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EVALUATION OF SEVEN DIFFERENT LAMINATION STRUCTURES BASED ON THE MECHANICAL AND PHYSICAL PROPERTIES

By:

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ABSTRACT

EVALUATION OF SEVEN DIFFERENT LAMINATION STRUCTURES BASED ON THE MECHANICAL AND PHYSICAL PROPERTIES

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This research will provide information and guidance on how to evaluate flexible packaging lamination structures. The laminations studied were: three different kinds of Dryflex material, three different kinds of Nylon material and one kind of Tyvek® material. A detailed explanation of the manufacturing process for each of them is included. This discussion is focused towards performance testing.

The tests performed were classified in eight different categories. Each test quantitatively compares the lamination structures on a variety of factors directly related to performance in the following applications: Capping, Cost, Dart Drop, Foil Delamination, Heat Seal, Performance on Pallets, WVTR and Sliding, Folding and Label Adhesion. Each test provides general information, the test description and test results. The testing was done according to ASTM standards or to in-house testing methods. A detailed ranking system was used for each test, to categorize the performance, with the intention of identifying the best structure or the best performance.

The results show better performance from the Dryflex-B and Dryflex-C structures, compared to the nylons and Tyvek®. Nylon laminations are suitable for corrugated packages, but do not have the strength needed for other applications. The lamination with the overall best performance was the Dryflex-C. The main reasons for this result were: its manageability (Sliding, Folding and Label Adhesion), the Foil Delamination test, and the WVTR test. In all these tests the lamination reached the top score.

This study also demonstrate how the mechanical properties of a lamination structure can be improved by adding a LLDPE layer. It is appropriate to mention that a layer of LLDPE adds to the structure desirable properties against puncture, in this study represented by the dart drop test. All the samples that contained the LLDPE layer performed six and above in the ranking scale, while those which did not have it performed lower, with the exception of Nylon-A, which has a thicker nylon layer.

This study provide guide lines to objectively evaluate and select different numbers of alternatives based on the lamination performance. The same concepts can be adapted to other applications, in which it will be necessary to select one alternative among others.

FOR:

To my friends, Carla, Sunetra, Henrique and Tatsutya, who supported me during two beautiful years in East Lansing and to Jeff, who constantly reminded me to finish.

To my family, Naydita, Mami and Papi, because you always motivate me to reach my dreams.

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1.0 INTRODUCTION

Survival, in today's world marketplace, is strongly influenced by a company's ability to maintain a competitive edge. Companies that are able to maximize product performance and quality, while minimizing cost, will remain profitable and will remain in business. These are the companies using the right tools for improvements. One of the most valuable tools a company can employ to maintain and to improve its competitive edge is packaging. This is accomplished by optimizing and standardizing the type of package used as well as preserving the value of the product at the lowest cost.

This study has been made on the primary package of the polyvinyl butyral roll. Tough, resilient polyvinyl butyral (PVB) is used as a plastic interlayer in manufacturing laminated glass for use in both commercial and residential applications. The performance benefits of laminated glass include improved safety, security, sound control, solar control, UV screening, structural strength, hurricane resistance, earthquake performance, and wide color range.

Laminated glass is the same type of glass used in car windshields, in the Louvre Pyramid in Paris France, and in aircraft windows. It consists of two pieces of glass bonded together permanently through heat and pressure. Once bonded together, this "sandwich" behaves as a single piece. The interlayer is invisible when viewed through the glass, and with glass on either side, the finished product is indistinguishable from plain glass when installed. Most often, laminated glass is produced using annealed glass, but heat strengthened or tempered glass can be used when special performance needs are present. If the glass is broken, the glass fragments adhere to the plastic interlayer rather than falling free and potentially causing injury. Laminated annealed glass can be cut or drilled (Monsanto, 1997).

The three main raw materials used to make polyvinyl butyral are: resin, plasticizer and stabilizer. The ingredients are mixed together and then fed into the extrusion process where the mix is melted and is flowed to a die roll to form the polyvinyl butyral sheet. The sheet is conveyed down the line over hot rolls to eliminate any stresses in the sheet, then into a hot tub to reach the desired moisture content. Next, the sheet goes into a cold bath to stiffen it. Following the cold bath, the sheet runs through air knives for drying. The sheet is checked online for thickness profiles. The edges of the sheet are trimmed for the desired winding width. Later, the sheet runs though an "on line" laser that detects any defects. The sheet is finally wound into rolls on the winder. The rolls off the winder are identified and packed in laminated bags. This constitutes the primary package of the polyvinyl butyral roll.

The bags are made of a lamination, or combination of different substrates added together. In-house, the lamination is heat sealed, cut to size and converted into a bag. The bag will protect the roll, not only from the migration of moisture, but also from damage during handling and transportation.

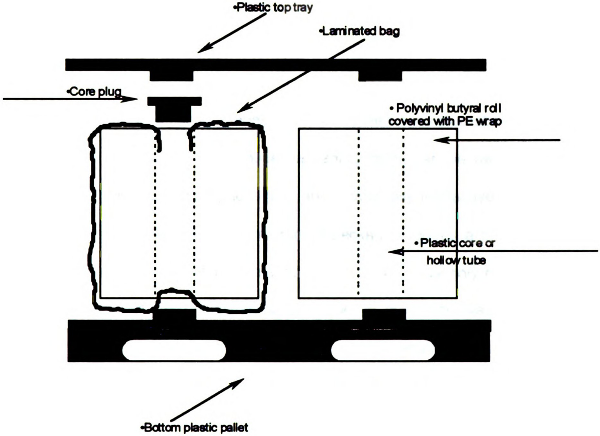
In the lamination, each layer has a specific function. For example, the outer layer is for the strength, puncture resistance, and most of the mechanical properties of the lamination. Two tie layers will work as adhesives to add the foil to the lamination. The aluminum foil layer will provide the barrier properties, the protection against the migration of moisture and oxygen into the roll. The sealant layer will manage the heat seal performance. Using an adhesion or an extrusion manufacturing process, all these layers are placed together to form the lamination structure. Different arrangements of the layers, as well as different kind of layers, will result in different physical and mechanical properties.

One of the objectives of this study is to develop an effective replacement alternative for the current lamination outer layer (Tyvek®). The criteria for a successful replacement were based on the performance of the mechanical properties, physical properties and cost of the lamination. During a period of eight months, several alternatives were considered. The following information contains the criteria for the selection of the replacement lamination structure for the polyvinyl butyral bag.

1.1 Package Description

The polyvinyl butyral roll is wound on a plastic core or tube. Each roll can weight more than 1000 pounds and overall measurements vary from ~ 30" wide up to 60" high. In the winder, it is covered with a polyethylene (PE) wrap to prevent contamination from flying or loose particles. At the same level of packaging, a bag (made of the lamination) is placed around the roll. One of the bag's end has been heat sealed; the other one is open for transportation and roll handling. Once the roll reaches the transportation pallet, it is conveyed to the capping station. Here the surplus bag length is inserted into the core and the bag is sealed with a core plug or cap. Figure 1 contains a description of the packaging elements.

Figure 1: Package Description



In summary, the primary elements of the package are:

- Plastic core or hollow tube, to wind on
- PE wrap, to prevent dust contamination
- Bag, principal element for protection

- Core plug, to seal the bag

There are two different kinds of secondary packages for the polyvinyl butyral roll: it can be packaged in a plastic returnable package or in a corrugated non- returnable package. The non-returnable package is composed of a wood pallet, a corrugated bottom tray, a corrugated pad, a corrugated side wall, and a corrugated top tray. It is banded with a polyethylene terephthalate (PET) band and then identified with a label. The returnable package is composed of a bottom plastic pallet and a plastic top tray. It is banded together with a PET band and then identified with a label. The corrugated non-returnable package contains more components. All these packaging items can be reusable and recyclable, but the corrugated package is environmentally ineffective compared with the returnable package. The returnable package requires a bigger initial cost investment, but with a reasonable number of turns, it not only reaches the break even point, but also gives an excellent return on the initial investment.

The industry trend is to implement the use of returnable packages to contribute not only to the environment, but also to the company source reduction policies. At this time, the primary package of the polyvinyl butyral roll becomes critically important. All the protection against transportation damage is provided by the laminated bag. This study will evaluate the performance of seven different lamination structures, with the aim of obtaining one, with reliable mechanical and physical properties to provide the desired protection. For identification purposes, all the bag laminations will be named by their outer layer.

The alternatives for consideration are:

* Dryflex-A, lamination with an outer layer of 3.0 mil Valeron®
* Dryflex-B, lamination with an outer layer of 2.5 mil Valeron®
* Dryflex-C, lamination with an outer layer of 2.5 mil Valeron® and low density polyethylene (LDPE) as the sealant layer
* Nylon-A, lamination with an outer layer of 67 gauge Nylon and a Saran® coating
* Nylon-B, lamination with an outer layer of 60 gauge Nylon and ethylene-vinyl acetate (EVA) as the sealant layer
* Nylon-C, lamination with an outer layer of 60 gauge Nylon and linear low density polyethylene (LLDPE) as the sealant layer
* Tyvek®, lamination with an outer layer of 2.0 mil Tyvek® (widely used in North America)

The layer by layer composition, as well as the manufacturing methods used to manufacture each of the above lamination structures, will be covered in Section 2.

2.0 The Film Lamination Process

Lamination of two or more films to each other can often achieve a more desirable balance of properties than could ever have been obtained by modifying one of the structures. One layer may provide mechanical properties while another provides controlled permeability, heat sealability, printability, fogging resistance, chemical resistance or other important qualities. Occasionally laminates may involve three or more layers of different materials. Thus, a manufacturer, by the installation of one piece of equipment for accomplishing such combinations, is immediately able to make a very broad range of possible packaging structures. The key step in laminating is the creation of a strong adhesive bond between the films (Osborn, 1992). Adhesive and extrusion lamination manufacturing processes were used to obtain the desired testing samples for the study.

2.1 Adhesive Lamination Process

Adhesive lamination is adaptable to short as well as long runs and it is well-suited to the one-step production of laminates when more than two components are present. The adhesive lamination manufacturing process was used during the manufacture of the lamination Nylon-C, when the aluminum foil was added to the Nylon outer layer. Another example of the adhesive lamination manufacturing process was when the Saran®, or polyvinylidene chloride

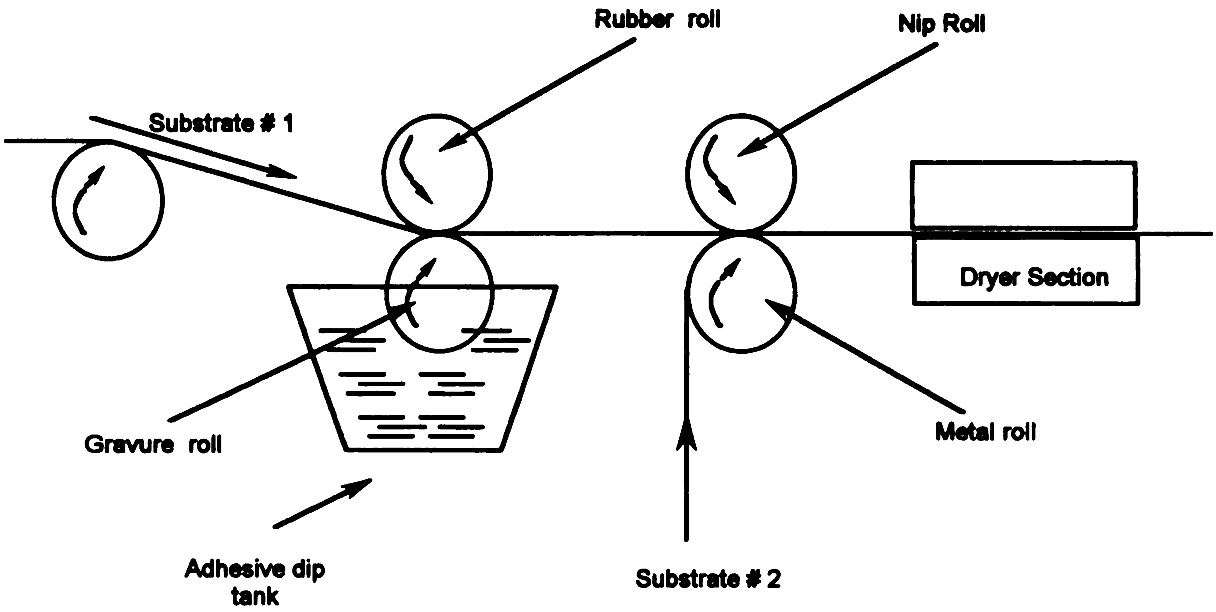
(PVDC), was added to the Nylon-A structure. Adhesive laminating processes can be divided into two major categories, namely, wet bonding and dry bonding.

