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Injection Molding-Sealing of Glass to Low Melting Metals

Daniel P. Kramer, Richard T. Massey,
and Danny L. Halcomb

July 15, 1985

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Contents

Abstract

Injection molding-sealing is an innovative processing technique useful in the fabrication of complex glass or glass-ceramic-to-metal seals which use low melting metals such as aluminum. During injection molding-sealing, molten glass, which may have a higher melting temperature than that of the metal parts, is injected under pressure into the metal parts while they are held in a mold. The process, which for the first time allows the formation of seals with metals that have a lower melting temperature than the glass, allows the fabrication of seals of complex geometry.

Introduction

In classical gravity fabrication of glass or glass-ceramic-to-metal seals, the selection of metals and glasses that can be used to form the seal has been limited. Typically seals were fabricated by first melting the glass and then allowing the glass to flow onto the metal parts. In most cases, the glass flows because of gravity. Other processing techniques have been developed to increase the glass flow, but all of the developed processes rely on the inherent limitation that the glass must have a lower melting temperature than that of the metal parts. This in turn limits the type of seals that can be produced. However, the application of the new injection molding-sealing process removes this temperature limitation and allows the successful fabrication of complex glass or glass-ceramic-to-metal seals with materials that would have been impractical or impossible using any other forming technique.

Injection molding-sealing is a relatively simple technique. The process uses pressure to increase the flow of glass during the formation of glass or glass-ceramic-to-metal electrical components. The use of pressure to flow the glass or glass-ceramic allows the fabrication for the first time of seals using metals which have a lower melting temperature than the glass.

Mold Design

Injection molding-sealing is based on a processing technique called Vacuum Injection Molding which was previously developed at Mound [1]. It uses the same type of equipment except no vacuum pump is used during the injection molding-sealing process. This is the case since injection molding-sealing uses only a pressurized piston to flow the glass, whereas vacuum injection molding uses a piston and a vacuum to move the glass. The mold used for both processing techniques is shown in Figures 1 and 2. It is made of high purity graphite and cast iron. When assembled, the four-piece mold is held together with four screws. From top to bottom the mold is composed of a top plate, an injection feedthrough section, a fixture holder, and a bottom vacuum plate. The top plate and the fixture holder are made of graphite. The top plate was designed with a 3.25-cm hole in the plate to allow the molten glass to enter the injection chamber. Once this is accomplished, the injection plunger is inserted into the injection chamber during the molding process.

The injection feedthrough section (Figure 2, top right) was designed to channel the pressurized molten glass from the injection chamber into the fixtured parts (housings, rings, pins, etc.) in the fixture holder body. In Figure 2, this

FIGURE 1 - Presently used mold consists of graphite and metal pieces.

section has been inverted for clarity. The critical aspect in developing the mold was designing the injection feedthrough section. The success of this processing technique hinged on determining the optimum number, size, and shape of the sprues. The present glass capacity of the injection chamber easily allowed eight channels to be built into the injection feedthrough section. This could be increased to 16 or more, but it is dependent on the selected diameter of the injection mold. The total length of the sprue, $\sim$1.0 cm, depended on the type of electrical component being fabricated. In almost all cases, the cross-sectional area of the sprue opening was $\sim$1.2 cm^2. A sprue opening of this size yielded the highest quality finished parts. The small volume, $\sim$2 cm^3, opposite the injection chamber from the sprue is called the sprue cavity. This volume was sometimes left open, but other times it was used to accommodate fixturing needed for the fabrication of certain complex electrical components. During the molding process, the molten glass was forced from the injection chamber through the sprue hole, past the sprue cavity, and into the fixtures in the fixture holder. In this manner, the injection feedthrough section allowed the direction of the molten glass to be changed 90°.

