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THERMAL CHARACTERISATION OF PROCESS CONTROL PARAMETERS FOR THE FABRICATION OF EVACUATED GLAZING

Ananya Ghosh[1], Trevor J. Hyde[2] , Subhasis Neogi[3+]

[1,3]*School of Energy Studies, Jadavpur University, Kolkata-700032, India.*

[2]*School of the Built Environment, University of Ulster, Newtownabbey ,Northern Ireland,UK.*

[+]Email: neogi_s@yahoo.com

ABSTRACT

The glazed window in a building system is used to allow natural daylight to penetrate through the external envelope to minimise the use of artificial lighting. Generally the glazed elements of the building system have poor heat resisting capability which leads to heat flowing in or out of a building system depending on the local climate conditions. An innovative approach is made to reduce the heat flow through the glazing by providing an evacuated narrow space (approximately 0.15 mm) between two layers of float glass. In the process of fabrication the edges of the two glass panes are sealed using a transition metal and by means of a pump-out device the glass pane assembly is evacuated. Suitable spacer pillars are uniformly spaced to maintain a constant spacing between two glass sheets which would otherwise touch under atmospheric pressure. During the fabrication, temperature and pressure are continuously monitored to determine the optimum process parameters. The out-gassing of the glazing is also observed during the fabrication process. When the glazing sample is heated in an evacuated chamber, the internal pressure of the chamber is observed to increase by a measurable amount. In the fabrication process of evacuated glazing samples, a pump-out device is incorporated to achieve the desired level of evacuation. The pumping out device has provision for measurement of the process parameters locally along with heater temperature for sealing the evacuation hole. The entire heating process is controlled by PID controller along with logging of all the process parameters.

Keywords: Vacuum glazing, Outgassing, PID controller

1. INTRODUCTION

A building envelope or building enclosure provides physical separation between the indoor and outdoor environments. A building assembly is any part of the building enclosure, such as a wall assembly, window assembly or roof assembly. From an energy point of view, window elements play a significant role in the building envelope providing thermal insulation and permit solar gain. The current drive to reduce the heat transfer through building components to minimise energy consumption has resulted in many design modifications of windows to improve the thermal performance. With the conventional glazing, most of the energy consumption of a building system is due to the windows. The heat flow through a glazing unit can be given by the following equation:

$$Q = UA\Delta T$$

Where, Q is the heat flow through the glazing unit; U is the Overall heat transfer co-efficient. It defines the heat flux per unit area of the glazing system induced due to the temperature difference between building interior and exterior; A is area of the glazing unit and ΔT is the temperature difference between interior and exterior of the building component.

This overall heat transfer co-efficient is inversely proportional to the thermal resistance of the window. The thermal resistance of the windows can be enhanced by using multiple glass panes rather than single pane glazing, so that the U- value of the glazing system can be minimized [1]. These multiple pane glazing systems are commonly termed insulated glazing units. Thermally insulated glazing is widely used to improve the energy efficiency of buildings. All such glazings consist of two or more panes of glass separated by a gas filled cavity. One of the possibilities for improving the thermal insulating performance of double glazing is to evacuate the space between the two glass sheets. Low heat loss and high solar transmittance can be obtained from a contiguously-sealed double glazing with an evacuated gap as illustrated in Fig.1. Several fabrication techniques have been developed and patented since the first vacuum glazing was reported in a German patent [2]. It appears that the first successful production of an insulating evacuated glazing occurred at the University of Sydney [3].

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A new form of insulated glazing called vacuum glazing has been developed in the last decade [4]. In the vacuum glazing the glass sheets are hermetically sealed together around the edges using a low melting point glass powder commonly referred to as solder glass , and the insulation is provided by a highly evacuated space~0.2 mm thick.

