

Shaping of glass melts by continuous pull extrusion¹⁾²⁾

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Continuous pull extrusion represents an important further development of the traditional extrusion process. It enables the manufacturing of arbitrary endless inner and outer profiles of glasses for common and special technical applications with a high trueness of shape and precision in a markedly more economical way than by the usual discontinuous extrusion method. This is achieved by a continuous supply of the glass into the equipment in connection with a considerable saving of the up to now unavoidable setting periods. The drawing process immediately following the extrusion procedure itself permits a defined cross-sectional diminishing of the extruded profiles and causes together with this a rectilinear straightening of the products.

Formgebung von Glasschmelzen durch kontinuierliches Ziehstrangpressen

Das kontinuierliche Ziehstrangpressen stellt eine bemerkenswerte Weiterentwicklung des herkömmlichen Strangpreßprozesses dar. Es ermöglicht die Herstellung vielfältiger endloser Voll- und Hohlprofile aus Gläsern für übliche und spezielle technische Anwendungen mit hoher Form- und Maßgenauigkeit auf bedeutend wirtschaftlichere Weise als mit dem bisherigen diskontinuierlichen Strangpreßverfahren. Dies wird durch eine stetige Glaszufuhr in die Einrichtung und die damit verbundene erhebliche Einsparung bislang unvermeidlicher Rüstzeiten erreicht. Der dem eigentlichen Strangpressen unmittelbar angeschlossene Ziehvorgang erlaubt eine definierte Verminderung der gepreßten Profilquerschnitte bis hin zu kleinsten Abmessungen und bewirkt zugleich eine geradlinige Ausrichtung der Produkte.

1. Introduction

The common process of glass extrusion is especially qualified for the manufacturing of complicated inner and outer profiles with a high degree of dimensional accuracy. This precision of shape results from the considerably low process temperature and the unusually high viscosity of the glass melt ($\eta = 10^7$ until 10^8 dPa s) compared with the traditional forming methods, such as drawing or blowing. By that means the corner radiusing effect of the surface tension is largely suppressed. Therefore, sharp-edged profiles can be manufactured.

Furthermore, on account of the isothermal mode of procedure and due to the decreased working temperature, which generally lies below the devitrification range, glasses with a steep viscosity-temperature curve (so-called short glasses) and also glasses with a strong tendency of crystallization can be processed [1 to 3].

2. Method of continuous pull extrusion

The shaping process at the high viscosities mentioned in section 1. requires a nearly all-round enclosing of the glass

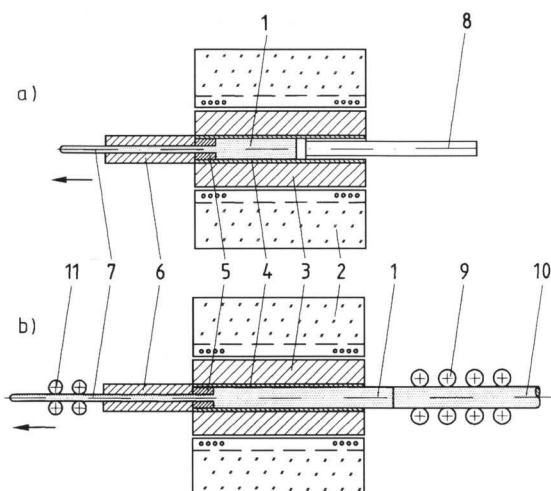
melt to be extruded combined with extraordinarily high deformation forces. To this end in the past a direct discontinuously working extrusion press has been designed and built up [4]. In that equipment a certain quantity of glass, which is filled into the container, is heated up to about its softening temperature ($\eta = 10^{7.6}$ dPa s) and then pressed by means of a metallic punch through the extrusion die (figure 1a). Hereby, the aperture of the die channel, the cross-sectional area of which is much smaller than the container, determines the profile of the emerging rod. After each extrusion stroke the container has to be refilled. This procedure gives rise to longer setting periods, which, however, can be considerably reduced by a changeover into a continuous work cycle [5 and 6]. That results in a more favourable economy of extrusion.

