# GLASS FUNDAMENTALS 1D
# THE EFFECTIVE THICKNESS OF LAMINATED GLASS

When considering laminated glass types under loading, consideration has to be given to the performance of the interlayer, and how this will influence the mechanical performance of the glass, with regards stress, and deflection.

## LAMINATED GLASS INTERLAYERS

For standard glazing applications, polyvinyl butyral (PVB) is the most common interlayer type, and is widely used through the UK and the rest of the world, including in the SGG STADIP product range. Other interlayer types are available, including ethylene vinyl acetate (EVA), ionomer based, such as SentryGlas® and cast-in-place resins, which may include polyurethane (PU), polymethyl methacrylate (PMMA) and epoxy.

For applications where fire resistance and protection is required, more complex interlayer compositions would be used, and these would be considered highly specialised configurations.

## INTERLAYER PROPERTIES

Interlayer properties will influence how the plies within a laminated glass behave under loading, and the shear modulus, *G*, and Young's modulus, *E*, are key parameters. The closer the shear modulus of an interlayer is to glass, the more it will behave in a monolithic manner.

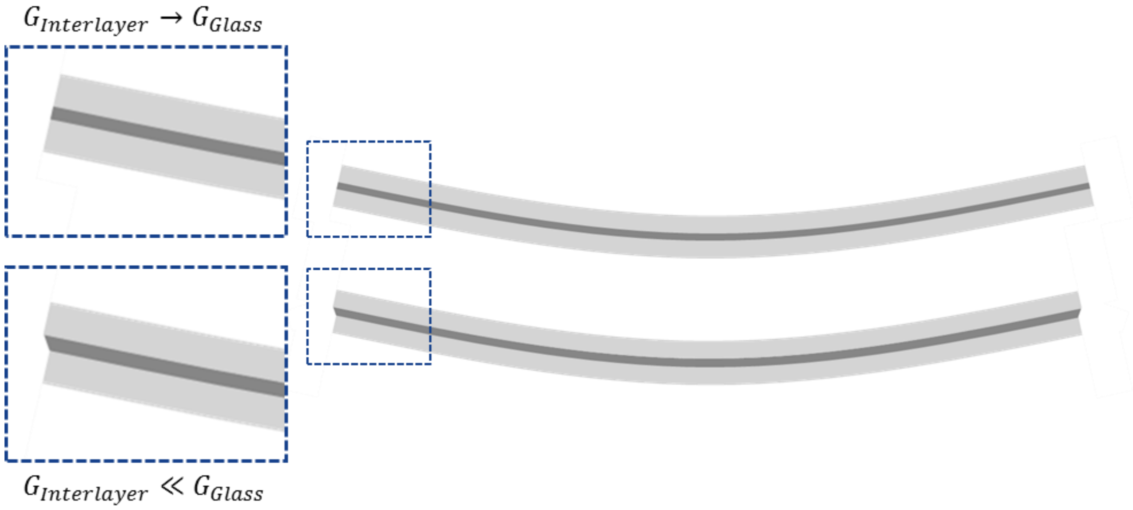


**Figure 1 - Schematic of Behaviour of Loaded Laminated Glass**

For polymeric materials such as PVB, EVA and PMMA, the shear modulus will be an order of magnitude different from soda-lime-silicate (SLS) glass. SLS glass will have a shear modulus typically in the region of 28.5 GPa, with PVB, at 20ºC, under a 1 second loading typically in the region of 0.2 GPa. As such, it would be expected that there will be some shear within the interlayer, and as such, a non-monolithic behaviour of the plies of glass.

## STRESS DISTRIBUTION THROUGH A LAMINATED GLASS BEAM

Two theoretical extremes, of an interlayer with the same properties as the SLS glass, and another with a shear modulus several magnitudes lower than the glass, can be considered. Modelling a beam under uniform loading across a span, the distribution of the stress through the glass would then be modelled as below;

