Determining the Optimal Material for Coffee Packaging

Oxygen Transmission Rates and Ink Abrasion Resistance

A Senior Project

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Abstract:
Like many packages, coffee packaging must attract consumers for purchase. In addition, coffee packaging has the specific requirements of keeping its contents fresh. This study attempted to determine the optimal material for coffee packaging under the subjects of ink abrasion resistance for printed graphics and content freshness. The materials that were chosen to compare were Aluminum (Al), low density polyethylene (LDPE,) polyethylene terephthalate (PET,) polyvinyl chloride (PVC), nylon and polystyrene (PS.) To determine which material was the best for ink abrasion resistance, ink rub tests were performed. Also, oxygen transmission rates (OTR) were gathered to determine which material would best keep oxygen from getting into the package so the coffee would stay fresh for longer. After tests were performed, PET was found to best optimize ink abrasion resistance and content freshness. This study provides material specific information to describe the potential of using one type of material for coffee packaging instead of a multilaminate material. However, further research is needed to see how using one material instead of the currently used multilaminates would benefit manufacturers.

Chapter 1

What makes coffee taste bitter? There are several aspects that could play into one's coffee not being of the best quality such as the beans that are harvested, package transportation, coffee making machinery and the technique of the barista. One subject that plays a role in aspects of coffee traveling to the consumer is coffee packaging. This study addresses coffee packaging and its role to preserve the freshness of coffee as well as attract the consumer with graphics. The research question of this study is: What is the best coffee packaging material based on its ability to keep the contents fresh and hold graphics to attract the consumer? This question will be addressed by discussing the topics of material oxygen transmission rates (OTR) and resistance to ink abrasion. The purpose of this study is to determine the coffee package material that best optimizes content freshness and ink abrasion resistance.

To first address the purpose of this study, the requirements of coffee must be known. Coffee needs packaging that has barrier properties that keep oxygen (O_2) out to preserve the freshness of coffee. Companies use several materials such as aluminum, paper, polyethylene and other multi-laminates as materials to preserve the coffee. In addition to a type of main substrate, the package needs to have a one-way vent that allows carbon dioxide (CO_2) to leave the package from the roasted coffee but does not allow O_2 into the package.

In addition to the quality of the coffee, the package must also attract the consumer with graphics. Coffee is an extremely consumer-driven product. Even if a package preserves the quality of the coffee beans, there is no purpose unless the consumer takes it off of the shelf and purchases it. Therefore, the material that is used for coffee packages must be able to hold ink even through transportation where the ink from the graphics may be rubbed off.

Not only does the package need to attract the consumer, but it also must have strength for shipping and handling. The package would be worthless if it broke when put in secondary packaging such as regular slotted containers (RSCs), palletized and shipped. Any quality-preserving properties of the package would be eliminated if the package breaks and lets O_2 in. The package has to be durable enough to handle rough handling and shock in transport without breaking. A material that has great O_2 barrier properties but is extremely fragile is not practical for the rough handling of shipping. However, due to testing limitations, this study did not test for material durability. Instead, this study focused on determining the material that performed the highest in terms of content freshness and ink abrasion resistance. Nevertheless, it is important that the reader acknowledges that packaging would be worthless if it does not protect its contents throughout its journey to the consumer.

To determine what types of materials hold ink for graphics and still have low O_2 permeability, data were collected from testing and analysis of different material to optimize content freshness and ink rub resistance. Oxygen transmission rates were researched to point to the best oxygen barrier for coffee packaging. Also, different materials were printed on and ink rub tests were performed to determine each material's ink abrasion resistance. This study includes current information from the coffee packaging industry as well as data tested for this specific study to determine which material achieves the best level of content freshness and ink abrasion resistance for coffee.

Chapter 2

Since coffee is the package contents, the package needs to have a one-way vent to let out gases produced from the coffee out while keeping oxygen (O_2) out that could damage the quality of the coffee beans. Since coffee is a highly consumer-driven product, graphics are also needed to attract the consumer. This study attempts to determine the best material for coffee packaging to maximize content freshness and ink abrasion resistance. To decipher the best material for coffee packaging in both of these areas, common materials used in coffee packaging were researched and tested. Common materials used today for coffee packages are aluminum, low density polyethylene (LDPE), polyethylene terephthalate (PET), polypropylene (PP) and paper. Aluminum, LDPE and PET were chosen to compare and contrast. Polyvinyl chloride (PVC), nylon and polystyrene (PS) were also tested to compare.

