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Experimental measurement of hermetic edge seal's thermal conductivity for the thermal transmittance prediction of triple vacuum glazing

Saim Memon

Division of Electrical and Electronic Engineering, School of Engineering, London South Bank University, 103 Borough Road, London SE17 0AA, UK

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ABSTRACT

Thermal conductivity of hermetic edge-sealing materials plays an important part in the thermal transmittance (U-value) of the triple vacuum glazing. Thermal conductivity of Cerasolzer CS186 alloy and J-B Weld epoxy-steel resin were measured and validated with the mild-steel and indium using transient plane source method with a sensor element of double spiral and resistance thermometer in a hot disk thermal constants analyser TPS2500s are reported. The thermal conductivity data of Cerasolzer CS186 alloy and J-B Weld epoxy steel resin were measured to be 46.49 W m^{-1} K^{-1} and 7.47 W m^{-1} K^{-1}, with the deviations (using analytical method) of ± 4% and ± 7% respectively. These values were utilised to predict the thermal transmittance value of triple vacuum glazing using 3D finite element model. The simulated results show the centre-of-glass and total U-value of 300 mm × 300 mm triple vacuum glazing to be 0.33 W m^{-2} K^{-1} and 1.05 W m^{-2} K^{-1}, respectively. The influence of such a wide edge seal on the temperature loss spreading from the edge to the central glazing area is analysed, in which the predictions show wider edge seal has affected the centre-of-glass U-value to 0.043 W m^{-2} K^{-1} due to the temperature gradient loss spread to 54 mm and 84 mm on the cold and warm side respectively.

1. Introduction

Vacuum glazing has the potential to reduce the heat loss of a building [1] and is one of the solutions proposed for the reduction of space-heating loads and carbon emissions [2]. To reduce the heat loss to a level where the U-value of the central glazing area is less than 0.5 W m^{-2} K^{-1}[3], the notion of triple vacuum glazing is introduced [4]. This consists of three sheets of glass, hermetic seal around the outer edge of the three glass sheets, and two evacuated gaps with a pressure below to 0.1 Pa to reduce the heat transfer by gaseous conduction and convection to a minimum level, such heat transfers can't be eliminated due to a need of an array of stainless steel support pillars, typically 0.15 mm high and 0.3 mm diameter [5], that maintain the separation of the three glass sheets. However, radiative heat transfer can be reduced by using low emittance coatings on the surfaces of the glass sheets, in this case tin-oxide coating were used.

A low temperature method of fabricating double vacuum glazing was first developed at the University of Ulster [6]. This method was based on indium or one of its alloys to seal the edges of the glass sheets hermetically at a temperature of less than 200 °C. The predicted, and experimentally determined, thermal transmittance of an indium based double vacuum glazing was reported to be less than 1 W m^{-2} K^{-1} for the central glazing area [7]. In this low temperature sealing method a radiative heat transfer can be reduced to a minimum possible level by using soft low-emittance coatings on the surfaces of the glass sheets such as silver (Ag) titanium dioxide

E-mail address: S.Memon@lsbu.ac.uk.

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Nomenclature

a	Overall radius of the sensor [m]
d	Thickness of the glass sheet [mm]
D	Dimensionless time dependent variable
k	Thermal conductivity [W m^{-1} K^{-1}]
P_o	Total output power from the sensor [W]
R	Resistance [ohms]
t	Time [s]
ΔT_i	Initial temperature difference [K]
$\Delta T_{ave}(\tau)$	Average temperature increase of the sample surface on the other side of the sensor [K]
T	Temperature [°C]
U	Thermal transmittance [W m^{-2} K^{-1}]

Abbreviations

ASTM	American Society for Testing and Materials
CALEBRE	Consumer Appealing Low Energy Technologies for Building Retrofitting
CIBSE	Chartered Institution of Building Services Engineers
FEM	Finite Element Model
TPS	Transient Plane Source
TVG	Triple Vacuum Glazing

