Experimental Tests of Composite Material Used for Compression Joints in Thermal Bridge Breaker Systems

Hyung-Joon Kim, Kyung-Suk Choi, and Dong-Hyeon Shin

***Abstract*—It is important to eliminate thermal bridge for achieving passive and environmental-friendly buildings. Structural members may frequently act as thermal bridges that become a conduit of energy. A thermal bridge breaker (TBB) system is effective to reduce energy transfer between inside and outside of a building. In order to be used for a structural member, the structural capacity of a TBB system should be larger than a demand resulting from external loads. This study concentrated on the development of a TBB system that will be applicable to connection between interior and exterior floors. The developed TBB system consists of anchorage devices and compression joints. The anchorage devices are used to ensure the continuity of reinforcements in inside and outside floors while the compression joints are used to resist compression stress occurring to the TBB system. Significantly high compressive stresses are usually applied to the compression joints since they are designed with relatively small section areas. This study carried out compressive tests of composite material which is developed to be used for compression joints in a TBB system. Based on test results, TBB systems are designed for the application of a typical floor system.**

***Index Terms*—Thermal bridge breakers, compression joints, composite material, compressive tests.**

I. Introduction

It is important to eliminate thermal bridge for achieving passive and environmental-friendly buildings which construction markets increasingly pay attention to. Thermal bridge breaker (TBB) systems are applied to reduce energy transfer between inside and outside of a building [1] and their structural capacity should be larger than a demand resulting from external loads in order to be used for a structural member. A TBB system usually consists of anchorage devices and compression joints and is used as a connection between interior and exterior floors.[2] With regard to the development of a new TBB system, this study carried out compressive tests of composite material which is developed to be used for its compression joints. Based on test results, a TBB system is designed for the practical application of a typical floor system.

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The authors are with the Department of Architectural engineering, University of Seoul, Korea (e-mail: thymos19@gmail.com)

II. Experimental Investigation

A. Experimental Specimen Description

Three square-shaped specimens with the dimension of Φ 50mm × 80 mm and three rectangular-shaped specimens with the dimension of 40mm × 40mm × 80 mm were prepared for a compressive testing program. The test specimens were made of Epoxy compounds that are mainly composed of liquidity epoxy mortar, fly-ash and silica. The mix proportion of Epoxy compound is summarized in Table I. Aggregate is mixed after compounding main material with hardener.

B. Set-up and Experimental Program

The specimen was loaded until the failure mode was observed under monotonically uniaxial compression. Strain gauges were attached at the mid-height of the specimen to measure axial strains, Poisson's ratios and volumetric strains. All specimens were tested 28 days after pouring of the epoxy compounds.

TABLE I: Mix Proportion of Compressive Joint Material

(A) Main Material

Material	Sphenol Epoxy	Reactive diluent	TiO_2 Base	Deformer	Dispersant
Prop.(%)	86	5	8	0.5	0.5

(B) Hardener

Material	Alicyclic Amine	Unreactive Diluent	Accelerant
Prop.(%)	80	10	10

(C) Aggregate

Material	Flyash	Round Silica(2-3mm)	Silica Sand(0.5mm)
Prop.(%)	33.4	33.3	33.3

III. Experimental Results

A. Failure Modes

The specimens present nonlinear behavior characteristics depend on combination of each component of the epoxy compounds. The nonlinear behavior results from bond micro-cracks observed on the surface. The elastic modulus of the specimen was determined using the secant line connecting the origin and 0.45 times maximum strength (f_{ck}). [3] The yield strengths were measured as about 90 MPa for the square-shaped specimens and around 80 MPa for the rectangular-shaped specimens. Diagonal cracks shown in Fig. 2(a) for the square-shaped specimens was observed at the failure stage while splitting failure mode was developed at the rectangular-shaped specimens presented in Fig. 2(b).

