EMBEDDING RADIO FREQUENCY IDENTIFICATION INLAYS INTO INJECTION MOLDED FOOD CONTAINERS USING IN MOLD LABELING TECHNOLOGY

By

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To my friends and family.

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First I'd like to thank my parents, my friends, my advisor Dr JP Emond, and all the members of my committee. I would also like to thank the ABE department staff who helped me along the way to success.

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RFID technology is slowly becoming a strong presence in the food packaging industries. The tracking and tracing capabilities that go along with RFID are making it an indispensable tool in any industry, let alone in the food industry where recent food scares have made the concept of product origins a highly desirable addition to any food product. Large organizations are committed to the use of this technology throughout open supply chains, and the focus centered on this technology has shifted from pilot and lab testing to full on implementation. As more companies adopt RFID usage, the costs of the technology, one of the biggest limiting factors, will decrease steadily and promote a movement to item level tagging. Item level tagging is where most benefits to the consumer can be seen.

Embedding RFID tags into individual injection molded containers was studied. The main objective was to develop a method for embedding RFID inlays into injection molded packaging using IML technology. Preliminary tests were run on establishing the effects of adding PETE to a PP matrix and IML film. Using the results from these preliminary tests, a process of holding an RFID inlay to an IML film using 2 different adhesives was developed and tested using 3 different inlay styles supplied by Avery Dennison (South Carolina, USA). In order to determine the best method for application, the inlays were studied with adhesives applied as follows: 1) to

the side holding the inlay to the film and 2) to both sides of the inlay for complete coverage of adhesive. The effects of embedding were studied through analyzing the different adhesive methods for amount of shift. The effect of injection molding on the inlay and sidewall of the container was also analyzed in order to determine the ability of the different tag types to survive injection molding.

The results showed that once thickness of an inlay is reduced, it is more likely to survive injection molding. Filling of the mold is affected when thickness of the inlay is more than 50%. However, with the Avery Dennison inlays the filling of the mold was not affected. Smaller surface area is also key in aiding an inlay to both survive molding unharmed and to increase the likelihood of a container sidewall to be unaffected by the addition. The two smaller types of tags survived molding, in terms of both physical damage and RFID readability, at a higher rate.

CHAPTER 1
INTRODUCTION

RFID, radio frequency identification, is a method of identifying unique objects using radio waves. This identification process is created through the use of a system of equipment that is generally composed of an antenna, reader, computer, and tag or inlay. The computer is attached to a reader and the reader is then attached to the antenna(s). The reader sends a signal to the antennas which start to transmit radio waves. The radio waves reach the tag/inlay, which are placed on a product or package, and are bounced back to the antennas. The data bounced back in that signal, by the tag, is sent through the reader to the computer where it will appear as information on a screen for the user. Large organizations such as Wal-Mart, Tesco, and US Department of Defense are now committed to using RFID throughout open supply chains. As a result of this commitment, the focus centered on this technology has shifted from pilot testing to full deployments.

Retailers are asking top suppliers to attach RFID tags to their cases and pallets of product. Currently only those large shipping containers are being tagged, not individual items. There are significant challenges associated with tagging individual retail products. There are certain packaging materials that can reflect a radio signal, and there are certain aspects that can absorb the signal. Much of these problems are associated with liquids and metals, which are the basic ingredients for perishable foods and food packaging. Once these challenges are overcome, there are certain factors which make item level tagging of interest and will further increase the value of the product.

Item level tagging is not only representative of tagging the smallest taggable unit, but it is also potentially one of the world’s largest RFID markets by value (Harrop, 2006a). There is therefore a strong financial incentive to item level tagging. Beyond the financial benefits, item level tagging will offer the ability to have intelligent packaging and shelving. For the food industry, especially, this is a benefit that should not be ignored. The tracking and tracing benefits of all tagging will be represented on an item level basis, but there is also the possibility of recognizing expired product on the shelf and being able to remove this product before a customer has a chance to buy it; thus creating an optimal atmosphere for product branding for both the food retailer and manufacturer. Those who invest in the adoption of item level tagging today look forward to multiple and rapid paybacks as the technology takes off with a projected 550 billion items to be tagged in 2016 (Harrop, 2006b).

Currently High Frequency (HF) tagging is the popular leader in the experiments with item level tagging, however, the near field ultra high frequency (UHF) tag offers a cost friendlier alternative and has smaller proportioned tags that will suit a more varied requirement set, such as would be required of an embedded tagging system.

For now, the cost of tags remains so high that it makes it hard, even for those wanting to invest in the technology, to afford item level tagging. As more companies adopt RFID usage the tags will decrease in price, but the current fashion of placing a tag onto a container with adhesive still leaves the possibility of tampering. Tagging methods currently leave a lot of room for improvement through reduction of materials, removing tampering possibilities, and improving placement creating an overall standardized location for the tag.

An inlay is the plastic framework on which the RFID microchip and antenna are created. A traditional tag is created when the inlay is sent by the manufacturer to a label converter, who places the standard label and face stock, with adhesive, over the inlay. This is done because the inlay is a very fragile, and could not survive being placed directly onto a box, pallet, or primary package. However, if the inlay of a tag were to be embedded into the packaging costs would be reduced, while eliminating the potential for tampering (whether it be with the function of the tag or in the complete removal of tag), and still protect the inlay from some of the elements to be faced throughout distribution. Embedding the inlay would also create a more uniform placement method and location for the tag and help to reduce potential counterfeiting that can be seen in the pharmaceutical industry. It would also promote a move to smart packaging and smart shelving which, with the recent fear of bio-terrorism, would be a very appealing addition into the market place.

There have been strides made to move toward embedding tags into packaging. Some companies have started with the case level first, using a printed design to embed into corrugated case packaging. However, this is not the item level and does not have the benefits as could be seen at the item level. Owens Illinois, looking to have the standardized placement issue solved, created a pharmaceutical bottle with an embedded tag on the bottom. Their product has the RFID inlay embedded in an injection molded disk which is then embedded into the bottle (Bacheldor, 2006). This product still leaves the possibility for removal of the RFID tag and is a multiple step process to get the tag into the package. Therefore, another solution should be considered, directly embedding the inlay into the packaging system, to resolve the extra steps that are time consuming and costly.

The main objective of this work is to develop a method for embedding RFID inlays into injection molded food packaging containers using in mold labeling technology. In order to meet this objective the following must be accomplished:

- Study the effects of filling a mold by adding an object to a label
- Develop a process to hold the RFID tag to an IML (in mold labeling) film,
- Study the effects of injection molding on the survival rate of different types of tag.

