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Stress Analysis of Silicon-Wafer-Based Photovoltaic Modules in Operation

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Introduction

Objective

To determine the stress distribution in a PV module during operation, in order to predict stress-driven interfacial delamination.

Fig. 1. PV module with severe delamination

Source: M.A. Munoz, M.C. Alonso-Garcia, N. Vela and F. Chenlo, "Early degradation of silicon PV modules and guaranty conditions," (2011) Solar Energy, 85(9), pp. 2264 – 2274.

Structure of a PV Module

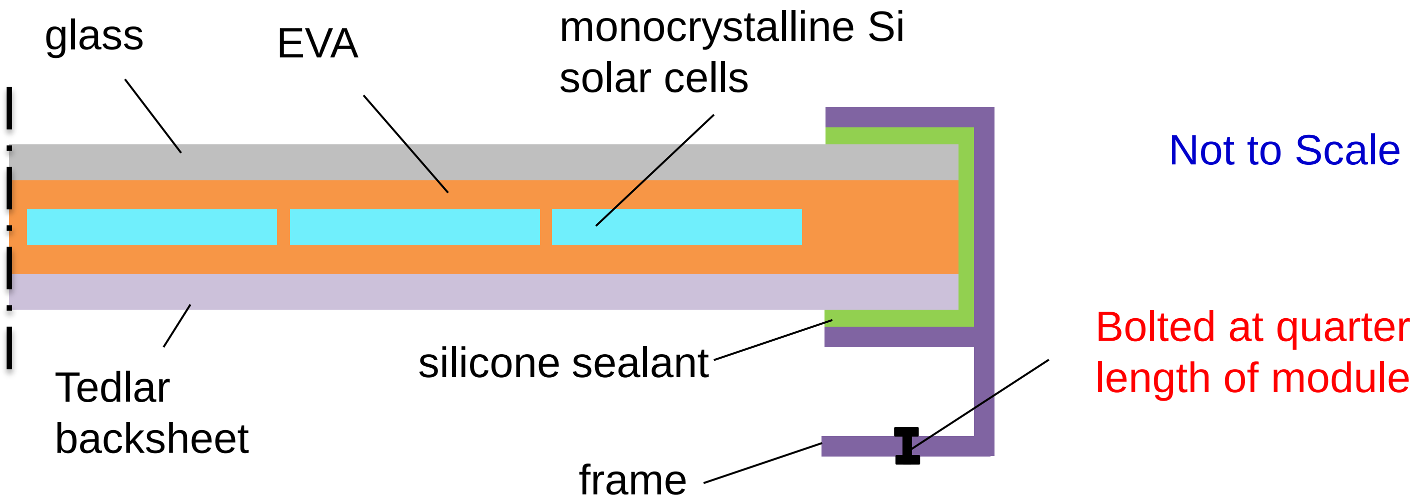

Fig. 2. Cross-section of one half of the investigated PV module

- The assembly is bonded at 145 °C.
- On cooling to room temperature, stresses are induced due to mismatch in coefficient of thermal expansion of constituents.
- On framing and subsequent exposure to the sun, a temperature distribution is generated and the stresses are redistributed.
- The effect of module cover material - float glass and tempered glass – on stresses in the module will be studied.

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FE Simulation of Post-Lamination Stresses

- Actual module has 6 x 12 wafer-based monocrystalline solar cells of dimensions 125 mm x 125 mm.
- Due to symmetry, only a quarter of the module is modelled.
- Boundary conditions.

