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MECHANICAL PROPERTIES OF STRUCTURAL STEEL AND HIGH-TENSION BOLT AT ELEVATED TEMPERATURE

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This paper presents the test results of the mechanical properties of three types of structural steel at high temperature, which are generally used for the Pre-Engineered Building (PEB) system. The PEB system is generally used for non-residential buildings, such as factories and warehouses. The structural steel members are installed without fire resistance protection, which means they are very weak in the case of fire. The end-plate connection could be critical in the case of fire because most of the moment is resisted by the tensile force of the bolts. Therefore, the mechanical properties of bolts at elevated temperatures are tested. Coupon test specimens for SS400(SS275), (SM490(SS355), and F10T bolts were tested according to ASTM E8M. The high-temperature coupon tests were performed at 20°C, 400°C, 500°C, 600°C, 700°C, and 800°C. The test results were compared with the design reduction factors obtained from the American and European standards. The yield strength and tensile strength satisfied the minimum strength of the specified standards at 20°C. However, the reduction factor for yield strength obtained at a high temperature was lower than that of the standard value suggested by the code. In particular, the reduction factors for the high-strength bolt (F10T) were lower than those of the structural steel members (SS400(SS275), SM490(SM355)).

Keywords: High temperature, Thermal properties, Reduction factor, Tensile test, Extensometer.

1 INTRODUCTION

The Pre-Engineered Building (PEB) system is an efficient structural system for long-span structures, such as factories or warehouses. If this system is adopted for non-residential buildings, the structural members are not fire-protected, which results in early collapse in the case of fire. Figure. 1 shows a PEB system and end-plate connection detail. The depth of the main steel girder is higher than that of the H-shaped beam and its slenderness ratio is very high. The member is critical for lateral torsional buckling in the case of fire because the flexural strength is governed by reduced yield strength and the modulus of elasticity. Especially in cases of fire, PEB, made of slender elements, loses strength at temperature more easily and collapses more quickly than general steel structure systems. The strength of the end-plate connection is governed by the reduced tensile strength of the bolts and end plate. This paper shows the material test results at high temperature for three main materials used in the PEB system. Three types of material, SS400(SS275) (F_y = 235MPa, F_u = 400MPa) for the web, SM490(SM355) (F_y = 315MPa, F_u = 490MPa) for the flange, and a F10T bolt (F_u = 1000MPa), were tested at 20°C, 400°C, 500°C, 600°C, 700°C and 800°C according to ASTM E8M (*ASTM, 2010a*). The test results were compared with the design reduction factors obtained from the American and European standards (*AISC 2005, CEN 2005, Choi et al. 2014, and Chen et al. 2006*).

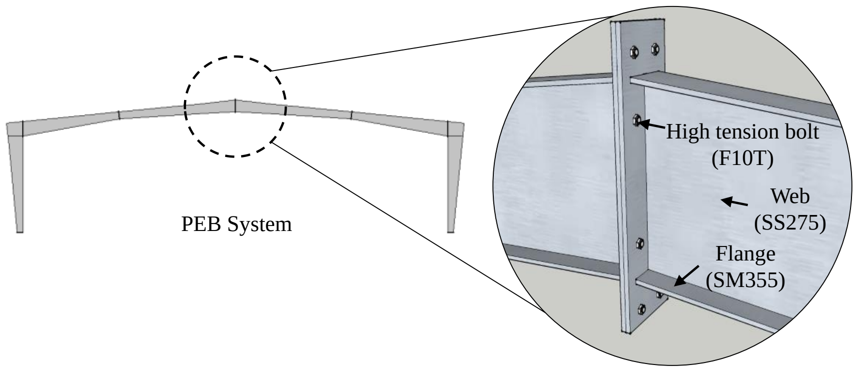


Figure 1. PEB system components.

