

Paper Clip Experiment: Properties and Failure

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Abstract:

This experiment introduces students to the properties of metals when paper clips are bent in a controlled manner until they fail. Paper Clip failure under repeated stress is called “fatigue” and the fatigue properties of different materials vary with material quality, material source, type of stress and duration of stress. Since paper clips are not high tech materials, they are usually made from cheap steels that have little strength and where variability in quality is not important. Some paper clips have serrations, which will hasten failure as they provide locations for cracks to start. In this experiment the student can experience fatigue and by comparing different types and sizes of paper clips, and can develop a simple understanding of the relationship between metal failure, design variables and processing variables of materials.

Module Objectives: The student will be able to:

- Demonstrate the variability of metal failure
- Compare failure of different products
- Observe relationships between properties and processing of steels
- Observe differences in properties of metals vs. plastics

MatEd core competencies addressed (most important in bold):

- 0A Demonstrate good communication skills
- 1C Demonstrate laboratory skills
- 8B Apply mechanical testing processes to solid materials
- 8E Perform tests on metallic materials
- 16A Distinguish effects of processing and manufacturing variations on materials properties**

Key Words: properties, fatigue, failure, design, processing.

Type of Module: classroom experiment/activity.

Time required:

As an introductory exercise:

15 minutes for one paper clip per student for a 30 student class.

45 minutes for several paper clips per student.

For more advanced classes:

20 minutes for 2 types of paper clips per student with full discussion.
30 minutes for 2 steel clips and 1 plastic clip with discussion on differences.

Grade levels:

Middle school to lower division college or technical school classes.

Equipment and supplies needed

- One box each of one or more types, sizes and brands of metal paper clips.
 - Standard steel paper clips (two different brands if available)
 - Jumbo steel paper clips (two different brands if available)
 - If available, serrated steel paper clips
 - If available, brass or copper paper clips
 - Plastic paper clips (with the same standard shape as steel paper clips)
- Easel with paper or white or chalk board for recording data

Instructor background and notes:

Bending a metal, as in this exercise, adds defects to the material. As defects accumulate, the metal gets harder and stronger, more difficult to bend. Cracks form, leading to a "fatigue" failure. It needs to be emphasized that failure occurs because the metal actually gets stronger as it is bent. An incorrect perception is that the metal gets weaker in this circumstance, causing failure. This is never true. Bending also puts energy into the material, causing it to get warmer.

In this experiment we use 90 and 180 degree bends in the paper clips. During bending, the material becomes stronger—and if the students touch the bent portion, they can usually tell that that section is warmer due to the friction of the metal atoms moving over one-another. Typically the 180-degree bend breaks the paper clip in less than half the number of bends due to the greater stress on the bending point. If serrated paper clips are available, the serrations give a point for cracks to start, so the clips will typically break sooner. Differences seen between clips and between brands are usually due to differences in manufacture and differences in the composition of the starting material.

Brass or copper paper clips will behave similarly to steels with different numbers of bends. Plastic paperclips will behave differently since the mode of failure will be different, a function of the different structure of plastics.

Module Procedure: Experiment 1

1. Each student is given two standard paper clips of each type (for middle school grades, using jumbo paper clips is perhaps better as the students can hold the larger clips more easily)
2. Instruct student to take one paper clip and to open it up to look like an "S" (see attached sketch)
3. Demonstrate to the students the means for bending to 90 degrees
4. Ask the students to bend the paper clip as demonstrated and to count how many times it can be bent before the paper clip breaks. Count each full cycle (up and back) as one bend.