CHAPTER 2
LITERATURE REVIEW

Radio Frequency Identification

An RFID, radio frequency identification, system consists of a computer, antenna, reader, and tags or inlays. The reader controls the emission of a radio signal from the antenna. The antenna emits and collects the radio signal. The antenna emits the radio waves in certain polarizations, either a linear polarization or a circular polarization. Polarization is considered the direction of the signal in reference to the earth (Lahiri, 2006, Clampitt, 2006). With the circular antenna, the signal is sent out from the antenna and rotates in circular fashion resembling a corkscrew. The read range for the circular antenna is not as long as that of the linear, but has a higher read success in uncontrolled environments (Clampitt, 2006). The linear antenna emits waves that fall in a direct line in a plane. This antenna has a longer reach, or read range, than the circular antenna. This antenna can be more successful in controlled environments with exact and precise placement and orientation of the tag can be controlled. There is a distinct advantage to the circular antenna in that it reduces the sensitivity to orientation on the tags part (Clampitt, 2006).

There are two generations of tags offered by RFID technology companies, generations 1 and 2. Generation 1 tags are divided up into three different classifications, class 0, class 0+, and class 1. Generation 2 tags are class 1 tags only. Class 1 tags offer an interoperability by many readers, and the class 1 function allow the tag to be read and written many times (Lahiri, 2006). Generation 2 tags have many benefits over generation 1 tags, and the foremost is that the gen 2 tag design works very well in a large scale integrated system and the chips overall size is smaller and easier to make than that of the gen 1. There are four frequency categories that tags operate in. They are low frequency(LF), high frequency(HF), ultra high frequency(UHF), and microwave (Clampitt, 2006, Lahiri, 2006). Of these four categories, the two that are associated with use near water, or food products containing water, are UHF and HF. HF tags have a slow data transfer rate between the tag and reader, while UHF tags allow a very fast data transfer rate between the tag and the reader (Lahiri, 2006, Clampitt, 2006). This research will focus on the use of UHF tags due to the smaller size tag availability and the higher performance rating. There are four frequency ranges that UHF tags operate in. 303.8 MHz, 433 MHz, 868 MHz, and 915 MHz. Of these frequencies, the only one that is approved for applications in the USA is the 915 MHz tag (Lahiri, 2006, Clampitt, 2006). These tags are made using a Polyethylene Terephthalate (PETE) substrate. PETE (polyethylene terephthalate) is used as a substrate because of its very specific tensile strength properties, appropriate dielectric properties and because of the advantages of lower costs associated with the polymer and those added properties (Rao, 2005). Often other materials, such as polypropylene, are disregarded by inlay manufacturers because they lack the appropriate strength properties and would make the creation of the functioning inlays less reliable and not viable in a mass based production system.

The inlay creation process requires very accurate placement of the chip and good adhesion of the antenna. A typical tag manufacturing process consists of four steps, the creation of the die, production of the tag antenna, creation of the inlay, and conversion of the inlay into a standard tag (Lahiri, 2006). The creation of the die is the step where the microchip is created through chemical etching of a silicon wafer. The chips are then given unique serial numbers. For UHF tags, the creation of the tag antenna step is where a tag antenna is etched from certain metals (usually copper or aluminum), or sometimes made with conductive inks (Rao, 2005, Lahiri, 2006). After the creation of the antenna, the inlay can be formed by connecting the antenna and microchip onto the inlay, which acts as the substrate. This step must be able to be performed rapidly, automatically, and efficiently, placing the microchip and antenna properly. The antenna is placed onto the substrate first and the chip must then be placed in a very highly precise location in order to have a functioning inlay (Rao, 2005, Lahiri, 2006). Flip chip technology, one method to attach the microchip to the substrate, is where the chip is picked and placed onto an antenna and conductive adhesives are used to adhere the two items to the substrate. This is generally done in a very fast paced environment, but speed can be limited by the adhesive cure time and the accuracy needed for the placement of the chip (Gilden et al., 2004, Miesner et al., 2000). Another method of attachment is the strapping method. In this method, the chip is first attached to “die strap” which is then attached to the antenna and inlay substrate using conductive adhesives. This technique is much faster than the other process, allowing a reel to reel manufacturing to take place and requires much less precision of placement, the disadvantage is that it can add a small amount thickness to the inlay (Shah et al., 2004, Streifler, 2006). The UHF inlays suitable (in size, appropriate thinness for the thin wall application package to be used, and capabilities near water) for embedding are created using the flip chip creation method. PETE is used in this method because of its tensile strength parameters and polypropylene is almost completely disregarded as a viable substrate by most RFID manufacturers because it does not possess the same properties (Miessner et al., 2000, Seshagiri et al., 2005). These properties are important to RFID inlay manufacturers because it is necessary to have very precise placement of the microchip in reference to the location of the printed antenna on the inlay, especially and specifically for smaller and thinner inlay designs. If the material that is used for creation of the inlay either tears or stretches during creation there will not be exact placement of the chip. If the chip is not in a position to have contact with the antenna the inlay will not work (Miessner et al., 2000, Seshagiri et al., 2005). PETE is used for multiple applications other than for RFID inlay creation, however, it should be noted that because of its chemical structure it is incompatible with other plastics, especially polypropylene (PP) which is another very widely used plastic (Zdrazilova et al., 2003).

Injection Molding

Injection molding is a method for plastic shaping that involves an extremely high temperature and pressure procedure. It is a process where molten plastic is forced through a small hole, the injection point, in order to fill a cavity system that will become the package. The cavity is the inverse of the shape of the package, and the simplest cavities separate into two parts, a male and a female(Soroka, 2002). Once the molten plastic has been allowed to cool, the cavity system opens and the part is ejected. The design of the mold must allow for part ejection, for example the wall should have a slight angle for easier ejection. If the side wall of a container is too straight and deep, the part may not be ejected properly which would ultimately be damaging to efficient running speeds (Rosato et al., 2000, Selden, 2000, Soroka, 2002 , Yao et al., 2002).

Injection speed of an injection molded thermoplastic part needs to be very fast. If the injection speed is to slow, the filling rate is therefore slow and the material that is entering into the cavity will cool quicker than the material following it (Ogando, 2001, Selden, 2000, Yao et al., 2002) This can result in an incomplete fill and possible warpage of the finished container (Selden, 2000, Yao et al., 2002). This is taken to the extreme when the part is a thin walled container due to the smaller area in the mold cavity. The cooler walls of the mold cause a rapid cooling effect on the smaller amount of molten plastic entering the mold. In a larger thickness mold, there is a wider gap between the mold walls and it will thus slow the plastic cooling rate due to the larger separation and larger amount molten plastic being inserted will also hold temperature longer(Chen et al., 2000, Yao et al., 2002, Selden, 2000). However, regardless of the thickness, if the fill rate is not fast enough the product will freeze near the injection point and incompletely fill the mold. This problem originates from the fact that in injection molding the filling process coincides with the cooling process (Yamaguchi et al., 2004) In order to keep the melt from freezing before completion it is necessary to have uniform high heat and high pressure near the injection point (Rosato et al., 2000, Yao et al., 2002). To further understand injection speed (which specific values are dependent on the individual molding machine and cavity) melt flow must be considered more closely.

