Impact of glass plates rigidity on load sharing in an aerogel composited glass unit

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Abstract: An aerogel composited glass unit consists of two glass sheets and an interlayer filled with aerogel granules. When it is subjected to a uniformly distributed load, part of the load is transferred to the leeward glass sheet through the interlayer. A numerical analysis method is employed to describe the effect of glass plates rigidity on load sharing of two glass plates and an experimental research is conducted to verify the validity of the numerical method. The experimental results suggested that the assumptions which were employed in the numerical method are valid when the difference of glass sheets rigidity is small, but it becomes inapplicable when the difference of glass sheets rigidity becomes much greater.

1. Introduction
The SiO2 aerogel has highly insulating property, yet its fragile mechanical property has against it for engineering application. However, in an aerogel composited glass unit (ACG unit) aerogel can be protected by placing the aerogel between two glass plates and this novel glazing system will also greatly improve the insulation property of existing buildings[1](see figure 1).

Fig 1. Diagram of the aerogel composited glass unit

Few researches has been done for the wind loading design of the ACG unit, but the structure of this glazing unit is similar to sandwich glazing material such as laminated glass and insulating glass. In the wind loading design of an insulating glass unit, CVG Vallabhan and WL Beason each employed a different iterative scheme for the interaction between two plates and obtained the load distribution of
each plate[2,3]. It is suggested by Behr that the mechanical behavior of laminated glass units is bounded by two limiting cases[4,5]. When the interlayer of laminated glass unit is considered ineffective (i.e., there is no shear transfer between two glass sheets), the structure behavior of the unit is like a layered system that two glass sheets act like there is no connection in between. In contrast, if the interlayer is strong enough to transfer 100% shear between two glass plates, the laminated glass behave like a monolithic glass plate when it is under pressure (see Figure 2).

![Figure 2. Limiting case of laminated glass units](image)

The bending property of the ACG unit resembles that of the layered system, as the shear transferred in the interlayer is negligible. A numerical analysis method based on layered glass system is illustrated in this paper.

2. Numerical analysis for loading design of ACG units

The interaction of the aerogel glazing system when under wind pressure is complicated. Since the mechanical respond of ACG units is similar to a layered glass system, several assumptions is added to the numerical analysis to simplify the numerical method. It is assumed that the windward glass sheet is subjected to a uniformly lateral load.

2.1. Assumptions for numerical analysis

1. The glass unit is assumed to have simply supported on four sides.
2. The spacer and boundary condition of ACG unit are assumed to be rigid.
3. As the interlayer of ACG unit can not restrict the relative slippage of glass sheets, it is assumed that two glass sheets act like there is no connection in between.
4. It is assumed that part of the wind load is evenly transmitted from the windward glass plate to the leeward glass plate.
5. The deformation of each glass plates is assumed to be the same.

2.2. Numerical method for loading design of ACG units

According to the basic assumption for the numerical model, it can be assumed that when the ACG unit is subjected to a uniform pressure \( P_0 \) the windward and leeward glass plate are sharing the total load. The load sharing of windward and leeward plate is \( p_1 \) and \( p_2 \) respectively. The flexural rigidity for each plate is \( D_1 \) and \( D_2 \) respectively and the deflection of each plate is \( w_1 \) and \( w_2 \) respectively.

According to the thin plate theory, the deflection \( w \) of each plate is positively correlated with external load \( P \) and negatively correlated with the rigidity \( D \) of each plate[6].

\[
\frac{w_1}{D_1} = \frac{p_1}{D_1}, \quad \frac{w_2}{D_2} = \frac{p_2}{D_2} \tag{1}
\]

As it is assumed that the deformation of each glass plate is the same \( w_1 = w_2 \) and the wind load is evenly transmitted from the windward glass plate to the leeward glass plate \( P = p_1 + p_2 \), the load sharing of each glass plate can be concluded as followed:

\[
p_1 = P \times \frac{D_1}{D_1 + D_2}, \quad p_2 = P \times \frac{D_2}{D_1 + D_2} \tag{2}
\]

