Simulation of Primary Plastic Package Damage in Tray-Based Unit Loads

It is clear that sustainability will be THE packaging topic for the next decade, and that interest and concern is global. To meet the growing demand for packaging-related engineering services, Stress Engineering Services (SES) has developed predictive computational methods and physics-based testing to achieve sustainability goals.

Less Material is More Sustainable

One of the most important tenets of sustainability is to use the minimum amount of material. The choice of which packaging material to use is important but, in general, the system that uses the lowest total packaging weight is usually the most sustainable solution. Traditional packaging systems for beverages and other liquids have historically used a rigid plastic bottle as the primary package, and a corrugated fiberboard box as the secondary package. An increasingly popular trend is to replace the case with a shrink-wrapped bundle (with or without a tray or pad) and light-weight the plastic bottles as much as possible (Figure 1).

Problems With Shrink-Wrapping

The trend towards packaging without cases to improve sustainability is not without problems. It is obvious that a shrink-wrapped bundle still needs to support the same load as before, but all of that load must now be carried in a package where the bottle is the primary structural element. Case size, shrink film selection, tray configuration, the use of tier sheets, pallet stacking patterns, stretch film wrap settings, pallet design and other practices can all contribute to overall unit load stability. However these are secondary effects that can rarely compensate for the loss of the case in the presence of a weak bottle.

Many life cycle analysis (LCA) studies evaluate only material usage (e.g. material type, quantity used, material source) when comparing packaging options. Failure to account for performance differences can cast significant doubt on the validity of some packaging LCA studies.
The Times They Are A Changin' 

The reality facing the packaging community is that decision makers have demonstrated a willingness to accept degraded packaging performance in the interest of supporting and advancing corporate cost reduction and stainability initiatives. This increases the difficulty of the challenges associated with ensuring products survive the manufacturing and distribution process and reach the consumer/end user undamaged.

Package designers and engineers have long been aware of the primary hazards to their packages such as top load forces during stacking and impact forces that can occur during handling and transportation. As light-weighting and other material reduction and substitution activities accelerate, secondary hazards have become more prominent as design criteria for packages have less design margin than ever before. These secondary events can include buckling or creasing during label application, impact damage during conveyor handling, and crushing during filling or capping.

Trading Damage Mechanisms 

Another new form of damage that has not historically been seen very often is bottle denting. With ever-expanding use of shrink-wrapped case packaging it is more common for bottle denting to be a problem. Shrink-wrapped cases have been in use since the mid-1980’s but bottles were not as aggressively light-weighted then as they are now. The more robust bottles that were commonly used did not dent as easily. With advancements in blow molding technology and environmental pressure to use less plastic, bottles have become significantly lighter.

With lighter weight, more easily damaged bottles, denting damage has emerged as a challenging issue that must be addressed by designers of shrink-wrapped packaging. In a conventional packaging development process this problem will often not surface until line trials and ship tests are conducted. Since these activities are not conducted until the latter stages of the project, there is great potential for this to negatively impact the project schedule and budget.

No Substitute For Early Detection: A Case Study

Early detection of the potential damage that can be caused to the primary plastic package of a shrink-wrapped case is crucial to the success of the package development process. To that end, physics-based predictive modeling, simulation and testing methods have been developed by SES to predict the response of packages to a variety of primary and secondary loads. The example in figure 2 illustrates the application of these methods to a PET vegetable oil bottle. This case study illustrates the use of predictive modeling, simulation and testing to predict damage caused by:

1. Shrink wrap and stretch film compression
2. Stacking loads
3. Dynamic loads during handling and transit
The primary package evaluated is a 48 oz PET bottle. The bottles are shrink-wrapped with 3-mil film in a 23 ECT B-flute corrugated fiberboard tray with a (3 x 5) configuration. The cases are palletized using an interlocked stacking pattern, 6 layers high, on a 4-way wood block pallet with a spiral wound stretch film pattern (Figure 2c). Transportation practices called for trucking unit loads in spring steel trailers without stacking but allowed 2-high stacking during warehousing.

Laboratory tests provided the following data to support the analysis:

1. True stress vs. true strain curves for the bottle, tray and shrink/stretch films (Figure 3)
2. Creep data for the bottle
3. Bottle fill temperature, fill level and filling facility altitude
4. Coefficient of friction values for the material combinations in contact (Figure 4)

FIG. 3: (below, A & B) Bottle PET material true stress vs. true strain curve and creep data at room temperature to predict short-term and long-term package performance

![PET Tensile Creep Data @ 73 F](image)

**3a. Bottle PET material true stress vs. true strain curves at room temperature**

**3b. ET Tensile creep data at room temperature**

FIG. 4: Measurement of friction coefficient between shrink wrap and bottle

![Measurement of friction coefficient between shrink wrap and bottle](image)

**FIG. 5: (left) Shrink and stretch wrap compression force test results**

**FIG. 6: (below, A & B) Transient dynamic stiffness test**

![Stress Engineering Services](image)

**6a. Horizontal vibration test apparatus**

![Transient dynamic stiffness test](image)

**6b: (left) Horizontal displacement at top layer of the unit load after a sudden stop; Test data and analysis result comparison**
5. Shrink and stretch wrap compression loads (Figure 5) SES continues to develop new test and simulation methods in support of unit load performance analysis. Figure 6 illustrates recent work related to measuring and simulating unit load transient dynamic stiffness.

**Avoiding Costly Trial & Error Development**

The modeling and simulation results (Figure 7) were compared with physical damage observed to the package and accurately predicted both denting damage on the bottle and buckling of the corrugated fiberboard tray (Figure 8). These analysis methods were developed in the mid-1980’s and have been continually refined since then. Numerous projects on a variety of packages for a wide range of clients have demonstrated that this predictive approach makes it possible to evaluate new designs or remediate problems with existing designs without the need to resort to costly and time-consuming trial-and-error methods.

**FIG. 7: Comparison of actual dent with predicted result**

**FIG. 8: Secondary package (tray) buckling is properly identified**

**Results That Impact the Bottom Line**

The physics-based modeling, simulation and analysis approach for tray-based unit load packaging developed by SES has been proven to be effective in predicting package damage. This predictive approach enables packaging suppliers and OEM’s to eliminate trial and error development by predicting the performance of packaging systems before manufacturing a single package. The method can also be used as a process development tool, enabling simultaneous optimization of the primary bottle design, shrink/stretch wrap selection/tension settings and unit load stacking patterns.

For Help Developing Sustainable Tray-Based Unit Load Packaging Systems That Work, Call SES today at 513-336-6701

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