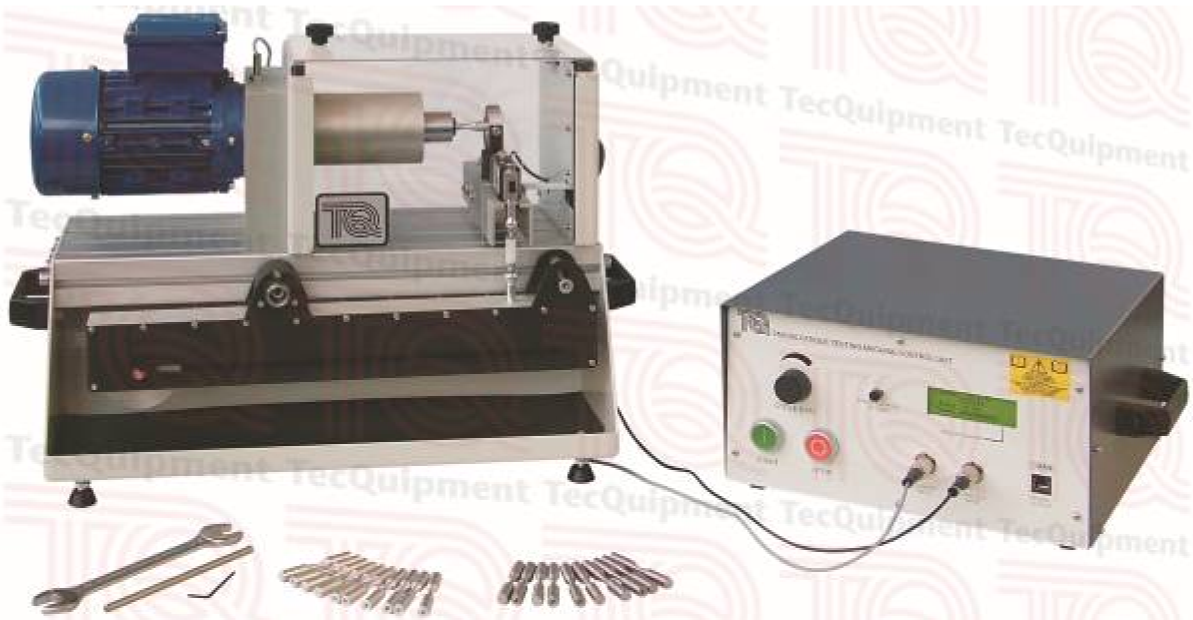
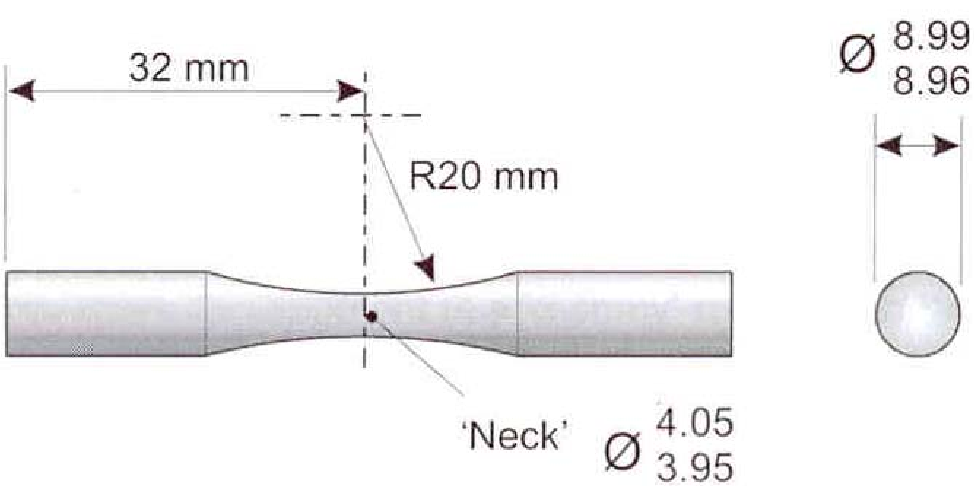
S-N Curve and Fatigue