5. Collect the data and draw a histogram of the results. The histogram should show the number to bends to failure vs. number of students with each result. Don't worry if the histogram has a lot of variation—this is normal.
6. Ask if the paper clip got more difficult to bend as the number of bends increased. Have the class discuss why this might be the case. Ask if this is what caused the breakage?
7. Did the paper clip get warmer during bending? What does this indicate?
8. Discuss the differences noted. Ask for ideas as to why there is such a variation in between paper clips. If needed, suggest
 - Speed of bending
 - Quality of steel
 - Defects in the metal
9. Repeat the experiment using the second standard paper clip
 - This time have the students bend the paper clip 180 degrees
 - Draw the histogram and discuss the differences
10. Discuss what these results mean in terms of
 - Why there is so much variability between clips and between bending modes,
 - Effect of bending stress (90 vs. 180 degrees) on the failure,
 - Possible effect due to variations in metal processing
 - Possible effects due to variations in quality of the steel

Module Procedure: Experiment 2

1. Repeat the process with serrated paper clips. Compare to the results of Experiment 1 using a histogram to compare.
2. Discuss differences observed:
 - What effect do the serrations have? Why?
 - What does this mean in terms of the influence of defects on metal properties?
3. Repeat the process if paper clips of different materials and different sizes, if available.
4. Complete the experiment by discussing
 - Possible causes of differences observed between different materials
 - How could one standardize the materials to reduce variability?
 - This is an example of accelerated life testing, used by engineers to determine how much stress a material can take. Why would engineers do this?

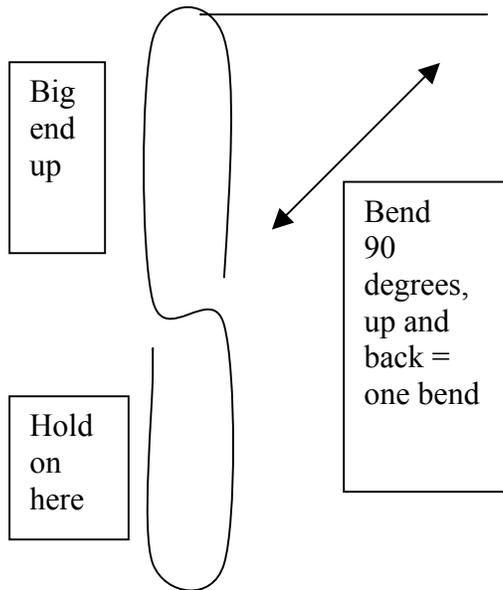
Further study (depending on grade level):

1. further comparisons between paper clips (that is, compare standard paper clips to the jumbo paper clips and to others)
2. internet research on metal fatigue

3. finding typical composition of steels used for paper clips
4. research possible causes of differences observed between different materials

References

1. For other paper clip experiments for kids, see <http://www.hunkinsexperiments.com/pages/paperclips.htm> and <http://www.lessonplanspage.com/ScienceExCanAPaperClipFloatInAirMO68.htm>
2. For some history, <http://www.uh.edu/engines/epi769.htm>
3. For a full technical analysis of the bending experiment, see http://www.weibull.com/AccelTestWeb/paper_clip_example.htm
4. Example of 90 degree bend:



Evaluation:

Student evaluation questions (discussion or quiz):

1. What caused the paper clip to break?
2. Give 3 reasons why different paper clips may break at different number of bends.
3. Does the bending technique make a difference? Why or why not?
4. If you were designing the world's best paper clip, what design criteria would you use? Explain each.

Instructor evaluation questions:

1. At what grade level was this module used?
2. Was the level and rigor of the module what you expected? If not, how can it be improved?
3. Did the activity work as presented? Did they add to student learning? Please note any problems or suggestions.

4. Was the background material sufficient for your background? Sufficient for your discussion with the students? Comments?
5. Did the activity generate interest among the students? Explain.
6. Please provide your input on how this module can be improved, including comments or suggestions concerning the approach, focus and effectiveness of this activity in your context.

Course evaluation questions (for the students)

1. Was the activity clear and understandable?
2. Was the instructor's explanation comprehensive and thorough?
3. Was the instructor interested in your questions?
4. Was the instructor able to answer your questions?
5. Was the importance of materials testing made clear?
6. What was the most interesting thing that you learned?