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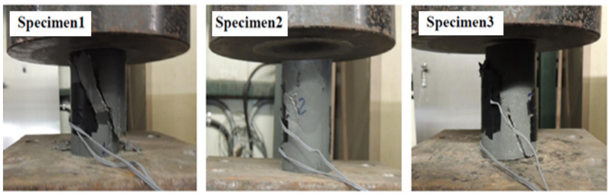
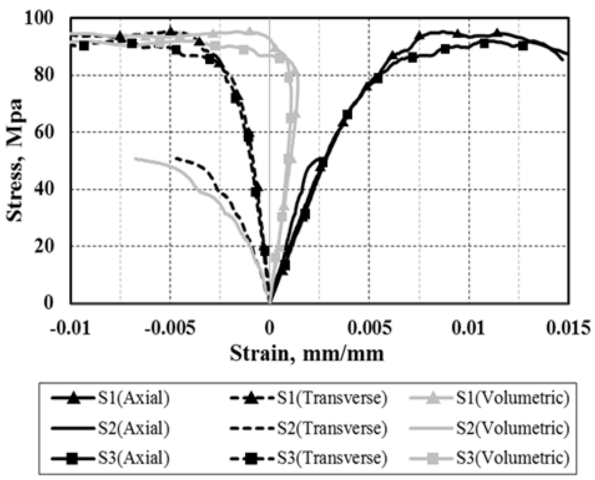


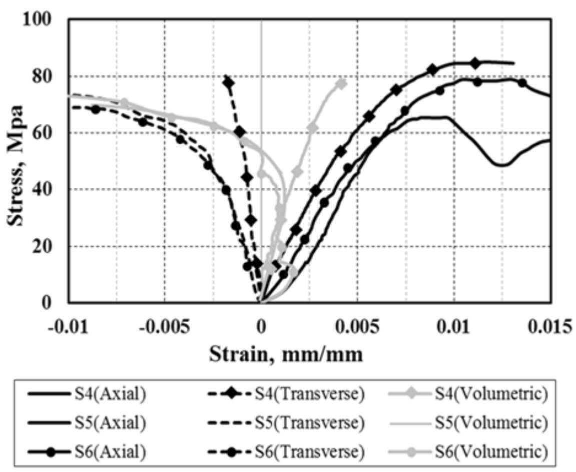
(a) Square-shaped Specimens

(b) Rectangular-shaped Specimens

Fig. 1. Failure mode of test specimen.



(a) Square-shaped Specimens



(b) Rectangular-shaped Specimens

Fig. 2. Variation of the Volumetric Strain.

TABLE II: RESULT OF THE EXPERIMENT

No	F_y (MPa)	E (MPa)	Poisson ratio (mm/mm)	Volumetric strain
1	95.2	17600	0.333	0.001
2	50.8	25200	-	-0.004
3	92.0	18000	0.300	0.001
4	85.0	13700	0.238	0.003
5	65.4	12700	0.381	0.001
6	78.8	12200	0.370	0.001

B. Stress-strain Response and Poisson's Ratios

The ultimate strains of the specimens are 3-4 times the ultimate strain, 0.003 of similar strength concrete, which causes in a higher ductility performance than concrete material. The elastic modulus ranges from 12 to 18GPa. From the Poisson's ratio presented in Table II, It is found that the composite material has homogeneity and isotropy characteristics. The Poisson's ratio of the specimens are 0.3~0.38 which is larger than that of the normal concrete, 0.2. The Poisson's ratios of the uniaxial- compressive specimens are considered under the linear-elastic area which means a section before occurring micro-crack[4][5]. The increase of ductility leads to more transverse extension strains than longitudinal contraction strains.

C. Volumetric Strains

Volumetric strain is developed in the positive direction and inflection point is shown in the range of 65-85% percent of maximum longitudinal contraction strain, then path of volumetric strain is changed to the negative direction after this inflection point [6]. In this study, the strains in the positive direction refer to the decease of total volume while the strains of negative direction mean the increase of total volume. This is due to the fact that fine discontinuity surfaces are occurred inside of the specimen after linear-elastic behavior. Four specimens of S1, S3, S5, S6 in six specimens were developed to have a inflection point on the upper level of stress-strain curves. The S2 specimen changes its volumetric strain in the negative direction. This is because transverse extension strain proportionally increases along with increase of axial compression force. A bearing failure occurred in upper part of this specimen and gives rise to ever-increasing of transverse extension, which results in the negative behavior in the point of volumetric strain. The S4 specimen was failed before the expected ultimate force. Its volumetric strain only changes in the positive direction and the total volume is ever-decreasing, which causes from eccentric loading during the test.

IV. TBB DESIGN WITH COMPRESSIVE JOINT

A TBB system should resist external loads such as bending moments and shear forces in order to be used as a structural member. The TBB system is composed with anchorage devices which obtain continuity between reinforcements placed in inside and outside structural floors, and compression joints which resist compression stresses. The anchorage devices resist to tension occurring upper part of element caused by bending of cantilever while the compression joints resist to compressive stress.

