glass WORLDWIDE

Filling line impact measurement

William G Slusser and Steven W Spence discuss the measurement of filling line impacts and the relationship to impact testing.

In the world of filling line handling, it is essential to establish appropriate impact specifications for glass containers. Unfortunately, there is a significant misunderstanding regarding the proper implementation of impact specifications developed from one of three sources:

- The maximum filling line speed.
- Supplier impact specifications used for quality control.
- Impacts that are determined with the use of an impact sensor (shock logger).

When impact specifications are established at levels that are either too high or too low, significant technological and financial issues can occur.

If the level of impact is overestimated, the consequences include the possible rejection of bottle designs that would have functioned acceptably. It can also force a company to implement significant and unnecessary increases in glass weight or design changes, which would result in added expense throughout the process. An example of overestimation is the conclusion that the trade impact magnitude is equal to the maximum filling line speed.

Conversely, if the level of impact is underestimated, the outcome can be the implementation of a bottle design that is not capable of handling the impact levels experienced in the filling operation and beyond. The result would be an excessive amount of breakage, which leads to filling line stoppage, quarantine of filled ware, product recalls and possibly consumer injury. So, in addition to higher costs, there are reputation and consumer issues that can arise.

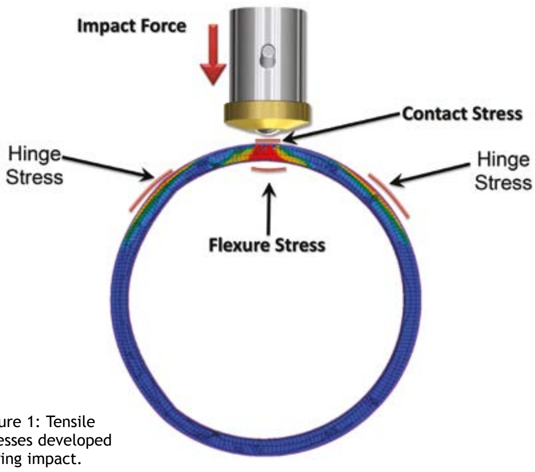

Figure 1: Tensile stresses developed during impact.

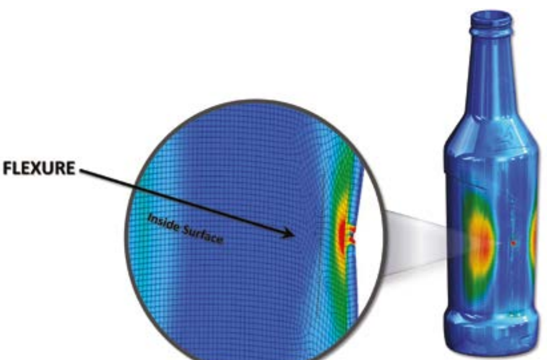

Figure 2: Flexure stresses.

The purpose of this article is to provide a clearer understanding of topics such as impact forces and the stresses that result, the proper establishment of impact criteria, the interpretation of impact testing data and the benefits of filling line audits. It is also intended to demonstrate that using a proven scientific methodology to determine the actual impact criteria is both viable and cost-effective.

IMPACT FORCES AND RESULTING STRESSES

Although nearly all glass containers are subjected to impacts in the filling line and while impact is a common cause of breakage, the distribution and magnitude of stresses developed during an impact event are not clearly understood. Two main reasons for this lack of understanding are[1]:

The absence of a single definitive impact value that can be applied for use with all containers.

In general, the nature and distribution of stresses produced by an impact are more complicated than those observed for other common loads.

In order to establish the force that is created during an impact event, the equation can be written in its simplest form as:

$F = ma$

where m is mass and a is acceleration.

This equation can be modified to allow for the inclusion of a velocity term, based on a quasi-static approach as described by M W Davis[2]

$F = v\sqrt{(km)}$

where v is velocity, k is stiffness and m is effective mass.

When considering this equation, it is apparent that impact forces will increase when each of these three variables (velocity, stiffness and effective mass) increases[3]. The following discussion will further clarify each of these three variables.

When considering striking velocity, v [which is typically measured in linear speeds such as centimeters per second or inches per second] and its relationship to impact forces, it is fairly intuitive to consider that the higher the velocity, the greater the impact forces that will be generated. Thus, increases in filling line conveyor speeds would have the general effect of potentially increasing the impact forces to which the bottles are subjected.

The concept of stiffness, k, refers to a measure of rigidity at the impact site. Contact stiffness will be greater as the diameter of a round container decreases or with increasing glass thickness (both producing structural reinforcement). Thus, a smaller, thick-walled bottle would exhibit more contact stiffness than a larger thin walled bottle. It is also noted that structural stiffening associated with the curvature created at the shoulder and heel region of the bottle make these regions stiffer than the mid sidewall of the same container, which would be inherently more flexible.

