

The benefits of annealing lehrs

Hans Strauven* explains how annealing lehrs are a critical step in the production of patterned, flat, electronic and foamed glass.

The purpose of annealing lehrs is to cool the glass gradually to near room temperature, giving it the desired properties.

The process involves travelling through the viscous-elastic region of the glass – which is still a matter of fundamental research – prevailing in modern annealing lehrs.

The fundamentals are critical for continuous glass ribbon annealing of architectural, automotive, electronics and foamed applications.

In the case of foamed glass, the role of the annealing lehr is to cool the continuous foam in a single piece to room temperature. After cooling, the foam must be easy to cut and be resistant to thermal shock on one side when submerged in a bitumen bath at 200°C. For patterned glass, the glass must be easy to cut during production and at the glass processing plant. In the case of float glass, the glass must also be scratch free up to a certain level.

Breakage

The breakage behaviour of foamed glass and flat glass is fundamentally different. In the case of flat glass, a single microscopic crack can grow continuously, as long as a certain stress level is present.

For foamed glass, the growth of a microscopic crack is the result of a combination of individual microscopic cracks, which can be identified by the cracking of individual cells^[1].

For this reason, a certain compressive membrane stress is put on the glass ribbon edge by installing a controlled temperature gradient, while for foamed glass a temperature gradient over the ribbon is not desired.

Good control of the temperature gradient over the full ribbon width is of major importance to avoid breakage in the lehr and to obtain a well controlled residual stress during cutting of the ribbon; both during production and at the glass processing plant. For this



reason, more or fewer control zones are used, depending on the required ribbon width. Good control of the temperature under and above the glass is important, to attain the required flatness. Therefore separate cooling beneath and above the glass is introduced.

Annealing temperature

The temperature profile needed to anneal the glass depends entirely on the velocity of the glass forming, thickness and nature of the glass. For 6mm thick glass, the maximum tensile residual stress due to the thickness gradient is recommended to be between 9kg/cm² and 12kg/cm². For foamed glass, a maximum tensile (residual) stress of 2.3kg/cm² is recommended for 110kg/m³ density foam^[11].

Size

Typical flat glass annealing lehrs are between 25m (electronic) and 200m (architectural) in length and depend on the required load, ribbon width and residual stress value specified. Similar lengths are possible for foamed glass lehrs^[11], allowing a velocity between 3.6 and 40cm/min for 12cm foam.

As a consequence, annealing lehrs occupy a large part of the production line and for this reason, accurate

calculations will drastically reduce capital expenditure (Capex). Above a certain lehr length, the glass quality cannot be improved further, so the extra Capex, incurred due to safety factors on estimates instead of accurate calculation, has no added value.

Process

Belgium-based Cnud-Efco offers technical solutions in terms of engineering and equipment for forming and annealing glass. The company works with soda lime glass which has an annealing point at 546°C and strain point at 515°C.

The points for other glass can be calculated by scaling to the respective viscosity points. **Fig 1** (overleaf) shows the actual annealing profile.

After glass forming, fast, indirect cooling from 600°C to 540°C is performed in zone A. By using fast cooling, the glass surface hardens rapidly and scratches by rollers are less likely. Below 540°C, there is slower cooling in zone B, down to 480°C, when stress relaxation at this stage becomes negligible. However, structural relaxation is still present at 450°C,

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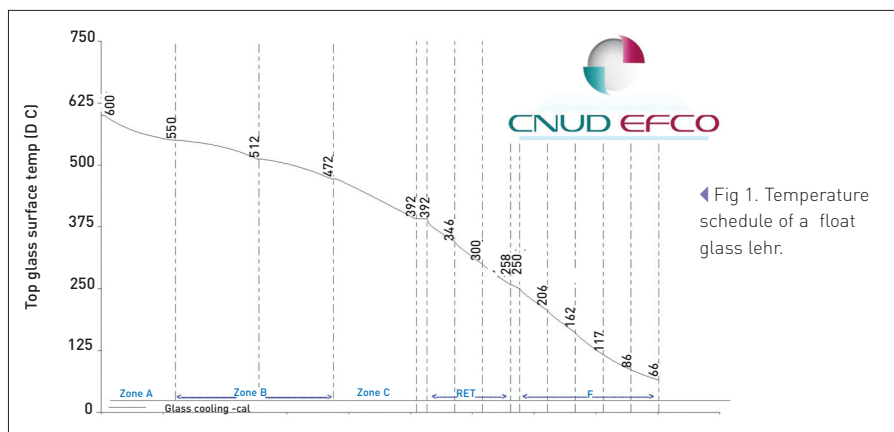


Fig 1. Temperature schedule of a float glass lehr.

which builds up additional residual stress. In the case of electronic glass, improved glass stabilisation can be used to avoid shrinkage, at electronic processing temperatures (400°C), by lengthening the first lehr zones.

