Fire Resistance Performance of Super High Tensile Strength Bolts

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Summary

This study found that 1,400N/mm^2-class super high tensile strength bolts (F14T) overcome delayed fracture at room temperature and have high fire resistance performance. Based on the results of the coupon and connection tests, F14T can provide high load bearing capacity and rationally bolted connection design for both structural and fire resistant designs.

Keywords: high tensile strength bolt; fire resistance performance; coupon test; tensile strength; breaking elongation; strength reduction rate; connection test; plastic deformation.

1. Introduction

High strength bolted connections are widely used for manifold steel structures as a way of providing reliable connections without welding. Generally, high strength bolts with a design tensile strength of 1,000 N/mm^2 (JIS F10T [1]) are widely used in Japan. However, there is strong demand for higher strength bolts for use in large sectional and high strength members of large-scale and high-rise buildings. It is well known that delayed fracture is a serious problem in bolts with tensile strength over 1,000 N/mm^2 (for example, JIS F11T and F13T). Consequently, these bolts have been prohibited for use in buildings. Many studies on delayed fracture have been conducted to elucidate this phenomenon, and some high performance steel having both super high strength and delayed fracture resistance have been developed. One example is the development of 1,400 N/mm^2-class super high tensile strength bolts (F14T [2]). These new bolts provide various advantages, including approximately 33% smaller connections by decreasing the number of bolts used, lower construction costs, shorter construction periods and more efficient steel frame erection.

This study found that F14T has superior fire resistance performance compared to conventional high strength bolts (JIS F10T and BS Grade 8.8 [3]). This difference was confirmed in both the coupon and connection tests using F14T at high temperature.

2. High temperature coupon test

High temperature coupon tests were conducted on F14T. Shank diameters of 16, 20, 22 and 24 mm were used. For each test temperature, two specimens were tested. Seven test temperatures were considered: RT, 350, 500, 600, 650, 700 and 800 °C.

Fig.1 shows a comparison of tensile strength reduction rate (factor) at high temperature for various types of high strength bolts. In this figure, the test results of F14T, JIS F10T [1] and BS Grade 8.8 [3] are co-plotted in the same graph. The vertical coordinate denotes the ratio $_b\kappa_u$ of tensile strength at high temperature to that at room temperature. It

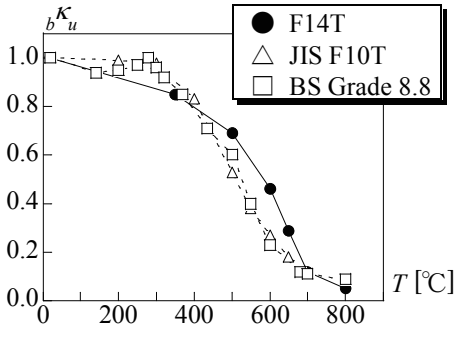

Fig. 1: Comparison of tensile strength reduction rate

cannot be confirmed which has a larger strength reduction in the region where there is no test data for F14T (20-350 °C); however, F14T has a smaller strength reduction at 400°C and higher. The alloys Mo, Cr and V are added to F14T with the aim of improving quenching ability and forming hydrogen trap sites by their precipitates in the steel. Among these alloys, Mo and Cr are recognized to improve both solute and precipitation strengthening of steel at high temperature, and thus, both yield and tensile strength at high temperature are improved. This is considered to be the reason why F14T has high fire resistance performance.

3. High temperature tensile test of connections

F14T used for the connection test were from the same lots as the M22 sample B bolts for the high temperature coupon test. The test apparatus consisted of double-shear connections using two bolts. The connection was made up of a main plate and two splice plates, which were respectively designed to have sufficiently high strength in comparison to the shear strength of F14T. Two shear planes were respectively located at the thread and shank of the bolt. Fillet welding was used for the opposite side of connection. Seven test temperatures were considered: RT, 350, 500, 600, 650, 700 and 800 °C. Two specimens were tested at each test temperature, excluding 700°C and 800 °C. Tensile load was applied at a constant strain velocity of 0.02 mm/sec. Relative deformation between the studs fixed on the main and splice plates was measured using a displacement meter.

For all test specimens, first, slip behaviour occurred, and subsequently, the bolts were under shear bearing. The maximum load ${}_eP_{max}$ was achieved by the shear strength of the bolts. For the test cases from 20 to 600 °C, the bolts fractured at a slightly lower load than ${}_eP_{max}$. Meanwhile, for the test cases from 650 to 800 °C, the bolts never fractured, even when the load declined to 0.4 times ${}_eP_{max}$. This is believed to be due to the fact that F14T exhibits sharply increasing elongation at 600 °C and higher. Accordingly, at such temperatures, F14T does not fracture immediately after maximum strength and continues to have residual shear strength. This indicates that connections can be expected to have a certain plastic deformation capacity at high temperature. Fig.2 shows a comparison of shear strength reduction rate (factor) at high temperature. The vertical coordinate denotes the ratio ${}_b\kappa_u$ of shear strength at high temperature to that at room temperature. As shown, F14T has a smaller reduction in shear strength compared to JIS F10T and BS Grade 8.8. In addition, when compared with Fig. 1, it is also revealed that both tensile and shear strength reduction rates are approximately the same.

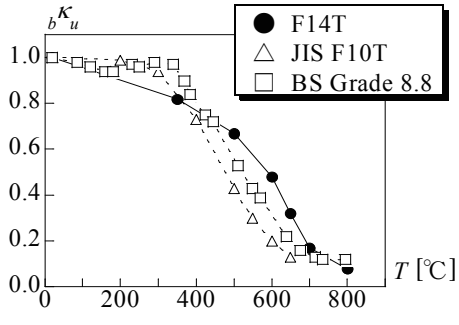

Fig. 2: Comparison of shear strength reduction rate

4. Conclusion

Based on the results of the coupon and connection tests, it was found that 1,400N/mm^2-class super high tensile strength bolts (F14T) overcome delayed fracture at room temperature and possess high fire resistance performance. Hence, it is expected that F14T can provide high load bearing capacity and rationally bolted connection design for both structural and fire resistant designs.

References

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