Name ______________________________ Date ___________________ Period _______

Do Materials Get Tired - How Long Will a Paperclip Last?

<u>Background</u>:

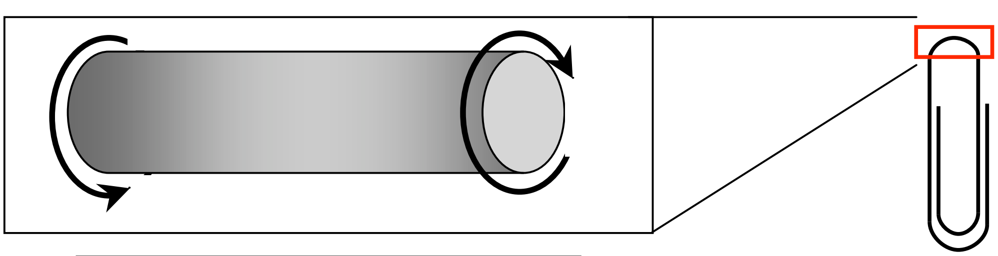
Materials such as *metals* (aluminum, iron, copper, etc.), *ceramics* (silicon carbide, porcelain) or *polymers* (milk jugs made of polyethylene) are tested by scientists and engineers to reveal certain mechanical properties, such as the maximum stress a material can withstand before it fails**.** The stress at which a material breaks is a measure of its strength. During use a material may degrade, which may cause it to fail at much lower stresses. For example, if a material is loaded over and over again and then fails it has undergone what is known as *fatigue*.

Fatigue is a very common mode of failure for materials and has been studied for centuries. Fatigue occurs every day in objects that you're familiar with. For example, airplane wings fatigue thousands of cycles on every flight and bridges fatigue every time a car drives over them. However, just because a material is undergoing fatigue does not mean that it will always break. In fact, engineers run careful experiments so that they can be sure that things will not break due to fatigue while you are using them.

Today you will be testing the fatigue resistance of something you have in your classroom: paperclips!

In previous experiments we have loaded pieces of material in bending. Today, we will be loading the material in **torsion**, which means we will be twisting the paperclip, as seen in the figures below.

Ideal torsion test: *Area of paperclip in torsion:*



Torsion being applied by twisting in opposite directions.

Some Definitions:

Torque- the measure of a forces tendency to create torsion
Polar Moment of Inertia- ability for an object to resist torsion
Shear Modulus of Elasticity- the ratio of shear stress to shear strain

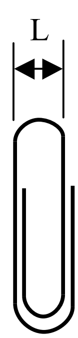
Stress is defined as force divided by area. '**Shear**' is a type of stress that occurs when the top and bottom of a material are pushed in the opposite directions. Because of the geometry of a torsion test, where the force is not applied uniformly to the bar, shear stress of the paperclip can be found using the following formulas:

$$\tau_{\max} = \frac{T \cdot r}{I_p}$$

$$T = \frac{\phi \cdot I_p \cdot G}{L}$$

$$\text{Therefore, } \tau_{\max} = \frac{\phi \cdot G \cdot r}{L}$$

τ_{max} = maximum shear stress in a circular shaft
T = torque
r = radius of the paperclip (in meters)
I_p = polar moment of inertia of a circular cross-sectional area ($I_p = \frac{1}{2} \cdot \pi \cdot r^4$)
ϕ = angle of twist in a circular shaft (in radians)
G = shear modulus of elasticity (in pascals)
L = length over which the twisting occurs (in meters)



You will need to know the following two facts in order to complete the calculation for shear stress. First, the shear elastic modulus of steel is ~ 85 GPa. And second, to convert from degrees to radians, multiply the number of degrees by $\pi\ radians/180^{\circ}$ (for example 90° = 1.57 radians.)

