REDUCING THE COST OF HPP PACKAGE DEVELOPMENT: A NEW AND NOVEL APPROACH

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Abstract

HPP (High Pressure Processing) is a high pressure sterilization processing technology that is of interest to many food products companies. Until now, HPP package development has relied exclusively on an iterative process of prototyping and package testing, both of which are expensive and time consuming. This paper describes new technology developed by Stress Engineering Services, Inc. (SES), Mason, Ohio, to accelerate development and reduce costs via the application of predictive computational methods, frequently referred to as 'in-silico' performance simulation testing. In-silico is intended to connote a process where digital computing (i.e. silicon wafers) is used to predict the performance of packaging (in computational space), rather than rely exclusively on physical trial-and-error testing as a means of advancing a design during development. This approach developed by SES is intended to rapidly provide directional support to the package development process by eliminating some or all of the trial-and-error iterations leading to significantly reduced risk and accelerated schedules. This paper outlines the in-silico HPP package development model and provides an example of its use on a stand-up pouch commonly used for a broad range of food products.

Introduction

HPP is a promising pasteurization technology in the food and beverage industry. Although it has been around since the early 1900s, it was only recently that the technology gained some commercial attention and momentum as an alternative to conventional thermal pasteurization methods. The process operates at cold temperatures (+4°C to 10°C) with high hydrostatic pressure, typically ranging from 50,000 to 120,000 psi. In SES's experience, the typical total cycle time is in the range of 9 to 15 minutes (including ramp-up, hold and ramp-down), a significant reduction relative to thermal methods. A package experiencing HPP must remain sealed throughout the process to avoid contaminating the product inside the package.

Flexible packaging formats, such as, flexible pouches and thermoformed trays, are used in HPP applications to combat the high pressure environment. The flexibility of these packaging platforms enables the sidewalls to conform to the internal product under high pressure, but regain (or largely regain) its original shape upon removal of the external pressure. Application of HPP to rigid packaging remains relatively rare at this point in time.

Discussion

Cheer Pack North America, an innovative manufacturer in the flexible packaging market, provided current package samples (HDPE straw and HDPE cap) and technical data to support this demonstration effort (Figures 1 and 2). The package is currently thermally-pasteurized. The in-silico HPP testing results indicate that the current closure system (HDPE straw and HDPE cap) will likely perform well in HPP applications without compromising the closure seal integrity. However, in the hypothetical case of a PET (polyethylene terephthalate) straw and PP (polypropylene) cap, there is a greater potential for thread jump and loss of seal integrity.

CHEER PACK
NORTH AMERICA

Figure 1: Cheer Pack portfolio of packages

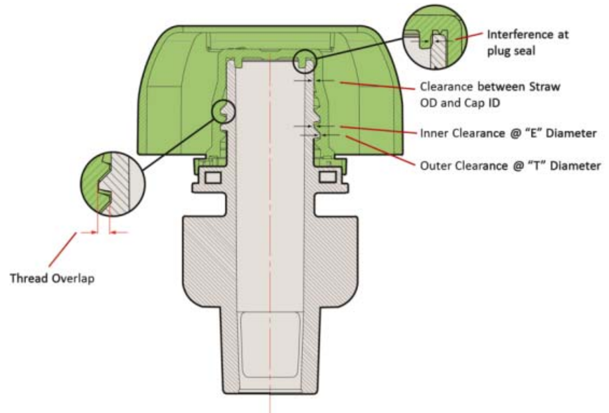

Figure 2: Cheer Pack closure system (straw and cap)

Material Characterization

It is important to note that both the food product (largely water content) and plastic components (closure, straw and their respective materials) behave very differently when under extreme high pressure:

- Under extreme high pressure (80,000 psi), the product inside the package will be reduced by about 15% relative to its volume at ambient pressure.
- The modulus of elasticity of PET is 40% higher at the elevated pressure, HDPE is 350% greater, and PP is more than 450% higher at 80,000 psi. The 'yield strength' also increases.
- For the plastics of interest, the material strain-to-yield and strain-to-break values are lower at high pressure.

Example Application

To assess the effects of the different plastic materials for a pouch in HPP application, two different material combination cases were studied:

- HDPE straw and HDPE cap
- PET straw and PP cap (a hypothetical case)

The stress-strain curves for each of the three materials at various HPP hydrostatic pressure conditions (Figures 3-5) are generated based on the published data in the referenced papers (see Reference section).

