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Solar Tube Impact Test Report

Date: 18th Nov 2004
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Location: Apricus Solar Factory, Nanjing, China

Test Objective: To determine the impact strength (break point) of ∅58mm x 1800mm twin glass solar tubes.

Apparatus:

1. ∅58x1800mm twin glass solar tube. (1.6mm thick Borosilicate 3.3 glass.)
2. Rubber protective caps for end of tubes (or similar)
3. ∅30mm steel ball, with central ∅1mm hole. (~105g)
4. 3.5m ∅0.8m nylon line (fishing line).
5. 3+ metre high attachment point for nylon line.
6. 2 x cradle for solar tubes (prevent movement during testing)
7. 2.5m long rod/pole with 5cm interval labelled measurement markings. (Zero point set at centre point of solar tube, ie. point of impact.)

Methodology:

Preparation

1. Place rubber caps on the ends of solar tube and lay tube horizontally in cradles. No direct contact between metal/wood cradle and glass should be permitted.
2. Attach one end of nylon line to attachment point (must be able to freely swing in any direction).
3. Thread other end of nylon line through ball, adjust length so the centre of ball aligns with central line of solar tube.
4. Position solar tube so that ball (hanging still) is gently touching the middle of tube (longitudinal).
5. Mark point below steel ball with X.
6. Draw a straight line on ground perpendicular to solar tube impact point.
7. Refer to Appendix A for ground layout details.

Testing

1. Pull steel ball (with tight line) up to fall height as indicated by height on measurements pole. Ensure fall path matches lines on floor.
2. Drop ball
3. The tube will either withstand impact or break. It is uncommon for any small cracks or other signs of damage to occur prior to breakage.
4. Increase height by 5cm increments after each successful strike.
5. Once break height is determined complete multiple tests at one level down (5cm lower) as well as at break level to determine the consistency of tube strength levels.
6. Repeat testing for any other angles required.

Results:

For each test angle obtain a drop height from which tubes are able to withstand multiple (>3) impacts without damage.

Actual Test Results – Safe Drop Heights (refer to Table 1)

0^o angle = 0.75m
30^o angle = 1.80m
45^o angle = 1.95m

Interpretation of Results:

By using the formula **Speed = (2*9.8*m)^0.5** the impact speed of the steel ball in m/s can be calculated. (m = drop height) This does not consider any speed losses due to air resistance (but at such speeds with a steel ball, such resistance is minimal)

Based on the ball weight and impact speed, the number of Joules of impact energy can be calculated:
Joules = g/1000*9.8*m (g = mass of steel ball in grams, m = drop height)

The impact energy levels are therefore:
0^o angle = 0.7717J
30^o angle = 1.8522J
45^o angle = 2.0065J

Using these Joule values, the impact speed and size of other objects can be calculated.
Eg. 25mm solid ice ball (perfectly shaped ball - no consideration of ball breakage or deformation upon impact)

To calculate the speed of the ice ball the following formulas are used:
Ice ball weight: **(g) = 3.1415926/6*(d/10)^3** (d = Ball diameter)
Ball drop height: **(m) = J*1000/g/9.8**
Ball speed: **(s) = (2*9.8*m)^0.5**

∴25mm solid ice ball @ 0^o acceptable impact speed = 13.73m/s
∴25mm solid ice ball @ 30^o acceptable impact speed = 21.27m/s
∴25mm solid ice ball @ 45^o acceptable impact speed = 22.14m/s

