SURFACE SCIENCE WESTERN

REPORT ON THE EVALUATION OF THE BOLTS PROVIDED BY MTO

Prepared by

Dr. S. Ramamurthy[1]; R.J. Klassen[2], P.Eng.; Dr. F.M. Bartlett[2], P.Eng.;
Mr. B. Kobe[1]; and Dr. David Shoesmith[1]
[1]Surface Science Western
[2]Faculty of Engineering
Western University, London, Ontario, CANADA

Prepared for

Ontario Ministry of Transportation (MTO)
Northwestern Region Office
615 James Street South
Thunder Bay, Ontario P7E 6P6
Canada

18 April 2016

SSW Reference : 03116.MTO

EXECUTIVE SUMMARY

Surface Science Western at the University of Western Ontario received fourteen pieces of 7/8-inch diameter bolts that had failed in service on 22 January 2016 and ten 7/8-inch diameter bolts, of which eight were intact, on 29 February 2016, which had not failed in service. Both sets of bolt pieces were evaluated using a number of analytical techniques to determine the following: (1) the chemical composition, (2) the mechanical properties (yield and tensile strengths, hardness and Charpy V-notch impact toughness), (3) the state of the fracture surface, and (4) the nature of the corrosion products on the fracture surface.

Chemical testing was conducted on blanks machined from two bolt pieces received on 22 January 2016. The chemical composition satisfies the requirements for Type 1 and Type 3 bolts as specified in ASTM Standard A490-14a "Standard Specification for Structural Bolts, Alloy Steel, Heat Treated, 150 ksi Minimum Tensile Strength".

Charpy V-notch impact testing was carried out on seven specimens fabricated from bolt pieces received on 22 January 2016. One specimen tested at -60 °C exhibited an absorbed energy of 27J, which is the minimum specified for fracture-critical members in Table 10.2 of the 2010 CHBDC. The tests indicated conclusively that this metal undergoes a ductile fracture when loaded at temperatures of -20 °C and -30 °C.

Small tension specimens were fabricated from three bolt pieces received on 22 January 2016 and tested in accordance with ASTM Standard E8/E8M-15a "Standard Test Methods for Tension Testing of Metallic Materials". All met the strength requirements, specifically the 2% Offset Yield Stress and Ultimate Tensile Strength requirements and the Area Reduction at Failure requirement of ASTM Standard A490-14a. The Elongation in 50 mm requirement could not be verified because the short lengths of the bolt pieces supplied limited the gauge length of the test specimens.

Eight intact bolts received on 29 February 2016 were tested full-scale, four with a 10 degree wedge under the head, in accordance with ASTM Standard F606/F606M - 14a "Standard Test Methods for Determining the Mechanical Properties of Externally and Internally Threaded Fasteners, Washers, Direct Tension Indicators and Rivets", and four with a 1-degree tapered washer under the round washer and nut. All met ASTM Standard A490 Proof Load and Tensile Load requirements.

Small tension specimens were fabricated from three bolts received on 29 February 2016 and tested in accordance with ASTM Standard E8/E8M-15a. All met the strength requirements, specifically the 2% Offset Yield Stress and Ultimate Tensile Strength requirements, and the Area Reduction at Failure requirement of ASTM Standard A490-14a. None met the minimum 14% Elongation at Failure in a 50 mm gauge length requirement, although the throat length-to-diameter ratio of these specimens was larger than specified in ASTM Standard E8/E8M-15a. Differences in the average strength and area reduction at failure values for the specimens machined from the bolt pieces received on 22 January 2016 and from the bolts received on 29 February 2016 were less than 1.5% and generally not statistically significant. The fact that small tension specimens machined from these bolts did not meet the ASTM Standard A490-14a minimum elongation at failure requirement indicates an apparent inconsistency in the standard: full-scale tests do not require a minimum elongation at failure, small tension specimens do.

Fracture surface investigations were conducted for all 14 bolts received on 22 January 2016 and for three bolts received 29 February 2016 after they had been tested full scale. It was concluded that:

1. Fracture initiated from the root of a thread and proceeded either directly across the bolt parallel to the nut, resulting in an essentially flat fracture surface, or at an angle across the bolt to a thread root below the nut.
2. The appearance of the fracture surfaces suggest that cracks nucleated on opposite sides of the bolt and grew together as a result of alternating cyclic tensile loading until final ductile fracture of the central region occurred.
3. The fracture surfaces did not display clear and regularly spaced striations characteristic of high-cycle fatigue crack growth. It was, therefore, not possible to estimate the number of loading cycles that the bolts were subjected to prior to failure.
4. Micro-indentation hardness measurements performed on the polished mid-plane of a bolt received on 22 January 2016 indicated an average Rockwell C hardness of HRC 35 ± 2, which falls within the hardness limits specified in ASTM Standard A490.
5. Some of the bolts received on 29 February 2016 displayed pre-existing heavily oxidized cracks, about 100 or 200 µm in length, emanating from the sides and top of the threads. However, because of their location away from the root of the thread it cannot be concluded that these pre-existing cracks influenced the bolt fracture process.

Corrosion product analyses using visual and optical microscopy were conducted on pieces of five different bolts received on 22 January 2016. Three distinct regions were observed, identified as “grey-coloured”, “white deposit”, and ”heavily corroded” regions. SEM/EDX, XPS and Raman analyses indicated that:

6. The grey-coloured regions were comprised of a mixture of different forms of iron oxides with lower amounts of iron hydroxides. Some locations within these regions contained a thin oxide/hydroxide layer as evidenced by the detection of the iron substrate in the XPS analyses.

7. The white deposit regions were found to be enriched in carbonate, and mostly in the form of sodium carbonate. The source of this carbonate is presently undetermined.
8. The heavily corroded regions exhibited greater amounts of iron hydroxide, compared to iron oxide phases, consistent with expectations in the presence of chloride.