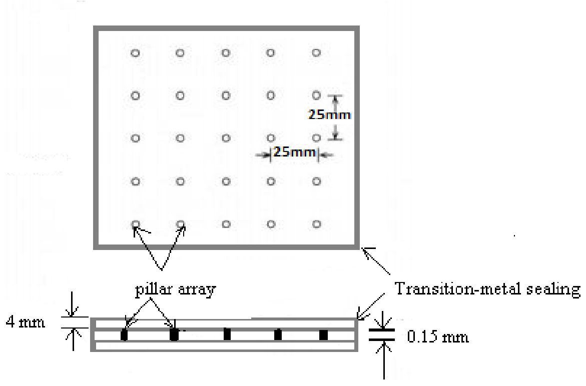

Fig.1 Transition-metal sealed evacuated glazing

The vacuum essentially eliminates internal heat transfer by gaseous conduction and convection. The separation of the glass sheets under the influence of atmospheric pressure is maintained by uniformly spaced spacer pillar array. Collins et al.[5] have fabricated vacuum glazing using solder glass to form a contiguous edge seal at a temperature of approximately 450^{o}C, after which evacuation was under taken through a pump-out tube attached to the upper glass pane [6]. Several methods have been developed for determining the magnitude of stresses in evacuated glazing analytically and by finite element modelling [7]. The University of Ulster has developed a low temperature technique to create an edge seal, comprising of an inner vacuum seal formed by a metal and an outer adhesive seal [8]. The technique developed at the University of Ulster enables vacuum glazing to be produced at temperatures less than 160^{o}C. The Ulster team have developed two processes for manufacturing vacuum glazing-one in which the vacuum glazing is manufactured in an evacuated chamber without the need for subsequent pumping-out and a second method in which the seal is formed either under vacuum or in an oxygen free nitrogen atmosphere with subsequent evacuation through a pump-out hole. Sealing of the pump-out hole is achieved by bonding a glass disc over the hole [9]. The thermal performance of the vacuum glazing sample was characterized using a guarded hotbox calorimeter and theoretically analyzed using finite volume model. The experimentally obtained result for determining the U-value was compared with that predicted theoretically [10].

The effect of different low-emittance coatings on the thermal performance of vacuum glazing was simulated using a finite volume model and compared to experimental measurements [11].

In this paper, the method of fabrication of vacuum glazing is presented. In the process of fabrication temperature and pressure are continuously monitored to determine the optimum process parameters. The outgassing of the glazing is observed during the fabrication process.

2. VACUUM GLAZING

To design energy-efficient buildings, it is essential that all parts of the building envelope should have good thermal performance providing effective insulation between the controlled indoor environment and the variable external environment. In general windows are considerably less insulating than other parts of the building envelope due to the requirement to transmit daylight to the building interior which reduces the reliance on artificial lighting system. This transmitted daylight in turn gets converted to heat after multiple reflections at the various surfaces of the building interior. This in turn leads to heat flowing in or out of the building system depending on local climatic conditions. Heat transfer through glazing systems occurs in three ways: conduction, convection and radiation. The general approach adopted for reducing heat transfer through glazing systems relies on the use of multiple glass sheets with air or inert gas filled spaces to reduce conduction and convection and low-emittance (low-e) thin film coatings on the glass surface used to reduce long-wave radiative heat exchange. An innovative approach in the form of vacuum glazing has been adopted to minimise conductive and convective heat transfer. Vacuum glazing is similar to similar to double glazing in which the gas-filled space is evacuated to a low-pressure. This reduces the levels of convection and gaseous conduction to negligible values. The remaining heat transfer is predominantly due to radiation which can be reduced by the use of low-e coatings. Radiative heat transfer between two parallel surfaces is not distance dependant, therefore, the spacing between the glass sheets can be reduced to provide a compact highly insulating glazing system.

To reduce convection and conduction to negligible levels it is essential that a vacuum pressure of < 0.1 Pa is achieved and maintained between the two glass sheets. On reducing the gas pressure in the space between the two glass sheets, atmospheric pressure will push the two glass sheets together. This necessitates a support structure in the evacuated space to hold the two glass sheets apart. An array of tiny support pillars are uniformly spaced so that the glass sheets do not touch in between the pillars and the glass structural integrity can be maintained.