Rotating Fatigue Machine Experiment



Specimen



Rotating Fatigue Machine

Theory

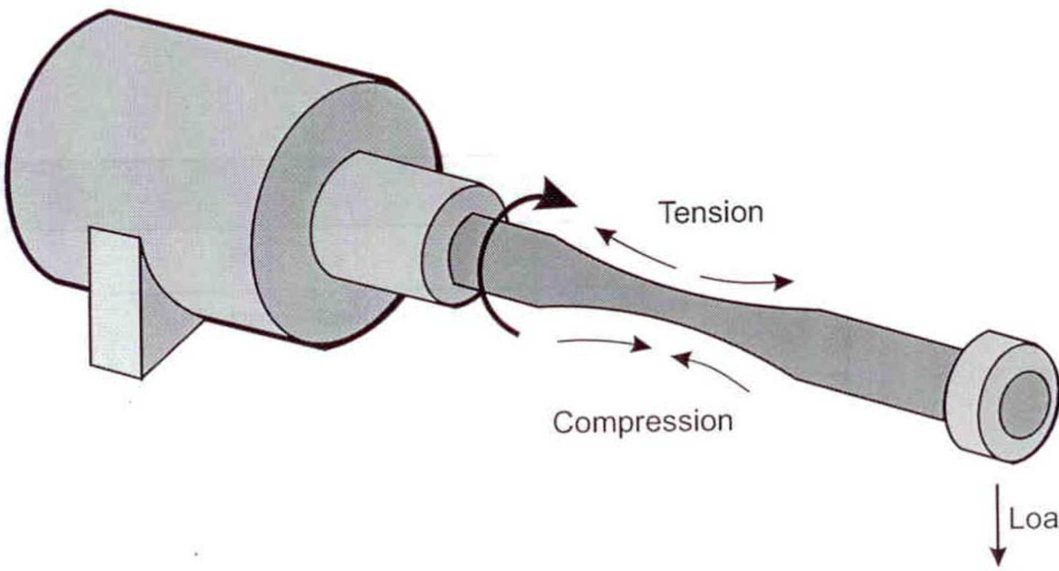


Figure 1: Rotating Cantilever

The Rotating Fatigue Machine clamps the specimen as a cantilever (figure 1). The load on its free end creates tension on the upper half of the specimen and compression on the lower half. However, because it rotates, it has alternate compressive and tensile stress on any given part along the unsupported length of the test specimen.

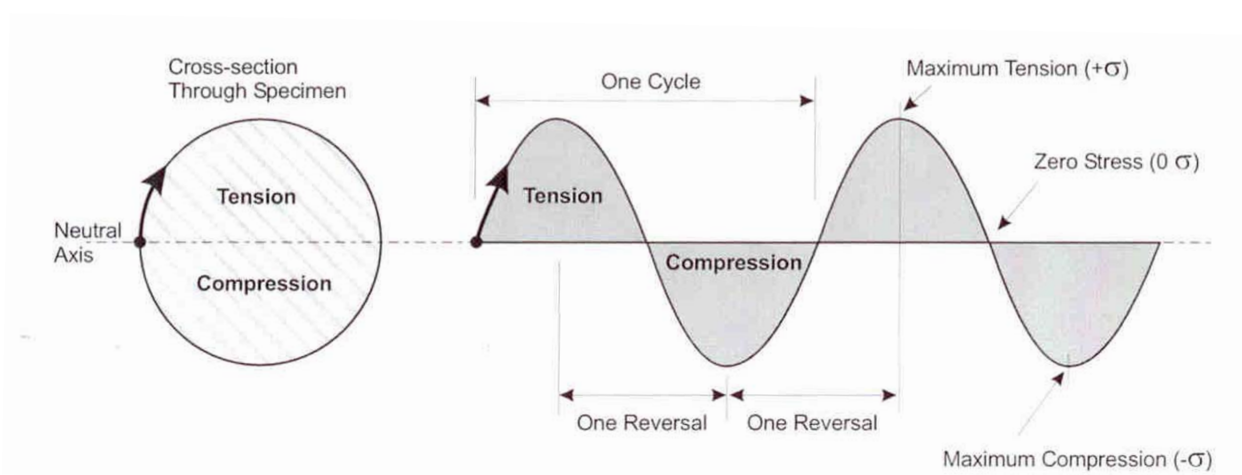


Figure 2: Cycles and Reversals

Figure 2 shows a cross section through the specimen as it rotates. Any fixed point on the unsupported length of the specimen moves through one **cycle** of compression and tension. In each cycle, the stress at that point moves from zero stress point to **maximum tension** (+σ), back through zero stress and to a **maximum compression** (-σ) point. It then moves back to zero stress and repeats the cycle. As the stress fully reverses (from positive to negative or vice versa), this is called **reversal. Each cycle has two reversals**.