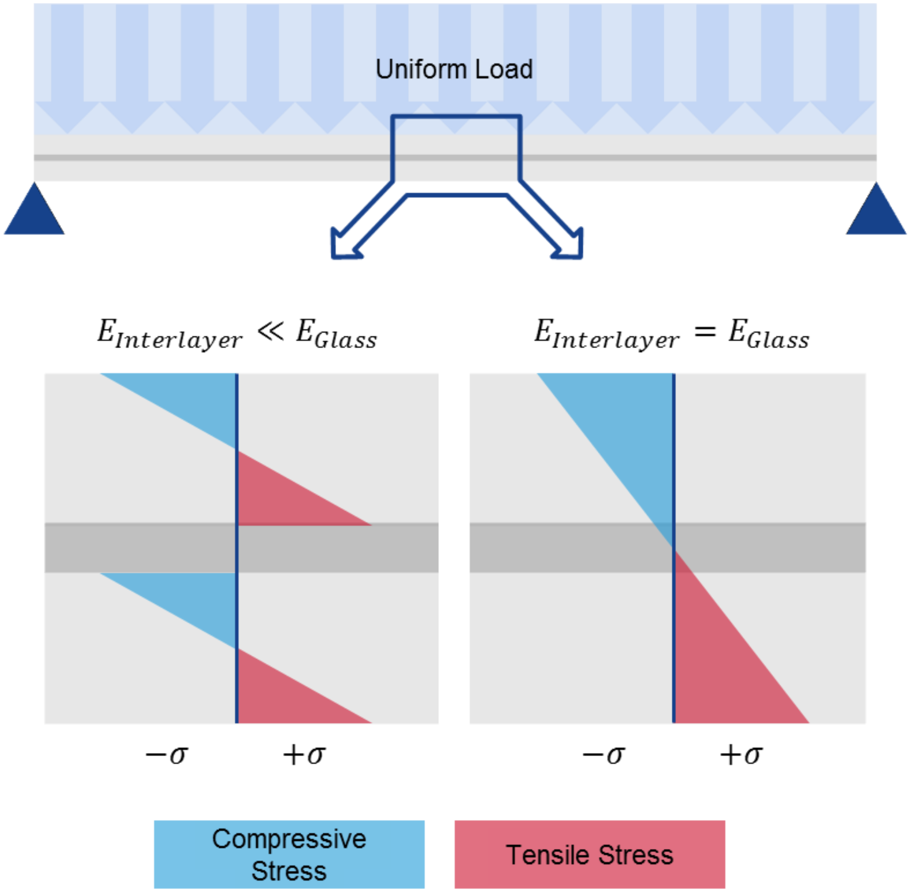


**Figure 2 - Stress Distributions through Laminate Configurations**

If the beam were a laminate comprising 2 plies of 4 mm SLS float glass, a 0.76 mm interlayer, 1000 mm length and 250 mm wide, simply supported along the short edges, then the results within Figure 3 can be obtained from finite element analysis of the configuration under a 1.0 kN/m$^2$ uniform load;

As can be seen from the data in Figure 3, as the shear modulus approaches that of glass, the stress distribution shifts, until ultimately, only surface 4 is subjected to higher levels of tensile (+ve) stress.

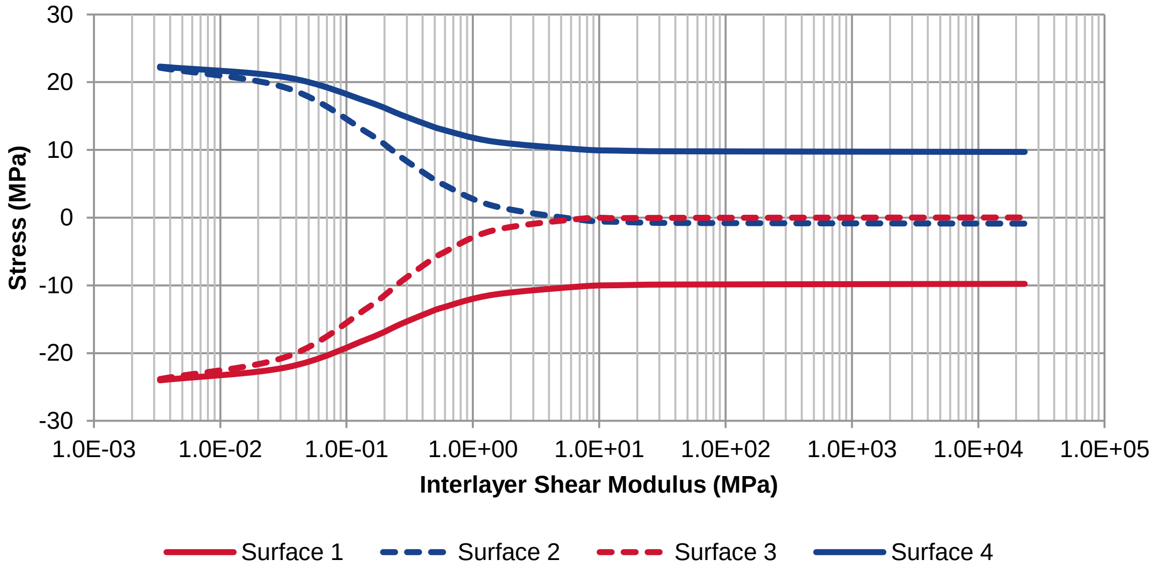


**Figure 3 - Surface Stresses vs. Shear Modulus (G)**

## DEFLECTION OF A LAMINATED GLASS BEAM

The deflection of a beam, as with stress, can also be modelled based on interlayer properties, and it's evident that as the shear modulus of the interlayer approaches that of glass, the deflection is reduced.