The major difference between wet and dry adhesive bonding in the manufacturing process is the location of the drying oven. In wet bonding, the drying oven is placed after both substrates are joined, while in dry adhesive bonding the drying oven is placed after the adhesive application, before the addition of the second substrate. In terms of performance, dry bonding is more suitable for film laminations than wet bonding.

2.1.1 Wet Bonding

Wet bonding (Figure 2) uses solvent or aqueous-based adhesives, and it can only be used when one or more of the webs is permeable to the water or other solvent used in the adhesive formulation. Adhesives can be either thermoplastic or thermoset. Thermoplastic adhesives, such as plasticized vinyl acetate/vinyl chloride copolymers, lack heat resistance so their bonding capability is restricted in their heat sealing range. Thermoset adhesives undergo crosslinking after the lamination has been made, leading to greater heat resistance. Emulsions of acrylics are also used, as is PVDC when gas barrier is needed, but they provide only moderate levels of adhesion.

Figure 2: Wet Bonding Adhesion

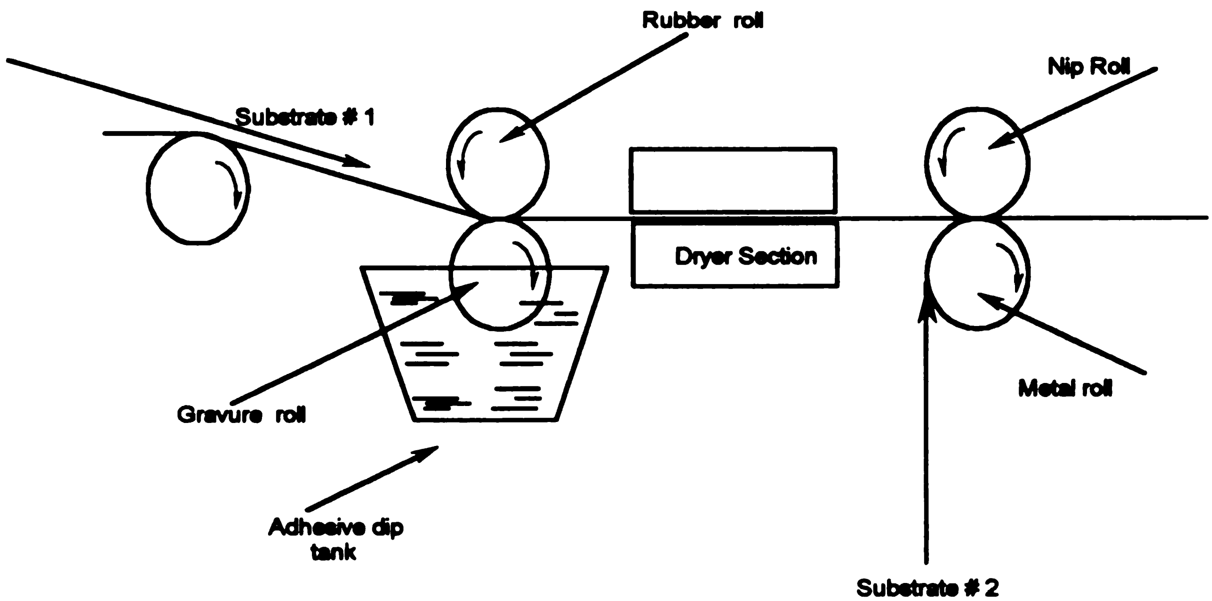


Wet bonding is not usually successful with plastic films even when laminating them to paper (Briston, 1989). However, wet bonding using organic solvent-based adhesives has been carried out in some instances, and even aqueous-based adhesive lamination can be carried out for films such as cellulose acetate when bonded to paper. The cellulose acetate is fairly permeable to water vapor and so aids drying out of the water after laminating. In any case, the finished laminate must be run through a drying oven to speed up the drying process. The gravure roll is the roll in contact with the adhesive and it is also the roll which applies the adhesive to the substrate. The rubber roll receives all the pressure made by the gravure roll and it secures the amount of adhesive placed on the substrate. The metal and the nip roll are the ones which bond the second substrate to the first substrate by surface contact pressure.

2.1.2 Dry Bonding

The dry bonding process incorporates either the use of an aqueous or solvent-based adhesive film that is dried prior to laminating, or a hot melt adhesive, based on wax or on one of a range of polymers. In the first case, the aqueous or solvent-based laminating adhesive is applied in precise amounts to one web by means of direct gravure or reverse kiss coaters. The coated web is then passed through an oven, to remove all water or solvent, and later it is combined with the other ply in a pressure nip, which sometimes may be heated. The setup is shown schematically in Figure 3.

Figure 3: Dry Bonding Adhesion



Factors affecting the success of this type of laminating process when used for plastic films include tension control, accurate adhesive application and accurate control of drying. Film tension should normally be kept to a minimum and will depend on the distance the film has to be pulled through the laminating equipment and on the sharpness of any change in direction as it passes over the various rolls. Smooth and accurate application of the adhesive is extremely important, and failure in this respect will probably lead to delamination.

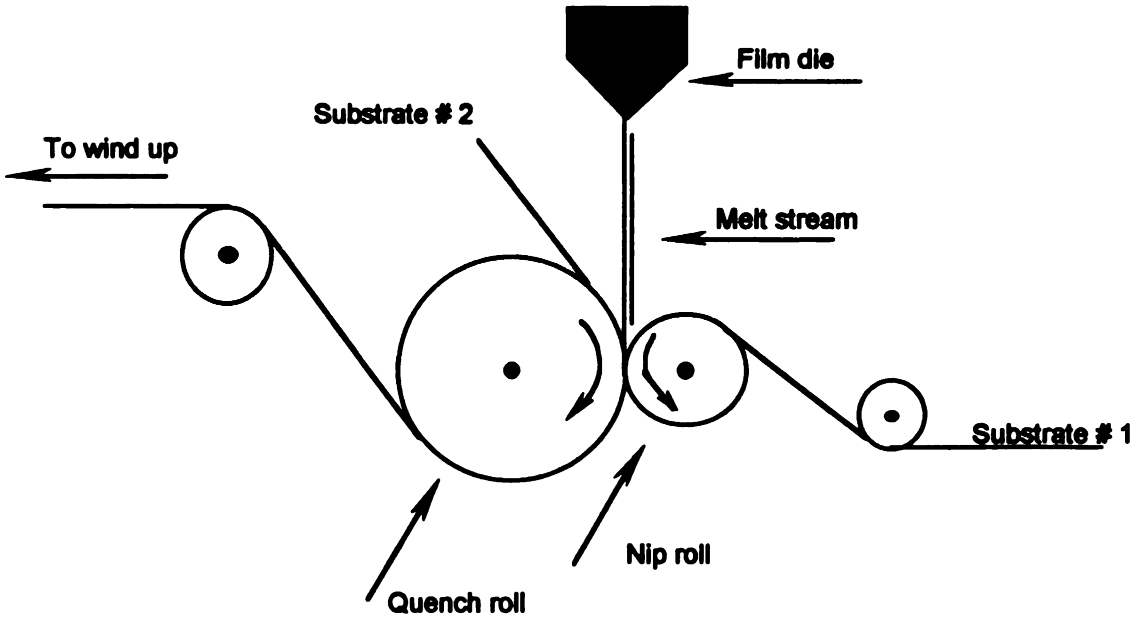
2.2 Extrusion Lamination Process

In the extrusion lamination manufacturing process, an extruded adhesive is used, such as polyethylene or ethylene copolymer. High adhesive application temperatures are often employed to oxidize the melt and improve adhesion. Waxes are used to modify melt properties. A lamination process using extruded adhesive is shown in Figure 4. A complication in laminating is that two different films or a plastic film and a non-plastic substrate must be simultaneously brought together to be combined. Good mechanical and electrical precision is necessary to keep film speed coordinated. Control of tension is critical to avoid wrinkles.

When plastic films are combined with non-plastic substrates, the appropriate techniques for handling the substrates must be employed. For instance, thin aluminum foil, such as the one used for this study which has a thickness of 0.00035 inches, has lack of ductility and low tear strength. It requires extreme care of tension control and avoidance of nicked foil edges.

This adhesion manufacturing process was used to make all the Dryflex and the Tyvek® laminations used in the study.

Figure 4: Adhesive Extrusion Process



2.3 Adhesive and Cohesive Failure

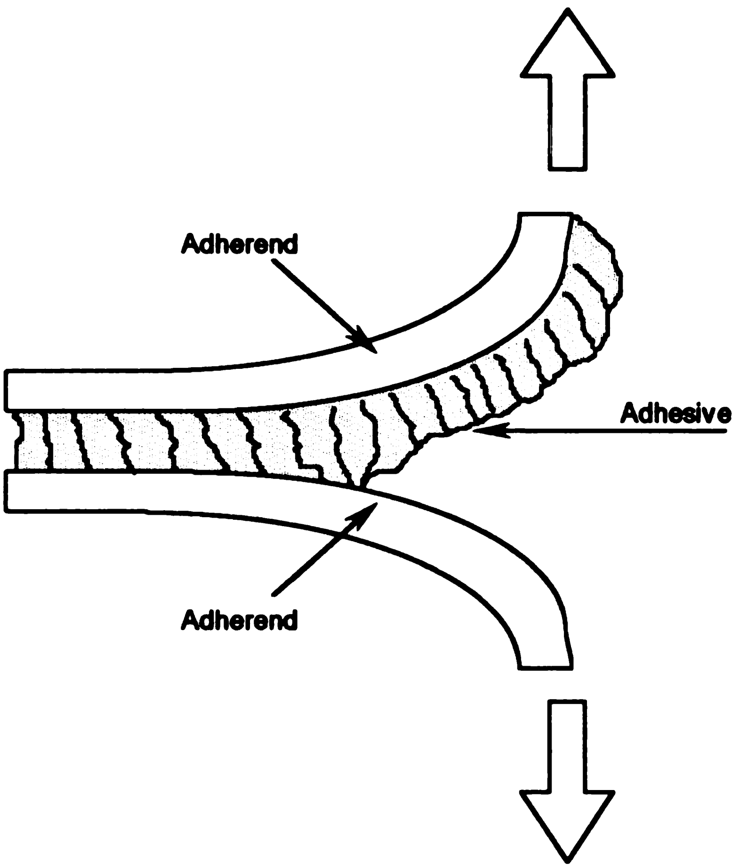
A wide variety of polymers are applied as a thin layer between two solid substrates, and employed primarily to bond and hold these two substrates close to each other. To be a good adhesive, a polymer must first have sufficient fluidity, polarity, and reactivity to flow and wet the surface of both substrates; and when the bond has been completely formed, the polymer must have in addition sufficient cohesive strength to hold itself as well as the substrates together (Deanin, 1972).

There are many factors to consider when evaluating the performance of seal strength in multi-layer laminated structures. One very important factor is the tenacity with which layers are held together by the tie layer adhesive. Structures having insufficient bond strength, for a given application, run the risk of field failure due to delamination. Once delamination occurs, the aesthetics and functionality of the package is destroyed. As a consequence, measurement of bond strength is one of the standard qualification tests of a multi-layer structure. The peel-type failure is probably the most common mode of field failure. For this reason, peel strength tests have been adopted as the predominant test for indication of bond strength. Within the numerous variations of peel test available, the T-peel test (ASTM D1876-95), is the most widely used and it was selected to perform the heat seal peel test in this study. There are two types of failures when performing a T-peel test: adhesive failure (Figure 5) and cohesive failure (Figure 6).

An adhesive failure occurs between two phases. This failure occurs when there is delamination at the adhesive and the adherend is exposed. Suppose we are situated between an atom of the adherend and an atom of the adhesive, in other words we will assume failure started "in adhesion". To continue "in adhesion", the crack must grow between the next pair of adherend and adhesive atoms. The alternatives are: to advance between two atoms of adherend or between two atoms of adhesive. If each atom occupies an approximately cubical space, it is easy to see that there are three paths between adherend and adherend and three paths between adhesive and adhesive for each path between adherend and adhesive. If the failure propagates into the adherend, the failure will be considered an adhesive failure. If the failure propagates only through the adhesive, it will be a cohesive failure (Bikerman, 1962).

