glass WORLDWIDE

Effects of distinctive recessed label panels

William G Slusser, Brad J Salitrik and Wenke Hu discuss how aggressive design alterations to recessed label panels can affect glass bottle performance and potentially change glass weight requirements.

The original purpose for employing recessed label panels was to provide protection to applied paper labels from becoming torn due to handling on filling lines. An additional benefit of this practice was to shield the glass surface in the recessed sidewall regions during normal bottle handling, thereby eliminating damage from occurring in this area. Since the barrel section of the container encompasses significant surface area, it was possible to remove a sizeable amount of glass from this region (in a lightweighting campaign), without large changes in glass thickness; and since this region was protected, the overall performance of the container would not be sacrificed.

In recent years, brand owners have introduced bottle designs that can be described as 'bold' or 'aggressive' in an effort to showcase their package through both visual shelf appeal and tactile feel within the hands of consumers. In order to differentiate their bottle design, deviations from standard bottle shapes were launched. Changes to the shoulder construction, heel heights, embossed or debossed decorations and label panel shapes with increased depths were introduced. Traditionally, recessed label panels were uniformly constructed around the entire circumference of the container. This entailed joining the recessed region to the larger diameter shoulder and heel regions via small radial contours creating 'dislocations' at either end of the label panel. These dislocations produced mismatches in both the circumferential and axial strains, which resulted in a concentration of stress at these locations, for example, when under an internal pressure load. Davis and Shott[1] acknowledged these stress increases but indicated that these isolated regions would not affect the overall performance of the container when noting that stresses in other outside surface regions of the container are typically higher than those associated with stresses from these 'dislocations'. They also noted the glass strength of these regions is additionally preserved by surface protective coatings.

The conclusions drawn from this earlier paper may not be applicable for some contemporary designs that employ constructions that require more than small radial contours and exhibit recessed depths far beyond what is required to simply offer label protection and involve only a portion of the bottle. In the present work, a series of experiments, involving 64 variants, were undertaken to examine the effects of varying label panel depth, sharpness of the transition radius and glass thickness in order to evaluate the effects on the stresses generated. The paper will also provide general guidance to designers regarding the compromises required to achieve a design with both visual appeal and acceptable performance, specifically for internal pressure loading.

Figure 1 shows two variants of the bottle design utilised in this study. The model on the left does not have a recessed label panel, while the model on the right has an isolated label panel recess of 2.0mm with a transition radius of 0.5mm. Both of the models have the same glass thickness in the label panel of 2.2mm.

Table 1 provides the stress indices for the key outside surface bottle locations for these two models. The highest stress on the outside surface for the model without a recessed label panel is located in the centre bottom and equals 2.3 Mpa/Bar. The maximum stress in the label panel section is comparably low at just 1.28 Mpa/Bar. However, for the model with an isolated 2.0mm recessed label panel, the highest stress on the outside surface is found within the label panel and equals 4.82 Mpa/Bar, which is more than double the value observed for the maximum bottom. Thus, the effect of adding the isolated recess label panel is likely to become the limiting factor for the performance of this bottle when placed under an internal pressure load.

Experimental set-up

A 355ml non-returnable beer bottle at a glass weight of 208g, a sidewall thickness of 2.2mm and a recessed panel depth of 2mm was selected as the reference design for this study, as shown in figure 1. While the overall shape and contour of the 355ml bottle was largely constant, the label panel design in the sidewall was varied, depending on the parameters chosen. ▸

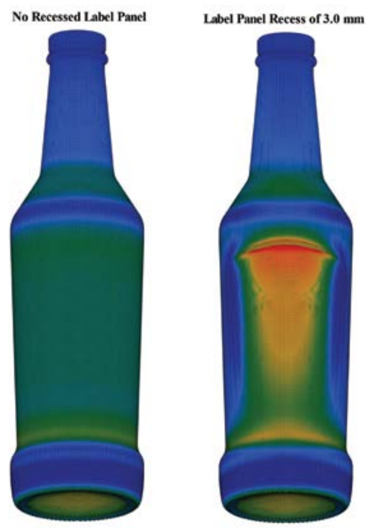

Figure 1: 355ml non-returnable beer bottle.

Figure 2: Cross-section of label panel recess variations.

