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# Large-scale anodic bonding mediated by a liquid tin solder

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ABSTRACT

Large area seals were prepared between a metal foil frame (Fe-Ni alloy with 48 wt% Ni) and a 901 × 814 mm$^2$ glass pane through the simultaneous application of activated liquid tin solder anodic bonding and soft soldering. An experimental facility including a liquid solder injector was built. Prototype seals were produced with tin solder alloys with variable Al contents and the hermiticity and interface integrity was determined. Solder alloys with an Al content of 112.5 ppm resulted in the strongest adhesion forces, broadly consistent with a previous study at the laboratory scale. The resulting prototypes consist of a bonded area of ~450 cm$^2$ along the perimeter of a 0.73 m$^2$ glass pane and display consistently strong bonds for sections over a meter in length, demonstrating that activated liquid solder anodic bonding is not restricted to small-area applications.



## 1. Introduction

Inorganic glass-to-metal seals provide a combination of good hermiticity with high chemical and dimensional stability over long periods of time. Such properties make them suitable for multiple applications in which organic adhesives perform poorly. These include classic examples such as Vacuum Tubes (CRTs, X-ray tubes, electrical discharge tubes) and Reed Switches as well as more recent applications. For example, Hunegnaw et al. (2014) produced interposers and Subbarao et al. (2010) packaged OLEDs. It is important to note that most of the applications mentioned are within electronic components or devices, where the bonded areas do not exceed a few squared centimetres and substrates are extremely flat and of very high surface quality. Other applications which require the performance of inorganic seals over large areas such as vacuum insulation glazing (VIG) and vacuum solar collectors do not make use of this technology because of practical limitations of current fabrication processes.

Donald (1993) described how, conventionally, inorganic glass-to-metal seals have been obtained by softening the glass and pressing it against a metal with an oxide layer on its surface, but this process is carried out at temperatures between 600 and 1000 °C, resulting in considerable deformation in the bonded materials. Furthermore, Hull and Burger (1934) detail how thermal stresses could appear if their thermal expansion coefficients are poorly matched. As a result, only few combinations of glass and metals can be sealed, and the size of the bonded pieces is usually kept small.

Another possibility to achieve this type of seals is brazing/soldering metals to pre-metallized glass surfaces usually made by either chemical (electro- and electroless-plating, CVD and PACVD) or physical methods (PVD, evaporation, ion plating or sputtering) as described by Messler (1993). However, this is also a challenging process. For chemical deposition methods, multiple arduous cleaning and surface preparation steps must be made on the glass to produce homogeneous coatings without imperfections. But even with ideal homogeneous coatings, Charbonnier and Romand (2003), Do Nascimento et al. (2003), and Gläser (1999) observed numerous challenges in producing large-area seals by brazing/soldering and producing large-area seals with this method is rather ambitious.

