Glass container knurling study

Dr. Wenke Hu, PhD from American Glass Research shares the results from a study on tensile stress generated for different ridges (knurls) on the base of a glass container.

Knurls, located on the bearing surface of glass containers, typically consist of four configurations: bar, crescent, dot or chain. Bar and crescent-shaped knurls are commonly used on beverage containers while bar, crescent and dot knurls are used on food jars. Chain knurls are sometimes found on liquor and still wine bottles but their use is limited because of the tendency to result in the creation of micro-cracks (checks) during the bottle-forming process.

Questions often arise concerning the stresses that are generated in the bearing surface of glass containers for various knurl configurations. In this study, finite element analysis models (FEA) were utilised to evaluate the distribution and magnitude of stress in the bearing surface for internal pressure and impact loads. An impact that is directed at the heel contact was included in this study because of the creation of tensile hinge stresses at the bearing surface.

Experimental procedure

A generic 330ml bottle (see Figure 1), was used in this study and 3D models for each knurl configuration were created using Solidworks (Figure 2). The Solidworks files were then imported into Autodesk Simulation. A quarter model with a mesh refinement technique at the knurl region was used in order to improve accuracy and efficiency. The knurls (66 total) were spaced uniformly around the circumference of the bearing surface with a knurl height of 0.43mm. Both the number of knurls and the knurl height are typical for most glass containers.

Figure 1: FEA model of a generic 330ml bottle.

All studies were undertaken with the same bottle profile in the bearing surface region and the same glass thickness, knurl height and number of knurls. Stress indices, which provide the amount of principle stress generated by a unit of applied load, were obtained from the FEA models for the area between the knurls and at the tip of the knurls.

Results from the current analyses are related to the specific bottle and knurl dimensions. However, it is anticipated that the trends in these analyses will be applicable to other container designs and glass thicknesses although the stress magnitudes may vary.

Summary of results

Stress magnitudes associated with the various knurl configurations are summarised in Tables I and II. The stress distribution patterns for the various knurl shapes are illustrated in Figures 3 through 6. For all knurl shapes, similar trends were observed – tensile stresses were reduced at the tip of a knurl and were elevated in the area between the knurls compared to the magnitude of stress in the absence of knurling.

Internal Pressure: Stress indices at the tip of bar, crescent and dot knurls ranged from 0.25 to 0.59 MPa/bar, values that were considerably less than the stress index in the absence of knurls (1.51 MPa/bar). Stress indices at the tip of the diamond and round chain knurls were considerably higher (1.04 and 1.39 MPa/bar) than the stress for the bar, crescent and dot knurls but still less than the stress index in the absence of knurls.

Stress generated in the area between the bar, crescent and dot knurls ranged from 1.96 to 2.15 MPa/bar. These values were greater than the stress index in the absence of knurls. Tensile stress in the corner of the chain knurls, both within the link and between the knurl link connections, was even higher (2.36 and 2.86 MPa/bar). As shown in Figure 4, the location of these elevated tensile stresses is very close to the tip of the knurl.

Heel Impact: For the bar, crescent and dot knurls, stress indices at the tip of the knurl ranged from 0.05 to 0.10 MPa/cps, considerably less than the stress indices in the absence of knurls (0.21 MPa/cps). Stress indices at the tip of diamond and round chain knurls (0.17 and 0.14 MPa/cps) were greater compared to the bar, crescent and ►