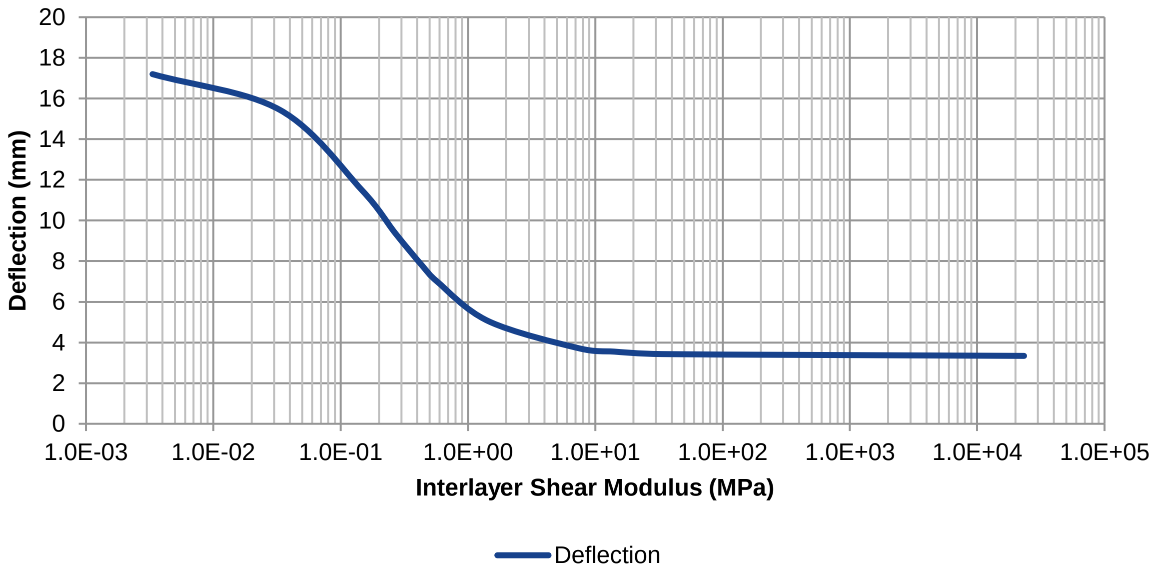


**Figure 4 - Deflection vs. Shear Modulus (G)**

## EFFECTIVE THICKNESS

The effective thickness of a laminated glass can be modelled based on the interlayer properties, using defined relationships from prEN 16612 [1], which relates to the relationships devised by Wölfel [2], and discussed in work by various others, including Galuppi and Royer-Carfagani [3].

The effective thickness can be determined for both deflection and stress calculations, and is highly dependent on the shear modulus of the interlayer. It should be noted, that the determination of the effective thickness is also dependent on a coefficient, $\beta$, being 9.6, which was determined by Wölfel for simply supported beams under uniform loading. For this reason, the accuracy should be considered when applying effective thickness to differing support conditions, such as four edge support and point support, as well as different load types, such as concentrated and line loads.

### TWO-EDGE SUPPORTED BEAM

For a simply supported beam, with the same parameters as discussed previously in this document, the difference between the deflection and stress determined from FEA of a laminated structure, compared with calculations based on the effective thickness, is shown, as below, to be negligible;