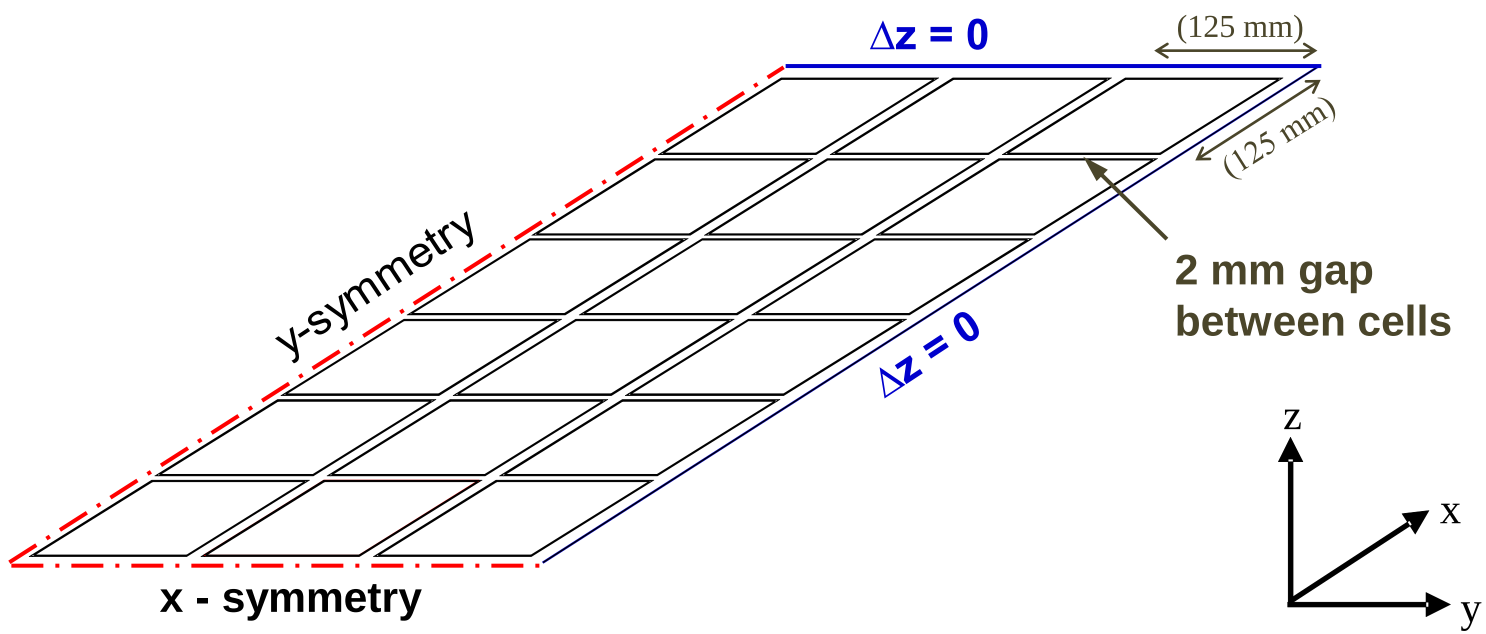

Fig. 3. Simulation model and boundary conditions applied

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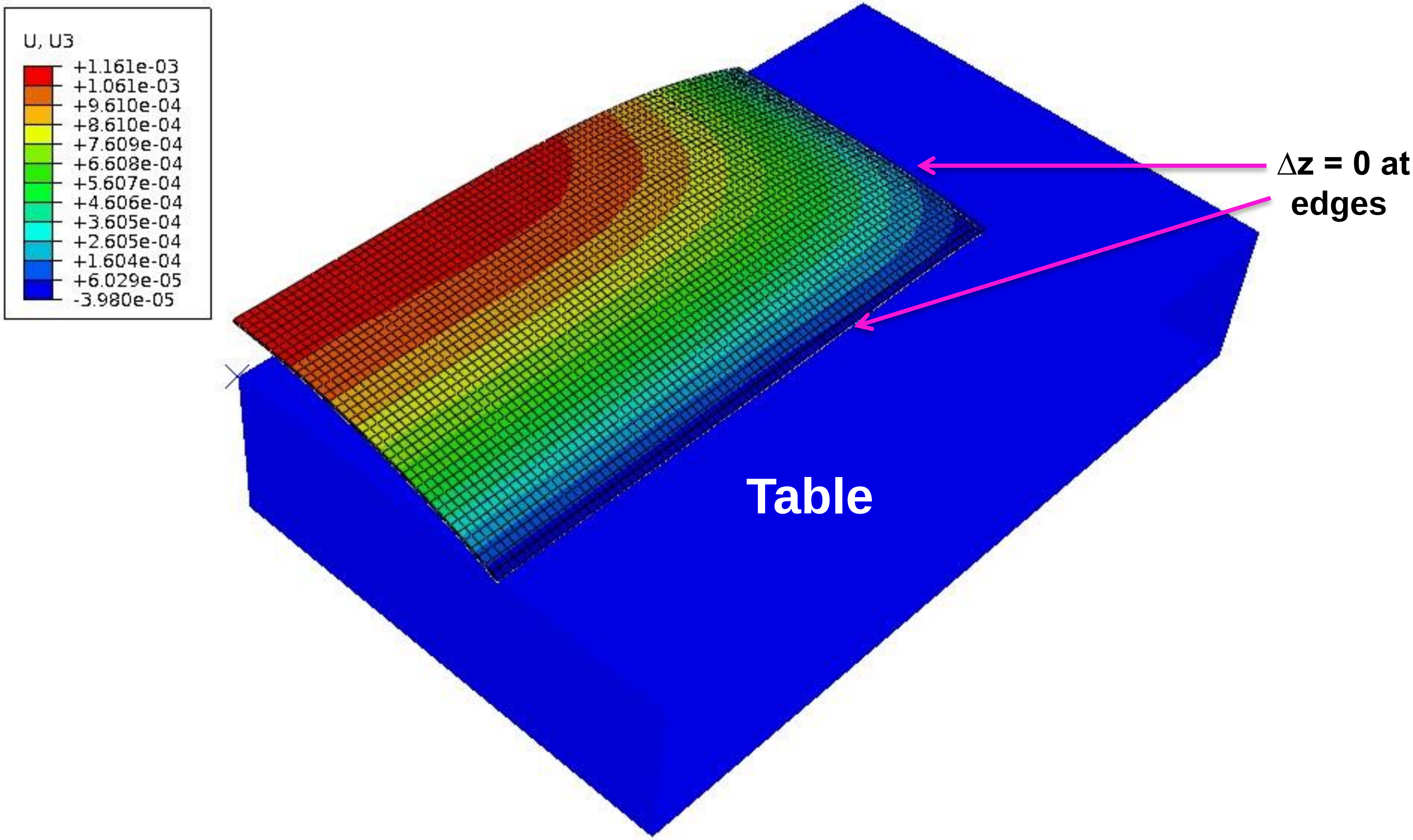
Justification for b.c. along edges



