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Chase Study: Hydrogen Embrittlement

By

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Subject

Examination of broken spring to determine cause of failure. The spring was examined by visual examination, hardness testing, scanning electron microscopic examination, and metallographic examination. The spring was a torsional spring fabrication for oil tempered spring wire, that broke during installation.

Visual Examination

Figure 1 – Fracture 1

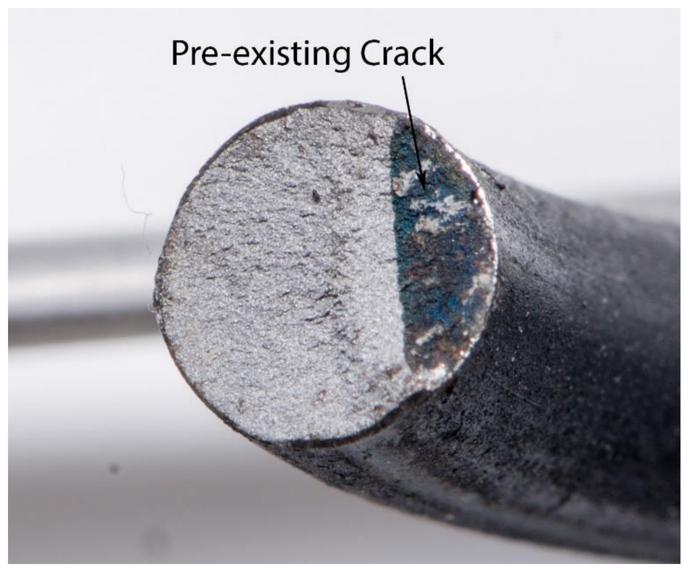

Figure 2 – Fracture 2

There were pre-existing cracks at the two fracture locations, Figures 1 and 2. The blue-black areas, indicating the pre-existing cracks, were probably open prior to the tempering of the wire. The blue-black color was caused by heating to over 700^{o} F. The light, sparkling surface appearance indicates intergranular fracture. This characteristic was present in the blue-black area also. The pre-existing cracks were on the inside diameter of the spring.

<u>Hardness Testing</u>

The hardness testing on the broken spring 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 and graphs that follow.

The average hardness across the diameter of the spring was 52.17 on the Rockwell C Scale. Typical spring wire has an average hardness across the diameter of 45 to 47 on the Rockwell C Scale.

Hardness Test Data (Rockwell C Scale)					
Location	Vickers	STD DEV	MAX VALUE	MIN VALUE	HARDNESS
Broken Spring Profile	580.00	29.51	631.00	521.00	52.17 RC
Typical Spring Profile	487.00	35.56	527.00	415.00	46.31 RC