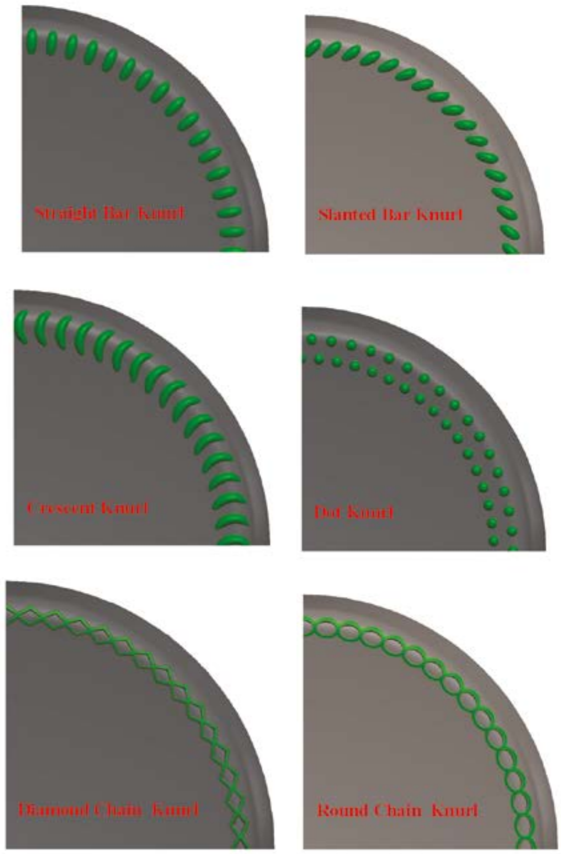

Figure 2: Bar, crescent, dot and chain knurls.

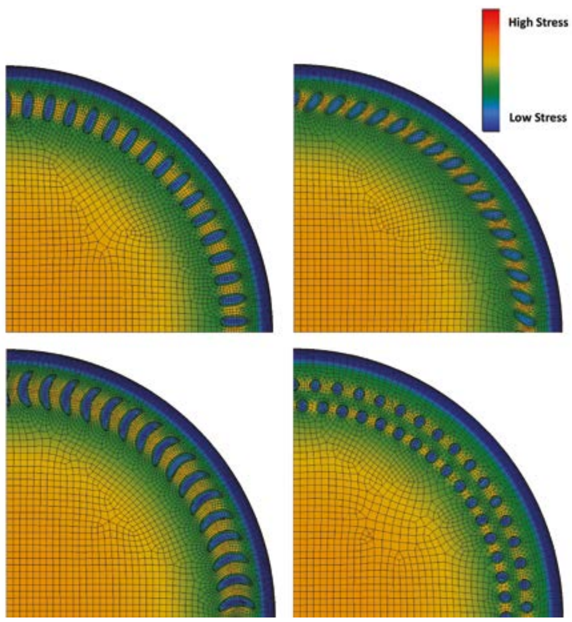

Figure 3: Internal pressure stress distribution bar, crescent and dot knurls.

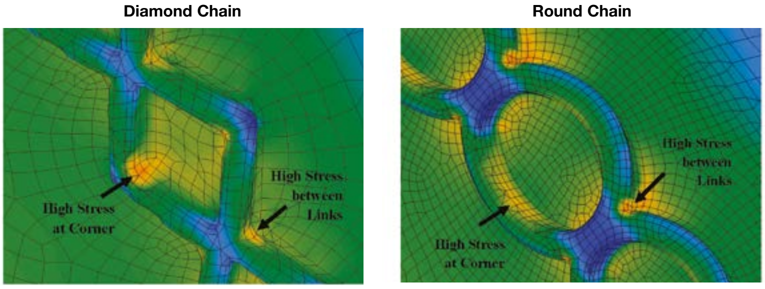

Figure 4: Internal pressure stress distribution diamond chain.

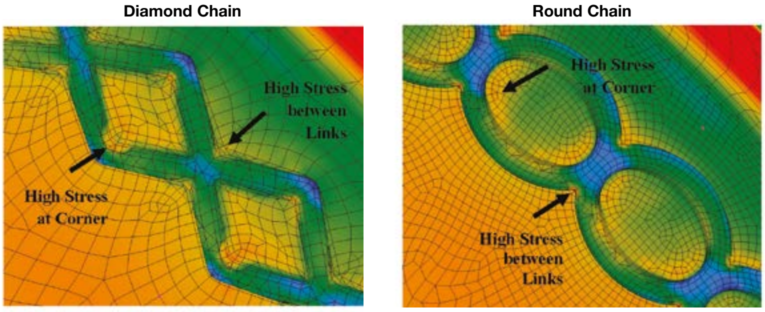

Figure 5: Heel impact stress distribution bar, crescent and dot knurls.

dot knurls but still less than the stress indices in the absence of knurls. Stress generated in the area between the bar, crescent and dot knurls ranged from 0.28 to 0.30 MPa/cps which was greater compared to the stress indices in the absence of knurls. Tensile stress in the corner of the chain knurls, both within the link and between the knurl link connections, was even higher (0.30 and 0.25 MPa/cps). As shown in Figure 6, the location of these elevated tensile stresses is very close to the tip of the knurl.