It is suggested by equation (2) that in this numerical model the load sharing of glass plates depends on the flexural rigidity of each plate. The flexural rigidity of plate is given by
\[ D = \frac{Et^3}{12\left(1 - \nu^2\right)} \]  

(3)

In which \( E \)=elastic modules of glass(72000Mpa); \( t \)=thickness of glass plate(\( t_1, t_2 \) for windward and leeward glass plate respectively); \( \nu \)=Poisson’s ratio for glass(0.2). According to equation (2) and equation (3), the load distribution can be given by

\[ p_1 = p \times \frac{t_1^3}{(t_1^3 + t_2^3)}, \quad p_2 = p \times \frac{t_2^3}{(t_1^3 + t_2^3)} \]

(4)

3. Experimental research

3.1. Methodology

In order to verify the numerical method an experimental research was implemented. Different specimens of ACG units were tested under uniformly distributed loads (see table 1).

| Set number | Geometry in mm | Size          |
|------------|----------------|---------------|
| 1          | 10+8+10        | 900mm × 900mm |
| 2          | 10+20+10       | 900mm × 900mm |
| 3          | 8+16+6         | 900mm × 900mm |
| 4          | 10+16+6        | 900mm × 900mm |

3.2. Test set up

In the experiment, one of the glass plates of the ACG unit was loaded with a uniformly lateral load. The gravity load of sandbags was used to simulate the uniformly distributed load (see figure 4). To get the maximal deflection of each glass plate, the deformation of the glass plate was measured at four locations (see figure 3). Two displacement gauges are located at the midspan of each glass plate and the other two gauges are located at two side of the glass in order to eliminate the error induced by the deformation at the support.

The loading method of the experimental research is step loading. As it is illustrated by figure 4, the deflection of each glass plate was measured and registered after each load step.

4. Results comparison

As it was suggested in the numerical analysis for loading design of ACG units, when the unit is subjected to a uniformly distributed load the load sharing of each monolithic glass plate can be given
by equation (4), then the deflection and stress of each plate can be obtained by using a finite
element method (ANSYS).

The deflection value of each glass plate of an ACG unit is demonstrated in table 2. The analytical
deflection of glass plates is calculated by the finite element software.