2 TEST COUPON INFORMATION

High-strength steel specimens for tensile strength tests were made according to American standards (*ASTM 2010a*). Table 1 shows the detail of test coupons. The tensile tests at elevated temperatures were carried out by preparing the specimens as shown in Figure 2 to be subjected to tensile testing at high temperatures between 400°C and 800 °C at 100 °C increments.

Table 1. Detail of test coupons.

Steel	Target Temp. (°C)	Standard	Section size (mm)
SS275 SM355 F10T	20 (Room Temp.)	Specimen 3 according to ASTM E8M	Φ6
	400		
	500		
	600		
	700		
	800		

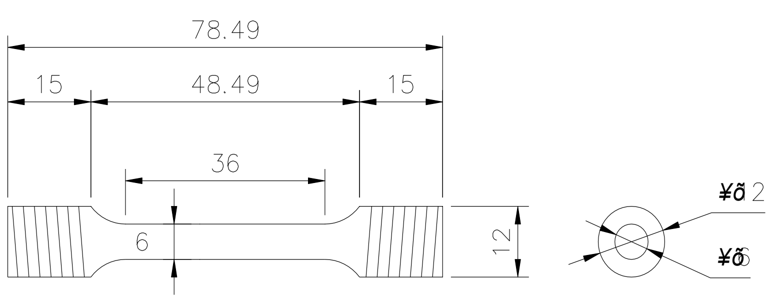
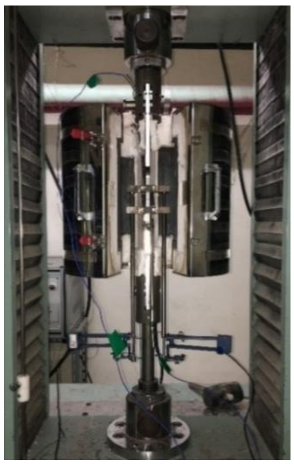
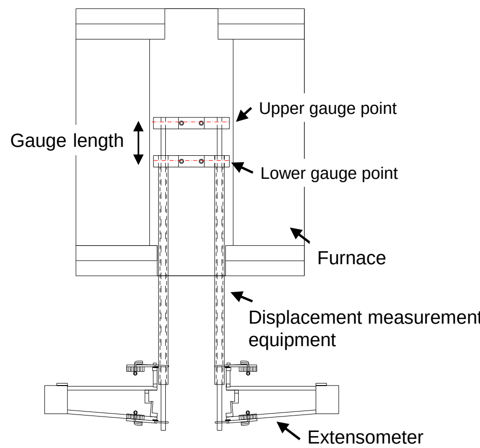


Figure 2. Dimension of tensile test specimen.

The displacement measurement equipment for the high-temperature tensile test was made as shown in Figure 3. It is composed of two extended bar sets, an inside bar connected to the upper gauge point, and an outside bar connected to the lower gauge point. The location of the gauge point that holds the specimen using a knife edge is inside the furnace, and the other side of the gauge point is exposed to the outside of the furnace. The inside bar connected to the upper gauge point slides into the outer tube, which is connected to the lower gauge point. Two extensometers were attached using the knife edge of one at each extended bar. The average value of the two extensometers is used as the strain for the coupon test. Many small holes outside the tube were made to compensate for the strain change of the inside bar induced by the temperature change. A thermocouple (K-type) was installed at the surface of the steel in the heating furnace for the tensile test at a precise target temperature. The heating velocity was 5°C/min due to the heating furnace capacity. In order to equalize the heat distribution, the experiment was performed after more than 20 minutes from reaching the target temperature (*ASTM 2010b*). Two extensometers were installed external to the heating furnace, as shown in Figure 3(a), (b). The average value of the measured strains was calculated.



(a) Test in foreground



(b) Displacement measurement equipment

Figure 3. High-temperature tensile test.

3 TEST RESULTS

3.1 Material Properties of Steel

Table 2 indicates the material properties of steel at high temperature. The modulus of elasticity was not measured because the measurement device is not sensitive enough to measure small displacements. As shown by the general high-temperature behavior, as the temperature increased, the yield strength and tensile strength decreased, whereas elongation increased.