Discussion

As observed in this study, stress at the tip of a knurl is less than the stress magnitude in the absence of knurling. This is attributed to a reduction in strain that is related to the stiffness of the complex shape of a knurl. Conversely, the area between knurls acts as a stress concentrator, resulting in an increase in stress. All knurl types in the current study exhibited such phenomena under both internal pressure and heel impact.

It is noted that chain knurl type was less effective in reducing stress at the knurl tip compared to the bar, crescent and dot knurls. Each individual knurl independently deforms under load for bar, crescent and dot knurls while the chain knurls are connected to each other. Therefore, as one link of a chain knurl deforms, adjacent links will be induced to deform. Accordingly, stress for a single link will have two components: one from its own deformation and a second caused by the deformation of adjacent links. Stress concentration was also observed at the corner of the linkage between two chain knurls which is caused by the transition of the corner radius.

Knurl Shape	Stress between knurl	Stress at the tip	Other Locations
Bar Knurl (45 degree)	2.15	0.59	
Bar Knurl (straight)	2.06	0.25	
Crescent Knurl	1.96	0.34	
Dot Knurl	2.03	0.40	
Chain Knurl (Diamond)	1.51	1.04	2.86
Chain Knurl (Round)	1.60	1.39	2.36

- Bearing Surface without Knurl: 1.51 MPa/bar

Table I: Internal pressure stress indices – MPa/bar.

Knurl Shape	Stress between knurl	Stress at the tip	Other Locations
Bar Knurl (45 degree)	0.29	0.07	
Bar Knurl (straight)	0.28	0.08	
Crescent Knurl	0.30	0.10	
Dot Knurl	0.29	0.05	
Chain Knurl (Diamond)	0.26	0.17	0.30
Chain Knurl (Round)	0.25	0.14	0.25

- Bearing Surface without Knurl: 0.21 MPa/cps

Table II: Heel impact stress indices – MPa/cps

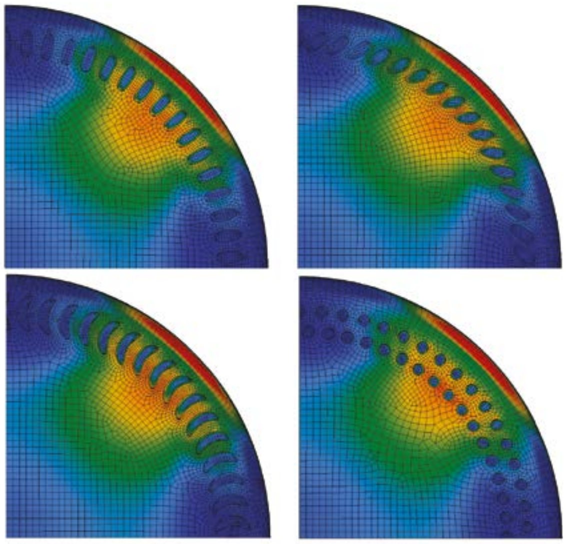

Figure 6: Heel impact stress distribution diamond chain.

Practical ramifications

General observations: During normal handling of bottles, damage generated in the bearing surface is usually confined to the tips of the knurls. In these situations, glass surface strength is reduced but is concentrated at a location where the stress indices are very low for both internal pressure and heel impact. This is one of the main purposes of placing knurls on the bearing surface of glass containers – to concentrate unavoidable damage in regions where tensile stresses are significantly reduced. The positive result is that breakage is typically averted.

However, some damage will inevitably occur between knurls. If this damage is sufficiently severe, then the coupling of reduced surface strength with relatively high stress could potentially lead to performance issues. Such effects will be more pronounced for chain knurls since the high stresses are positioned close to the tip of the knurls, thus making it more likely that serious damage could be created at the location of high stress.

Choice of knurls: As noted by the data in this study, some differences were observed in the generation of stress for the various knurls. However, the choice of knurl type is usually more dependent on ascetics and forming concerns rather than decisions to reduce the magnitude of tensile stresses. Often, when the type of knurl is chosen for a new design, bottle stability and forming considerations play a much larger role than stresses produced from expected loads. ●

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