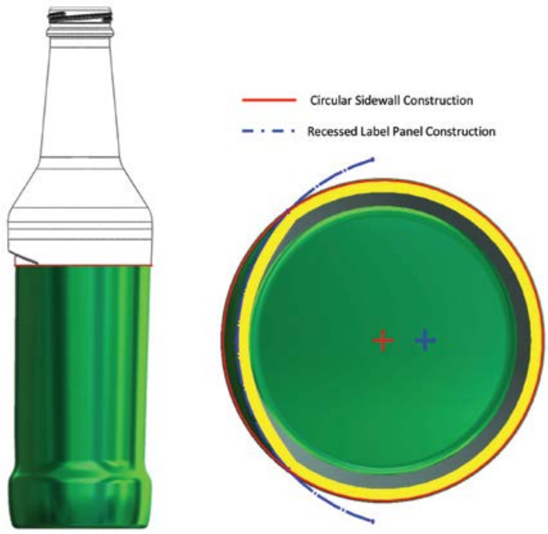

Figure 3: Construction of a recessed label panel.

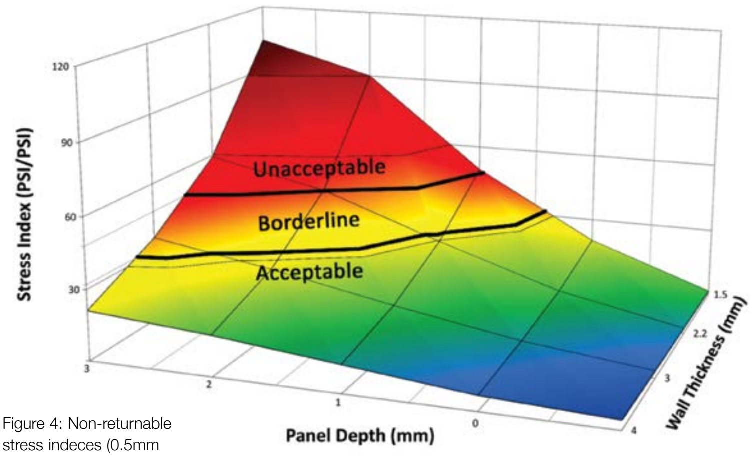

Figure 4: Non-returnable stress indeces (0.5mm transition radius).

Outside Surface Location	No Recessed Label Panel (Mpa/Bar)	Recessed Label Panel-2.0 mm (Mpa/Bar)
Heel Contact	0.43	053
Shoulder Contact	0.74	0.86
Maximum in the Shoulder	1.15	1.34
Bearing Surface	1.65	1.80
Maximum Label Panel	1.28	4.82
Maximum Bottom	2.32	2.35

Table 1: Stress indices for outside surface locations.

Panel Depth (mm)	Transition Radius (mm)	Wall Thickness (mm)
0 (no recess)	0.5	1.5
1.0	1.0	2.2
2.0	2.0	3.0
3.0	3.0	4.0

Table 2: Variables for each of the three parameters.

	Label Panel Depth, mm			
Glass Thickness, mm	0.0	1.0	2.0	3.0
1.5	2.01	4.92	9.00	10.41
2.2	1.28	2.97	4.82	5.92
3.0	8.9	1.78	2.77	3.62
4.0	6.4	1.18	1.72	2.12

Table 3: Transition radius = 0.5mm, maximum stress in label panel (MPa/Bar).

	Label Panel Depth, mm			
Glass Thickness, mm	0.0	1.0	2.0	3.0
1.5	2.01	5.52	8.32	10.07
2.2	1.28	2.66	4.16	5.20
3.0	0.89	1.68	2.49	3.01
4.0	0.64	1.09	1.51	1.85

Table 4: Transition radius = 1.0mm, maximum stress in label panel (MPa/Bar).

	Label Panel Depth, mm			
Glass Thickness, mm	0.0	1.0	2.0	3.0
1.5	2.01	4.2	7.66	9.51
2.2	1.28	2.48	3.89	4.92
3.0	0.89	1.56	2.33	2.94
4.0	0.64	1.01	1.42	1.78

Table 5: Transition radius = 2.0mm, maximum stress in label panel (MPa/Bar).

	Label Panel Depth, mm			
Glass Thickness, mm	0.0	1.0	2.0	3.0
1.5	2.01	4.07	7.51	9.28
2.2	1.28	2.39	3.91	4.74
3.0	0.89	1.51	2.27	2.79
4.0	0.64	0.98	1.36	1.71

Table 6: Transition radius = 3.0mm, maximum stress in label panel (MPa/Bar).

Three parameters were selected for this study: Recessed panel depth, which is defined as the horizontal distance inward from the maximum sidewall diameter located at the shoulder contact; the transition radius, which is defined as the radius used to join the maximum sidewall diameter to the base of the recessed label panel; and glass thickness. Each parameter was evaluated at four discrete levels, as shown in table 2. For each recessed panel depth, four different transition radii and four different glass thicknesses were evaluated. This practice was repeated for each of the four recessed label panel depths, resulting in the analysis of 64 label panel designs. A 3D symmetrical model was created using Solidworks for each set of variables. The model was then imported into Autodesk Simulation for the purpose of performing finite element analysis (FEA). For these analyses, it was assumed that the glass was uniformly distributed in the circumferential direction.