<u>Equipment</u>:

- 4 different paper clips, for example:
  1 Small metal paperclip
  1 Large metal paper clip
  1 Small plastic paperclip
  1 Large plastic paperclip
- Metric ruler

<u>Hypotheses:</u>

Read through the "Procedure" section to get an understanding of the experiment, then create the following hypotheses.

a. State a hypothesis comparing the small and large paperclips for a given material type to the number of "twists" it will take until the object fails.

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b. State a hypothesis comparing the metal and plastic paper clips to the number of "twists" it will take until the object fails.

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c. After you have completed step 4 of the procedure, state a hypothesis comparing 45°, 90°, 180°, and 270° angles of rotation to failure.

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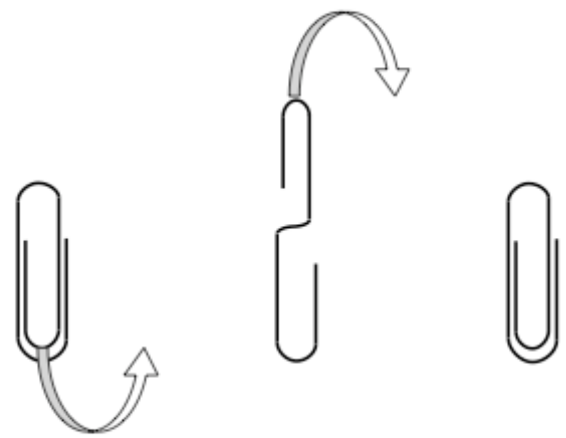
Procedure:

Note: During the actual experiment, record all observations (i.e., changes in surface finish, color, etc.)

RUN #1:

1. Using your hands, open up the inner loop of one of the paperclips so that it makes a 180 degree angle with the outer loop.
2. Bend the paperclip back to its original position. This counts as one loading cycle.

Example schematic of a paperclip torsion test for 180° rotation:

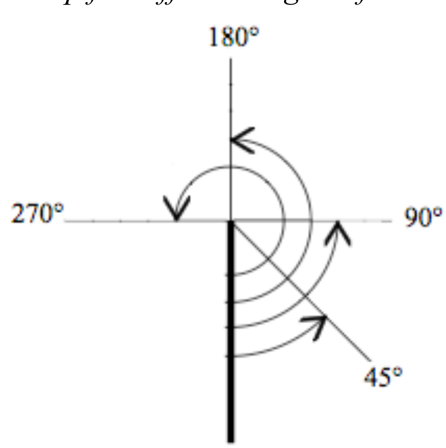


3. Repeat steps 1 and 2 until the paperclip breaks. Record the number of loading cycles in Table A (Trial 1) that elapse. (Note: if the paper clip breaks mid-cycle, that cycle does not count in the 'number of cycles to failure')
4. Complete steps 1 – 3 for the other paper clips.
5. After completing experiment for 180 degree angle, fill in hypothesis c.

RUN #2-4

6. Repeat steps 1 through 4 for 45, 90, and 270 degree angles. Use Tables B, C, and D for these runs.

Side-view of paperclip for different angles of torsion test:



7. Look at the fracture surface and write down any observations in the corresponding table.
8. Plot your results on the graphs shown below.

TABLE A (Run #1: 180°)

Type of Paperclip	Cycles to Failure

TABLE B (Run #2: 45°)

Type of Paperclip	Cycles to Failure

TABLE C (Run #3: 90°)

