Name ______________________________ Date ___________________ Period _______

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

Background:

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 to determine what uses the materials may have. One property that is tested is the amount of stress a material can handle before it breaks. You have probably tested the amount of stress a material can handle before by twisting or pushing on an object such as a toy until it breaks. The amount of stress a material can handle before it breaks measures how strong the material is. Also, as a material gets older, it can handle less stress which can 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*.

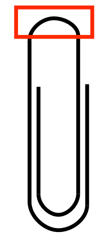
Fatigue is a very common mode of failure for materials and has been studied for centuries. Fatigue occurs every day in objects that you're familiar with. For example, airplane wings fatigue thousands of cycles on every flight and bridges fatigue every time a car drives over them. However, just because 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:



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.

Equipment:

4 different paper clips, for example:

1. Small metal paperclip
2. Large metal paper clip
3. Small plastic paperclip
4. Large plastic paperclip
5. Metric ruler
6. Protractor (to measure angles)

Hypotheses:

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

a. State a hypothesis comparing the amount of stress a large and a small paperclip can take before it breaks.

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b. State a hypothesis comparing the amount of stress a metal and plastic paper clip can take before it breaks.

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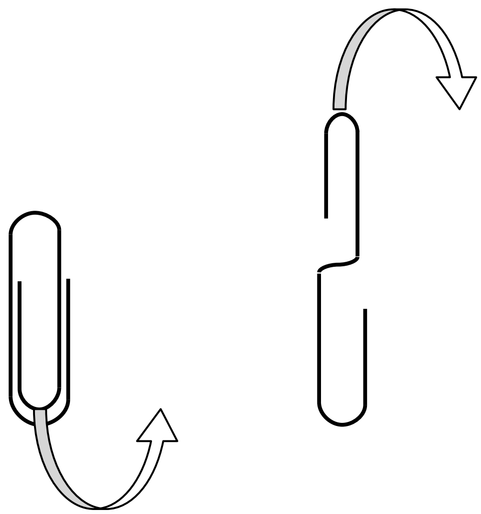
Procedure:

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

1. Using your hands, open up the inner loop of the paperclip 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 that elapse. (Note: if the paper clip breaks mid-cycle, that cycle does not count in the 'number of cycles to failure')
4. After completing experiment for 180 degree angle, make a hypothesis below:

After the 180° experiment is completed, state a hypothesis comparing 45°, 90°, 180°, and 270° angles of rotations, at which angle will the paperclip break first? At which angle will the paperclip break last?

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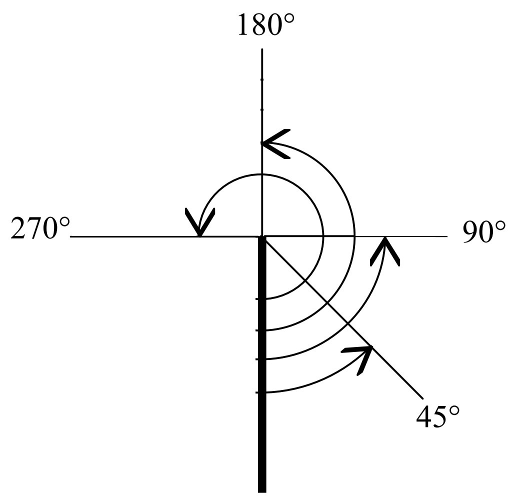
5. Repeat steps 1 through 3 for 45, 90, and 270 degree angles.

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



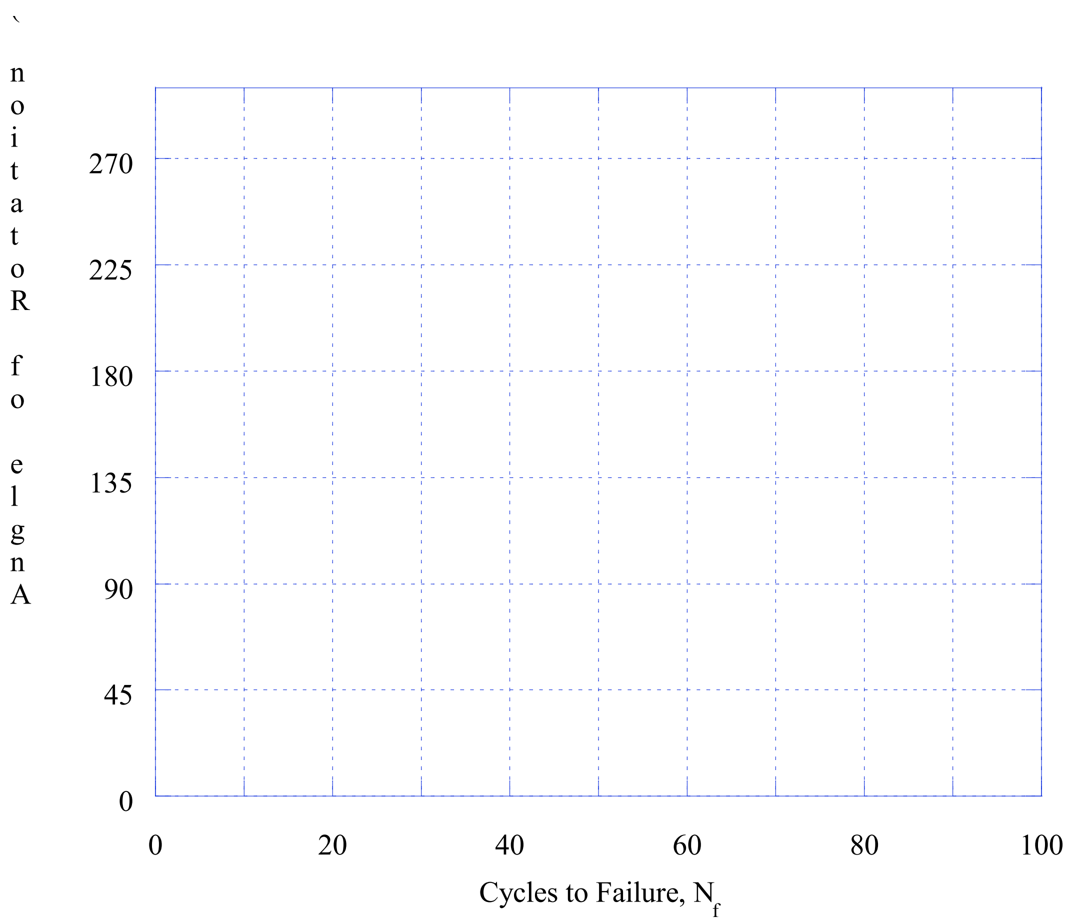
6. Record the following for each paperclip in Table A:
   - Size
   - Rotation angle
   - Cycles to failure
7. Look at the fracture surface and write down any observations in the Table B.
8. Plot your results on the graphs shown below.
9. Repeat entire experiment for a paperclip of a different size or material (such as plastic).

TABLE A

Type of Paperclip	Angle of Rotation	Cycles to Failure

TABLE B

Type of Paperclip	Description of Fatigue Failure



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

Analysis Questions

1. Which angle caused the paperclip to break first? Which angle allowed the paperclip to break last?

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2. In this experiment, you compared two types of paperclips that were made from either a different size or a different material. Which paperclip lasted the largest number of cycles before failure? Least amount?

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3. Explain how you think the experiment would be useful for engineers that build new objects. For example, in what ways could they apply knowing how a material fails?

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4. In every experiment, there are sources of human error. These can include miscounting the number of rotations or not keeping the bending angle consistent. What are some sources of human error that you had during the lab?

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5. 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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