EXPERIMENTAL STUDY ON TENSILE CREEP BEHAVIOR OF ADHESIVELY BONDED JOINTS

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1. INTRODUCTION

Adhesively bonded joints have become more important as an alternative in joining components for repairing and strengthening steel structures instead of conventional methods such as welding, riveting, and bolting (JSCE ed. (2013)). However, because of the viscoelastic nature of adhesives, adhesively bonded structures exhibit time-dependent behavior when subjected to a constant load, known as the creep phenomenon. This paper aims to contribute to a better understanding of the creep behavior of the adhesively bonded joints by the tensile tests.

2. SPECIMENS AND MATERIALS

Fig. 1 shows the specimen of the adhesively bonded joints. It is the butt-bonded joints of the hollow cylindrical steel members based on JIS K 6868-1. The inner and outer diameters are 60 and 72 mm, respectively, giving the width of the bonded area of 6 mm. The creep tests are conducted following the static tensile tests. Material properties of steel and epoxy resin adhesive are given in Table 1. The epoxy resin adhesive used is Konishi E258R.

3. STATIC TENSILE TESTS

3.1 Test device

Fig. 2 shows the schematic view of the tensile test device. The device consists of a die set (precisely movable up and down), spacer, center hole hydraulic jack (capacity of 300 kN), nut, and bolt (M24). The die set is to fix and support the specimen. The space between the die set is fixed by inserting the steel plate spacers. The bolt is connected to the specimen, and tensile force is applied by the center hole hydraulic jack.

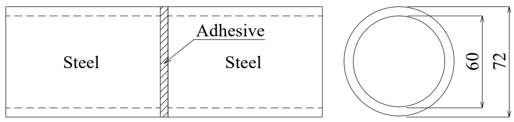

Fig. 1 Schematic view of the specimen (JIS K 6868-1)

3.2 Specimen preparation and experiment

The surfaces of steel are prepared by bristle blaster before bonded. After bonding, the specimens are cured at 40 °C for 24 hours. The adhesive thickness is controlled to be approximately 0.4 mm using glass beads. 13 specimens are prepared for the static tensile tests.

Table 1 Material properties

Materials	Elastic modulus E (GPa)	Poisson's ratio ν	Tensile Strength σ_{tu} (MPa)
Steel (S45C)	205	0.30	–
Adhesive (Konishi E258R)	3.6	0.34	33

3.3 Experimental results

Table 2 shows the experimental results of tensile tests. The average adhesive thickness is 0.49 mm. The average maximum load measured by the load cell is 45.5 kN (tensile strength σ_{tu}=36.5 MPa). The standard deviation is 6.4 kN, and the coefficient of variation is 0.140. The average of the maximum strain value of the adhesive layer obtained from strain gauge is 12,647×10^{-6} (SD=3,729×10^{-6}, CV=0.295). It should be noted that three specimens with adhesive failure mode are not included and considered in this result.

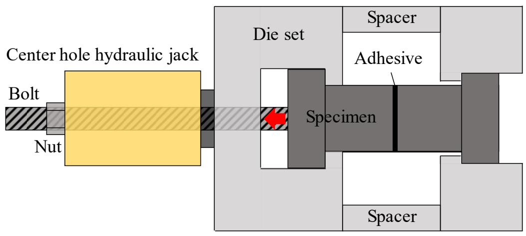

Fig. 2 Schematic view of the tensile test device

4. CREEP TESTS

4.1 Design and setup of creep test

Fig. 4 shows the design and setup of creep test. A lever beam balance, a well-known technique for creep test, is designed. The fulcrum is fixed to the basement roof by a PC steel rod (M36, tension by 377 kN). The length of the steel H-beam (300×300×10×15 mm) is 3,300 mm (2,000 mm to the weight side and up to 1,000 mm to the loading side). Six bearing units of square flange shape refueling type (ϕ80×6 units, the capacity of static load per unit: 86.5 kN). The weight of approximately 1.5 tonnes (15.2 kN) is attached to one side of the steel H-beam. Multi-eyebolt (M24) is used as a hinge on the weight side. On another side, the specimen is attached to the upper part through the universal joint (Kyowa, SC-50-00A) and load cell (capacity of 50 kN), and to the lower part of another steel H-beam (200×200×8×12 mm) through

Table 2 Experimental results

Specimen No.	Adhesive thickness t_e (mm)	Maximum load P_{max} (kN)	Tensile strength σ_{tu} (MPa)	Maximum strain (×10^{-6})
1	–	56.4	45.3	–
2	–	48.2	38.7	–
3	0.48	49.6	39.8	14,307
4	0.52	44.3	35.6	17,781
5	0.47	34.4	27.7	6,623
6	0.47	41.6	33.4	10,111
7	0.49	51.9	41.7	11,823
8	0.53	47.4	38.1	18,205
9	0.48	44.3	35.6	9,856
10	0.50	36.6	29.4	12,467
Average	**0.49**	**45.5**	**36.5**	**12,647**
SD	0.02	6.4	5.1	3,729
CV	0.043	0.140	0.140	0.295

Keywords: Creep behavior, Adhesive joint, Adhesive failure, Creep lifetime, Static strength
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another universal joint and length adjustment of 4 bolts (M16). Steel H-beam is fixed to the concrete floor slab by chemical anchors (R-type, M22×10 bolts). The capacity of each anchor bolt is 47.4 kN (long term). The attachment distance from the fulcrum is designed at 200, 400, 600, 800, and 1,000 mm, which provide the maximum applied load of 10 times (10, 5, 3.3, 2.5, 2 times accordingly). It should be noted that the end of the steel rod to fix the weight is extended to the hole of the concrete floor slab as a stopper for a countermeasure during the earthquake.

