Software Tools for a Material Testing Curriculum

Sixth Symposium on Application of Automation Technology in Fatigue and Fracture Testing and Analysis

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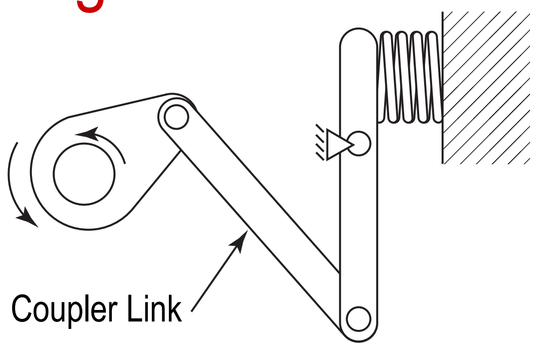
University (and also Industry?) Curriculum to teach the basic principles of

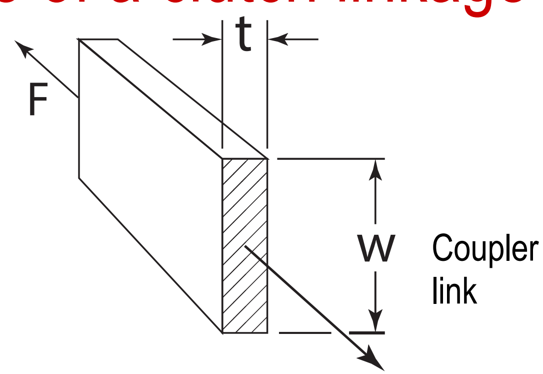
- Tension
- Fatigue
- Fracture

The “integrated” Curriculum consists of

- Lecture Notes
- Lab assignment
  - ❖ Test/Report Templates (student and professor versions)
- Homework

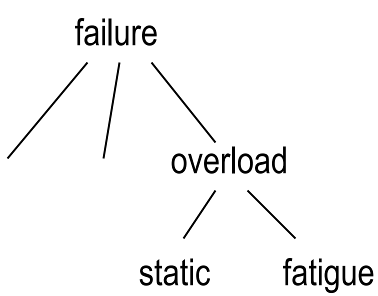
Begin with an example of a clutch linkage





The coupler link is a two-force member loaded in tension, carrying a maximum load of 4.5 kN.

Q: How might it fail?



One obvious answer: if the 4.5 kN load is too much for the link to carry.

An “overload” failure in this case could occur in (at least) two different ways – a static failure, or a fatigue failure.

Material Properties

Let's begin this design by choosing the dimensions "t" and "w" that will guard against a static overload.

Material Properties

The property we are most interested in is the yield strength S_y

» If the stress, σ exceeds the yield strength

$$\sigma > S_y$$

the link has yielded, and we consider this failure

» The yield strength is determined especially from the "tension test", which in the United States is defined by ASTM (American Association of Testing of Materials)

Naming Conventions

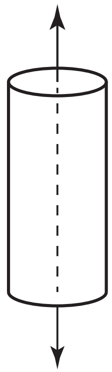
S: "strength" i.e. a maximum allowable stress

subscripts indicate what kind of strength, e.g.

S_{UT}: ultimate tensile strength

S_y: ultimate tensile strength

Tension Test



Take a sample of the material and increase the load until it fails.

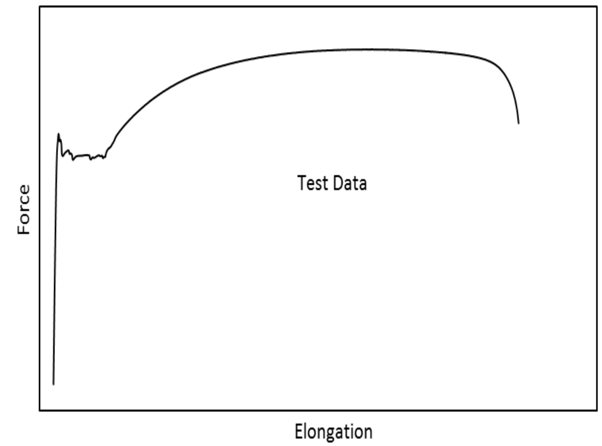
Simple enough ***BUT***…

For this test to be repeatable in labs around the world, the sources of variability in the test results must be minimized.