Finally, effective mass, m, is the measure of resistance of the object (container) and its contents to motion. It is equal to the effective weight of the container along with its contents, divided by the gravitational constant. Similar to stiffness, the effective mass is dependent on the impact location for a particular bottle design. Effective mass is at its highest when the impact occurs coincident to the centre of gravity of the container and it decreases the further away the impact location is in relation to the centre of gravity. This is the reason it is advisable to avoid a shoulder contact height that is coincident with the centre of gravity, as it would significantly magnify the impact forces for that item.

With this general understanding of impact forces in place, the next topic of discussion involves the resulting stresses developed during an impact event[4].

When the sidewall of a cylindrical container is impacted, as depicted in figure 1, there are three primary tensile stresses that are developed during the impact event. These stresses are referred to as (1) contact stresses, (2) flexure stresses and (3) hinge stresses. >

Figure 3: Hinge stresses.

Contact stresses are developed on the outside surface of the container and are limited to the region of contact between the impacting object and the bottle. They are generally the highest stresses created during an impact event. However, they are largely dependent on the stiffness of the region being impacted. Although contact stresses are quite high in magnitude, failures from this type of stress are not the most common type of impact breakage. The reason is the highly localised nature of the impact, which places a relatively small surface area under tensile stress. Thus, the probability that a stress concentrator or flaw is located within the region of tensile stress is low.

Generally, the second largest tensile stresses developed during an impact are flexure stresses. This stress is created on the inside surface of the container. The inward deformation of the bottle at the impact location creates bending stress that comprises a very localised stress region, as shown in figure 2. When blow-blow technology was the only choice for container forming operations, flexure stresses were of little consequence due to the high inside surface strengths achieved. However, with the introduction of narrow neck press and blow technology, contact between the plunger and the inside glass surface results in the deposition of inside surface inclusions. These inclusions are stress concentrators that lower the inside surface strengths and allow flexure stresses to become more relevant. Impacts directly opposite microscopic inside surface inclusion flaws such as embedded materials (black specks) could result in relatively low magnitude impact failures.

The lowest magnitude tensile stresses developed during an impact are hinge stresses. These bending stresses cover fairly large outside surface regions at a distance away from the point of impact. For a cylindrical container with a sidewall impact, hinge stresses are maximised at locations of approximately 45° to either side of the impact (as shown in figure 3). In addition, hinge stresses are magnified around corners of a bottle. In a square or rectangular bottle, this would be apparent in the sidewall. However, even a cylindrical bottle exhibits a transition from the sidewall to the bottom of the container that behaves similar to a corner. Thus, an impact to the heel contact can produce hinge stresses below the impact point, as well as in the bearing surface region, as shown in figure 4.

Understanding the regions of tensile stress created and their relative magnitude during an impact event is critical, particularly when evaluating a new bottle design. With this knowledge, it is possible to predict which region placed under a tensile stress will be the limiting factor in the bottle's ability to handle an impact.

IMPACT EQUIVALENCE

The method of impact equivalence states that when two identical bottles are impacted at the same location under two differing situations, the two bottles will fail at the exact same impact force. In other words, the impact force required by a Pendulum Impact Tester (PIT) to break the container from an impact to the shoulder contact is equal to the impact force required in the filling line to cause the same type of breakage. However, since the masses involved in those two impact situations (PIT versus filling line) are different, the striking velocity to create the same level of impact force will be different. The concept of impact equivalence allows for the conversion of striking velocity between the PIT and the filling line created impacts.

In order to qualify the two containers as identical, the glass surface strengths of the two bottles must be the same. Thus, containers tested using the PIT must exhibit the same level of surface strength as those that have been handled in the filling operation. Under this requirement, it is important to test bottles on the PIT with damage created either by a line simulator or through abrasions applied with emery paper to ensure the same level of surface strength as would be expected for bottles with filling line handling damage.

In order to complete the impact equivalence conversion, key aspects of the bottle design and usage are needed. These key attributes include overall bottle dimensions, glass weight, centre of gravity, the radius of gyration and the distance from the centre of gravity to the natural contact points of the bottle design.

Utilising the concept of impact equivalence, the results obtained using an AGR PIT can be converted into impact strengths anticipated for the filling line. From these results, the maximum allowable filling line impact levels can be established. Conversely, if the maximum filling line impacts are known (through measurement with a shock logger) then a pass or acceptance level can be established for PIT testing of containers, assuming it is undertaken on bottles with the same surface conditions.

DIFFERENCES EXPLAINED

So why is the actual impact/bottle velocity different than the filling line speed?

A fairly common practice in the food and beverage packaging industry is the assumption that the maximum filling line speed is equal to the maximum level of impact that a container will experience. This misconception probably originates with the similarity in units for two differing scenarios. The quality control specification for impact testing is often reported in terms of velocity (inches per second or centimeters per second), while filling line speeds, the rate at which bottles can be filled with product, are also expressed in a 'velocity-like' value such as bottles per minute or per hour. The fallacy of equating these two entities (filling line speed and impact test velocity) is revealed when noting the manner in which the 'bottles per minute' value on the filling line is achieved.