The compression joints are designed to meet the structural load capacities of existing similar prototype products. A 180 mm thick cantilever slab, as shown in Fig. 4, is generally used in Korea and its reinforcements presented in Fig. 3 are arranged with D13@150 mm spacing which is designed along with Korea Building Code 2009. [7] The connection between the cantilever slab and structural wall should resist to a bending moment of 31.5 kN·m and a shear force of 43 kN which is calculated by the prototype cantilever balcony slab. Compression and tension force which has relation with a couple of force is calculated by dividing required moment into distance between tensile rebar and compressive joint. In sequence, tensile rebar arrangement is decided by required area of rebar which is obtained from strength capacity of unit rebar. This process can be realized from (1).

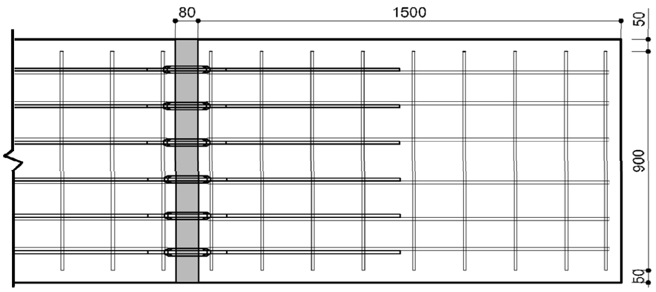


Fig. 3. Reinforcing detail regarding connection between rebar and TBB

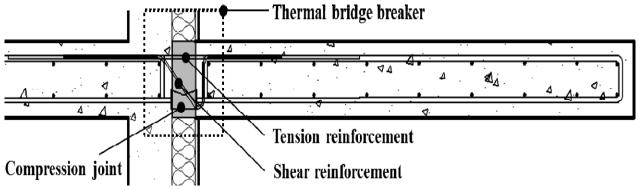


Fig. 4. Application TBB system to cantilever structure

$$A_s = \frac{M_u}{hf_y} \quad (1)$$

where,

A_s: area of tension rebar

h: distance between tension rebar and compression joint

In order to insert this thermal bridge breaker system into existing balcony slab during the construction work process, it is needed to match rebar arrangement of anchorage device with those of tensile rebar in balcony slab. In addition, reinforcing bar splice is also inevitably occurred because of this feature under construction work. So, anchorage device length is designed to having above this reinforcing bar splice length. 660mm calculated by (2) is determined as optimal length of anchorage steel bar of thermal bridge breaker.

$$l_{db} = \frac{0.6 d_b f_y}{\sqrt{f_{ck}}} \quad (2)$$

$$l_d = 0.8 \times \alpha \times \beta \times l_{db}$$

where,

l_{db}: basic development length of steel bar

l_d: development length of steel bar

α: position coefficient of rebar arrangement

β: epoxy coating coefficient

Fig. 5 shows a process of calculating required compression capacity of compression joint using internal force equilibrium condition. This process is abstracted like following. A depth of neutral axis is calculated by using relation between concrete strain of compressive surface part and strain of tensile rebar. And then, the strain which is corresponded to the location of compression joint inserted in the concrete covering is calculated. A stress strain curve of compression joint material is assumed as a parabola -rectangle shape according to the CEP-FIP specification[8] because it is considered that the stress-strain curve of compression joint material is not significantly different from that of common concrete through the experiment results. In this study, 50mm diameter of compression joint is determined by considering concrete covering and slab depth, and then compression strength of it is calculated by using (3).

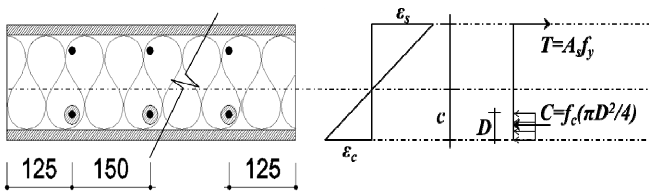


Fig. 5. Calculation of the Required Compressive Strength

$$c = \frac{\varepsilon_c}{\varepsilon_c + \varepsilon_s} d \quad (3)$$

$$\varepsilon_b = \frac{c - h_c}{c} \varepsilon_c$$

$$\int \sigma_c dx = 0.85 f_c \int \left| 2\left(\frac{\varepsilon_x}{\varepsilon_{c1}}\right) - \left(\frac{\varepsilon_x}{\varepsilon_{c1}}\right)^2 \right| dx + \int 0.85 f_c dx$$

