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Off Road Equipment Failure and Repair

By

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## Subject

Examination of Sweep 6 to determine cause of failure and repair procedure. A section of material removed from the support was examined by visual examination, chemical analysis, hardness testing, metallographic examination, and fracture mechanics to determine the cause of failure, and the best way to weld repair the tube. Replacement of the tube was not an option.

## Visual Examination

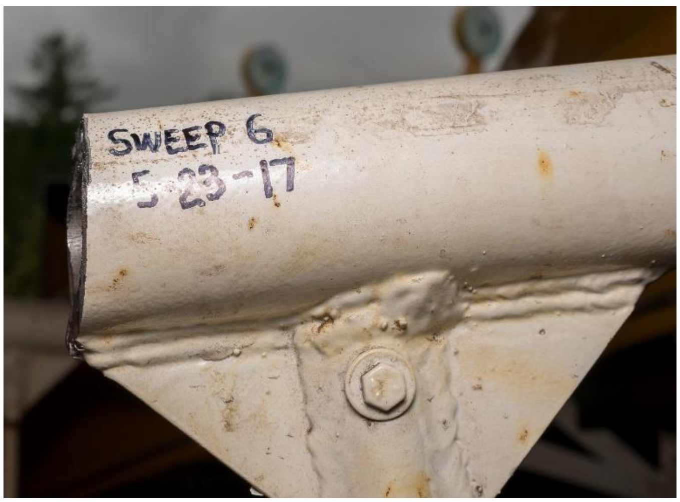


Figure 1 –Sweep 6 Failure Location

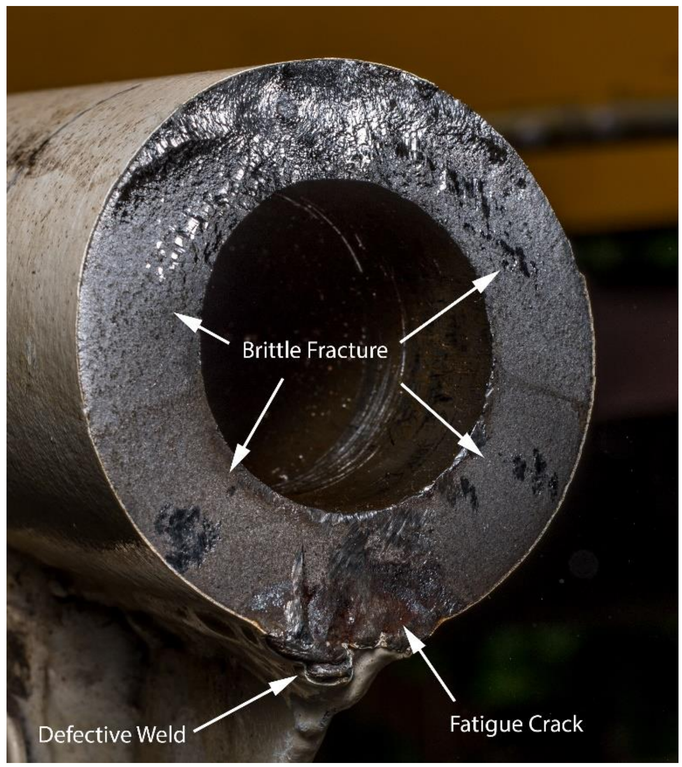


Figure 2 – Sweep 6 Fracture Surface

Figure 1 shows the location where Sweep 6 broke. The failure started at the gusset start/stop weld location as a fatigue crack, Figure 2. The weld on the left-hand side, indicated by an arrow, shows lack of fusion and was therefore defective. The fatigue crack had been present for some time, as indicated by the rust on the surface. The remainder of the fracture was brittle and appears to have been the result of two different

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events, as indicated by differing coloration on the surface. The lower section in Figure 2 was one event, and the upper section was an additional event.

