TEMPERED FOR SAFETY

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Abstract
Demonstrating the fracture behavior of annealed and tempered safety glass is one way to introduce students to the interesting materials that surround them in everyday life. Examining the fracture behavior of glass and understanding how that behavior can be modified, shows how materials can be made safer by altering their properties. In this demonstration, the students will observe the fracture toughness of tempered glass, understand the method and mechanisms used to toughen the glass and be introduced to fractography of glass. This demonstration can be used for students from elementary to college, with the depth of information easily altered for each age group. The materials required for this demonstration are obtained locally at discount and window glass stores. The glass sheets are sealed in polymer film for participant safety and to allow the students to observe the resulting fractures.

Module Objective
The objective is to demonstrate the fracture toughness of tempered glass, explain the method and mechanism used to toughen glass and observe the resulting fractures.

Student Learning Objectives
Describe the properties of glass
Observe properties of tempered glass
Observe fracture characteristics of tempered glass

MatEd Core Competencies Covered
0.B Prepare tests and analyze data
7.E Describe the general nature of ceramics and glass
7.J Demonstrate how materials properties are used in engineering design
14.A Describe structure, properties and behavior of glass
16.B Describe the effects of defects on materials properties

Keywords
Glass, brittle fracture, tempered

Prerequisite Knowledge
Glass is a common material and breaks catastrophically.

Target Grade Levels
This demonstration can be used for students from elementary to college, with the depth of information easily altered for each age group.

Table of Contents

Equipment and Supplies needed (all components should be available at a local hardware store)
Tempered glass pane
Clear contact paper
Clear sealing tape
Steel Balls, 1" & 1.5"
Wood blocks
Tile Nippers

Curriculum Overview and Notes for Instructor
Glass is a brittle material. Brittle materials under mechanical forces are very strong in compression but weak in tension. Heat treating glass objects can place their surfaces and edges in compression. Impacts and thermal stresses must overcome these compressive forces before there is a possibility of fracture.

During production, glass objects are cooled slowly under carefully controlled conditions. This process is referred to as annealing and removes any undesirable stresses to prevent the breakage of the object during cooling. Annealed glass can then be reheated to near its softening point and forced to cool rapidly in a controlled manner. Very carefully controlled air blasts are directed at the glass object and the surface quenched. This produces induced stress so that the surface edges of the object are held in compression and the interior left in tension. The resulting tempered glass is 4 times stronger than annealed glass.

When tempered glass breaks, the glass fractures into small, relatively harmless fragments that we refer to as "dices". This dicing of the glass greatly reduces the likelihood of injury because there are no shards or jagged edges. For this reason, tempered glass is used in environments where human safety is an issue. But remember, once a glass object has been tempered it can not be cut without complete failure. The glass must be cut to its desired size and any drilling, sanding or etching must be done before tempering.

When failure occurs, the fracture starts from the point where the highest stress occurs or at a defect point where the stress exceeded the materials strength. For fractures occurring in the planar glass panes, crack branching is easily observed. Just like moving along a branch from a tree trunk, as we move away from the origin of the crack, there are an increasing number of forks (branches). With increasing failure stresses, branch cracks as well the main crack can branch again and again. In the high stresses associated with the failure of tempered glass, the branching is extensive and the branches quickly intersect resulting in the dicing of the glass. To cause a fracture of a tempered glass pane, the magnitude of the applied stress must be great enough to overcome the residual compressive stress plus the stress necessary to start a crack in the tensile area of the pane. For annealed glass panes, a crack will initiate at a lower stress level and

consequently, the fracture strength will be smaller with less crack branching. The result is large shards that resemble and behave as sharp knives.

Keep safety at the forefront by making sure the glass is entirely sealed in polymer film and wear safety glasses when you fracture the glass. Occasionally a volunteer will successfully break the glass pane by jumping rather than stepping on the glass or dropping the steel ball so that it strikes near the edge. These types of results still allow great discussions.

Module Procedure

1. Completely cover both sides of the glass pane with the clear contact paper and seal the edges with clear carton tape, as shown in Figures 1 and 2.
2. Speak to the audience about the properties and method of fabrication of thermally tempered glass. Point out that this glass pane has been sealed with polymer sheets for safety during the demonstration.
3. Place the wood blocks on the floor. Set the glass pane on the wood blocks, Figure 3.
4. Invite members of the audience to walk up and step on the suspended glass pane. Watch for flexure.
5. Have volunteers assist in dropping steel balls on to the pane. Hold the 1” steel ball 3 ft. above the pane and drop it on to the center of the glass pane, Figure 4 and 5. Increase the distance to the volunteer’s maximum reach.
6. Repeat Step 5 with the 1.5” steel ball
7. Explain why the glass pane does not fail.
8. Have volunteers help hold up the glass pane for the group to view. Place the jaws of the tile nippers on the very corner of the pane, Figure 6. Pinch!
9. Examine the fractures of the glass pane and discuss the fracture patterns, Figure 7.
10. Follow up with a series of question for the audience, such as:
    Can you determine where the fracture started and how it progressed?
    What do the cracks tell you about the energy dissipated?
    Why is tempered glass safer?
    Where are places or applications where tempered glass would be used?

Figures and Handouts

Figure 1- Peel contact paper and wrap glass pane.

