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Formation mechanism of sealing edge pores for vacuum glazing using laser brazing technique

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ABSTRACT

In view of the pore defect of vacuum glazing sealing layer, the research on side edge sealing of laser was made. The phase analysis of microstructure on sealing layer was investigated using scanning electron microscope (SEM) and energy spectrum analysis (EDS) to study the formation mechanism of sealing pores. The influence of laser power and welding rate on sealing edge porosity was researched. The results show that the sealing layer has evenly distributed bilayer structure of wetting layer with few pores caused by the residual gases between the solder particles (external) −melting layer with a large number of mutually disconnected isolated pores (inside). As the increase of laser power, the interface layer is compact and smooth and the pores decline in numbers. When the power exceeds a certain value, the interface becomes unsmooth with the increasing number of pores. The phenomenon of surface defects and blocky structures is generated with lower welding speed and greater energy output. On the other hand, the blocky structures, unmelted solders, pores and cracks are formed by the higher welding speed and smaller energy output. Therefore, the pore defect can be effectively avoided and reduced by the reasonable control of laser power and welding rate.

1. Introduction

The vacuum glazing with the advantages of thermal insulation, sound insulation and noise reduction has been applied to the fields such as building, vegetable greenhouse, solar energy application and refrigerated transport, as one of the few new energy saving and environmental protection cutting-edge products with intellectual property in China. Its research and development complied with the requirements of the national scientific and technological innovation policy and energy saving and emission reduction strategy, with the extensive application prospect. Its processing technology is the domestic and overseas research focus at present [1–4]. The elements vaporization, the oxide film on the surface of the residual material, and the original solder hole were the main causes of porosity of sealing edge among plate glasses [5–10]. The porosity of sealing layer plays a leading role in the quality of welding, which can significantly reduces sealing performance and service life of vacuum glazing. Vacuum glazing was side sealing using vacuum furnace by Miao et al. in Ref. [5], which discussed the effect of heating temperature on the welding joint. The temperature of sealing in vacuum furnace was the main factor on causing changes of stress, microstructure and mechanical performance of glazing by Miao et al. in Ref. [5]. The sealing properties were intensive studied under different temperature in vacuum furnace [5]. The insufficiency melt of sealing solder and large viscosity of the fusion solder in vacuum furnace were considered the main factors of pores formation.

The sealing of vacuum plate glass mostly adopts the high temperature vacuum furnace sealing method [5]. The principle of glazing sealing is to place the support pillar between two pieces of plate glass, apply the solder in the sealing edge, put the whole into the high temperature vacuum furnace for heating, make two plate glass seal together, and form a sealing vacuum chamber between two pieces of plate glass [1]. Fig. 1 shows the vacuum furnace used to sealing the plate glass. This method is relatively mature, but there are two problems. Firstly, it has extreme requirements on the high temperature vacuum furnace [5]. In the case of the larger glass size, it is difficult to manufacture the large inner chamber in high temperature furnace. Secondly, the coating on the plate glass suffers from the thermal decomposition at high temperature, and the visible light transmittance and infrared reflectivity of the coating film are adversely affected, so as to reduce the sealing efficiency and

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Fig. 1. Vacuum furnace.

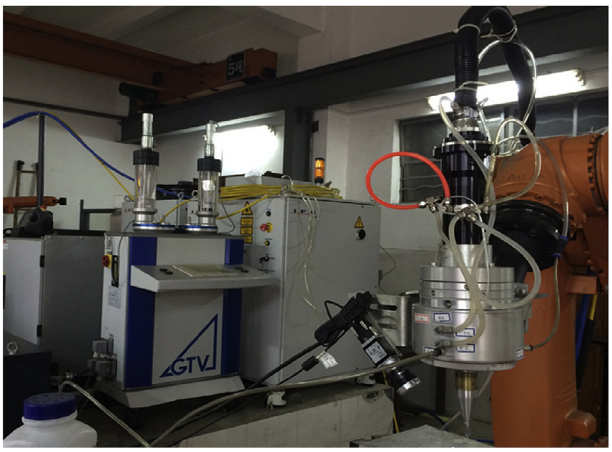

Fig. 2. YLS-2000-CT fiber laser.

influence the sealing quality. Therefore, seeking a new sealing technology is the urgent need to solve the problem at the present stage.

