THEORETICAL AND EXPERIMENTAL ANALYSIS OF THE VACUUM PRESSURE IN A VACUUM GLAZING AFTER EXTREME THERMAL CYCLING

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ABSTRACT

Details of theoretical and experimental studies of the change in vacuum pressure within a vacuum glazing after extreme thermal cycling are presented. The vacuum glazing was fabricated at low temperature using an indium edge seal. It comprised two 4 mm thick 0.4 m by 0.4 m low-emittance glass panes separated by an array of stainless steel pillars with a diameter of 0.32 mm and a height of 0.2 mm. After thermal cycling in the temperature range -30°C to +50°C on one side of the sample, while maintaining 22°C on the other side, it was found that the glass to glass heat conductance of the sample had increased by 8.2%. The vacuum pressure within the evacuated gap was determined to have increased from 0.01 Pa to 0.15 Pa using the model of Corrucini. This is at the upper limit of the range where the effect of gas pressure on the thermal performance of vacuum glazing can be ignored. The degradation of vacuum level determined was corroborated by the change in glass surface temperatures.

1. INTRODUCTION

Flat vacuum glazing as shown in figure 1 consists of two plane glass sheets, separated by a narrow internal evacuated space, contiguously sealed together around their periphery. The space, maintained by an array of tiny support pillars, is evacuated to a pressure of less than 0.1 Pa, effectively eliminating both gaseous conduction and convection. The low-emittance coatings on the internal glass surfaces within the evacuated gap reduce the radiative heat transfer through the vacuum glazing to a very low level. The vacuum glazing concept was first patented by Zoller (1924) [1]. However, after many years the first successful vacuum glazing was fabricated by Robinson and Collins (1989) [2]. A solder glass powder laid along the periphery of the glass sheets melted to form the edge seal of the vacuum space when the entire glazing unit was heated to 450°C. This high temperature method of fabricating vacuum glazing prevents the use of tempered glass and some types of soft low-emittance coatings thus preventing the high levels of
performance predicted from being achieved. The University of Ulster has developed a methodology and system for the manufacture of low temperature sealed vacuum glazing that can incorporate soft low-emittance coatings and tempered glass [3, 4]. A total heat transmission U-value of less than 1.0 Wm$^{-2}$K$^{-1}$ for a vacuum glazing of small size (0.4 m by 0.4 m) has been experimentally determined [5] using a guarded hot box calorimeter.

Outgassing and long-term vacuum stability of vacuum glazing is an important issue [6, 7]. Vacuum glazing samples have been subjected to different temperatures for various periods of time. The levels of outgassing measured by using spinning rotor gauge when subject to static ageing conditions were experimentally measured and were in good agreement with the predictions [7]. In this paper vacuum glazing manufactured at low temperature was subjected to extreme dynamic thermal cycling, and the effect on the vacuum pressure in the evacuated gap analysed using a model for heat conduction at low pressure [8]. The results were compared with the results of thermal testing using the guarded hot box calorimeter [5].

![Diagram of a vacuum glazing](image)

Fig. 1: Schematic diagram of a vacuum glazing.

2. MODELLING APPROACHING

A three dimensional finite volume model [9] and a two dimensional finite element model [5] extensively validated experimentally in previous reported research [3, 10] were used to analyse heat transfer through a vacuum glazing with the practical boundary conditions within the guarded hot box calorimeter.

In the finite volume model, the analytic model for heat flow through individual support pillars [6] was not employed since the pillar array was incorporated and modelled directly. The circular cross section of the pillar in the fabricated system was replaced by a square cross section pillar of equal area in the model. A graded mesh was used with a high density of nodes in and around the pillar to provide adequate representation of the heat transfer in this region. The residual gas pressure was assumed to be below that at which conduction was an issue. Simulations [11] predicted that for 0.4 m by 0.4 m vacuum glazing rebated into a solid wood frame by 15.4 mm, the lateral heat transfer conducted through the edge seal increased the heat conductance of the central glazing area by 3.1%.

The finite element model used the Galerkin approach with eight-node isoparametric elements. Further details of the finite element model employed can be found in [9]. In the finite element model, the conductance of the central evacuated gap was determined by the analytic model of support pillars and radiative heat transfer between two glass panes. Using the same boundary conditions, the difference of heat conductance of the vacuum glazing predicted by the finite volume model and the finite element model is 1% [10].

In this finite element model, the influence of the residual gas on the heat conductance of the glazing can be modelled. When the measured temperature profiles do not match the predictions calculated using the finite element model, the effects of the residual gas should not be neglected [5]. Total glass to glass heat conductance of the central glazing area is determined by:

$$C_{centre} = C_{gas} + C_{radiation} + C_{pillars} + C_{lateral}$$

$$= C_{gas} + 4\varepsilon_{effective} \sigma T_{average}^3 + 2k_{glass}a/p^2 + C_{lateral}$$

Where $C_{gas}$ is the residual gas heat conductance, $C_{radiation}$ is the radiative heat conductance between two glass panes, $C_{lateral}$ is the lateral heat conductance, $\sigma$ is the Stefan Boltzmann constant $(5.67 \times 10^{-8}$ Wm$^{-2}$K$^{-4}$), $T_{average}$ is the average of the two glass temperatures $T_1$ and $T_2$, $k_{glass}$ is the glass thermal conductivity, $a$ is the pillar radius, $p$ is the pillar separation and the effective emittance $\varepsilon_{effective}$ is...