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Case Study: Fatigue Failure

By

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Subject

Fatigue failures provide an excellent opportunity to establish a definitive cause of failure. This is especially true when dealing with equipment related failures. Evaluation of the stress levels involved with the failure through the use of fracture mechanics can point to improper maintenance and/or installation. In this case study, two decorative finished fasteners were used to hold an equipment seat in place. The fasteners were exposed and accessible so that adjustments could be made to the equipment seat. Two of the broken fasteners were examined by scanning electron microscopic examination, fracture mechanics, hardness testing, and metallographic examination. Properly torqued threaded fasteners rarely fail by fatigue. Note that these two bolts were not of the same grade.

Scanning Electron Microscopic Examination

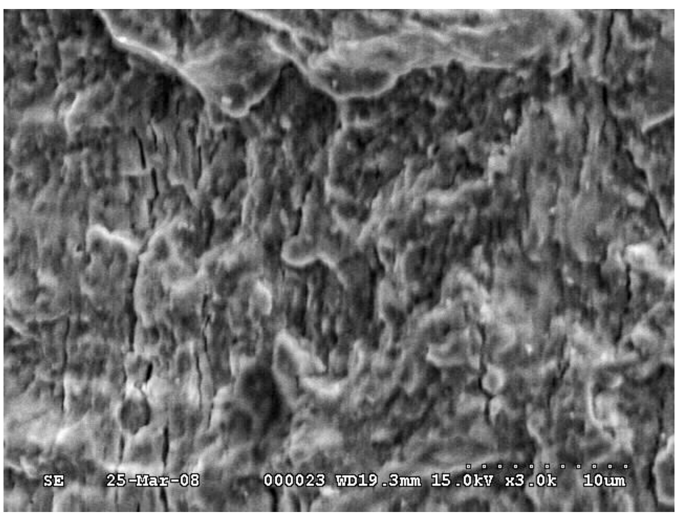

Figure 1 – 3500X Fracture Surface Bolt 1

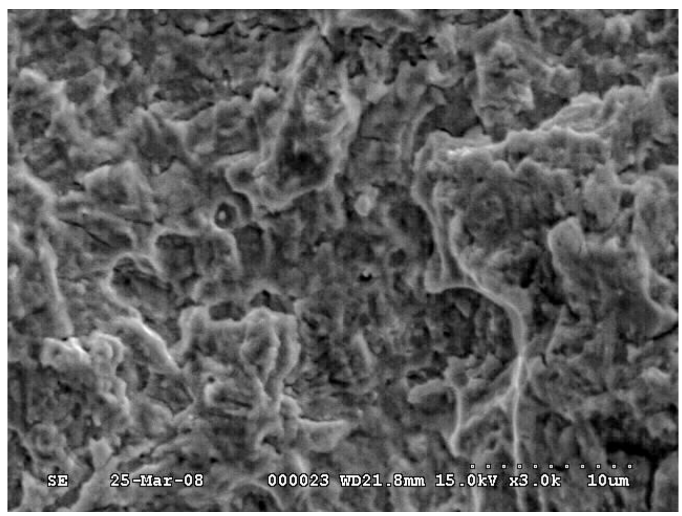

Figure 2 – 3000X Fracture Surface Bolt 2

The fracture mode of Bolt 1 was clearly fatigue, Figure 1. The fatigue striation spacing shown in Figure 1 is 1.42 X 10^{-5} inches. Fissile fracture is present, indicating that the localized cyclic stress exceeded the tensile strength of the bolt.

The fracture mode of Bolt 2 was also fatigue, Figure 2. The fatigue striation spacing shown in Figure 2 is 1.77 X 10^{-5} inches. There are only a few fissure cracks present, indicating that the cyclic stress was below the tensile strength of the bolt.

Fracture Mechanics

Fracture mechanics was used to estimate the stress levels that were on the parts at the time of fracture. Knowing the location and spacing of the fatigue striations permits the estimation of the cyclic fatigue stress by the following equation: $\Delta\sigma = \dfrac{E\sqrt{\dfrac{spacing}{6}}}{Y\sqrt{a}}$. The terms are defined below:

$\Delta\sigma$	The applied cyclic stress.
E	The modulus of elasticity equal to 30,000,000 psi for steel alloys.
a	The distance the fatigue striations progressed from the fracture origin.
Y	A constant equal to 2.1. It is defined by the shape of the crack.

The value of ***a*** for Bolt 1 was 0.218 inches. The estimated cyclic stress on this bolt was 47,000 psi, which is below the endurance limit of around 60,000 psi. This indicated that the bolt had not been properly torqued.