Melt Flow

As the melt enters the cavity of the mold, it balloons outward in a fountain like behavior. The outer surface of this fountain, generally called the melt front, will expand outward in a ninety degree angle to the rest of the melt flow (Rosato et al., 2002). This difference in alignment will result in shearing pressure being exerted on the flow immediately following the melt front. This pressure will in turn cause another layer of orientation called the subsurface orientation. The subsurface orientation in turn will affect the amount of core polymer orientation. If injected at a high speed, most of the orientation will be concentrated at the surface of the part (Rosato et al., 2000, Weis, 2002). The speed at which all this occurs is critical. If injection speed is too slow, the polymer will relax and expand, creating a very large and spread out band of orientation. There will be less shearing stresses and less concentrated orientation on the surface. The shear stress is related to the viscosity of the plastic. The viscosity is the ratio of shear stress to shear rate (Rosato et al., 2000). The shear stress is the force per unit area acting on the liquid fountain layer of flow (F/A), while the shear rate is the rate of change in velocity to the molten polymers flow (V/h) (Rosato et al., 2000). With rapid mold filling, there is a maximum shear rate at the center due to the significant difference in the temperatures of the middle and the frozen outer layer of polymer (Rosato et al., 2000). If injected too slowly there is not a defined difference in the temperatures and shear rate or stress, which can lead to the freezing of the polymer before the filling process is completed (Rosato et al., 2000, Yao et al., 2002). The polymer will also be cooling faster, than if at higher injection speed, because of the reduced shearing forces. These forces slightly elevate temperatures while occurring and in higher injection speeds are beneficial to aiding complete filling of the mold (Rosato et all., 2000, Yao et al., 2002, Weiss, 2002). The resulting part, formed without the shearing forces elevating temperature and helping to create the thinner surface orientation, can have a poorer quality. Plastic, if exposed to stress directly in line with its molecular orientation will break. The resulting spread out orientation of molecules in the polymer, now aligned throughout the whole of the part, will cause breakage very easily when dropped (Rosato et al., 2000). Therefore, for ideal melt flow and proper molecular orientation fast injection speeds are critical.

In Mold Labeling

The process known as in mold labeling (IML) is relatively new in North America. It is a form of creating a no label look on an injection molded package through placing the label in the mold before injection. The label is statically held into the mold and as molten plastic is pumped into the mold, it becomes a part of the finished product. The label meshes with the substrate plastic and is impossible to differentiate from the substrate (Knights, 2004, Shelton, 2007). This technology works through use of a robotic arm that picks up a label out of a stack, moves it to the mold where it is held on either by static, most common method, or by a vacuum. The static method of holding a label requires the label material to have the capabilities to hold a charge. Once the label is held in the mold, the male and female parts of the mold are brought together and the injection process takes place (Shelton, 2007).

IML originated in Europe in the early 1970’s and the world leaders in IML technologies are still located in Europe. IML slowly, and only recently, caught on in North America and as result of the slow increase in use there has been little formalized research on this technology. What research has been done, shows that certain properties, such as impact strength, can be affected in the finished product and the amount of effect is very dependent on film and resin solubility (Leong et al., 2004). Not only is impact strength affected, but the appearance of the final product is also affected if the film and resin are not compatible. The damage is done through the higher and more extreme warping and shearing effects that the film faces because of the incompatibility (Leong et al., 2004). Therefore it is imperative, when using IML to try and find a way to blend film and resin either through use of films with similar properties as the polymer matrix or through adhesives that will help bond the polymers together. The alternative of adding compatible layers to the film could also work as a method of resolving the solubility. However, for thin wall molding applications that are commonly seen in food packaging this is not a viable solution.

Challenges

This project will study the embedding of RFID inlays into injection molded containers using in mold labeling technology. The incorporation of the RFID inlay into the already existing use of an IML film, by affixing the inlay to the film, will present many challenges. One challenge to be face is the incompatibility of the polymers. Polypropylene and PETE, known for their incompatibility, represent a series of issues to overcome. The insolubility of the two polymers will cause problems during molding and structure of the molded package, and can lead to problems such shifting of the tag, an air bubble forming between the PETE and polypropylene films, warping due to differing shrink rates and possible other unknown issues. Similar issues were faced by Rafsec (Kymmene Corp., Finland) when designing a very durable embeddable tag for use in large packaging applications such as pallets and containers (Bacheldor, 2003). The issues were solved by laminating the RFID tag with several layers of other types of plastics. The result is a more durable tag that will blend with the multiple substrates and be more able to withstand warping caused by high temperature and pressure scenarios(Bacheldor, 2003). However this type of solution would not work in thin wall applications due to the required thickness parameters.

Another challenge to be faced during molding is the addition of thickness to the IML film that could cause incomplete filling in the mold and represent an added bump on the surface of the package (Selden, 2000, Yao et al., 2002, Rosato et al., 2000). Also, the inlay surface area could represent a critical issue for incomplete filling and disturbance to the mold. The addition of an insoluble material affecting the mold is most likely to cause increasingly more disturbance to the surface of the package as the surface area of the inlay increases (Selden, 2000).

When examining further into problems to be faced, the turbulence present in the injection molding atmosphere, as molding is occurring, is also likely to present a problem. The inlay is very fragile, and the turbulence seen in injection molding could cause the microchip to malfunction and also increases the possibility of movement of the inlay in the mold, or cause removal of the microchip from the inlay surface, thus warping the shape and structure of the inlay which could be critical for proper function of the inlay.

The microchip part of the inlay is very sensitive to static electric discharge (Lahiri, 2006). A method of holding IML into place involves a static electric charge of approximately 3-4,000 volts to keep the label on the wall of the mold for proper placement when filling occurs (Shelton, 2007). This could pose a problem in the functioning of the RFID microchip after molding. The static charge could render the microchip useless. However, it may be possible to form a barrier between the chip and the electric discharge through placing the chip on the reverse side of the label. This way when molded the majority of the static holding the label in place will be on the opposite side of the label. The adhesive used may also help add to this barrier between chip and static discharge. This will also keep the inlay on the inside of the package with both the plastic matrix and polymer label between the inlay and the consumer. This could help further prevent any attempt at tampering with the RFID microchip during distribution.