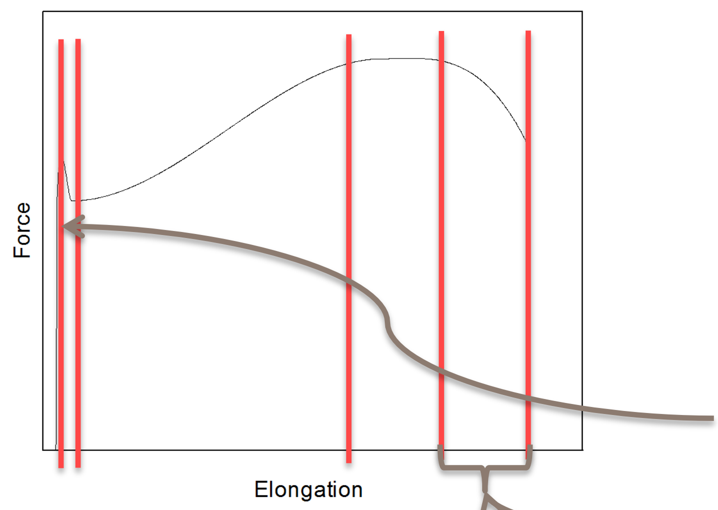
e.g.

- If one lab uses 1/4 inch diameter specimens, a lab using 1 inch diameter specimens might get a different result.
- If one lab applies load at 500 MPa/min, another lab using 1000 MPa/min might get a different result.

Tension Test - Lecture



Real data



Simulation

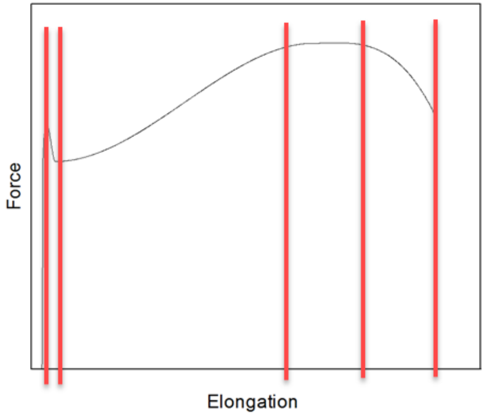
Model for approximated Force-Elongation response via 5 polynomials

$y = 207x$; (Hooke's Law), from 0 to 0.130 m/m

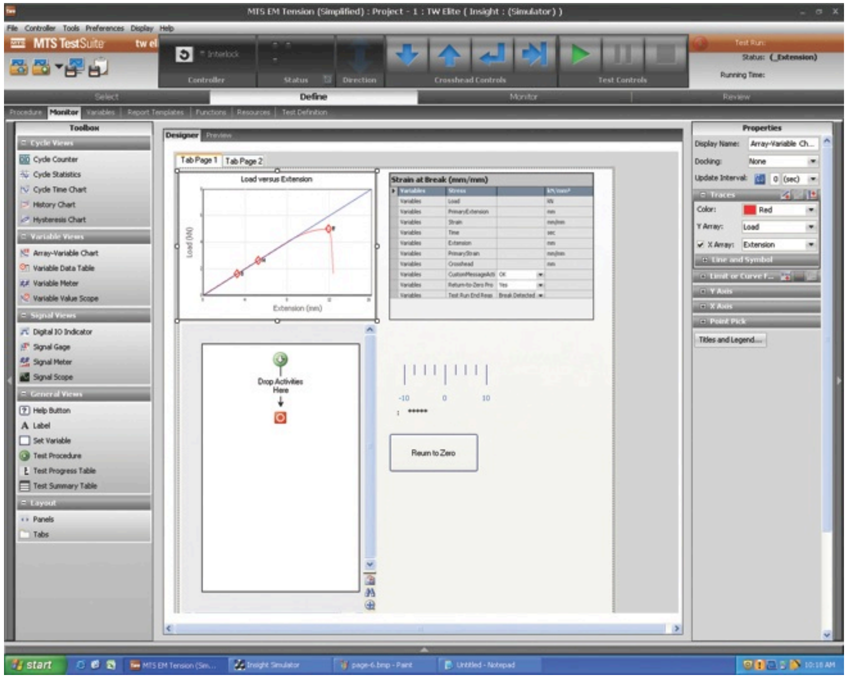
$y = -0.101343x^3 + 7.90634x^2 - 205.235x + 2221.09$; from 24.9 to 36 m/m