## Chemical Analysis

The chemical analysis was done according to ASTM E1019 for carbon and sulfur, and E415 for the other elements. The results of the analysis are given in the table that follows.

| **Chemical Analysis** (Percent by Weight) | |
|---|---|
| Element/Location | Tube |
| Carbon | 0.28 |
| Manganese | 0.66 |
| Phosphorous | 0.007 |
| Sulfur | 0.011 |
| Silicon | 0.16 |
| Nickel | 0.01 |
| Chromium | 0.02 |
| Molybdenum | 0.01 |
| Copper | 0.01 |
| Carbon Equivalent | 0.42 |

The tube was fabricated from an AISI/SAE 1030 steel that may have been sold as ASTM A36 steel tubing. The calculated carbon equivalent is 0.42. The carbon equivalent is high enough to require preheating. Post heating should be done due to the fact that the tube failed by brittle fracture. The manganese content is low. The combined manganese-carbon indicates that the ductile brittle transition temperature is above room temperature.

## Hardness Testing

The hardness testing was done according to ASTM E385, using a Vickers indenter and a 500 gram load. The results of the testing are given in the table that follows.

| **Hardness Test Data** (Rockwell B Scale) | | | | | |
|---|---|---|---|---|---|
| Location | Knoop | STD DEV | MAX VALUE | MIN VALUE | HARDNESS |
| Sample 1 | 234.00 | 6.22 | 240.00 | 225.00 | 96.40 RB |
| Sample 2 | 225.00 | 15.22 | 243.00 | 202.00 | 94.75 RB |

The hardness is not unusual for this grade of steel, but is high for the microstructure of the steel. More discussion is included in the metallographic examination section.