Laser welding has the advantage of high energy, small heat affected zone, non-contact, fast welding speed, and high welding efficiency [6–9], which can effectively solve the problem when the high temperature vacuum furnace seals the glass [10]. YLS-2000-CT Fiber Laser is shown in Fig. 2. At present, the research of domestic and overseas scholars on the laser welding of vacuum glazing mainly focuses on the aspects involving laser welding heat transfer, stress strain, technological parameter, and brazing quality of vacuum glazing [7–13]. Although the theory of laser sealing is improved gradually, the technology related to the laser welding of vacuum glass has yet to be further studied [8]. The forming mechanism of pores and mechanical properties among sealing interface using laser brazing technology were different from using vacuum furnace brazing process in Ref.5. Therefore, it is essential to totally studied pores forming mechanism in sealing edge of plate glass using laser brazing process.

This paper takes side edge sealing of vacuum glazing using laser soldering method under a relative vacuum environment, prepares the solders by the excellent performance of PbO-TiO_2-SiO_2-R_xO_y system sealing solder to seal the vacuum glass [14–17], and the microstructure and energy spectrum analysis of the sealing layer has been conducted. In view of the problem that the vacuum glass has the pores easily during the process of sealing edge, it explores the mechanism of pore cause, makes the experimental study on different laser powers and welding rates of the vacuum glass, analyzes the influencing factors of the sealing edge porosity, provides the important theoretical basis for the application verification, life prediction and optimum structural design of the vacuum glazing, and offers the guidance for the manufacturing and industrialization of the vacuum glazing. This research work can provide a reference for additional research of the edge sealing of vacuum glazing to improve the brazing performance of sealing edge and realize the application of laser brazing technology on vacuum glazing sealing.

2. Test material and methods

2.1. Test material

The size of the laser sealing test of vacuum plate glass is 20 mm × 20 mm × 4 mm. Soda-lime glass is used for experimental plate glass, whose principle component in glass including 71% $SiO_2$14%MeO(Al_2O_3, CaO, MgO, BaO)15%flux(Na_2O, K_2O, BO, SO_3). The mechanical properties of soda-lime glass are given in Table 1.

The solder filler used by the test is PbO-TiO_2-SiO_2-R_xO_y system powder. The ingredients and various indexes are shown in Table 2 [5]. PbO, TiO_2, SiO_2, CuO and Fe_2O_3 powders are mixed uniformly by the definite mass fraction ratio, and put into the stainless steel ball mill for ball milling after adding a certain amount of dispersing agent. Therefore the PbO-TiO_2-SiO_2-R_xO_y powder preparation can be gained using ball mill methods with powerful particle size range of 1–25 μm. After that the powder are put into a drying box for further treatment. The SEM diagram of sealing solder powder and fusion solder filler after heating under vacuum condition are displayed in Fig. 3. The solder filler is produced using powder pressing machine, with the pressure of 8 MPa and the holding time for 12 min. It can be seen that the fusion state of solder filler after heating is relatively flat without crack, which has good fluidity in melt state and good wetting property.

2.2. Experimental process

The vacuum glazing deposition test adopts ultrasonic cleaner to clean the glass at room temperature for 10 min, wipes the glass sheet with the absolute ethyl alcohol, and makes the drying treatment. Fig. 4 shows that the cylindrical solder is placed on the plate surface, and heated at 280 °C for thermal insulation of 10 min in the digital heating plate (model: C-MAGHP4), to complete the thermal pretreatment. The sealing solder after thermal pretreatment is filled around two plate glasses. Finally the test sample is placed on the fiber laser platform, and different laser technological parameters are selected for the test study.

Table 1
Mechanical properties of plate glass.

Properties	Modulus of elasticity (E) (MPa)	Poisson's ratio (μ)	Tensile strength (Rm) (MPa)	Compressive strength (f) (MPa)
Value	72.45	0.22	40	880