In order to achieve a continuous process of glass extrusion the metallic punch (figure 1a) has to be replaced by a self-consuming glass ram in the shape of a long cylindrical unfinished glass rod (figure 1b). This is continuously fed into the container by means of a number of friction wheels. The container is surrounded by an electric resistance furnace. During its forward motion the front region of the glass rod is gradually heated up to the softening temperature and pressed through the die channel showing the required cross-sectional profile. The supplied glass rod is immediately followed by another one and so on so that a continuously working process can be maintained. After leaving the die and passing a cooling tract

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Figures 1a and b. Fundamental methods of discontinuous extrusion (figure a) and continuous pull extrusion (figure b). 1: glass billet, glass rod; 2: resistance furnace; 3: container; 4: liner; 5: extrusion die; 6: cooling tract; 7: extruded glass rod; 8: metallic punch; 9: feeding friction wheels; 10: following glass rod; 11: drawing friction wheels.

the semifinished product gains the drawing wheels, which – without a reheating procedure – reduces its cross-sectional area to a wanted measure. Finally, the drawn and aligned rods pass through a cross-cut machine.

3. Equipment for continuous pull extrusion

Arrangement and mode of operation of the continuously working pull extrusion pilot plant, which has been designed and developed at the Institute of Material Science and Mechanical Technology of the University of Kai-

serlautern, are shown in figures 2 and 3. The maximum pressure load amounts up to 60 kN. The cylindrical unfinished glass rods to be extruded of about 32 mm in diameter and about 1100 mm in length are pressed with a vertical load by three unison hydraulic press cylinders between two friction drive units. These are activated by two electronically coupled direct-current shunt-wound bevel-gear drive motors. In this way, the glass rods are continuously fed into the container under a constant pressure of some hundred bars. The supplying velocity is infinitely variable in a range between 0 and 100 mm/min and enables depending on the extrusion ratio at present velocities of the extruded rods up to about 500 mm/min. In order to reduce wall friction the container, which is made of a high-strength nickel-base alloy, is lined with a non-wettable material of good antifriction properties in relation to the glass melt, such as electric graphite or austenitic grey cast iron.

The heating up of the glass rods to their softening temperature, which varies according to the applied kind of glass between about 700 and 900 °C, is accomplished by a four-shell electric resistance furnace. The possibility of the separate heating and temperature control of two by two shells enables the generating of a special axial temperature distribution along the zones of preheating and of deformation within the container. Figures 4a and b show exemplarily two profiles of temperature over the length of the furnace. As can be seen the temperature gradually increases from the entry of the container and reaches its maximum value somewhat higher than the softening point of the used kind of glass at the beginning of the deformation region. Here the combined effects of temperature and pressure cause a complete fusing of the successively fed glass rods.