Subscripts

ave	Average
o	Before the sensor is heated at t = 0 s
c	characteristic

Chemical formula

Ag	Silver
Al_2O_3	Aluminium oxide
In	Indium
SnO_2	Tin Oxide
TiO_2	Titanium dioxide
ZnO	Zinc oxide

Greek Letters

ρ	Density [kg m^{-3}]
α	Thermal diffusivity of the sample [mm^2 s^{-1}]
τ	Dimensionless time dependent function
φ	Temperature coefficient of the resistivity [K^{-1}]
ϕ	Heat loss [W]
ε	Emittance

(TiO_2), zinc oxide (ZnO) and aluminium oxide (Al_2O_3) [6]. Due to the cost and scarcity of indium, this method has limitations for mass production. A recent low-temperature composite edge sealed triple vacuum glazing shows promising results which was first developed at Loughborough University and reported in Memon et al. (2015) [8].

In this paper the study of experimentally measuring and comparatively analysing the thermal conductivity data of the hermetic edge-seal for the thermal performance prediction are presented, because the thermal conductivity data are one of the important boundary parametric condition in the FEM of the triple vacuum glazing for which the influence of new hermetic edge seal materials on the U-value and temperature loss are analysed. It is pertinent to mention that no thermal conductivity data is supplied in the manufacturers and suppliers' datasheets for the successful application of it as hermetic edge seal materials. Some properties of Cerasolzer alloy, such as the coefficient of thermal expansion and melting temperature are provided and for J-B Weld epoxy steel resin, properties such as mechanical strength and minimum/maximum working temperatures, are available [9–11]. Fig. 1 shows the developed vacuum glazing systems facility with the modified vacuum cup for evacuation and pump-out hole sealing of the hermetic edge sealed triple vacuum glazing. The hermetic edge seal consists of the Swiss made Cerasolzer CS186 as a primary edge seal and US made J-B Weld epoxy steel resin as a secondary edge seal for the successful fabrication, by achieving a vacuum pressure of 4.8×10^{-2} Pa, in the two cavities of 500 mm × 500 mm sample of triple vacuum glazing. The primary edge seal, Cerasolzer CS186, is a composite of Sn(56%), Pb(39%), Zn(3%), Sb(1%) and Al-Ti-Si-Cu (1%) alloys [8]. This metal alloy composition was disclosed in the Japanese patent 20098/1968 [12] and is a commercial product of Asahi Glass Co., Ltd. The secondary edge sealing material used is a steel reinforced epoxy known under the commercial trade name of J-B Weld epoxy steel resin [13].

2. Methodology

A number of different instruments are available for the measurement of the thermal properties of materials [14]. There are two main methods, steady state method and transient. The steady state approach is further divided into one dimensional heat flow and radial heat flow techniques. One dimensional heat flow technique include the guarded hot plate method which is the ASTM standard based measurement system used for highly insulating materials. The radial heat flow technique includes cylindrical, spherical and ellipsoidal methods. There are a number of transient methods, which can be used for the measurement of thermal conductivity such as hot wire, transient hot strip and transient plane source methods. The experimental measurements of thermal conductivity performed in this study were undertaken using a Hot Disk thermal constants analyser TPS 2500s. This system is based on the transient plane source (TPS) method. The TPS method consists of a sensor element in the shape of a double spiral which acts both as a heat source to increase the temperature of the sample and a resistance thermometer to record the time dependent temperature increase [15]. In the current experiments, a sensor of design 7577 was used which is made of a 10 µm thick Nickel-metal double spiral. The radius of the sensor was chosen to be 2.001 mm in order to reduce the size of the sample. It is advised [16] that the diameter of the sample should not be less than twice that of the sensor diameter and the thickness of the sample should not be less than the radius of the sensor. The sensor element is usually insulated with a material to provide electrical insulation. The material used is dependent on the operating temperatures. A thin polyamide (Kapton) insulating material was chosen for the sensor insulation which is suitable