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A preliminary analysis of PET barrier technologies and mechanical performance related to a 3L PET wine bottle

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A Preliminary Analysis of PET Barrier Technologies and Mechanical Performance Related to a 3L PET Wine Bottle.

By

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Dedication

This thesis is dedicated to my parents Paul and Jayne who have made many sacrifices while I have pursued all of my goals in life including this one. Without their love and support I would not have been able to accomplish this goal.

A Preliminary Analysis of PET Barrier Technologies and Mechanical Performance

Related to a 3L PET Wine Bottle.

By

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Abstract

The objective of this study was to test and compare Monolayer, Amosorb 2%, and Multilayer 3% PET wine jugs for package integrity and mechanical properties. In addition, two secondary package configurations were tested and analyzed. The first a shipper with load bearing inserts, the second configuration consisted of no inserts. Further, both shipping configurations and PET material have different costs associated. A Monolayer PET bottle has a savings of 17% a case compared to Amosorb and Multilayer PET bottle substrate. Shippers not utilizing inserts are $.20 less per case. The analysis was broken into three test and result phases. Phase I used compression testing to compare PET variables with two different shipper configurations. One shipper configuration was tested with load bearing inserts, the second with no inserts. The minimum compression force calculated was 500 lbs (based on warehouse stacking). Phase II testing included drop and vibration for secondary package configurations. Phase III tested primary package compression strength and drop testing. The results concluded both shipper configurations met the minimum 500 lbs compression force. Therefore a shipper with no insert is recommended for a savings of $.20 a case. Multilayer PET did not pass performance testing due to delaminating. Both Monolayer and Amosorb passed testing, however, Monolayer is recommended for production due to the 17% cost savings on material.

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Introduction

Historically wine packaging has consisted of a glass bottle and cork. Recently wine packaging has been evolving to other alternatives beyond the glass bottle. Polyethylene terephthalate, or PET has been slowly making its way into the wine industry. PET has many benefits to offer both consumers and manufacturers, but the question lingers, can wine sustain quality when packaged in a PET container? Shelf life is a critical element to a good wine. Strides in PET development have resulted in barrier technologies that can improve the shelf life of a PET bottle. Barrier technologies help PET perform more comparably to glass. In addition to shelf life, glass has excellent top load compression strength for warehouse stacking, and ROPP capping during bottling production. Package performance between glass and plastic PET bottles is recognizably different. Barrier technologies have been developed to increase shelf life performance of PET, but what about package performance and integrity? This study will discuss barrier technologies of PET and the affect each technology has on the mechanical properties, and package performance of a 3L PET wine jug.

What is PET?

Polyethylene terephthalate is a thermoplastic polyester material that can be blow molded into beverage, food, and other liquid containers (Polyethylene Terephthalate, 2007). Over the past forty years polyethylene terephthalate has become a more popular means of packaging consumer products in the market place. Sixty percent of the world's PET production is for synthetic fibers (Polyethylene Terephthalate, 2007). Bottle production accounts for around thirty percent of all global demand (Polyethylene Terephthalate, 2007). PET first exploded into the consumer market in the 1970s when a need was identified for a light weight unbreakable bottle for soft drinks (KenPlas Industry Limited, 2007). Today, in addition to soft drinks PET bottles are widely used for packaging mineral water, juice, edible oil, pharmaceuticals, cosmetics, and more (KenPlas Industry Limited, 2007).

PET bottles are extremely lightweight, and weigh on average ten percent less then their glass counterparts (KenPlas Industry Limited, 2007). Due to the decrease in weight PET bottles can also help reduce shipping costs by approximately thirty percent when compared to glass (KenPlas Industry Limited, 2007). Unlike their glass counterpart PET is unbreakable and safe. This is not only crucial to the consumer but also the manufacturer. Glass loss or breakage on productions lines is a significant issue for manufacturers packaging their product in glass. Convenience equally plays a tremendous role in the appeal of a PET bottle for consumers' bottles can be taken anywhere and re-sealed for use later(Goode, 2007). Many sports arenas prohibit glass and have taken advantage of this unbreakable PET bottle in their arena's and stadiums.

PET & Wine

Although PET is prevalent in the beverage industry, wine has yet to make a strong presence in the PET market. Nonetheless the benefits of PET are starting to convert many in the wine industry. Over the last few years a handful of wine brands have merged onto the marketplace in a plastic PET container. Wine companies started introducing some of their smaller size SKU's to consumers in a PET bottle. Currently Sutter Home packages several wine varietals in a PET 187ml bottle (Tinney, 2007). Recently 750ml sizes have been slowly creeping into the marketplace as well. For example, an article from Package Design (2007) states “Yellow Jersey Wine from Boisset Vins & Spiritueux in Bourgogne, France was the first 750ml PET bottle commercially manufactured and filled in North America.” The 750ml PET bottle is the largest PET wine bottle in the North American retail market place today. However the PET trend is moving to larger size wine bottles such as 1L, 1.5L, 3L and 4L in the near future.

Traditionally packaged wine in glass bottles can cause issues for manufacturers. Unfortunately glass is very difficult to obtain in small quantities with custom shapes and colors (Birkby, 2004). Correspondingly glass molds are extremely expensive and can cost 5-10 times higher than PET molds (Birkby, 2004). PET containers can be produced more economically than glass with run sizes as low as 50,000 units (Birkby, 2004). On the other side wine consumers in the United States are evolving as well, and are willing to explore and embrace alternative packaging including PET wine bottles (Tinney, 2007).

