EFFECT OF FOREHEARTH EXIT PLANE NON-UNIFORMITIES on final container quality

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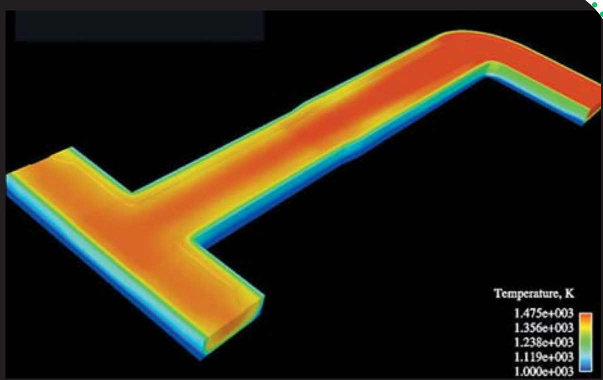
Large deviations from the ideal gob shape and trajectory can have severe consequences on the penetration of the glass into the transfer equipment and moulds. Additionally, asymmetric loading of the gob into the blank moulds can cause uneven temperature and wear patterns on the mould interiors. In order to investigate how various forehearth performance affects gob shape and weight, a numerical study was performed. The numerical simulation modelled flow of glass through the forehearth, the formation of the gob at the feeder, and the subsequent formation of the container in the IS machine. Of particular interest in this study were the effects poor forehearth performance has on the final container quality.

FIGURE 1
Forehearth configuration and temperature contours



Introduction

Since the glass gob represents the transition point from a continuous melting process to the discrete glass forming operation, it is important to control various gob parameters such as weight, geometry, viscosity, temperature, and fall orientation. Traditionally, gob shape control is conducted by trial and error based on past experience and operator knowledge. The forehearth exit plane temperature is the primary control point for thermal consistency of gob formation. Generally, it has been thought that tight control on the forehearth exit plane temperature profile is required for consistent gob and container quality.

Beyond the forehearth, feeder plunger shape, location, and stroke, along with feeder orifice size and glass temperature are usually varied until the desired gob shape and weight have been achieved. Recent advances in numerical techniques and computer capabilities have made the numerical modelling of the effect of forehearth performance on the gob and container forming processes feasible.

A numerical investigation has been carried out on the flow and thermal conditions of molten glass during its passage through the forehearth, a double gob feeder, delivery equipment, and finally through the container forming process of an IS machine. Of particular interest were the impacts of the forehearth exit plane temperature on the final container quality.

Forehearth

The computational model starts by analyzing the glass as it flows through the forehearth. Figure 1 shows the forehearth geometric and thermal configurations which were selected for evaluation. The inlet temperature was 1575 K and the mass averaged outlet temperature was 1450 K. The pull rate per forehearth was about 80 mTPD. The model included all radiation, convection and conduction effects. The heat fluxes at the surface of the glass were based on experimental measurements combined with a simulation of the roof block and combustion space. The mass average temperature and the 9-point grid were matched between the actual forehearth and the model.

Figure 2 shows the glass as it flows toward the feeders. The thermal profile in the cooling sections is symmetric. But it is obvious that the thermal profile never straightens out after the turn into the equalizing sections. Hotter glass is pushed to the outside as it enters the feeder. In cases like these, glass manufacturers often use mechanical stirrers in the equalizing sections in order to improve glass homogenization. However, in this study, the effects of these non-uniformities were studied to determine if, in fact, they carry downstream to the final container.

Feeder

In order to determine the thermal condition of the gob as it enters the IS machine, a numerical model of a standard double gob feeder was developed (Figure 3). The forehearth exit plane temperature shown above was mapped to the feeder entrance. The glass flow at the feeder exit was integrated to define the gob temperature profile.