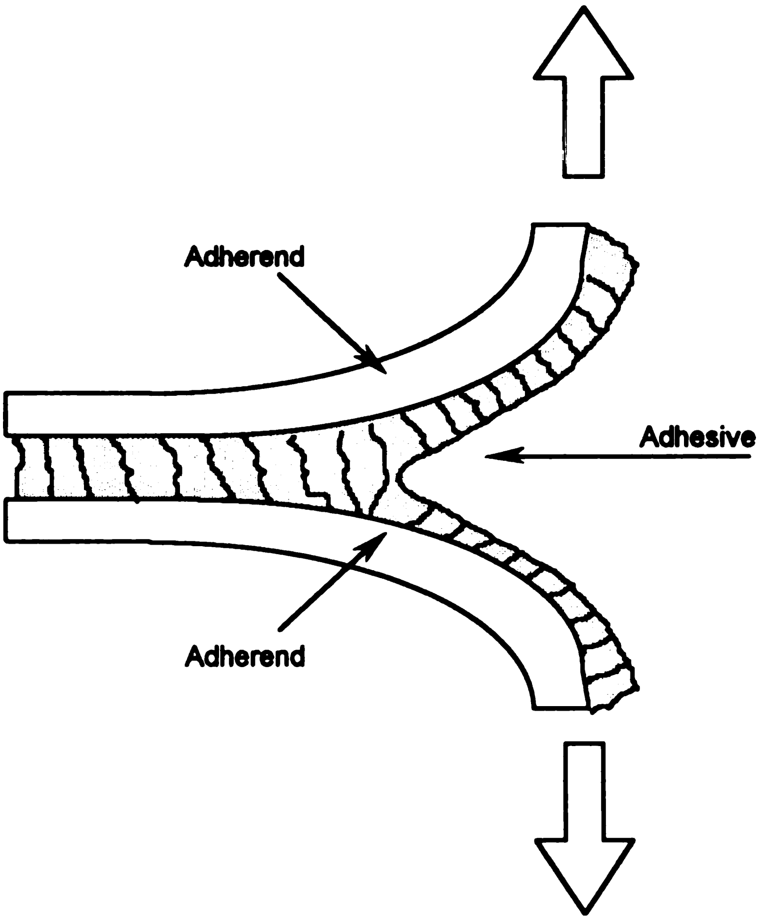
This type of failure (adhesive) will expose to the peel surface the other components of the multi-layer structure. An example of this failure is when the seam was tested in section 3.5, and after the test, aluminum foil particles flew out of the lamination.

Figure 5: An Adhesive Failure



A cohesive failure occurs within a phase or within the adhesive. This type of failure is desirable when the laminations studied are opened during the peel test. At this point, the failure is desirable (for the studied laminations or package) in the heat seal layer, i.e. LDPE, LLDPE or EVA. This failure will assure the other components of the lamination remain in place, without being exposed to the surface. In general, for this experiment, is desirable to obtain cohesive failure within the adhesive layer.

Figure 6: A Cohesive Failure



2.4 Description of The Film Laminations

Seven alternative lamination structures were studied. Each of them differs from the others in either thickness, layer composition or material used. Even though they differ in composition, all of them follow a generally similar arrangement, i.e.:

- An outer layer, which provides most of the mechanical properties; this layer is always placed in the outside of the structure.

- A tie layer, which is used to adhere the barrier layer (aluminum foil) to the lamination; the tie layer always follows the outer layer in the structure.

- A barrier layer, which will provide the oxygen and moisture protection; it is always located in the middle of the structure.

- A tie layer, to add a cover to the barrier layer and prepare the structure for the addition of the sealant layer.

- A sealant layer, which provides all the heat seal properties of the structure.

In addition to the general arrangement of the layers in the structure, the laminations also have in common the barrier layer composition and thickness. All of them have aluminum foil film with a thickness of 0.00035 inches. The outer layer, as well as the sealant layer and the tie layer, vary from lamination to lamination. In fact, this variation gives the specific mechanical and physical properties of each of them.

One of the most critical properties of the film is the protection against moisture migration. Polyvinyl butyral is a hygroscopic product. Migration of moisture through the film will result in shelf life reduction and eventually product damage. This requires utilization of aluminum foil in the lamination. Keeping the generation of pin holes in the aluminum to a minimum is important as well. The generation of pin holes in the structure will be covered in more detail in the water vapor transmission rate (WVTR) testing (Section 3.8).

2.5 Composition of the Laminations

This section will describe the layer by layer composition and the thickness of each of the lamination structures studied. As described in section 1.1, the lamination structures for evaluation are:

- three different arrangements using Valeron® as the outer layer, structures Dryflex-A, Dryflex-B and Dryflex-C.

- three different arrangements using a polyamide as the outer layer, structures Nylon-A, Nylon-B and Nylon-C.

- one arrangement using Tyvek® as the outer layer, Tyvek® structure.

Valeron® is manufactured by Valeron Plastics, Inc. in Houston, Texas, part of the Van Leer international organization. They produce a unique HDPE film lamination for commercial use. One of the applications of Valeron® is to make heavy duty shipping sacks (Bruins, 1974). Valeron® is cross laminated by adding two film layers of HDPE in a 45° degree orientation. The result is one new film layer with superior tear strength in the machine (MD) and cross machine direction (XMD).

Nylon films are a commodity item, and they can be obtained easily from a variety of suppliers. Tyvek®, spunbonded olefin, is a trade mark of DuPont. It is stronger than paper and more versatile than fabric. Made from HDPE fibers, this spunbonded olefin is an extremely versatile material that combines some of the properties of paper, film and cloth, (Dupont, 1997). Its unique combination of properties makes Tyvek® ideal for a broad range of applications. In the following sections, the details of each lamination will be covered.

2.5.1 The Dryflex-A Structure

The Dryflex-A structure (Table 1), is composed of five layers. This structure was developed, manufactured and experimentally tested with excellent results. In fact, it was the strongest structure, but at the same time, it was difficult to work with. The layer by layer composition is:

Table 1: The Dryflex-A Structure

Material	Layer in the lamination	Thickness
Valeron®	outer	3.00 mil
LDPE	tie	1.20 mil
Aluminum Foil	barrier	0.35 mil
LDPE	tie	0.80 mil
LLDPE	sealant	1.25 mil
	total thickness =	6.60 mil

2.5.2 The Dryflex-B Structure

The Dryflex-B structure (Table 2), is composed of five layers, the same as Dryflex-A. The major difference between them is the decrease in thickness of the outer layer. This structure was developed, manufactured and experimentally tested with excellent results. The layer by layer composition is:

Table 2: The Dryflex-B Structure

Material	Layer in the lamination	Thickness
Valeron®	outer	2.50 mil
LDPE	tie	1.20 mil
Aluminum Foil	barrier	0.35 mil
LDPE	tie	0.80 mil
LLDPE	sealant	1.25 mil
	total thickness =	6.10 mil

2.5.3 The Dryflex-C Structure

The Dryflex-C structure (Table 3), is composed of four layers. Differently than the previous two structures, Dryflex-C uses the second tie layer of LDPE simultaneously as a sealant layer. In order to make the seal reliable, additional thickness was added to the layer. The outer layer is the same as Dryflex-B. This structure was developed, manufactured and experimentally tested with excellent results. The layer by layer composition is:

Table 3: The Dryflex-C Structure

Material	Layer in the lamination	Thickness
Valeron®	outer	2.50 mil
LDPE	tie	1.20 mil
Aluminum Foil	barrier	0.35 mil
LDPE	sealant	1.20 mil
	total thickness =	5.25 mil

2.5.4 The Nylon-A Structure

The Nylon-A structure (Table 4), is composed of six layers. This lamination contains the highest amount of Nylon of all structures tested and it is the only one that contains a Saran® coating. The second tie layer is a co-extrusion of ethylene-methacrylic acid copolymer (EMAA) and LDPE, to enhance the lamination properties of the structure. The layer by layer composition is:

Table 4: The Nylon-A Structure

Material	Layer in the lamination	Thickness
Nylon	outer	0.67 mil
Saran®	coating	0.05 mil
LDPE	tie	1.20 mil
Aluminum Foil	barrier	0.35 mil
EMAA / LDPE	tie	0.066 / 0.60 mil
EVA	sealant	1.50 mil
	total thickness =	4.43 mil

2.5.5 The Nylon-B Structure

The Nylon-B structure (Table 5), is composed of five layers, different from Nylon-A. It does not contain the Saran® layer, nor the EMAA co-extrusion for the second tie layer. The layer by layer composition is:

Table 5: The Nylon-B Structure

Material	Layer in the lamination	Thickness
Nylon	outer	0.60 mil
LDPE	tie	1.20 mil
Aluminum Foil	barrier	0.35 mil
LDPE	tie	0.80 mil
EVA	sealant	1.50 mil
	total thickness =	4.45 mil

2.5.6 The Nylon-C Structure

The Nylon-C structure (Table 6), is composed of five layers, the same as Nylon-B, but it was the thinnest structure. This structure does not contain extruded LDPE, and for adhering the nylon to the foil, the dry bonding process was used. The sealant layer is a blend of 90% LLDPE and 10% LDPE; this layer provides excellent puncture properties. The layer by layer composition is:

Table 6: The Nylon-C Structure

Material	Layer in the lamination	Thickness
Nylon	outer	0.60 mil
Adhesive	tie	0.30 mil
Aluminum Foil	barrier	0.35 mil
Adhesive	tie	0.10 mil
LDPE:LLDPE	sealant	2.90 mil
	total thickness =	4.25 mil

2.5.7 The Tyvek® Structure

The Tyvek® structure (Table 7), is composed of five layers. This structure is similar to the Dryflex structures in configuration, but it possesses excellent tear and puncture properties. The overall performance of this lamination was excellent; the major disadvantage is the cost compared to the other laminations. The Tyvek® lamination can be three times as expensive as the Nylons and twice as expensive as the Dryflex. The layer by layer composition is:

Table 7: The Tyvek® Structure

Material	Layer in the lamination	Thickness
Tyvek®	outer	2.00 mil
LDPE	tie	1.20 mil
Aluminum Foil	barrier	0.35 mil
LDPE	tie	0.80 mil
EVA	sealant	1.50 mil

3.0 Performance Testing and Results

This study is focused on the evaluation of the performance of the mechanical and physical properties of the lamination structures described. In order to adequately identify which lamination performs best and which performs worst, they must be tested. The results of this testing will be objective criteria to categorize the laminations.

This section contains the description of the testing performed on the laminations, as well as the results of each test. A total of nine different tests and a cost comparison were considered in this study. They were grouped in nine sections:

3.1 Capping test

3.2 Cost analysis

3.3 Dart drop (puncture resistance) test

3.4 Foil delamination test

3.5 Heat seal test

3.6 Performance on pallets test

3.7 Sliding, folding and label adhesion test

3.8 Water vapor transmission rate test

3.9 Summary of the results

The testing covers all the operations to which the lamination or bag will be subjected from the moment it is manufactured. Test are listed in alphabetical order with descriptions and the results obtained. Some of the tests were designed for in-house operation and they lack an ASTM standard. In such cases, this study will provide all the details necessary for reproducibility. All test samples were conditioned according to ASTM D 4332-89 (Standard Practice for Conditioning Containers, Packages, or Packaging Components for testing).