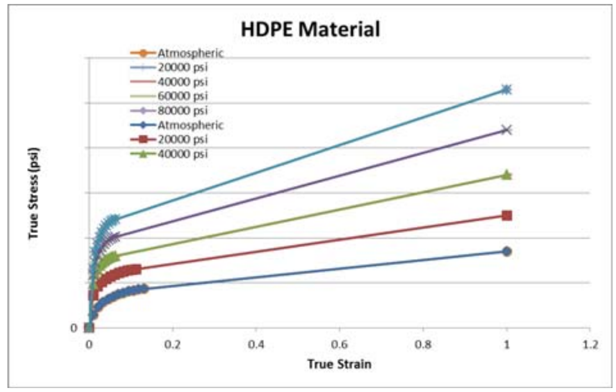

Figure 3: HDPE material stress-strain curve as a function of HPP hydrostatic pressure

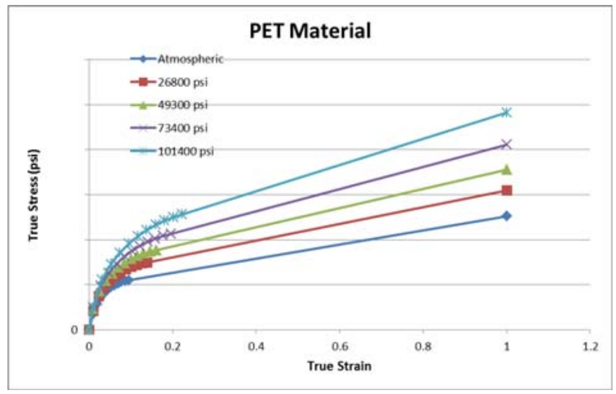

Figure 4: PET material stress-strain curves as a function of HPP hydrostatic pressure

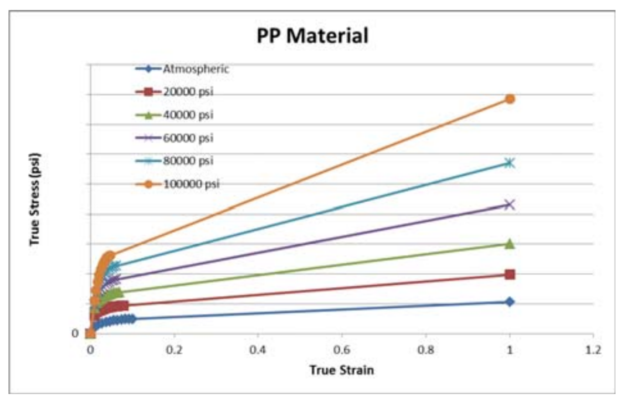

Figure 5: PP material stress-strain curves as a function of HPP hydrostatic pressure

In-Silico HPP Simulation Testing

The in-silico HPP testing simulation is intended to mimic the actual package assembly and subsequent HPP sterilization process. In this example, a comparison of closure sealing performance for an HDPE/HDPE cap/straw combination as well as a PP/PET combination is of primary interest.

The simulation of the cap and straw assembly is conducted at ambient conditions for both material combination cases. Pre-sterilization contact seal pressures are then calculated as a function of normal injection molding variability. After assembly, the package is computationally (in-silico) exposed to an HPP testing protocol where the pressure is ramped from 0 psig to 80,000 psig in 3 minutes, held at 80,000 psig for 3 minutes and ramped back down to 0 psig over a 3 minute period. The primary (plug) seal, secondary (nub) seal and tertiary (OD) seal forces (Figure 6) are closely monitored during the entire HPP cycle (9 minutes). The monitoring of the seal integrity during the sterilization cycle is something that cannot be done in the 'real world.' The ability to do this is enabled by the in-silico simulation process. The closure thread engagement is also monitored to track any potential for thread jump that could be caused by insufficient thread engagement (Figure 7).

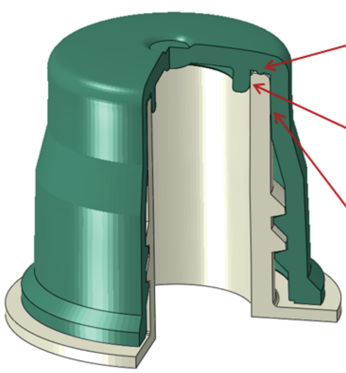

Figure 6: Cheer Pack closure seals

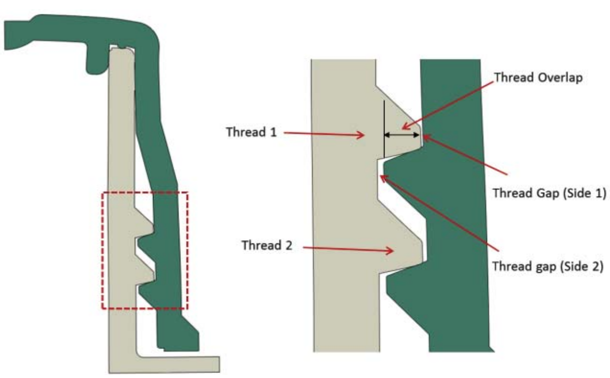

Figure 7: Thread engagement tracking

In-Silico Simulation Results

The in-silico HPP simulation testing results are summarized in Figures 8-10 and Tables 1 and 2. The key results are:

