Using NNPB forming technology for refillable beer bottles

Dr Wenke Hu, William Slusser, Peter de Haan and Gary Smay consider the internal pressure and vertical load implications of using NNPB forming technology for refillable beer bottles.

Prior to 1970, most glass beverage containers were manufactured by the blow and blow (BB) process. However, it became apparent that to achieve the goal of reduced glass weight, innovations in the forming process were needed for greater control of glass distribution. This led to the innovation of the narrow neck press and blow (NNPB) process[1, 2, 3, 4]. Initially this technology was used to manufacture non-refillable bottles at reduced glass weights, while continuing to meet conventional minimum thickness requirements. This was achieved through the ability of the plunger to actively position glass, creating more uniform thickness distributions for a given glass weight. Today, NNPB technology is widely used in the production of non-refillable beverage bottles throughout the worldwide glass container industry.

In recent years, the industry has begun to consider the potential use of NNPB technology for refillable beverage containers, which had been historically formed using the BB process. The interest in the NNPB process is the same as the established use for non-refillable bottles – to reduce weight by taking advantage of improved glass thickness distributions inherent in the NNPB process. However, refillable bottles present distinct challenges due to reduced glass surface strengths that are associated with repeated use. Therefore, the current study was undertaken to evaluate the viability of using bottles that have been manufactured by the NNPB process in the refillable marketplace.

This study utilised computer stress analyses to evaluate refillable bottles made by the NNPB process compared to the same bottles made using BB technology. In this initial study, internal pressure and vertical load results will be discussed. Impact considerations will be reported in a subsequent presentation.

Four different beer bottle sizes and designs (330ml, 500ml, 650ml and 750ml) were evaluated, as shown in figure 1. The internal pressure and vertical load stress indices of each design were obtained through finite element analysis (FEA), utilising an Autodesk mechanical simulation programme[5, 6]. Two different approaches were evaluated:

- Approach No 1: Minimum glass thicknesses were held constant while the maximum and average thicknesses were allowed to fluctuate based on typical maximum to minimum (max to min) thickness ratios for the NNPB and the BB processes.
- Approach No 2: Average glass thicknesses were held constant while the minimum and maximum thicknesses were allowed to fluctuate based on typical max to min thickness ratios for the NNPB and the BB processes.

The physical dimensions of the bottles were maintained constant throughout the analyses. This was done to avoid dimensional changes that would add complexity to the stress analysis. It is understood that keeping the dimensions constant will affect the overflow capacities. For the current bottle designs, these were found to vary by about 3%. While this variation would have to be accounted for prior to the commercial release of the package, it did not significantly alter the results of the stress analyses.

CONTAINER FINITE ELEMENT ANALYSIS

Thickness distributions and computer modeling: The max to min thickness ratios that were used in this study for the NNPB and BB processes are shown in table 1. These values are based on numerous measurements of bottles made by the BB and NNPB processes in unrelated studies. The minimum thickness values for refillable beer bottles were chosen based on the body diameter of the container and the carbonation level of typical beers, as established by worldwide specifications.

A 3D symmetrical model was created using Solidworks for each of the four glass container designs. The outer surface profile was created from information that was provided on technical drawings of these four specific bottles. The glass weights shown in table 2 were calculated on a theoretical basis, starting from the minimum thicknesses, while simultaneously considering the max to min thickness ratios for each of the two forming processes, along with the two approaches being evaluated in this study.

Finite element analysis: The Solidworks file for each model was imported into Autodesk simulation for the purposes of finite element analyses. For the internal pressure analyses, a unit pressure load was applied to the entire inside surface profile of the bottle. For the vertical load analyses, the load was applied vertically upward along the entire circumference of the bearing surface, with the top of the finish being fixed. This loading configuration was used to simplify the computing process; the results would be the same if the load were applied downward to the top of the finish, with the bearing surface being fixed.