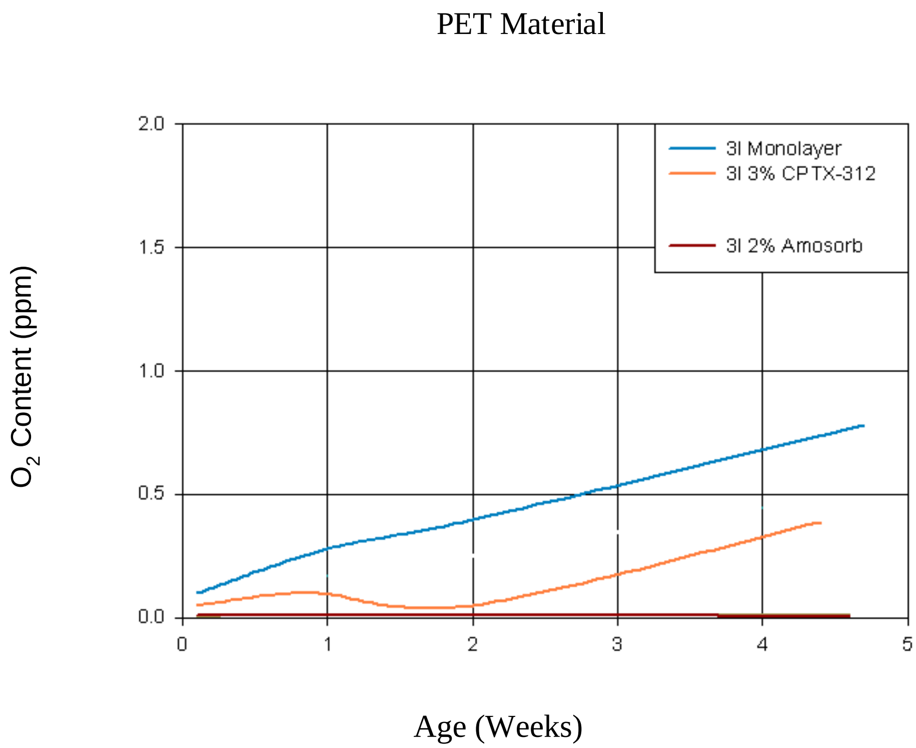
Oxygen Ingress

One important benefit a glass container possesses over PET is preventing gas migration which protects many flavors in wine (Birkby, 2004). Glass is impervious to any gas ingress and that includes oxygen. This statement is not true for PET bottles. Although PET offers superior packaging benefits, wine companies have been reluctant to move towards a PET package. This is largely imparted to concerns with gas barrier properties of PET. Primarily the ingress of oxygen gas into the package is the major distress. Winemakers are concerned that using a PET package will decrease wine quality throughout shelf life. Over time, with exposure to oxygen wine can oxidize and form unfavorable flavors (Birkby, 2004). The color of the wine can also be affected by oxygen ingress, as well as mouth feel (Birkby, 2004). Shelf life is significantly reduced with the ingress of oxygen though a wine package. This is true not only for wine, but oxygen can also have a degrading effects on vitamins, color, and flavors in many beverages (EIAmin, 2006).

To meet consumer and retail requirements, advancements in PET have been made to increase shelf life and deter oxygen permeation (Bucklow & Butler, 2000). There are two main approaches to obtaining improved gas barrier proprieties in PET. The first is an active barrier technology (Sheffield Academic Press, 2002). The second Sheffield Academic Press (2002) describes "as the use of a barrier material as a layer in a multilayer PET structure that can be injection molded into a preform and incorporated as the barrier layer in the structure" (p.106).

In this study three PET materials will be discussed; Monolayer PET, Multilayer PET with 3% CPTX-312, and Monolayer PET with 2% Amosorb (oxygen scavenger). Figure 1 outlines the different oxygen ingress of all three materials. The Amosorb displayed the most effective oxygen barrier technology over a four week span, in comparison with multilayer and virgin monolayer. As shown in Figure 1 below multilayer PET allows oxygen to ingress through the package but at a slower rate than the virgin monolayer PET.

Figure 1. Oxygen Ingress Graph (Age by weeks)



PET Barrier Technologies

Monolayer PET does not include any additional barrier technologies in its PET resin; it is a virgin PET material. Monolayer is inexpensive because it does not contain a multilayer structure or oxygen scavengers. Monolayer 2% Amosorb contains oxygen scavengers to help improve and increase the virgin monolayer gas ingress and digress properties.

Amosorb is a resin that is used directly with converters (Van Doornik, 2001). Amosorb is a polyester copolymer which is blended with PET. The active ingredient contained in Amosorb protecting against oxygen ingress is an iron salt (Sheffield Academic Press, 2002). Paul Maul (2005) explains the scavenger reaction “as a classic oxidation reaction” (p. 2). An oxidizable plastic is used for the reaction which in this case is PET (Van Doornik, 2001). The reaction is catalyzed by a transition metal such as iron (Van Doornik, 2001). Reactions are triggered by gas movement through the plastic matrix (Van Doornik, 2001). Amosorb prevents the ingress of oxygen into the PET bottle by using the iron salt to react with the oxygen thus preventing movement into the bottle. Oxygen scavengers or Amosorb will react with the oxygen already present in the headspace inside the bottle (Van Doornik, 2001). Thus, after initial bottling oxygen will decrease over time (Van Doornik, 2001).

One downside to that technology is the shelf life is initiated immediately after the bottle is blown and molded. Amosorb starts working instantaneously scavenging oxygen. Therefore, bottles blended with Amosorb are best utilized when filled with product immediately. If these PET bottles sit in a warehouse for a prolonged period of time there will be a decrease in product shelf life. The material will scavenge the entire time bottles are stored in the warehouse, and thus active package will already be in progress. The longer the bottle scavenges in the warehouse, the less it will scavenge to protect your product throughout its lifecycle. Amosorb technology would be a viable solution for a facility that self manufactures bottles and then places them right onto their bottling lines to avoid the warehouse step completely.

Oxygen scavengers can be incorporated in a multilayer platform or a monolayer platform. However Amosorb, as a monolayer blend is significantly cheaper to produce because it utilizes standard injection equipment, unlike a multilayer (Van Doornik, 2001).

Amosorb can currently be found in the market as PET beer bottles (Van Doornik, 2001). For the purpose of this study Amosorb monolayer will be the only material discussed.

Amosorb is only one option when protecting your product from oxygen. Another option is a multilayer platform. Approximately 70% of barrier PET bottles in the market place today are multilayer structures (Leaversuch, 2005). Multilayer PET can be a combination of 3 or 5 layers. These layers consist of PET, nylon, and/or a metal catalyst. This study will concentrate on a 1.5 CPTX-312 multilayer material. CPTX-312 is a mixture of MXD6 or nylon and "cobalt" as the catalyst (Cheveron v. Continental, 2005). Nylon is an excellent barrier to gases such as oxygen and CO2. Should oxygen pass through the PET/Nylon plastic matrix the cobalt will be enabled and start to oxidize the ingress of oxygen in order to protect the product.

The composition of the multilayer PET with a 3 layer system will consist of PET for the two outer layers of a 3 layer PET system. CPTX-312 is a blend of MXD6 and "cobalt", and will compose the inner layer which does not come into contact with the product. Figure 2 below demonstrates a 3 layer multilayer composition and the oxygen ingress halted by CPTX-312. In a five layer system the layering composition is as follows; PET/ (MXD6/Cobalt)/PET/ (MXD6/Cobalt)/PET. PET is always on the outer two layers (refer to Figure 3).

