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Experimental and Theoretical Study of Vacuum Pressure in Evacuated Windows Used in Energy Efficient Buildings

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Abstract:

Vacuum glazing is a highly insulating window typically used in energy-efficient buildings. It consists of two or more glass panes hermetically sealed together around their periphery enclosing a vacuum gap. Arrays of tiny support pillars maintain the separation of the panes under atmospheric pressure [1]. This paper reports a detailed experimental study of the internal pressure of vacuum glazing using a newly developed optical system which, unlike the conventional method of measuring vacuum pressure which involves drilling a hole in the glazing and the physical connection of a vacuum gauge [2, 3], enables the measurement of the internal pressure without affecting the integrity of the glazing. Samples of indium sealed vacuum glazing incorporating a getter were fabricated. The experimentally and theoretically determined internal pressures of the glazing were in good agreement.

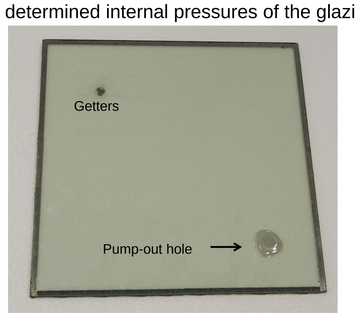

Fig 1: Fabricated vacuum glazing

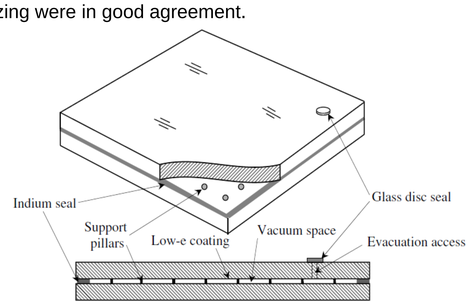

Fig 2: A schematic diagram of indium based vacuum glazing

Design of Optical System:

Due to atmospheric pressure a high level of stress exists across a vacuum glazing especially in the vicinity of the support pillars. Since the stress in the glass panes can change the orientation of the polarization of polarized light, 3-D glasses can reveal such an effect [4]. Based on this principle a system has been designed and calibrated to measure the pressure inside vacuum glazing. The system is a vacuum chamber with two ports; one port is connected to a vacuum pump and the other port is connected to a vacuum gauge. The box has four aluminium and two glass walls as schematically shown in Fig 3.

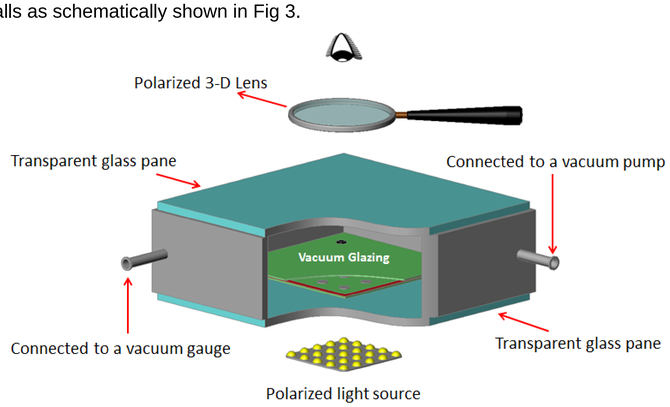

Fig 3: A schematic diagram of vacuum chamber used to measure the internal pressure in vacuum glazing

Internal Pressure Measurement:

Vacuum glazing is placed inside the box and polarized light is directed at the glazing. The light is observed through a 3-D polarized lens after passing through the box as schematically shown in Fig 3. By evacuating the vacuum chamber the pressure difference between the internal space within the vacuum glazing and the vacuum chamber reduces and consequently the stress pattern across the glazing reduces When the two pressures equalize, the stress around the pillars disappears, therefore the pressure on the gauge connected to the vacuum chamber is equal to the pressure inside the vacuum glazing. Using this technique the internal pressure of vacuum glazing samples were measured and the results are presented in Table 1.

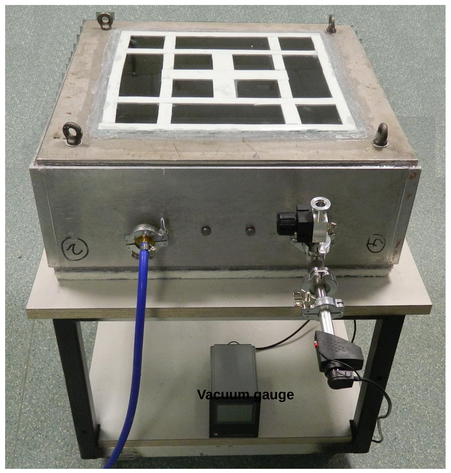

Fig 4: System used to measure the internal pressure in vacuum glazing

Fabrication and Characterization of Vacuum Glazing:

Vacuum glazing samples were fabricated with an indium seal using an ultrasonic soldering technique [6]. The vacuum glazing comprised two K-glass panes, 0.4m×0.4m with low-e coatings (emittance of 0.16) on one side of each pane. Arrays of stainless steel support pillars were spaced at 25mm intervals on a regular square grid. The pillars had a diameter of 0.4mm and a height of 0.15mm. Getters were positioned in one of the samples and after completing the fabrication process, the getters (St707 Pill/4-2/50) were activated at 250°C using an induction heater. Thermal performance of the samples were characterized experimentally using a guarded hot box calorimeter [5] and their internal pressure were calculated using the Equation below [5] and the result is presented in Table 1.

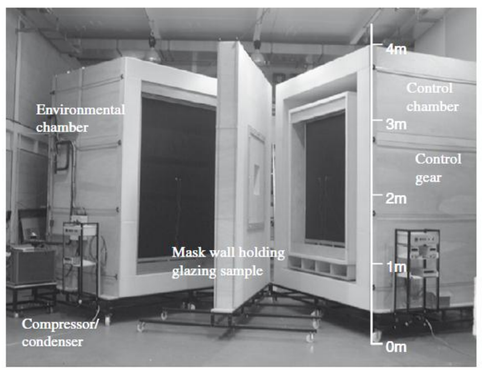

Fig 5: Hot box calorimeter available at the University of Ulster

$$C_{glass-glass,centre\ of\ glazing} = 0.8P + 4\varepsilon_{effective}\sigma T_{average}^{3} + 2k_{glass}\, a/\lambda^{2}$$

Results:

Table 1: Results from the Hot Box Calorimeter and the Vacuum Box for vacuum glazing

Sample	Glass surface temperature		Thermal conductance ($Wm^{-2}K^{-1}$)	Internal pressure	
	Cold side	Warm side		Calculated	Measured by new system
Sample 1	1.4°C	12.26°C	3.51	$3.8 \times 10^{-2} mbr$	$1.9 - 2.5 \times 10^{-2} mbr$
Sample 2	0.79	13.41	2.99	$3.19 \times 10^{-2} mbr$	$1.3 - 2.7 \times 10^{-2} mbr$

Discussion and Conclusion:

A study of internal pressure of vacuum glazing can provide valuable information about the insulation properties of the glazing. The internal pressure has a direct influence on both the stress profile across vacuum glazing and thermal performance. In this project the relationship between these factors has been studied using system which enables an evaluation of the internal pressure of vacuum glazing. The thermal performance of vacuum glazing samples has been evaluated using the hot box calorimeter and their internal pressure has been calculated. The results from both methods are in good agreement. The pressure measurement eliminates the need for the physical connection of a vacuum gauge and thus damage to the glazing. The system may also be used to study the internal pressure of vacuum insulation panels.

References:

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