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3. FABRICATION PROCESS

The evacuated glazing shown in Fig. 2 is made from two sheets of float glass. The size of each glass pane is taken 300 mm by 300 mm and a glass thickness of 4 mm. The glass sheets are separated by an array of tiny support pillars on a regular square grid. The glass sheets are hermetically sealed together around the edges to form a narrow evacuated space. The support pillars are manufactured from stainless steel having a diameter of 0.5 mm and a height of 0.15 mm. The support pillars are located on the lower glass pane in a 25 mm by 25 mm array.

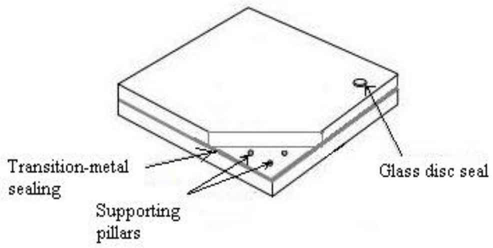

Fig.2 Schematic diagram of an evacuated glazing

The main stages of the laboratory fabrication process of vacuum glazing are outlined as follows:

Glass preparation:

i) Drill a hole in one glass sheet for evacuation after edge sealing.
ii) Clean the glass sheets with acetone and isopropyl alcohol.

Soldering process:

i) Heat glass sheets on a hot plate.
ii) Deposition of a thin layer of the transition-metal around the periphery of the two glass sheets.

Placement of pillar array:

i) Support pillars are uniformly spaced on lower glass sheet.
ii) Upper glass sheet is positioned over the pillars.

Formation of edge seal:

i) The sample is introduced into the vacuum chamber and pressure is reduced.
ii) The vacuum chamber temperature is increased to a level at which a seal is formed by the transition-metal reflow.

Evacuation of glazing:

i) The vacuum glazing sample is removed from the chamber, visual inspection undertaken and a secondary adhesive seal is applied.
ii) Evacuation of the space between two glass sheets using pump-out system.
iii) Sealing the evacuation hole using a glass cover disc.

Prior to the fabrication process, a 3 mm-diameter hole for glazing evacuation is drilled into one of the glass panes. This hole is sealed using the transition-metal coated glass cover disc when the required level of evacuation has been achieved. Using such an access hole for evacuation eliminates the incorporation of a small glass tube into the glass pane for evacuation and the formation of a tube stub after sealing as in the technique developed by Collin's et al. [5]. The glass panes are cleaned using acetone and isopropyl alcohol. Then the glass panes are placed on a hot plate having a temperature in the region of 100^{o}C. After heating, deposition of a thin 5 mm wide layer of a transition metal around the periphery of two glass sheets has been done by using an ultrasonic soldering iron which promotes a good bonding between the transition- metal sealant used here and the glass. The edge seal material used in this work is a malleable metal with excellent capability to join materials with greatly mismatched coefficients of thermal expansion. This edge seal can withstand the stresses induced in the vacuum glazing due to a thermal gradient between the glass panes during thermal cycling.

During the fabrication process, the formation of edge seal is performed in a high vacuum chamber as shown in Fig.3. The vacuum chamber is a horizontally mounted single walled rectangular construction made of stainless steel. The front side of the chamber is welded with a rectangular flange fitted with 'O' ring to achieve vacuum seal with the front door.

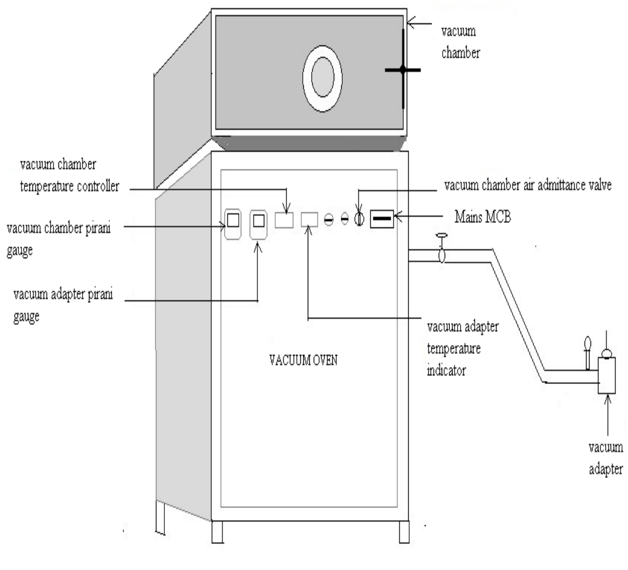

Fig.3 Vacuum oven assembly

The chamber is fitted with number of ports for connecting a vacuum pump, thermocouple feed through port, heater feed through port etc.