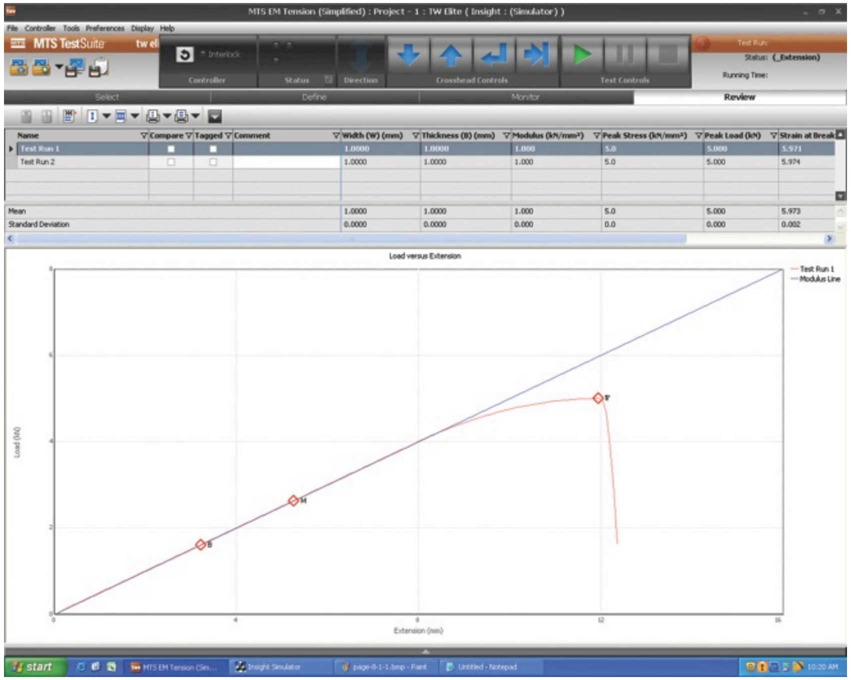
Simulation - Python

```
def SimulatedLoad_Steel(displacement_m):

        strainCurve = [0.0, 0.130,  0.360, 1.3, 24.9, 36 ]
        coef1 = [0.0, 207, 0.0, 0.0]

        coef2 = [151.43, 1214.62, -2871.36, 2450.51]
        …  …  …

        strain = displacement_m/GageLength*100

        if (strain <= strainCurve[1]):
                stress = Polynomial(strain, coef1)

        …  …  …

        return stress * Area
```