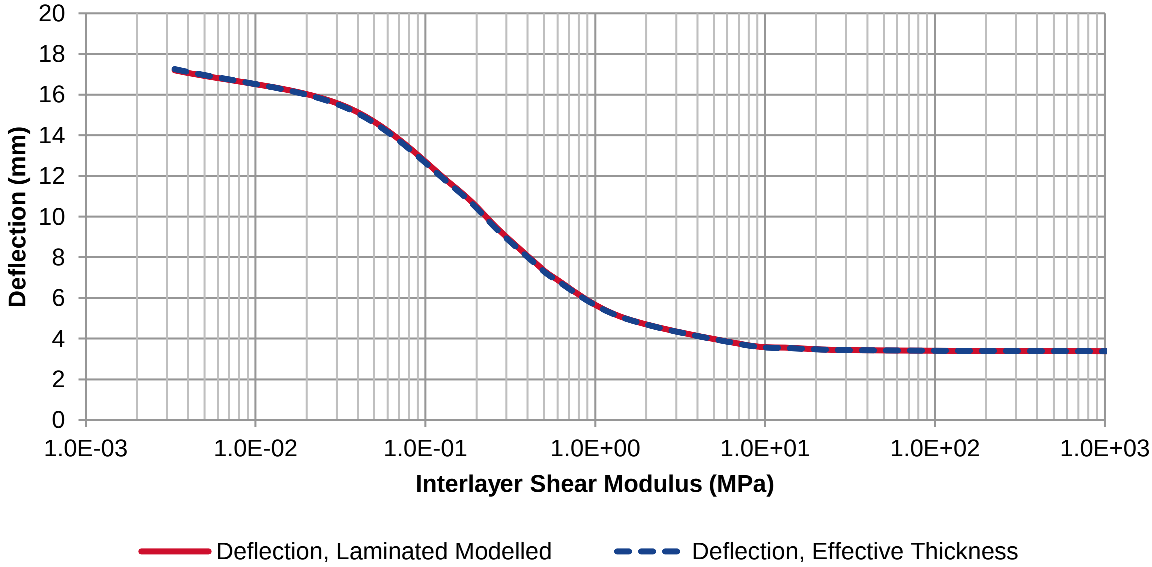


Figure 5 – Calculated Deflection for a Modelled Laminate and Effective Thickness Monolithic

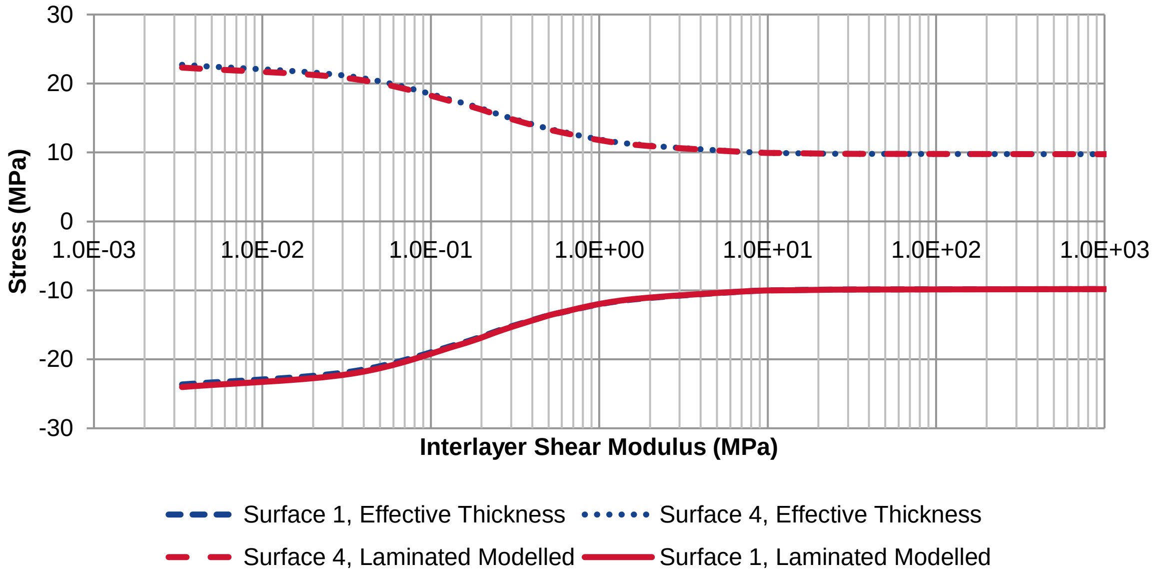


**Figure 6 – Calculated Stress for a Modelled Laminate and Effective Thickness Monolithic**

## FOUR EDGE SUPPORTED PLATE

If we consider a four edge supported plate, under uniform loading, and again assess calculated deflection and stress, differences begin to manifest in the results, which does lead to questions over the accuracy. The below results are based on a laminated plate comprising 2 plies of 4 mm SLS float glass, a 0.76 mm interlayer, 2000 mm length and 2000 mm wide, simply supported along all four edges, under a 1.0 kN/m$^2$ uniform load;