| Geometry in mm | Pressure in Kpa | Experimental deflection in mm (windward) | Numerical deflection in mm (windward) | Error | Experimental deflection in mm (leeward) | Numerical deflection in mm (leeward) | Error |
|----------------|-----------------|------------------------------------------|----------------------------------------|-------|------------------------------------------|----------------------------------------|-------|
| Set No.1 10+8+10 | 1.936 | 0.514 | 0.412 | 19.8 | 0.418 | 0.412 | 1.4 |
| | 2.420 | 0.633 | 0.515 | 18.6 | 0.530 | 0.515 | 2.8 |
| | 2.904 | 0.744 | 0.618 | 17.0 | 0.640 | 0.618 | 3.5 |
| | 3.388 | 0.856 | 0.720 | 15.9 | 0.748 | 0.720 | 3.7 |
| | 3.872 | 0.971 | 0.822 | 15.3 | 0.869 | 0.822 | 5.4 |
| | 4.356 | 1.079 | 0.924 | 14.3 | 0.983 | 0.924 | 6.0 |
| | 4.840 | 1.203 | 1.026 | 14.7 | 1.106 | 1.026 | 7.2 |
| | 5.323 | 1.309 | 1.128 | 13.8 | 1.221 | 1.128 | 7.6 |
| | 5.565 | 1.354 | 1.178 | 13.0 | 1.268 | 1.178 | 7.1 |
| Set No.2 10+20+10 | 1.936 | 0.557 | 0.412 | 26.0 | 0.394 | 0.412 | 4.6 |
| | 2.420 | 0.681 | 0.515 | 24.4 | 0.498 | 0.515 | 3.4 |
| | 2.904 | 0.802 | 0.618 | 23.0 | 0.601 | 0.618 | 2.8 |
| | 3.388 | 0.928 | 0.720 | 22.4 | 0.704 | 0.720 | 2.3 |
| | 3.872 | 1.047 | 0.822 | 21.4 | 0.815 | 0.822 | 0.9 |
| | 4.356 | 1.167 | 0.924 | 20.8 | 0.922 | 0.924 | 0.3 |
| | 4.840 | 1.281 | 1.026 | 19.9 | 1.028 | 1.026 | 0.2 |
| | 5.323 | 1.400 | 1.128 | 19.4 | 1.133 | 1.128 | 0.4 |
| | 5.565 | 1.452 | 1.178 | 18.9 | 1.188 | 1.178 | 0.8 |
| Set No.3 8+16+6 | 1.936 | 1.245 | 1.123 | 9.8 | 1.366 | 1.116 | 18.3 |
| | 2.420 | 1.513 | 1.398 | 7.6 | 1.689 | 1.385 | 18.0 |
| | 2.904 | 1.746 | 1.668 | 4.5 | 1.978 | 1.648 | 16.9 |
| | 3.388 | 1.979 | 1.935 | 2.2 | 2.277 | 1.906 | 16.3 |
| | 3.872 | 2.206 | 2.197 | 0.4 | 2.57 | 2.140 | 16.7 |
| | 4.356 | 2.396 | 2.455 | 2.5 | 2.84 | 2.377 | 16.3 |
| | 4.840 | 2.602 | 2.692 | 3.5 | 3.115 | 2.606 | 16.3 |
| | 5.323 | 2.802 | 2.933 | 4.7 | 3.372 | 2.826 | 16.2 |
| | 5.565 | 2.881 | 3.052 | 5.9 | 3.501 | 2.934 | 16.2 |
| Set No.4 10+16+6 | 1.936 | 0.81 | 0.677 | 16.4 | 1.138 | 0.507 | 40.7 |
| | 2.420 | 0.978 | 0.845 | 13.6 | 1.397 | 0.675 | 39.8 |
| | 2.904 | 1.15 | 1.013 | 11.9 | 1.646 | 0.841 | 38.9 |
| | 3.388 | 1.313 | 1.180 | 10.1 | 1.901 | 1.005 | 38.6 |
| | 3.872 | 1.488 | 1.346 | 9.5 | 2.143 | 1.168 | 38.0 |
| | 4.356 | 1.626 | 1.511 | 7.1 | 2.367 | 1.329 | 37.1 |
| | 4.840 | 1.771 | 1.675 | 5.4 | 2.588 | 1.488 | 36.5 |
| | 5.323 | 1.915 | 1.838 | 4.0 | 2.809 | 1.644 | 36.0 |
| | 5.565 | 1.974 | 1.919 | 2.8 | 2.917 | 1.799 | 35.7 |

Error= | (Numerical deflection – Experimental deflection)/ Experimental deflection × 100% |

As it is stated in table 2, when the flexural rigidity of each glass plate in an ACG unit is equal (i.e.
the thickness of each glass plate is equal), the theoretical deflection value correspond closely to the
experimental value (see set No.1). At the same time, with the interlayer thickness of ACG units
increasing, the deflection error of windward glass plate increases slightly (see set 1 and 2). As the
difference of flexural rigidity of each glass plate is small, the numerical analysis is still applicable for the loading design of the ACG unit (see set No.3). However, in set No.4 the numerical method becomes invalid, since the deflection error for the leeward glass plate reach at 40%.

5. Conclusion
A simple scheme for load sharing between the windward and leeward plates of an ACG unit is developed. The following conclusions are reached from the comparison between theoretical results and the experimental results.

(1) For an ACG unit with unequal plate thicknesses, the thicker plate shares a higher percentage of the load.

(2) From the experimental result it can be found that the windward glass plate assumed more load than the leeward plate even if two glass plates have the same rigidity. Therefore, it is suggested that the load sharing of the windward plate should multiplied by an amplification factor.

(3) As the difference of plate thickness is increasing to a certain level, the load sharing scheme of the ACG unit lose its effectiveness, especially for the leeward glass plate. The main reason for the failure of the scheme is that the basic assumption that the deformation of each glass plate is equal is inapplicable anymore. The unequal deformation of two glass plate is partly due to the low elasticity of the aerogel granules. Because of the low elasticity of the thick interlayer, the flexural deformation of the windward and the leeward plate are inconsistent.

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