Table 2. Material properties of steel at high temperature.

Steel	Temp (°C)	Yield strength (MPa)	Tensile strength (MPa)	Elongation (%)
SS400 (SS275)	20	287.5	432.6	36.6
		300.6	450.7	36.6
		295.4	432.7	28.8
	400	221.6	391.1	32.0

Table 2 *(contd)*. Material properties of steel at high temperature.

SS400 (SS275)	400	205.9	373.1	39.2
		220.1	344.5	31.9
	500	164.1	236.0	36.2
		177.6	256.7	34.5
		165.1	184.2	33.3
	600	133.7	159.2	36.0
		116.3	150.3	33.1
		146.0	171.1	28.7
	700	83.5	103.9	35.0
		58.7	101.2	36.3
		57.8	106.4	41.1
	800	38.5	52.0	45.3
		32.2	64.9	57.4
		23.3	64.9	56.1
SM490 (SM355)	20	310.1	486.8	26.0
		317.8	476.6	28.4
		321.7	474.1	38.3
	400	222.3	419.6	25.3
		228.7	435.1	28.5
		252.7	391.1	29.0
	500	179.6	248.8	34.8
		209.7	264.3	35.6
		156.1	217.6	40.3
	600	141.0	186.7	39.1
		138.2	155.7	36.0
		107.1	155.7	41.5
	700	85.6	85.7	39.3
		75.4	98.6	34.8
		55.5	83.1	39.8
	800	70.0	83.1	30.2
		34.8	83.0	35.1
		36.3	64.9	42.3
F10T	20	981.5	1,037.7	16.2
		1,002.1	1,048.1	14.9
		996.2	1,040.2	10.3
	400	792.9	888.2	13.3
		748.5	865.0	15.5
		837.3	880.7	12.7
	500	532.1	640.5	13.8
		415.1	609.6	15.3
		508.2	625.1	16.5
	600	179.2	271.5	38.6
		142.9	287.0	42.0
		159.3	302.4	35.3
	700	73.4	106.2	37.0
		35.1	90.0	38.4
		67.7	98.6	37.8
	800	61.4	64.8	49.7
		59.0	71.1	47.2
		72.6	78.8	49.5

Figures 4–6 show the stress–strain curves at different temperatures. The strain-hardening section between yield strength and tensile strength decreased as the temperature increased. Additionally, as the temperature increased, the difference between yield strength and tensile strength decreased. Yield strength was obtained by 0.2% offset of the stress–strain curve.

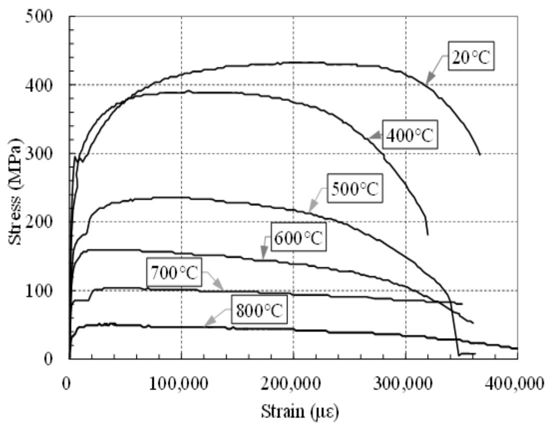


Figure 4. Stress–strain relationship (SS400(SS275)).

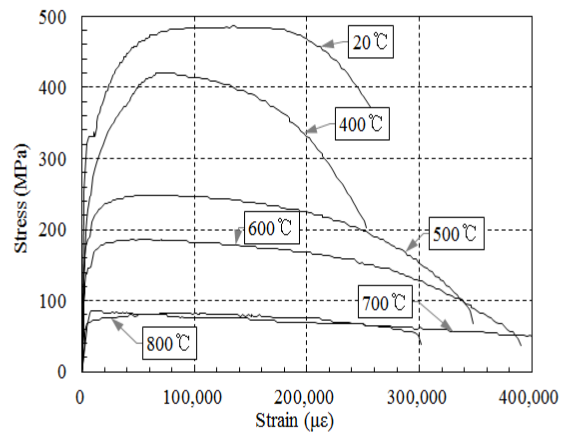


Figure 5. Stress–strain relationship (SM490(SM355)).