There are many benefits that can be achieved by embedding an RFID tag into a package. Currently, to create a tag that can be placed on the outside of a package, the inlay manufacturer sends the inlay to a label converter. The label converter uses an adhesive to place the inlay onto an ordinary label face stock. This process is done in order to protect the inlay from the harsh distribution environment that it would have to otherwise face naked. Since the inlay is so fragile, it is necessary to protect it with the face stock. However, with the ability to embed the inlay itself into the package, there would be elimination of needless steps in the process and reduce some of the materials costs. Embedding of an inlay into a package also eliminates the possibility of tampering with the RFID microchip and antenna and can also prevent the possibility of complete removal of the tag, which can be seen in the traditional tagging method. Once tampering and removal have been eliminated, the risk of theft and possible contamination of a product can be reduced or eliminated. Furthermore, there can be a move toward a more standardized placement of the tag and inlay on a container. This would help to increase read rates of the tag and improve the visibility of the product, throughout distribution, through coordinated antenna placement.

Embedding inlays into packaging can lead into the creation of the smart shelf. As a result of the high prices of RFID, item level tagging has not yet evidenced itself in large scale deployments. With the reduction of costs that would follow the initial start with embedding, the item level tag will become a common occurrence. When item level tagging occurs in a mass scale, the price of the tags will reduce further due to the increased volume of production (Harrop, 2006a). Once the commonality of item level tagging is in place, it follows that there is an investment that could be made in placing antenna on shelving or other similar locations throughout a retail store. Data on the RFID chip can contain expiration information which would allow the possibilities of knowing when the product was expired. Following this could be proper product placement and removal, from the shelves, before consumers have an option to purchase the product. It will also make it easier to find recalled product faster and further increase product tracing capabilities in case of a product recall.

There are currently many items containing embedded RFID tags or inlays on the market. One such item is a personal identification card with a tag embedded inside of it, in order to track employees and give them access to specific areas (Stanford, 2003). In some instances, tags are being injected into animals, such as cows or horses; this almost always done in order to track and count the animals (Stanford, 2003). There is also embedding of RFID tags into watches and other personal items such as luggage itself or in a paper tag used when checking baggage at airports. There is some animal injection of RFID tags being done for tracking and counting purposes, and even some humans have injected tags in order to be able to track medications and store medical and allergy information (Schuman, 2005, Stanford, 2003). There is also a method of using a printed antenna tag system into the layers cardboard in a corrugated container available for package tracking and inventory control capabilities. Another paper product utilizing this technology is the Euro, which has an embedded tag to attempt to reduce the amount of counterfeiting due to the internationality and widespread acceptability and availability of this money (especially in higher denominations) (Juels et al., 2003) . Also due to fear of counterfeiting, theft, and tampering pharmaceutical products are a something that RFID is now appearing in. Owens Illinois is experimenting with a form of embedding into plastic containers.

These items are embedded using a two step process, of embedding an inlay into a plastic disk and then embedding the disk into a pharmaceutical package (Bacheldor, 2006). This process is less efficient than the method to be studied because its embedding process contains multiple steps. However, it does recognize the ability to standardize placement of the tag and addresses some of the issues with embedding tags (Bacheldor, 2006).

CHAPTER 3
MATERIALS AND METHODS

Determine a Method for Embedding RFID Inlays into Injection Molded Food Packaging Using In Mold Labeling

There is relatively little known about IML in North America and it has never previously been an attempt to embed an RFID inlay into an injection molded package. Therefore it was required to do preliminary tests on this process before developing a successful method.

Preliminary Tests

Initially it was required to do preliminary tests of inserting RFID labels into the packaging using IML. The preliminary tests displayed the need to control the size of the tag and the issues that would need to be solved with reference to the mold filling problems and warping of the container.

Equipment

The injection molder used in these tests was a Husky 660C IML injection molder supplied by IPL (Quebec, Canada). This machine has a cycle time of 6.6-8.8 seconds with injection speeds of 60 mm/s for the first 15mm and 120 mm/s for 45mm and the average temperature of the plastic is held at approximately 271 degrees Celsius. The resin used for the polymer matrix was a PPC-04 a clear resin obtained from Bassell (Maryland, USA) by IPL (Quebec, Canada). The IML film used was a bi-axially oriented polypropylene film purchased by IPL (Quebec, Canada) from Propyplast (Retournac, France). The film has a thickness of 100μ. The RFID equipment used for the preliminary tests was a squiggle T RFID class 1 passive tag and a Tyco Sensormatic Reader IDR-300 with four linear antennas supplied by Alien Technologies (California, USA). This tag was chosen because it was the smallest tag available at the time of the preliminary tests and an image of it can be seen in figure 3-1. This tag is assembled using the strapping technique and has poor functionality near water.

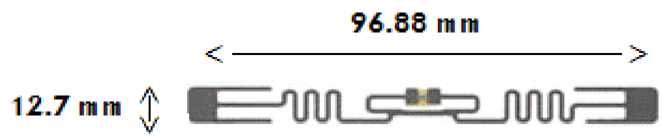


Figure 3-1. Alien squiggle tag

Preliminary Test Procedure

RFID tags were placed onto the IML film using the adhesive that was located on the paper backing. These tags were not the inlay alone, they were ready to use tags that had adhesive and paper backing in order to be placed onto any surface as a press on tag, see figure 3-2 for detailed description of the layers. This tag has a total thickness of .3556mm.

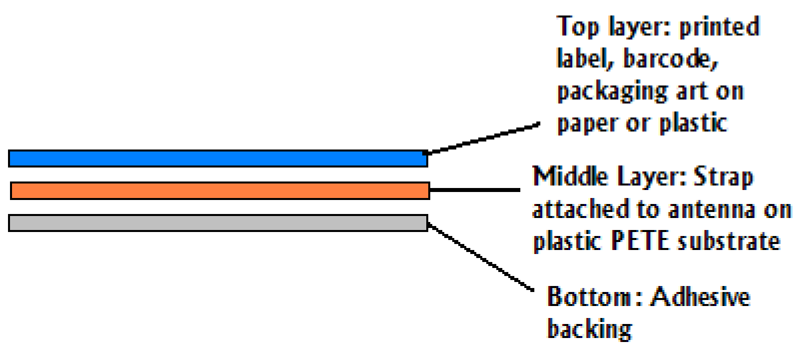


Figure 3-2. Layer description of Alien squiggle tag

The tags were placed horizontally along the top, middle, and bottom of the IML film in order to determine if the mold fill would be affected by location. The film was then run through the injection molding process. The film was placed into the mold and held by static electricity into the mold while the male and female parts of the mold are brought together. Once the two parts of the mold are brought together to form the cavity of the mold, the plastic is injected. The plastic container will then be ejected and the containers are ready for use (images can be seen in figure 3-3).

