Troubleshooting: Blow Molding

Get a Handle on Stress-Cracking In HDPE Bottles

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One of the first applications for blow molded HDPE bottles was the replacement of glass for bleach packaging. A standing joke among the bottlers was that their bottles only cracked in the summertime, usually on the back seat of a Cadillac, and next to a fur coat being taken in for storage. All joking aside, the potential for environmental stress cracking (ESCR) of HDPE bottles has always existed because of the material's inherent semi-crystalline characteristics. The most common victims are HDPE containers for liquid detergents, motor oil, and industrial chemicals. The phenomenon occurs regardless of the size of the container—even large IBC containers for similar liquids can be susceptible.

In the summer, ESCR problems are exacerbated due to several factors related to increased heat and humidity. Processors need to be acquainted with these sources of stress and the testing options. Some countermeasures are available to deal with this age-old problem.

ESCR TEST LIMITATIONS

Fig. 1—A classic example of stress-cracking in HDPE containers is found at the end of the pinch-off eye.

In the 1930s, Western Electric was an early adopter of LDPE as a replacement for lead sheathing on multi-pair telephone cables. Before long, in-service cracking of the cable jacket was noted. Western Electric's R&D department, known as Bell Laboratories, devised a test for ESCR. Informally known as the Bell Lab test, this test method is today called ASTM D1693. Ten 0.5 x 2 in. specimens are die-cut from a 0.125-in. compression molded plaque. These are scribed with a 0.010-in.-deep imperfection and then are bent into a "U" shape and inserted into a channel, notch-side out. The holder with the 10 specimens is inserted into a test tube filled with Igepal 630 surfactant and placed in a 122 F bath. As each specimen cracks, the time is plotted. F0 is the number of hours until the first one cracks, F50 is when half have cracked, and F100 is when the last one breaks.

In the early 1950s, new and stiffer HDPE was introduced. In the Bell Labs test, HDPE specimens sometimes broke upon initial bending so the test thickness was reduced to 0.075 in., now known as test condition "B."

The ASTM D1693 test method is generally regarded as neither precise nor reproducible. The estimate for inter-laboratory precision is 2.9 at 2 Sigma (two standard deviations). This means that a F50 value of 10 hr reported by one lab could vary (95% of the time) within a range from 3.4 to 29 hr when the same specimens were tested by another laboratory. To address the lack of precision, the concentration of the Igepal soap solution was revised to 10%, so yet another test condition was added to the ASTM method. This gives users a choice of four conditions (0.125 or 0.075 in. thickness and 10% or 100% Igepal). Datasheet values typically mention the ASTM method but fail to identify the all-important test conditions, which drastically affect the time to failure. Thus a comparison of one resin's ESCR to another based on datasheet values is suspect.

PREFERRED TEST METHOD

The bent-strip test is a constant-strain test and the initial bending stress decays with time due to relaxation. Consequently, many manufacturers of pipe, geomembranes, and containers have migrated to some form of a constant-stress test whose conditions are more representative of in-service situations.

Another groundbreaking HDPE bottle application was the replacement of the metal detergent can in the mid-1950s. These detergents contained surfactants that caused stress cracking and the bent-strip test was unable to predict field performance. Thus the container/bottle industry pioneered the use of testing methods based on constant stress.

Two methods are generally used to produce a sustained stress on the bottle to determine the container's resistance to ESCR. In the constant-top-load test, a fixed weight is applied to each bottle. This test method, also known as the P&G test (named for Procter & Gamble), mimics the stress encountered from a stack of multiple cartons. Meanwhile, the ASTM D2561 test method uses a constant internal pressurization of 5 psig to produce a sustained stress. A variation of this test uses sealed bottles warmed in a 140 F oven. The thermal expansion of the contents produces about 5 psi in the bottle. In both methods, the bottle contains a known stress-cracking agent. Each method has its proponents, but data interpretation is a common problem: "Will 50 hr to failure translate to a crack-free summer season for us, or do we need 100 hr?"

SUMMER ADDS STRESS

During the summer months, stress-cracking of HDPE containers reaches its peak. This is because stress from different sources increases during the summertime. Premature cracking can be caused by top-load stress, internal pressure, molded-in stress, and tail swing.