The effect of the various recessed label panel configurations was investigated for the 355ml bottle when subjected to internal pressure loading. For the internal pressure analysis, a unit pressure load was applied to the entire inside surface profile of the bottle. Stress indices were then obtained from the finite element analysis, with emphasis placed specifically on the outside surface of the label panel region. The stress index represents the amount of principal stress generated by a unit load of internal pressure.

In these studies, the major dimensions of the bottles, such as bottle height and bottle diameter, 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 major dimensions constant while changing recessed panel dimensions may affect the overflow capacities. However, the changes in the recessed label panel had very limited influence on the overflow capacity, which was found to vary by no more than 1% through the entire assortment of models evaluated.

Results

Figure 2 provides a cross-sectional view for each of the glass thickness variations shown in a side-by-side manner. Tables 3, 4, 5 and 6 provide the maximum stress indices in the label panel region for each of the variants evaluated in this study. A discussion of the effects on pressure stresses for changes to each of the variables follows.

* *Effect of label panel depth* - Four label panel depths were evaluated: 0mm (no recess), 1mm (which is a comparable depth to historical recessed label panels), 2mm and 3mm (which are more aggressive panel depths).

As shown by the data in tables 3-6, the maximum stress indices increased as the label panel depths increased. For example, assuming a consistent transition radius of 0.5mm (table 3) and a consistent glass thickness of 2.2mm (the row highlighted in yellow), the stress index increased from 1.28 Mpa/Bar (at 0mm) to 5.92 Mpa/Bar (at 3mm). The effect is even more pronounced for a sidewall thickness of 1.5mm (the row highlighted in blue). In that series, the baseline stress index of 2.01 Mpa/Bar for a non-recessed label panel increases to 10.41 Mpa/Bar for the maximum recess of 3mm.

The reason for the dramatic increase in stress with increasing label panel recess depth is the cross-sectional divergence from a circle that is created by the recess, as shown in figure 3. As the divergence increases, the construction of the panel tends more towards a straight chord, slicing across the circle. Thus, the stress developed in the panel changes from a purely uniform tension stress to a form of bending stress, which is known to dramatically increase the total tensile stress levels[2, 3].

* *Effect of transition radius* - Four transition radii were evaluated: 0.5mm, 1mm, 2mm and 3mm. As shown in tables 3-6, the maximum stress indices generally decrease as the transition radius increases or becomes less sharp. For example, assuming a label panel depth of 2.0mm and a glass thickness of 2.2mm (highlighted with red numerals in each table), the maximum stress index decreases from 4.82 Mpa/Bar (at 0.5mm) to 4.16 Mpa/Bar (1mm), and then to 3.89 Mpa/Bar (2mm) and finally plateauing at 3.91 Mpa/Bar (3mm), indicating minimal change in stress when varying from a 2mm to 3mm transition radius.

The reason for the stress decrease with increasing transition radius is related to a physical dislocation at the edges of the label panel. The dislocation causes a mismatch in both the circumferential and axial strains, which ▸

glass WORLDWIDE

in turn produces a concentration of stress at the transition radius. When the transition radius is larger, the amount of dislocation is lessened and consequently, the concentration of stress at this location is lowered. A similar effect was noted previously by Davis and Shott[1].

* *Effect of glass thickness* - Four glass thicknesses were evaluated: 1.5mm, 2.2mm, 3mm and 4mm. As shown in table 4, the maximum stress indices significantly decrease as the glass thickness increases. For example, assuming a consistent label panel depth of 2.0mm and a transition radius of 1.0mm (the column highlighted in orange), the maximum stress index decreases from 8.32 Mpa/Bar (at 1.5mm) to 1.51 Mpa/Bar (at 4mm).

The reason the stress decreases with increasing glass thickness is directly related to stress creation. Stress is simply force per unit area. With increasing thickness, the unit area over which the same amount of force is distributed is physically greater, resulting in lower levels of stress.

Predicting container performance

* *Concept of stress and strength index* - In previous papers[1,2], the principle of stress index was discussed. This index relates the magnitude of the stress that is developed in glass surfaces as a function of the load that is applied to the container and has the following form:

$$SI = \frac{\sigma}{L} \qquad (1)$$

where SI is the stress index, σ is the stress and L is the load. In a similar manner, a concept termed the strength index was introduced in a previous paper[3] and can be formulated as follows:

$$\sigma_c = \frac{\sigma_s}{P} \qquad (2)$$

where σ_c is the strength index, σ_s is the surface strength (from table 7) and *P* is the expected maximum load magnitude. Strength values are selected on the basis of the manufacturing process, container usage conditions and load duration (to account for static fatigue), as determined by the nature of the product. The expected load magnitudes, such as internal pressure in the current case, can be determined from knowledge of the nature of the filled product, the conditions of the filling process and the time/temperature history concerning the storage of filled ware.