Figure 2. Three Layer Multilayer PET Constructions

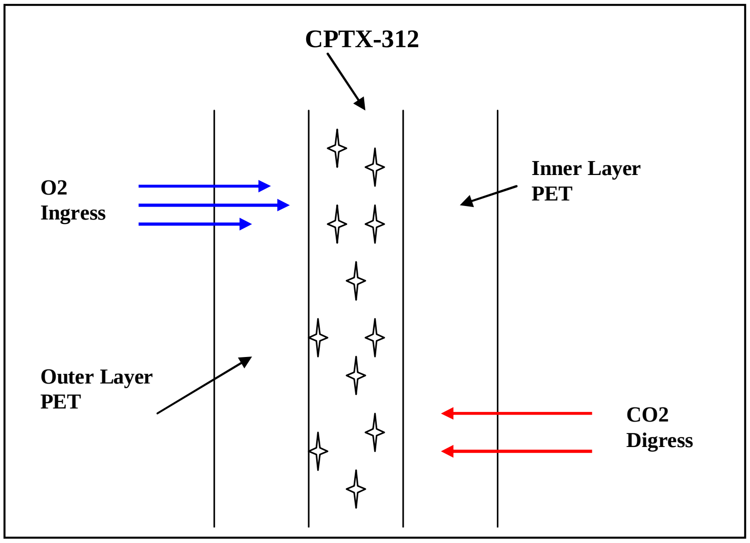
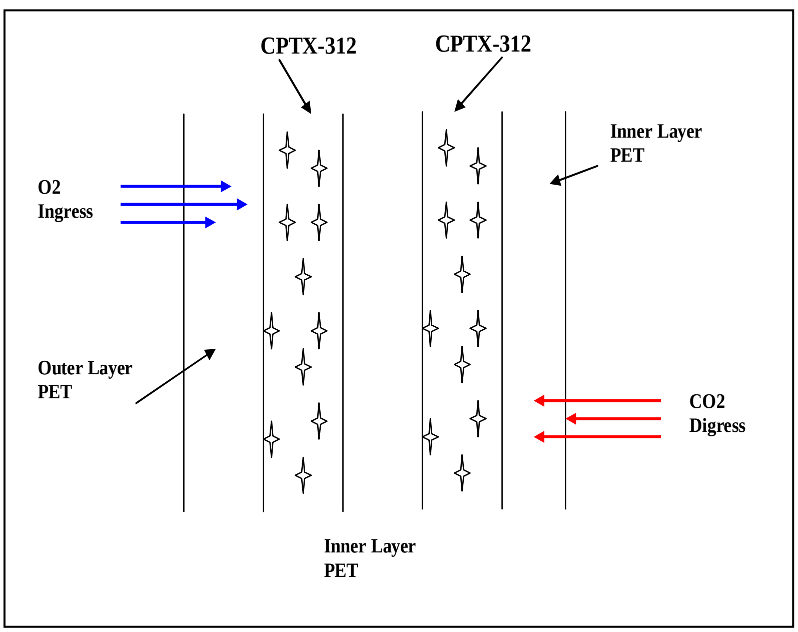


Figure 3. Five Layer Multilayer PET Constructions



Multilayer provides approximately six times the barrier protection over a monolayer PET bottle (Bucklow & Butler, 2000). There is some disadvantage to using a multilayer platform. Multilayer manufacturing is a two-step process and tooling can become costly (Peters, 2001). In addition, multilayer PET bottles are also prone to delimitation between the layers (Peters, 2001). Demalination can occur when a PET multilayer structure experiences disbonding between two layers due to stress/flex or heat (EIAmin, 2005). Layers can distort and flex at different rates, and this is what promotes the bonds between layers to break. Layers can also distort at different temperatures causing bonds to break. This can become a serious issue during the bottling and supply chain environment.

Wine Bottling & Distribution

For the wine industry converting to a PET packaging seems like a simple choice now that new barrier technologies have been developed. Nonetheless what about package integrity and structural performance? As the trend for larger volume wine packages increasingly moves towards PET what observations can be made regarding package integrity? Do barrier properties used in PET reduce mechanical properties, and package strength? For an industry primarily using glass, a rigid material, and now making a switch to PET, this is an important question.

The challenge associated with PET and wine bottle design is to simulate the look of the current wine glass bottle in order to create brand association. Keeping the concept of a traditional wine bottle will provide an easier transition to PET for the consumer. Sustaining the look of a glass bottle in a PET package can prove difficult when trying to keep package integrity. Many of the PET advancements in structural integrity can not be taken advantage of when trying to conform to the look of a traditional wine bottle. For example, adding horizontal ridges to the container can help provide top load support and decrease paneling (indentation in a bottles sidewalls). These ridges would not be conducive for a glass bottle appeal. Adding more material to provide a stronger package can cause a cloudy look to the bottle. This cloudy look does not give off the perception of a glass bottle.

The ideal package for a 3L wine container will look similar to the current glass bottle/jugs in use and perform adequately during bottling and distribution environments. In the distribution/supply chain environment 3L wine PET pallets could potentially be stacked 3 high in the warehouse for a one year time period. A disadvantage in the wine industries supply chain is the “middle man” or distributor. After bottling, product is shipped to a distributor’s warehouse and then from the warehouse shipped to the final customer (liquor store, Wal-Mart, etc.). During shipping and warehousing, boxes of the 3L containers are subjected to large variations of crush loads and could be permanently deformed or even leak if package integrity is lacking and shippers are stacked too high (Grant, 2005). The 3L PET wine bottle/shipper configurations must also withstand warehouse and truck load stacking compressions.

In this study when producing the 3L PET wine bottles a 38mm ROPP (Roll on Pilfer Proof) metal cap will be utilized. This means the bottle will have to withstand top load capping pressures of approximately 200lbs without sidewall paneling or buckling. On the bottling lines 3L bottles are also dropped into shippers by the case packer. This is usually at a drop height of 6". Bottles will have to perform in all of the above conditions to meet customer demands.

Objectives and Assumptions

The objective of this research is to evaluate mechanical properties and integrity of Multilayer 3%, Amosorb 3%, and Monolayer 3L PET wine bottles. A comparison of strength and integrity between the different barrier technologies will be evaluated. Through a series of performance testing including compression, vibration, top load bottle compression, and primary package drop tests it will be determined if there is any significant difference in package integrity between the PET variables. This study will also determine the secondary package configuration. Compression testing will conclude which shipper is required to obtain sufficient stacking strength for the 3L PET bottles. A shipper containing four 3L PET jugs with load bearing insert will be tested and compared with a shipper containing only four 3L PET jugs and no inserts.