## **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.

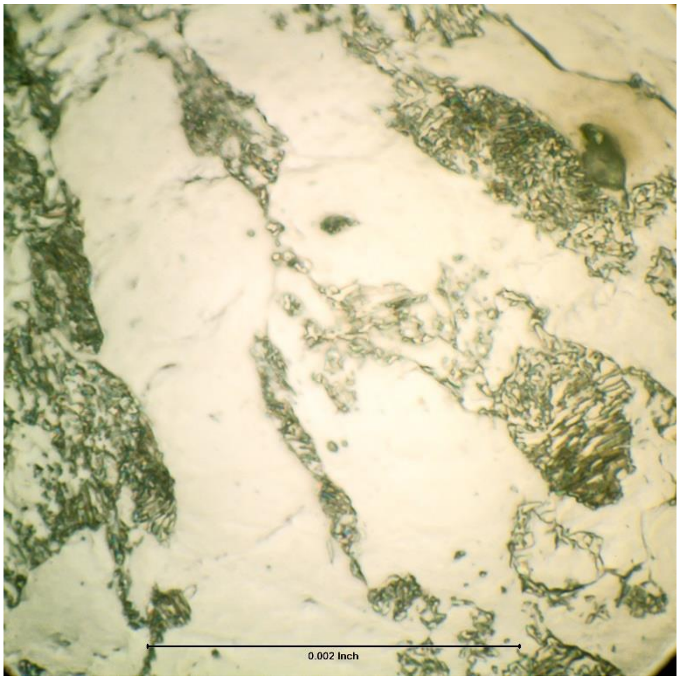

Figure 3 – 1500X Tube Steel Microstructure

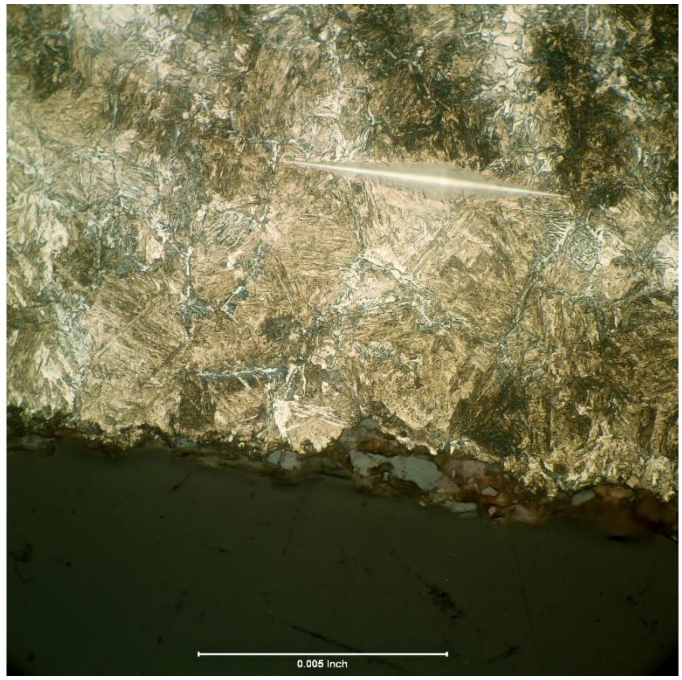

Figure 4 – 400X Weld HAZ

Figure 3 shows the microstructure of the tube used for Sweep 6. The microstructure is fine grained and consists of coarse pearlite and carbides. The microstructure is similar to the microstructure produced by subcritical annealing. A 0.28% carbon steel having this microstructure would be expected to have a hardness in the 70 Rockwell B scale range. The hardness in the mid 90's Rockwell B scale range indicates that this tubing was highly cold worked after annealing. The condition of the steel in the sweep tube was a contributing factor in the failure of Sweep 6.

Figure 4 shows the martensitic heat affected zone near the origin of the fatigue crack. The Knoop indenter impression shown in the photo indicated a hardness of 40 on the Rockwell C scale. That is too hard for a heat affected zone in a carbon steel containing 0.28% carbon. There is also iron oxide scale on the surface, indicating the crack had been open for a long period of time.