The effects of the reciprocating needles in the feeder were taken into account by programming in the needle CAM profile and utilizing dynamic remeshing techniques. This produced a gob temperature profile and size which was used in the forming models. Figure 4 shows what the temperature profile of the needles looks like based on the measured forehearth exit plane temperatures. The

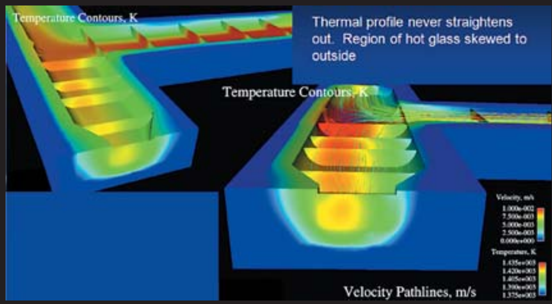


FIGURE 2
Cut planes through forehearth glass as it flows to the feeder

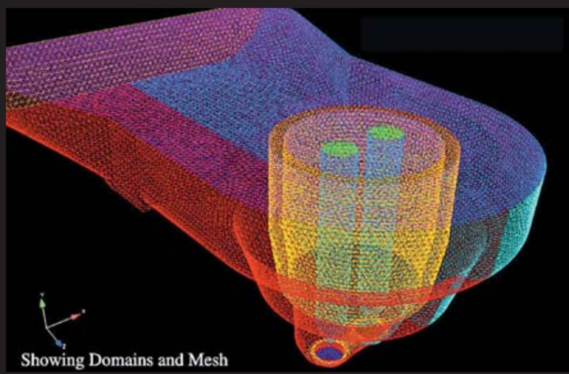


FIGURE 3
Feeder configuration and typical computational mesh

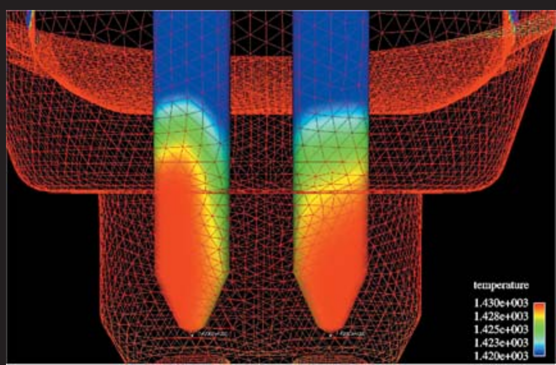


FIGURE 4
Temperature non-uniformities on feeder needles

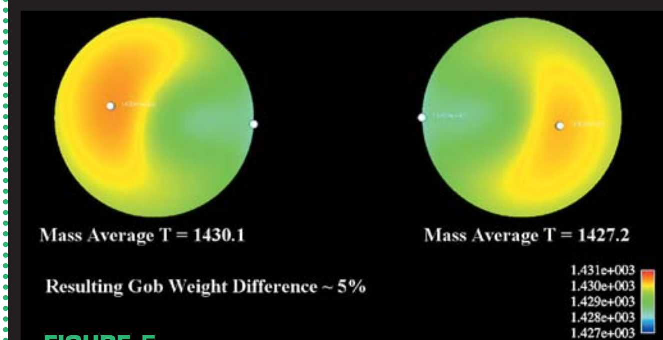


FIGURE 5
Temperature Contours on Orifice Exitis

FIGURE 6
Thermal forming times (all times in seconds)

Blank contact	0.99
Baffle contact	0.78
Blank side reheat	1.66
Reheat stretch	1.24
Mould contact	1.70
Hanging dead plate cooling	0.022
Hanging dead plate free cooling	1.53
Neckring contact	2.07
Parison invert recovery	0.046
Blow mould precooling	0.011
Vacuum blow lead	0.022
Total process	8.55

Plunger cooling	2.30
Final blow	1.34
Vacuum blow	1.67
Finish cooling	0.00
Blank cooling left	1.48
Neckring cooling left	0.76
Blow mould cooling	1.66
Pressing	0.71

asymmetry coming from the unequalized temperatures is apparent.

Figure 5 shows the temperatures at the exit of the feeder (leaving the orifices). Again, the skewed temperatures which originated at the forehearth exit plane are easily visible. Additionally, there is a 3°C temperature difference between the two orifices which leads to a five per cent difference in container weights. Already, the effects of the poor forehearth exit plane temperature profile are becoming noticeable.