While bottles on the conveyer just prior to the filler are moving at a velocity equal to the filling rate and can contact one another, a properly designed line will not allow a speeding bottle to run into an accumulation of bottles that combined, have sufficient mass to act like a solid immovable object.

Understanding of the previous concept allows for the consideration of a more realistic model for filling line impacts. Thus, the characterisation of a filling line impact involves the measurement of sudden changes or reductions in velocity that are experienced by individual

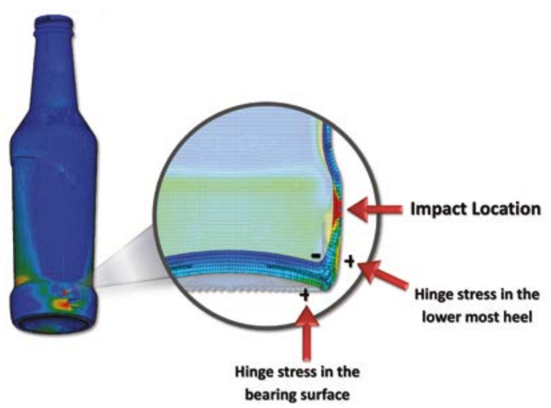

Figure 4: Hinge stresses with complex curvature.

Figure 5: Impact sensor.

is usually established somewhat arbitrarily and without a direct connection to filling line impacts and therefore, could cause a potentially acceptable bottle to be rejected when in fact it may be capable of performing acceptably. In some instances, the reverse may be true as well.

Impact surveys, undertaken using a shock logger, at the customer's filling lines indicated that a typical maximum impact velocity experienced for this size and type of bottle was in the order of 40cm/sec (16in/sec). Thus, the acquisition of real impact data from a line survey would reveal a significantly lower value than would be implemented under the assumption of filling line speed or even typical specifications. Consequently, the bottle in this practical example could be designed and tested against a much lower criterion, which allows for more design flexibility and/or lightweighting opportunities through the use of realistic criteria for finite element analysis. In addition, line surveys identify areas where maximum recorded impacts occur. This allows focused efforts to be implemented to improve handling and reduce impact forces in the targeted sections of the line, providing even greater economies with the design.

containers. The net change in velocity should be documented or measured when an individual bottle overtakes a single bottle or group of bottles that precede it. These differences in velocity are actually measured in terms of acceleration. This necessitates the use of a device capable of measuring this quantity. These measurement devices are commonly referred to as 'shock loggers' or 'impact sensors' although in reality, they do not directly measure either quantity (shocks or impacts). Rather, these devices consist of a set of accelerometers that measure the variations in acceleration experienced in the filling line and report those values in terms of 'g-force'. The g-force acceleration experienced by a container is the result of the vector sum of all non-gravitational forces acting on the bottle's freedom to move. In practice, these are impact forces between bottles that generate stresses within the glass. As described earlier, a thorough understanding of these forces and the resulting stresses are needed in order to interpret the data generated by these types of devices.

In order to utilise a shock logger effectively, it is embedded in an acrylic model (as shown in figure 5), that has been machined to the dimensions of the container design. This is critical in order to ensure that the natural contact locations between the glass bottles and the shock logger are the same.

The acceleration measured by the shock logger is not equivalent to the forces experienced by a glass container. This is because the mass and stiffness of the acrylic model differ from an actual container. Thus, a conversion from the shock logger acceleration measurement into glass container impact forces must be accomplished. A methodology has been established by American Glass Research that accurately converts 'g's to impact velocity and also incorporates the factors (size, shape, product type) that are individual to each container design. Drawing from the experience gained in performing filling line audits and laboratory testing, while also incorporating the concept of impact equivalence, this approach has been proven to be a highly accurate method to convert shock logger output into impact velocity of the glass bottle.

PRACTICAL EXAMPLE

In this example of a typical filling operation, bottles were filled at a rate of 1200 bottles per minute. This equates to a velocity of 180cm/sec (71in/sec) when the bottle diameter and bottle spacing is considered. Based on experience and considering the typical specification commonly used in the industry, installing this value as the impact criteria would have the potential to cause significant over-engineering, as discussed at the beginning of this article.

A corresponding representative impact specification employed by a multi-national filling operation required the bottle design to be capable of surviving an 85cm/sec (33in/sec) velocity impact. While this values appears more reasonable, it

CONCLUSIONS

It has been shown that setting impact criteria in the absence of measured filling line impact levels can have negative consequences. Diagnosing an impact failure requires a full understanding of the three tensile stresses developed when an impact force is applied.

Applying the concept of impact equivalence allows for a direct conversion between the impact forces a bottle experiences on a filling line to impacts created with a pendulum impact tester (PIT). The output of a shock logger or impact sensor is in units of g-force. This output can be converted to impact velocity with an understanding of the relationship between bottle design, while accounting for differences between an acrylic bottle and a glass bottle.

Combining the results obtained from a filling line survey into a finite element analysis (FEA) of a bottle design along with impact testing of the as-produced ware is a proven method to ensure a successful product introduction. This methodology is also highly effective in identifying lightweighting opportunities. ■

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