In order to fairly compare the alternatives a ranking system was developed. This ranking will be found in the results section, in the tables with the summary for each test. The ranking was developed using the following method:

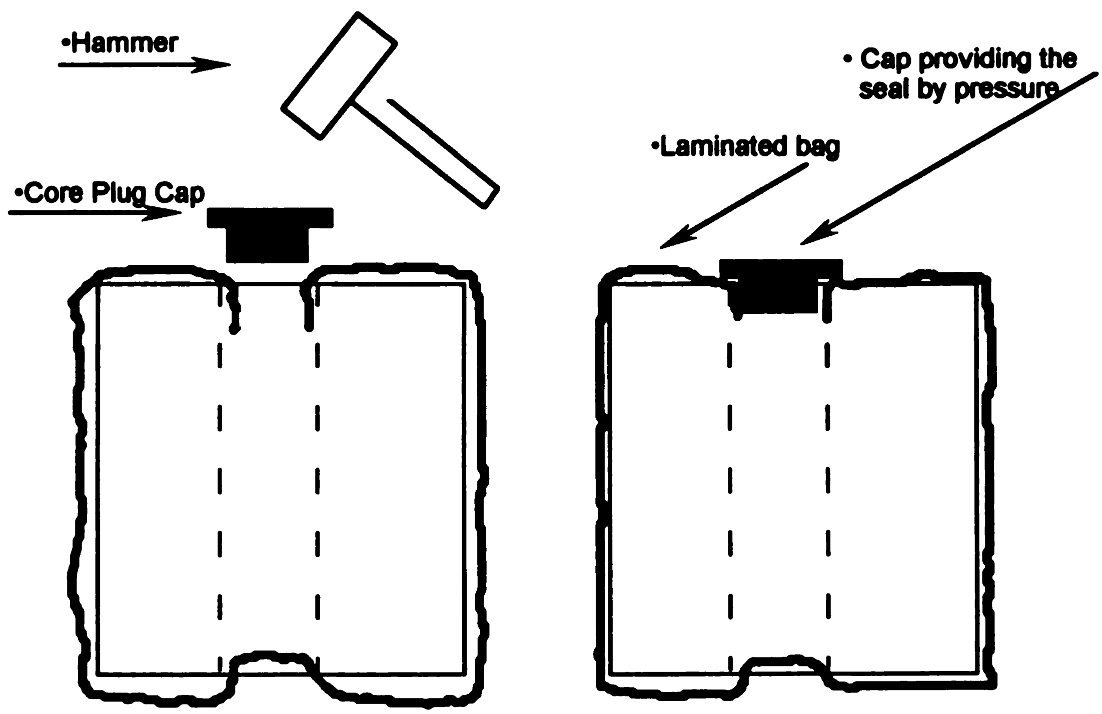
- Use the highest result of each specific test as the top score.
- Divide the top score by eleven.
- The result is the increment unit for eleven intervals, from zero to ten (0-10), to be used in each section.

A detailed description of the increment of the scale will be given in each section. A summary of all the tests in a tabulated form is in Section 3.9.

3.1 Capping Test

The capping test is an in-house test that provides information about the lamination's resistance to cuts during the capping operation. Earlier, in Section 1.1, the packaging elements were described, as well as the way the bag is tucked or inserted into the core. Since the polyvinyl butyral roll is hygroscopic and the bag is its moisture barrier, the seal must be as good a barrier as the bag itself. Otherwise, moisture will migrate through the seal. The seal is provided by a cap inserted into the core with an interference fit, providing the seal by the pressure placed on the tucked bag against the core walls The right side of Figure 7 shows an inserted cap. The capping operation (Figure 7) is performed by inserting the core plug cap into the core using a hammer. The caps are made of HDPE and they are inserted by pressure into the core, sealing the bag in place. Sometimes while performing the capping operation, if the lamination is weak, it can be cut by the pressure generated during the penetration. If the bag is cut, the barrier properties will be lost, and with them the quality of the product. For this reason, this test is important. It becomes even more important when the roll is partially used and the capping operation is performed repetitively.

Figure 7: The Capping Operation



3.1.1 Capping Test Description

The method used to perform this test was based on the repetition of the capping operation. The number of times in which a core plug cap was inserted into the core without making a cut in the bag was taken as the result. This test was performed on three samples for each lamination and the average determined.

3.1.2 Capping Test Results

The data for the capping operation tests are listed in Appendix A in Tables A1 to A7. The average number of times the capping operation can be repetitively performed before a cut or a failure occurred in the lamination structure is reported in Table 8.

Table 8: Results of the Capping Operation Test

Laminations		Capping Results	Ranking Results
Dryflex-A	=	38.7	10
Dryflex-B	=	29.3	8
Tyvek®	=	17.7	4
Dryflex-C	=	16.7	4
Nylon-C	=	14.7	4
Nylon-A	=	11.3	3
Nylon-B	=	9.3	2

From the results, it can be concluded that the strongest lamination in terms of cut resistance during the capping operation is Dryflex-A. The structure most susceptible to cutting was the Nylon-B structure. An interesting result from evaluation of the nylon structures, was that better results were obtained by having the sealant layer of LLDPE (Nylon-C) rather than by increased thickness in the Nylon layer (Nylon-A). All the Dryflex structures performed better than the nylons in this test. Also the Tyvek® structure performed acceptably.

In order to categorize the results, as described in Section 3.0, a ranking or a scale was developed (Table 8: Ranking Results column). In this scale, a grade of ten was given to the best performance and a grade of zero to an unacceptable performance. The scale was developed by using equal increments of 3.52 units, i.e. from 0 to 3.52 was rated as a "0", from 3.53 to 7.05 was rated as a "1" and so on. A ranking of 10 was given to Dryflex-A with an average number of times that capping operation was performed before a cut of 38.67, while a ranking of 2 was given to Nylon-B with an average of 9.33 times before a cut.

3.2 Cost Analysis

Since the cost information on these lamination structures is classified as confidential information, this study will present a comparison of the price on a per roll basis (Table 9). In order to maintain confidentiality, the roll size and the roll width will not be described. In general, the roll sizes are equal in terms of length and width, making the same numbers of bag out of each roll.

Making a lamination structure is labor intensive, and it requires technology and expertise to put all the layers together, making the final product an expensive one.

Table 9: Lamination Cost per Roll

Laminations		Cost per Roll ($)	Ranking Results
Nylon-A	=	307.38	6
Dryflex-C	=	347.78	6
Dryflex-B	=	368.54	5
Dryflex-A	=	473.43	4
Nylon-C	=	491.34	4
Nylon-B	=	583.64	2
Tyvek® is	=	779.07	0

In order to categorize the results, as described on Section 3.0, a ranking or a scale was developed, (Table 9: Ranking Results column). In this scale, a grade of ten was given to the best performance and a grade of zero to an unacceptable performance. The scale was developed by using equal increments of 70.8 dollars, i.e. from 0 to 70.8 was rated as a "10", from 70.9 to 141.7 was rated as a "9" and so on. Since no roll cost under seventy-one dollars, no ranking of 10 was given. A ranking of six was given to Nylon-A and Dryflex-C, while a ranking of 0 was given to Tyvek® as the most expensive material.

One roll of Nylon-A, Dryflex-C or Dryflex-B, can be obtained for less than half the price of the Tyvek® material. These prices are associated with minimum order quantities and periodic orders.

3.3 Dart Drop (Puncture Resistance) Test

This test was performed according to ASTM standard D1709-85, Impact Resistance of Polyethylene Film by the Free Falling Dart Method. One measure of impact strength or puncture resistance is the force required to rupture a plastic film. This test method covers the determination of the energy that causes the different films to fail under specified conditions of impact of a free falling dart. This energy is expressed in terms of the weight (mass) of the missile falling from a specified height which would result in 50% failure of the specimens tested.

3.3.1 Dart Drop Description

The dart drop method used in this study was Method B, the standard staircase technique. Using this technique, a uniform weight increment is employed during the test and the missile weight is increased or decreased by the uniform increment after test of each specimen, depending upon the result (fail or not fail) observed for the specimen. The testing procedure used as well as the apparatus is described in the ASTM standard.

The following summarizes some conditions of the experiment:

drop height	=	60 inches
dart weight	=	48.35 grams
rings	=	15.25 grams

3.3.2 Dart Drop Test Results

The entire data for each drop test in this study on laminated film are listed in Appendix B in Tables B1 to B7. These tables list the impact failure weight (IFW), along with failures and non failures at each tested weight. A summary of the data is presented in Table 10.

Table 10: Results of the Dart Drop Test

Laminations		Dart Drop Result	Ranking Results
IFW for Dryflex-A	=	601.44 grams	10
IFW for Dryflex-B	=	521.76 grams	8
IFW for Nylon-A	=	413.93 grams	6
IFW for Nylon-C	=	395.63 grams	6
IFW for Nylon-B	=	299.53 grams	4
IFW for Tyvek®	=	290.40 grams	4
IFW for Dryflex-C	=	252.28 grams	4

From the above results, it can be concluded that the strongest lamination in terms of puncture is the Dryflex-A. The most susceptible to puncture is the Dryflex-C. There are two major differences between these two laminations. Dryflex-A has an additional 1.25 mil thickness layer of LLDPE, and an increase in the outer layer (Valeron®) of 0.5 mil thickness in the lamination structure.

Nylons performed similarly in terms of puncture resistance. Nylon-A is a thicker sample than the other two and performed the best among the nylons. Nylon-C is the thinnest structure overall, but it contains the thickest layer of LLDPE, contributing to the structure's resistance to puncture.

In order to categorize the results, as described on Section 3.0, a ranking or a scale was developed, (Table 10: Ranking Results Column). In this scale a grade of ten was given to the best performance and a grade of zero to an unacceptable performance. The scale was developed by using equal increments of sixty grams, i.e. from 0 to 60 was rated as a "0", from 61 to 120 was rated as a "1" and so on. A ranking of 10 was given to Dryflex-A with an energy absorbency of 601.44 grams while a ranking of 4 was given to Dryflex-C with an energy absorbency of 252.28 grams.

3.4 Foil Delamination Test

The key step in laminating is the creation of a strong adhesive bond between the films. Nevertheless, when foil is present, there is always the possibility of having it fly out of the lamination when it is ripped. The bag can be opened in two ways: by opening the seam or peeling, or by ripping the bag off.

A good lamination must be able to be opened by either method without creating foil flakes.

The seam has been heat sealed (section 3.5), and it is expected to peel easily all the way through the roll height, facilitating the use of the roll. When performing this operation, if an adhesion problem is present in the lamination structure, the foil might break and fly out of the lamination. If this happens, the most probable event is that the foil will fly directly onto the roll's surface, due to the static effect generated. Foil particles are very small and cannot be easily removed, causing serious contamination problems. One foil particle can contaminate a whole section of the roll, and it will only be discovered after it has been laminated inside the glass. This will create waste and loss for the customer, as well as undesired complaints. For this reason, a test was developed to evaluate this critical problem. The foil delamination test is an in-house test that will provide information about the security of the foil adhesion in the lamination. This test is designed to prevent the problem of having foil particles flying out of the lamination when the bag is opened to use the polyvinyl butyral roll.

3.4.1 Foil Delamination Test Description

Two methods have been developed to evaluate the foil adhesion in the lamination structure. The first one will simulate what happens when the lamination structure is opened along the heat-sealed seam. The second method will simulate what will happen if the bag is ripped off the roll. These will be named Method A and Method B. Method A is the regular "T" test according to ASTM D-1876-95, which will be covered in detail in Section 3.5 on testing the heat seal properties. This method was used to evaluate how easily the foil flies out of the lamination when opening. The second method, Method B, also evaluates the adhesion of the foil to the other layers. This one was an in-house test, in which the following steps were used:

Step-1, Obtain a sample

Step-2, Stretch the sample

Step-3, Cut the sample

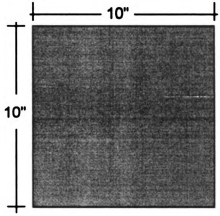
Step-4, Foil delamination

Step-5, Count the particles

Step-1: Obtain a sample of the lamination of about ten square inches as shown in Figure 8.

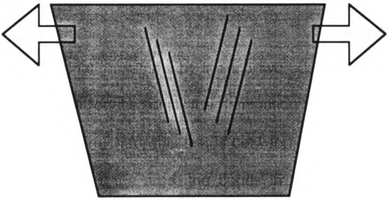
Make sure this test is performed on a clean surface, with a solid color, i.e. black or brown. Light colors like yellow or white would not allow contrast and would make impossible to quantify the foil particles.

Figure 8: Lamination sample of ten square inches



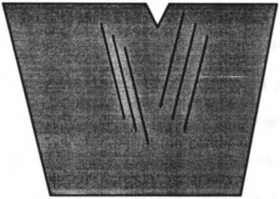
Step-2: Grasp the lamination sample by the top two edges and manually apply opposite forces to the edges until the lamination structure is noticeably stretched. A desirable stretch for this test is between ¼ and ¾ inch, as shown in Figure 9. By stretching the area, the bonds in the lamination have been weakened and broken, potentially allowing foil particles to fly out of the lamination.

Figure 9: Stretched lamination sample



Step-3: Make a cut about ½ inch deep at the center of the stretched area with scissors, (the cut is a simple cut not a "V" shape cut) as shown in Figure 10. This will facilitate the next step.