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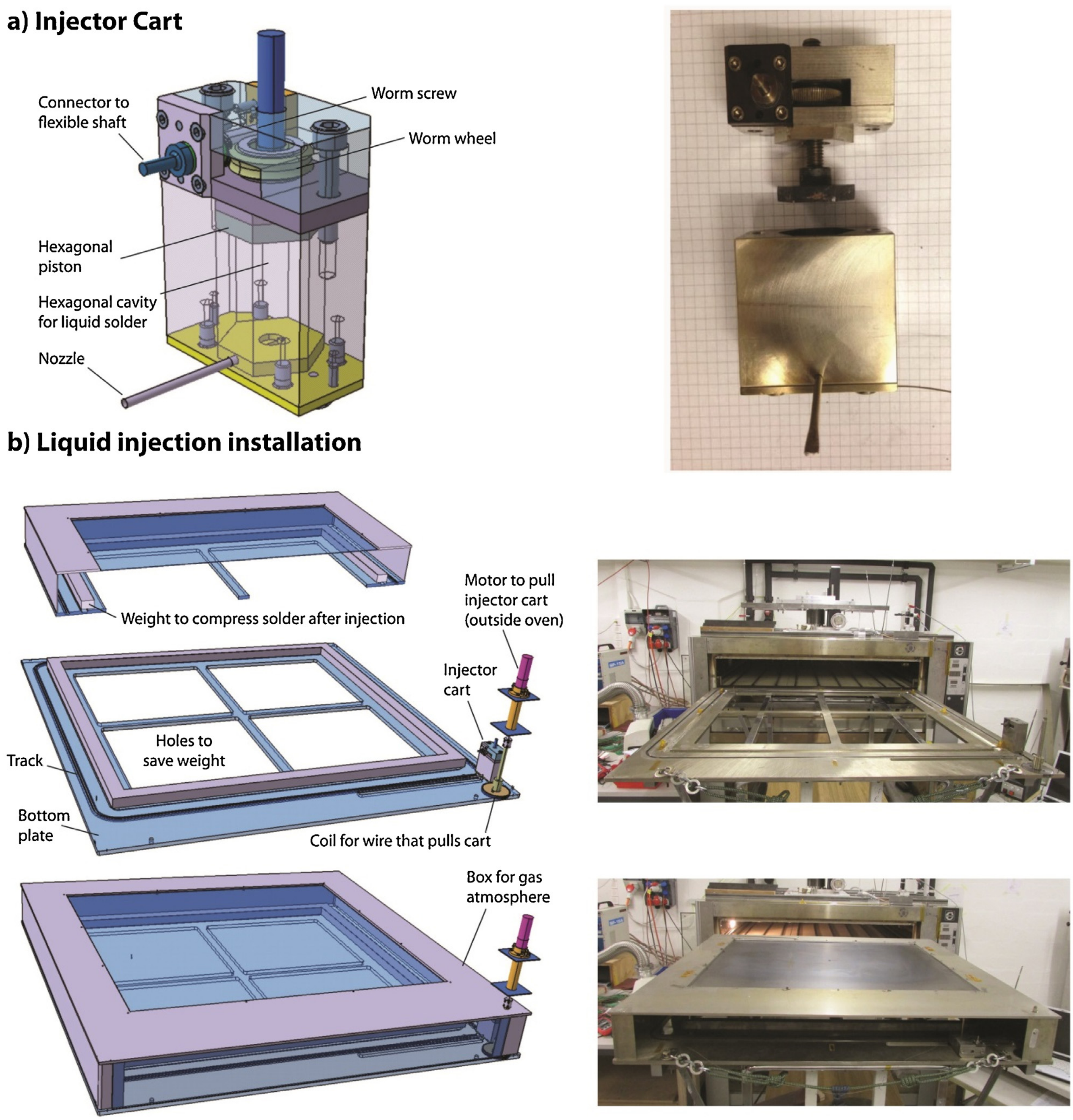


**Fig. 1.** a) Liquid solder injector cart. b) Bottom plate with track for injector cart and enclosure to maintain a controlled gas atmosphere (5% $H_2$ in $N_2$).

Wallis and Pomerantz (1969) overcame those difficulties by field assisted sealing, best known as anodic bonding. This method consists of applying a DC voltage at temperatures well below the softening temperature of glass (250–350 °C) to generate bonds without the need of pre-metallization. With TEM, Van Helvoort et al. (2003) observed that the anodic bonding process results in a cation depleted layer near the metal-glass interface. Multiple alloys have been bonded successfully to different types of glass by this process, and Knowles and Van Helvoort (2013) achieved shear strengths between 10 and 20 MPa. Even so, anodic bonding presents some limitations, particularly the need for an intimate contact between the bonded surfaces. Anthony (1983) discovered that the process of achieving an intimate contact is hindered by multiple practical complications, which gain more significance as the size of the bonded pieces increases and anodic bonding has been limited to small size applications as a result: the maximum bonded areas do not exceed ~80 $cm^2$, and still suffer from imperfections, as observed by Anthony (1983) and Yang et al. (2014).

Koebel et al. (2011) and El Hawi et al. (2013) reported the so called Activated Liquid Tin Solder Anodic Bonding (ALTSAB) process in which a tin-based solder in the liquid state is bonded to glass by means of small quantities of aluminium as an activating element. The role of the latter is to oxidize to $Al^{3+}$ and migrate into the glass to form an aluminosilicate compound in the interfacial bonding layer through the application of a DC voltage. The main advantage of this method over classical solid state anodic bonding is the improved surface contact between the liquid solder and the glass and the potential to produce large-area seals. Elrefaey et al. (2014) and later Malfait et al. (2016) coupled this process with soft soldering to produce metal/solder/glass joints.