Initial Stress in Tempered Glass Cover

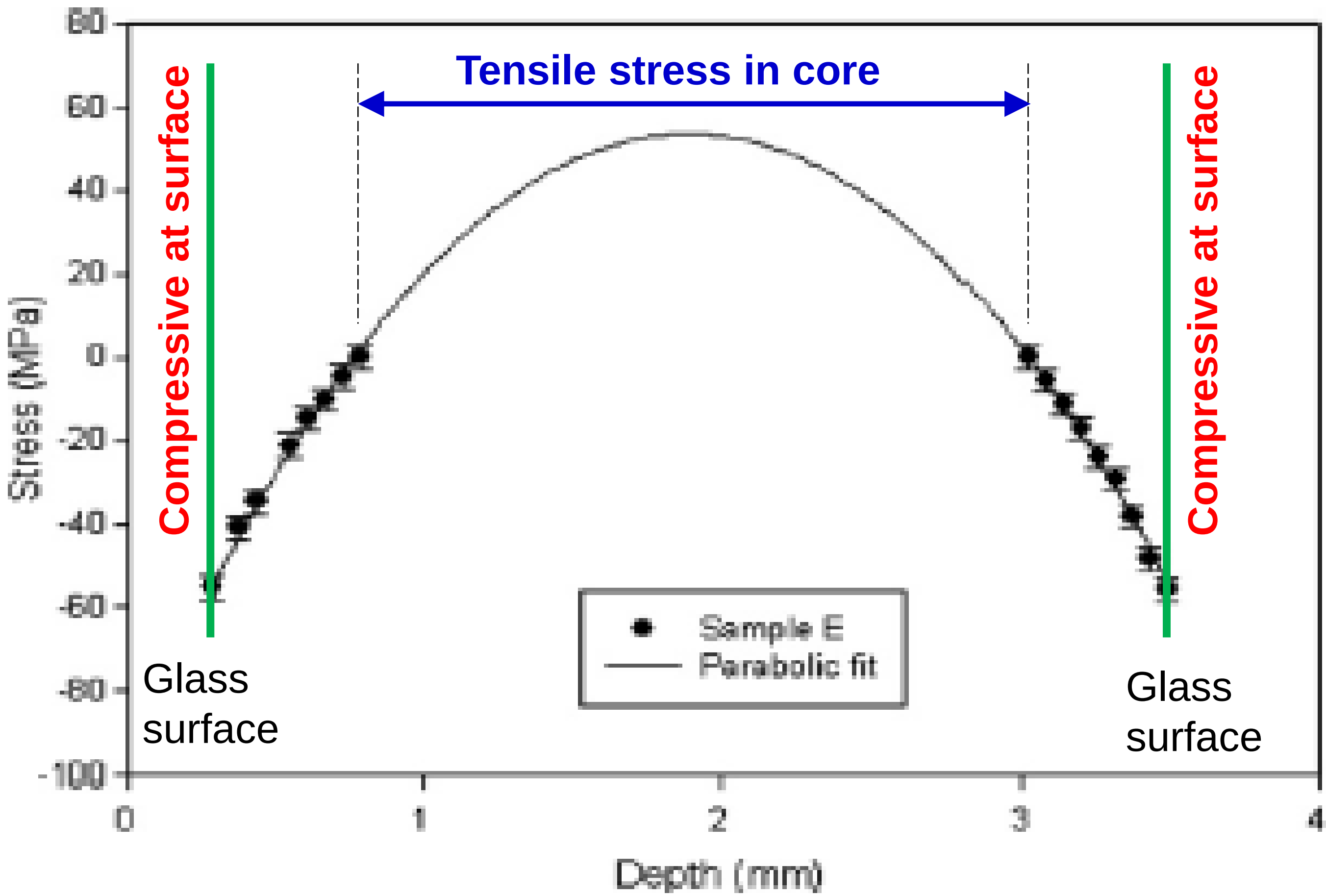


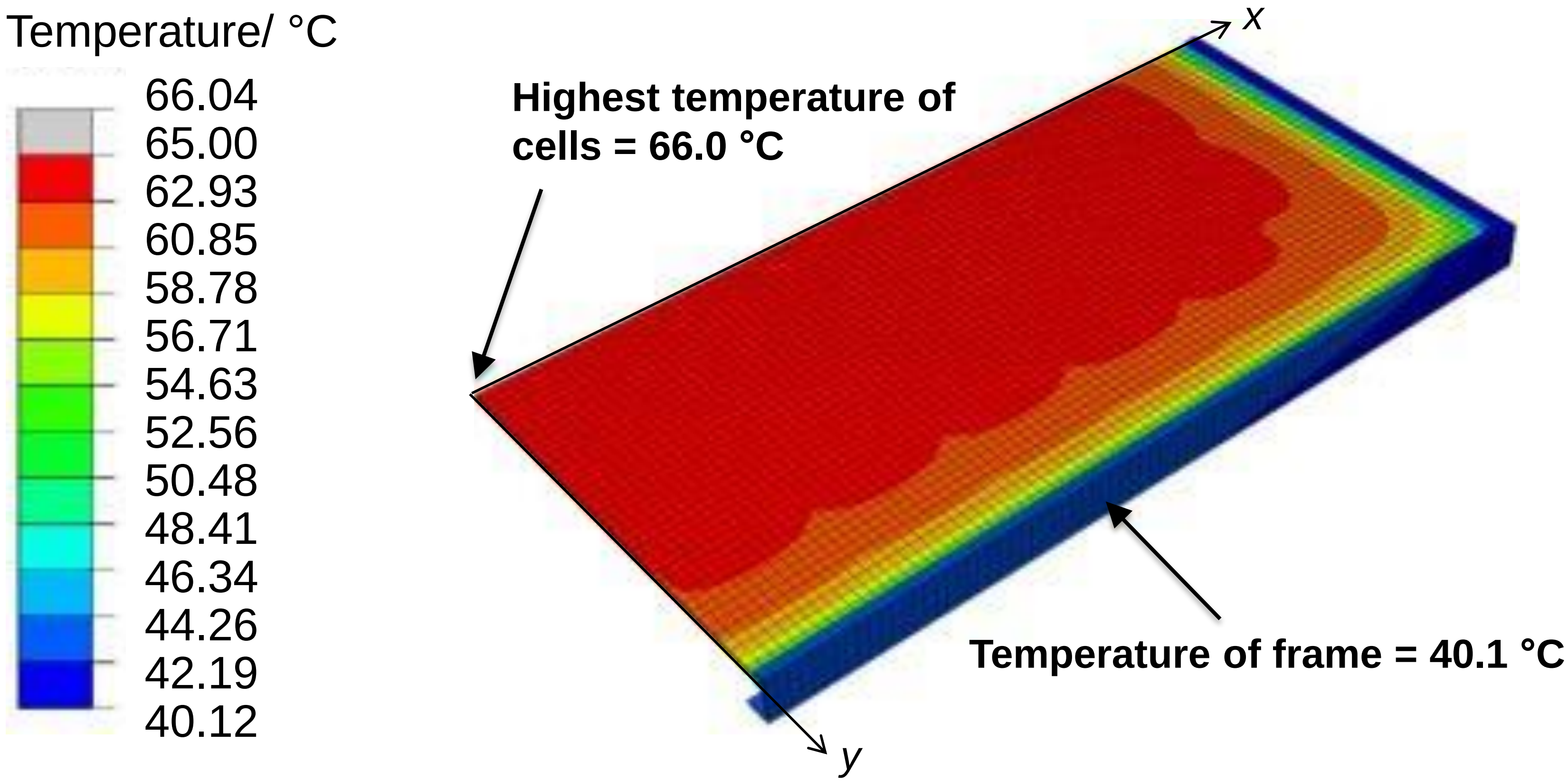
Fig. 4. Typical stress profile across the thickness of a tempered glass sheet.
Source: Petit et al., 2007 F. Petit, A.C. Sartieaux, M. Gonon and F. Cambier, Fracture toughness and residual stress measurements in tempered glass by Hertzian indentation, Acta Materialia 55 (2007), pp. 2765–2774.