The value of ***a*** for Bolt 2 was 0.152 inches. The estimated cyclic stress on this bolt was 62,900 psi. The endurance limit would have been around 75,000 to 80,000 psi, indicating this bolt had also not been properly torqued. Based on the comparative estimated cyclic stress of the bolts, Bolt 2 likely failed after Bolt 1 had failed.

Hardness Testing

The hardness testing was done according to ASTM E384, using a Knoop indenter and a 500 gram load. The results of the testing are given in the table that follows.

Hardness Test Data
(Rockwell C Scale)

Sample	Knoop	Std. Dev.	Maximum	Minimum	Hardness
Bolt 1 Core	334	15.88	352	314	32.88
Bolt 1 Thread Root	347	16.95	359	317	34.38
Bolt 2 Core	448	4.34	452	443	43.64
Bolt 2 Thread Root	462	22.02	474	423	44.62

The hardness test data indicates that the two bolts were different grades. Bolt 1 was an SAE Grade 8 bolt, and Bolt 2 was a special high strength fastener whose hardness puts the bolt at the top end of Metric Class 12.9.

Metallographic Examination

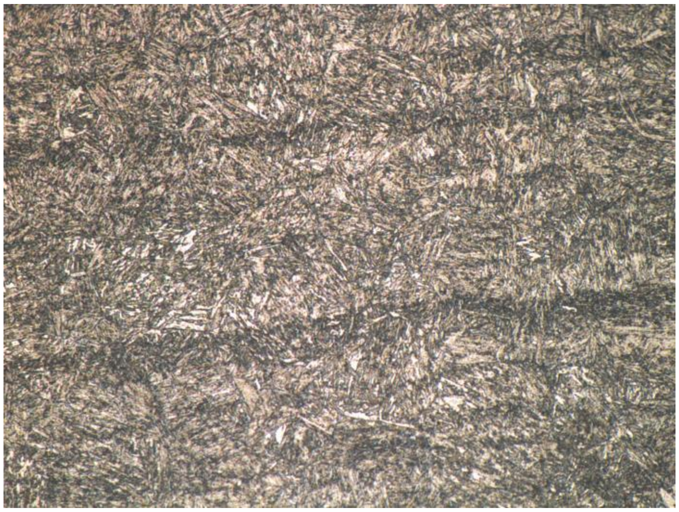

Figure 3 – 400X Tempered Martensite, Bolt 1

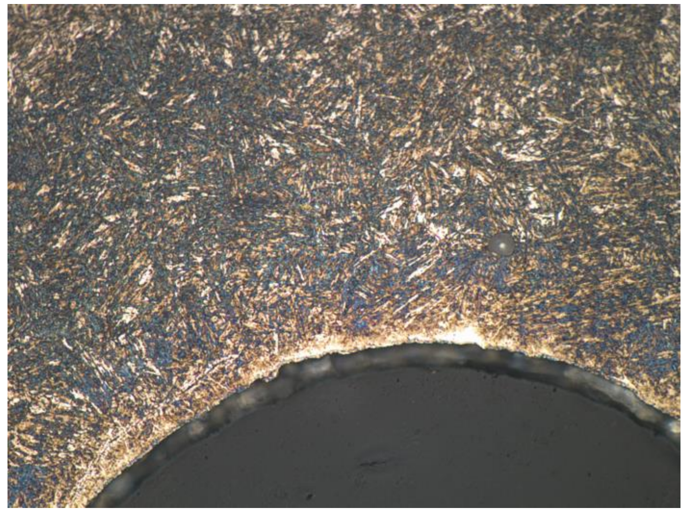

Figure 4 – 400X Tempered Martensite Thread Root, Bolt 1

Bolt 1 had a microstructure of tempered martensite, Figure 3, which is typical of SAE Grade 8 fasteners. The bolt had rolled threads, Figure 4, and was a good quality Grade 8 fastener.