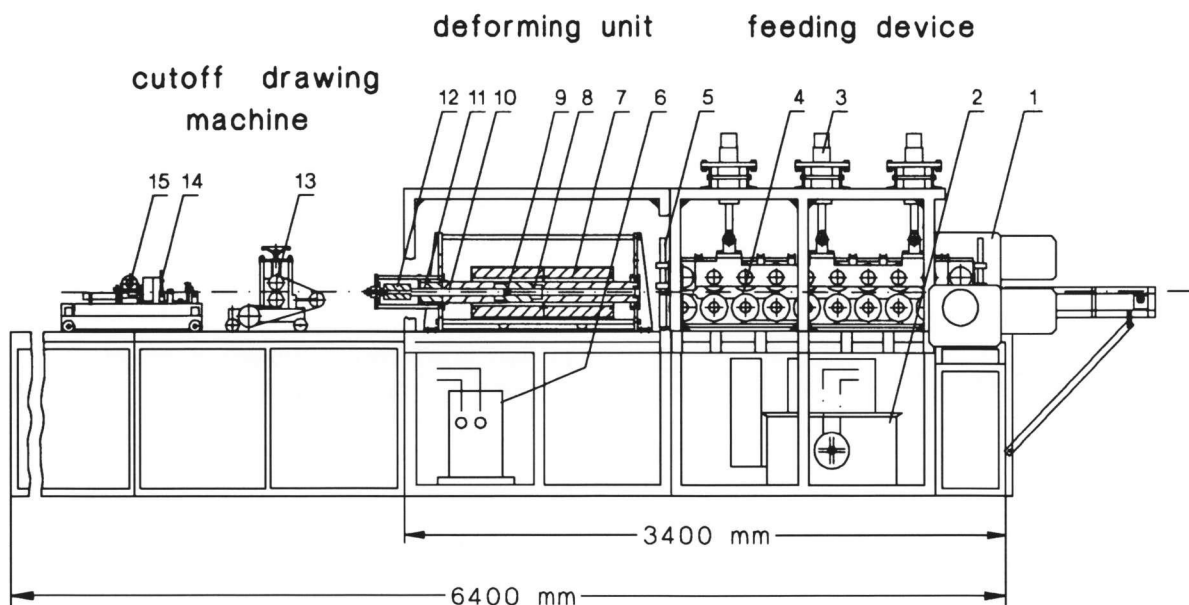


Figure 2. Schematic view of the continuously working pull extrusion equipment for glass. 1: bevel-gear drive motor; 2: hydraulic control unit; 3: hydraulic press cylinder; 4: feeding friction wheels; 5: vertical guide of the upper friction drive; 6: refrigerator; 7: resistance furnace; 8: container; 9: extrusion die; 10: cooling tract; 11: wall frictional force load cell; 12: die force load cell; 13: friction wheels; 14: scratch wheel; 15: shearing pin.

The extrusion die according to circumstances is generally made either of electric graphite or of a high-strength heat-resisting steel. The material first mentioned exhibits excellent antifriction properties and therefore, enables favourable extrusion rates. Metallic dies, by contrast, show a higher endurance but due to wall sticking of the glass melt cause considerably lower emerging velocities of the extrudate.

After leaving the die channel the extruded rod is drawn without reheating in its rather viscous state in order to guarantee a high dimensional stability. This process accomplishes an exact alignment of the extruded rods, prevents possible twisting and renders a defined reduction of their cross-sectional area under maintenance of the geometrical similarity as long as the drawing velocity is higher than the extrusion rate. The drawn profiles finally are cut into well-defined lengths by means of an electronically controlled cross-cut machine. This occurs by scratching the rods at well-proportioned temporally intervals and then breaking off and gathering the pieces in a storage box.

By means of various measuring devices all process variables which are important for the extrusion procedure can simultaneously be computer-aided recorded. These are e.g., the preheating and transforming temperature within the container, the die load, the friction force at the container wall and the velocities of extrusion and drawing. Thus, the most important parameters are available at all times for a scientific process analysis.

4. Results

The highly transparent soda–lime–silica glass B 270 (DESAG AG, Grünenplan (Germany)) with a softening temperature $\vartheta_{\text{soft}} = 708^\circ\text{C}$ at a viscosity $\eta = 10^{7.6}$ dPa s was used as test material. During the pull extrusion of rods with simple circular cross-sections at a pressure of about 400 bar and a temperature close to the softening point efficiencies of transformation are attained up to 80 %. The realized drawing velocities up to now have been of the order of 2 m/min in the case of manufacturing circular profiles with cross-sectional areas reduced more than 90 %, but higher rates can still be expected, because the whole equipment has not yet been strained up to its limiting values. In the present stage of development the maximum tolerance of diameter amounts to $\pm 2\%$ without any special controlling of the pressing and drawing velocity. Better values seem to be attainable by using an automatic control system.