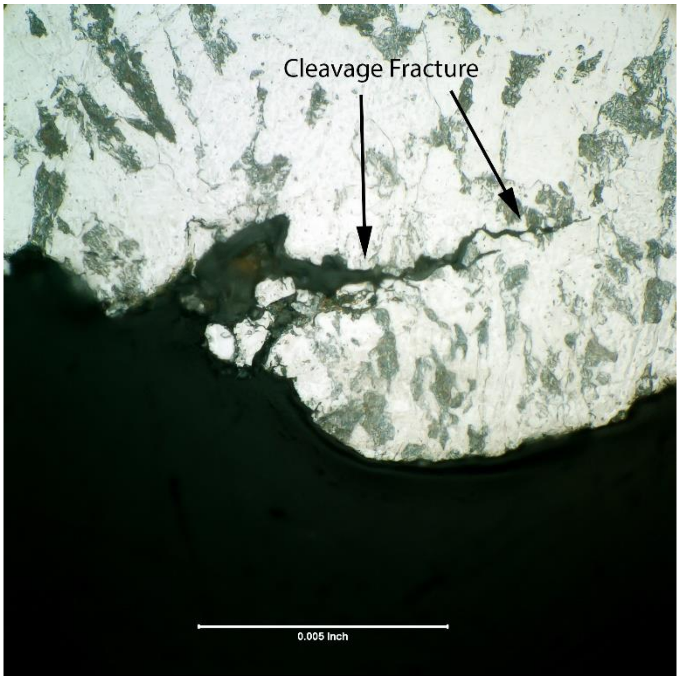

Figure 5 – 400X Cleavage Fracture

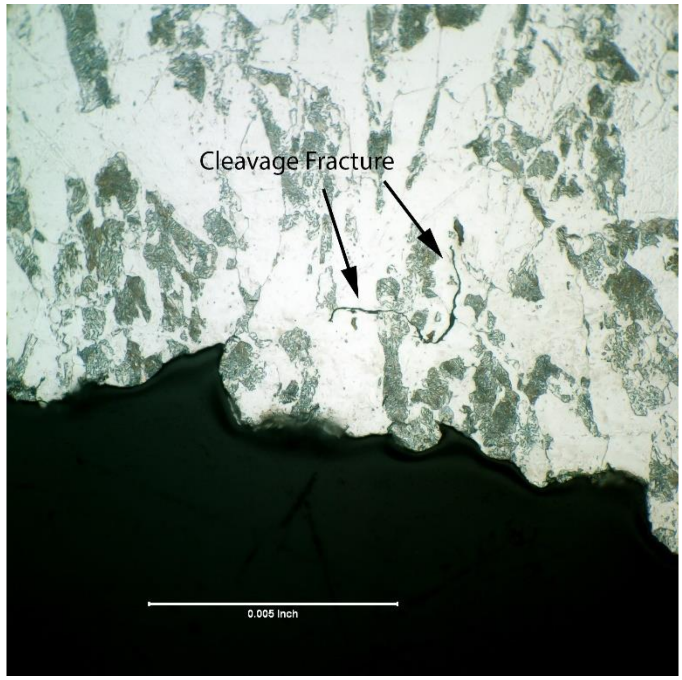

Figure 6 – 400X Cleavage Fracture

Figures 5 and 6 show examples of cleavage fracture. Cleavage fracture is a brittle fracture mode found usually in highly cold worked carbon steels. They are both temperature and strain rate (impact loading) dependent.

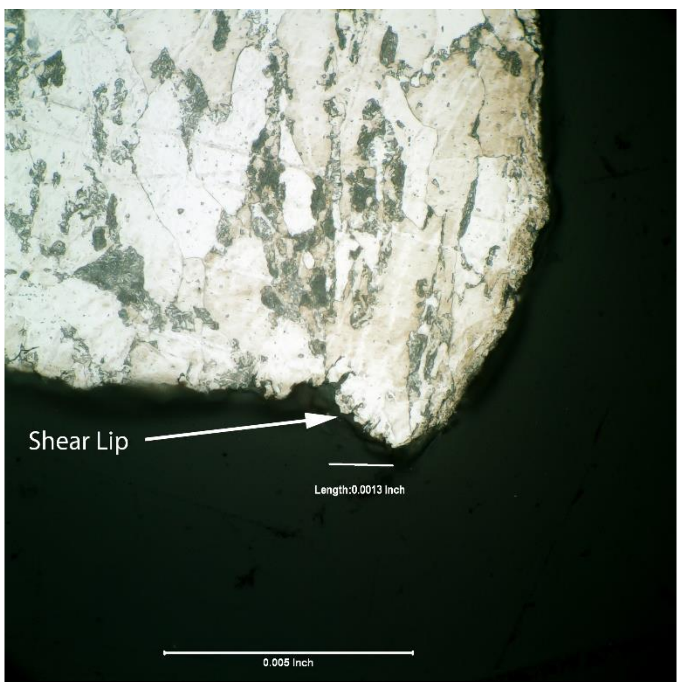

Figure 7 – 400X Shear Lip

Figure 7 shows a very small shear lip. The size of the shear lip is an indication of the load required for the failure to occur. Fracture mechanics can be used to estimate this load.

## Fracture Mechanics

The following equation can be used to estimate the load required to cause a failure based on the size of a shear lip: $shear\ lip = \frac{Y^2 \sigma^2 a}{2\pi\sigma_{ys}^2}$. Sigma squared sub ys is the value of yield strength squared. The yield strength is estimated at 80,000 psi. Y is a geometry factor of 2.1, sigma squared is the applied load, and "$a$" in this instance is the thickness of the tube wall of 0.516 inches.

The estimated impact load that caused the failure was 4800 pounds. That is a very small load considering the length of the Sweep as a moment arm. Temperature was also a factor in the failure. The temperature was down to 44 degrees F. on the 23rd of May.

## Conclusions

1) Sweep 6 was fabricated from highly cold worked AISI/SAE 1030 carbon steel.
2) Sweep 6 failed by brittle fracture at a very low stress level due to the cold working, the presence of a defective weld start/stop, a fatigue crack, and cold weather.
3) The carbon equivalent of the steel is high enough to require pre-heating prior to weld repairing, and the highly cold worked steel means that post heating after welding is required.

## Recommendations

1) Preheat to 150 degrees F. prior to welding.
2) Post heat to a minimum of 600 degrees F. following welding.
3) Preheat and post heat a minimum of 6 inches either side of the weld area.

The repaired sweep has been in service for a number of years after the repair without any additional problems.