SAE Welded Square Tube

The SAE Fatigue Design and Evaluation Committee coordinated a series of experiments and analysis to compare fatigue analysis techniques used by various industries to assess the durability of welded structures. Two steel tubes were welded into a T" shape to simulate the production component taken from shown in Figure 1. This is a common weld configuration found in agricultural equipment.

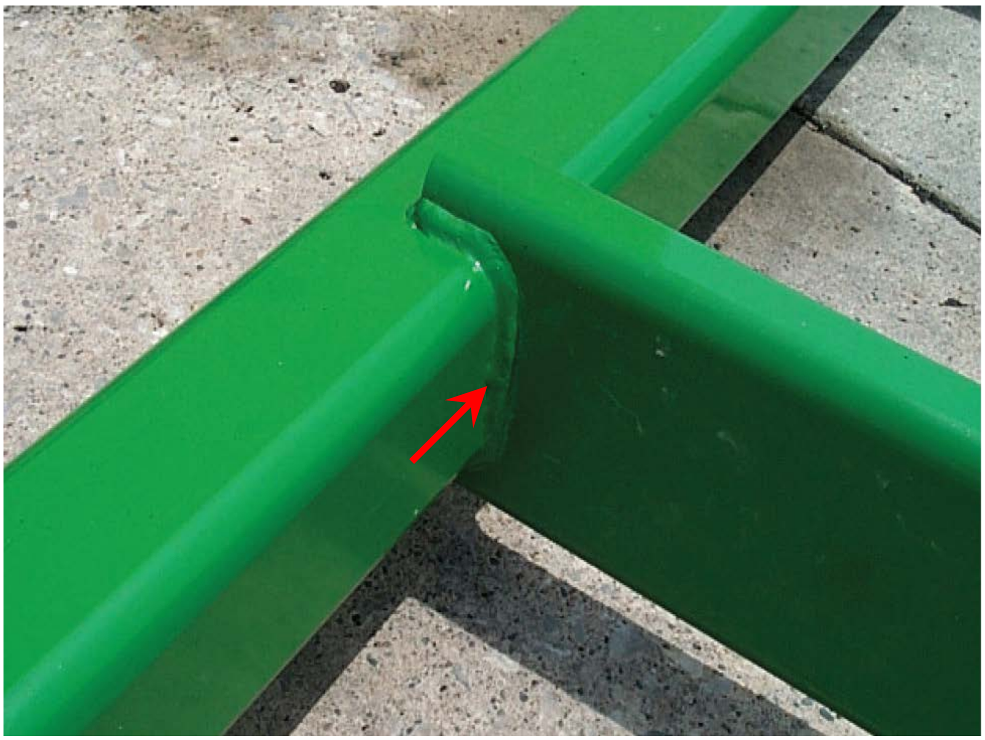

Figure 1. Typical weld detail found in agricultural equipment

This joint is subjected to combined bending and twisting loads. This detail served as the basis of a laboratory specimen that could be easily tested. The specimen, Fig. 2, is fixed on two ends and forces are applied through a lever arm attached to the third end. This design produces both bending and torsion stresses in the square tube. The distance from the force to the weld toe in bending is 271.5 mm and the distance of the applied force to the centerline of the square tube is 317.5 mm.

The specimen is manufactured from a 4" (101.6 mm) square structural steel tube and a 2" x 6" (50.8 x 152.4 mm) rectangular tube, both with a 0.312" (7.9 mm) wall thickness. The partial penetration fillet weld is the same size as the tube wall thickness and was manufactured with the MIG welding process.