The fixture holder section (Figure 2, bottom right) consisted of eight $\sim$1.5 cm diameter holes into which the fixtured parts were inserted. This rather simple

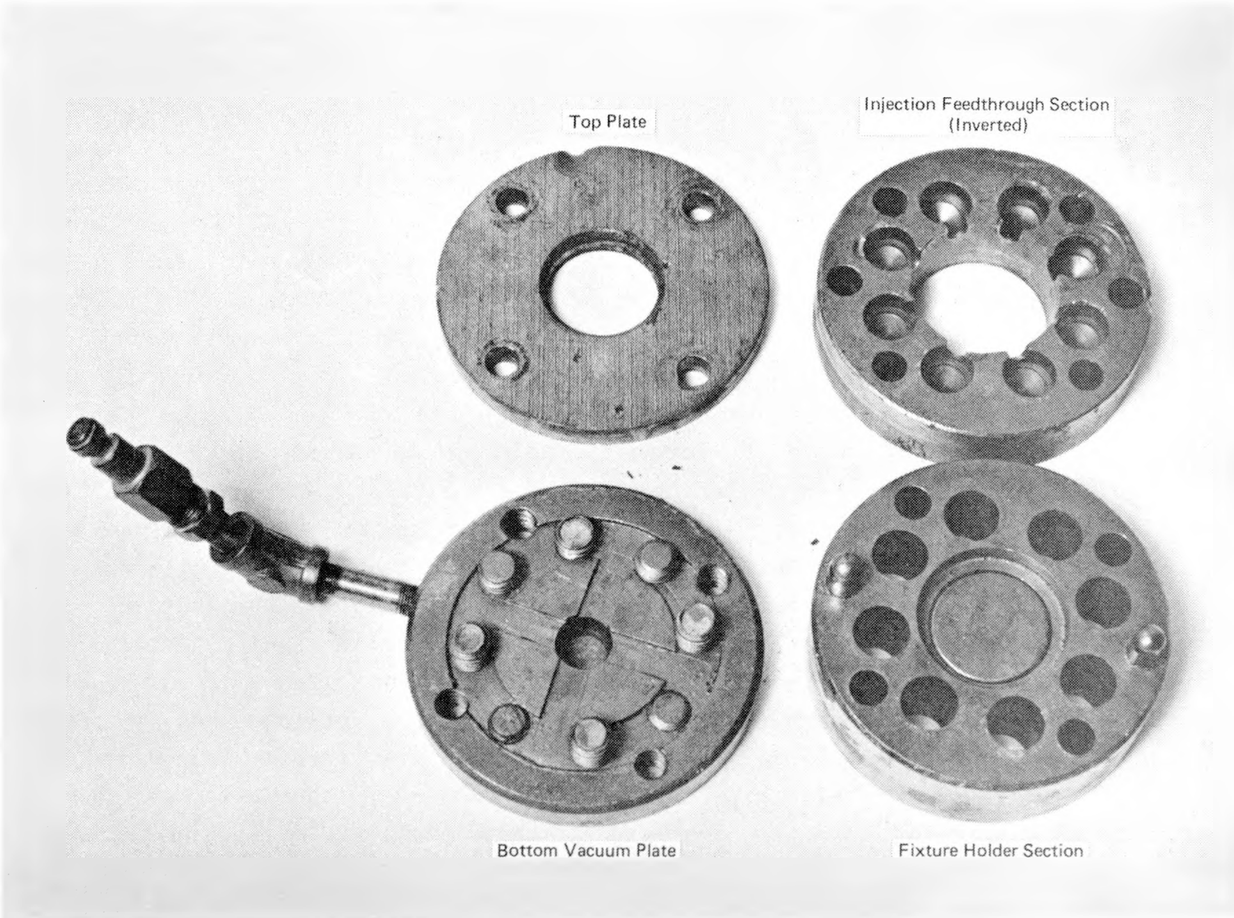


FIGURE 2 - The present mold allows up to eight components to be injection molded-sealed at a time.

part of the mold played a critical role in the success of the processing technique. A counterbore ~1 cm deep was machined in the center of the fixture. This small counterbore increased the working time of the molten glass in the injection chamber. Without it, the relatively cool mold acted to "freeze" the molten glass on contact, but with it, the counterbore allowed the "freezing" of the molten glass to occur below the sprue holes in the injection feedthrough section. The design of the injection plug in the center of the fixture holder facilitated removing the "frozen" plug of glass when the molding operation was completed.

The principal function of the bottom plate in injection molding-sealing (Figure 2, bottom left) is to allow positioning of the fixtured parts. Since the bottom vacuum plate was designed to contain eight threaded screw holes, up and down positioning of the fixtured parts in the fixture holes and greater ease of assembly are possible. Since no vacuum is applied during this processing, the vacuum port was not used. When assembled, as in Figure 1, graphite gaskets are used between the bottom vacuum plate and the fixture holder and between the fixture holder and the injection feedthrough section to ensure a vacuum-tight fit.