Figure 1: 3D Solidworks model for four different bottle sizes. The green coloured region represents the thickness distribution.

	Sidewall region	**Bottom region**
NNPB	1.50-to-1	1.25-to-1
Blow and Blow	2.00-to-1	1.50-to-1

Table 1: Typical max to min thickness ratios for the NNPB and the BB processes.

Stress indices were obtained from the finite element analysis for key regions along the entire inside and outside surfaces of the containers. The stress index represents the amount of principal stress generated by a unit load of either internal pressure or a unit load of vertical force. These values represent the tensile stress distributions in each of the four designs and for each of the two manufacturing processes.

RESULTS AND DISCUSSION

The results from the evaluations of the four different bottles produced the same general trends. Consequently, for simplicity of the discussion, only the results from the analyses of the 330ml capacity bottle will be presented in this section.

Approach No 1: Identical minimum thicknesses - With identical minimum thicknesses, the resulting glass weights were approximately 14% lighter for the bottles made

by the NNPB process than for bottles made by the BB process, as shown in table 2. This weight reduction was expected since the typical max to min thickness ratios were less for the NNPB process compared to the BB process.

As shown in table 3, both internal pressure and vertical load stress indices were approximately 1% to 9% higher for bottles made by the NNPB process compared to the BB process, due to the overall higher glass weights that were associated with the BB process. The maximum difference was observed for the bearing surface region (9.2%), while the minimum difference was observed for the heel contact region (1.0%). The stress index differences for vertical load were approximately 4% to 7% higher for the NNPB ware. The largest difference was observed for the maximum stress at the heel region (6.6%), while the smallest difference was observed for the shoulder contact region (3.8%). Thus, bottles that were manufactured by the BB process, using this theoretical approach, would exhibit less stress. However, this improvement would be at the expense of an increase in glass weight.

Approach No 2: Identical average thickness - When the average glass thickness was maintained constant, the calculated bottle weight resulting from the use of the NNPB process and the BB process were nearly identical, as shown in table 2. However, as shown in table 4, the internal pressure stress indices for the NNPB bottles were 2% to 21% lower as compared to the bottles made by the BB process. The maximum difference was observed for the heel contact region (21.0%), while the minimum difference was observed for the inside knuckle region (1.8%). The stress index differences for vertical load were approximately 14%

Bottle Size	Identical Minimum Thickness		Identical Average Thickness	
	NNPB	**Blow and Blow**	**NNPB**	**Blow and Blow**
330 ml	153	177	177	177
500 ml	231	266	266	266
650 ml	261	302	302	302
750 ml	315	366	366	366

Table 2: Calculated glass weights (g).

Internal Pressure	Stress Indices (MPa/Bar)	
Key Bottle Regions	NNPB	Blow and Blow
Maximum Shoulder	2.25	2.16
Shoulder Contact	0.95	0.94
Maximum Sidewall	2.62	2.56
Heel Contact	1.06	1.05
Inside Knuckle	4.58	4.32
Bearing Surface	3.21	2.94
Maximum Bottom	3.15	2.98

Vertical Load	Stress Indices (KPa/Kg$_f$)	
Key Bottle Regions	NNPB	Blow and Blow
Maximum Shoulder	65.4	62.3
Shoulder Contact	41.0	39.5
Heel Contact	35.0	33.4
Maximum Heel	48.6	45.6

Table 3: Internal pressure and vertical load stress indices for 330ml bottle with identical minimum thickness.

to 17% lower for the NNPB ware. The largest difference was observed for the maximum stress throughout the heel region (16.7%), while the smallest difference was observed specifically for the heel contact region (13.5%).

Thus, bottles made by the NNPB process in these considerations of nearly equal bottle weight would exhibit significantly lower stresses compared to bottles made by the BB process. These stress index reductions were due to the higher minimum thickness achieved with the NNPB process, which is the result of less thickness variation and improved glass distribution. It should also be noted that there are certain practical limitations associated with the NNPB process, as discussed in the next section.