Business Case

When comparing the three PET variables there is a noticeable difference in price between Monolayer and Barrier PET (Amosorb and Multilayer). Table 1 shows a .36 cent or 17% increase in cost when purchasing a barrier material. Based on a yearly volume of 700,000 cases purchasing a barrier technology PET would incur an added $252,000 a year in material cost.

Table 1: Bottle Cost Analysis

Bottle	Mono Layer	Amosorb/Multilayer	Total Difference
Cost/Case	$2.10	$2.46	$.36

Shipper configurations also show a $.20 increase per case for inserts. Eliminating the need for inserts can save $140,000 a year. Total packaging savings for a Monolayer package configuration with no inserts will be $392,000 annually.

Materials and Method

PET wine bottles with a volume of 3 liters will be tested and evaluated through a series of packaging performance testing to determine package integrity (refer to appendix for bottle drawing). This study will focus on three phases of performance testing. Phase I will include compression testing to determine if load bearing inserts are necessary in the secondary package configuration. It will be determined in Phase I if the secondary package will require load bearing inserts to withstand designated compressive forces. One shipper variable will be eliminated from the remainder of the testing based on the results from Phase I. Phase II will include secondary package drop testing and vibration testing. Shipper configurations include four 3L PET wine bottles capped with a 38mm ROPP closure. All bottles will be filled with water to a fill height of 9.45”. Phase III will consist of primary package testing through a series of compression and drop tests. Tables 1 through 7 below outline the secondary and primary performance testing to be conducted.

Equipment

This study will utilize the Rochester Institute of Technology packaging lab and equipment located in Rochester, NY.

Table 1. Test Equipment

Test	Equipment	Max
Compression Test	Lansmont 122 – 15 Compression Tester	15,000 lbs max force
Drop Test	Lansmont PDT 227 Drop Tester	500 lbs Capacity
Vibration	Model 7000 Vibration Tester	2500 lbs max weight
Top Load	Lansmont 122 – 15 Compression Tester	15,000 lbs max force

PHASE I: Secondary Package Compression Testing

Table 2. Compression Test: Materials and Test Samples

PET Variable and Sample Number	**RSC Shipper** **11.875 x 11.875 x 12.31** **32 ECT C**	**RSC with H divider (Load Bearing Insert)** **11.93 x 11.93 x 12.31** **32 ECT C**
Multilayer 3%	10 RSC shippers 40 Multilayer PET Bottles 40 38mm ROPP caps per case	10 HLC shippers 40 Multilayer PET Bottles 40 38mm ROPP caps per case
Amosorb 2%	10 RSC shippers 40 Amosorb PET Bottles 40 38mm ROPP caps per case	10 HLC shippers 40 Amosorb PET Bottles 40 38mm ROPP caps per case
Monolayer (Virgin)	10 RSC shippers 40 Monolayer PET Bottles 40 38mm ROPP caps per case	10 HLC shippers 40 Monolayer PET Bottles 40 38mm ROPP caps per case

60 Total Test Samples, each weighting 29 lbs.

PHASE I: ASTM D 4169-99

Compression Testing: Test Method ASTM D 642

The purpose of compression testing is to measure a containers ability to withstand the compressive forces of warehouse stacking. Compression testing will be conducted on secondary packaging configuration. It was found through the calculation below a shipper on a bottom tier pallet configuration consisting of twelve cases per layer stacked four layers high must withstand a minimum compression strength of 435 lbs. To account for humidity, stacking configuration, rotation, etc. a safety factor of 5 was used. Two corrugate variables will be tested. The first a RSC shipper and second a HLC shipper with load bearing inserts. The goal would be to reduce cost and material by using a shipper with no inserts for production. However, it must first be determined if a shipper without load bearing inserts can withstand compressive loads of 500 lbs. Shippers will be tested for a peak force at a rate of deflection.

Table 3: Compression Load Calculation per Bottle

$$\frac{\text{\# Bottles x \# Cases per layer x weight of bottle x (\# of columns high - bottom layer)}}{\text{\# bottles on the bottom row}}$$

= 21.75 lbs per bottle x 4 (bottles per case) x 5 (safety factor) = 435 lbs

PHASE II: Secondary Package Drop Testing and Vibration Testing

Table 4. Phase II Secondary Packaging: Drop Testing.

MATERIAL/BOTTLES	RSC Shipper 11.875 x 11.875 x 12.31 32 ECT C	RSC with H divider (Load Bearing Insert) 11.93 x 11.93 x 12.31 32 ECT C
Multilayer 3%	10 RSC shippers 40 Multilayer PET Bottles 40 38mm ROPP caps per case	10 HLC shippers 40 Multilayer PET Bottles 40 38mm ROPP caps per case
Amosorb 2%	10 RSC shippers 40 Amosorb PET Bottles 40 38mm ROPP caps per case	10 HLC shippers 40 Amosorb PET Bottles 40 38mm ROPP caps per case
Monolayer (Virgin)	10 RSC shippers 40 Monolayer PET Bottles 40 38mm ROPP caps per case	10 HLC shippers 40 Monolayer PET Bottles 40 38mm ROPP caps per case

60 Total Test Samples, each weighting 29 lbs.

PHASE II: Drop Testing: Test Method ASTM D 5487

Drop testing will help determine how the package withstands handling in the distribution environment. The drop test will be dependent on the results of Phase I whether both shippers with and without inserts will be tested. If one of the corrugate shipper variables can be eliminated through compression testing in Phase I drop testing will include only one shipper variable. Drop test acceptance criteria will include no holes or rips in the shippers. Denting is acceptable. Inner bottles will have no scuffing or punctures.