Coffee Package Requirements: Letting Carbon Dioxide Out

Before one focuses on the materials of coffee packaging, the particular packaging requirements for coffee as the package contents must be recognized. Coffee is particularly difficult to package because it needs to allow carbon dioxide (CO_2) out while keeping oxygen (O_2) out. According to an article in the *Journal of Food Engineering* titled "The Diffusion Kinetics of Carbon Dioxide in Fresh Roasted and Ground Coffee," coffee has certain package requirements because of the CO_2 that is produced when the beans are roasted. The journal wrote that, "Although some carbon dioxide is released during roasting and upon grinding, some is trapped and slowly released creating a packaging problem" (Anderson et al. 71). The issue with coffee bean packaging is that the package will explode or billow if it does not have the ability to release the CO_2. This article also stated that darker roasted coffee beans contain more CO_2 than lighter roasts. This is because darker roasts require more time to roast and more roasting creates more CO_2 (Anderson et al. 71). Therefore, level of roasting should be taken into consideration by the packager.

Another aspect that must be addressed when calculating CO_2 emission is whether or not coffee is ground or kept as a whole bean when packaged. According to the *Wiley Packaging*

Technology Encyclopedia of 2009, CO_2 content is around 1000 cm^3/lb when the bean is roasted but not ground. When the bean is ground, about half of the CO_2 is released (Vacuum-Bag Coffee Packaging). Therefore, whole roasted coffee beans have a higher need for venting than ground beans.

Coffee Package Content Freshness: Low Oxygen Permeability

In addition to letting CO_2 out, coffee packaging must also keep O_2 from permeating the packaging and making the contents lose quality (Brody and Marsh 1256). Even though one can wait for the coffee to degas before packaging, this takes a twenty-four hour period, where O_2 can compromise the quality of the coffee (Fres-co). "Application of Weibull Hazard Analysis to the Determination of the Shelf Life of Roasted and Ground Coffee" was a study that involved consumer testing to determine the shelf life of coffee taking into account exposure to O_2 (Carbella and Labuza 275). The shelf life for the product ended when 50 percent of the tested consumers said that the coffee was unacceptable (Carbella and Labuza 273). The findings of the study showed that for every 24 hours that coffee was in room temperature; there was a decrease in shelf life of ten percent due to exposure to O_2 (Anderson. 1).

To address this issue of O_2 permeation, the oxygen transmission rates (OTR) of common coffee packaging materials was researched. For this study OTR is defined as amount of O_2 that can get through a given amount of area with pressure within a certain time frame.

These are some issues that the packager needs to be aware of when manufacturing coffee packaging. A type of one-way vent is usually used to reduce CO_2 and keep coffee from being damaged.

Coffee Printing Package Graphics for the Consumer

Even after achieving high quality coffee in a low OTR packaging material, one must also make sure that the substrate is printable for graphics that will attract the consumer. The bottom line is whether or not the consumer purchases the product.

Data on the ink adherence of LDPE, PET, nylon, aluminum, PS and PVC were included after ink rub tests were performed. However, this study also provides information on what the coffee packaging industry is doing currently for printing aesthetic graphics for the coffee-drinking consumer.

PJ's Coffee of New Orleans shows an example of this with converging packaging material knowledge with graphics knowledge. They used Sonoco as their packaging vendor who created a "new matte-finished, three-ply foil-based bags that feature the sophisticated imagery of New Orleans" (Package Design). The printing was done with Sonoco's rotogravure press capable of using seven colors with a matt finish. The matt finish gave a warmer look to the package that attracting the coffee-drinker:

> The softer finish minimizes the glare that often occurs in flexible coffee packaging. As a result, the detail of the photos is emphasized, imparting a sense of nostalgia and reflecting the sophisticated flavor consumers expect of New Orleans roasted coffee (Package Design).