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The vacuum chamber is provided with four IR lamp heaters on four sides to raise the temperature as required for glass panels edge sealing. The temperature measurement and control is done by means of Digital PID controller which works in conjunction with Chromel /Alumel type K thermocouple. Three Pirani gauges are provided in the system, one for measuring pressure in the vacuum chamber and other two are for pressure measurement in the vacuum line and vacuum adapter. A change of pressure in vacuum system brings about a rise or fall in number of gas molecules present and hence a rise or fall in the thermal conductivity of the gas. Thus the heat loss with a constant input voltage to the heated filament in the system varies with the pressure. The Pirani gauge head filament has high temperature co-efficient of resistance. So a small change in system pressure brings about a useful change in filament resistance resulting in an out of balance of the wheat stone bridge where filament forms one of the arms. In this mode the bridges balanced at pressure less than 10^{-3} m.bar. Any increased in pressure unbalances the bridge and results in a pressure dependent deflection in the meter, which is calibrated in terms of m.bar. The Pirani gauge head indicates the total pressure of combined gases and condensable vapours in the system as the heated wire can lose heat to both gas and vapour molecules.

After ultrasonically applying the transition-metal sealant around the edges of the glass panes, the support pillars are positioned onto the lower glass pane in a 25 mm by 25 mm array. The upper glass pane is then placed in a parallel alignment with lower glass pane maintaining a narrow space of 0.15 mm between them. Then the glazing sample is introduced into the vacuum chamber and the vacuum chamber pressure is reduced to 10^{-3} m.bar. The initial outgassing of the internal surfaces is undertaken in the vacuum chamber at a temperature below 200^{o}C.

After the edge seal has been undertaken the final stage of the fabrication process is the evacuation using a pump-out system. The pump-out system is composed of a vacuum adapter which is manufactured from stainless steel and has four flanged ports for evacuation, thermocouple feed through, electrical feed through for the power supply to a heating element and a pressure needle valve connected to a port. The bottom side of the adapter is welded to a flange with an ‘O’ ring inserted in a groove to achieve vacuum sealing with the glass surface. The centre of the adapter has a heating block with a linear shaft seal assembly. The heating system comprises a small diameter cartridge heater capable of achieving a temperature of 250^{o}C. This heater is attached to a fined ground shaft seal through an insulator. This fined ground shaft passes through the linear vacuum shaft seal and terminated with a handle.

The shaft with heater assembly has 50 mm of travel to allow sealing of the glass disc over the pump-out hole. A type ‘K’ thermocouple is provided to measure the temperature of the temperature of the heater and another ‘K’ type thermocouple is attached to the glass surface in close proximity to the glass cover disc to measure the heat propagation from the heating block to the glass cover disc.

After the formation of edge seal, the glazing sample is placed over the hot plate maintaining temperature < 100^{o}C. The vacuum adaptor is positioned around the pump-out hole and the heating block is then placed onto the transition-metal coated glass cover disc over the access hole. The evacuation inside the vacuum adapter is then performed until a required level of evacuation is achieved in the narrow space between two glass sheets. When the internal space between the two glass sheets is evacuated to a pressure near about 10^{-3} m.bar, the heating block is switched on. The temperature of the heating block is controlled by a K-type thermocouple fitted into the heating block and controlled by a PID controller. Heat is propagated from the heating block to the transition-metal coated glass cover disc. The hole is sealed when the temperature reaches the melting point of the transition-metal.

4. THERMAL CHARACTERISTICS

During the fabrication process, the thermal characteristics of different process parameters such as temperature and pressure are continuously monitored and recorded using a data acquisition system. The characteristics nature of temperature and vacuum pressure are examined during the fabrication process to determine the optimum process parameters.