A

B

C

Figure 3-3: The containers resulting from the preliminary tests. A) Container that failed to fill completely along the top edge (the alien tag is around the corner on the lower right hand side). B) Another container with similar aspects and if you closely at the tag, it is almost completely separated from the sidewall. C) The IML film on this container slipped due to the addition of the tag and the tag is also not attached.

First Round Results and Implications from Preliminary Tests

The results of the preliminary tests yielded ever tag as still functioning. However, there were many issues with this process in the mold. There was not a single container that had the mold completely filled and there was severe warping of the tag. The tag did not adhere to the plastic in any location, there was an air bubble over the tags. Not one of these products was remotely marketable. The RFID capabilities were still functioning. The read range, however, was severely reduced. The tags had to be within a 40-50mm of the antenna to read properly.

The wall thickness of the containers was .64mm and the tag thickness was approximately .36mm. Therefore, due to the fact that the tag was attempting to take place of more than half the thickness of the wall (56% of the wall thickness) it can be concluded that these results were due to the thickness of the whole tag in the system. It was then determined to use the inlay portion only, and remove the extraneous paper layers. This would reduce the thickness of the foreign object that was being introduced into the system. As a result of the severe warping affect, it was determined that smaller tags would be necessary to use. It was decided to use a tag that was smaller in surface area would be the most suitable and because this application is directed at food container usage, it would be necessary to find a tag that would function near water.

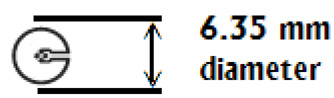
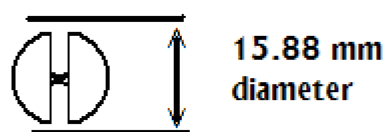
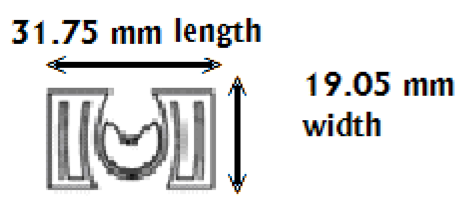
Second Round of Preliminary Tests

Before testing a new type of antenna, another set of preliminary tests was run to study the effects of polyethylene terephthalate (PETE) alone on the injection molding system. Three different sizes of PETE were cut out and applied to IML film using polyvinylpyrrolidone adhesive. The sizing was approximately the size of the tags below. The tests were run in the same manner as before and the results were much more promising. For these pseudo tags the mold performance was much better. For each size the mold completely filled. The issue that presented itself after this set of tests was that the PETE was warping and moving around the mold, in some cases it completely vanished from the mold. There was also an air bubble forming above the PETE when it was still present in the mold. It was concluded that there needed to be a better attachment method that would hold the PETE in place. It was also concluded that the incompatibility issue needed to be solved, and could be solved using an adhesive that would cause the films to bond under the high heat environment present in the injection molder.

Test Materials

Three inlay styles were selected for this study. They are all known to function in close proximity of water and were the smallest tags available on the market at the time of the tests and images and descriptions of these tags can be seen in table 3-1.

Table 3-1. The three inlay designs and their measurements that were selected for this study.

Tag Number:	Type:	Picture and measurements:
Tag 1: Button Tag	Near Field UHF	
Tag 2: Disk Tag	Near Field UHF	
Tag 3: Satellite Tag	Near Field and Far Field UHF	

These inlays are Avery Dennison (South Carolina, USA) inlays and each of these has a thickness of 0.29 mm (over the microchip). The large rectangular tag (tag 3) has the largest surface area and has the largest read range. This tag was chosen to test the upper bounds of the size limit and performance in the mold. This tag has the best performance with read rates for RFID, being both near field and far field tag, it performs well at a distance ranging from 25mm to 2.5 meters away from the reader. When initially testing this tag it was necessary to keep all tags that were to be tested behind a metal wall to block the signal so that one tag could be tested at a time. The next sized tag (tag 2) was chosen because of the smaller surface area (than the satellite tag) and still a high performance read rate, meaning that this tag can be automatically read from about a meter away. The smallest tag, the button tag (tag 1), was chosen because at the time of testing it was the smallest tag on the market. However, this tag has a much poorer performance on read rates, and must be very close to the reader to function (10-20 mm away from the reader). The sacrifice for size is the readability of the tag. However, it was assumed that the smallest tag would have the best performance in the mold because of the smaller surface area of incompatible material that is added to the mold; that to sacrifice tag performance would be in order to gain better performance in the mold. Sixty inlays, twenty each of three types of inlays, were used for this experiment.

As a result of the switch to Avery Dennison inlays, it was required to switch to a different RFID reader and antenna system. An XR400 reader and an Andrew RFID 900 CRW circular polarized antenna from Symbol Technologies, Inc (New York, USA) were used. The same injection molding equipment and materials were used as in the preliminary tests.

There were two adhesive types used to attempt to solve the incompatibility issue. They were HB Fuller (Minnesota, USA) adhesive HL 9939-M and HB Fuller (Minnesota, USA) PHF 9952 adhesive. These are hot melt adhesives that are applied specifically bond PETE and PP under high heat conditions. The adhesive was applied using a Nordson (Ohio, USA) mini Squirt adhesive extruder gun.

In order to achieve a consistent and thin layer of adhesive applied to the inlays it was necessary to work with the adhesive and inlays somewhat to establish a process. The adheisve is extruded at 177 ºC but was found to be very quick drying and cooling after the extrusion (this was the case for both adhesive types). When applying the adhesive, any manipulation of thickness would have to be immediate because once cool it was impossible to manipulate. When initially attempting to apply the adhesive in a thin layer, the adhesive was difficult to manipulate into a consistent thickness with the applicator on the mini Squirt which can be seen in figure 3-4 (seen below, under table3- 2) . As a result of the attempt to maintain the adhesive in a thin layer as extrusion is taking place, the adhesive was cooling at a much faster rate than if it was applied in a thick amount. To get around this quick cooling property and to attain full and consistent coverage of the inlay, it was necessary to dispense at least enough adhesive to cover half of the inlay surface (the surface area of each tag type) and be about 6mm high off the inlay at once. This is much more adhesive than is needed to have a thin and complete coverage. This adhesive was dispensed on the left half of the adhesive. The large amount of adhesive being dispensed at one time helped maintain the adhesive temperature fractionally longer than when attempting the thin surface initially. Once the adhesive was dispensed, it is then immediately necessary to manipulate the adhesive with a straight edge. The straight edge was quickly moved from the left half of the inlay to the right, and used to spread the adhesive consistently across the inlay while pressing firmly down on the hard surface laboratory surface. During this movement the inlay was held firmly into place. This process removed the excess adhesive from the inlay surface and while leaving behind a flat and consistent layer of adhesive. The weight of the final inlay was used as a measure to ensure that the same amount of adhesive was applied to each inlay. The inlay weights are displayed in table 3-2. Every tag was measured to ensure that it was within this weight range and tolerance before it was attached to an IML film.