Another essential requirement for a high economy of the pull extrusion process is the flawless fusing of the successively supplied cylindrical unfinished glass rods within the deformation zone of the container and within the die channel. The quality of the joining depends both on the extrusion conditions and above all on the mechanical pretreatment and thus on the resulting state of the front surfaces of the individual glass rods. In order to obtain weldings of a good optical quality the frontal areas have to be polished with diamond paste and subsequently cleaned in

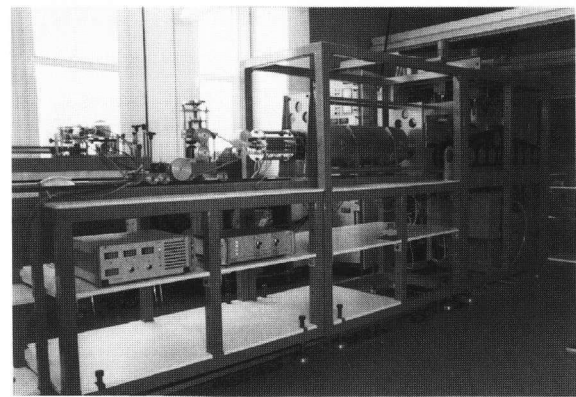
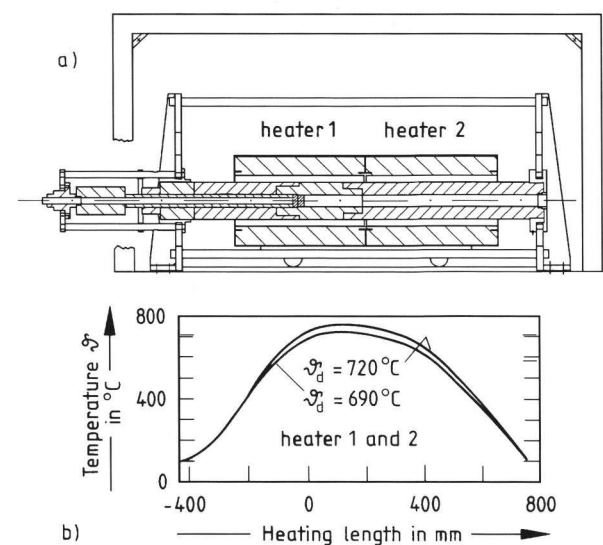


Figure 3. 60 kN-laboratory plant for continuous pull extrusion.



Figures 4a and b. Set-up of the furnace arrangement (figure a) and the axial distribution of temperature within the furnace for two die temperatures ϑ_d (figure b).

an ultrasonic bath. Figure 5 shows exemplarily an optical microphotograph of the vertex range of the paraboloidically shaped welding seam. Extensive mechanical tests under tensile and bending load of extruded glass rods containing a welding seam established that they exhibit no detriment in rigidity and strength compared with seamless specimens.

Investigations of the influence of the drawing process on the trueness to size of the extruded rods with complicated inner profiles showed that certain cross-sectional deviations from the die aperture originating in the die swell phenomenon [7 and 8] were markedly diminished with an increasing amount of reduction. Thus, a satisfying similarity to the die aperture profile can be obtained at high reductions as is demonstrated in figures 6a to c by means of two typical pull-extruded examples. As earlier discontinuous extrusion experiments have shown, a further improvement of trueness of shape and precision of dimensions could be achieved by using materials for dies and mandrels with a low wall friction [8]. This step simultaneously leads to a higher extrusion rate.