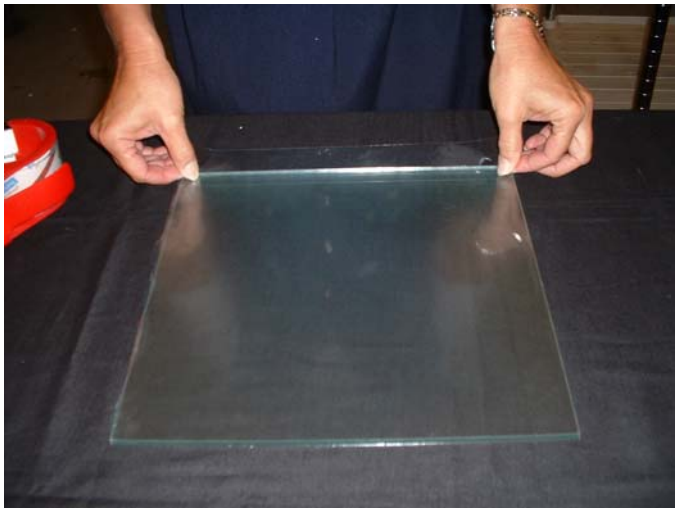

Figure 2- Tape all edges with sealing tape.

Figure 3- Place the wrapped glass pane on the wood blocks.

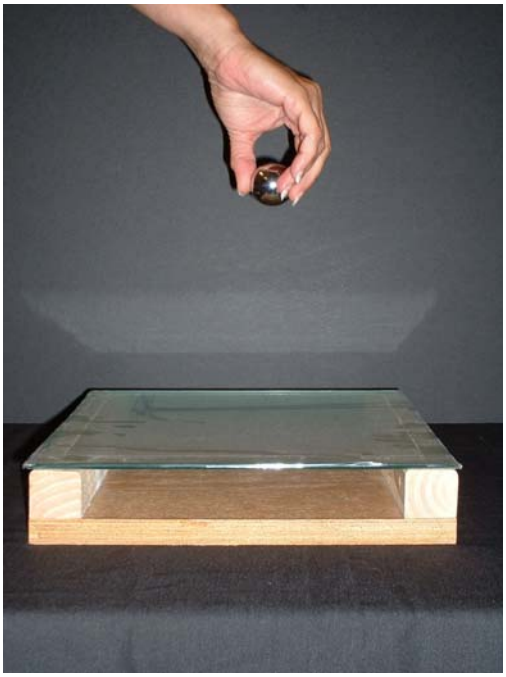

Figure 4- Line up over the glass pane.

Figure 5- Drop the ball on to the center.

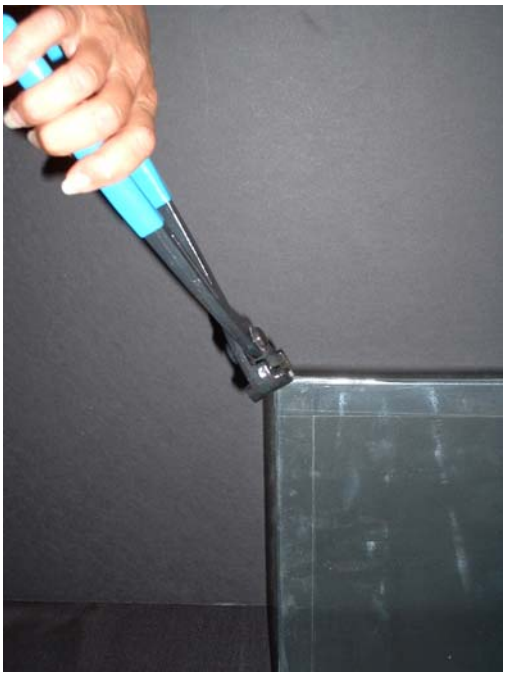

Figure 6- Place nippers on the glass corner & pinch!

Figure 7- Study and discuss the fracture.

Useful Vocabulary (may be used as a handout)
Amorphous- having no crystalline structure
Annealing- the cooling of glass with prescribed schedule to reduce residual thermal stresses
Crack- a break in a ceramic or glass body
Crack branching- in a fracture surface, macroscopic cracks that propagate outward beyond the hackle marks
Crystalline- composed of crystals
Crystals- a chemically homogeneous solid body having a definite repeatable internal molecular structure
Fractography- the study of fractures
Fracture- a crack caused by mechanical failure due to stress
Glass- an amorphous, ridge, inorganic, nonmetallic material that solidified from the molten state without crystallization
Tempered glass- glass that has been cooled from near its softening point to room temperature under rigorous control to increase its mechanical strength and thermal endurance by the formation of a compressive layer at it surface
Toughened glass- see tempered glass

Bibliography
Richerson, David W., The Magic of Ceramics, The American Ceramic Society, 2000. ISBN 1-57498-050-5, p.90-92 "Ceramics and Stress" and p. 204-205 "Ceramics in the Passenger Compartment".

Evaluation Packet

Student evaluation questions (discussion or quiz):

1. How can you determine where the fracture started and how it progressed?
2. What do the cracks tell you about the energy dissipated?
3. Why is tempered glass safer?
4. Where are places or applications where tempered glass would be used?

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 lab/demonstration work as presented? Did they add to student learning? Please note any problems or suggestions.
4. Was the background material on glass sufficient for your background? Sufficient for your discussion with the students? Comments?
5. Did the demonstration/lab 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 lab/demonstration 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?