Methodology

- Initial stress distributions obtained earlier from the FEA of the post-lamination cooling process are imported into the FE model.
- The laminate is then installed into an aluminium frame and the PV module is exposed to the sun.
- A FE thermal analysis is then performed to obtain the temperature distribution in the module.
- The solar irradiation was assumed to be 1000 W/m^2 and the ambient temperature 30 °C.
- Heat dissipation in the PV module was taken to be the solar irradiation minus the fraction reflected from the module (4%), the fraction reflected from the cells (8%) and the fraction converted to electricity (12%).
- Heat loss by convection and radiation from the module to the ambient was taken into account.

Results and Discussion

Temperature Distribution of Framed PV Module in Operation



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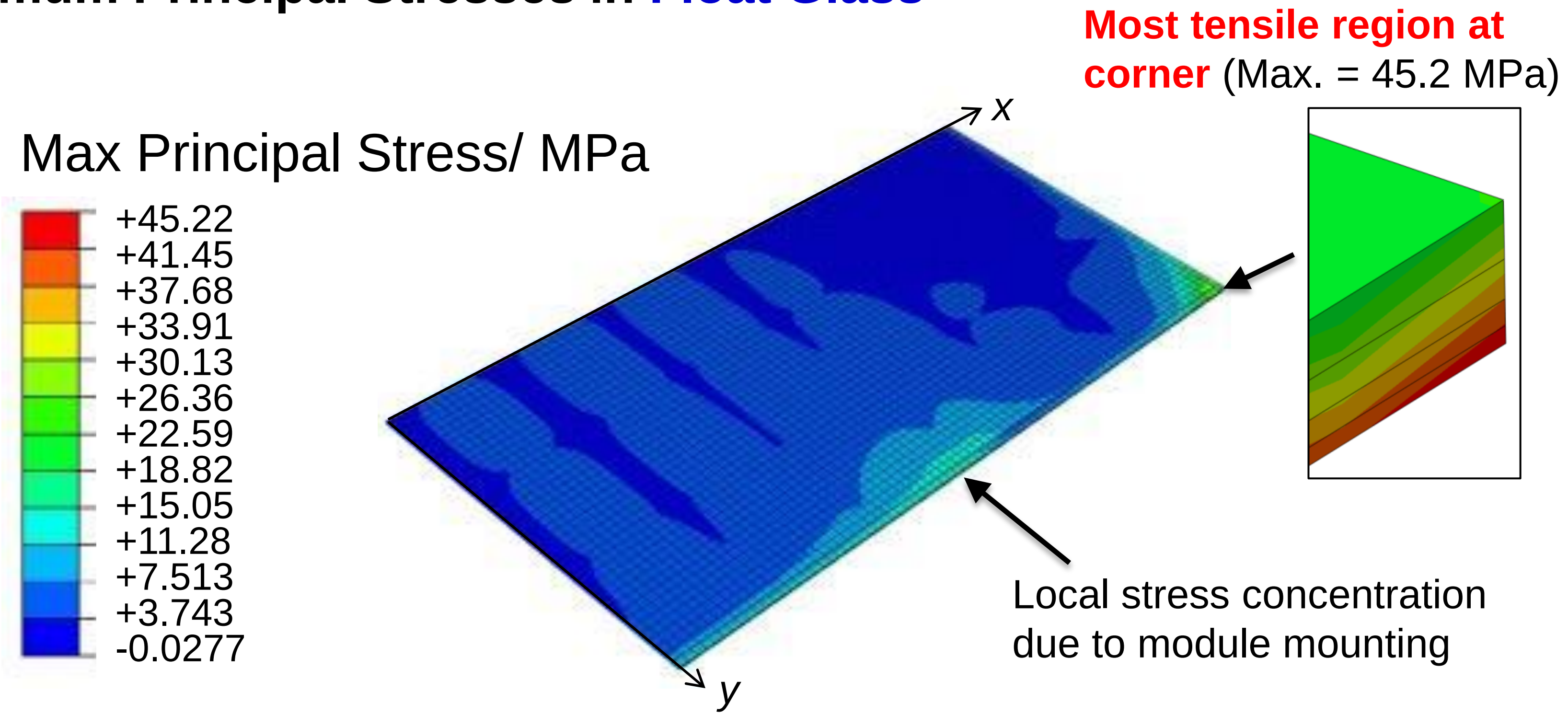
Results and Discussion