Software Interface Demonstration in the Classroom



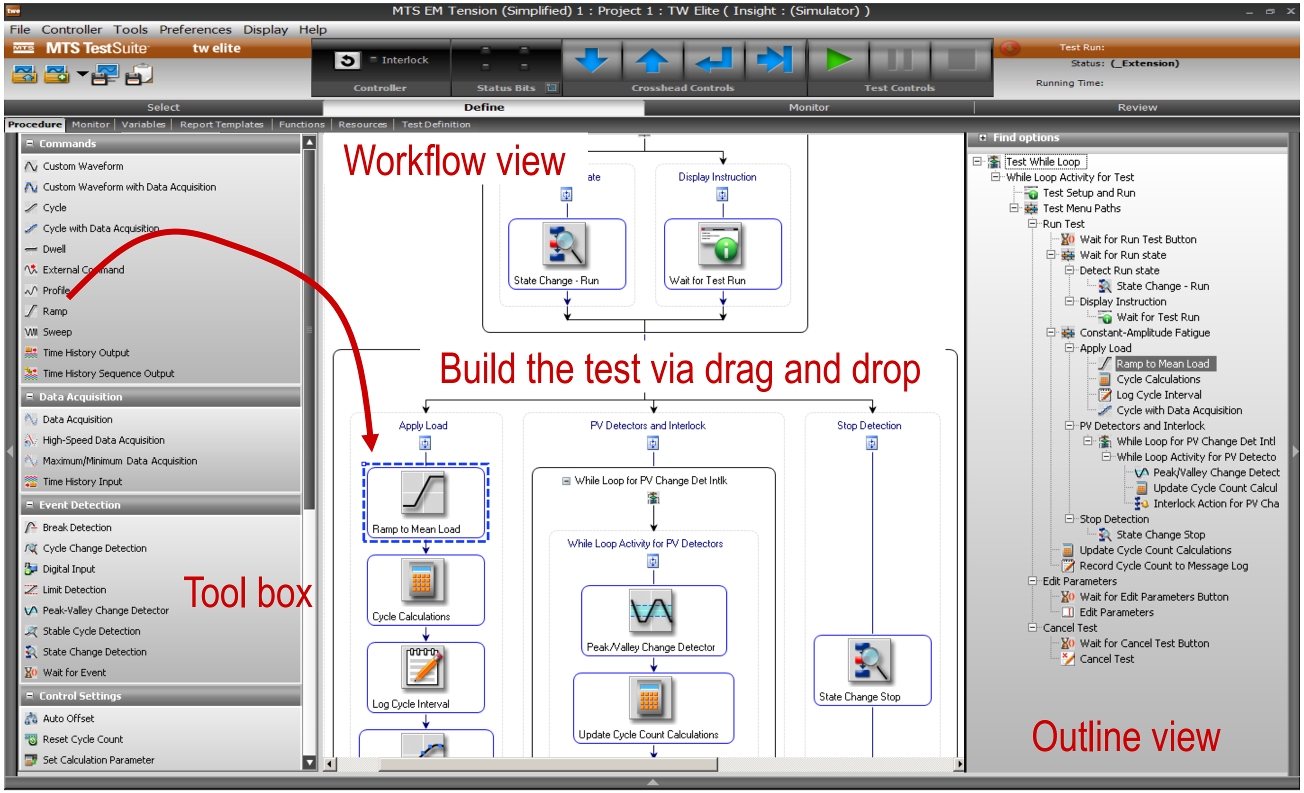


TestSuite Interface

MTS MATERIALS SOLUTIONS

» Creating the Test

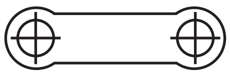
– 2-D Workflow editor, also with 1-D outline view



Intuitive test design, saves time in creation and troubleshooting

Summary of Lecture

- Knowing the yield strength and ductility of our material, we were able to properly size the body of the coupler link in our mechanism.
- The tension test provided us with the basic information we needed to guard against failure by static overload



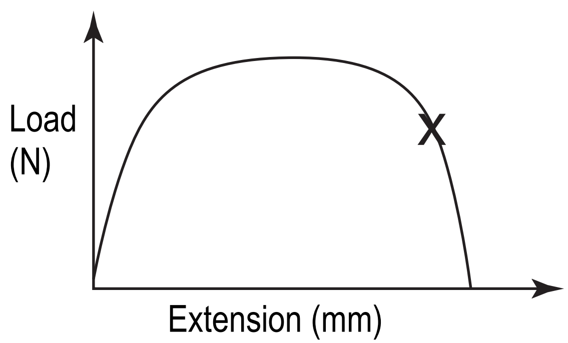
The ends need separate attention of course, because of the holes.

- To guard against other kinds of failure – fatigue, for instance – requires additional material properties not provided by the tension test.
- We'll discuss these other properties, and their corresponding tests another time.

Tension Test - Lab

Tension Test

- With an electromechanical (EM) test system, an electric motor drives a power source which raises the crosshead of the test machine at a specified rate.
  - *Safer and easier than servo hydraulic*
- The specimen is loaded at a uniform rate, until it eventually fails. This is shown in the graph below.



Tension Test - Lab

Yield Strength Determination

The transition of the material behavior under load from elastic to inelastic (plastic) deformation is called "yielding," and is delineated by the yield strength. Accurate determination of the yield strength requires the use of an extensometer.