1. The closure is approximately 5% smaller in diameter for both material combination cases (Figure 8).
2. Strain in the inner corner of the cap is increased after HPP, indicating increased deformation (Figure 9).
3. For Case 1 (HDPE straw & HDPE cap), the primary seal force is increased slightly after HPP, but the secondary seal is reduced by 35% and the tertiary seal is lost completely. However, both primary and secondary seal forces remain positive throughout the HPP cycle (Table 1).
4. For Case 2 (PET straw and PP cap), the primary seal force is significantly reduced by 50% after HPP, indicating potential degraded sealing performance, especially for the tolerance extremes. It is also noticed that both secondary and tertiary seals are lost at t=6 min (the end of hold), indicating potential product contamination during HPP (Table 1).
5. For Case 2 (PET straw and PP cap), the thread engagement is reduced by 25% at the end of the pressure hold period just before pressure ramping down during HPP, indicating potential thread jump during HPP, especially for the tolerance extremes (Table 2).

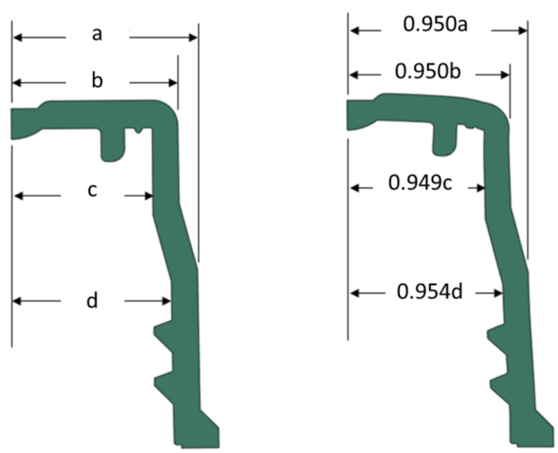

Figure 8: Predicted change in closure dimensions as a result of HPP processing (left – original, right – change)

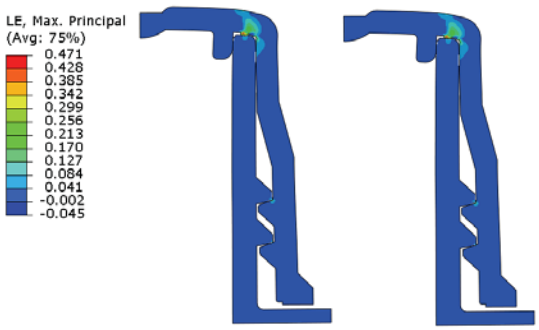

Figure 9: Maximum tensile strain before & after HPP

Table 1: Contact forces during HPP

Closure Seal	Contact Normal Force (lbf) (before pressure)		Contact Normal Force (lbf) (after pressure)		Contact Normal Force (lbf) (after pressure removal)	
	HDPE/HDPE	PET/PP	HDPE/HDPE	PET/PP	HDPE/HDPE	PET/PP
Primary Seal	14	22.8	40.3	148	15.7	11.5
Secondary Seal	75.5	128.8	237.8	0	48.9	139.3
Tertiary Seal	1.5	0	50.3	0	0	12

Table 2: Thread engagement during HPP

	Thread Parameter	(before pressure)		(after pressure)		(after pressure removal)	
		HDPE/HDPE	PET/PP	HDPE/HDPE	PET/PP	HDPE/HDPE	PET/PP
Thread 1	Thread Overlap (in)	0.0250	0.0251	0.0250	0.0189	0.0259	0.0255
	Thread Gap (Side 1) (in)	0.0015	0.0015	0.0000	0.0075	0.0007	0.0013
	Thread Gap (Side 2) (in)	0.0043	0.0042	0.0038	0.0090	0.0034	0.0039
Thread 2	Thread Overlap (in)	0.0244	0.0242	0.0217	-	0.0243	0.0248
	Thread Gap (Side 1) (in)	0.0032	0.0033	0.0038	-	0.0029	0.0028
	Thread Gap (Side 2) (in)	0.0049	0.0050	0.0065	-	0.0051	0.0044

The in-silico HPP testing results indicate that the similar material make-up (HDPE straw and HDPE cap) makes the closure more favorable in surviving HPP without compromising the closure seal integrity. This is largely due to the fact that the similar materials expand or contract similarly under the pressure cycle. The dissimilar material make-up (PET straw and PP cap) experiences a different expansion and contraction level during HPP. The analysis results show there is a greater potential for thread jump and loss of seal integrity for the PET/PP than HDPE/HDPE make-up. Design safety factors for the primary seal and thread engagement need to be increased if dissimilar make-up is considered for an HPP closure.

Future Work

This study assumes the temperature remains at room temperature during the entire HPP application. However, according to an FDA report, the temperature increase of water (initially at room temperature) is ~3°C/100MPa (~3°C/14,500psi) under pressure. That implies a total of ~18°C temperature increase at 80,000 psi. The effect of temperature rise on material properties and bottle stability will be studied. In addition, in a full production scenario the pressure ramp-up and ramp-down periods are likely to be shorter. The higher loading and unloading rates will likely create a dynamic effect that needs to be understood.

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