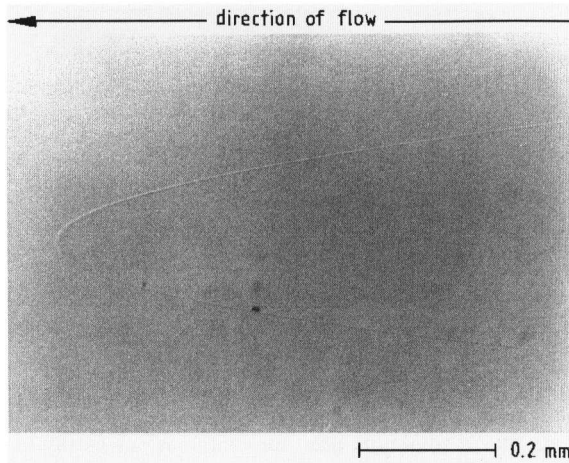
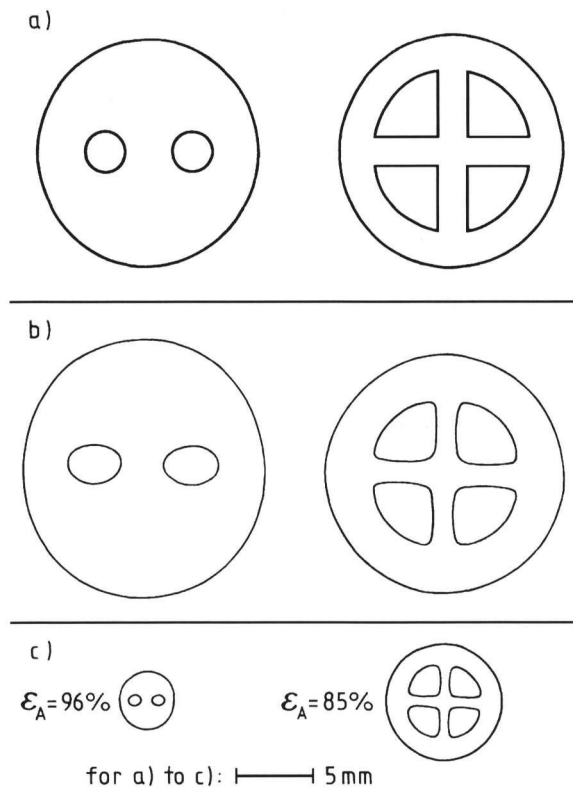


Figure 5. Contour of a welding seam within a rod of soda-lime-silica glass. Experimental conditions: graphite die with a circular orifice, extrusion temperature $\vartheta = 700^\circ\text{C}$, viscosity $\eta = 10^{7.76}$ dPa s, extrusion pressure $p = 180$ bar. The front surfaces of the glass bars were polished with diamond paste and afterwards cleaned in an ultrasonic bath. The welding seam could be made visible only by special photographic moves.



Figures 6a to c. Two-hole profile (left) and profile with diagonal cross brace (right) of a soda-lime-silica glass, a) aperture profile of the extrusion die A_1 ; b) extruded profile with die swell phenomenon; c) cross-sectional area after pulling A_2 : amount of reduction $\epsilon_A = ((A_1 - A_2)/A_1) \cdot 100$ in %. Experimental conditions: die of CrNi steel, extrusion temperature $\vartheta = 700^\circ\text{C}$, viscosity $\eta = 10^{7.76}$ dPa s, extrusion pressure $p = 415$ bar.

5. Summary

In comparison to the common direct discontinuous extrusion method the continuous pull extrusion process exhibits an increased efficiency. This advantage is obtained

by replacing the usual metallic punch by a self-consuming ram in shape of successively supplied long cylindrical unfinished glass rods. In that way uneconomical setting periods can be saved. The following drawing process renders besides an exact alignment of the extruded rods an optionally adjustable reduction of their cross-sectional area.

The development work, which has been done up to now with a pilot equipment designed and manufactured at the University of Kaiserslautern proves pull extrusion to be a suitable process for the production of complicated inner and outer profiles. The obtainable trueness to size and edge sharpness due to the considerably increased melt viscosity, however, has to be bought with a lower output in comparison to the conventional drawing process.

Possible applications of pull-extruded high-quality inner and outer profiles of glasses with special chemical or physical properties could lie in the field of chemical engineering, in precision engineering, in the optical and optoelectronic industry as well as in the pharmaceutical and medical field.

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