Type of Paperclip	Cycles to Failure

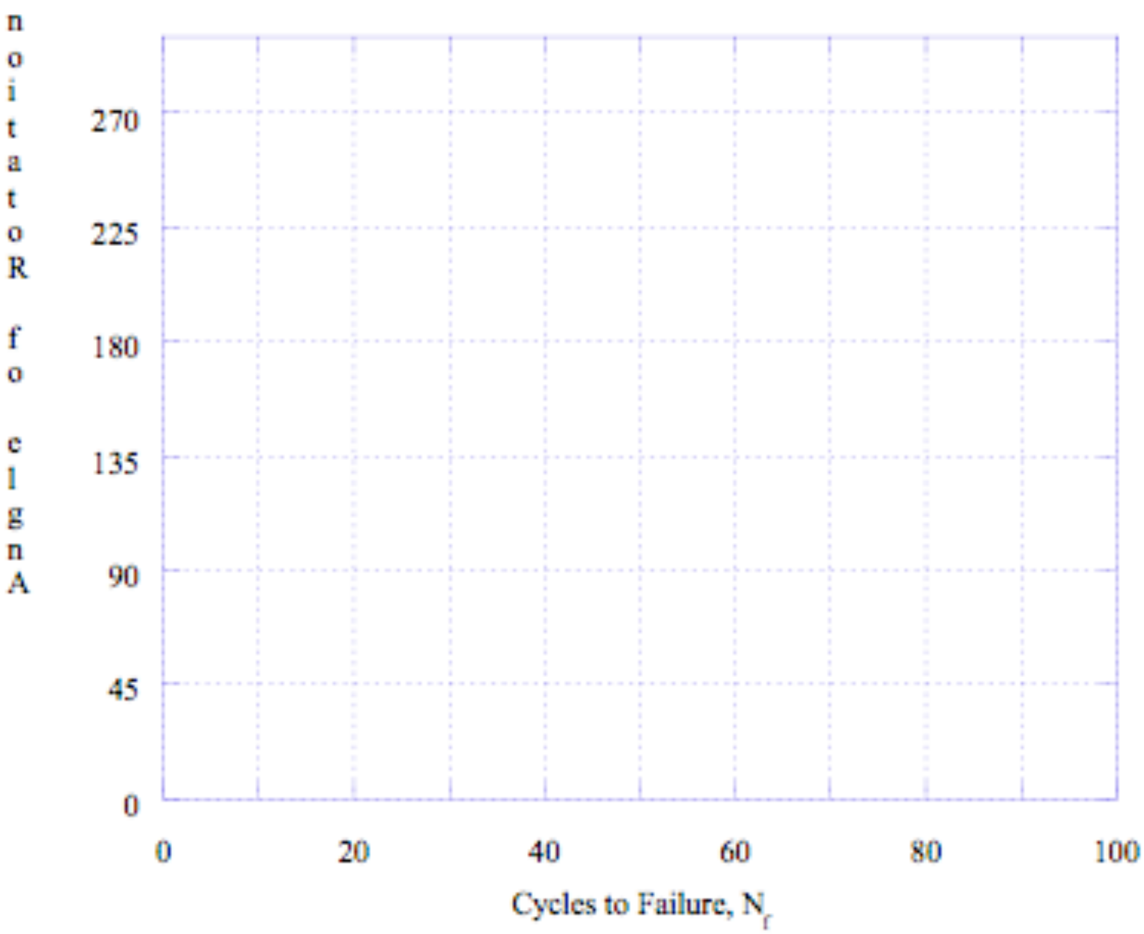
TABLE D (Run #4: 270°)