To assess the thermal characteristics of the process parameters, a glazing sample consisted of two glass panes of area 300 mm by 300 mm and each of thickness 4mm are separated by a narrow space of 0.15 mm has been produced. The evacuated space is maintained by support pillars having diameter of 0.5 mm and height of 0.15 mm uniformly spaced at 25 mm. This sample is introduced into the vacuum chamber and the vacuum chamber pressure is reduced. When the pressure inside the vacuum chamber is approximately 10^{-3} m.bar, the vacuum chamber heater is switched on. The temperature is increased with a dwell period at the melting point of the transition metal and the outgassing in the vacuum chamber is observed. The temperature of the vacuum chamber is increased to the level at which a seal is formed as a result of the melting of the transition-metal. From the figures 5 & 6, we find that when the temperature inside the vacuum chamber is allowed to increase by switching on the vacuum chamber IR heater, the vacuum pressure of the chamber is observed to drop by a measureable amount. This process continues for sometime to stabilize due to outgassing.

The outgassing phenomenon is more distinct in the vacuum chamber. After reaching a certain temperature, the pressure stabilizes inside the chamber as well as in vacuum line.

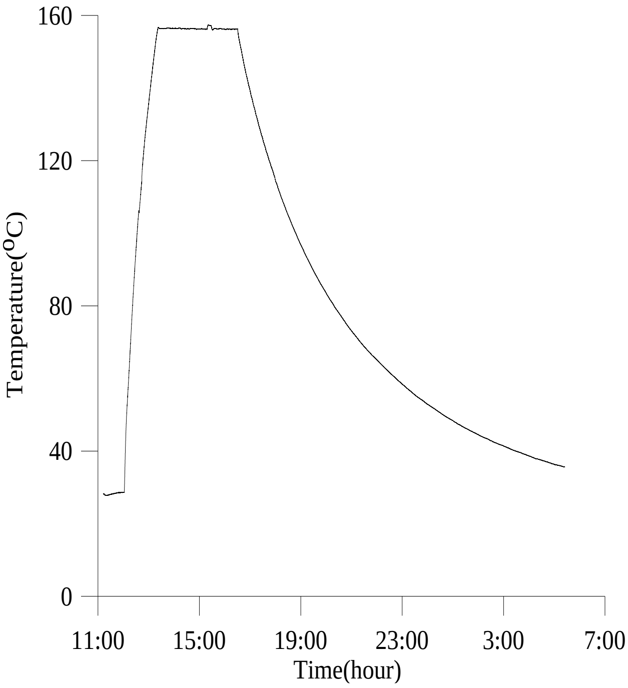

Fig.4 Time-Temperature characteristic curve.

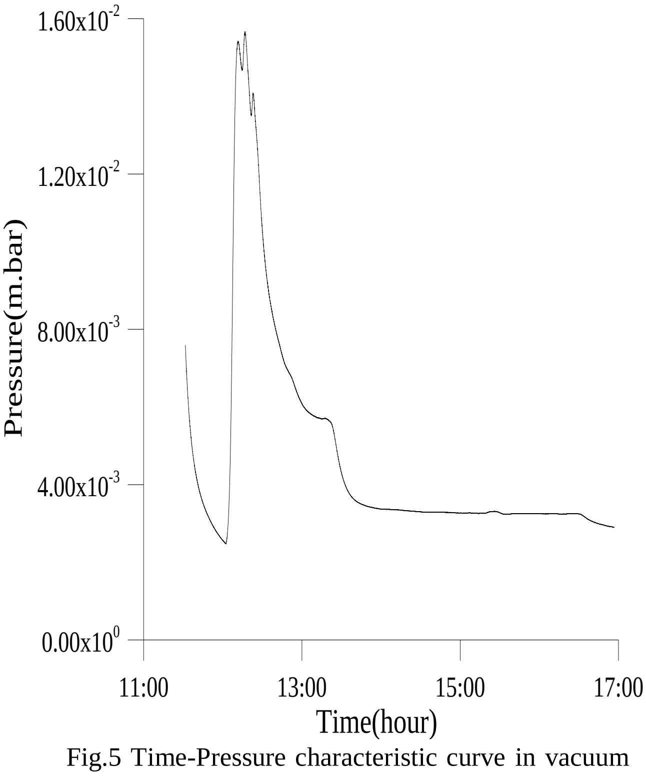

Fig.5 Time-Pressure characteristic curve in vacuum chamber .