Injection Molding-Sealing Process

The injection molding-sealing process is performed by placing the required parts in the assembled injection mold. Figure 3 shows a simplified cross-section of the assembled mold and the position of the parts with the various parts labeled. The process is accomplished by first placing the fixture holder on the bottom plate and between them a graphite gasket is inserted. Next, the eight assembled parts are placed into the eight fixture holes. The height of the parts in the fixture holes is then adjusted to the correct height, by turning the screws in the bottom vacuum plate. Usually the tops of the fixtured parts were adjusted so that they were flush with the top of the fixture holder. Once this was accomplished, a graphite gasket was placed on the fixture holder, and the injection feedthrough section was positioned on the fixture holder. Finally, the top plate was put on top of the injection feedthrough section, and the mold was bolted together with the four fastening screws. After assembly, the mold was readied for processing by first preheating it in argon in a small electric box furnace. During the actual processing operation, the mold was first removed from the small furnace and glass was poured from a crucible into the injection chamber in the center of the mold and injected into the fixtured parts by the action of a piston. The press used was an air-activated press which had a plunger velocity of ∿15 cm/s and produced an estimated injection pressure of ∿50 psi. After 1 to 10 s, depending on the setting time of the glass, the injection pressure was relieved, the plunger was removed from the injection chamber, and the mold was disassembled for the removal of the parts.

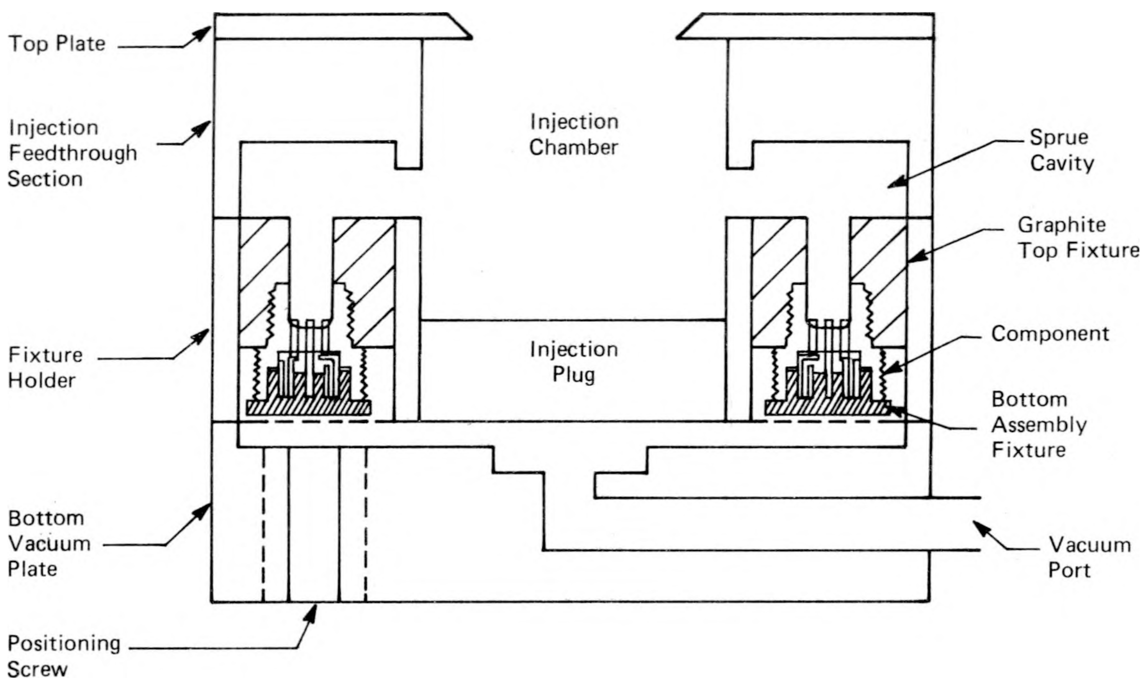


FIGURE 3 - Cross-section of injection mold showing position of fixtured parts.