ASTM D 5487 - Simulated Drop of Loaded Containers by Shock Machines

Table 5. Secondary Package Drop Sequence: (Each Shipper)

Drop Height	**Impact Orientation**
13 in (330mm)	Top
13 in (330mm)	Bottom Edge
13 in (330mm)	Adjacent Bottom Edge
13 in (330mm)	Bottom Corner
13 in (330mm)	Diagonally Opposite Bottom Corner
13 in (330mm)	Bottom

Vibration Testing: Test Method ASTM D 4728

Table 6. Secondary Package Monolayer Vibration Testing

MATERIAL/BOTTLES	RSC Shipper 11.875 x 11.875 x 12.31
Monolayer (Virgin)	1 Full Pallet (48 Cases)

Random vibration testing of shipping containers is intended to determine the ability of the shipping units to withstand the vertical vibration and dynamic compressions resulting from transport and stacking. The vibration describes a motion regarding a fixed reference point. Hertz represents the frequency and g^2/Hz measures the intensity of the random vibration (Soroka, 1999). The most troublesome frequencies when transporting via truck occur below 30 hertz because they are most prevalent in vehicles (Soroka, 1999). Frequencies above 100 hertz are usually of very little concern because the vibration output will be less than the input received (Soroka, 1999). For this test protocol bottle acceptance criteria will be minimal scuffing, no bigger than .25 in diameter. Vibration testing samples will be dependant on the results from Phase I. Test Samples will run through the random vibration sequence referenced in Table 7.

Table 7. Truck/ Vibration Profile
Test Duration: 180 min

Frequency (Hz)	PSD (g^2/Hz)
1	0.00005
4	0.01
16	0.01
40	0.001
80	0.001
200	0.00001

PHASE III: Primary Package Compression and Drop Testing

Table 8. Material, Samples, and Testing For Primary Packaging

MATERIAL/BOTTLES	Bottle Compression Test NO secondary package
Multilayer 3%	10 Bottles 10 38 mm ROPP caps
Amosorb 2%	10 Bottles 10 38 mm ROPP caps
Monolayer (Virgin)	10 Bottles 10 38 mm ROPP caps

During preliminary studies it was determined each bottle is to be sealed with a ROPP cap, which requires a minimum of 200 lbs during application. If the ROPP cap is applied under 200 psi application the removal torques were found unsatisfactory. All 3L variables must withstand a minimum of 200 lbs. Bottles will be tested for a peak force at a rate of .050 deflection.

Table 9. Primary Package Drop Sequence.

Drop Height	Impact Orientation
13 in (330mm)	Bottom Corner
13 in (330mm)	Diagonally Opposite Bottom Corner
13 in (330mm)	Bottom

ASTM D 5487 - Simulated Drop of Loaded Containers by Shock Machines will also be performed on the bottle itself without the shipper. Drop testing of the bottling will determine if scuffing or delimitation will occur during handling and case packing. Acceptance criteria will include no delaminating of the multilayer material. Scuffing will not be great than an area of .50” and no punctures will exist on any PET variable test.

Results & Discussion

PHASE I: Secondary Package Compression Testing Results

Phase I consisted of compression testing including Monolayer, Amosorb, and Multilayer PET variables in a shipper configuration with and without load bearing inserts. A pass/fail compression force was previously established at 500 lbs. Both shipper configurations with and without inserts were tested for peak compression force at a deflection rate of .050. All samples passed the minimum 500 lb compression force. Monolayer had a higher average peak compression force vs. Amosorb PET and Multilayer PET.

Table 10. Multilayer PET Secondary Package Compression Data

MULTILAYER			
Samples with Inserts	**Peak Force (lbs)**	**No Inserts**	**Peak Force (lbs)**
Sample 41	1518	Sample 51	814
Sample 42	1733	Sample 52	519
Sample 43	1250	Sample 53	1274
Sample 44	1147	Sample 54	989
Sample 45	1036	Sample 55	923
Sample 46	1008	Sample 56	1071
Sample 47	1220	Sample 57	1162
Sample 48	1245	Sample 58	1110
Sample 49	1343	Sample 59	1025
Sample 50	1197	Sample 60	1124
Total Average	**1269.7**		**1001.1**

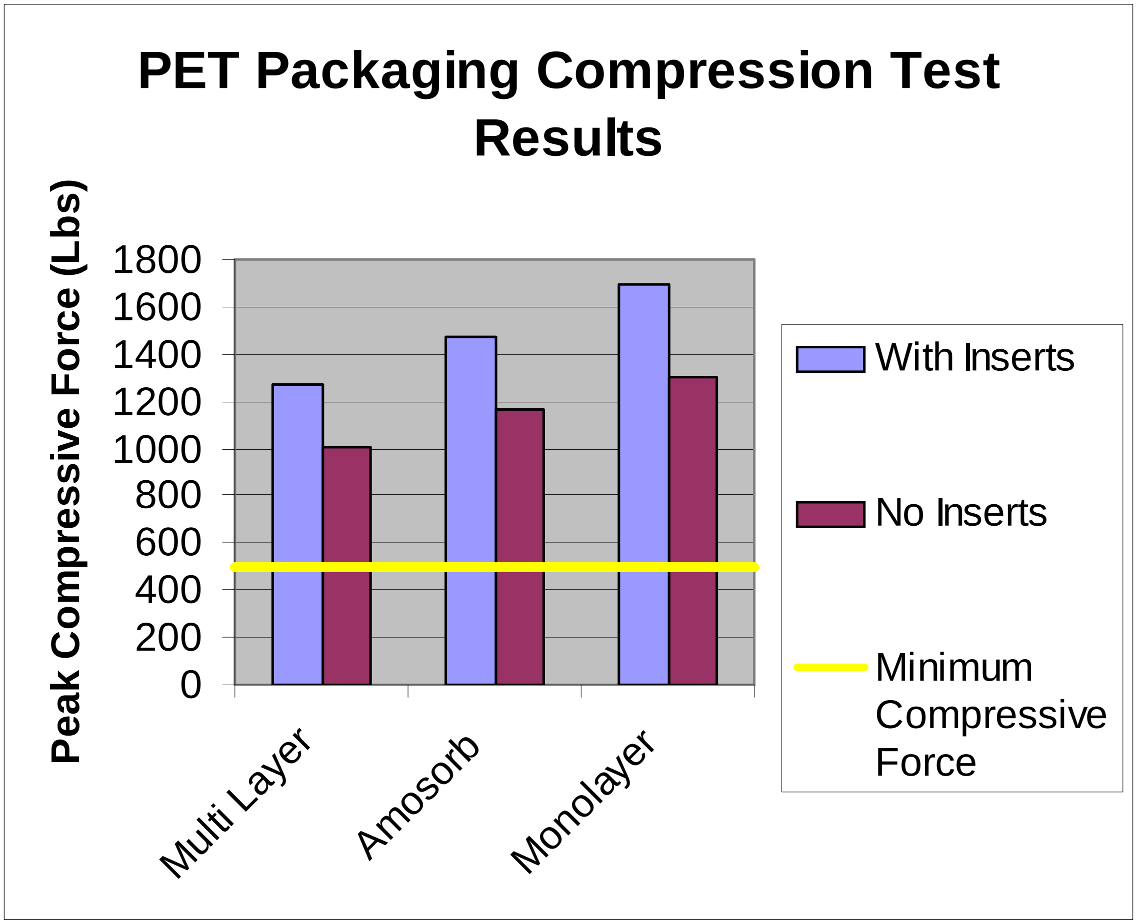
Table 11. Amosorb PET Secondary Package Compression Data