Type of Paperclip	Cycles to Failure

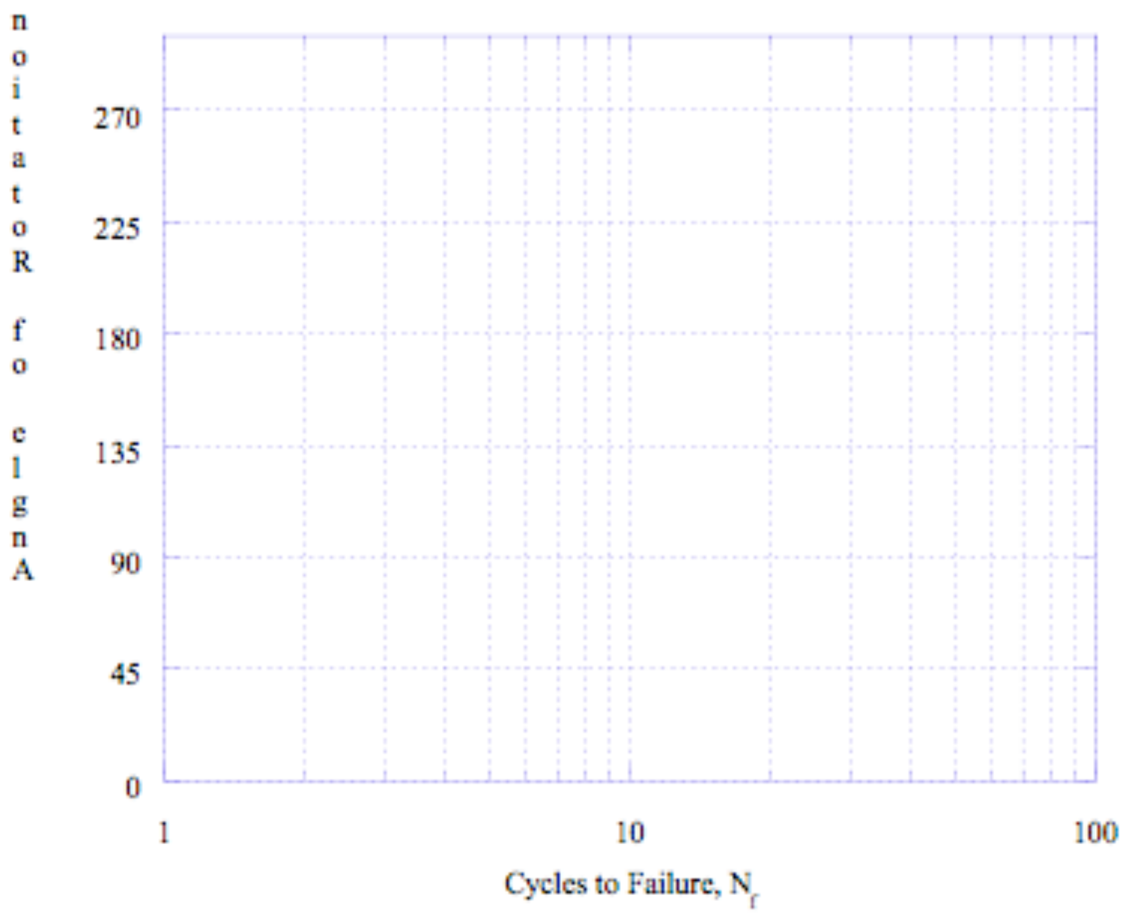
OBSERVATIONS

Type of Paperclip	Description of Fatigue Failure

Plot for angle of rotation in degrees versus number of cycles to failure on a linear scale.



Plot for angle of rotation in degrees versus number of cycles to failure on a log scale.



Analysis Questions

1. Which paperclip lasted the largest number of cycles before failure? Least amount?

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2. Which angle (45°, 90°, 180°, 270°) was associated with the fewest cycles before failure?

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3. Using the equations and values listed in the "Background" section, calculate what the maximum shear stress (τ_{max}) of the paperclip should be for each angle of failure. SHOW YOUR WORK and CIRCLE YOUR ANSWERS!

$$\tau_{\max} = \frac{\phi \cdot G \cdot r}{L}$$

(Run #1: 180°)

Type of Paperclip	Max Shear Stress τ_{max}

(Run #2: 45°)

Type of Paperclip	**Max Shear Stress** τ_{max}

(Run #3: 90°)

Type of Paperclip	**Max Shear Stress** τ_{max}

(Run #4: 270°)

Type of Paperclip	Max Shear Stress τ_{max}

4. What set of circumstances (cycles, angle, type of paperclip, etc.) yielded the <u>highest</u> shear stress?

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5. What set of circumstances (cycles, angle, type of paperclip, etc.) yielded the <u>lowest</u> shear stress?

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6. List three sources of error in your experiment.

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7. Excluding the errors above, what changes would you make to the experiment in order to yield more accurate results? Explain your reasoning.

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