Sonoco's PJ's Coffee Packaging
(Package Design)

PJ's Coffee did an excellent job of achieving printability from a sustainable standpoint in terms of reduction of materials. The multi-laminate of the packaging material is made up of polyester and foil while the seal is made from polyethylene. When compared to a four ply laminate package, this three-ply package achieves a reduction in material by 10 percent. It also uses 15 percent less energy in production and 10 percent less carbon emissions (Package Design).

One can see there are multiple aspects of coffee packaging with the added concern for maintaining the freshness of the coffee. Knowing the quality of print on the different materials this study covers allows manufacturers to include graphics that can attract the consumer. In addition ink adherence for graphics, one must also keep the quality of the coffee at the forefront of knowledge when designing coffee packaging.

Chapter 3

Although there are several important aspects to packaging such as durability, sustainability and graphics, coffee packaging in particular has the additional requirement of preserving the quality of coffee that consumers demand. Although there are many aspects to packaging, this study focuses on the subject of substrates that preserve the freshness of coffee through low O_2 permeation. This study also compares material to see which is the most capable of holding graphics that can attract the consumer. The purpose of this study is to determine the coffee packaging material that will best optimize content freshness and resistance to ink rub-off.

There are many types of film materials that are used for coffee packaging. However, the specific materials that this study addresses are polyethylene terephthalate (PET), polyvinyl chloride (PVC,) aluminum (Al), polystyrene (PS,) low density polyethylene (LDPE) and nylon. These films were chosen upon availability in California Polytechnic State University, San Luis Obispo's (Cal Poly) Industrial Technology's Plastics Lab. Current coffee packages are usually composed of a combination of materials in a multilaminate material. However, to see the basic physical characteristics of coffee packaging, each material was analyzed separately for the purpose of this study. The purpose of this study is to distinguish the best coffee packaging material to optimize content freshness and ink abrasion resistance.

To determine the best coffee packaging material, the scientific method of research was conducted as defined in Dr. Harvey Levenson's book titled, *Some Ideas about Doing Research in Graphic Communication*.

The scientific method is a method where one addresses the problem through performing experiments instead of relying on previously known information. The scientific method is broken up into several stages:

1) Identify and define the problem
2) Formulate a hypothesis
3) Collect, organize and analyze data
4) Formulate conclusions (Levenson, 19).

This method is appropriate when needing to address specific issues that may not be available in past, published data through historical research (Levenson, 19).

Using the scientific method, rub tests were performed on LDPE, PET, Al, Nylon, PVC and PS in the Inks and Substrates Lab at Cal Poly. Each material was corona treated to create a surface tension on the substrate to aid the ink's adherence to each material. After this, a flexographic hand proofer was used to print on each material with brown water-based ink. To determine how much ink was rubbed off, three ink density readings on different locations of the materials were taken before and after testing each material. The testing was done on an ink rub tester where the printed substrate was taped to a four-pound block. This block rubbed back and forth across a material of the same type that was not printed on. For example, a piece of printed PET film was rubbed against a non-printed PET film. Each material rubbed back and forth a hundred times at a cycle time of forty-two rubs per minute. These tests helped point to the best performing material for ink adherence.

Secondly, oxygen transmission rates (OTR) were gathered from Nippon, Gohsei, a Japanese company that specializes in polymers, adhesives and gas barrier films. This company provided OTRs of LDPE, PET, Al, Nylon, PVC and PS (Nippon).

Through gathering data from Nippon Gohsei and rub testing several materials, this study was able to provide information that pointed to the highest performance coffee packaging that optimized content freshness and ink adhesion.

<u>Chapter 4</u>

The purpose of this study is to determine the best material for coffee packaging to optimize the freshness of its contents and its ability to hold graphics to attract the consumer. To do this, the materials of PET, PVC, Al, PS, LDPE and Nylon were studied and compared with rub tests and oxygen transmission rate (OTR) findings.