$$C = b_c \int \sigma_c dx$$

$$f_c = \frac{A_s f_y}{0.85 b_c \int \left| 2\left(\frac{\varepsilon_x}{\varepsilon_{c1}}\right) - \left(\frac{\varepsilon_x}{\varepsilon_{c1}}\right)^2 + 1 \right| dx}$$

where,

ε_s: tensile strain in extreme layer of rebar

ε_c: maximum strain of compression joint (ε_{c1}: 0.002)

f_c: compression strength of compression joint

f_y: yield strength of rebar

c : distance from extreme compression part to neutral axis

b_c: slab cross sectional dimension of member

The required compressive capacity was decided along with tension capacity in the condition of design loads. The section area of the connection is calculated by considering a penetrative hole for placing of the reinforcements. Cylinder-shaped compression joints with ϕ50 mm diameter are considered and each rebar is assumed to be connecting to the corresponding compressive joint. Since the net area of a compressive joint is 1649.3mm^2, the required compressive strength of 60.1MPa is calculated to resist the compression force. It is found that the calculated compressive strength is satisfied with the experiment result of composite material. When compression force is transferred to existing balcony slab through high strength compression joint with small area, it is needed to consider bearing failure which can be occurred in concrete part of slab. Bearing strength of compression joint has 58.0kN in case of applying 6 compression joints with 13mm diameter penetrative hole and this is considered as safe design with regard to 52.5kN compression force occurred by required moment. At last, bearing stress of concrete slab which is calculated by (4) is more than compression force which can be supported by one unit compression joint block.

$$F = \phi(0.85 f_c \sqrt{\frac{A_2}{A_1}}) A_1 \quad (4)$$

A_1: loaded area of contact surface

A_2: area of pyramid having for its upper base the loaded area and having side slopes of 1 vertical to 2 horizontal

Balcony slab applying thermal bridge breaker system requires additional structural element which can support shear strength by comparison with existing slab which can effectively resist to the shear force due to shear capacity of concrete area. In case that one unit shear reinforcing steel is applied to certain area and *n* unit of reinforcing is inserted to one unit thermal bridge breaker system, determination of reinforcing area and number can be conducted by using (5). In other words, this diagonal shear reinforcing steel is designed to resist shear strength until its total cross area is preceded to yielding state. Finally, diagonal shear reinforcing is arranged with D10@250mm spacing in case of the prototype balcony slab.

$$V_s = F \sin\theta = n A_v f_y \sin\theta > V_u \quad (5)$$

where,

A_v: area of shear steel bar

V_s: shear strength of reinforcing steel

V_u: shear force due to external load

θ : inclined angle of reinforcing steel (θ =45°)

V. Conclusion

This paper makes an effort to develop an application and a design method of thermal bridge breaker to a typical floor system using experimental results of compression joints. It is found from the tests that Epoxy compounds presents high compressive strength and ductility performance. In designing A TBB system, both thermal breaker capacity and structural performance should be considered. For this reason, it is important to arrange structural member and thermal insulation material to meet both criteria. With this result, further experimental investigation of mock-up models is required to verify structural performance of TBB application.

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Hyung-Joon Kim was born in 1971 and currently lives in Seoul, Korea. He has received his PhD from the University of Toronto (2007). Then he worked as a post-doctoral fellow at there (2007~2008) and subsequently, served as Associate Professor at the University of Seoul (2009~Present).

Mr Kim has specialized in the development of high-performance aseismic structures, evaluation of seismic performance of existing building and development of nonlinear structural models to capture seismic response of structure. He has published refereed journal publication.

Kyung-Suk Choi was born in1983 and currently lives in Seoul, Korea. He has received his master's degree from the University of Seoul (2012) and currently works as researcher in the Structural Vibration Control System.

Mr. Choi is involved in some practical project like "Development of Seismic Design Procedure for Damped Structures", "Development of Effective Seismic Retrofit Methods for Typical Power Plant Steel Structures", "Development of Seismic Loss Estimation Methodologies and Systems" and "Development of Thermal Breaker systems".

Dong-Hyeon Shin was born in 1988 and currently lives in Seoul, Korea. He has received his Bachelor degree from the University of Seoul (2012) and currently works as researcher in the Structural Vibration Control System.

Mr. Shin is involved in the practical project; "Development of Seismic Loss Estimation Methodologies and Systems" and "Development of Thermal Breaker systems".