Maximum Principal Stresses in Float Glass

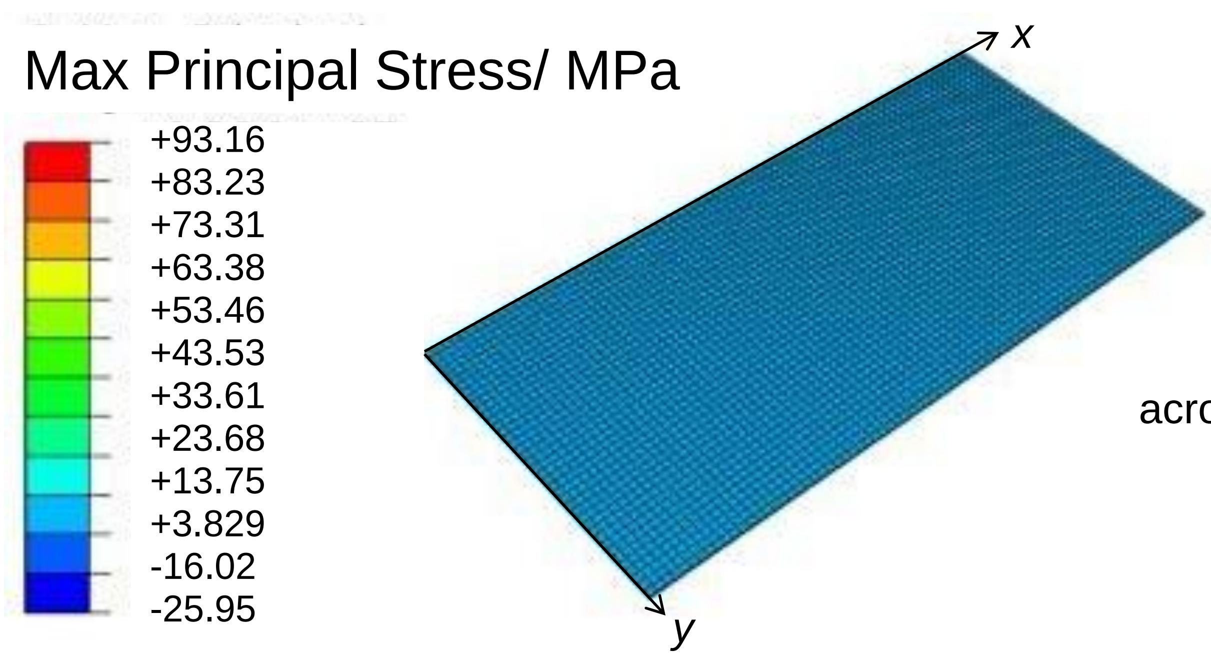


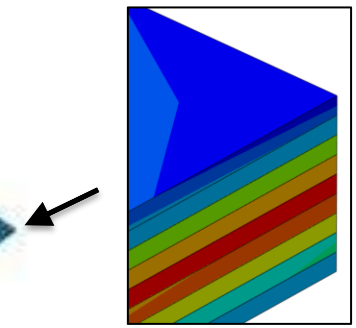
- Failure due to breakage has a high probability of occurring at the corner.
- Tensile stress experienced by the float glass layer may exceed its strength of 24 – 69 MPa, resulting in fracture.

Results and Discussion

Maximum Principal Stresses in Tempered Glass

- Stresses in the tempered glass cover is still compressive on the surface and tensile in the core.
- Hence, tempered glass offers greater durability than float glass.





Stress distribution across glass thickness

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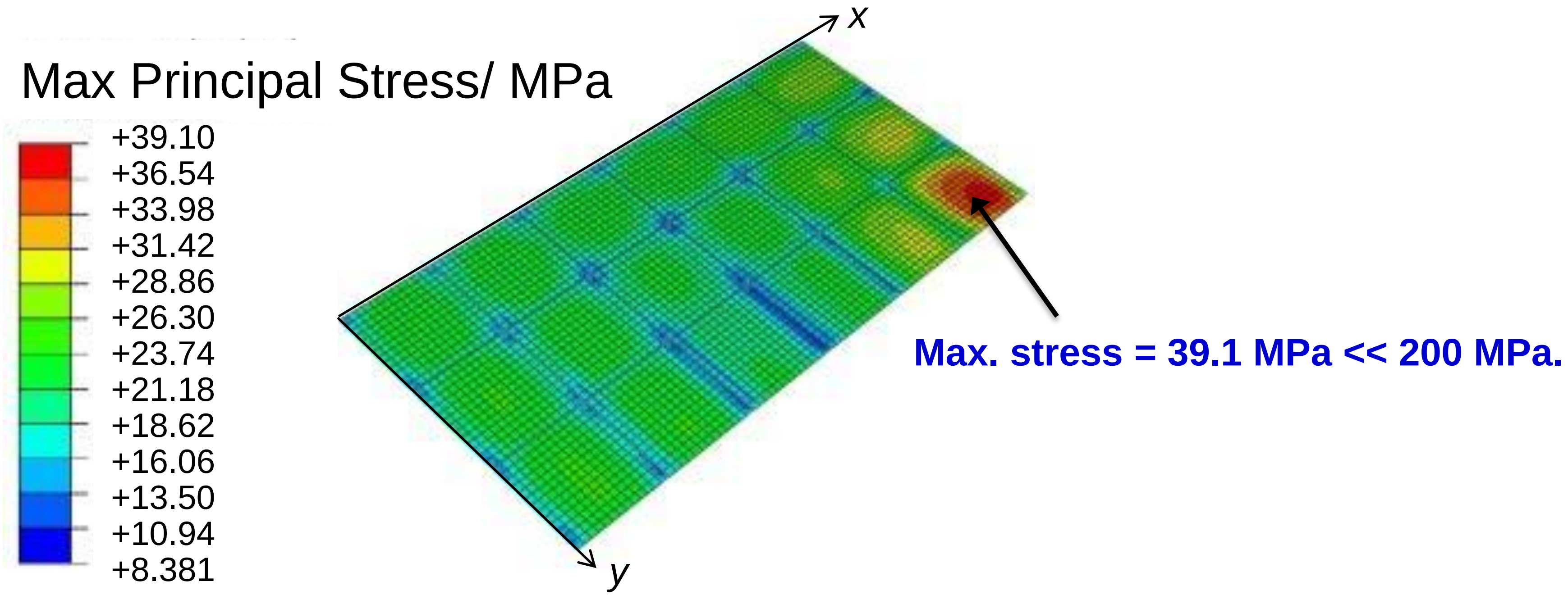
Results and Discussion

Maximum Principal Stresses of Cells in Float Glass Module

- ❑ All the cells are in tension.
- ❑ Maximum tensile stress in corner cell.
- ❑ Strength of silicon = 200 MPa, hence cells should be safe from fracture.