MANUFACTURING CONSIDERATIONS

From the time of its inception to the present day, many of the technical barriers associated with NNPB technology have been overcome[7]. This has allowed a substantially wider range of glass containers to be manufactured using this technology. However, one barrier that remains is the inability to manufacture large capacity bottles that require higher glass weights. The most important limiting factor impeding the production of higher weight containers is the inability to adequately control the temperature of the plunger. In the glass industry, it is generally acknowledged that the plunger temperature is critical in the

forming process. Higher temperatures in combination with the mechanical stresses imposed on the plunger during sliding contact with the semi-molten glass causes plunger wear that typically leads to premature plunger failure due to material loss[8].

There is a practical rate at which the plunger can be cooled effectively and there is a corresponding glass weight maximum, beyond which that practical cooling rate is exceeded. The result is the heat transfer rate will be insufficient to properly form the parison at higher glass weights. While it is anticipated that this barrier will either be mitigated to some extent or eliminated altogether through innovation in material composition and forming technology, it should be recognised that the results presented here were based on idealised theoretical calculations and therefore, did not account for the practical limits associated with the NNPB forming process discussed in this section.

CONCLUSION

In this study, both identical minimum thicknesses and identical average thicknesses for NNPB and BB processes were analysed for internal pressure and vertical load stresses through finite element analysis. It was concluded that:
- When minimum thicknesses were maintained at the same value, bottle weight could be reduced approximately 14% through the use of the NNPB process. This weight reduction can be achieved with manageable increases in the stress index.
- When the average thicknesses are held at the same value, both the internal pressure and the vertical load performance can be significantly improved through the use of the NNPB process, while the bottle weight remains unchanged.

Based on these results, NNPB would appear to be a viable candidate for refillable bottle production. However, additional work to include the effects of NNPB production on impact resistance is planned using the same approaches that were utilised in this study. These results will be reported in a future presentation. ■

Internal Pressure	Stress Indices (MPa/Bar)	
Key Bottle Regions	NNPB	Blow and Blow
Maximum Shoulder	1.81	2.16
Shoulder Contact	0.81	0.94
Maximum Sidewall	2.08	2.56
Heel Contact	0.83	1.05
Inside Knuckle	4.24	4.32
Bearing Surface	2.69	2.94
Maximum Bottom	2.69	2.98

Vertical Load	Stress Indices (KPa/Kg$_f$)	
Key Bottle Regions	NNPB	Blow and Blow
Maximum Shoulder	51.7	62.3
Shoulder Contact	33.4	39.5
Heel Contact	28.9	33.4
Maximum Heel	38.0	45.6

Table 4: Internal pressure and vertical load stress indices for 330ml bottle with identical average thickness.

REFERENCES
1. H J Moder, Lightweight Glass Technology for Aseptic Filling, Verpackungs, 30 (11), 72-76, 1987.
2. H Griffel, Lightweighting in the Glass Container Industry, Ceram Eng Sci Proc, 8 (3,4) 156-170, 1987.
3. R Chinella, Lightweighting of Glass Containers, Ceram Eng Sci Proc, 10 (3,4) 173-181, 1989.
4. P Silvester, NNPB Breaks New Ground, Package Today, 17 (6), 23-24, 1995.
5. M W Davis, Effect of Lighweighting on the Impact Performance of Glass Containers: Further Discussions, Glass Technology, 34(4), 163-165, 1993.
6. M W Davis and A R Shott, Optimum Thickness Distribution for Lightweight Glass Containers, Glass, June 221-222, 1995.
7. R Penlington, Advancing NNPB Plunger Technology, Glass, 74 (9), 337, 339, 1997.
8. M Sarwar and A W Armitage, Tooling requirements for glass container production for the narrow neck press and blow process, Journal of Materials Processing Technology 139 (2003) 160-163.

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