Figure 10: Cut to the lamination

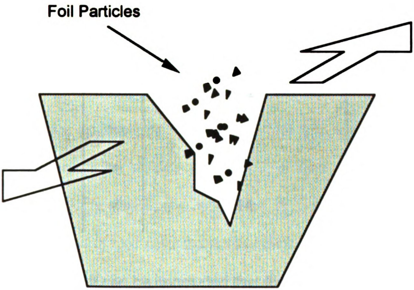


Step-4: Propagate the cut made in Step 3. Grasp the stretched ends and apply forces in opposite directions as shown in Figure 11. This will liberate all the foil particles with a weak or a broken bond to the other substrates.

Step-5: Count the foil particles. Look carefully to the working surface described in Step-1 and count the number of foil particles found. Categorize them into none, low, medium of high as described below.

This part of the test is critical, due to the fact that polyethylene stretches. That means all lamination structures having LDPE as a tie layer are susceptible to foil flaking. Another contributor for failure during this test is the kind of cut propagation when performing the last step. Laminations like Dryflex, with a Valeron® layer as the outer layer, do not tears easily. Valeron is a cross lamination of two layers, each one oriented at 90 degrees apart from each other in the machine direction. This will allow for more broken bonds on the foil adhered when tear than in the Nylons. Laminations like the Nylons propagate easily, allowing for a minimum of bonds to be broken while propagating the cut. This test was performed three times for each lamination. Each time a grade of: none, low, medium or high was given to each lamination based on the results. "None", meaning no foil particles were found after performing the test, was rated as 0.1. "Low", meaning one or two particles were found after performing the test, was rated 1. "Medium", meaning three to four particles were found after performing the test, was rated 2; and a "high" presence of foil particles was rated as 3. High was defined as more than four foil particles were found after performing the test. The scores for the three test pieces were summed for Method A and Method B, and these two sums, added together to give the overall score.

Figure 11: Foil Delamination



3.4.2 Foil Delamination Test Results

The data for the foil delamination tests in this study on laminated film are listed in Appendix C in Tables C1 to C7. A summary of the data is presented in Table 11. The scores of the three samples by each method were added together, and then the totals were added for the final result.

Table 11: Results of the Foil Delamination Test

Laminations		Foil Delamination Results	Ranking Results
Nylon-C	=	0.60	10
Nylon-B	=	2.4	9
Nylon-A	=	3.3	8
Dryflex-C	=	4.2	7
Tyvek® is	=	5.1	6
Dryflex-B	=	11	2
Dryflex-A	=	14	0

From the above results, it can be concluded that the lamination least susceptible to foil delamination is Nylon-C. This is due to two important factors. First, the foil adheres to the nylon by a strong bond made by the thin layer of adhesive. The second factor is the ease of tear propagation. Both the nylon and foil tear easily. Once the cut is started, propagation continues without resistance. Since the foil is very well bonded to the nylon, they behave as a single substrate. The other nylon structures and the Dryflex-C perform excellently as well. Dryflex-A performed the worst due to its strength properties and resistance in propagating the cut.

In order to categorize the results, as described in Section 3.0, a ranking or a scale was developed, (Table 11: Ranking Results Column). In this scale, a grade of ten was given to the best performance (least foil delamination) and a grade of zero to an unacceptable performance. The scale was developed by using equal increments of 1.27 units, i.e. from 0 to 1.27 was rated as a "10", from 1.28 to 2.54 was rated as a "9" and so on. A ranking of 10 was given to Nylon-C, which had minimal foil delamination.

3.5 Heat Seal Test

Packages that open by peeling the heat seal seam, rather than tearing, are desired for many applications such as pouches and bags. Peel seals are achieved by weakening the normal strength of a heat seal by reducing the cohesive strength of the layer, the adhesion of the coating layers to the substrate, or the degree of fusion during heat sealing (Osborn, 1992).

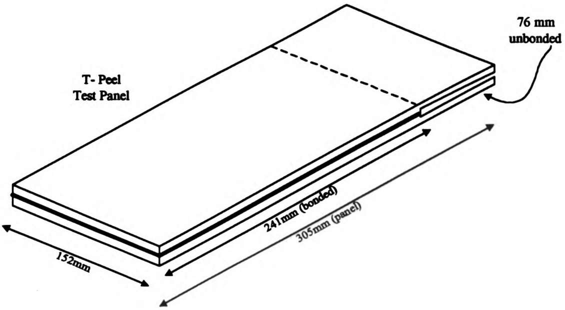
Hot tack is a term that denotes the degree of strength, or resistance to peeling apart, that a sealant layer can develop while it is still hot after just being released by the sealing bars. Widely used packaging films such as LDPE have relatively poor hot tack. Low cost ethylene copolymer films such as EVA have better hot tack than LDPE, and ionomer films have the highest hot tack of any plastic film used in packaging. Outstanding heat sealing characteristics are the primary advantage of the thicker coatings attainable by extrusion coating. The specific characteristics are determined by the kind of sealant layer and the thickness. LDPE is the most common and lowest cost choice. The minimum sealing temperature for LDPE is about 120°C, while HDPE is higher at about 140°C. Where lower temperature sealing is required for higher packaging machine speeds, ionomers with a minimum seal temperature of 104°C or EVA coatings that seal at 65°C are used.

As the seal cools and hardens, it slowly develops its ultimate strength. A strong seal is vital, since the bag must frequently withstand severe mechanical stresses during distribution and handling. For this reason, this test was included in the evaluation criteria of this study. The testing was performed according to ASTM D1876-95, Standard Test Method for Peel Resistance of Adhesive (T-Peel Test).

3.5.1 Heat Seal Test Description

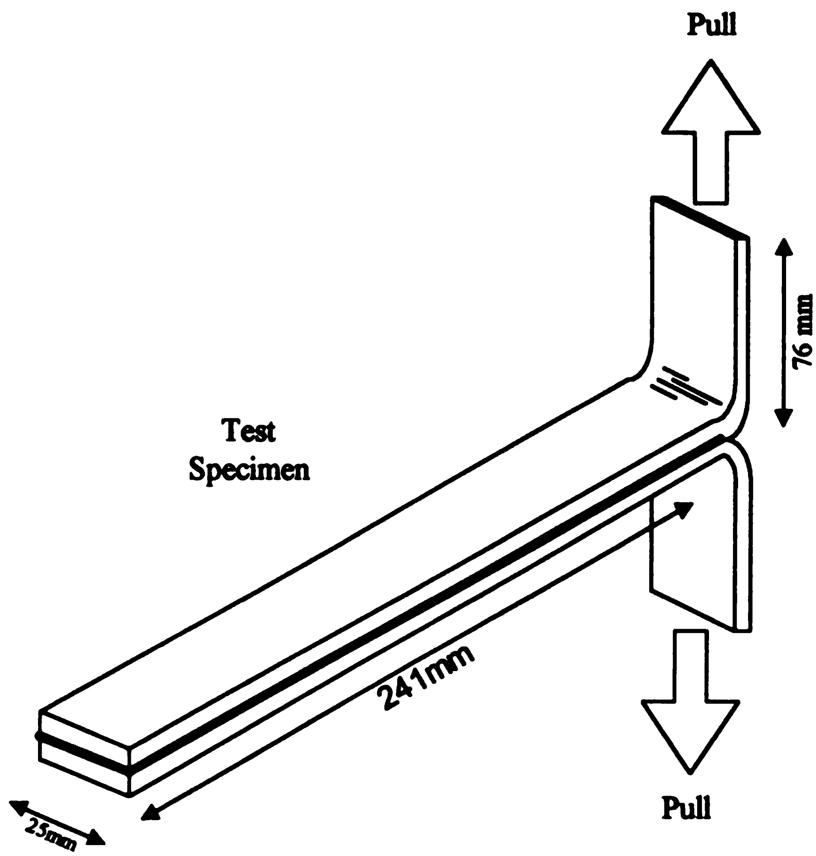
This test method is primarily intended for determining the relative peel resistance of adhesive bonds between flexible adherends by means of a T-type specimen. The machine used for this test s the Instron Universal Testing Machine ±0.005 lb. (load), ±0.0005 inch (extension). The first step is the preparation of the laminated test panels (Figure 12). They consist of two flexible adherends properly prepared and bonded together in accordance with the adhesive manufacturer's recommendation.

Figure 12: Test Panel



The test panels were 152 mm (6 in.) wide by 305 mm (12 in.) long, but were bonded only over approximately 241 mm (9 in.) of their length. Test panels of the same dimension may be cut from larger, fully laminated panels. Next the bonded panels were cut into 25 mm (1 in.) wide test specimens as shown in Figure 13. The 76 mm (3 in.) long unbonded ends were bent apart, perpendicular to the glue line, for clamping in the grips of the Instron machine. A total of ten specimens were tested for each lamination sample.

Figure 13: Test Specimen



Once the test specimen was prepared, the unbonded ends were clamped in the grips of the Instron machine. A rate of deformation of 254 mm (10 in.)/min was applied. The peak load per unit width of bond line required to produce progressive separation of two bonded, flexible adherends was measured for each lamination structure.

3.5.2 Heat Seal Test Results

The data for the heat seal tests in this study on laminated film are listed in Appendix D in Tables D1 to D7. These tables list the results of the average peak peeling load in pounds per inch for each lamination structure. A summary of the data is presented in Table 12.

Table 12: Results of the Heat Seal Test

Laminations		Heat Seal Results	Ranking Results
Dryflex-A	=	14.29 lb./in.	10
Dryflex-B	=	13.86 lb./in.	10
Nylon-C	=	13.54 lb./in.	10
Tyvek® is	=	11.81 lb./in.	9
Nylon-A	=	10.98 lb./in.	8
Nylon-B	=	9.73 lb./in.	7
Dryflex-C	=	8.17 lb./in.	6

Laminations using LLDPE as the sealant layer provide the highest strength in terms of peeling. However, they also exhibit the highest level of adhesive failure. Adhesive failure was identified in Section 3.4 (Foil Delamination Test) as a critical problem for this lamination. On the other hand, nylon structures performed as well as the Dryflex A & B, but did not show adhesive failure. The Tyvek® lamination failed most of the time in cohesion, but exposed the foil in one occasion. Dryflex-C, with the sealant layer made of extruded LDPE, showed the lowest strength when peeled. This is good and bad at the same time, good because it requires the least amount of force to open the package and bad, because the seal is more susceptible to being opened prematurely. Dryflex-C was the only lamination that consistently failed in cohesion.

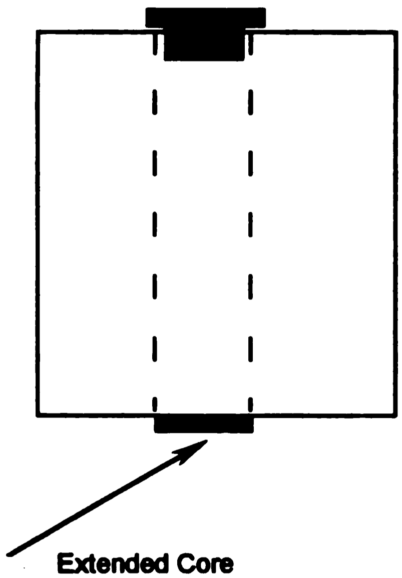
In order to categorize the results, as described in Section 3.0, a scale was developed, (Table 12: Ranking Results Column), with a grade of ten given to the best performance (highest strength when peeled) and a grade of zero to an unacceptable performance. The scale was developed by using equal increments of 1.29 units, i.e. from 0 to 1.29 was rated as a "1", from 1.30 to 2.59 was rated as a "2" and so on. A ranking of 10 was given to Dryflex-A, Dryflex-B and Nylon-C.

3.6 Performance on Pallets Test

One of the most critical tests for the laminations is the performance of the bag during distribution on the plastic pallet. It is critical because the laminated bag can be broken during transportation and handling. If this happens, the usability of the roll is in danger, as moisture gain can cause the rolls to become a piece of plastic as solid as concrete. The two major factors influencing the results of this test are: the extended cores and the shift of the load.

Most of the time during the manufacturing process, in the winder, the roll is wounded on extended cores (Figure 14). This facilitates the unwinding process for the customer. The extension can be anything between ¼ and 3/8 of an inch, on the bottom side, and here will be the critical problem. The whole weight of the roll will rest on the core, creating strong friction against the plastic pallet. If the lamination is weak or susceptible to friction, this results in the creation of holes and cuts, which allow moisture to penetrate into the polyvinyl butyral roll.