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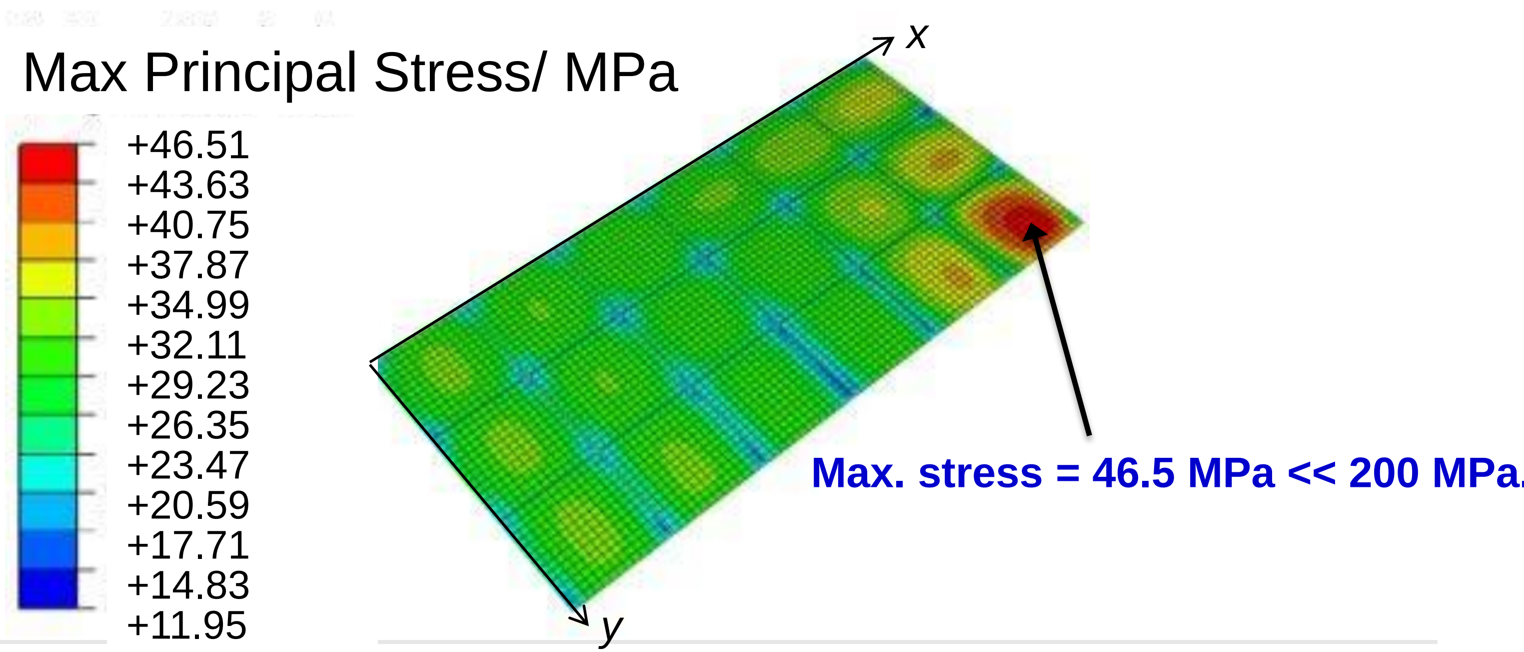
Results and Discussion

Maximum Principal Stresses of Cells in Tempered Glass Module

- All the cells are in tension.
- Maximum stress in corner cell greater than for float glass.
- Tempered glass is beneficial for durability, but at the expense of a higher tensile stress at the corner cell.
- This is not crucial since higher stress is still < failure stress (200 MPa).