Stress (σ)

This is the force applied to a material over a known area, shown by Equation 1.

$$\sigma = \frac{F}{A} \tag{1}$$

Compressive stress is where the material is compressed. It has a negative value.
Tensile stress is where the material is stretched. It has a positive value.

Cantilever Theory

Second Moment of Area and Stress

The second moment of area for either axis of a symmetrical circular cross-section beam is:

$$I_x = \frac{\pi D^4}{64} = I_y$$

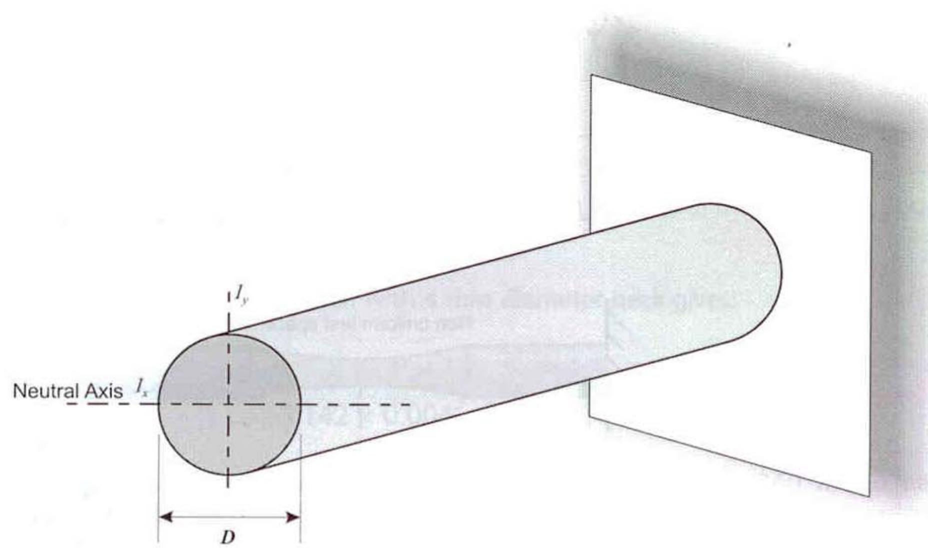


Figure 3: Cantilever Circular Cross-section Beam

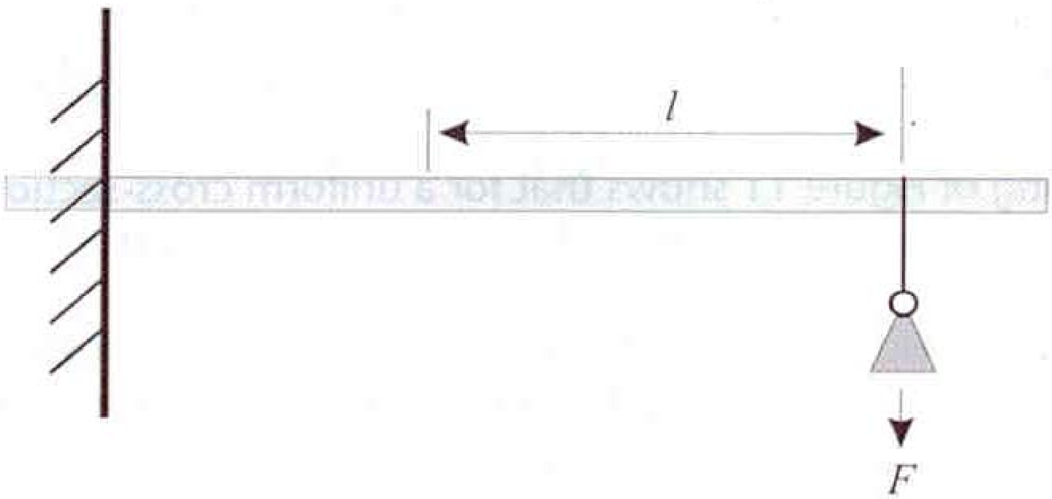


Figure 4: Bending Moment for a Beam

Beam Bending Moment (M)