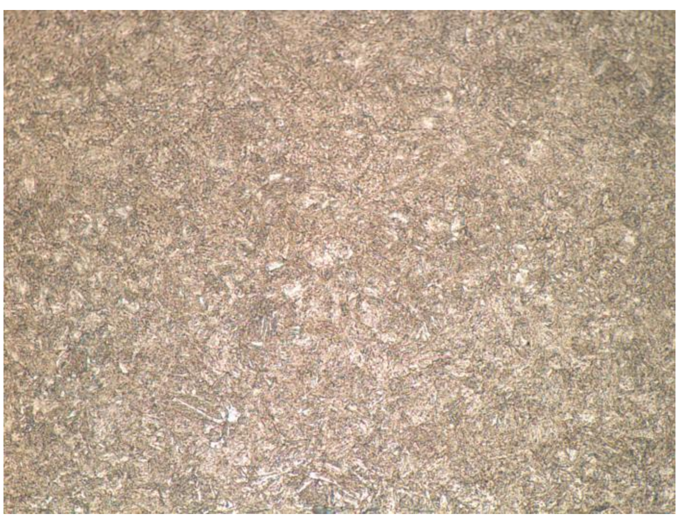

Figure 5 – 400X Tempered Martensite Microstructure, Bolt 2

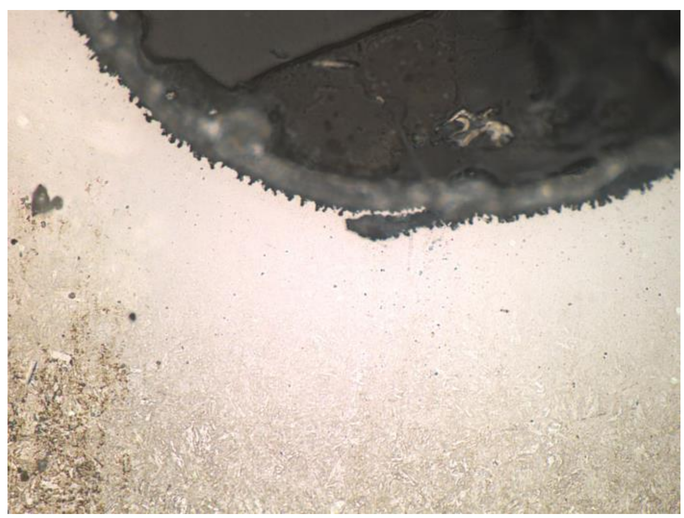

Figure 6 – 400X Pitting Corrosion Thread Root, Bolt 2

The microstructure of Bolt 2 was fine grained tempered martensite, Figure 5. The microstructure was typical of a bolt of this hardness. The outer surface of the bolt showed pitting corrosion, Figure 6. The type of corrosion shown is typical of excessive-acid pickling prior to electroplating. Pits on the surface and in the thread roots can act as stress risers for fatigue failures.

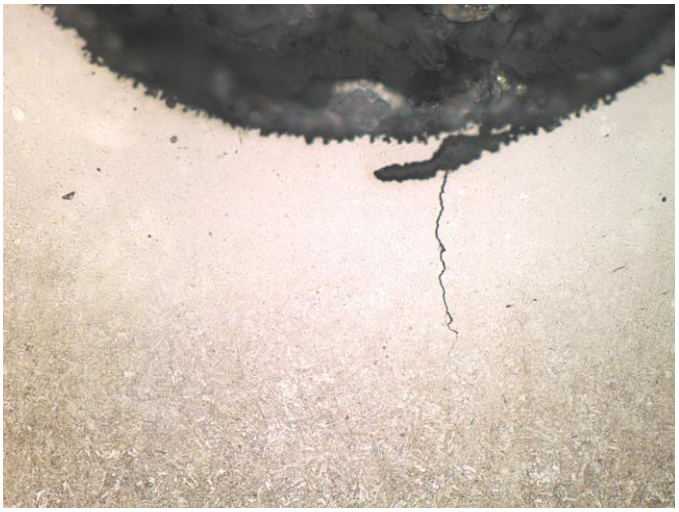

Figure 7 – 400X Intergranular Cracking, Thread Root, Bolt 2

Figure 8 – 400X Intergranular Cracking, Thread Root, Bolt 2

A number of the thread roots of Bolt 2 showed intergranular cracking. Figures 7 and 8 are examples of this. The intergranular cracking was likely the result of hydrogen embrittlement. These cracks can act as stress risers for fatigue.

Discussion

The estimated cyclic stress on the two fasteners was low enough that they should not have broken if they had been properly torqued. The proof-load for Bolt 1 was 120,000 psi. Bolt 1 should have been torqued to approximately 90,000 psi, or 36 foot-pounds. The proof-load of Bolt 2 was 150,000 psi, or 60 foot-pounds.

If Bolt 2 had been properly torqued it would still have failed by hydrogen embrittlement.

Using mixed grades of bolts in the same application can over-stress the lower grade bolt, resulting in failure of the lower grade bolt, followed by over-stressing of the higher grade bolt and its eventual failure.

Conclusions

These two bolts failed because they were not properly torqued *based on their individual grades*.

Recommendations

Use a specified grade of bolt in a given application.