Egg Crusher

Demonstration

This demonstration dramatically shows how not just the strength of a material, but how it is designed, is important when withstanding forces.

Hennessy, Wikimedia Commons. Gaoliang Bridge of The Summer Palace

Number of Participants: 1-30

Audience: Middle (11-13) and up

Duration: 20-30 min

Difficulty: Level 3

Materials Required:

- Egg crushing apparatus (schematic provided)
- Raw eggs (at least 1)
- Egg shell chips (clean and dried)
- Heavy weights (lead bricks recommended)

Setup:

1. Prepare the crushing assembly on a mechanically sturdy, easy-to-clean surface. A solid lab or a hard floor is recommended. Be careful with the heavy weights.

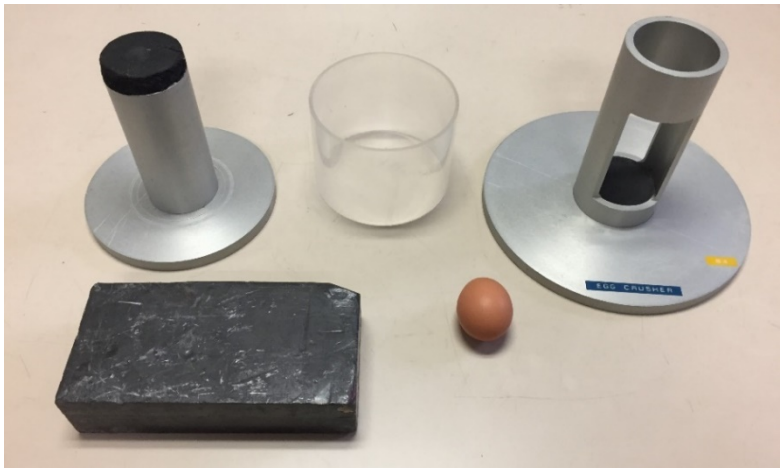

Figure 1: Egg Crusher apparatus (Aluminum) shown with egg, and one 11 kg weight (~25 lb).

Presenter Brief:

A working knowledge of static forces as well as forces, force diagrams, and stress is required.

Vocabulary:

- Force – a push or pull on an object
- Static – physical systems which exhibit no change
- Impulse – a force exerted over a period of time
- Load Point – point on a structure which bears the weight of the supported load
- Pressure – force exerted over an area
- Stress – forces felt by a rigid body's structure when experiencing an outside force

Physics & Explanation:

Middle (11-13) and general public:

Most people would agree that an egg is a fragile object. After all, it's very easy to break one, and not much force is required to do so. Typically, eggs can be broken the edge of a bowl or by simply not being careful.

> It should not be difficult to convince participants that egg shells are fragile. Pass around clean and dried egg shell chips you prepare before-hand to show how thin egg shells are. While they are being passed around, explain what a force is and that weight is a force. Explain that dense and heavy objects are pulled by gravity which puts a lot of force on them.
>
> Ask how much force they think it takes to break an egg. If possible, keep the lead bricks hidden so that they are inclined to guess small values.
>
> After the audience guesses, take an egg and ask them if they answer would change if you could spread out the force and ask why.

There are two key topics to explain: pressure and if the force is dynamic or static. However, only talk about pressure at this time. Eggs can withstand very large forces but only if they are steady and spread out over the top and bottom of the egg.

Many materials are strong but everything breaks if you apply a large force just right. You will now test the egg and see how much force it can withstand.

> Carefully place the egg elongated direction vertically within the egg crusher. The closer to normal, the more weight the egg should withstand. It is worth the extra

time to make sure it is standing up as straight as possible, a properly placed egg can withstand over 300 lbs. Do not tell the audience this, as you want to surprise them with the result.

Begin by carefully loading the top of the crusher with a small weight (such as a normal brick or hammer), emphasizing that the point of the apparatus is to load the egg with weight: a) spread out over an area and b) very slowly.

The black foam is to spread the force over a larger area. A needle can easily pierce an egg while a finger must apply a much larger force. The foam also minimizes vibrations and abrupt changes to the amount of force on the egg. The rest of the apparatus is just designed to be sturdy, and to make it easy to apply large forces/loads. Note that dropping a brick or if someone jumps around while under load can cause the egg to break. Testing by SPS found a wide range of maximum loads from ~100 lb to some as high as +300 lbs for standard, large eggs.