Table 1 – Solar Tube Impact Strength Results

Solar Tube Impact Strength

Steel Ball Test Data		Steel Ball Calculated		Solid Ice Ball Calculated	
Perpendicular Impact					
Steel Ball Diameter (mm)	30	Steel Ball Diameter (mm)	25	Ice Ball Diameter (mm)	25
Steel Ball Weight (g)*	105	Steel Ball Weight (g)	63.8136	Ice Ball Weight (g)	8.18123
Drop Height (m)	0.75	Drop Height (m)	1.23406	Drop Height (m)	9.62569
Impact Speed (m/s)	3.83406	Impact Speed (m/s)	4.91809	Impact Speed (m/s)	13.7355
Impact Speed (km/h)	13.8026	Impact Speed (km/h)	17.7051	Impact Speed (km/h)	49.4477
Impact Energy (J)	0.77175	Impact Energy (J)	0.77175	Impact Energy (J)	0.77175
30deg Impact					
Steel Ball Diameter (mm)	30	Steel Ball Diameter (mm)	25	Ice Ball Diameter (mm)	25
Steel Ball Weight (g)*	105	Steel Ball Weight (g)	63.8136	Ice Ball Weight (g)	8.18123
Drop Height (m)	1.8	Drop Height (m)	2.96175	Drop Height (m)	23.1017
Impact Speed (m/s)	5.9397	Impact Speed (m/s)	7.61908	Impact Speed (m/s)	21.2789
Impact Speed (km/h)	21.3829	Impact Speed (km/h)	27.4287	Impact Speed (km/h)	76.6041
Impact Energy (J)	1.8522	Impact Energy (J)	1.8522	Impact Energy (J)	1.8522
45deg Impact					
Steel Ball Diameter (mm)	30	Steel Ball Diameter (mm)	25	Ice Ball Diameter (mm)	25
Steel Ball Weight (g)*	105	Steel Ball Weight (g)	63.8136	Ice Ball Weight (g)	8.18123
Drop Height (m)	1.95	Drop Height (m)	3.20856	Drop Height (m)	25.0268
Impact Speed (m/s)	6.18223	Impact Speed (m/s)	7.93019	Impact Speed (m/s)	22.1478
Impact Speed (km/h)	22.256	Impact Speed (km/h)	28.5487	Impact Speed (km/h)	79.7321
Impact Energy (J)	2.00655	Impact Energy (J)	2.00655	Impact Energy (J)	2.00655

The values shown indicate impact levels that the solar tubes can withstand without sustaining damage.

* Weight less than calculated weight due to hole drilled in centre.

Conclusions:

There is minimal conclusive literature on hail terminal velocity. A rough model for the calculation of terminal velocity of a hail stone has however been developed. The calculation does not take into consideration the effects of wind (ie. updraft, crosswind…) or contact with other objects (rain, other hail stones) during the path of decent. Please refer to excel file FTD-700-3 – Hail Stone Terminal Velocity Calculation Model.

A key factor to consider is the structural makeup of hail stones. Most hail stones are not solid balls of ice, but rather layers of ice of varying densities, or simply a conglomerate of smaller hail stones. Many large hail stones therefore break apart when they impact a hard object. This further reduces the energy (Joules) which is imparted to the solar tube upon impact.

The estimated terminal velocity of a 1" hailstone is 9.61 m/s, at which speed the solar tube would be undamaged even when impacting at a perpendicular angle. Table 1 shows that by installing the solar tubes at an angle of at least 30^o the ability to withstand impact from large hail stones is excellent. 1" hails stones should not cause damage to solar tubes unless travelling at speeds far beyond the norm.

For hail stones that exceed the levels that solar tubes can withstand, damage is likely to be caused to house roofing cars and flat plate collectors too. Household insurance should cover any such damage. One advantage of the solar tube design is that if one or two tubes are broken they may be easily and cheaply replaced, whereas an entire flat plate collector would need to be replaced if damaged.