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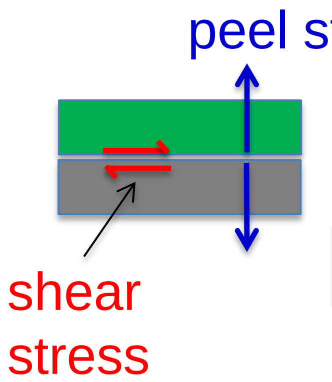
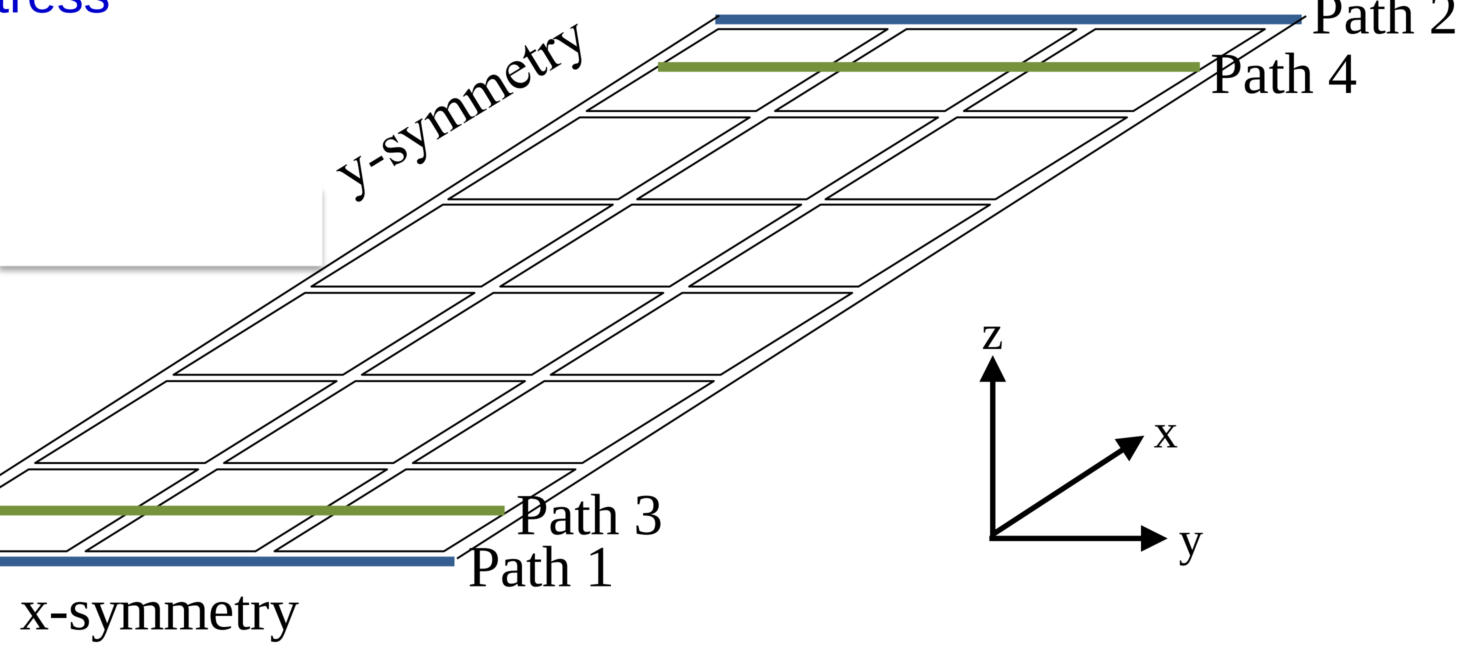
Stress Distributions Along Interfaces

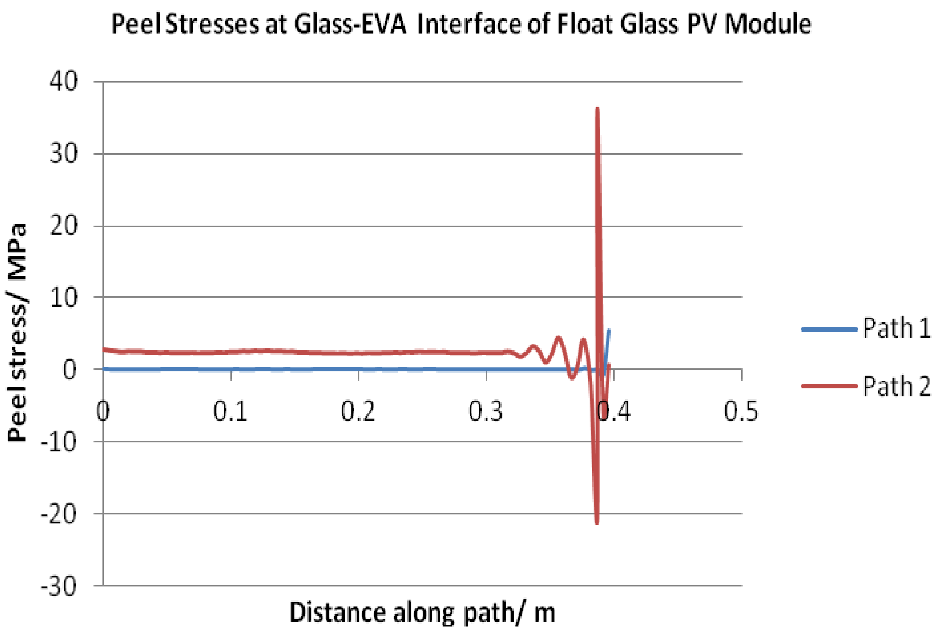
- Interfacial peel and shear stresses at the interfaces of the PV modules are analyzed to determine the likelihood of delamination.
- 4 paths are chosen parallel to short sides as the stresses were higher than those along paths parallel to the long sides.