By comparing the stress index to the expected strength index, bottle performance can be predicted as it relates specifically to the stresses in the recessed label panel region. If the stress indices from the FEA calculation in the recessed label panel are less than the corresponding strength indices, the bottle should perform adequately for internal pressure. However, if any of the stress indices exceed the corresponding strength indices, it is expected that the bottle would experience performance problems. The solution to such an occurrence would require design changes and/or weight adjustments to the bottle, in order to reduce the specific stress index value. In the discussion that follows, it is assumed that the strength index has been optimised through proper manufacturing practices, the bottle has been well coated and subsequently handled properly through the filling line and by the consumer.

Predicting performance

In the current analysis and consistent with proper engineering considerations, a factor of safety has been employed to account for variations in bottle manufacture, glass thickness variations and deviations in the expected load levels. For an internal pressure load that creates a fairly uniform and global tension stress across the majority of the outside surface of the bottle, a safety factor of 50% was added to the maximum expected load level in these analyses.

In the current example, a pressure load of 7.5 Bars (107 psi) was considered based on a 3.0 volume carbonated beverage, pasteurised at a temperature of 63°C (145°F) for a period of 20 minutes. The assumed surface strength of the region takes into consideration that the recessed label panel is not a natural contact location between bottles and therefore is not damaged to the same severity as the contact points on the container. Figure 4 provides a 3D projection of the maximum stress levels in the recessed label panel as a function of both label panel depth and wall thickness. In this example, the transition radius was held constant at 0.5mm. Stress indices were colour-coded with blues and greens, indicating relatively low levels, yellows and oranges indicating moderate levels and reds indicating high levels.

For stress indices that are lower than the strength index, even in the absence of a factor of safety, the stress index is considered ‘acceptable’ and the bottle would be expected to perform well. For stress indices that exhaust a portion of the 50% factor of safety, the stress index is considered ‘borderline’. Finally, for stress indices that exceed the strength index along with the full factor of safety, the stress index is considered ‘unacceptable’. Each of these boundaries is labelled as an overlay on the 3D projection of figure 4.

It is noteworthy that at a glass thickness of 4mm, all of the stress indices in the recessed label panels remain within the acceptable region (it is understood that this glass thickness exceeds common commercial standards for non-refillable bottles of this capacity but was included in this study for comparative purposes). At a more typical sidewall thickness of 2.2mm, the stress indices move into the ‘borderline’ region at recesses of just slightly more than 1mm. The stress indices quickly escalate into the ‘unacceptable’ region at a recess of 2mm, clearly indicating that designs with aggressive label panel recesses cannot be introduced at typically conventional glass weights. The inverse of this conclusion is that designs with significant label panel recesses (greater than 1mm) are not candidates for routine lightweighting.

Conclusions

Distinctive label panels offer visual appeal and potential consumer recognition but may require significantly more glass weight for the container than would be needed in the absence of the label panel feature. In addition, the most sensitive variable is label panel depth (depths of greater than 1mm need to be avoided, unless significantly higher glass weights can be accepted). ●

Surface Condition	Impact < 1ms	3-seconds	ASTM 1-minute	20-minutes	Long Term Load
Pristine Inside	689.5	424.0	344.7	274.1	187.7
Pristine Molded	275.8	169.6	137.9	117.2	82.7
Mild/Moderate Abrasions	68.9	42.4	34.5	29.3	20.7
Moderately Severe Abrasions	46.2	28.4	23.1	19.7	15.5

Table 7: Typical surface strengths of soda-lime glass (Mpa).

References:
1. Michael W Davis and A Robert Shott, ‘Recessed Label Panels – Another View’, Glastech Ber 66 (1993), No 9, pp 221.
2. Leonard G. Ghering, ‘Improving the Strength of Glass Containers through Design’, The Glass Industry, December 1939.
3. Frank W Preston, ‘Bottles for Internal Pressure’, The Glass Industry, Vol 21, 1940, pp 272.

About the authors:
William G Slusser is Director of Research, Brad J Salitrik is Research Engineer and Dr Wenke Hu is Senior Scientist at American Glass Research

Further information:
American Glass Research, Butler, PA, USA
tel: +1 724 482 2163
email: agresearch@agrintl.com
web: www.americanglassresearch.com