Container forming – the IS machine

The container being formed as part of this study was a standard long neck beer bottle. The forming timings which are derived from the standard IS machine timings are shown in Figure 6. The thermally non-uniform gobs were used as inputs to a series of models which cover the container forming process – in this case narrow neck press and blow. The gob, which was slightly hotter, is also slightly larger because of the lower viscosity exiting the feeder. The details and validation of the forming models has been published previously in a series of papers and will not be covered in this article (see References).

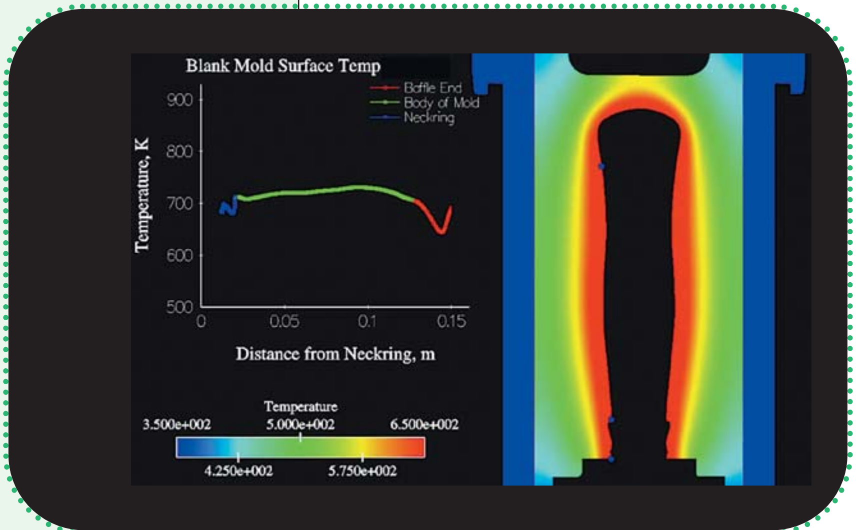
One of the issues that can cause problems during forming is the loading of consistently hotter gobs. This leads not only to larger gobs, but also raises the average surface temperature of the moulds creating variances in weight and final container thickness distribution. These effects were seen during the analysis of the moulds as they were cycled through their cooling timings. The mould temperature distributions were determined by continuously loading the gobs into a blank mould and using the machine timings to determine when the mould cooling was turned on and off. This gives a complete thermal history of the moulds. This type of analysis has previously been used for the optimization of mould cooling holes patterns and cooling strategies. Figure 7 shows a snapshot of the thermal profile inside the blank mould during the forming process. Similar models are made for the blow mould.

Figure 8 shows the geometry and temperature contours of the parisons after invert before the stretching and reheating process. The parison on the right was formed starting with the larger/hotter gob. The region of the parison which will eventually form the heel of the bottle is thicker than for the smaller/colder gob. This is due to the larger capacity factor of the hotter gob, and the overpressing of the smaller gob.

Figure 9 shows the geometry and temperature contours of the parisons after reheat and before the final blow. As one would expect, the larger/hotter parison has stretched farther than the smaller/colder parison. So, for the same machine timings on this IS section, the smaller gob final blow will be turned on too early. This usually results in thinner bottoms and thicker necks.

Finally, Figure 10 shows the thickness distribution of the containers formed by the thermally non-uniform gobs after final blow. The difference is significant. As expected, the smaller gob produced a

FIGURE7
Blank mould temperature contours at blank mould open



much thinner region at the heel and base of the container. The thickness variations are quite large. This is primarily due to the overpressed parison and premature initiation of final blow. The larger gob thickness distribution changes are much less dramatic and result in a container with much higher burst pressure strengths.