Recommendations

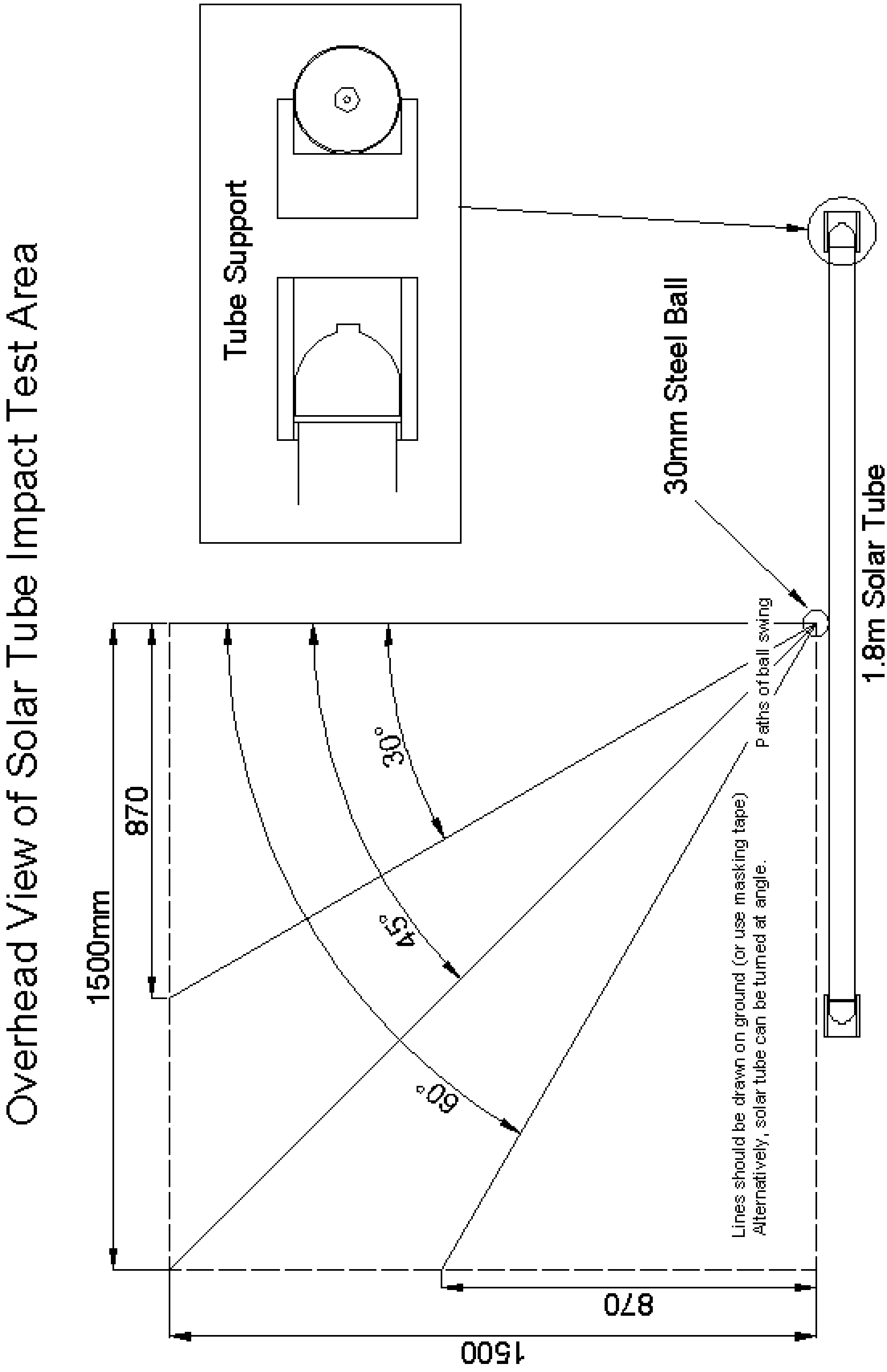
1. The testing protocol outlined in this document form the basis for new standardised testing procedures for impact strength of glass evacuated tubes (solar tubes).

2. Based on the results of this testing (and subsequent confirmatory testing), a Joule impact strength minimal level for glass evacuated tubes be set, according to which testing can be conducted.

3. Evacuated tubes solar collector manufacturers/resellers are required to make a statement regarding hail impact resilience. (up to 25mm).
Eg: "For areas prone to hail larger than 20mm in diameter, solar collector must be installed at a minimum angle of 30^o. For areas prone to hail commonly exceeding 25mm in diameter an installation angle greater than 45^o advised, or some form on hail guard must be installed."

4. Solar tube manufacturers (or OEM companies) must incorporate random impact testing into standard solar tube quality control procedures.

Appendix A



Overhead View of Solar Tube Impact Test Area
Tube Support
30mm Steel Ball
1.8m Solar Tube
Paths of ball swing
Lines should be drawn on ground (or use masking tape)
Alternatively, solar tube can be turned at angle.
1500mm
870
30°
45°
60°
870
1500