# Energy-efficient process strategies for the production of glass components by cutting and joining

Susanne Kasch*†1, Thomas Schmidt , and Stefan Link

[1]Günter-Köhler-Institut für Fügetechnik und Werkstoffprüfung GmbH, Jena – Germany

**Abstract**

The melting of glass, the subsequent technological shaping and cooling processes for stress relief, require high temperatures. This makes it one of the most energy-intensive industries in the world. Currently, the glass industry is subject to considerable restrictions due to increased energy prices and numerous energy and climate policy regulations, which have an influence on production, prices and thus also on the competitiveness of the companies.
Laser-based manufacturing technologies have great potential for saving energy-, material- and time-intensive processes and for improving the product properties. They can open up new processing possibilities and hitherto unimaginable effects in terms of material, geometry and applications.

Glass tubes are used in a wide range of applications in glass apparatus engineering and laboratory equipment, especially in chemical, pharmaceutical and semiconductor industries. Mostly borosilicate glass (B33) is used here, but it can only be used up to temperature ranges of approx. 400 $\circ$C. For higher temperatures up to 1100 $\circ$C only quartz glass can be used. Irrespective of the type of glass, glass tubes for plant construction are first cut or blast off at an angle. Flanged connections can be used to attach them to each other or to other apparatus. In reactor applications, connection systems with gaskets provide a seal against the environment. In this way, different types of glass apparatus with different functions can be produced. For this reason, material-locking tube-ring and tube-plate or tube-round disc connections are often found at the ends to enable different laboratory vessels to be adapted to one another.

The paper presents recent results on the development of processes for glasses using CO2 lasers. The investigations focus on the near-net-shape blasting of glass tubes (borosilicate glass, soda-lime glass) at a specified angle and the direct joining (borosilicate glass, quartz glass) of component combinations in the form of tube-ring or tube-round disc joints. For the investigations on the blasting and joining of glass tubes, the respective system technology including heat guidance and laser irradiation strategy was developed and the glass quality was verified by material testing on sample glasses typical for industry.

During thermal blasting, a CNC-controlled CO2 laser beam generates a stress line on the circumference of the glass tube corresponding to the final contour through the local application of energy and precise heating. For this purpose, the laser beam is moved along the tube axis during the rotation of the glass tube and the tube is selectively broken along this

*Speaker

†Corresponding author: skasch@ifw-jena.de

stress line. Break-off at a given angle with respect to the tube axis was investigated on glass tubes with higher thermal expansion coefficients (borosilicate and soda-lime glass).

In order to be able to perform the cutting process for different tube diameters, the focusing of the laser beam conditions were varied. Furthermore, a water-cooled deflection mirror was developed and manufactured to deflect and focus the laser beam inside the tube. Process control was achieved by integrating a pyrometer into the beam path of the laser.

The programming of the axis control is an essential part of the cutting process, especially if it is to be performed at an angle. For a bevel cut the linear axis must follow a sinusoidal curve during one revolution of the tube, whereby the feed speed on the tube wall remains constant.

The main focus of the research work was the determination of the laser and process parameters. In addition to the usual process variables such as laser power, beam diameter and speed, the introduction of an initial crack and additional methods for generating the highest possible temperature gradient also play a role here. An integrated temperature control system ensures reproducible melting of the cut edges if desired. As a result of the investigations, clean, almost microcrack-free, sharp-edged and vertical edges are produced, which, depending on the application, can also be executed as a fire-polished C-shaped edge in one clamping.

The high-quality welding in the Tee geometry was investigated for borosilicate glass tubes (ø 29 mm with wall s = 1.5 mm and ø 53 mm with wall s = 2 mm) and corresponding glass compacts (hexagonal plate) by heat conduction welding and for quartz glass (Ø15 - 60 mm, wall s = 1.2 - 5 mm) by deep welding. CO2 laser sources ($\lambda = 10.6\ \mu$m) with laser powers up to 3.5 kW and flexible focusing conditions, various preheating techniques such as adapted electric heaters, an induction power source or gas burners were used for the experiments. A CNC-controlled glassmaker's lathe was used as a handling system. Pyrometric temperature measurement and temperature-controlled laser power control was used for the experiments. For the process, the various process parameters (joining temperature, gap at the start of the process, speed during joining/upsetting, upsetting distance, dwell time after joining/upsetting, stretching distance, stretching speed, rotational speed, preheating temperature, focus position/beam cross-section), their influence on the joining process and the dependencies on the joint and seam quality were investigated. The quality of the joints with respect to the formation of fillet welds was examined and evaluated by optical microscopy and 2D/3D X-ray radiography. An analysis of stresses was performed by means of a stress microscope.

As a result of the investigations, it was possible to demonstrate that the quality of the fillet weld for laboratory measuring vessels (B33) can be significantly improved by means of laser joining compared to torch-based production. In terms of process time, further optimization potential from the experimental setup to an industrial plant is necessary for automated industrial introduction. This can be realized, for example, by multi-station operation, higher laser powers or preheating.
Laser welding of quartz glass can be implemented for wall thicknesses up to 2 mm as heat conduction welding (e. g. filigree structural components) and up to 15 mm with the hybrid deep welding process. Proof of feasibility was provided on the basis of a real component and other functional samples.

**Keywords:** Glass, CO2 laser, cutting, joining, manufacturing technology, energy efficiency, automation