Application

An example of an application of this processing, as it is used in fabricating complex glass-to-metal seals, is shown in Figures 4-7. On the right of Figure 4 are the parts that will be used in fabricating the seal. In this example the shell (top right) was fabricated of aluminum-2024, and the pin-ring assembly (bottom right) was made of Hastelloy C-276. Aluminum-2024 is an aged, hardenable aluminum with relatively high strength. Hastelloy C-276 is a nickel-based superalloy that has excellent corrosion resistance. (The melting points of these metals, along with other metals and glasses used in developing this technique, are shown in Table 1.) At the top left of Figure 4 is the graphite top fixture, and below it is the bottom assembly fixture. These fixtures are used to position the shell, pins, and rings so that the required tolerances are met. The seals being demonstrated consist of a glass-to-metal seal with each of the rings, pins, and shell.

The assembled parts and fixtures, ready for insertion into one of the eight holes in the fixture holder, are shown in Figure 5. Once eight of these part assemblies were placed in the fixture holder, the mold was assembled. The mold was then preheated in argon in an electric box furnace to ∿200°C.

The injection molding-sealing process in this example was performed using S-glass which is a multicomponent lithia-alumina-silica glass. The composition of S-glass is shown in Table 2. This particular glass was melted in an electric furnace at 1350°C until it was used in the processing of the component. After the mold

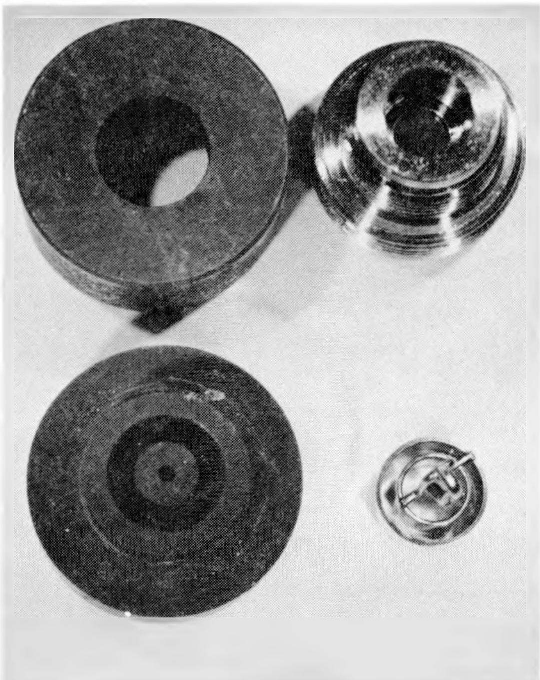


FIGURE 4 - Metal parts and graphite fixtures used to fabricate component.

FIGURE 5 - Fixtured component ready for placement within the injection mold.

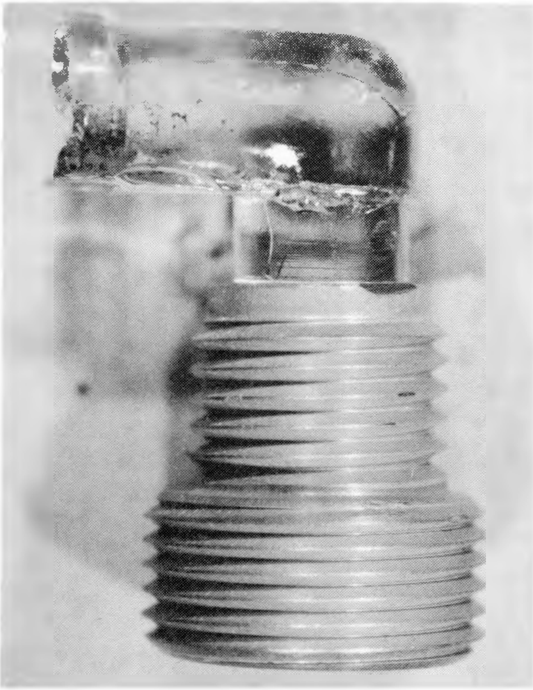


FIGURE 6 - Injection molded-sealed component after removal from the injection mold with glass sprue still attached.