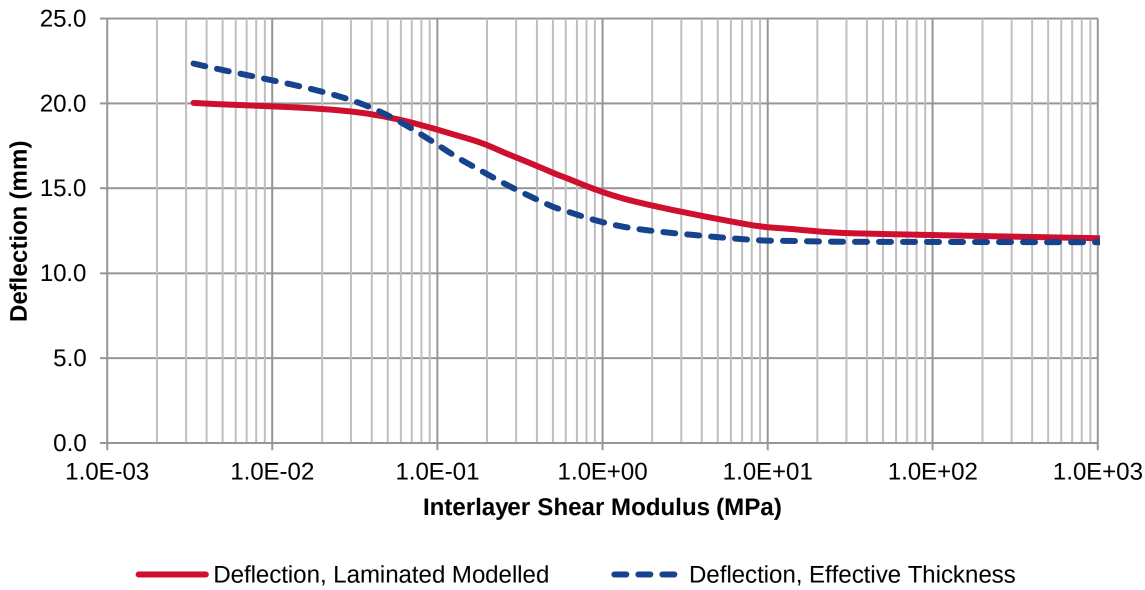


**Figure 7 - Calculated Deflection for a Modelled Laminate and Effective Thickness Monolithic**

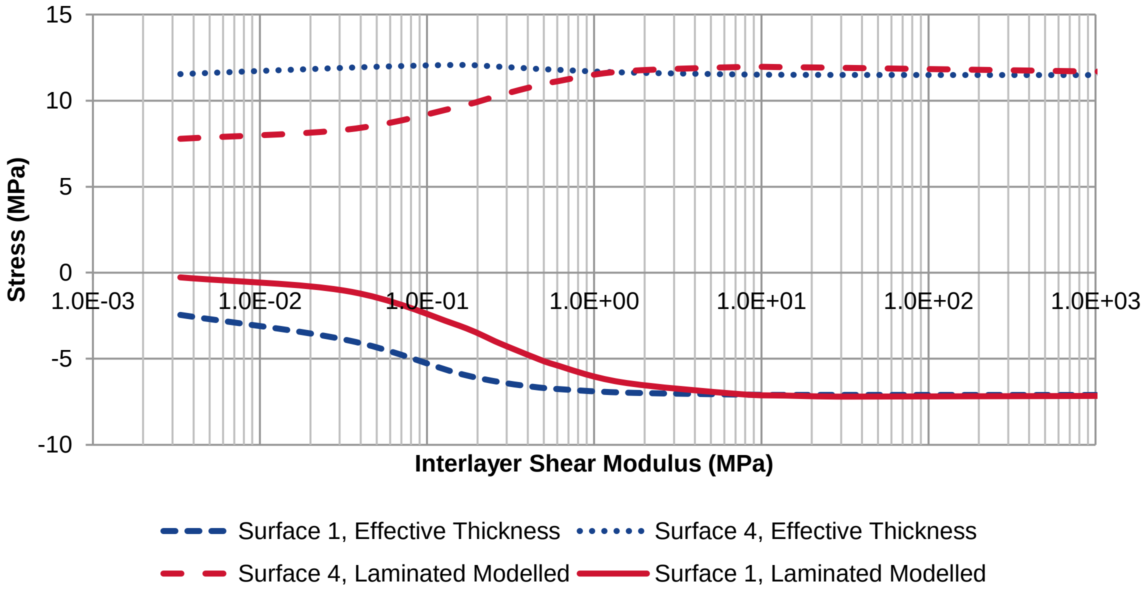


**Figure 8 - Calculated Stress for a Modelled Laminate and Effective Thickness Monolithic**

## INFLUENCING FACTORS

Various factors will influence the shear modulus of a polymeric interlayer material, specifically composition, load duration and temperature.