Figure 14: Extended Core



The second major cause of poor performance on the plastic pallets is the load shifting from its original position. If the lamination is too brittle or too stiff, it will tend to break under these conditions due to stress exceeding tear strength.

3.6.1 Performance on Pallets Test Description

The performance on plastic pallet test is a dynamic test. It involves a simulation of the distribution environment in which two rolls are placed on top of the plastic pallet and submitted to shocks and vibrations when handled by a fork truck. The ideal test would use the standard ASTM D 4169-93 (Standard Practice for Performance Testing of Shipping Containers and Systems), but it was impossible to perform this test due to its cost and lack of resources.

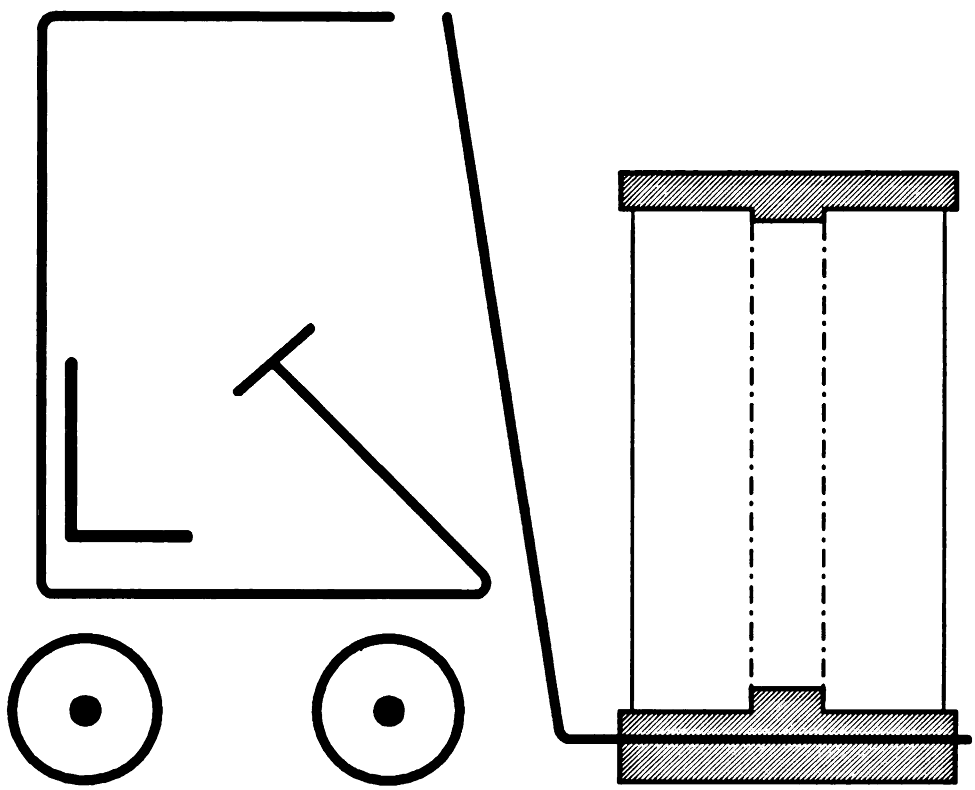
Using this concept as a model, a dynamic test was developed. The test was performed on wood and on plastic pallets. It consisted of loading two rolls on a pallet (the heaviest rolls weigh approximately 1200 lb. each), and then packaging them with all the additional package elements as explained in Table 13.

Table 13: Packaging Elements for Wood and Plastic Pallets

Wood Package	Plastic Pallets
strapping	strapping
top tray (cardboard)	top pallet (HDPE)
pad (cardboard)	bottom pallet (HDPE)
sidewall (cardboard)	
cushion pad (cardboard)	
bottom tray (cardboard)	
wood pallet	

The load is then picked up with a forklift (Figure 15), and submitted to about five minutes of dynamic shock and vibration.

Figure 15: Loaded Forklift



There were two kinds of test, the moderate test and the severe test. Both tests used the same route, which included driving the forklift with the package over a rough road with holes, bumps and crossing over railroad lines. The moderate test lasted for three minutes at a speed of approximately 2 to 3 miles per hour. The severe test consisted of the same elements as the moderate test, but at a speed of approximately 5 to 6 miles per hour. Also, the severe test crossed twice over railroad lines and lasted six minutes. At the end of the test the rolls were removed from their bags and they were inspected for damage. Each test always used a new bag.

In order to have enough information relevant to the different environments to which the packaged bag may be exposed, the test was conducted using wood and plastic pallets. Each pallet was exposed to the moderate and the severe test. The criterion used to rate this test was based on the amount of bag damage (creation of holes or cuts to the bag at the bottom of the roll). After the test, each hole or cut was counted, multiplied by the test rating factor (severe=5, moderate=10) and the tests added. In the severe test, the probabilities of failure are higher than in the moderate test.

3.6.2 Performance on Pallets Test Results

The data for the performance on pallet tests in this study on laminated film are listed in Appendix E in Tables E1 to E7. These tables list the number of failures found in each test. A summary of the data is presented in Table 14.

The severe test is an overkill test; the moderate test is similar to the distribution environment. For this reason, the number of failures (holes or cuts) in the moderate test was multiplied by ten (10), while the number of failures in the severe test was multiplied by five (5). Each test was performed twice, for each type of pallet, for a total of eight different test results per kind of bag. The totals for the two pallet types were added together to give the score for the test.

Table 14: Results of the Performance on Pallets Test

Laminations		Damage Score	Ranking Results
Dryflex-A	=	0	10
Tyvek® is	=	5	10
Dryflex-B	=	5	10
Dryflex-C	=	10	9
Nylon-A	=	45	4
Nylon-C	=	55	2
Nylon-B	=	75	0

From the data for the performance on the wood pallets, it can be concluded that this test is not critical. None of the seven laminations were damaged in either test. All the laminations performed very well on the wood pallets. On the other hand, on plastic pallets the result varies. The least susceptible lamination structure to punctures, holes or cuts is the Dryflex-A, with excellent results on both pallets. Dryflex-B and Tyvek® perform similarly; they both are also rated as excellent Dryflex-C performed acceptably. Nylons performed poorly on plastic pallets, but excellently on wood pallets.

In order to categorize the results, as described in Section 3.0, a scale was developed (Table 14: Ranking Results Column), with a rank of ten given to the best performance (least failures) and a rank of zero to the worst performance. The scale was developed by using equal increments of 6.81, i.e. from 0 to 6.81 was rated as a "10", from 6.82 to 13.63 was rated as a "9" and so on. A ranking of 10 was given to Dryflex-A, Dryflex-B and Tyvek®. On the other hand, Nylon-B was rated zero, as it had the highest failure score.

3.7 Sliding, Folding and Label Adhesion Test

Another important criterion for the comparison of the alternative materials is their fitness for use. The bag must be used effectively for whatever it was designed to do, and it must perform acceptably. Therefore, it was necessary to perform a test which considered the day to day operations involving the bag. Sliding, Folding and Label Adhesion are in-house tests that will provide information regarding routine handling. These are the things the operators will do to the bags repeatedly. They are performed sequentially in the same order they are written.

During the sliding operation, the operator opens the bag and then covers the roll with it, protecting the roll from any possible damage. At this point the coefficient of friction (COF) between the LDPE film covering the roll and the material inside the bag is critical. If the material has a high COF, the bag will be hard to insert on the roll. On the other hand a low COF will facilitate the operation. Once the bag covers the roll, it is folded, adjusting it to the roll size.

The folding operation is performed manually and all the folds are secured with adhesive tape. At this point the manageability of the bag is important. A rigid or stiff bag can be hard to work with. On the other hand if the bag folds easily it will make the manufacturing operation easier. The last, but not least important, is the product identification or labeling operation. After folding the bags, a label is placed on the side of the lamination for the proper identification of the roll. This label will travel with the product, retaining the identity of the formulation until it reaches the customer.

3.7.1 Sliding, Folding and Label Adhesion Test Description

The method used to perform this test was based on the repetition of the sliding, folding and label adhesion operation. Each operation was performed three times for each lamination by the same operator. Similarly to section 3.3 (foil delamination), each time a grade of: none, low, medium or high was given to each lamination. "None" means no problems in performing the operation, (easy to slide the bag over the roll, easy to fold, and the label adheres well), and was rated as 0.1. "Low" was rated as 1, and means the operator found a minor problem while performing the operation. 'Medium" was rated as 2, meaning the operator had more trouble in performing the operations than in "Low". "High" means high difficulty in performing the operation and was rated as 3.

Each test was performed three times for each lamination. The results of each separate test were individually added and then added together. The arithmetical addition was taken as the result of the sliding, folding and label adhesion test for each lamination.

3.7.2 Sliding, Folding and Label Adhesion Test Results

The data for each sliding, folding and label adhesion test in this study are listed in Appendix F in Tables F1 to F7. These tables list the results of the subjective evaluation by an experienced operator, in terms of how difficult it was to perform the operation. A summary of the data is presented in Table 15.

Table 15: Results of the Sliding, Folding and Label Adhesion Tests

Laminations		Test Results	Ranking Results
Dryflex-C	=	1.8	9
Nylon-C	=	5.5	7
Nylon-B	=	8.3	5
Tyvek® is	=	9.3	5
Nylon-A	=	9.3	5
Dryflex-B	=	12.3	3
Dryflex-A	=	18.3	0

From the above results it can be concluded that the easiest lamination to work with is the Dryflex-C. This lamination folds better than any other lamination evaluated; in addition it slides very easily. On the other hand, Dryflex-A is the most difficult lamination to work with. The outer layer of this lamination is very stiff and hard to shape to the roll size. Nylon structures perform acceptably once again. The thickest nylon (Nylon-A), was the most difficult to work with. Regarding the label adhesion test, the results showed no difference in adhering the label from lamination to lamination. The Tyvek® structure has the most roughness on its surface, but this was not significant enough to interfere with the operation.

In order to categorize the results, as described in Section 3.0, a scale was developed (Table 15: Ranking Results column), with a grade of ten given to the best performance and a grade of zero to an unacceptable performance. The scale was developed by using equal increments of 1.66 units, i.e. from 0 to 1.66 was rated as a "10", from 1.67 to 3.33 was rated as a "9" and so on. Neither lamination obtain a "10" on this test. A ranking of 9 was given to Dryflex-C which was the most manageable lamination, while a ranking of 0 was given to Dryflex-A which was the most difficult lamination to handle.

3.8 Water Vapor Transmission Rate (WVTR) Test

This test was performed according to ASTM standard F 1249-90 (Water Vapor Transmission Rate Through Plastic Film and Sheeting Using a Modulated Infrared Sensor). This test method covers a procedure for determining the rate of water vapor transmission through flexible barrier materials. The method is applicable to sheets and films up to 3mm (0.1 in.) in thickness, consisting of single or multilayer synthetic or natural polymers and foils, including coated materials. WVTR is the rate of water vapor flow normal to the surfaces, under steady-state conditions, per unit of area. The units of the test are grams divided by meters squared per day (g / M^2 day).

The purpose of the test is to obtain reliable values for the WVTR of the lamination structures. WVTR is an important property of packaging materials and can be directly related to the shelf life and packaged product stability. In fact the shelf life of the polyvinyl butyral is determined by the WVTR of the lamination and the damage it may sustain. The equipment used for this experiment was the Permatran-W machine.

3.8.1 WVTR Test Description

This test method was performed by an expert on the equipment, a graduate student from the Michigan State University School of Packaging. The test procedure to perform this test is described in detail in the ASTM standard. The general equation to calculate WVTR is:

$$\text{WVRT} = (\,C) \times (ES - EO)$$

where:

C = Calibration factor expressing rate as a function of voltage or mV. The value of C is derived from test of a known reference film.

EO = Permeation system zero level voltage

ES = Equilibrium voltage obtained with the test specimen

3.8.2 WVTR Test Results

The data for the WVTR tests for this study on laminated film are listed in Appendix G in Tables G1 to G7. These tables list average WVTRs for two samples per lamination. A summary of the data is presented in Table 16.