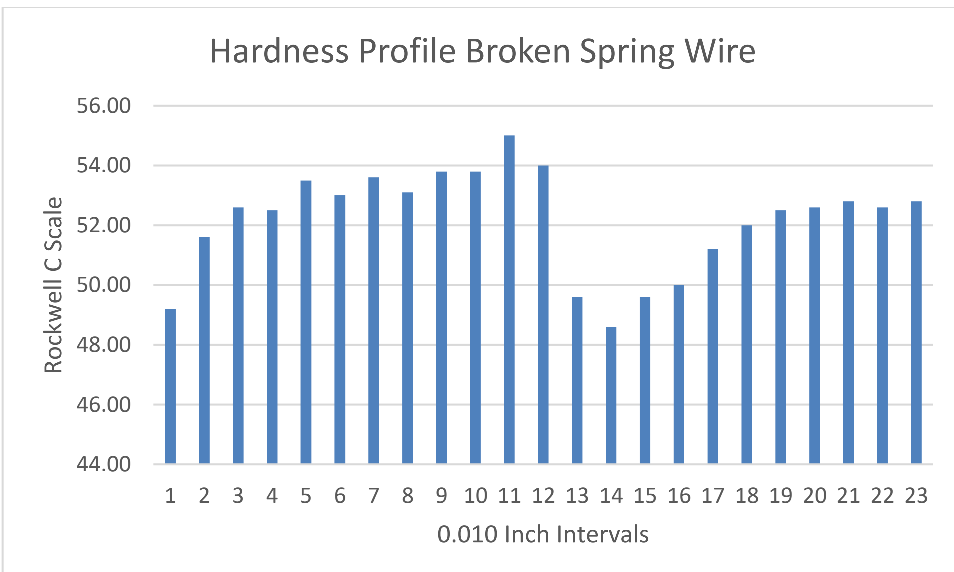

Figure 3 – Hardness Profile Across Diameter of Broken Spring – Spring OD to ID

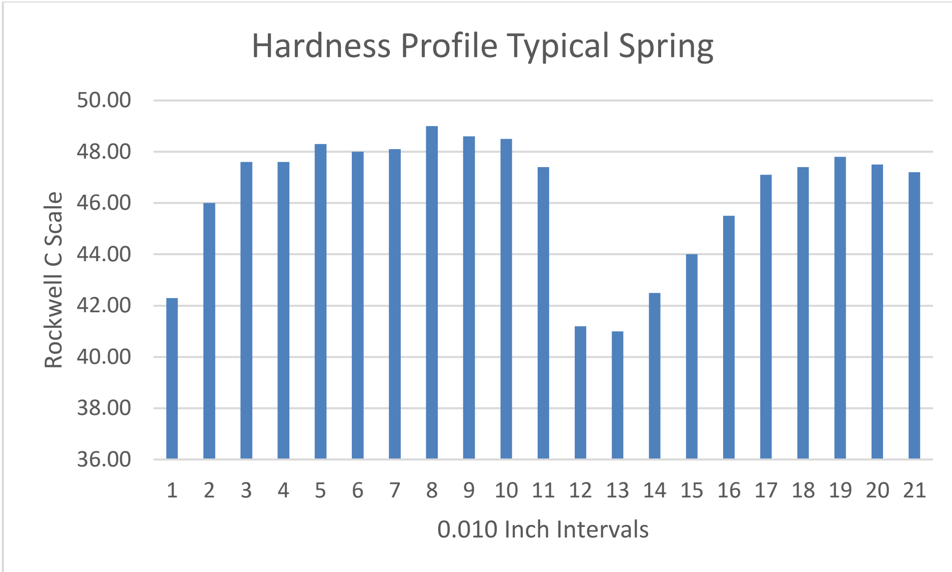

Figure 4 – Hardness Profile of Typical Spring – Spring OD to ID

Figure 3 shows the hardness profile of the broken spring wire. The appearance of the profile is typical of wires examined in the past, but the wire was harder. Reading 1 was near the outside diameter of the wire.

Figure 4 shows the rechecked hardness profile for Typical Spring – spring outside diameter to inside diameter. The hardness of this failure is greater than the normal hardness in a typical spring.