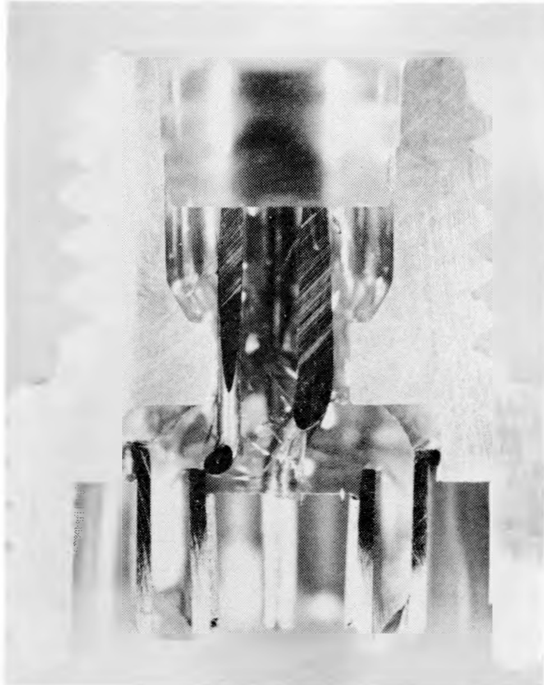


FIGURE 7 - Cross-section of injection molded-sealed component fabricated with aluminum-2024 shell and Hastelloy C-276 rings and pins and sealed with S-glass.

Table 1 - MELTING TEMPERATURES OF SOME MATERIALS USED IN EVALUATING INJECTION MOLDING-SEALING PROCESSING

Material	Melting Point (°C)
Aluminum (99.9%)	660
Aluminum-2024	638
Aluminum-6262	652
Aluminum-6061	652
Hastelloy C-276	1370
Beryllium (1.9 wt%) - Copper	950
Pemco P-25 Glass	790
S-Glass	960

Table 2 - BATCH COMPOSITION OF S-GLASS

Oxide	Content (wt %)
SiO_2	71.7
Li_2O	12.6
Al_2O_3	5.1
K_2O	4.9
B_2O_3	3.2
P_2O_5	2.5

reached the preheat temperature, it was removed from the furnace, and the molten glass was poured into the injection chamber.

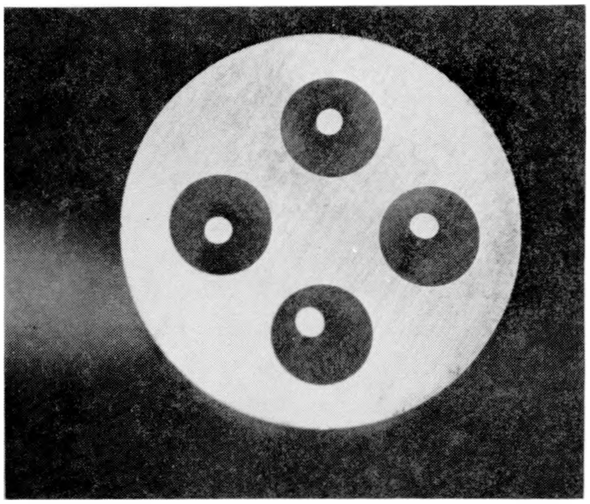
The glass was then injected throughout the mold by application of the pressurized piston. The mold was next disassembled, and the part assemblies were removed. Figure 6 shows an injection molded-sealed part after the top and bottom assembly fixtures were removed with the glass sprue still attached. Figure 7 shows a cross-section of the component after removal of the sprue and the grinding of the charge cavity. The cracks in the cross-section are from the necessary cutting of the component. Injection molding-sealing allowed the fabrication of this component and resulted in complete glass throughout, forming glass-to-metal seals with each of the pins, rings, and shell.