AMOSORB			
Samples with Inserts	**Peak Force (lbs)**	**No Inserts**	**Peak Force (lbs)**
Sample 21	1521	Sample 31	1153
Sample 22	1287	Sample 32	1198
Sample 23	1321	Sample 33	1198
Sample 24	1334	Sample 34	1005
Sample 25	1622	Sample 35	1243
Sample 26	1467	Sample 36	1196
Sample 27	1566	Sample 37	1214
Sample 28	1655	Sample 38	1005
Sample 29	1432	Sample 39	1217
Sample 30	1524	Sample 40	1216
Total Average	**1472.9**		**1164.5**

Table 12. Monolayer PET Secondary Package Compression Data

MONOLAYER			
Samples with Inserts	**Peak Force (lbs)**	**No Inserts**	**Peak Force (lbs)**
Sample 1	1738	Sample 11	1176
Sample 2	1944	Sample 12	1338
Sample 3	1790	Sample 13	1619
Sample 4	1765	Sample 14	1052
Sample 5	1915	Sample 15	1535
Sample 6	1453	Sample 16	1469
Sample 7	1566	Sample 17	1425
Sample 8	1338	Sample 18	1103
Sample 9	1619	Sample 19	1217
Sample 10	1821	Sample 20	1058
Total Average	**1694.9**		**1299.2**

Figure 4. PET Secondary Package Comparative Bar Graph.



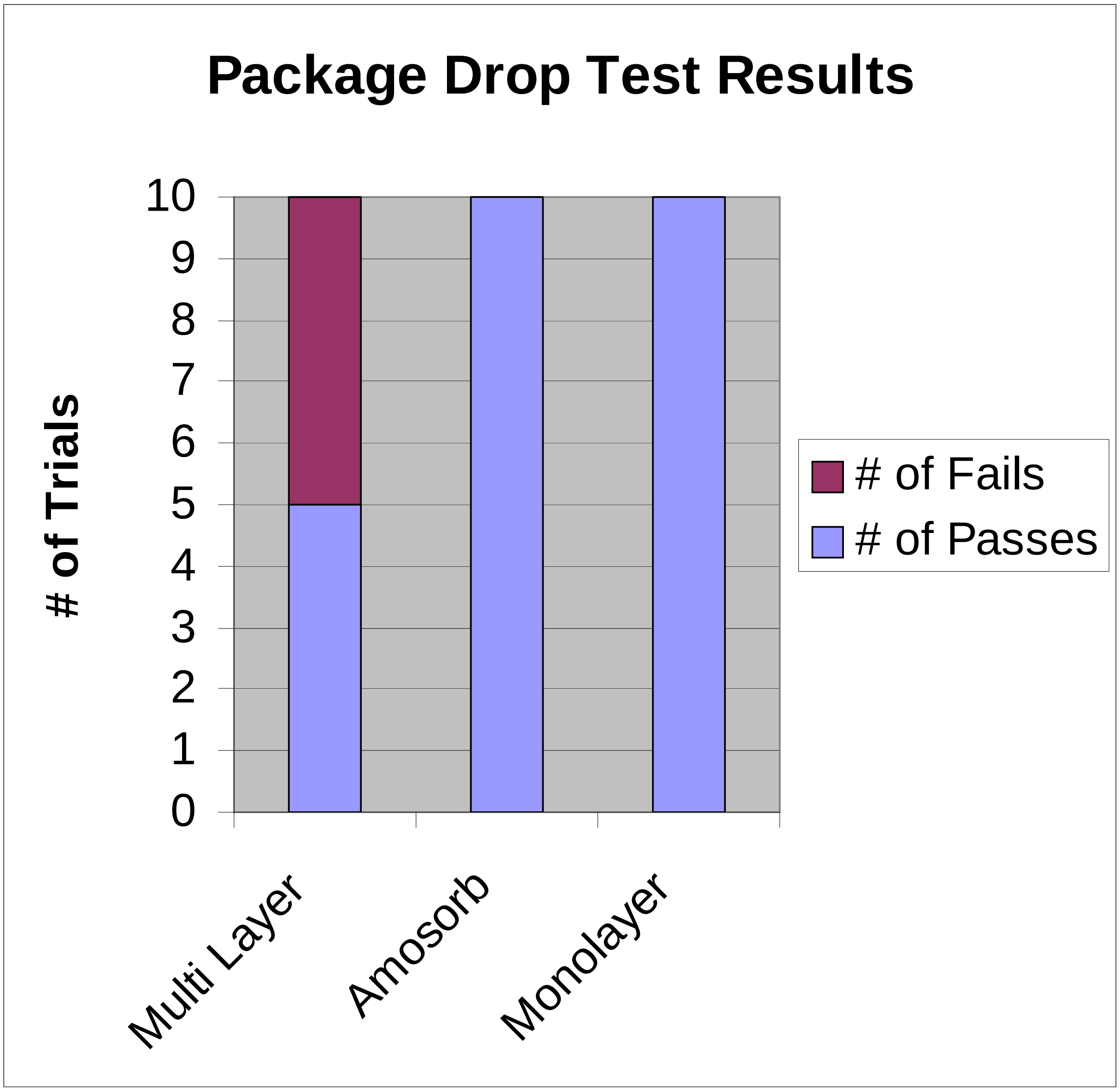
PHASE II: Secondary Package Drop Testing and Vibration Testing Results

Drop test acceptance criteria included no holes or rips in the shippers, denting was acceptable. Inner bottles can not display any scuffing or punctures. Multilayer PET had 5 test packages fail or a 50% failure rate due to delamination.

Table 13. PET Secondary Package with No Inserts Drop Test Results.