Table 16: Results of the WVTR Test

Laminations		WVTR Results	Ranking Results
Dryflex-C	=	0.001 (g / M^2 day)	10
Nylon-A	=	0.194 (g / M^2 day)	6
Nylon-B	=	0.207 (g / M^2 day)	5
Nylon-C	=	0.221 (g / M^2 day)	5
Dryflex-B	=	0.263 (g / M^2 day)	4
Tyvek® is	=	0.435 (g / M^2 day)	0
Dryflex-A	=	no data (g / M^2 day)	4

As the results reflect, the best lamination structure in terms of WVTR is the Dryflex-C with an average level of 0.001 g / M^2 per day. Tyvek® performed the poorest. Since all the laminations contain the same amount of foil as the barrier layer, this may happened due to higher diffusion of moisture particles though the material itself or though the seal. Nylon laminations, overall, performed as well as Dryflex laminations. Nylon-A, with Saran® coating, performed the best of the nylons. The test was not performed on the Dryflex-A structure. Since it is manufactured identically and has very similar composition to Dryflex B, it was assigned the same ranking as Dryflex-B.

In order to categorize the results, as described in Section 3.0, a scale was developed (Table 16: Ranking Results Column), with a grade of ten given to the best performance (lowest WVTR level) and a grade of zero to the lowest performance. The scale was developed by using equal increments of 0.0396 units, i.e. from 0 to 0.0396 was rated as a "10", from 0.0397 to 0.0792 was rated as a "9" and so on. A ranking of 10 was given to Dryflex-C, while a ranking of 0 was given to Tyvek®. This does not mean that Tyvek® is unacceptable for this application. This result means it performed the worst when compared to the other laminations during this WVTR test.

3.9 Summary of the Results

This section contains the summary of the results of all the testing performed on the lamination structures (discussed in detail in Section 3). Table 17 (Summary of the Test Results) contains the results of each independent test for the laminations. An overall ratings summary is presented in Table 18 (Summary of the Rating Results). The independent rating from each test were added to provide a tabulated representation of the overall performance among the alternatives considered.

Table 17: Summary of the Test Results

Tested Laminations Structures

Test	Dryflex-A	Dryflex-B	Dryflex-C	Nylon-A	Nylon-B	Nylon-C	Tyvek®
Capping (holes)	37.8	29.3	16.7	11.3	9.3	14.7	17.7
Cost Analysis	$473.43	$368.54	$347.78	$307.38	$583.64	$491.34	$779.07
Dart Drop (Puncture Resistance)	601.44 g	521.76 g	252.28 g	413.93 g	299.53 g	395.63 g	290.40 g
Foil Delamination (particles)	14	11	4.2	3.3	2.4	0.6	5.1
Heat Seal (lb./in.)	14.29	13.86	8.17	10.98	9.73	13.54	11.81
Performance/ Pallets (holes)	0	5	10	45	75	55	5
Sliding, Folding Label Adhesion	18.3	12.3	1.8	9.3	8.3	5.5	9.3
WVTR / Pin Holes ($g/M^2/day$)	X	0.263	0.001	0.194	0.207	0.221	0.435

Table 18: Summary of the Rating Results

Tested Laminations Structures

Test	Dryflex-A	Dryflex-B	Dryflex-C	Nylon-A	Nylon-B	Nylon-C	Tyvek®
Capping	10	8	4	3	2	4	4
Cost Analysis	4	5	6	6	2	4	0
Dart Drop (Puncture Resistance)	10	8	4	6	4	6	4
Foil Delamination	0	2	7	8	9	10	6
Heat Seal	10	10	6	8	7	10	9
Performance/Pallets	10	10	9	4	0	2	10
Sliding, Folding Label Adhesion	0	3	9	5	6	7	5
WVTR / Pin Holes	4	4	10	6	5	5	0
Overall Performance	48	50	55	46	35	48	38

4.0 Conclusions

Considering the complete performance analysis covering all the manufacturing operations, the results show better performance from the Dryflex-B and Dryflex-C structures, compared to the nylons and Tyvek®. Nylon laminations are suitable for corrugated packages, but do not have the strength needed to be used on plastic pallets. The other laminations are also good, but they possess weak points. The Tyvek® lamination is excellent from a performance perspective, but inefficient from a cost point of view.

The lamination with the overall best performance was the Dryflex-C. The main reasons for this result were: its manageability (Sliding, Folding and Label Adhesion), the Foil Delamination test, and the WVTR test. In all these tests the lamination reached the top score and at the same time it performed very well in the performance on plastic pallets test. Dryflex-B was the second best performer. Dryflex-A is the strongest structure, but it is the most difficult to work with. Its stiffness makes the structure not desirable for manageability. On the other hand, Dryflex-C, is more balanced between the three Dryflex alternatives. Dryflex-A is too rigid to be used and also has the delamination problem.

Nylon-C and Nylon-A performed the best of the nylons with scores of 48 and 46 points respectively. The good performance of Nylon-C structure is due to the thicker LLDPE layer this structure possesses. This layer enhance the structure allowing good results in the Dart Drop and Heat Seal test. Tyvek®, had the second lowest score overall for two major reasons; the expensive cost and the water vapor transmission rate results. Dryflex-C had the best overall performance results on the mechanical and physical properties evaluated in this study. The lamination with the poorest overall performance was Nylon-B.

The mechanical properties of a lamination structure can be improved by adding a LLDPE layer. It is appropriate to mention that a layer of LLDPE adds to the structure desirable properties against puncture, in this study represented by the dart drop test. All the samples that contained the LLDPE layer performed six and above in the ranking scale, while those which did not have it performed lower, with the exception of Nylon-A, which has a thicker nylon layer.

This study provide guide lines to objectively evaluate and select different numbers of alternatives based on the lamination performance. The same concepts can be adapted to other applications, in which it will be necessary to select one alternative among others. During this study there were some critical test and some that have no impact on the overall performance for the laminations. If this study is performed again, changes to the performance testing section should be consider. Experiments like performance on wood pallets and label adhesion were not relevant to the final score. On the other hand, test like: stress and strain analysis, aro burst test and gas permeability should be added and correlate their results to mechanical and physical properties.

APPENDICES

APPENDIX A

Table A.1: Capping Operation Test Results of the Dryflex-A Structure

Capping Test data 1	Capping Test data 2	Capping Test data 3	Average	std.
35	37	44	38.67	4.73

Table A.2: Capping Operation Test Results of the Dryflex-B Structure

Capping Test data 1	Capping Test data 2	Capping Test data 3	Average	std.
31	27	30	29.33	2.08

Table A.3: Capping Operation Test Results of the Dryflex-C Structure

Capping Test data 1	Capping Test data 2	Capping Test data 3	Average	std.
15	19	16	16.67	2.08

Table A.4: Capping Operation Test Results of the Nylon-A Structure

Capping Test data 1	Capping Test data 2	Capping Test data 3	Average	std.
11	10	13	11.33	1.53

Table A.5: Capping Operation Test Results of the Nylon-B Structure

Capping Test data 1	Capping Test data 2	Capping Test data 3	Average	std.
8	9	11	9.33	1.25

Table A.6: Capping Operation Test Results of the Nylon-C Structure

Capping Test data 1	Capping Test data 2	Capping Test data 3	Average	std.
13	16	15	14.67	1.53

Table A.7: Capping Operation Test Results of the Tyvek® Structure

Capping Test data 1	Capping Test data 2	Capping Test data 3	Average	std.
17	22	14	17.67	4.04

APPENDIX B

Table B.1: Dart Drop Results of the Dryflex-A Structure

grams	R	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Ni	i	iNi
653.43	7						X															1	5	5
638.18	6					0		X		X												2	4	8
622.93	5		X		0				0		X											2	3	6
607.68	4	0		0								X										1	2	2
592.43	3												X				X					2	1	2
577.18	2													X		0		X		X		3	0	0
561.93	1														0				0		0			
546.68	0																					11	15	23
																						N		A

Failure Weight

Wf = Wo + (^W (A/N - 1/2))

Where Wo is missile weight with an i value of 0 = 577.18 grams
Where A is the sum of the iNi values = 23
Where N is the sum of the Ni's = 11
Where ^W is the weight increment = 15.25 grams

Wf for Dryflex-A = 601.44 grams

Table B.2: Dart Drop Results of the Dryflex-B Structure

grams	R	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
559.20	9																							
543.95	8															X								
531.70	7				X		X								0		X				X			
519.45	6			0		0		X		X				0				X		0		X		X
507.20	5		0						0		X		0		Ni	I	iNi		0				0	
494.95	4	0										0			1	3	3							
482.70	3														4	2	8							
470.45	2														5	1	5							
458.20	1														1	0	0							
445.95	0														11	6	16							
															N		A							

Failure Weight

Wf = Wo + (^W (A/N - 1/2))

Where Wo is missile weight with an i value of 0 = 507.20 grams
Where A is the sum of the iNi values = 16
Where N is the sum of the Ni's = 11
Where ^W is the weight increment = 15.25 grams

Wf for Dryflex-B = 521.76 grams

Table B.3: Dart Drop Results of the Dryflex-C Structure

grams	R	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Ni	i	iNi
323.95	7																							
308.70	6																							
293.45	5																	X				1	4	4
278.20	4																0		X			1	3	3
262.95	3	X		X										X		0				X		4	2	8
247.70	2		0		X				X		X		0		0						0	3	1	3
232.45	1					X		0		0		0										1	0	0
217.20	0						0																	
																						10	10	18
																						N		A

Failure Weight

Wf = Wo + (^W (A/N - 1/2))

Where Wo is missile weight with an i value of 0 = 232.45 grams
Where A is the sum of the iNi values = 18
Where N is the sum of the Ni's = 10
Where ^W is the weight increment = 15.25 grams

Wf for Dryflex-C = 252.28 grams

Table B.4: Dart Drop Results of the Nylon-A Structure

grams	R	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Ni	i	iNi
461.20	7																							
445.95	6									X												1	3	3
430.70	5						X		0		X		X		X							4	2	8
415.45	4			X		0		0				0		0		X				X		3	1	3
400.20	3		0		0												X		0		X	2	0	0
384.95	2	0																0						
369.70	1																					10	6	14
354.45	0																					N		A

Failure Weight

Wf = Wo + (^W (A/N - 1/2))

Where Wo is missile weight with an i value of 0 = 400.20 grams
Where A is the sum of the iNi values = 14
Where N is the sum of the Ni's = 10
Where ^W is the weight increment = 15.25 grams

Wf for Nylon-A = 413.93 grams

Table B.5: Dart Drop Results of the Nylon-B Structure

grams	R	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
339.20	8																						
323.95	7								X						X								
308.70	6							0		X		X		0		X				X		X	
293.45	5				X		0				0		0				X		0		0		X
278.20	4			0		0												0					
262.95	3		0										Ni	i	iNi								
247.70	2	0																					
232.45	1												2	2	4								
217.20	0												5	1	5								
													3	0	0								
													10	3	9								
													N		A								

Failure Weight

Wf = Wo + (^W (A/N - 1/2))

Where Wo is missile weight with an i value of 0 = 293.45 grams
Where A is the sum of the iNi values = 9
Where N is the sum of the Ni's = 10
Where ^W is the weight increment = 15.25 grams

Wf for Nylon-B = 299.53 grams

Table B.6: Dart Drop Results of the Nylon-C Structure

grams	R	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Ni	i	iNi
461.20	7																					Ni	i	iNi
445.95	6																							
430.70	5																X					1	3	3
415.45	4									X						0		X				2	2	4
400.20	3				X				0		X		X		0				X		X	5	1	5
384.95	2	X		0		X		0				0		0						0		2	0	0
369.70	1		0				0															10		12
354.45	0																							
																						N		A

Failure Weight

Wf = Wo + (^W (A/N - 1/2))

Where Wo is missile weight with an i value of 0 = 384.95 grams
Where A is the sum of the iNi values = 12
Where N is the sum of the Ni's = 10
Where ^W is the weight increment = 15.25 grams

Wf for Nylon-C = 395.63grams

Table B.7: Dart Drop Results of the Tyvek® Structure

grams	R	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	Ni	i	iNi
323.95	7									X													1	3	3
308.70	6				X		X		0		X										X		4	2	8
293.45	5			0		0		0				X								0		X	2	1	2
278.20	4		0										X		X		X		0				3	0	0
262.95	3	0												0		0		0							
247.70	2																						10	6	13
232.45	1																						N		A
217.20	0																								

Failure Weight

Wf = Wo + (^W (A/N - 1/2))

