Glass container knurling study – part 2

Using FEA computer models, Dr. Wenke Hu, PhD from American Glass Research evaluates the effect of knurl height and knurl spacing on the magnitude of stress when a glass bottle is subjected to either internal pressure or a heel impact.

In part one of this study in the July/August issue of *Glass Worldwide,* stress magnitudes generated in the bearing surface region of a bottle with different knurl types (bar, crescent, dot, and chain) – when subjected to internal pressure and heel impact – were evaluated by finite element analysis (FEA). The current study expanded on the previous work to evaluate the effect of knurl height and knurl spacing on the magnitude of stress. Chain and slanted bar knurls were excluded in the current study due to their infrequent use.

Experimental procedure

The same modelling and FEA procedure that was used in the previous study was repeated in this investigation. Design sensitivities were conducted using the parameters listed in Table I (additional data for 6 and 26 knurls were included as appropriate to more fully assess the trends in the data plots even though such knurl numbers are commercially impractical). For comparative purposes, an FEA model with no knurls was included.

Figure 1 shows the cross section of various knurl heights. In all cases, the length and width of each individual knurl was maintained constant as the knurl height was varied (thus, the radius at the knurl tip decreased slightly as the knurl height increased). Figure 2 shows the effect on knurl spacing as the number of knurls was varied.

Stress indices between the knurls (also referred to as 'valley' for conciseness in the figures) and at the tip of the knurls were obtained from the FEA models. The calculated stress index ▸

Parameters	Baseline Value	Sensitivity Analysis
Number of Knurls	66	46, 56, 66, 76
Knurl Height (mm)	0.43	0.25, 0.43, 0.61

Table I: Summary Summary of baseline value and sensitivity analysis.

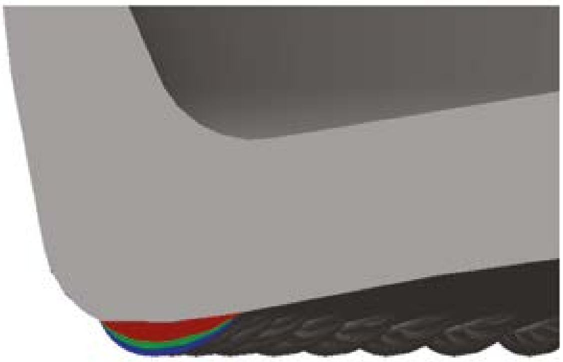
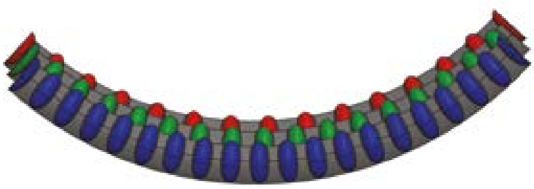


Figure 1: Cross-section of different knurl heights.



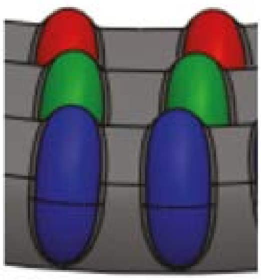


Figure 2: Model of knurl spacing resulting from different numbers of knurls.

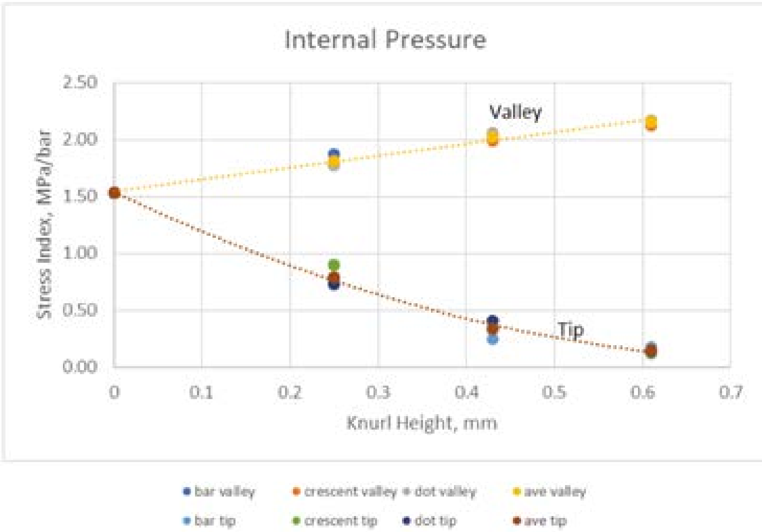


Figure 3: Stress index vs knurl height – internal pressure.