Multilayer		Amosorb		Monolayer	
Sample # No Inserts	Pass/Fail	Sample # No Inserts	Pass/Fail	Sample # No Inserts	Pass/Fail
Sample 51	Pass	Sample 31	Pass	Sample 11	Pass
Sample 52	Pass	Sample 32	Pass	Sample 12	Pass
Sample 53	Pass	Sample 33	Pass	Sample 13	Pass
Sample 54	Fail	Sample 34	Pass	Sample 14	Pass
Sample 55	Fail	Sample 35	Pass	Sample 15	Pass
Sample 56	Pass	Sample 36	Pass	Sample 16	Pass
Sample 57	Fail	Sample 37	Pass	Sample 17	Pass
Sample 58	Fail	Sample 38	Pass	Sample 18	Pass
Sample 59	Pass	Sample 39	Pass	Sample 19	Pass
Sample 60	Fail	Sample 40	Pass	Sample 20	Pass

Figure 5. PET Secondary Package Drop Comparative Bar Graph



Vibration Test Results

A pallet consisting of 12 cases per layer, 4 layer high configuration went through a random vibration test for 180 minutes. Bottle acceptance criteria will be minimal scuffing no bigger than .25 in diameter. The results concluded no visible damage to the primary or secondary package. The secondary package displayed minor denting.

Table 14. Monolayer Secondary Package Vibration Test Results

Monlayer Vibration Test Samples							
Sample	**Pass/Fail**	**Sample**	**Pass/Fail**	**Sample**	**Pass/Fail**	**Sample**	**Pass/Fail**
Pallet Shipper 1	Pass	Pallet Shipper 13	Pass	Pallet Shipper 25	Pass	Pallet Shipper 37	Pass
Pallet Shipper 2	Pass	Pallet Shipper 14	Pass	Pallet Shipper 26	Pass	Pallet Shipper 38	Pass
Pallet Shipper 3	Pass	Pallet Shipper 15	Pass	Pallet Shipper 27	Pass	Pallet Shipper 39	Pass
Pallet Shipper 4	Pass	Pallet Shipper 16	Pass	Pallet Shipper 28	Pass	Pallet Shipper 40	Pass
Pallet Shipper 5	Pass	Pallet Shipper 17	Pass	Pallet Shipper 29	Pass	Pallet Shipper 41	Pass
Pallet Shipper 6	Pass	Pallet Shipper 18	Pass	Pallet Shipper 30	Pass	Pallet Shipper 42	Pass
Pallet Shipper 7	Pass	Pallet Shipper 19	Pass	Pallet Shipper 31	Pass	Pallet Shipper 43	Pass
Pallet Shipper 8	Pass	Pallet Shipper 20	Pass	Pallet Shipper 32	Pass	Pallet Shipper 44	Pass
Pallet Shipper 9	Pass	Pallet Shipper 21	Pass	Pallet Shipper 33	Pass	Pallet Shipper 45	Pass
Pallet Shipper 10	Pass	Pallet Shipper 22	Pass	Pallet Shipper 34	Pass	Pallet Shipper 46	Pass
Pallet Shipper 11	Pass	Pallet Shipper 23	Pass	Pallet Shipper 35	Pass	Pallet Shipper 47	Pass
Pallet Shipper 12	Pass	Pallet Shipper 24	Pass	Pallet Shipper 36	Pass	Pallet Shipper 48	Pass

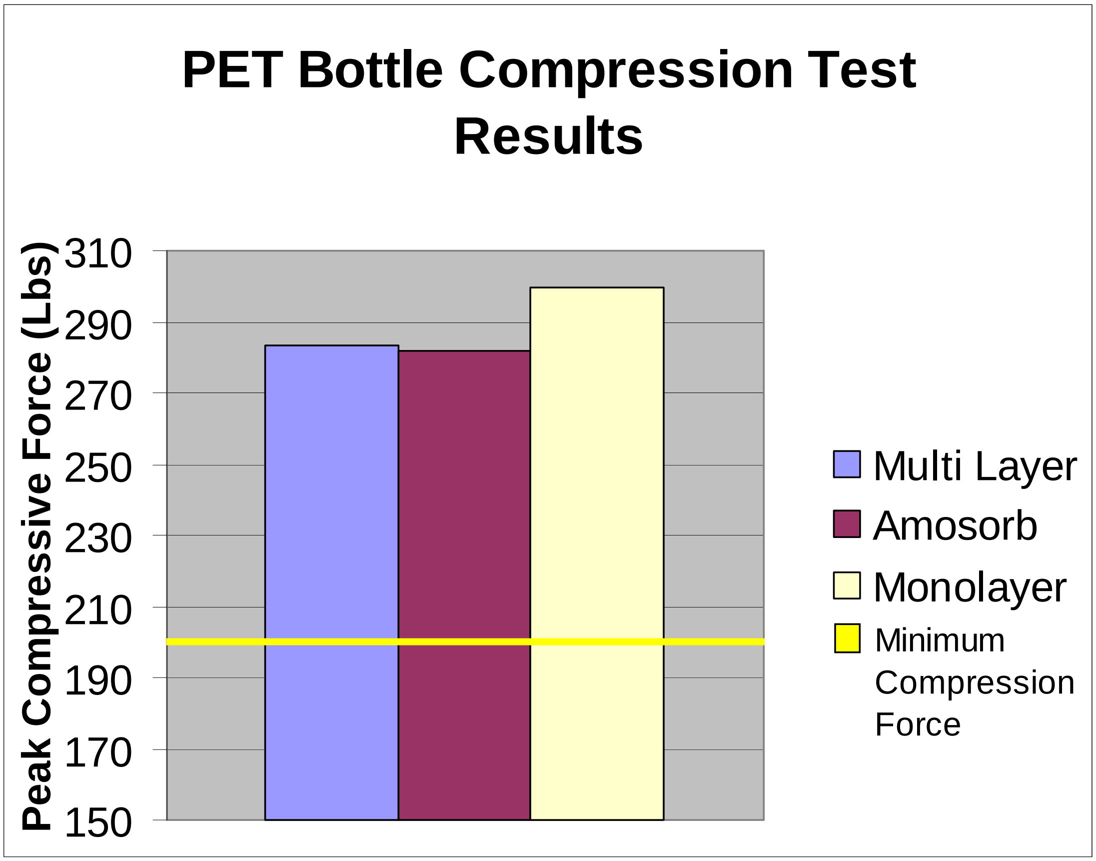
PHASE III: Primary Package Compression and Drop Testing

All PET variables must withstand a minimum of 200 lbs compression force. Bottles were tested for a peak force at a rate of .050 deflection. All bottles passed the minimum 200 lbs peak compression force, all variables performed comparably.