4.2 Creep test series

Table 3 shows the creep test series. Two specimens (C1 and C2) are conducted under the same applied load (approximately 67% of the maximum load). Strain gauges are attached to the adhesive layer in the longitudinal direction (2 strain gauges for C1 and 4 strain gauges for C2). The data is recorded at 10-minute intervals (1 and 10 seconds until t=70 hours) for C1 and each second for C2. The oil heater is used to maintain the temperature at approximately 20 °C (from t=70 hours of C1). Noted that there is no change of specimen size and method of specimen preparation from static tensile tests.

4.3 Creep test results

Fig. 4 and 5 show the experimental results of specimen C1 and C2, respectively. In specimen C1, the value of strain S2 is almost two times greater than the value of strain S1. This is due to the bending effect of the specimen during the test setup. The unstable temperature at the early stage is due to the working operation in the measurement area. The temperature suddenly increases at t=70 hours due to the installation of an oil heater. In specimen C2, the temperature is more stable (approximately 20 °C), and the strain value difference is much improved compared with C1. In both specimens, the change of strain value can be seen in 3 stages: quick increasing in the early stage, gradual increasing in the middle stage, and quick increasing again in the last stage to failure. The average axial load value measured from the load cell is 30.3 and 30.1 kN for C1 and C2, respectively (calculation value from weight: 30.3 kN). Table 3 summarizes the results of creep tests. The maximum strain value at failure is 32,520×10^{-6} (S2) and 37,395×10^{-6} (S1) for C1 and C2, respectively. This value is approximate 2.8 times greater than the maximum strain value from static tensile tests (12,647×10^{-6}). It should be noted that the maximum strain value at the failure of C1 is underestimated due to data measurement of 10-minute intervals. However, the time to failure is much different, 199.7 hours for C1 and 13.4 hours for C2. Although some voids are confirmed, the failure modes are the cohesive failure. Fig. 6 plots the experimental data of static tensile tests and creep tests under applied load and average lifetime to failure.

5. CONCLUSIONS

The device for the static tensile tests and the creep test apparatus for large-scale experiments are designed. The temperature at conducting room can be maintained at room temperature (approximately 20 °C). The maximum strain value of the adhesive layer at failure can be considered at approximately 32,000-38,000×10^{-6} (about 2.8 times greater than that from the static tensile tests, 12,000×10^{-6}). The lifetime to failure can be confirmed under 67% of the static failure load. Future work will deal with the data collection from the creep tests and the improvement of test apparatus to reduce the bending effect.

REFERENCES

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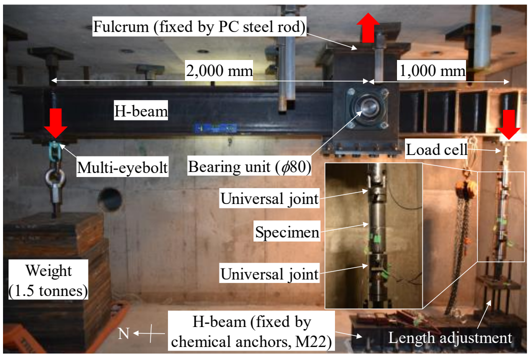

Fig. 3 Setup of creep test

Table 3 Creep test series

Specimens	Maximum load P_{max} (kN)	Applied load P (kN)	Applied load % of P_{max}
C1	45.5	30.3	67
C2	45.5	30.3	67

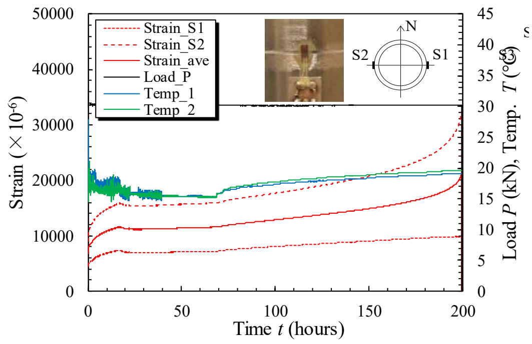

Fig. 4 Specimen C1

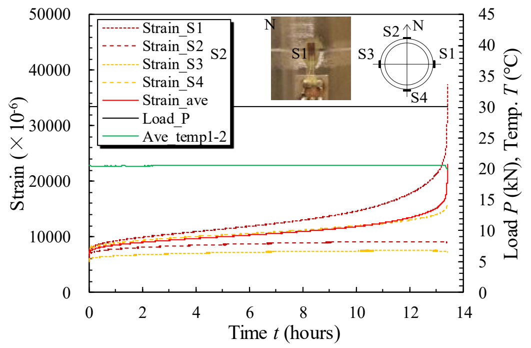

Fig. 5 Specimen C2

Table 4 Creep test results

Specimens	Applied load (% of P_{max})	Strain value at failure ε_{tu} (×10^{-6})	Comparison to static test (times)	Time to failure (hours)
Ref. (static)	100	12,647	1.0	0
C1	67	32,520	2.6	199.7
C2	67	37,395	3.0	13.4

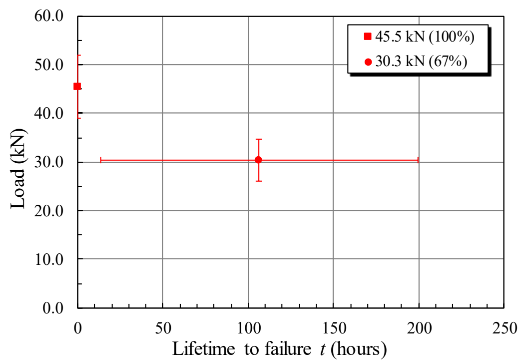

Fig. 6 Load versus average lifetime