Ink rub testing was performed in the ink and substrates lab on the ink rub tester at California Polytechnic State University in San Luis Obispo. The testing was done face to face using the 4 lb block. The machine rubbed this block back and forth on the same type of material for a 100 strokes. One could observe that certain materials had more ink loss than others after the rub tests. For example, PVC appeared to have the most ink loss out of all six materials. However, for the purpose of this study, density readings were chosen as the means of comparison between materials for ink abrasion resistance. To do this, three ink density readings were taken before and after each rub test. Three readings were taken at different locations of the materials to account for the possible ink lay down differences across materials from the flexographic hand proofer. Density readings before rub tests were performed are shown in the table below:

	Density $Before_1$	Density $Before_2$	Density $Before_3$
PET	1.59	1.68	1.61
PVC	0.8	0.81	1.56
Al	0.45	0.97	1
PS	1.58	1.62	1.57
LDPE	1.72	1.72	1.63
Nylon	1.55	1.52	1.47

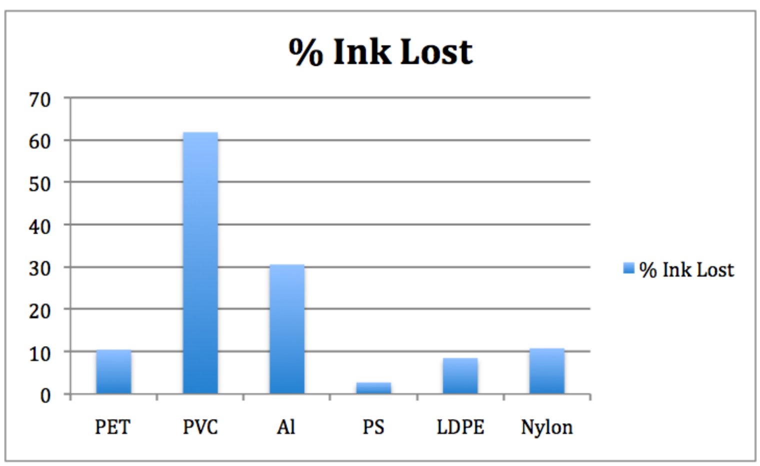
As one can see, there are differences of ink density across each material. This study acknowledges that in materials such as PVC, these differences are significant. PVC had a density in one location that was as low as 0.8 while in another location it had a density reading of 1.56, which gives it a density difference of 0.76. To account for these differences in ink lay-down, three readings were taken before and after rub tests and the readings were averaged.

Three density readings were also taken after rub tests were performed and are provided below:

	Density After$_1$	Density After$_2$	Density After$_3$
PET	1.27	1.52	1.58
PVC	0.28	0.47	0.46
Al	0.49	0.53	0.66
PS	1.59	1.56	1.49
LDPE	1.56	1.55	1.53
Nylon	1.45	1.21	1.39

These readings were averaged and then divided by the averaged densities that were taken before rub testing. This number was then subtracted from one to determine the percent of ink lost for each material. The results are shown below. One should note that lower numbers are better than higher numbers here because higher numbers represent more ink loss.

Substrate	% Ink Lost
PET	10.5
PVC	61.8
Al	30.6
PS	02.7
LDPE	08.5
Nylon	10.8

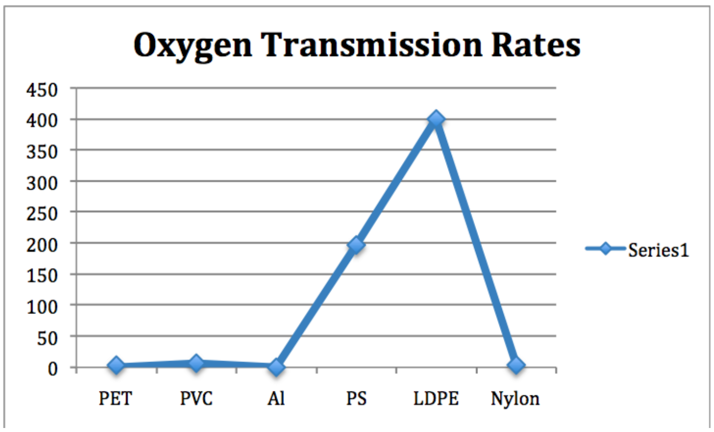


As one can see, the material that lost the most ink due to abrasion was PVC (also confirmed by eye) and the material that lost the least amount of ink was PS.

