test pieces were prepared. Combinations of timber, steel, and mortar for each type are illustrated in Figure 1.

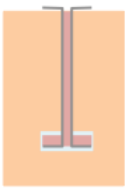
Type of Combination (Abbreviation)		Timber (T)	Timber & Steel (TS)	Timber & Steel & Mortal (TSM)
Number of Pieces (Spurs)		2	2	2
Observed Parameter	Charring	✓	✓	✓
	Thermal mass (Steel)		✓	✓
	Thermal mass (Mortal)			✓
Diagrams	Notes: Timber part, Steel part, Mortal, Gap (Air)			

Figure 1: Type of Test Pieces

Important aspects of material selection for this common development are “availability of purchase in Japan” and “simple production with standard (or reasonable cost) profiles”. Thus, spruce is selected as common species because that is available to purchase both EU countries and in Japan. Compounded standard timber profiles (maximum 120 mm width and 450 mm height) are used for the timber part of the test pieces.

3 mm clod-formed steel is used for the steel part. The thickness is decided from three different points*, availability of purchase, cost benefit (direct and indirect), and thermal behavior.

Standard ready-made mortar-based boards are used for mortar parts. The ready-made board has less density than normal and can be cut by handsaw.

Length of test pieces is 1 m. The length was decided for handling of test pieces during manual trial productions.

* We discussed about choice of thickness between 3 mm or 4 mm.
Availability of purchase: It took a long time to find out a factory, which can produce same profiles for load bearing tests.
Cost benefit: In Europe, resource efficiency (less amount of steel) nearly equal to cost efficiency. Nevertheless, it cannot be truth in Japan because standard steel profiles are cheaper in Japan compare to Europe. In Japan, special order with less material can be far more expensive than standard products with more material. Therefore tax category is considered for indirect cost benefit. Structure with thinner steel is classified into immovable with shorter tax durable year. According to former case studies, shorter tax durable year can be indirect cost benefit. At this point less than 3 mm is an important factor.
Thermal behavior: Less thickness of steel (= less thermal mass) is on the severe side of fire test condition and on the safe side of test results.
We need to have further discussions about steel profiles. (E.g. Logistics, distributions of size, etc.)

3.2 Settings and Method

6 test pieces are tested in 3 days. (See Table 1.)

In each test, two test pieces are burnt for 90 minutes with ISO 834 heating curve in the middle-sized furnace without load bearing. After 90 minutes heating, the test pieces observed in the furnace for 150 minutes to precise thermal analysis. "R 90 (+ K 60*)" is the fire scenario of this series of tests. The R 90 is a category of European clarification for fire resistance. In direct translation, R 90 means equivalent to Japanese 90 minutes quasi-fire-resistance (=90 分準耐火).

The test pieces were placed upside down on the floor of the furnace to avoid accidents from falling of test pieces because the performance of spurs based timber-steel hybrid structure was unknown.

Table 1: List of Tests and Results

Abbreviations: T, TS, and TSM (See Figure 1) / A-test piece No. 1, B- test piece No. 2

Test	Test Pieces	Testing Time (+ Observation)	Extra time for Extinguishing	Visual Observation	Temperature Measurement
No. 1 26. Mar. 2015	TA (Left)	90 min (+150 min)	30 to 60 min	[]	-
	TSMA (Right)			[]	-
No. 2 30. Mar. 2015	TSA (Left)	90 min (+150 min)	20 to 30 min	[]	-
	TB (Right)			[]	-
No. 3 31. Mar. 2015	TSB (Left)	90 min (+150 min)	10 to 20 min	[]	[]
	TSMB (Right)			[]	[]

*About K60: We do not have clear conclusion about "how to define K 60?"
K 60 is one of criteria for timber structures in German speaking countries. For qualification of K 60, test pieces are heated under same condition as Japanese quasi-fire-resistance (QFR, 準耐火) and criteria for timber surface is same as Japanese fire-resistance (FR, 耐火). (In case of fire test for K 60, test piece is burnt for 60 minutes and cooled down immediately. Criteria after heating time are "without brawn color on the timber surface".)
According to the test method, K 60 is more similar to QFR than FR. Because test method for K is on the assumption of active extinguishment (fire fighting) after certain heating time. In other hand, test method for FR is on the assumption of self-extinguishment (without fire fighting after big earthquake).

3.3 Results

- By Visual Observation

TA & TB: Deeper charring depth was observed in the direction of height of beam compare to direction of width (= parallel to glue line). The differences of depth seem related to deep cracks (through two to three laminas) perpendicular to glue lines.

TSB & TSMB: Remaining areas of timber sections were similar to each other. Nevertheless, TSMB kept more healthy timber edges, which touch to bottom flanges. The healthy timber edges will work positively for load bearing behavior.

TSA & TSMA: Both test pieces caught direct fire from burners and got heavier damage

compare to TSB and TSMB. In comparison of TSA and TSMA, TSMA remained more areas of timber sections. In this case, intermediate mortal layer between steel webs worked as a safety factor.

- By Temperature Measurement (TSB & TSMB)

We confirmed equivalent performance of R90 of the steel part even with less amount of steel than best amount for load bearing capacity (= safe side of the fire test). All the measuring points on steel profiles kept under 200 degrees. The most critical point of timber part (, where is expected to work for load bearing capacity) kept below 250 degree. We observed long constant temperature around 100 degrees at some measurement points in TSMB. The constant temperature seems to be caused by the latent heat of mortar part. Further detail of these thermal conditions are going be analyzed in the future.

3.4 Achievement

- About Discussions / 50%

Concerning fire scenario, we discussed about potential of R 90 as a common issue in Japan and Austria. (70 to 80%) Nevertheless, we did not have to discuss about detailed criteria of timber-steel hybrid for K 60 in Austria. (20 to 30%)

- About Experiments / 50 to 60%

We could measure sufficient data for thermal analysis; even we suffered measurement trouble caused by short circuit of thermo-couples.

Unfortunately, we had to reduce the planned number of test pieces because of certain accident.

3.5 Attached documents

Detailed discussions are described in attached documents.

(1) Background discussions on settings of T-CS fire tests and overview of results

(2) Pre-design thermal analysis

(3) Summarized results of load-bearing capacity tests

４．今後の展望（今後の発展性，見込み等についても記述）／ Future Perspectives

- Common fire scenario and load bearing capacity before and after fire will be discussed.
- Definition of K60 for hybrid structure will be discussed.
- The fire tests for T-CS beam were supported by Japanese collaborators associated with universities, an architects' office in Japan, and a timber product company. The possibility of development of the structure will be discussed among collaborators.

５．成果の公表状況（学会への発表，学術誌への投稿等を記述。予定も含む）
/ Publishing (presentation, paper, etc. incl. plans in the future)

World Conference on Timber Engineering 2016 (submission of abstract Sep. 2015)

６．経費の使用状況 / Usage of Budget

Consumables and Personal Expenses	
Contents	Cost
Thermo-couples, insulation of test pieces, and operations of tests	Yen 837,216 -
Subtotal	Yen 837,216 -
Burden of Tokyo University of Science / Total Yen 497,124-	
Burden of Vienna University of Technology / Total Yen 340,092-	

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