We will consider two methods for specifying the yield strength. When the transition from elastic to inelastic strain is gradual and continuous on the stress-strain plot, then the offset yield strength is used to determine yielding. A more or less arbitrary amount of inelastic strain is chosen to define yielding. The unloading curve shown in red in Figure 1, for example, illustrates this definition. Since the unloading curve will have the same slope as the loading curve (i.e. the modulus of elasticity), the offset yield strength can be found by drawing a line parallel to the linear portion of the loading curve, offset by 0.2%.

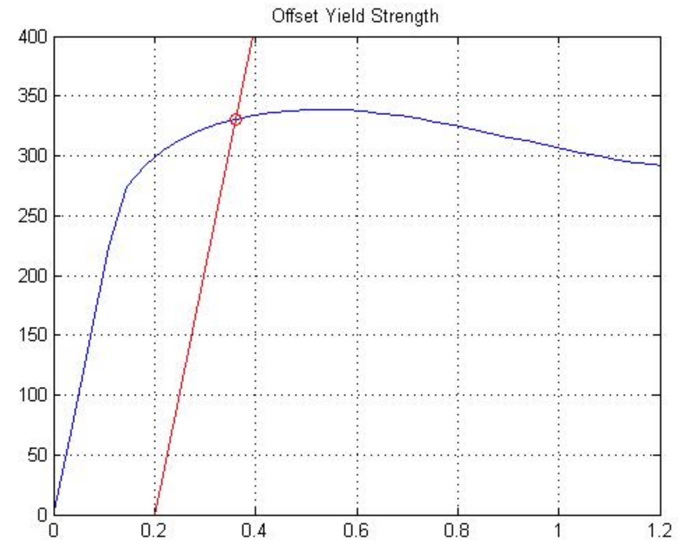


Figure 1: Offset Yield Strength

Tension Test - Lab

Procedure

CAUTION: Use eye protection when operating the test system.

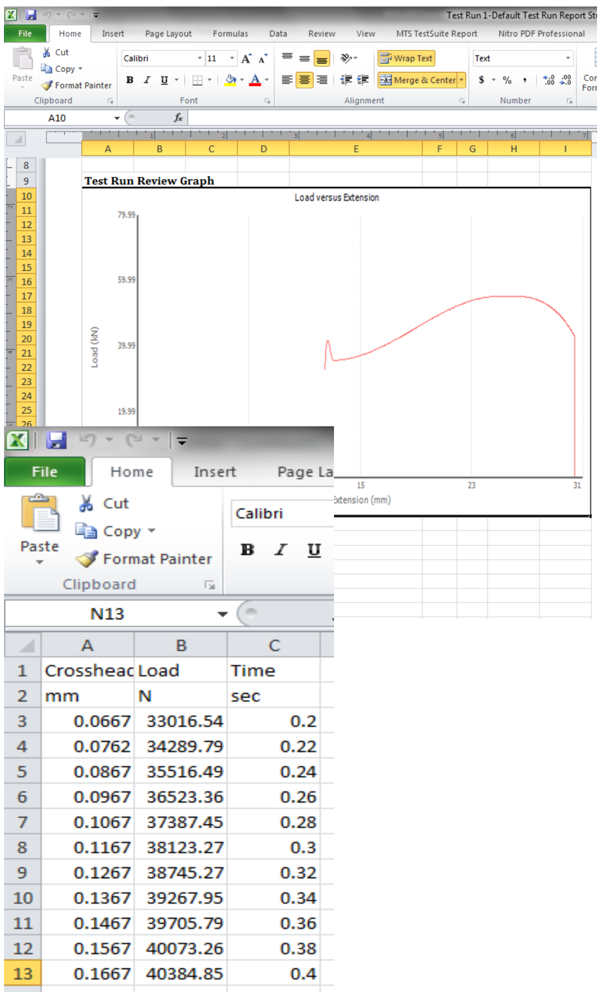
Using the MTS TestSuite software, run the TW Tension Test. Enter the width, thickness and gage length of the Acetal specimen.
Mark the gage length on the specimen to allow for the post-test determination of elongation at fracture.
Zero the sensors and install the specimen. Set safety interlocks as appropriate.
Start the test, move the crosshead at the predetermined rate

Repeat this procedure for the steel specimen.