For a cantilever beam (supported at one end), the bending moment:

$$M = Fl \qquad (2)$$

Stress Along A Beam

From the Engineer's theory of bending, the theoretical stress at any point along a uniform cross-section cantilever beam (in elastic bending) is:

$$\sigma = \frac{My}{I_X} \qquad (3)$$

Where y in this case is D/2

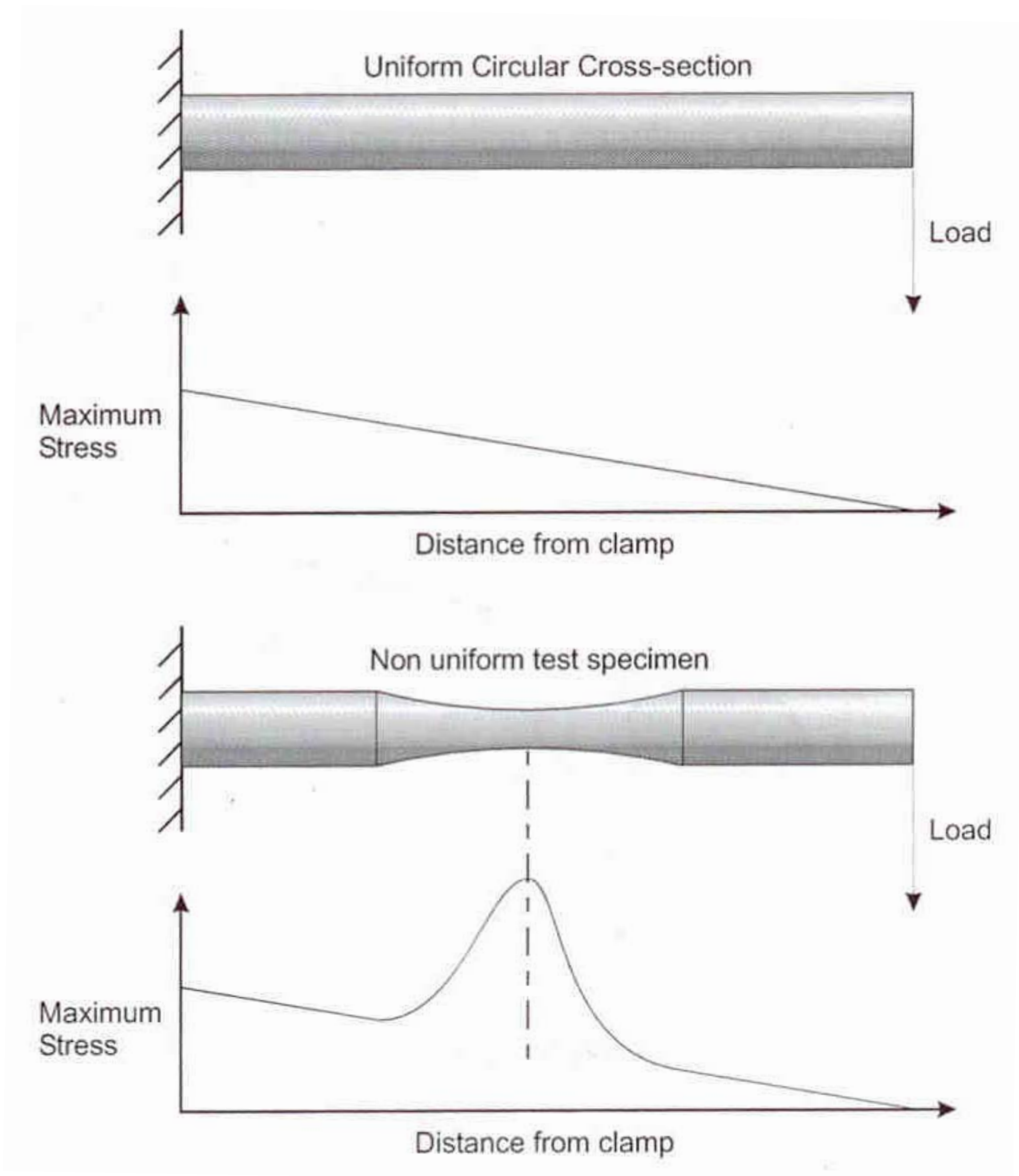


Figure 5: Stress and Distance Charts for Uniform and Non-uniform Cantilevers

The upper drawing of Figure 5 shows that for a uniform cross-section cantilever with a load at its end, maximum stress is at the clamped end. Its most likely to break at that point.

The lower drawing of Figure 5 shows that for a non-uniform cross-section beam, the max stress point may be somewhere else along the beam. The standard specimen has a max stress point halfway along the thinner section (its neck) and it should fail at this point.