The residual stress is calculated with the R. Gordon - O. S. Narayanaswamy model^[IV]. This model gives an accurate description of the stress and structural relaxation, making up the residual stress. The phenomenon of structural relaxation, responsible for 50% of the residual stress of flat glass was first reported elsewhere^[V]. In the case of thick-foamed glass, annealing is slow and the glass can be considered as stabilised or without structural stress.

Below 480°C, the cooling rate is 400°C in zone C (structural relaxation is rather slow). It is general practice to use indirect cooling down to 400°C and even lower. Below this temperature, cooling by radiation, assisted by natural convection becomes too slow.

Zones A, B and C consist of an insulated metallic tunnel with air-cooled heat exchangers above and below the glass, which are organised in different control zones covering the ribbon width. In zones A and B, it is still above 450°C and more or less SO₂ is injected to cover the glass and rollers with a protective layer. Zones A and B are built with AISI304 while standard ST37 is used in zone C.

It makes sense to increase the efficiency of the heat exchangers in zone A by using a different geometry or material. Underneath the ribbon, the heat exchangers are susceptible to the possibility of broken glass during start up or production changes.

The exchangers are easy to clean using doors in the sidewalls. In addition, peepholes are foreseen above the glass level. The typical pitch of the rollers for architectural glass is 500mm in zone A, B

and 600mm in zone C. The diameter, material type and surface of the rollers^[VI] depend on the glass produced. It is important rollers are installed in such a way that cleaning of the rollers during production can be done efficiently^[VII] to ensure a perfect glass surface.

Sidewall adjustable heaters are installed to heat up the lehr and to adjust the temperature of the ribbon edge. Heating drawers over the full ribbon width are typical with electronic glass, on line coated float glass and foamed glass.

Below 400°C for standard architectural glass, forced convection can be used to speed up the cooling of the glass. For electronic glass, it is necessary to start this type of cooling at a lower temperature, especially when glass with a high expansion coefficient is used, as with chemical strengthening. In the case of foamed glass, natural convection and radiation allow a cooling rate where the maximum temporary stresses (2.3kg/cm²) are reached because glass foams become highly insulating at lower temperatures^[VIII]. For this reason, an adapted insulated tunnel can be used over the full length and forced convection is not advised.

The forced convection is performed with heated air (RET zones^[IX]) down to 200°C. The air is heated by the glass (architectural glass) or an extra heater for ultra-thin glass and is blown through nozzles organised in different control zones above and beneath the glass, to control the temperature across the ribbon.

Below 200°C in the F zones, air at ambient temperature is used to cool the glass to 70°C. The geometry and localisation of the nozzles is the key to getting maximum cooling with minimum energy consumption and still allow cleaning of the glass cullet during a production change. Today, RET and F zones are designed with the state of the

art knowledge of turbulence to reduce the pressure drop^[X].

Conclusion

Although annealing lehrs are in production for long periods, there are still improvements to be made. Today at least 10kWh/tonne or about 1.5% of the total primary energy (operating expenditures = Opex) for float glass is used to cool the glass to 70°C, while the extracted heat can be converted in enough mechanical energy to drive all the fans of the lehr. In the case of electronic and foamed glass, the load (and so heat input) of the lehr is rather low and extra heating is necessary. This is always done electrically, but the use of waste heat from other parts of the production line could also be considered to keep the lehr at the desired temperatures. Electronic glass always has edges, which are more difficult to cool. This was accomplished by lengthening the lehr, but could also be done today by improved heat exchangers.

Annealing lehrs have to be built with the smallest environmental footprint possible. This has to be achieved by accurate calculations and innovative engineering, using new technology and materials. On-line simulation can be also be organised to improve production changes and operator training. ■

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