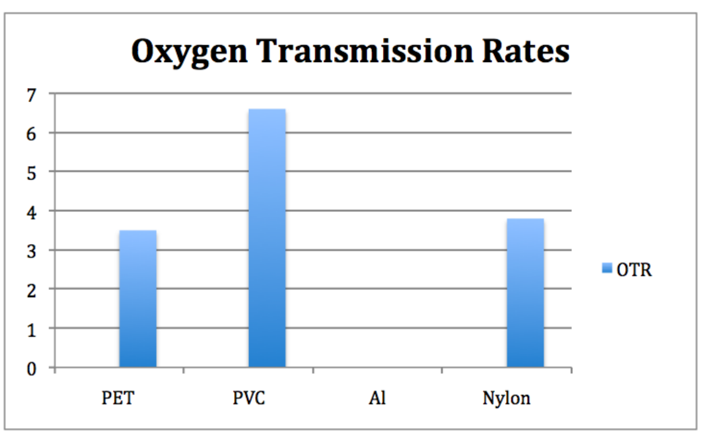
Oxygen Transmission Rates

Freshness of coffee is equally important as the graphics outside of the coffee package. Published oxygen transmission rates of materials were used to determine which film would be best for coffee packaging. This study uses oxygen transmission rates of materials to determine which substrate will perform the best to optimize content freshness as well as ink abrasion resistance. This study defines oxygen transmission rate (OTR) as the amount of O_2 that can get through with pressure through a given amount of area and time.

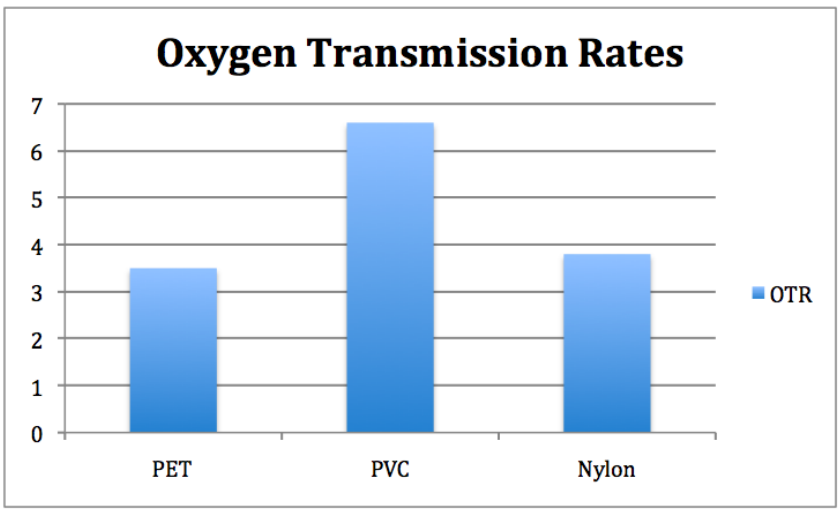
Research was performed using Nippon Gohsei data. The following information was collected from this company as shown below:



This graph depicts oxygen transmission rates in units of cc x mil/m^2 x day x atm, atm being an amount of pressure equaling 101,325 Pa. Lower OTR numbers mean that the material lets in less O_2. Given this information, one can see that PS and LDPE cannot compete with the other lower materials when it comes to protecting the coffee from the damages of O_2. Therefore, a more detailed graph is provided that compares PET, PVC, AL and Nylon and excludes PS and LDPE:



Aluminum as shown above, serves as a complete O_2 barrier; however, this is only the case when the material is in perfect condition. Because aluminum is usually used in flexible packages in the form of a film that is less than 1.0 mil, it is rarely perfect. Aluminum foil that is 1.0 mil or less usually has pin holes that increase the material's OTR (SPMC). However, using aluminum in addition to other layers has been proven to decrease OTR in comparison to not using an aluminum layer even with this pinhole effect (Murray). As stated earlier, AL can act as a complete barrier when in perfect condition; however, pinholes and tears are common in this material substantially lowering the material's barrier properties. With tears, Al can have an OTR that is even higher than LDPE. Therefore, the variety of materials narrowed further, focusing exclusively on PET, PVC, and Nylon. Out of these three material PET scored as the best defense against oxygen with an OTR of 3.5 cc x mil/m^2 x day x atm.