Table 15. PET Primary Package Compression data and comparative bar graph.

PET	Multi Layer		Amosorb		Monolayer
Sample #	**Peak Compressive Force (Lbs)**	**Sample #**	**Peak Compressive Force (Lbs)**	**Sample #**	**Peak Compressive Force (Lbs)**
Bottle 1	274	Bottle 11	296	Bottle 21	323
Bottle 2	278	Bottle 12	276	Bottle 22	275
Bottle 3	316	Bottle 13	277	Bottle 23	315
Bottle 4	273	Bottle 14	281	Bottle 24	301
Bottle 5	281	Bottle 15	271	Bottle 25	299
Bottle 6	283	Bottle 16	292	Bottle 26	279
Bottle 7	276	Bottle 17	263	Bottle 27	306
Bottle 8	290	Bottle 18	298	Bottle 28	293
Bottle 9	274	Bottle 19	285	Bottle 29	311
Bottle 10	288	Bottle 20	278	Bottle 30	295
Total Average	**283.3**		**281.7**		**299.7**

Figure 6. PET Primary Package Compression Test Results and Comparative Bar Graph

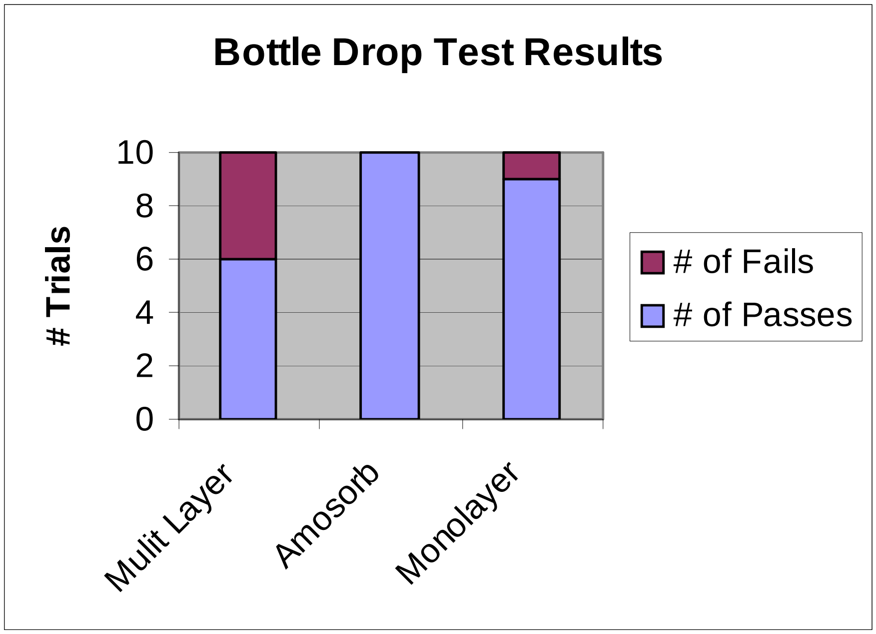


Through preliminary research it has been determined the 3L PET bottle itself must withstand 200 psi of pressure in order to be bottled. Due to the thickness of the sidewall it will be important to watch for paneling during testing. Expected results include utilizing a shipper with no inserts over a shipper with load bearing inserts. Multilayer bottles will succumb to delaminating during drop testing. There will be a significant difference in performance between multilayer and monolayer variables. Drop test acceptance criteria include scuffing at a minimum area of .50" and no punctures will exist on any PET variable tested.

Table 16. PET Primary Package Drop Test Results

Multilayer		Amosorb		Monolayer	
Sample # No Inserts	**Pass/Fail**	**Sample # No Inserts**	**Pass/Fail**	**Sample # No Inserts**	**Pass/Fail**
Bottle 21	Pass	Bottle 11	Pass	Bottle 1	Pass
Bottle 22	Pass	Bottle 12	Pass	Bottle 2	Pass
Bottle 23	Fail	Bottle 13	Pass	Bottle 3	Pass
Bottle 24	Pass	Bottle 14	Pass	Bottle 4	Pass
Bottle 25	Fail	Bottle 15	Pass	Bottle 5	Pass
Bottle 26	Fail	Bottle 16	Pass	Bottle 6	Pass
Bottle 27	Pass	Bottle 17	Pass	Bottle 7	Pass
Bottle 28	Pass	Bottle 18	Pass	Bottle 8	Fail
Bottle 29	Pass	Bottle 19	Pass	Bottle 9	Pass
Bottle 30	Fail	Bottle 20	Pass	Bottle 10	Pass

Figure 7. PET Primary Package Drop Test Results and Comparative Bar Graph



Conclusions and Recommendations

The findings in this study are meaningful. In Phase I the study demonstrated both package configurations with and without load bearing inserts out performed the minimum 500 lb peak compression force. Since both package configurations passed the minimum requirement load bearing inserts are not necessary to keep package integrity and were eliminated from the remainder of the testing. A shipper configuration with no load bearing insert is recommended with a savings of $.20 a case or $140,000 annually. Phase I also demonstrated Monolayer PET out performed Amosorb with a peak compression force variance of 135 lbs greater, and Multilayer with a variance of 298 lbs greater.

Phase II findings displayed Multilayer having a 50% failure rate due to delaminating of material at a drop height of 13". This is meaningful and suggests multilayer has the potential for a 50% failure rate throughout the distribution cycle.

Phase III primary package testing concluded this study. Monolayer out performed both Amosorb and Multilayer during top load compression testing. All three variables met the minimum of 200 lb peak compression force. Multilayer material displayed a 40% failure rate during single bottle drop testing due to delaminating.

Based on the data and business case Monolayer material has proved to be the best option. Monolayer passed all performance testing and is $.36 a case less expensive than Amosorb or Multilayer PET. This equals an annual savings of $252,000. This eliminates Amosorbs and Multilayer as a potential PET material due to a 17% higher price point.

Recommendation for future areas of study

Potential areas for future studies:

1) Measure the PET material Plasmax (developed by Ball Plastics) for performance testing vs. Monolayer PET.
2) This study was limited due to the number of samples obtained from the supplier. A further study utilizing more samples to reiterate and prove findings is suggested.
3) Research PET vs. glass in regards to energy and freight/fuel savings.
4) During this study multilayer bottles were found to delaminate. Further testing can prove or disprove the results, and provide significant data regarding multilayer and delaminating.

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Appendix A
3L PET Wine Bottle Drawing