Tension Test - Lab

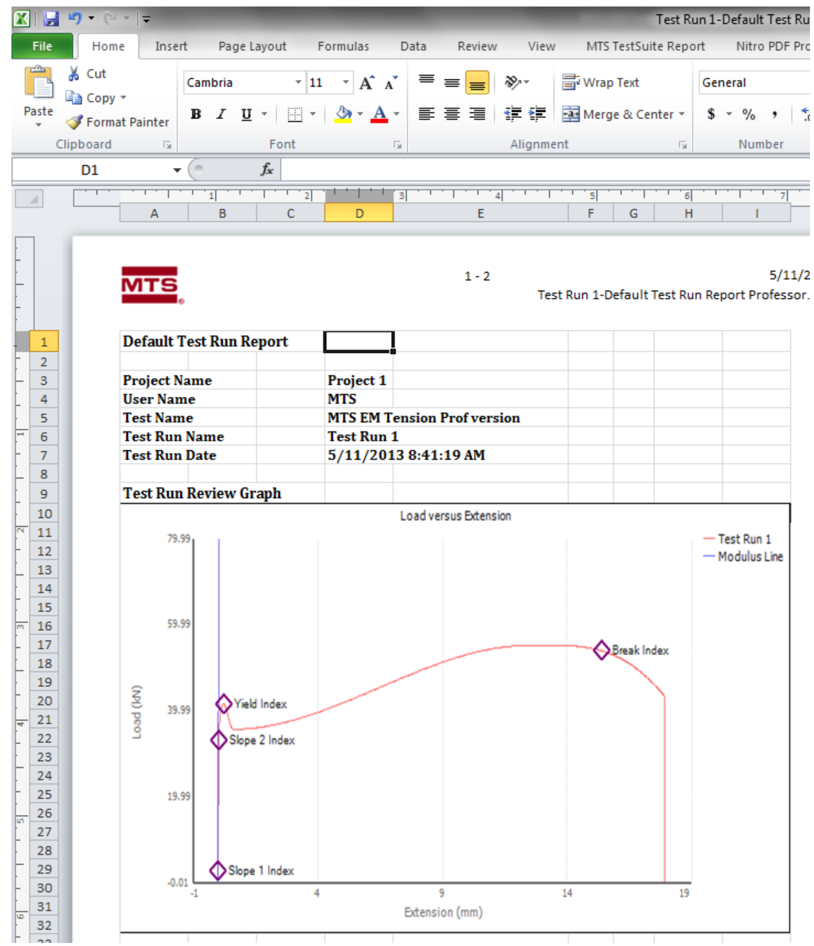
MTS MATERIALS SOLUTIONS

Student Test Report



A	B	C
Crosshead	Load	Time
mm	N	sec
0.0667	33016.54	0.2
0.0762	34289.79	0.22
0.0867	35516.49	0.24
0.0967	36523.36	0.26
0.1067	37387.45	0.28
0.1167	38123.27	0.3
0.1267	38745.27	0.32
0.1367	39267.95	0.34
0.1467	39705.79	0.36
0.1567	40073.26	0.38
0.1667	40384.85	0.4
0.1762	40642.29	0.42

Professor Test Report



Default Test Run Report	
Project Name	**Project 1**
User Name	**MTS**
Test Name	**MTS EM Tension Prof version**
Test Run Name	**Test Run 1**
Test Run Date	**5/11/2013 8:41:19 AM**

Tension Test - Homework

1. Using the TestSuite software in simulator mode, run a tension test and collect load-extension data for the Acetal specimen. Complete a post-test analysis on the test data and determine the following properties:
   a. Modulus of Elasticity
   b. Offset Yield Strength (0.2%)
   c. Ultimate Tensile Strength (UTS)
   d. elongation at fracture

2. Comment on the use of an extensometer for this test. Is it required? What precautions must be taken during an actual test? Why?

3. A connector link in a clutch mechanism is a two-force member which will experience a 4.5 kN tensile load in service. It is currently made of a mild steel. Would the Acetal tested in Problem 1 make a good replacement for the steel? (It's less expensive and easier to fabricate.) Calculate link dimensions that provide a safety factor of 5 guarding against static tensile overload.