Test Procedure

Sixty tags were used in this experiment because there would be ten tags for each adhesive type to be used, with 5 of each type having a one sided application of adhesive and the other 5

Table 3-2. The inlay weights and tolerance levels for each adhesive method and inlay type.

Inlay type	weight single sided adhesive	weight double sided adhesive	
	(g)	(g)	(± g)
Type 1 (Button)	0.03	0.04	0.005
Type 2 (Disk)	0.09	0.1	0.005
Type 3 (Satellite)	0.25	0.35	0.005

Figure 3-4. The Nordson Mini Squirt

having a double sided adhesive application. The sixty tags were tested for functionality (reading properly) using the XR400 reader and the Andrew circular antenna system from Symbol Technologies, Inc (New York, USA). This is done because tags will sometimes be damaged during manufacturing. The creation of tags is very precise and if there is some variable off they can be damaged and never work properly. Button tags (tag 1) were determined to be functioning when brought within 10mm of the reader and giving at least one read per 10seconds. The disk and satellite tags (tag 2 and tag 3) were determined to be functioning properly when brought within a one meter range and they were reading at minimum one read per second. All of the tags were given at least 15 seconds to give a read. After all sixty tags were tested and proved to be functioning they were then split up into two groups, with each group consisting of ten of each type of inlay. These groups were labeled group 1 and group 2. Each group was then applied with a different type of adhesive supplied by HB Fuller (Minnesota, USA). These adhesives were chosen for their unique bonding properties between the incompatible polyethylene terephthalate (PETE) and polypropylene (PP). Both of these items are hot melt adhesives that were applied using a Nordson (Ohio, USA) Mini Squirt gun.

Group 1

The first group was applied with HB Fuller (Minnesota, USA) adhesive HL 9939-M. Five of each type of inlay had adhesive applied to the side of the inlay that is opposite the microchip (this side only), while the other five had adhesive applied to both sides of the inlay, for complete and thin adhesive coverage of the inlay. The adhesive was applied in two different methods to study the effects of only one side of adhesive and the reaction of the product in the mold versus the double sided application method. The double sided method would have a higher probability to bond fully with the matrix and film, but there would be added disruption in the mold. Figure 3-5 represents the application methods used.

Once the adhesive was applied, as a result of the quick cooling nature the inlays needed to be reheated using a hot air gun in order to be applied, and adhere, to the surface of the IML film. The air from this gun reached a temperature of at least 170 ºC in order to melt the adhesive. Each inlay was held with tweezers over the gun for a time of 5 seconds and then immediately applied to a single IML label. Each tag was placed onto the label using the graphics on the label to align

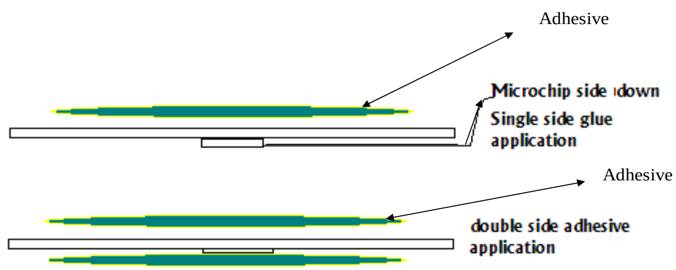


Figure 3-5: The adhesive application method.

it properly for consistent placement as seen in figure 3-6 and 3-7 (below). This placement was specifically chosen at the meeting point of a nested container (as seen in figure 3-7). This was done to prevent nesting problems that could occur if molding produced a bump in the sidewall. Where containers without a microchip would have a perfect sidewall angle that matches and nests well together, a container that contains a bump could create a tendency for the nesting to lean or tilt.

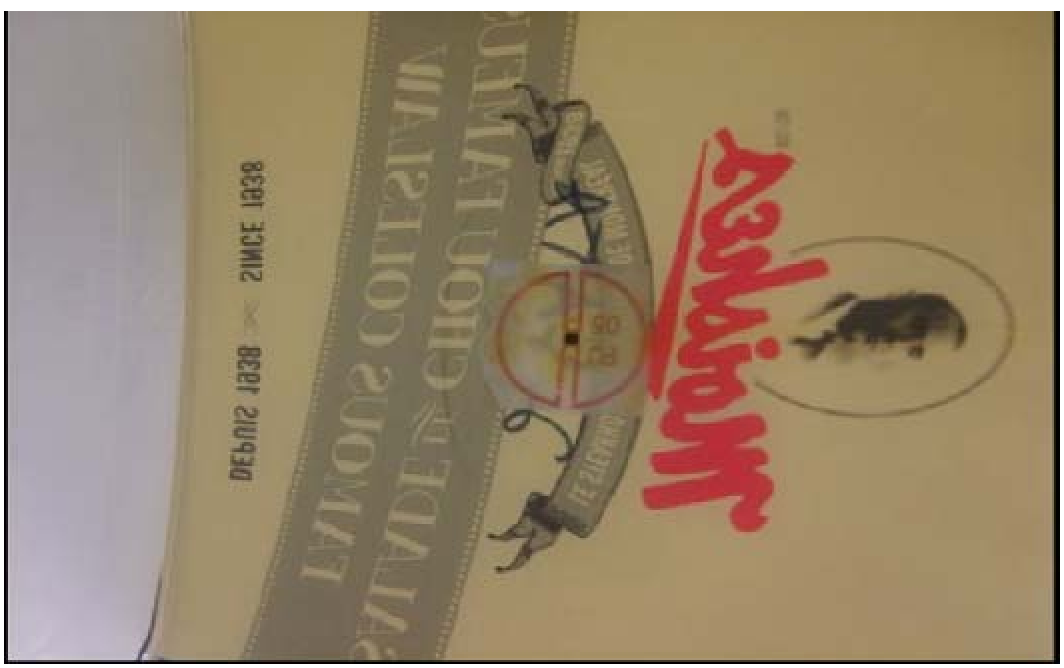


Figure 3-6. Alignment of the inlay.