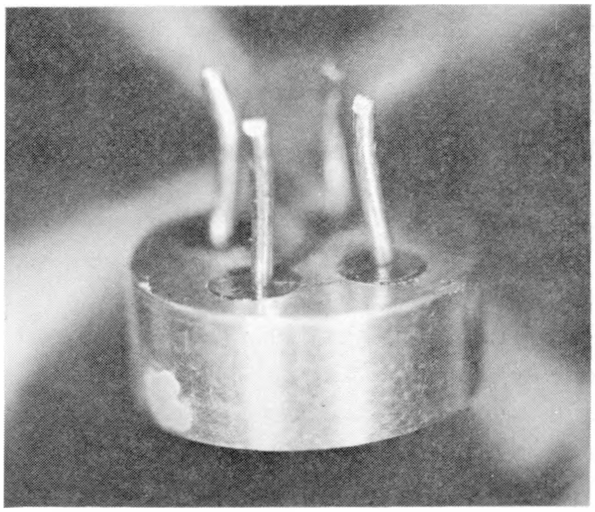
Discussion

The advantage of this processing technique becomes rather clear when it is realized that the component shown in Figures 6 and 7 consists of "impossible" seals. The glass has a melting temperature of ∿960°C, but because of viscosity restraints, it was poured into the mold at a higher temperature. In this study the glass was melted to ∿1350°C. The aluminum-2024 shell has a melting temperature of ∿638°C. By conventional processing techniques it would be impossible to form this glass-to-aluminum-2024 seal. This is the beauty of injection molding-sealing. It allows the fabrication of glass or glass-ceramic-to-metal seals where the metal parts have a lower melting temperature than the glass. This is feasible because the injection mold acts as a heat sink, and because processing temperatures are carefully selected. Correct preheating of the injection mold is critical. If the injection mold is not preheated or is preheated to too low a temperature, then the glass, when poured into the relatively cool mold, would tend to "freeze" and not flow. Preheating the injection mold too much could result in the metal parts melting when the glass is poured into the mold. In addition, the pour temperature of the glass is critical since it needs to be high enough to increase the flowability of the glass, but low enough to be heat sinked by the mold and the metal parts. The formation of "impossible seals" is relatively easy once the correct processing temperatures have been selected.

The ultimate usefulness of this processing technique lies with its ability to fabricate high quality seals. Components produced using this technique have exhibited excellent mechanical properties. Helium leak tests have demonstrated that these seals can have a leak rate $<10^{-8}$ cm^3/s of helium. The seals of the aluminum component shown in Figure 6 were also tested for strength. At hydrostatic pressures up to 40,000 psi, the aluminum-2024-to-glass seals did not leak or fail, but the component did fail as a result of the yielding of the aluminum threads. The seals were stronger than the yield strength of the threads.

The adaptability of injection molding-sealing to the processing of various types of components is shown in Figure 8(a and b). This development connector component was injection molded-sealed and consists of an aluminum-2024 body, S-glass, and pure aluminum (99.9%) pins. The melting temperatures of these





(a) (b)

FIGURE 8 - Injection molded/sealed development connector sealed with S-glass with an aluminum-2024 body and aluminum (99.9%) pins.

materials are ∿632°C, ∿960°C, and ∿660°C, respectively. Again, a component with this "impossible" seal system was fabricated by careful heat sinking using pin materials with low melting temperatures.

Another application of this processing technique which has far-ranging consequences is based on the fact that "classical" furnace processing of seals necessitates that the metal parts be processed at elevated temperatures to form the seal. This can have a detrimental effect on the properties of the metal parts such as decreasing the strength of the material. It may also cause unwanted phases or phase transformations to occur in the metal parts, or the furnace cycle could cause the diffusion of detrimental species to the metallic surface resulting in harmful reactions between the metal and the glass. Injection molding-sealing processing reduces or eliminates these detrimental effects of "classical" high-temperature-furnace processing since the maximum temperature to which the metal parts are subjected can be kept quite low. Components have been fabricated using metal parts that were heat treated before processing in order to obtain maximum tensile strengths of the parts. Since injection molding-sealing uses low processing temperatures the metal parts maintained their strength even after processing. If "classical" furnace processing had been used, the higher processing temperatures would have annealed the metals resulting in weaker parts.

Components have also been heat treated after the injection molding-sealing process in order to increase the strength of the component. Certain components fabricated out of beryllium (1.9 wt %) - copper shell, S-glass, and Hastelloy C-276 pins were found to have a hydrostatic burst strength of ∿85,000 psi after being injection molded-sealed. But by heat treating these components at 330°C for 2 hr after sealing, the strength increased to over 100,000 psi.

Summary

Injection molding-sealing processing allows the fabrication of "impossible" seals and opens a whole new range of material selections for the design engineer. Some of the inherent limitations of "classical" furnace processing of seals are removed. The advantages of this processing technique have been demonstrated in the fabrication of different complex glass-to-metal seals.

Reference

1. Kramer, D. P., and R. T. Massey, "Vacuum Injection Molding of Glass-Metal Electrical Components," Forming of Ceramics, Advances in Ceramics, 9, 265-273, The American Ceramic Society (1984).

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