Scanning Electron Microscopic Examination

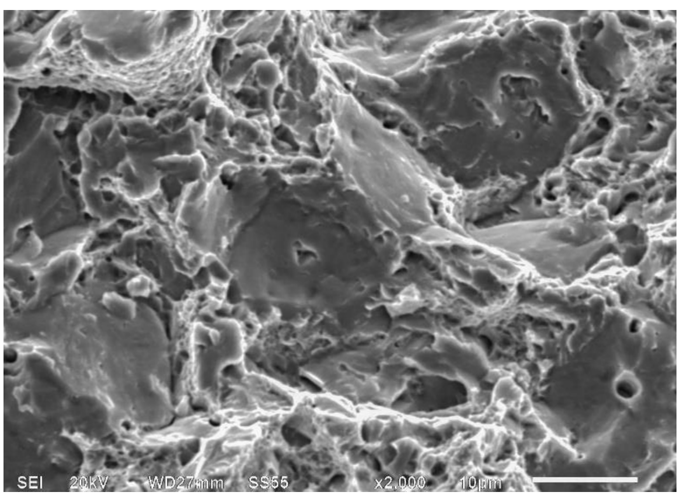

Figure 5 – 2000X Fracture 1 – Mixed Mode Fracture

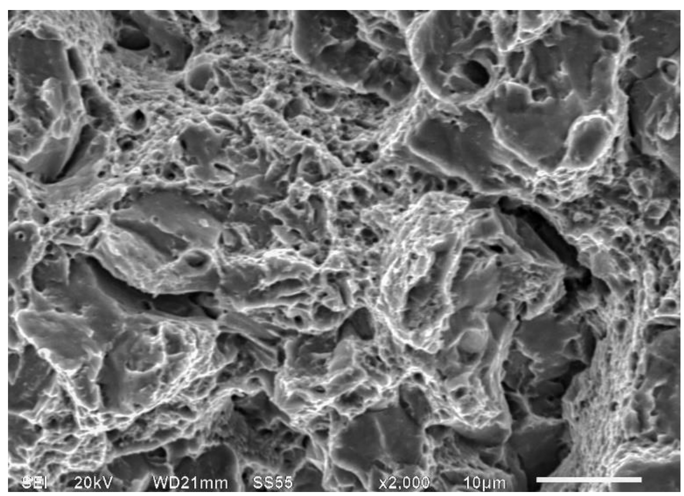

Figure 6 – 2000X Fracture 2 – Mixed Mode Fracture

Figure 5 shows the fracture surface of Fracture 1. Both intergranular fracture and ductile rupture are present. There are apparent bubbles associated with the intergranular facets. These characteristics are typical of hydrogen embrittlement. Hydrogen can be picked up at any point in the spring wire manufacturing process, during melting and formulating steel, pickling and cleaning of the wire, and exposure to rusting. To my understanding, there are no processes at the spring manufacturers that will cause hydrogen embrittlement.

Figure 6 shows Fracture 2, which has similar conditions to Fracture 1. This fracture was the result of hydrogen embrittlement.

The higher than normal hardness of the spring wire makes it more susceptible to hydrogen embrittlement.

Metallographic Examination

The magnification shown for the photos is the magnification at which the photos were taken. The photos shown in this report may be smaller or larger in size than the originals.

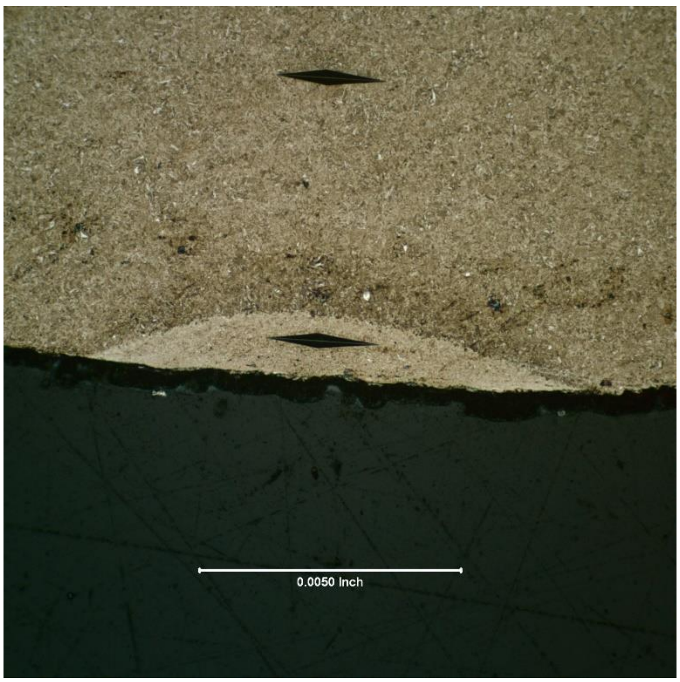

Figure 7 – 400X Tool Mark – Spring OD

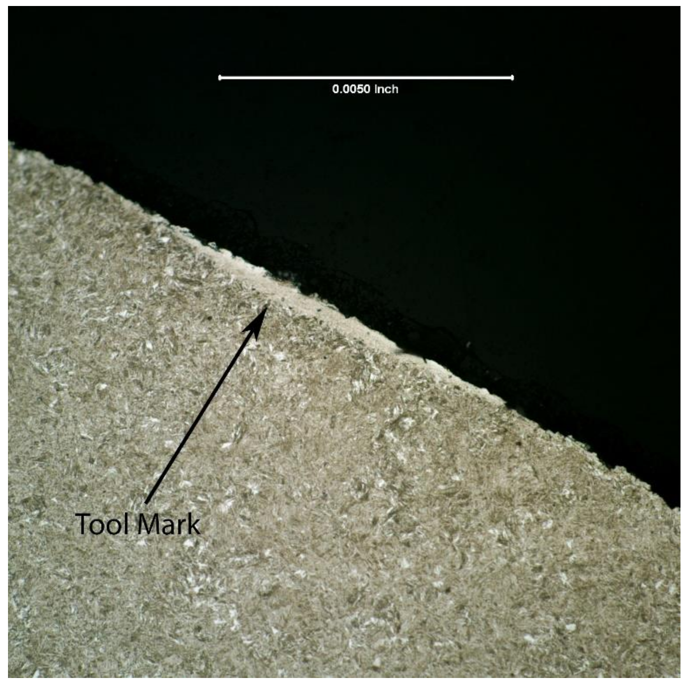

Figure 8 – 400X Tool Mark

Figure 7 shows a tool mark that was on the outside diameter of the spring. Tool marks are indications of lubrication breakdown during forming of the spring, and often are the cause of spring failure. This is larger than a typical tool mark. The hardness impression in the tool mark was the first value given in the graph in Figure 3. The hardness at this location was 49.2 on the Rockwell C scale. The presence of tool marks lowers the fatigue strength of the spring by causing localized reduction ductility. The tool mark shown in Figure 8 is typical of tool marks found on the springs that have previously been evaluated for this client.