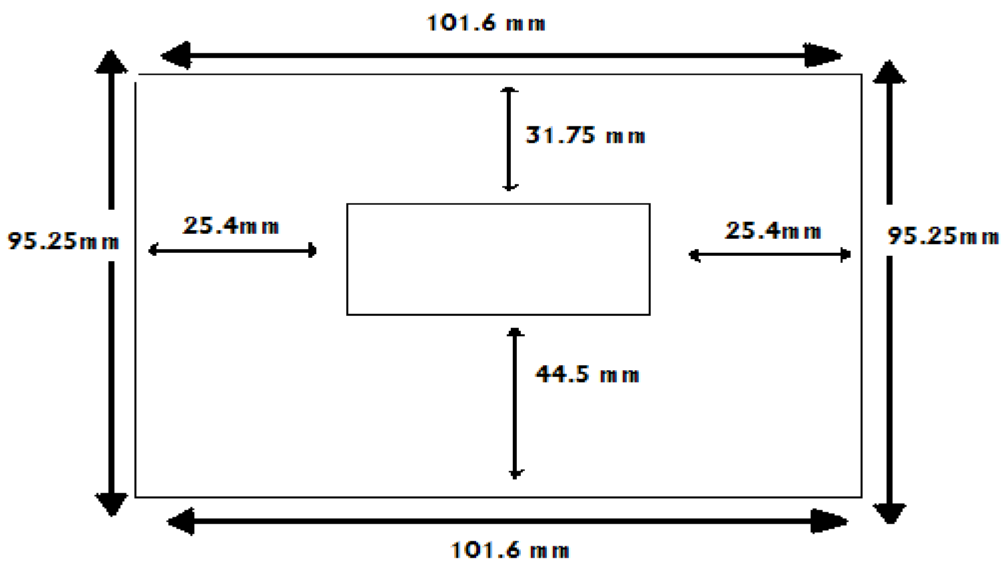


Figure 3-7. Alignment of inlay with measurements (a range of placement to allow for different sizing of tags used in experiment)

After placement was complete, each unit was individually and clearly labeled, using a permanent marker so that adhesive type, tag type, and an indication of whether there was adhesive on one side or both sides could be determined, and tracked after molding. All inlays were placed with the microchip facing the inside of the package, on the underside of the label. In other words, when looking into figure 6 it can be noticed that the writing is reversed, this is because the inlay was placed on the side without the ink on it. This method was chosen because the ink side of the label is displayed towards the consumer. With the placement that was chosen the inlay would be on the inside of the label protecting it from damage from the consumer. The inlay would be between the film and the polypropylene matrix of the package once molding would be complete. This will help prevent any potential tampering with the inlay and possible bumps formed from incomplete bonding of the PETE of the inlay and polypropylene of the matrix might be more likely to appear on the inside of the package, as opposed to the outside. If the chip were to be facing the outside of the IML film (toward the consumer) it would be likely to aid in the creation of the air bubble due to the inlays uneven surface resulting in air gathering around the microchip. The placement of the chip towards the inside of the mold, on the inside of the IML film (away from the consumers view of the final product) might further benefit the inlay by protecting the microchip from the static that is used to hold the IML in place during molding because it is the ink side that is statically held to the outside of the mold.

This method of application will, however, expose the chip and the inlay to an increased risk of shear stress during the molding process. The chip will be facing towards the inside of the mold and the flowing plastic. The molten plastic will be flowing at high speeds through the mold in order to compensate for the freeze effect that occurs when the molten polymer hits the cooler walls of the mold. Figure 3-8, represents the application methods discussed.

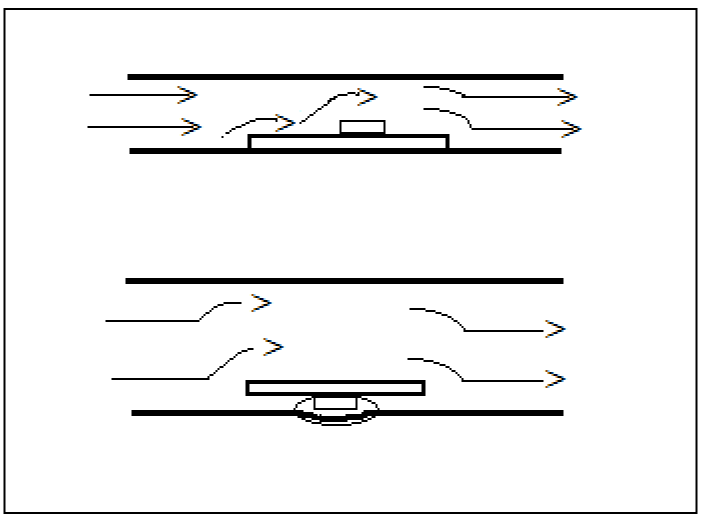


Figure 3-8: Two pictures represent the flow for the two different inlay applications. Top: inlay method used depicting the flow pressures and shear stress the chip would face. Bottom: Depicts the flow for the method discussed (but not used) and the air bubble that forms from the uneven surface and the poor bonding of the polymers.

Group 2

The second group of inlays were treated exactly the same as the first group. However, this group was adhered with HB Fuller (Minnesota, USA) PHF 9952 adhesive. As a result of the extremely quick drying aspect of this adhesive, these inlays were also reheated using the high heat air gun. Immediately after reheating, the inlay was placed onto an IML label and the information was indicated using a permanent marker. All inlays were placed with the microchip facing the inside of the package, on the underside of the label.

Further Test Procedure

After gluing and placement, both groups were retested using the same RFID system to determine if the gluing process had any adverse effects on the inlays. This was done using the same system as that which the inlays were originally tested with. Once the inlay/label combinations were confirmed to be working properly, they were shipped to IPL plastics (Quebec, Canada) to be run in the same way and on the same injection molding equipment as in the preliminary tests. A robotic arm, which can be seen in figure 3-9, with suction cups grabs and electrifies the label. It then places it into the mold. The IML is held in place by a static discharge present in the mold until the molding process starts. Once molding begins, the molten plastic that is forced into the mold, between the male and female parts, sticks to the label and bonds blends/bonds to it. Once the filling process is complete, the male and female parts separate and the new container is ejected. The label combination was molded into a 1.49 L thin walled food container displayed in figure 3-10. Once molding was accomplished, the samples were analyzed.

Analysis of the Containers

After injection molding was complete, the inlays in each container were then tested using the same RFID equipment as in the original testing and also using the same standards for distance and time to give a reading as in the initial qualifying of functionality. The tags were then recorded as functioning or not functioning using those standards as a qualification.