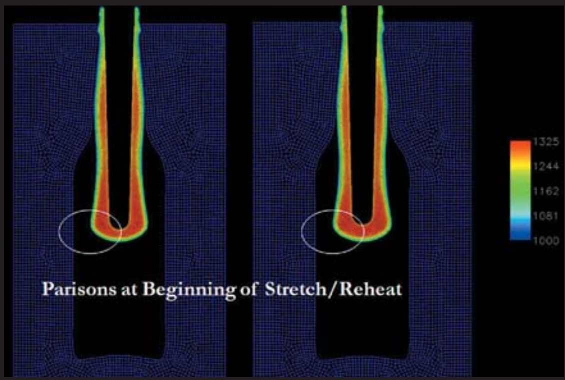


FIGURE 8
Parison geometries and temperature contours before stretch

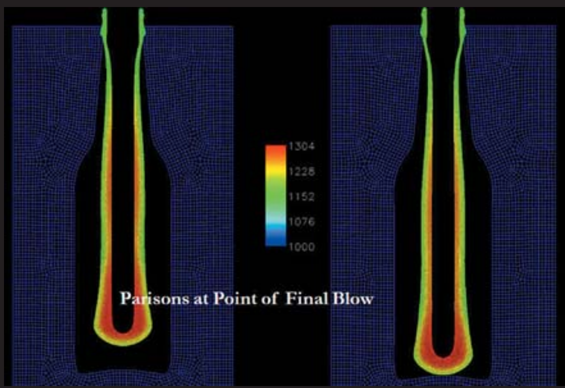


FIGURE 9
Parison geometries and temperature contours after stretch

Conclusions

There has been some controversy among forehearth and container manufacturers concerning the importance of forehearth exit plane temperature and its impact on the final container properties. This issue has been difficult to resolve because it is nearly impossible to experimentally track forehearth exit plane variances to final container variances. Recent advances in computational capabilities are starting to shed light on how problems that show up early in the forming process impact the final container quality and strength. Preliminary indications are that large variations in forehearth exit plane temperatures can dramatically affect the thickness distribution of the final container. These types of models are now being incorporated into control algorithms for better control of both forehearths and feeders.

References

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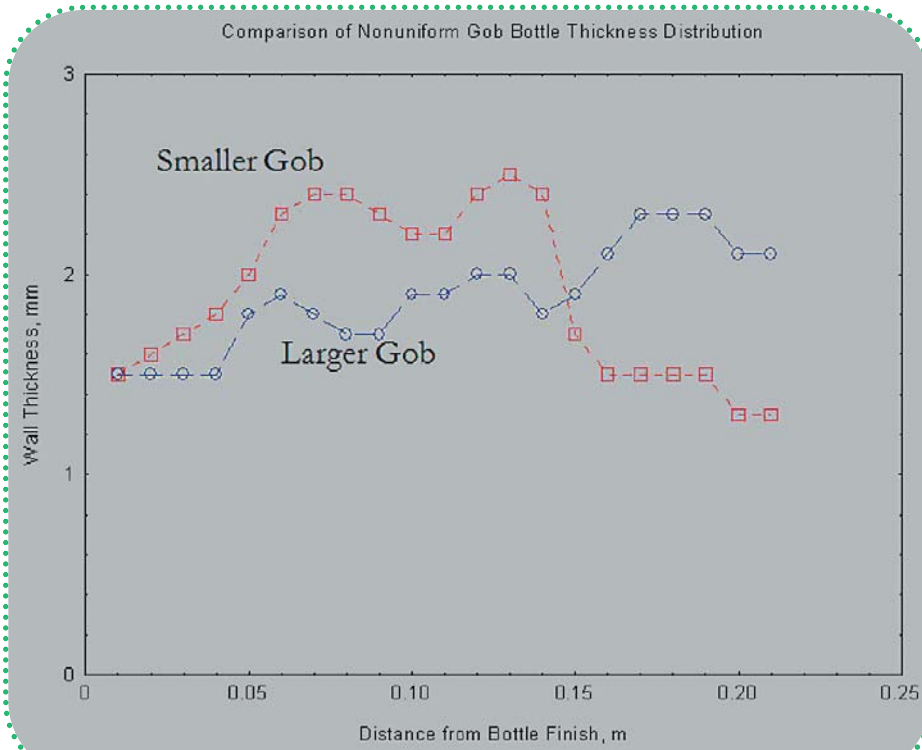

FIGURE 10
Container thickness distribution from finish to heel