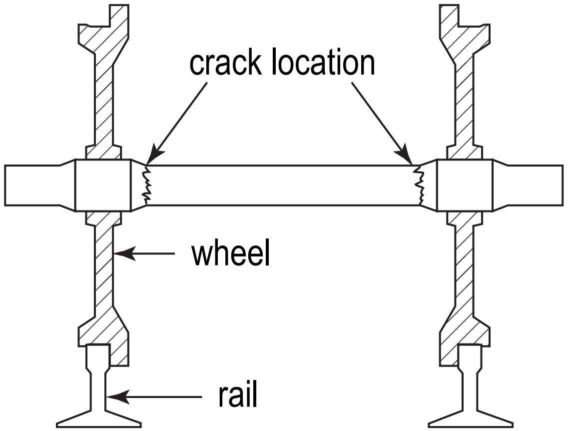
4. Repeat Problem 1 for the mild steel specimen.

5. Report the three different yield strengths that are evident in the data for the mild steel tension test simulation. Which would you choose as the "official" yield strength? Why?

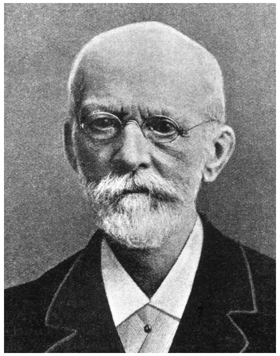
Versailles Railway Accident May 1842

- Axle failure
- 40 – 80 people dead
- No Engineering explanation:

  Another in an epidemic of failure since the industrial revolution ushered in the transition of wood and stone to metal as building materials
- August Wöhler, was the first to conduct experiments and try to quantify what was happening



Failures
Boilers
Ships
Trains
Track
Bridges
Buildings
machinery

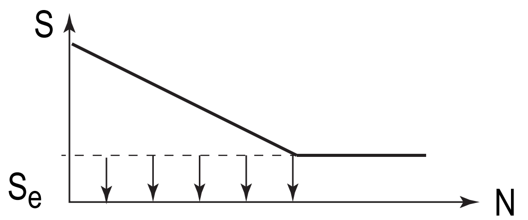


August Wöhler Fatigue Experiments

This extremely useful diagram was named after him (the Wöhler diagram) also called an S – N diagram