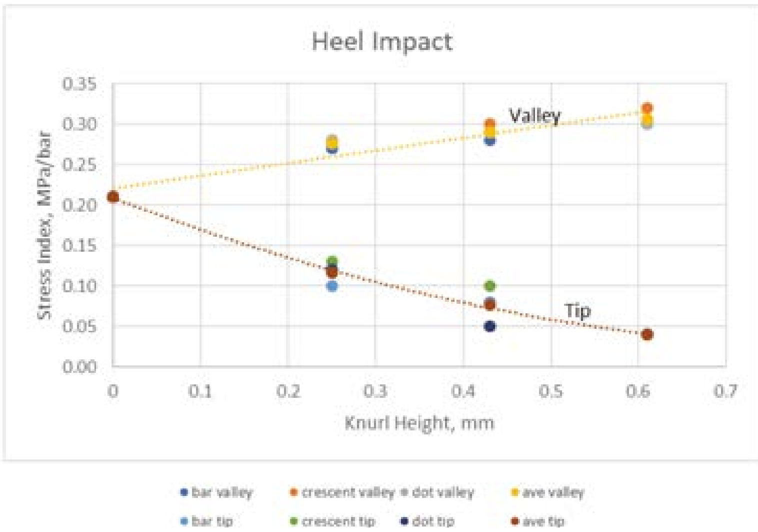


Figure 4: Stress index vs knurl height – heel impact.

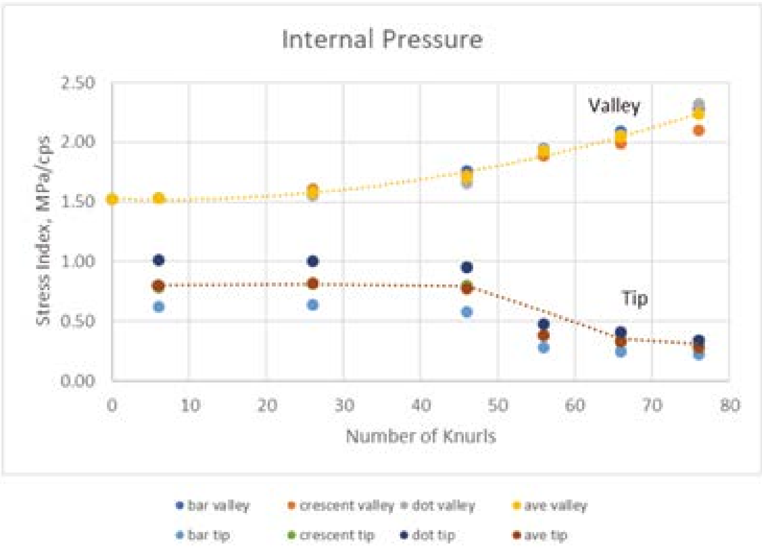


Figure 5: Stress index vs knurl number – internal pressure.