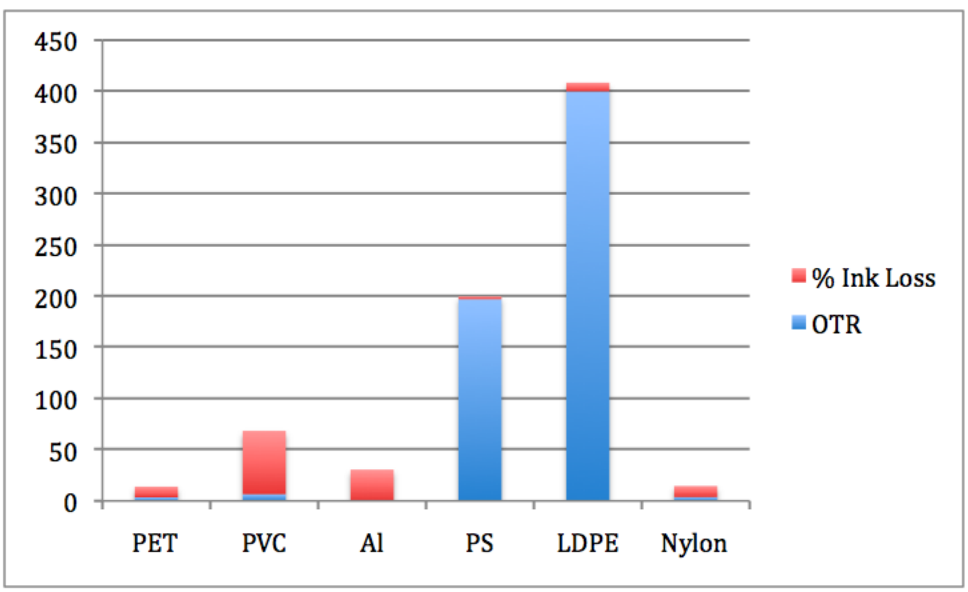


Highest Performance Material that Optimizes Content Freshness and Ink Abrasion Resistance

After gathering the data above, the materials were compared to see which was the best material to optimize content freshness and ink abrasion resistance. The study found that PET was the optimal choice. This included both OTR and percent ink lost as shown in the table below:

	OTR	% Ink Lost
PET	3.5	10.5
PVC	6.6	61.8
Al	0	30.6
PS	197	2.7
LDPE	400	8.5
Nylon	3.8	10.8

To best show this data, a graph is provided:



Even though, PS and LDPE had low amounts of ink loss from the rub tests, the material OTRs are too high to be considered for the purpose of this study. Similarly, although PVC's OTR seems competitive with Nylon and PET, its loss of ink from the rub tests is too high to compare with the OTR of PET and Nylon. Since lower bars mean lower OTR and less ink loss, one can see that the two materials that were compared the most were Nylon and PET.

PET falls lower than Nylon with ink loss and OTR; therefore, PET was determined to be the material that best optimized content freshness and resistance to ink abrasion.

Chapter 5

As one can see, coffee is a particularly challenging product to package. Not only does the manufacturer need to pay attention to strength of materials and graphics to attract the consumer, but he or she must also focus on preserving the freshness of coffee that consumers demand. To tackle these subjects, this study focused on content freshness with OTR and graphics for coffee packaging with ink abrasion resistance.

Through these two focuses of research and testing, this study found that PET was the optimal single material for content freshness and ink abrasion resistance with nylon as a close second.

As one can see, this study researched individual materials, not multilaminates. The reason that multilaminates are used is to decrease OTRs by having multiple layers of material and therefore extra barrier properties. Usually in the coffee packaging industry, multilaminates are used where one material is reverse printed on and adhered to the rest of the multilaminate material. In this case, ink rub resistance is not as applicable.

However, this study provided material specific ink abrasion resistance and OTR data. By providing this information, one can examine the potential of using one type of material instead of a multilaminate. Manufacturers can use this information to see how individual materials would perform without having to reverse print and adhere to another material. Further research is needed to determine the specifics on how this can benefit coffee package manufacturing.

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