### INTERLAYER COMPOSITION

The performance of the various interlayer types will differ, and the below shows a comparison of typical mechanical properties considered based on a 3 second and 1 hour load, at 30ºC. If these load conditions were considered typical, then ionomer based and "structural" PVB interlayers would be expected to be stronger, with standard PVB and EVA the weaker options.

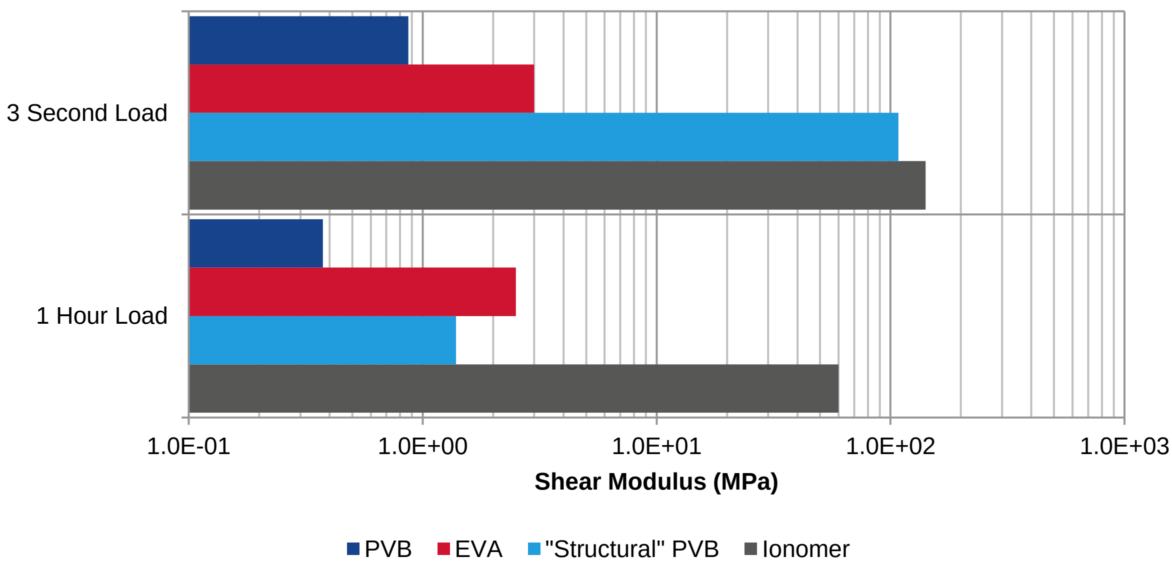


**Figure 9 - Comparative Shear Modulus for Interlayer Types**

## LOAD DURATION

The longer the duration of a load, the lower the effective shear modulus of the interlayer, due to creep of the polymer. The below shows the relationship between load duration and shear modulus for a Saflex R Series PVB, and a SentryGlas SG 5000 Ionomer interlayer at 20ºC