Figure 9 shows corrosion pits on the surface of the spring wire. The presence of the corrosion pits indicates that the most probable cause of the hydrogen embrittlement was corrosion of the wire.

Figure 10 shows another area on the spring wire surface where there was corrosion and intergranular cracking.

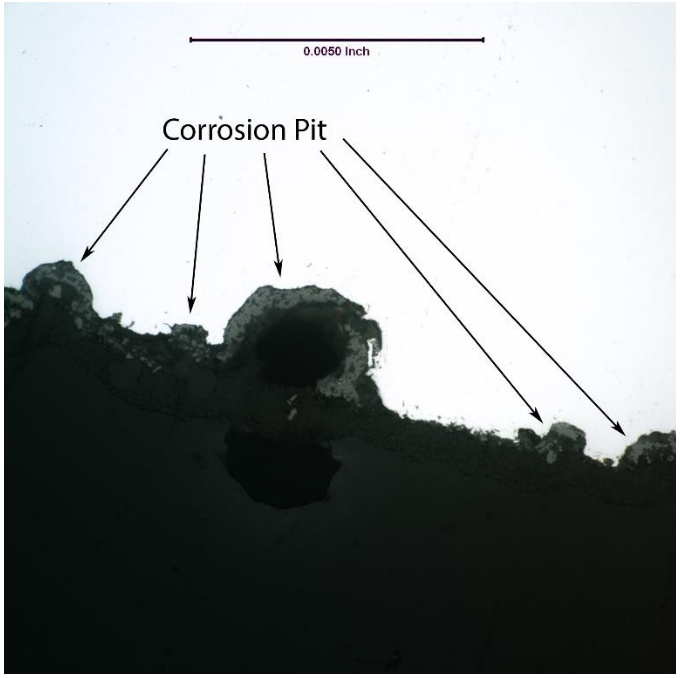

Figure 9 – 400X Corrosion Pits on Spring Wire Surface

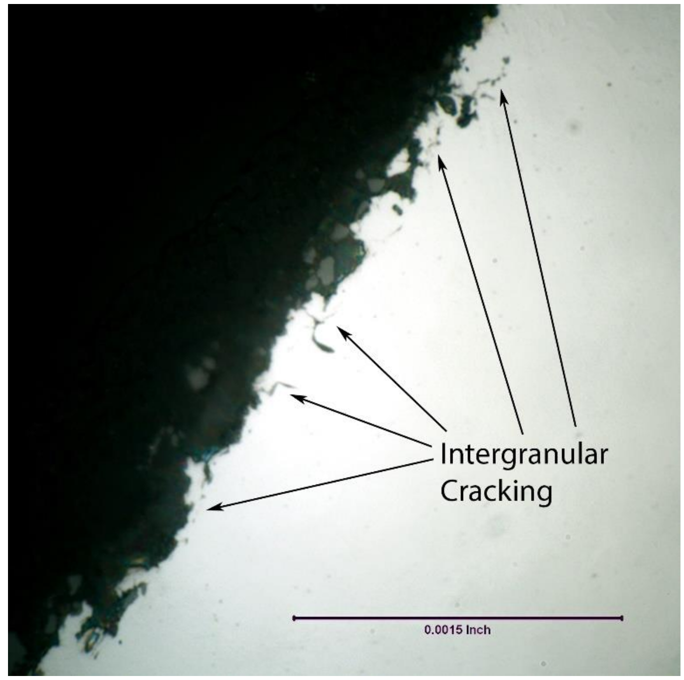

Figure 10 – 1500X Intergranular Cracking on Spring Wire Surface

Conclusions

1. The spring failed in two locations due to hydrogen embrittlement of the spring wire.

2. The most probable source of the hydrogen embrittlement was corrosion on the surface of the wire, as shown in Figures 9 and 10.

3. The hardness of the spring wire was significantly harder than the wire normally used. The higher hardness makes the wire more susceptible to hydrogen embrittlement.

4. The tool marks were not involved in the failure of this spring.