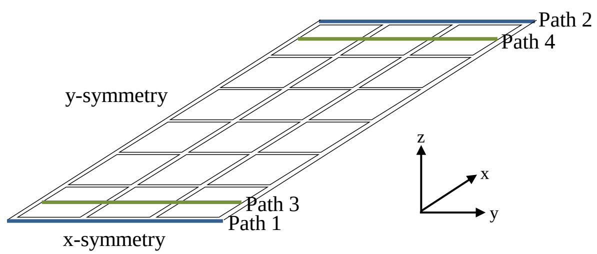




Stress Distributions Along Glass-EVA Interface

Peel stresses at Glass-EVA interface

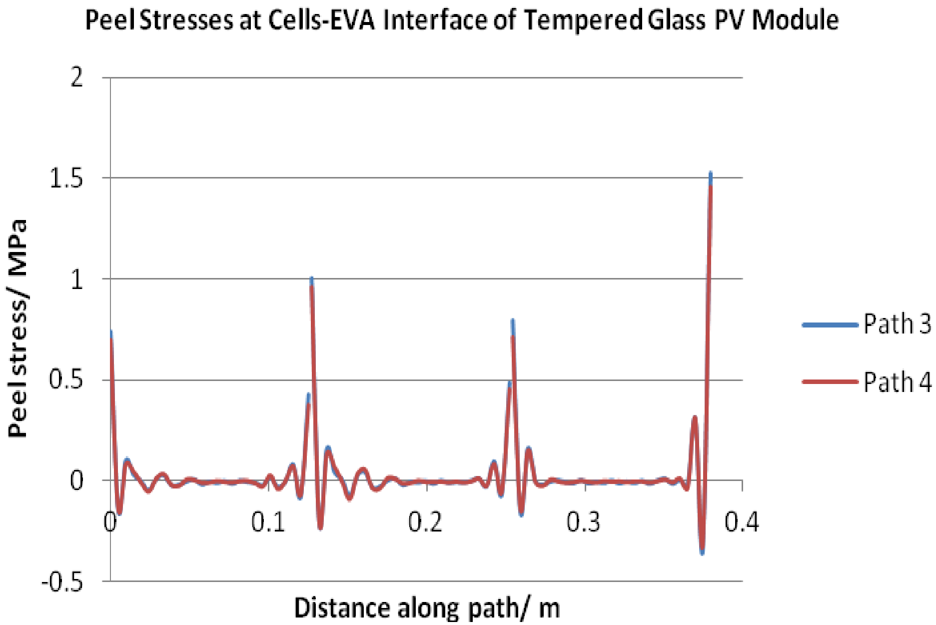


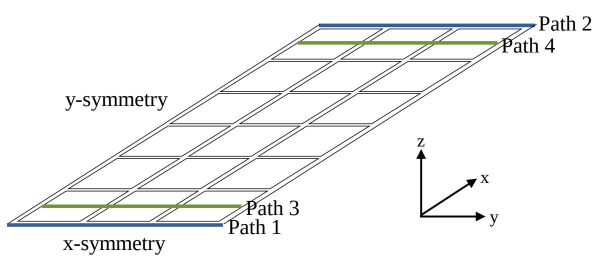


- The trends are similar for both types of modules with float glass and tempered glass.
- Peel stresses increase sharply at edge/corner, and that at corner is higher.

Stress Distributions Along Cell-EVA Interface

Peel stresses at Cell-EVA interface

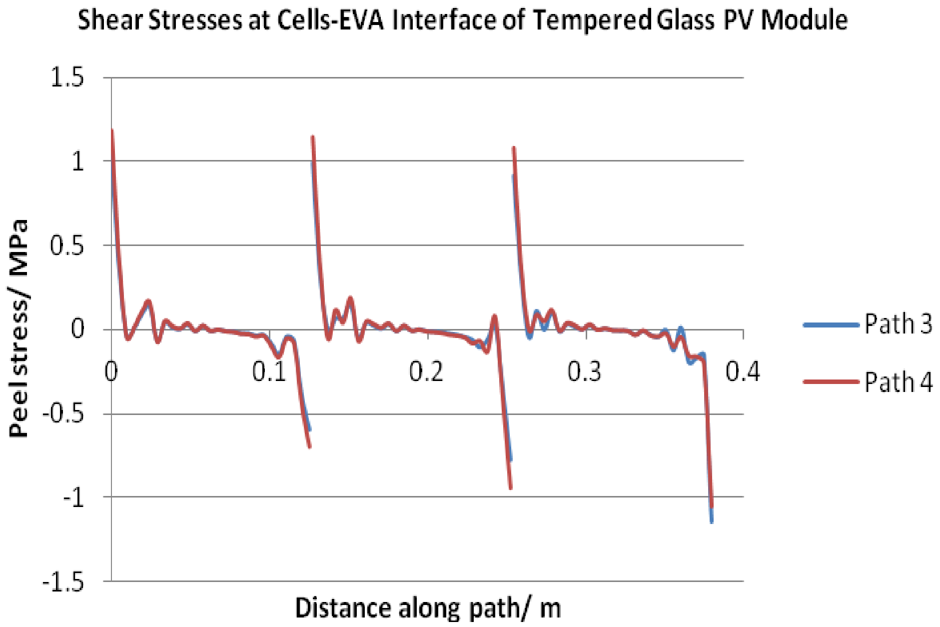


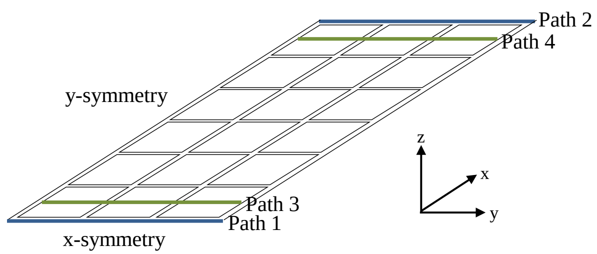


- The trends are similar for both types of modules.
- There is a 2 mm gap between adjacent cells, hence the peel stresses are discontinuous there.
- Peel stresses are zero at the centre of cells and rises rapidly at the edges.
- Magnitudes are much smaller compared to that at the Glass-EVA interface.

Stress Distributions Along Cell-EVA Interface

Shear stresses at Cell-EVA interface





- The trends are similar for both types of modules.
- Shear stresses are zero at the centre of cells and rises rapidly at the edges.
- Magnitudes are much smaller compared to that at the Glass-EVA interface.

Conclusions

- Stresses in PV modules can be affected by heating from exposure to the sun and by the manner of its attachment to the support structure.
- Tempered glass covers retain their compressive surface stress and are hence more reliable than float glass covers which experience a high tensile maximum principal stress at the corner.
- Tempered glass covers lead to a higher tensile stress at the centre of the corner solar cell but this is not an issue as the increased stress is still way below the fracture stress of silicon.
- Peel and shear stresses at the Glass-EVA and Cell-EVA interface are relatively low in the central region of the module but increase rapidly towards the edges and corners. The highest stresses occur at the corners and any delamination at this interface is most likely to occur at the corner.

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