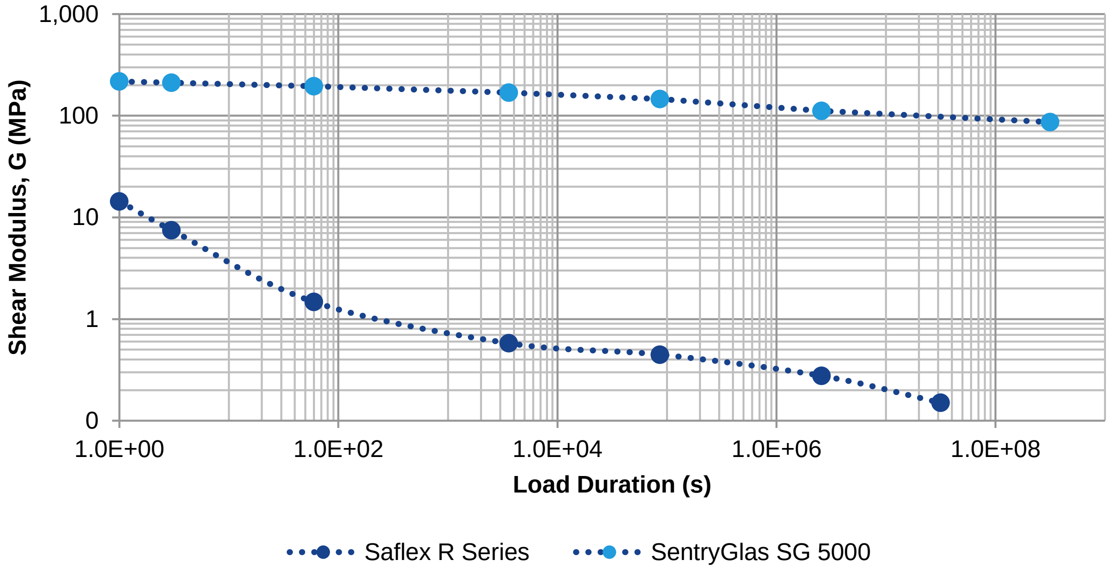


**Figure 10 - Data for Saflex R Series and SentryGlas SG 5000 Interlayer at 20ºC**

As can be seen in Figure 10, a load duration increase from 1 second to 3 seconds almost halves the shear modulus of the PVB interlayer material, which for a an 8.8 mm laminate, could decrease the effective thickness from 7.26 mm to 5.57 mm for deflection. The effect is significantly less pronounced with an ionomer interlayer due to the molecular structure of the interlayer.

## TEMPERATURE

The higher the temperature the interlayer is at, the lower the shear modulus, and as per previous, the lower the effective thickness the laminate would be. The below figure shows the properties of a Saflex R Series PVB, and a SentryGlas SG 5000 Ionomer, under a 3 second load, with an increasing temperature.

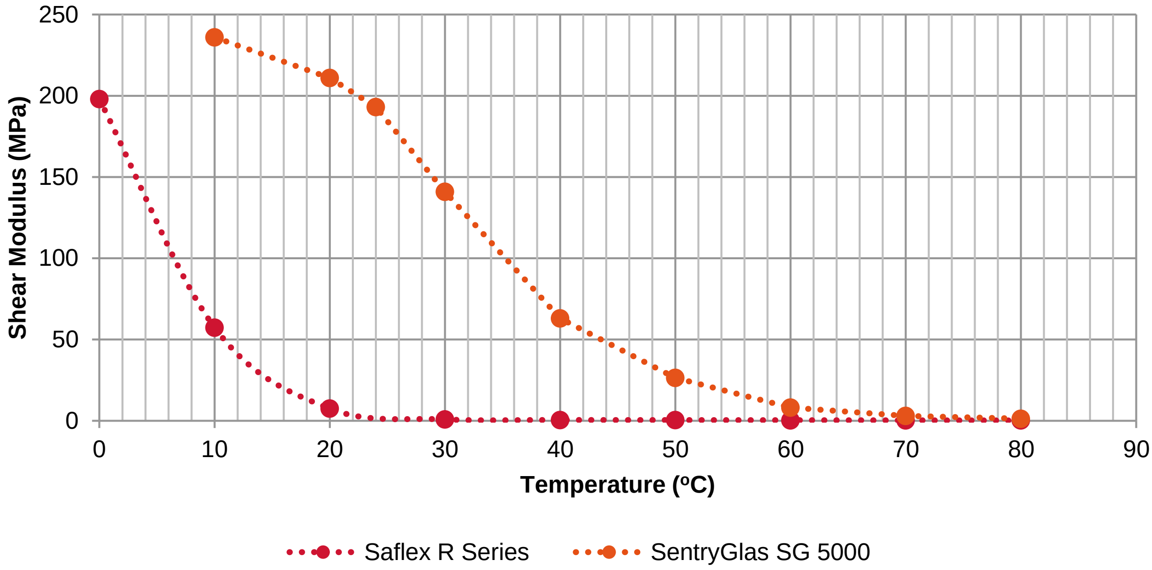


Figure 11 - Data for Saflex R Series and SentryGlas SG 5000 Interlayer under a 3 Second Load

There is ultimately a similar drop off between PVB and Ionomer based interlayers, however, in what may be considered more realistic service temperatures, the Ionomer interlayer has a significantly better performance.

## COMBINED LOAD DURATION & TEMPERATURE

If we then consider load duration and temperature combined, under worst case conditions, an interlayer at a higher temperature, under a long term load, would be expected to be under worst case conditions with regards the resultant stresses and deflections generated in any given glazing system.