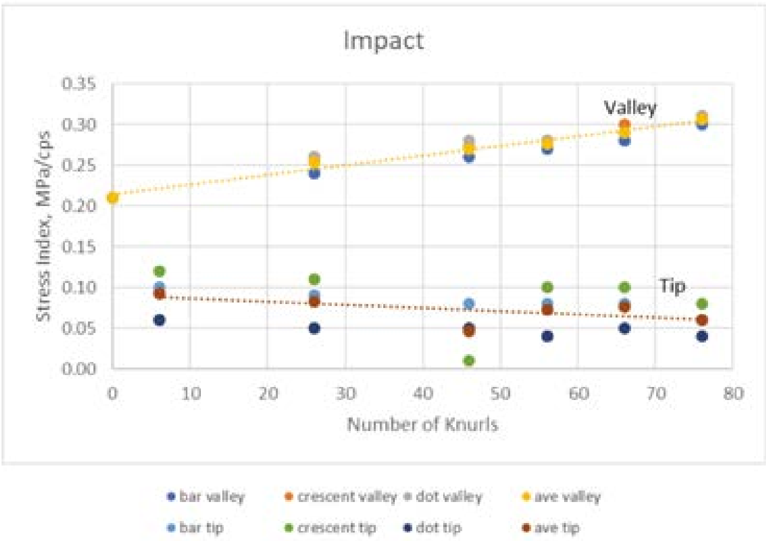


Figure 6: Stress index vs knurl number – impact.

represents the amount of principle stress generated by a unit of applied load. The stress levels from the current analyses are related to the specific bottle and knurl dimensions that were used in this study. It is anticipated that the trends in these analyses will be applicable to other container designs although the stress magnitudes may vary.

Results

Variation of Knurl Height: As shown in Figures 3 and 4, stress in the area between the knurls increased when the knurl height was increased. Conversely, stress at the tip of the knurls decreased when the knurl height was increased. For both internal pressure and heel impact, there was little variation between the three knurl types.

Variation in the number of knurls: As shown in Figures 5 and 6, stress in the area between the knurls increased as the number of knurls increased with little difference between the various knurl types. Stress at the tip of knurls decreased as the number of knurls increased for internal pressure while the stresses at the tip of the knurls was essentially constant for heel impact. Some differences were observed for the various types of knurls but the overall trends were consistent.

Discussion

Number of knurls: As shown by the data in this study, some differences were noted in the generation of stress as a function of the number of knurls. While it is interesting to consider these trends, the choice of the number of knurls is usually made at the time of bottle design and is based primarily on forming considerations.

Knurl height: Conversely, knurl height is a parameter that can change as a function of forming time. These changes are related to three possible causes - physical wear of the bottom plate due to friction between hot glass and the mould surface, build-up with mould dope from swabbing of the bottom plate and improper filling of the knurls because the glass is too cold. The first factor causes a permanent decrease in knurl height while the second two factors are temporary and will diminish once the problems have been resolved.

Since the decrease in knurl height can occur during normal operations, it is important to focus on how changes in knurl height can affect the magnitude of stress generated in the bearing surface region when bottles are subjected to internal pressure or heel impact.

As shown in Figures 3 and 4, stress between the knurls decreased for both internal pressure and heel impact as the knurl height decreased. This would initially lead to the conclusion that no important significance should be given to the loss of knurl height that may occur during normal operations. However, it is imperative to also consider that stress at the tips of knurls increased significantly as the knurl height decreased and reached a peak when the knurl had disappeared.

It is important to realise that the purpose of knurling is to separate damage created during normal handling of containers from the highly stressed region of the bearing surface. For normal knurl height, little if any damage will be produced in the valley between the knurls. However, as the knurl height diminishes, it is increasingly likely that damage could be created between the knurls during normal handling. This combination of relatively high stress and the presence of surface damage would invariably lead to performance problems if the knurl heights are left to diminish unchecked.

Conclusion

Based on the current example of a bottle being subjected to internal pressure or heel impact, an optimum knurl height ranged from 0.43mm to 0.61mm and knurl number ranged from 56 to 66. However, it should be noted that the optimum knurl height and knurl number could be different for other bottle designs and capacities. Therefore, detailed stress analysis should be performed on specific bottle designs in order to provide a guideline for a proper knurl height and number. In addition, the bottle forming process should be considered to avoid any potential manufacturing related issues related to the choice of knurl configuration. By combining both theoretical stress analysis and practical manufacturing concerns, the best possible knurl design with optimised knurl height and knurl number can be achieved. ●

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