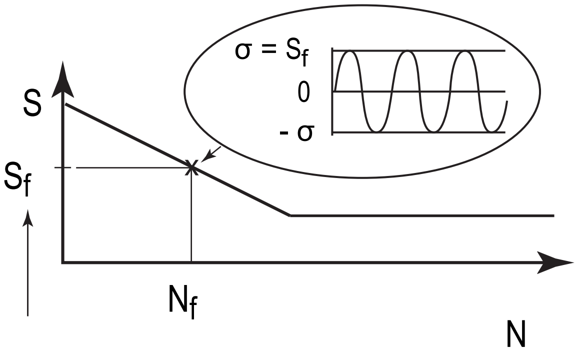
Strength vs Cycles

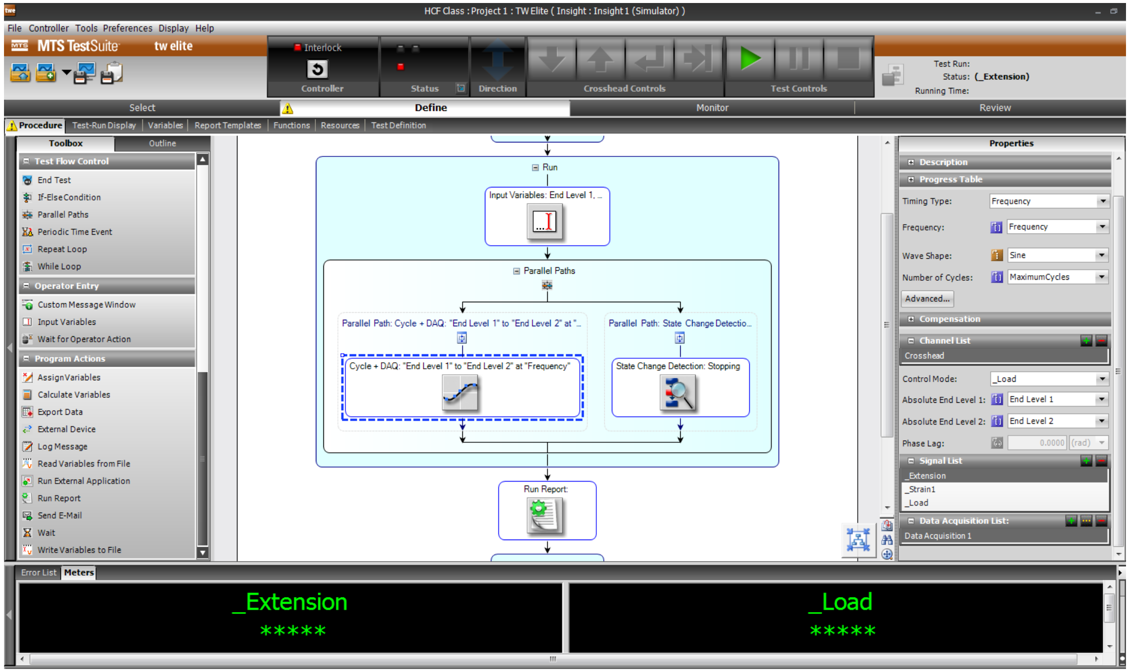
- Perhaps his most important discovery was that “knee” in his diagram called the “endurance limit” which – if the stresses stayed below – would not fail in fatigue
- That’s an important stress level to document for design purposes!



Keep the stresses below the endurance limit, S_e

Test program





Example:

S_f = 190 Mpa (10,000 cycles)

or

"the 10^4 cycle fatigue strength is 190 MPa"

HCF Test - Lecture

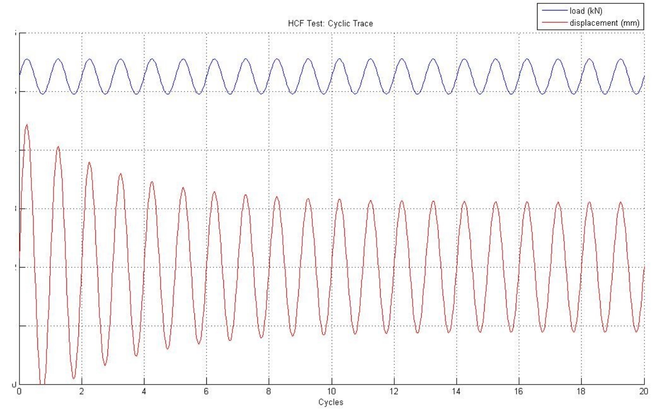
Power of simulation

Accelerate the test

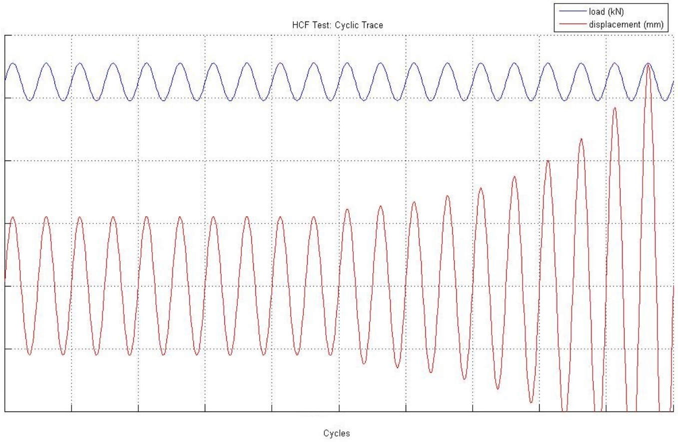
Learn about hardening, softening, etc.

No specimens needed

Test Design via trail and error



"Settling In"



Increase in Displacement Amplitude Signals a Crack

Summary of Benefits to Integrated Curriculum Teaching

» WYSIWIG teaching of principles and visualization of material behavior

» Familiarization with testing beyond brief and crowded labs

» Reduction of testing material costs/access need to test equipment

» Understanding power (and limitations) of simulation

» Exposure to the connection of testing and analysis

Questions please?