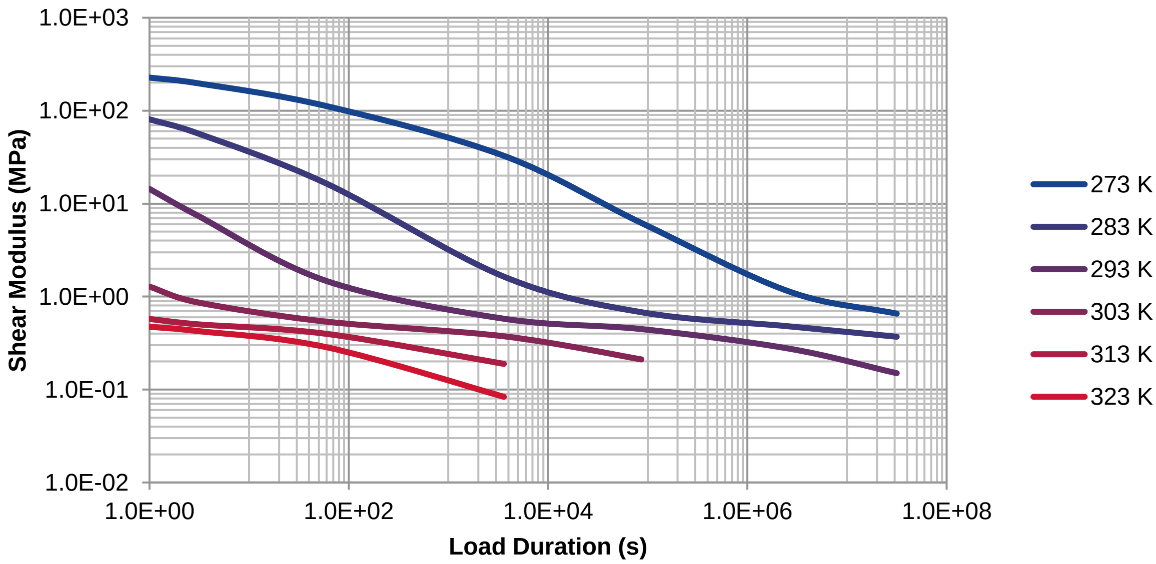


Figure 12 - Combined Load Duration & Temperature for Saflex R Series PVB Interlayer

The same applies to ionomer type interlayers, amongst others, although the duration and temperature, as seen in previous data, has less of an influence over the performance.

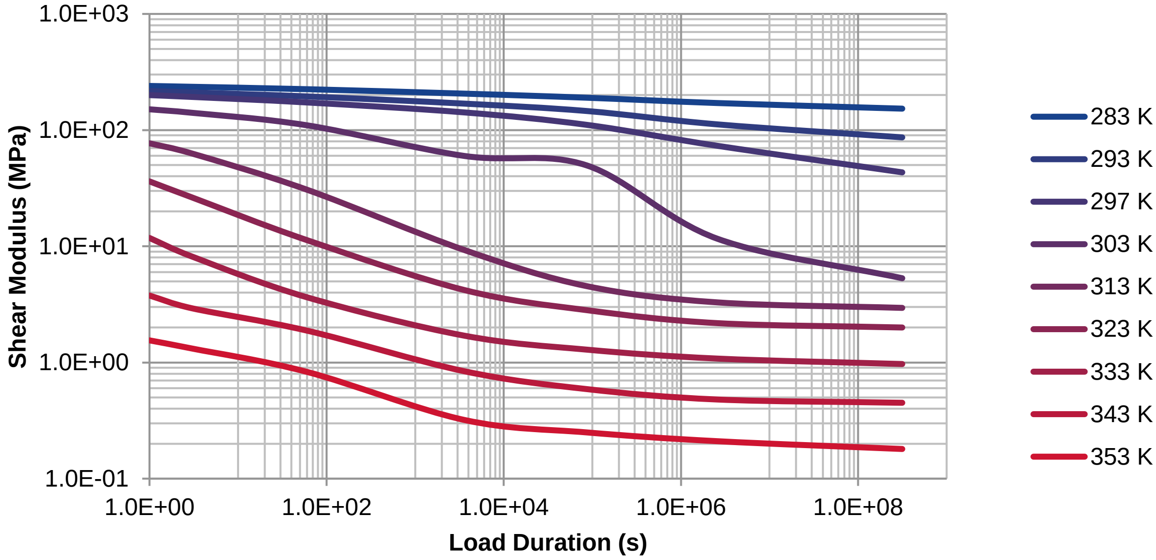


**Figure 13 - Combined Load Duration & Temperature for SentryGlas SG5000 Interlayer**

## REFERENCES

[1] European Committee for Standardization, prEN 16612:2013 - Glass in Building - Determination of the load resistance of glass panes by calculation and testing, CEN, 2013.

[2] E. Wölfel, “Nachgiebiger Verbund: eine Näherungslösung und deren Anwendungsmöglichkeiten,” *Stahlbau,* vol. 56, no. 6, pp. 173-180, 1987.

[3] L. Galuppi and G. Royer-Carfagani, “The Effective Thickness of Laminated Glass Plates,” *Mechanics of Materials and Structures,* vol. 7, no. 4, pp. 375-399, 2012.