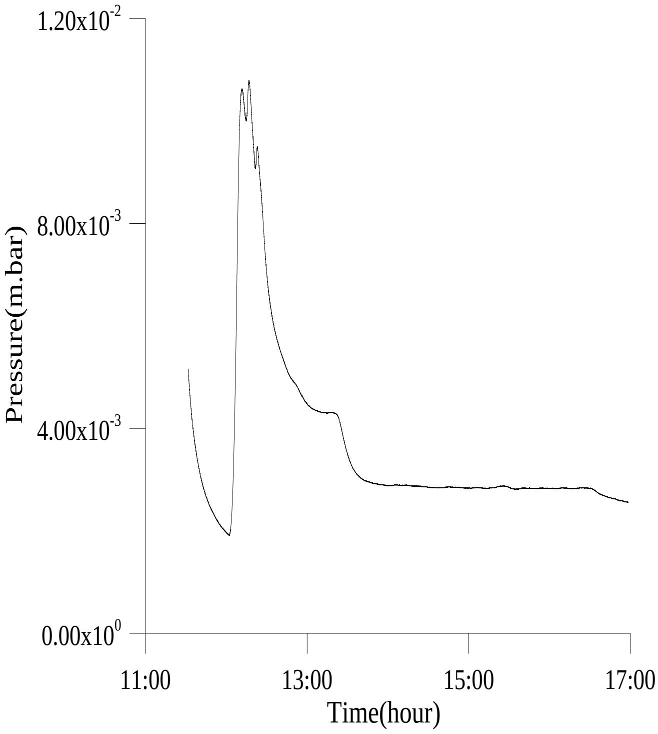

Fig.6 Time-Pressure characteristic curve in vacuum chamber connecting line.

5. CONCLUSION

Significant research over the last decade has led to the development of several fabrication processes for the evacuated glazing. Extensive numbers of glazing systems are produced and experimentally characterised by incorporating high and low temperature sealing technique. The evacuated glazing fabricated in this work is based on a low temperature edge sealing technique. The pump-out method provides several opportunities for the fabrication of evacuated glazing. During the pump-out process rapid and effective evacuation can be obtained. The pump-out method is potentially flexible for producing any size of glazing as this process of evacuation can be carried out outside the vacuum oven. Using the transition metal-based edge sealing, the internal gas pressure inside the evacuated glazing can be reduced and maintained to provide a high thermal performance. It is considered that extensive surface temperature measurements are required so as to identify the exact condition at which edge sealing is evolved. This will in turn reduce the cause of over-heating of the edge sealing which leads to edge seal leakage at times.

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NOMENCLATURE

Symbol

U Heat transfer coefficient (W/m^{2}K)
A Surface Area (m^2)
Q Heat gain or loss (W)
T Temperature (K)

AUTHOR BIOGRAPHY

Ms. ANANYA GHOSH is an M.Tech. scholar at the Department of School of Energy Studies at Jadavpur University, Kolkata, India. She has specialization in Solar Thermal Energy Systems, Building Energy Management and Biomass Energy.

Dr. TREVOR J HYDE is a Reader at School of the Built Environment at University of Ulster, North Ireland, UK. He has 6 years of teaching experience in Construction Technology and Building Services. He has 10 years of research and industrial experience. He has research interests in Design methodologies and fabrication of vacuum glazing, Characterisation and environmental performance of advanced glazing and window systems for Sustainable energy technologies. He has several publications in international journals.

Prof. SUBHASIS NEOGI is an Professor at School of Energy Studies at Jadavpur University, Kolkata, India. He has 25 years of teaching experience and 5 years of industry experience. He has research interst in Energy Conservation & Management, Energy Efficient Buildings, Wind Energy, Solar Thermal Engineering etc. He has several publications in various national and international journals.