Low Cycle and High Cycle Fatigue

Normal 'high cycle' fatigue tests use forces that stress the specimen in its ***elastic*** region (below its yield strength). This will take many stress reversals (and therefore cycles) before the specimen fails. The high number of cycles needed to fail the specimen gives this type of fatigue the name 'high cycle fatigue'. High cycle fatigue tests usually last for at least 100000 cycles.

Another useful and equally valid test is the low cycle fatigue test, which uses larger forces than the high cycle tests and stresses the specimen in its ***plastic*** region (above yield strength). Low cycle fatigue tests usually last for between 100 and 10000 cycles.

High Cycle S-N Curves and Fatigue

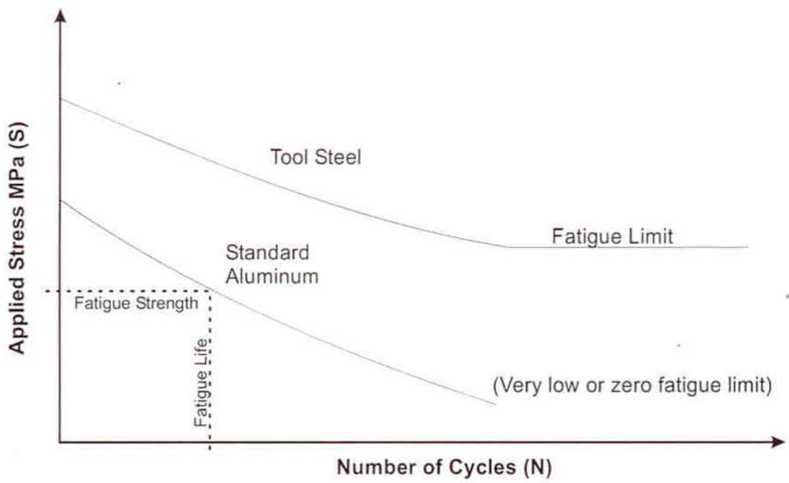


Figure 13 Typical S-N Curves (High Cycle Tests)

Figure 13 shows typical S-N (stress - number of cycles) high cycle test curves for identical parts made of two different metals. The curves help engineers to compare different materials to choose the best for the job.

Important Information Taken from High Cycle S-N Curves

Figure 13 also shows a special property of steel - it has a ***fatigue limit***. This means that below a given applied stress, it will not fail due to fatigue. So, designers would normally make sure that any parts made of steel do not have repeated applied stress above its fatigue limit.

Aluminium will fail due to fatigue even at low repeated stress levels. It has a zero or a very small fatigue limit. So, if designers use aluminium and it is under repeated stress, they can use the curves to find a ***fatigue life*** for a given applied stress (its fatigue strength).

Because some metals (including aluminium) have no fatigue limit, specifications for these metals show ***fatigue strength.*** This is the maximum stress you can use for a given number of cycles. The dotted line under the aluminium curve in Figure 13 shows this. Textbooks and other sources of specifications normally show fatigue strength based on a given number of cycles (for example - 5×10^7 or 5×10^8 cycles).

Engineers often use ***fatigue ratio*** to compare materials. This is the ratio of the fatigue limit to the tensile strength of the material.

$$FatigueRatio = \frac{FatigueLimit}{TensileStrength}$$

Fatigue ratio is normally approximately 0.5 for most iron based (ferrous) materials, because its fatigue limit is usually approximately half its tensile strength.