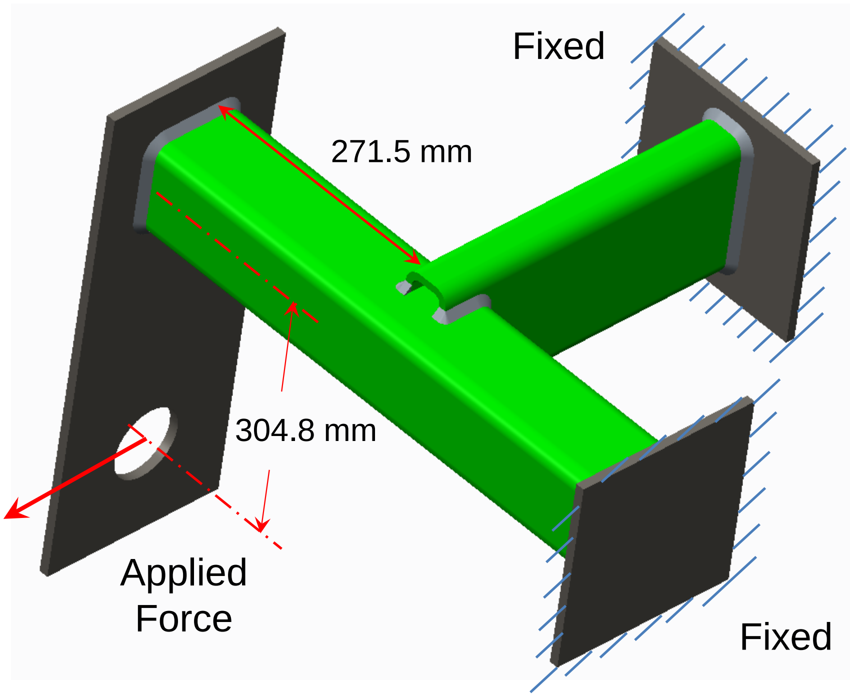

Figure 2. Test specimen

Test setup is shown in Fig. 3. Specimens are typically painted white to aid in visual crack detection. Fatigue tests were conducted with a completely reversed load (R = -1) of 17.8 kN.

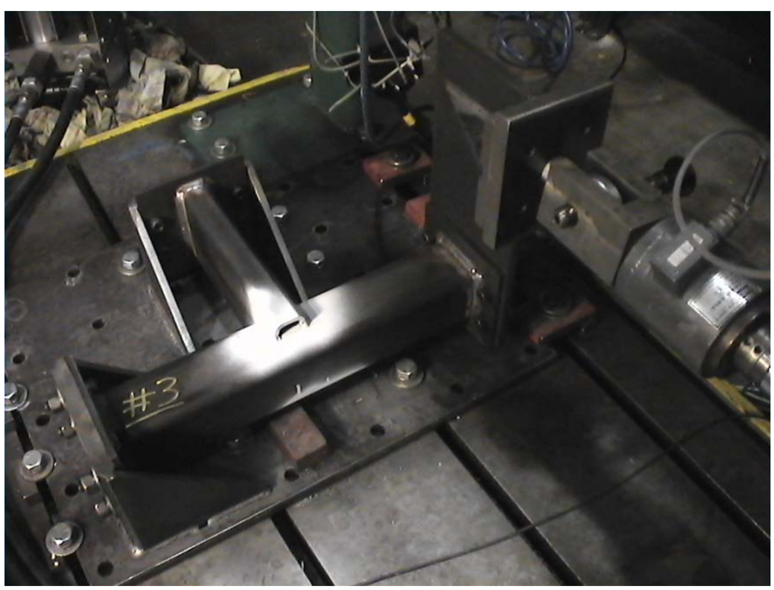

Figure 3. Test fixture

Tube Properties

Structural steel tubes are specified as the dimension on the outside thus a 4" square tube measures 4" on the outside. The corner radius is typically equal to the thickness on the inside and twice the thickness on the outside. They are manufactured from ASTM A36 steel. This low carbon steel is equivalent to steel ranging from SAE 1010 to SAE 1025. It has a minimum yield strength of 250 MPa and a tensile strength ranging from 400 – 550 MPa.

Here is some strain-life fatigue data for A36 steel taken from *Miller and Reemsnyder "Strain Life Fatigue of Sheet and Plate Steels I: Test Method Development and Data Presentation" SAE paper 830175, 1983*.

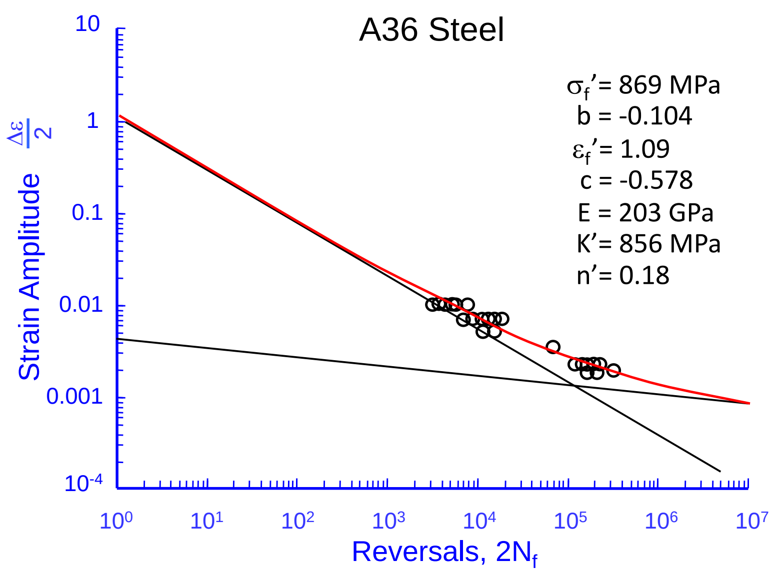

Figure 4. Strain life data for A36 steel

Crack growth data for A36 steel is available from *Barsom, "Fatigue Crack Propagation in Steels of Various Yield Strengths" Journal of Engineering for Industry, Trans. ASME, Series B, Vol. 93, No. 4, 1971, 1190-1196.*

Barsom suggests a single crack growth relationship for all Ferritic-Pearlitic steels.