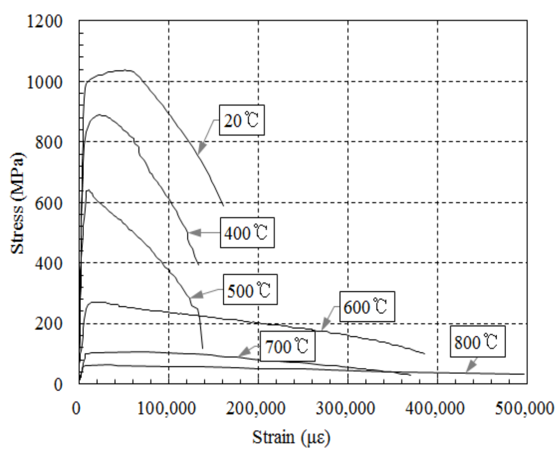


Figure 6. Stress–strain relationship (F10T).

3.2 Comparison of Reduction Factor with Existing Standards

Figure 7 shows the reduction factors of the yield strength. The reduction factors of the yield strength in AISC and Eurocode 3 were plotted using linear interpolation methods. Findings showed that the reduction factors of all the coupons were lower than the specified AISC and Eurocode 3 standards. In particular, the reduction factors of high-tension bolts (F10T) decreased more sharply than those of SS400 and SM490 at 500°C. When the heating temperature reached 400°C, the yield strengths of all coupons were similar, each with 73–83% of yield strength from normal temperature. However, when the heating temperature reached 500°C, the yield strengths of all coupons decreased sharply.

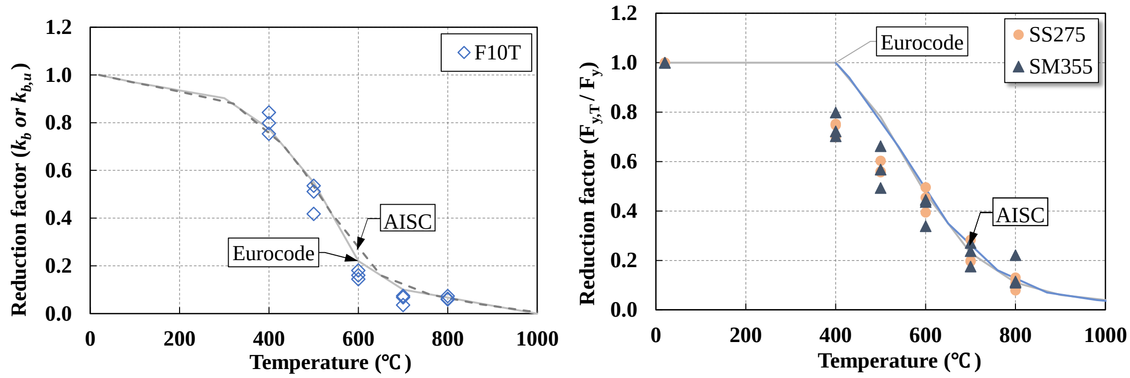


Figure 7. Reduction factor of yield strength compared with existing standards.

4 CONCLUSION

The tensile test of steels (SS400, SM490, and F10T) used for the PEB system was performed at an elevated temperature. The strength of steel and reduction factor obtained from the tests were compared with the existing standard values at high temperature. The reduction factor of yield strength obtained from the tests was lower than those of AISC and Eurocode 3. Fire protection may be required at the bolted area even though the PEB system may not require fire protection according to the design code. The measured reduction factors data of steel used in the PEB system at an elevated temperature are not enough to make a concrete conclusion. More test data on high-strength bolts are especially needed.

Acknowledgments

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