Other Useful Information about Fatigue

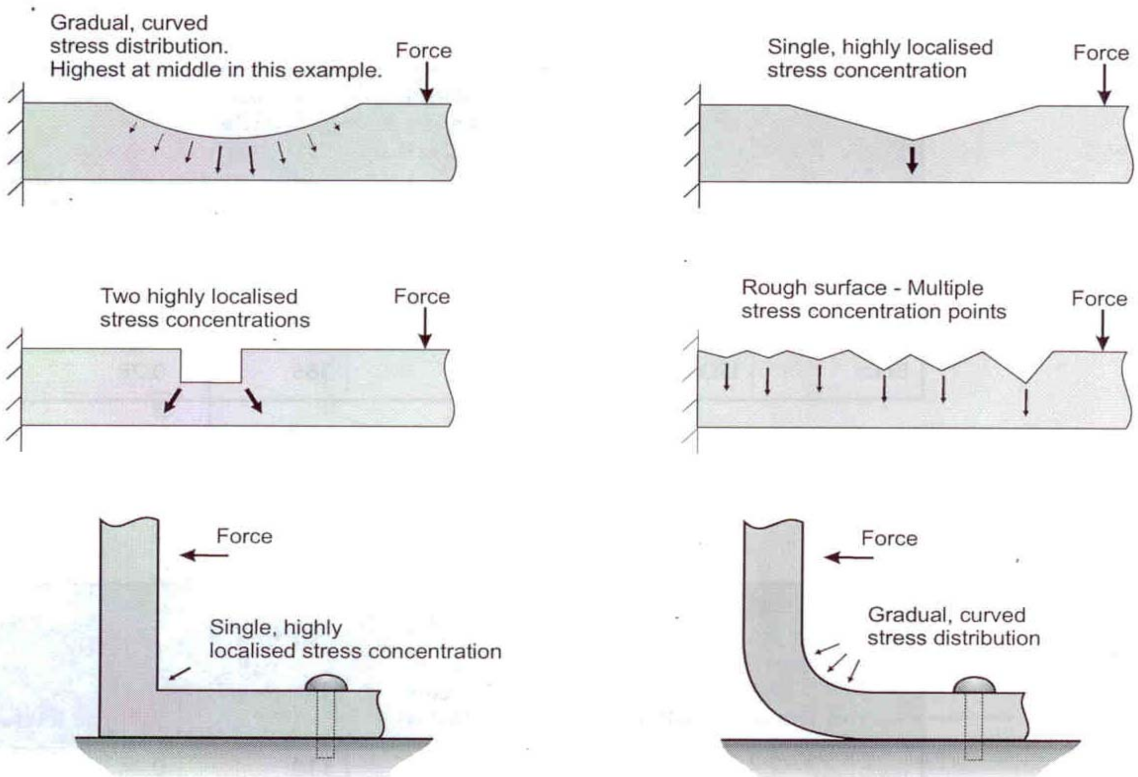
Fatigue and Temperature

Temperature affects fatigue resistance in most materials. As they get hotter, they also get weaker and their fatigue life decreases.

Fatigue and Stress Concentrations

Fatigue tests use ideal specimens tested in ideal conditions. The fatigue fracture occurs at the known point of highest stress. In reality, many parts may have localised points of ***stress concentration***, which will cause premature fatigue failure.

Consistent material quality is important. If part of the material is incorrectly made, or changed during manufacture (for example - uneven heat treatment), its tensile strength will be wrong and it may have localised stress concentrations. Both will cause unpredictable and possibly premature fatigue failure.



Procedure

1. Create a blank table of results similar to the one below.

Fatigue Test		
Specimen	Type	RF 1020
	Material	Aluminum Alloy
	Yield Stress	220 MPa
	Tensile Strength	395 MPa
	Surface Finish	Shinny
	Diameter at neck	4.01 mm
Test	Test Load (N)	55.4
	Test Stress (MPa)	
	Cycle Rate (Hz)	60 Hz
	Start time of test	
	Stop time of test	
	Cycles to fatigue fracture (Cycle Count)	50,900
	Time taken to fracture	14:11

Year	09	10	11	12	13	2014	2015	2016	2017	2018	2019
Load, F (N)	75.5	71	59.4	54.5	49.8	46.4	66.2	74.6	61.5	55.4	
Stress, MPa	384	363.96	304.5	275.3	255.5	234.4	334.4	376.8	310.6	261.7	
Cycles Count	7,022	10,014	30,068	39,490	113,091	140,404	13,443	6,780	19,814	50,900	

2. Measure the specimen for accuracy.
3. Fit the aluminum specimen into the machine. Fit the safety guard
4. Move the dead weight to the furthest left position (lowest of neutral stress position).
5. Turn on the machine. Make sure the speed control of the Control and Instrumentation Unit is set to minimum (fully anticlockwise). Move the dead weight along the arm to select a suitable load for the specimen material.
6. Gently support the loading arm so the load display shows zero and press the motor start button on the Control and Instrument Unit. Record start time.
7. Slowly turn the motor speed up until the cycle rate is 60 Hz (+/- 1 Hz).
8. Take your hand away from the loading arm and allow the motor to run.
9. Record the Cycle Rate.
10. When the specimen breaks, record the cycle count and stop time.

Requirements

1. **1.** From your results, create an S-N Curve to fit your data and the data (from previous experiments) given by the instructor.
   - Plot stress (linear vertical axis) against cycle count (logarithmic horizontal axis) and compare to standard results for the material.
2. **2.** Make a report including your observations and S-N plot.