Where Wo is missile weight with an i value of 0 = 278.2 grams
Where A is the sum of the iNi values = 13
Where N is the sum of the Ni's = 10
Where ^W is the weight increment = 15.25 grams

Wf for Tyvek® is = 290.40 grams

APPENDIX C

Table C.1: Foil Delamination Results of the Dryflex-A Structure

Classification	Rate	Method-A	Method-B
None	0.1		
Low	1		
Medium	2	X	
High	3		X
None	0.1		
Low	1	X	
Medium	2		
High	3		X
None	0.1		
Low	1		
Medium	2	X	
High	3		X
		5	9
			14

Table C.2: Foil Delamination Results of the Dryflex-B Structure

Classification	Rate	Method-A	Method-B
None	0.1		
Low	1	X	
Medium	2		X
High	3		
None	0.1		
Low	1	X	
Medium	2		X
High	3		
None	0.1		
Low	1		
Medium	2	X	
High	3		X
		4	7
			11

Table C.3: Foil Delamination Results of the Dryflex-C Structure

Classification	Rate	Method-A	Method-B
None	0.1		
Low	1	X	X
Medium	2		
High	3		
None	0.1	X	
Low	1		X
Medium	2		
High	3		
None	0.1	X	
Low	1		X
Medium	2		
High	3		
		1.2	3
			4.2

Table C.4: Foil Delamination Results of the Nylon-A Structure

Classification	Rate	Method-A	Method-B
None	0.1	X	
Low	1		X
Medium	2		
High	3		
None	0.1	X	
Low	1		X
Medium	2		
High	3		
None	0.1	X	
Low	1		X
Medium	2		
High	3		
		0.3	3
			3.3

Table C.5: Foil Delamination Results of the Nylon-B Structure

Classification	Rate	Method-A	Method-B
None	0.1	X	X
Low	1		
Medium	2		
High	3		
None	0.1	X	
Low	1		X
Medium	2		
High	3		
None	0.1	X	
Low	1		X
Medium	2		
High	3		
		0.3	2.1
			2.4

Table C.6: Foil Delamination Results of the Nylon-C Structure

Classification	Rate	Method-A	Method-B
None	0.1	X	X
Low	1		
Medium	2		
High	3		
None	0.1	X	X
Low	1		
Medium	2		
High	3		
None	0.1	X	X
Low	1		
Medium	2		
High	3		
		0.3	0.3
			0.6

Table C.7: Foil Delamination Results of the Tyvek® Structure

Classification	Rate	Method-A	Method-B
None	0.1		
Low	1	X	X
Medium	2		
High	3		
None	0.1		
Low	1	X	X
Medium	2		
High	3		
None	0.1	X	
Low	1		X
Medium	2		
High	3		
		2.1	3
			5.1

APPENDIX D

Table D.1: Heat Seal Results of the Dryflex-A Structure

Test #	Load	Peak average peeling load (#/in)
1	10 in./min	12.6
2	10 in./min	13.5
3	10 in./min	14.3
4	10 in./min	16.7
5	10 in./min	13.4
6	10 in./min	15.6
7	10 in./min	13.7
8	10 in./min	16.2
9	10 in./min	12.2
10	10 in./min	14.7
Average		14.29
std.		1.50

Table D.2: Heat Seal Results of the Dryflex-B Structure

Test #	Load	Peak average peeling load (#/in)
1	10 in./min	14.3
2	10 in./min	13.5
3	10 in./min	15.3
4	10 in./min	12.6
5	10 in./min	13.7
6	10 in./min	14.2
7	10 in./min	14.6
8	10 in./min	12.3
9	10 in./min	13.4
10	10 in./min	14.7
Average		13.86
std.		0.94

Table D.3: Heat Seal Results of the Dryflex-C Structure

Test #	Load	Peak average peeling load (#/in)
1	10 in./min	11.2
2	10 in./min	7.2
3	10 in./min	5.9
4	10 in./min	6.3
5	10 in./min	7.0
6	10 in./min	12.2
7	10 in./min	6.3
8	10 in./min	8.3
9	10 in./min	6.5
10	10 in./min	10.8
Average		8.17
std.		2.35

Table D.4: Heat Seal Results of the Nylon-A Structure

Test #	Load	Peak average peeling load (#/in)
1	10 in./min	10.3
2	10 in./min	12.4
3	10 in./min	11.7
4	10 in./min	10.8
5	10 in./min	12.1
6	10 in./min	9.6
7	10 in./min	10.3
8	10 in./min	9.7
9	10 in./min	11.1
10	10 in./min	11.8
Average		10.98
std.		1.00

Table D.5: Heat Seal Results of the Nylon-B Structure

Test #	Load	Peak average peeling load (#/in)
1	10 in./min	9.0
2	10 in./min	9.8
3	10 in./min	10.4
4	10 in./min	10.6
5	10 in./min	7.6
6	10 in./min	10.8
7	10 in./min	10.1
8	10 in./min	8.6
9	10 in./min	9.9
10	10 in./min	10.5
Average		9.73
std.		1.03

Table D.6: Heat Seal Results of the Nylon-C Structure

Test #	Load	Peak average peeling load (#/in)
1	10 in./min	15.2
2	10 in./min	14.6
3	10 in./min	14.2
4	10 in./min	11.6
5	10 in./min	12.8
6	10 in./min	12.7
7	10 in./min	10.3
8	10 in./min	18.2
9	10 in./min	12.6
10	10 in./min	13.2
Average		13.54
std.		2.17

Table D.7: Heat Seal Results of the Tyvek® Structure

Test #	Load	Peak average peeling load (#/in)
1	10 in./min	11.6
2	10 in./min	10.8
3	10 in./min	13.5
4	10 in./min	9.8
5	10 in./min	11.7
6	10 in./min	13.1
7	10 in./min	12.6
8	10 in./min	10.9
9	10 in./min	12.4
10	10 in./min	11.7
Average		**11.81**
std.		1.13

APPENDIX E

Table E.1: Performance on Pallets Results of the Dryflex-A Structure

Test severity	Rate	Wood Pallet # holes or cuts	Plastic Pallet # holes or cuts
Moderate	10	0	0
Severe	5	0	0
Moderate	10	0	0
Severe	5	0	0
		0	0
			0

Table E.2: Performance on Pallets Results of the Dryflex-B Structure

Test severity	Rate	Wood Pallet # holes or cuts	Plastic Pallet # holes or cuts
Moderate	10	0	0
Severe	5	0	1
Moderate	10	0	0
Severe	5	0	0
		0	5
			5

Table E.3: Performance on Pallets Results of the Dryflex-C Structure

Test severity	Rate	Wood Pallet # holes or cuts	Plastic Pallet # holes or cuts
Moderate	10	0	0
Severe	5	0	1
Moderate	10	0	0
Severe	5	0	1
		0	10
			10

Table E.4: Performance on Pallets Results of the Nylon-A Structure

Test severity	Rate	Wood Pallet # holes or cuts	Plastic Pallet # holes or cuts
Moderate	10	0	1
Severe	5	0	2
Moderate	10	0	1
Severe	5	0	3
		0	45
			45

Table E.5 Performance on Pallets Results of the Nylon-B structure

Test severity	Rate	Wood Pallet # holes or cuts	Plastic Pallet # holes or cuts
Moderate	10	0	2
Severe	5	0	3
Moderate	10	0	2
Severe	5	0	4
		0	75
			75

Table E.6: Performance on Pallets Results of the Nylon-C Structure

Test severity	Rate	Wood Pallet # holes or cuts	Plastic Pallet # holes or cuts
Moderate	10	0	1
Severe	5	0	2
Moderate	10	0	2
Severe	5	0	3
		0	55
			55

Table E.5: Performance on Pallets Results of the Tyvek® Structure

Test severity	Rate	Wood Pallet # holes or cuts	Plastic Pallet # holes or cuts
Moderate	10	0	0
Severe	5	0	1
Moderate	10	0	0
Severe	5	0	0
		0	5

APPENDIX F

Table F.1: Sliding Folding and Label Adhesion Results of the Dryflex-A Structure

Classification	Rate	Sliding	Folding	Label Adhesion
None	0.1			X
Low	1			
Medium	2			
High	3	X	X	
None	0.1			X
Low	1			
Medium	2			
High	3	X	X	
None	0.1			X
Low	1			
Medium	2			
High	3	X	X	
		9	9	0.3
				18.3

Table F.2: Sliding Folding and Label Adhesion Results of the Dryflex-B Structure

Classification	Rate	Sliding	Folding	Label Adhesion
None	0.1			X
Low	1			
Medium	2	X	X	
High	3			
None	0.1			X
Low	1			
Medium	2	X	X	
High	3			
None	0.1			X
Low	1			
Medium	2	X	X	
High	3			
		6	6	0.3
				12.3

Table F.3: Sliding Folding and Label Adhesion Results of the Dryflex-C Structure

Classification	Rate	Sliding	Folding	Label Adhesion
None	0.1	X	X	X
Low	1			
Medium	2			
High	3			
None	0.1	X	X	X
Low	1			
Medium	2			
High	3			
None	0.1		X	X
Low	1	X		
Medium	2			
High	3			
		1.2	0.3	0.3
				1.8

Table F.4: Sliding Folding and Label Adhesion Results of the Nylon-A Structure

Classification	Rate	Sliding	Folding	Label Adhesion
None	0.1			X
Low	1		X	
Medium	2	X		
High	3			
None	0.1			X
Low	1		X	
Medium	2	X		
High	3			
None	0.1			X
Low	1	X		
Medium	2		X	
High	3			
		5	4	0.3
				9.3

Table F.5: Sliding Folding and Label Adhesion Results of the Nylon-B Structure

Classification	Rate	Sliding	Folding	Label Adhesion
None	0.1			X
Low	1	X	X	
Medium	2			
High	3			
None	0.1			X
Low	1			
Medium	2	X	X	
High	3			
None	0.1			X
Low	1	X	X	
Medium	2			
High	3			
		4	4	0.3
				8.3

Table F.6: Sliding Folding and Label Adhesion Results of the Nylon-C Structure

Classification	Rate	Sliding	Folding	Label Adhesion
None	0.1			X
Low	1	X	X	
Medium	2			
High	3			
None	0.1	X		X
Low	1		X	
Medium	2			
High	3			
None	0.1	X		X
Low	1			
Medium	2		X	
High	3			
		1.2	4	0.3
				5.5

Table F.7: Sliding Folding and Label Adhesion Results of the Tyvek® Structure

Classification	Rate	Sliding	Folding	Label Adhesion
None	0.1			X
Low	1	X	X	
Medium	2			
High	3			
None	0.1			X
Low	1		X	
Medium	2	X		
High	3			
None	0.1			X
Low	1			
Medium	2	X	X	
High	3			
		5	4	0.3
				9.3

APPENDIX G

Table G.1: WVTR Results of the Dryflex-A Structure

Lamination	Source	Result (g / M^2 day)
Dryflex-A Dryflex-A	MSU-PKG MSU-PKG	No data No data

(g / M^2 day)

Table G.2: WVTR Results of the Dryflex-B Structure

Lamination	Source	Result (g / M^2 day)
Dryflex-B Dryflex-B	MSU-PKG MSU-PKG	0.276 0.249

0.263 (g / M^2 day)

Table G.3: WVTR Results of the Dryflex-C Structure

Lamination	Source	Result (g / M^2 day)
Dryflex-C Dryflex-C	MSU-PKG MSU-PKG	0.001 0.001

0.001 (g / M^2 day)

Table G.4: WVTR Results of the Nylon-A Structure

Lamination	Source	Result (g / M^2 day)
Nylon-A	MSU-PKG	0.235
Nylon-A	MSU-PKG	0.152

0.194 (g / M^2 day)

Table G.5: WVTR Results of the Nylon-B Structure

Lamination	Source	Result (g / M^2 day)
Nylon-B	MSU-PKG	0.193
Nylon-B	MSU-PKG	0.221

0.207 (g / M^2 day)

Table G.6: WVTR Results of the Nylon-C Structure

Lamination	Source	Result (g / M^2 day)
Nylon-C	MSU-PKG	0.249
Nylon-C	MSU-PKG	0.193

0.221 (g / M^2 day)

Table G.7: WVTR Results of the Tyvek® Structure

Lamination	Source	Result (g / M^2 day)
Tyvek®	MSU-PKG	0.414
Tyvek®	MSU-PKG	0.456
		0.435 (g / M^2 day)

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