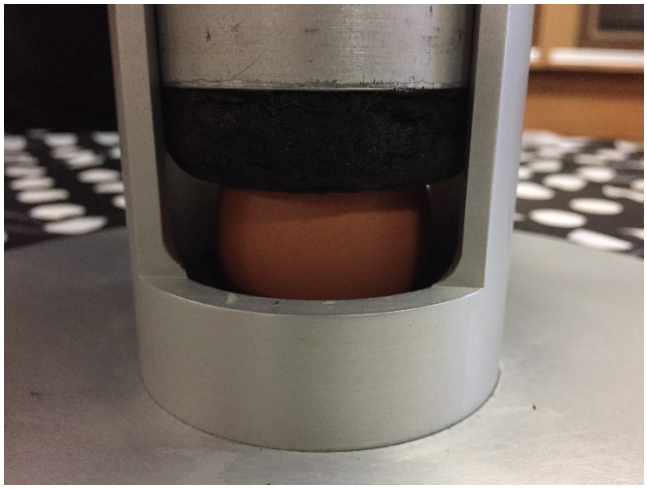

Figure 2: The proper upright orientation of the egg in the crusher.

Explain to the audience that the reason the egg can withstand such forces is because the foam decreases the pressure the egg experiences. This can shown by using a single brick to crush an egg (but this often isn't necessary to do but simply state as much).

🔑 Pressure is force over area. The same force spread out over an area is a much smaller pressure.

Common area examples include a wide mallet versus pick axe OR standing on one foot versus laying on a surface.

Also explain that there are impactive forces, which are dynamic, and static forces, which do not vary with time. A good analogy is jumping versus standing.

🔑 Eggs are fragile, as they break easily under large impulses, but are very good at withstanding large static forces.

> Often students will ask what happens to the force. Explain that the top and bottom of the egg are more difficult to break because of the way the egg is structured.

The shape of the egg allows it to spread any forces that it encounters on its top or bottom throughout its whole body, reducing the stress on any one area. To demonstrate that the egg is real, you may wish to continue loading the device until the egg is crushed, or remove the egg and break it with a light tap.

🔑 Certain structural designs create load points in objects which are more efficient at bearing weight. Show examples of bridges, walls, and domes.

> A fun interactive example is have students make a dome with blocks or marshmallows but have them explain where the forces go.

Highschool (14 +):

> After completing the previous section, explain that the type of structural reinforcement the egg demonstrates is that of arches.

Arches have a load point located at their apex which disperses the force across its body. They can withstand more weight at the load point because their shape efficiently spreads the stress of the load throughout the body of the structure.

A shape's strength comes from its ability to distribute a load when it is applied at a certain location. A sphere is perfectly symmetric so whichever load point is chosen for it is arbitrary, as it is equally strong in all orientations. However, in some shapes such as the egg's oblong, elliptical form, it is crucial where the weight is applied. Pressure exerted on the sides of an egg will fracture it easily, however pressure that acts on it from the top and bottom will need to be much more substantial to break the egg.

You may notice that as the egg is made to bear the weight of the load, it does not remain perfectly rigid. It bows out slightly around the middle, deforming due to the pressure exerted over it. This phenomenon is well documented in physics, and is related to the stress a rigid body feels when a force is acting upon it.

Essentially, there are three stages a body can go through when it is being stressed. Stressing below the yield strength (S_y), stressing between the yield strength and ultimate strength (S_u), and stressing past the ultimate strength. Rigid bodies that are stressed less than the yield strength will deform, but return to their original shape when the stress is removed. Stressing beyond the yield strength will deform a rigid body to the point where its shape has been permanently altered, and it will no longer return to its original form. Stressing past the ultimate strength will fracture or break the body. This would be the point where the egg cracks.

🔑 The benchmark thresholds for structural strength are the yield strength and the ultimate strength.

Some shapes don't occur naturally very often, however humans can employ them in their own designs. For example, many truss bridges use triangles to reinforce their shape because triangles are very strong and have a low profile.

Microstructures, such as carbon nanotubes, have been proposed as solutions to problems in which a figurative material needs to be very strong but also very light.

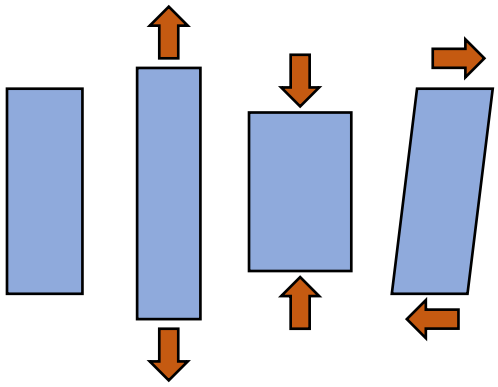

Figure 3: The three main types of stressing forces. From left to right- no stress, tension, compression, and shear.

Additional Resources:

- Halliday, Resnick, Walker. *Fundamentals of Physics,* 2001 (p 283-287).

Useful Equations:

Impulse	$Impulse\ (I) = F\Delta t = m\Delta v$
Pressure	$Pressure\ (P) = F/A$

$m = mass$

$F = force$

$\Delta t = change\ in\ time$

$\Delta v = change\ in\ velocity$

$A = area\ of\ application$