$$\frac{da}{dN} = 6.9 \times 10^{-12} \left(\Delta K \, MPa\sqrt{m}\right)^{3.0}$$

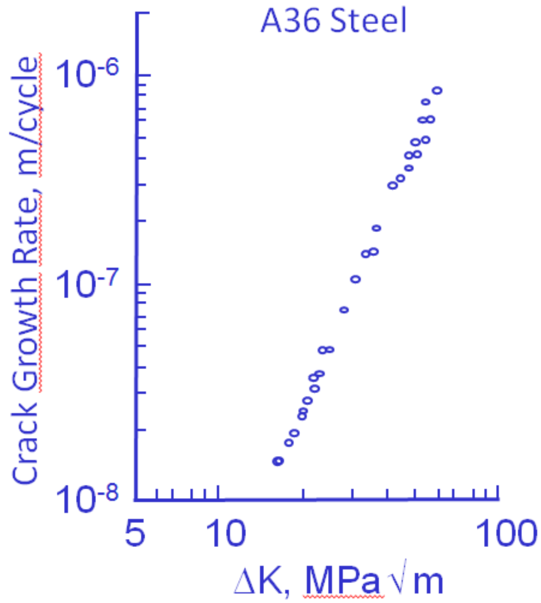

Figure 5. Crack Growth Rate for A36 Steel

Stress Analysis

Nominal bending stress, σ, at the toe of the weld (red arrow in Fig. 1) in the tube may be computed from simple beam theory.

$$\sigma = \frac{Mc}{I} = \frac{M}{Z}$$

The 4" square tube with round corners has a section modulus, Z, of 3.8×10^6 mm^4.

σ = (17800 N ·271.5 mm ·50.8 mm) / (3.8×10^6 mm^4) = 64.6 MPa

Solutions for shear stresses in torsion are obtained from *Ridley-Ellis, Owen and Davies "Torsional Behaviour of Rectangular Hollow Sections" Journal of Constructional Steel Research, 59 641-663, 2003.*

The principal stress in torsion is equal to the shear stress. The stress is a maximum in the center of the tube face and decreases in the corners where the material is farther away from the centerline.

$$\sigma = \tau = \frac{T}{C_t}$$

For the 4" tube, $C_t = 1.17 \times 10^5$ mm^3.

$\sigma = \tau$ = (17800 N · 304.8 mm) / (1.17×10^5 mm^3) = 46.4 MPa

Test Results

Test results are presented in Fig. 6 for the welded tube. Fatigue lives for twelve constant amplitude tests are presented in a log-normal probability format. These tests were conducted in completely reversed loading, R = -1, so that the stress ranges are twice those computed above.

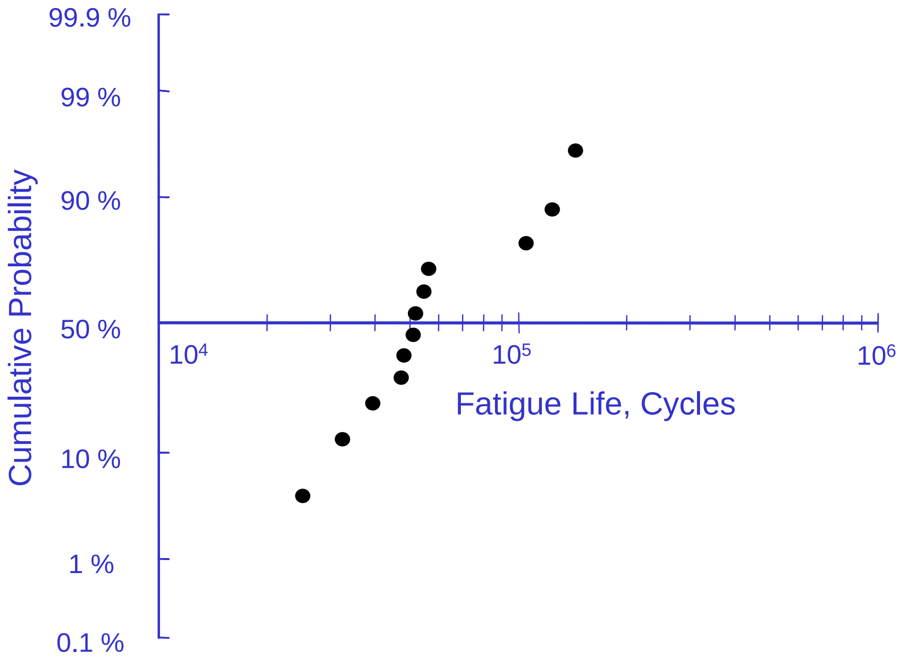

Figure 6. Fatigue Test Results

Calculation Exercises / Discussion Questions

1. Provide an analysis to show where the most likely failure location is located.

2. What is the expected fatigue life? How does your estimate compare to the experiments?

3. Comment on the observed variability in fatigue life. Better than expected, worse than expected, etc.