With the advent of zero-head-space cartons to save space and corrugated costs, the bottle is in a load-sharing condition with the carton sidewall or dividers, if they are used. But corrugated cardboard can lose up to 50% of its compressive strength under summer's high humidity. Theoretically, the bottle itself also loses a bit of its compressive strength as its temperature increases. This combination often results in a creased or deformed container. Common examples are quart oil bottles cracking at a top-load-induced fold or crease in the bottom corner, or cylinder rounds cracking at the neck-body junction.

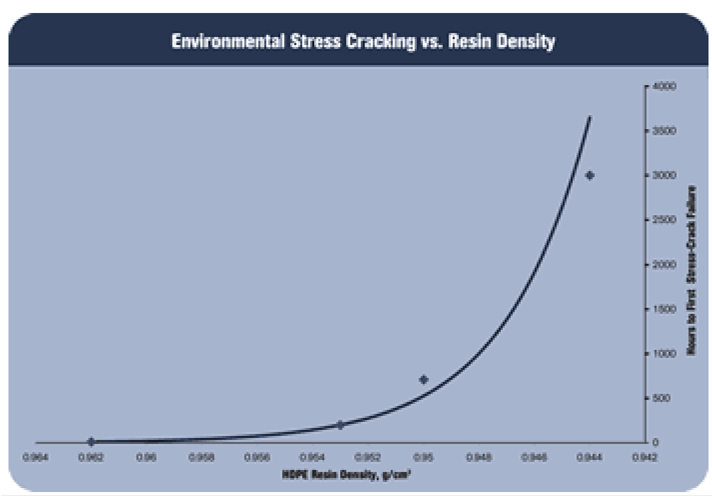

Fig. 2—Lower HDPE resin density corresponds to increased resistance to ESCR.

An increase in internal pressure is another source of stress. Most filling operations are done at ambient temperature, possibly even in an air-conditioned plant. The capped container is then moved to a non-air-conditioned warehouse, or worse, stored in an aluminum trailer. Enclosed trailer temperatures of 145 F have been reported during the summer. This heat will generate an internal pressure in the container of 4 to 5 psi, depending on the bottle's contents and the amount of head space.

Molded-in stress can be another contributor to stress-cracking. HDPE, like steel, is a semi-crystalline material, with no crystals in the melted state. The amount of crystalline content in the container depends on the rate of cooling. While crystallinity provides strength, it also can lead to cracking. Since blow molding has only single-side cooling, thicker sections will not cool as fast as thinner sections. Since crystallization always involves shrinkage, there is always some molded-in stress at the end of the pinch-off, where the thicker eye meets the thinner bottom corner of the container. This is the classical location of a stress-crack failure (Fig. 1).

Cosmetic surface defects, called water spots, often develop during humid months due to moisture condensation on the chilled molds. In response, molders raise the mold temperature to stop condensation, but without adding a corresponding increase in cycle time. This means the container exits the mold warmer, which results in greater crystallization and an elevated amount of molded-in shrinkage stress.

Tail swing occurs when a parison doesn't fall straight and wanders. As molding plant temperatures soar in the summer, there is an observed drop in operator attention to such process deviations. A pinch-off eye located over on the chime of the container is more prone to cracking than a centered one.

SOME REMEDIAL STEPS

Manufacturers can employ several remedies to correct stress-cracking problems. First, use a stronger "summer carton" from June to September. Switching from 200-lb to 225-lb rated corrugated is inexpensive insurance. Reducing carton stack heights in summer is another option. Consider using an internal "Z" or "H" divider during this season.

Switch to a more crack-resistant resin. A slightly less crystalline HDPE will have better crack resistance, and density is a direct measure of crystallinity. If you are molding with a 0.954-g/cc resin, consider a 0.950 density for the summer (Fig. 2).

Monitor and control product warehousing. Your known crack-prone products should not end up on the top floor of the warehouse, nor stored in trailers.

Maintain consistent process cooling. Lengthening molding cycles by a few seconds is a hard sell to management but it's the only way to compensate for the higher mold temperatures used to inhibit condensation and water spots.

About the Author

Robert DeLong has more than 50 years of experience in the plastics industry, much of it in blow molding. He began his work in blow molding at Hercules in 1956, molding what was then experimental PP on a hand-operated Plax machine. Since then he has worked in machinery, plant operations, and material development at Rainville Corp., Owens-Illinois, Captive Plastics, and a 17-year stint at Solvay and its successor companies. He was elected an SPE Fellow in 2003 and was awarded a Lifetime Achievement Award by the Blow Molding Div. in 2004. He now runs Blasformen Consulting and can be reached at (281) 360-5333 or by e-mail at done7106@earthlink.net.