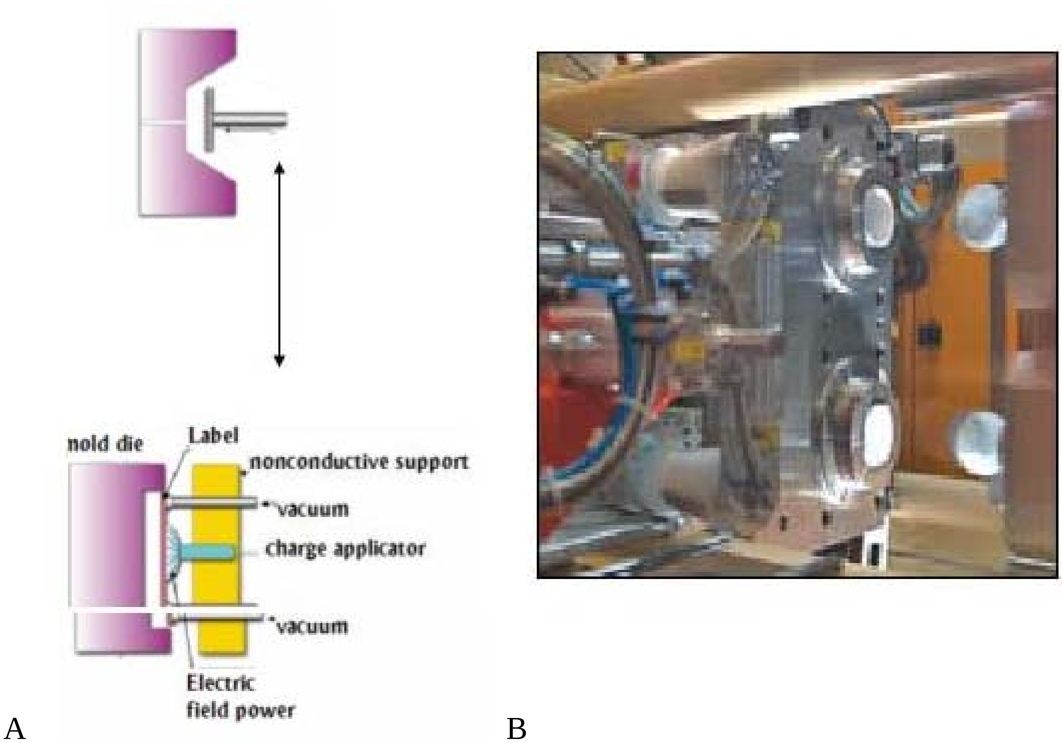


Figure 3-9: Displays the injection molding arm used in IML. Image A taken from (Shelton, 2007),) is a zoomed in version of what the arm would look like. B) image taken from (Knights, 2004) and is a Husky model similar to the one used in the experiment.

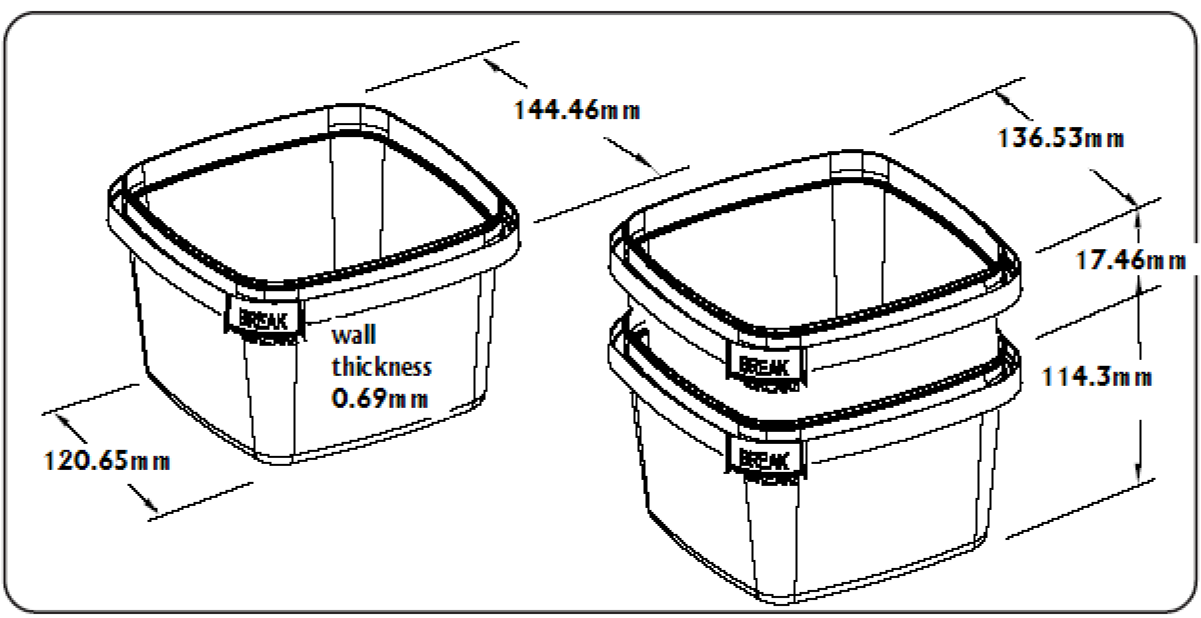


Figure 3-10. Container and measurements for thickness and sizing. Image used with IPL(Quebec, Canada) permission, taken from spec sheet.

The appearance of the container was then examined in order to analyze the quality of the container and an evaluation grid was created for the results to be recorded in. The container was examined based on incomplete filling using weight as an indicator, sidewall warping, inlay substrate or antenna warping, and shifting of the inlay. Using an Ohaus scale, model number ES50L, the containers weight was measured to determine if the filling process was completed and to determine if there was an incomplete fill or light weighting. The IML injection molded container, measured with the same scale as seen above, without an inlay weighs 49.97g (± .009g standard deviation) with the weight of the IML film taken into account. Ten containers were measured to establish this number as an average. Without the film weight, the container weighs 46.50 g with a standard deviation of about 0.05g. This was established by subtracting the film weight (3.45 g). To establish the weight for the film, 10 samples of sidewall film were measured at an average of 3.45 g with a standard deviation of 0.05. The amount subtracted from the IPL container was less than the amount subtracted from the sample containers, due to the standardized container containing only a sidewall IML film. The sample containers were molded with an additional bottom label whose weight was measured in a sample of 10 labels that were averaged out to be 0.052 g with a standard deviation of 0.006 g. Thus, the sample container weights had a weight of approximately 3.5 g removed. It should be noted that the inlay thickness (over the microchip) is 42% of the wall thickness.

The side wall containing the RFID inlay was very closely examined. The objective was to determine if there was warping in any location on the wall. A ruler was held to the container along the vertical access directly across the inlay, following the angle of the wall. The purpose was to examine if the wall integrity was maintained and side wall angle was correct compared to the wall angle without the inlay present in molding. This data was recorded as zero warping to the sidewall, light warping to the sidewall (characterized by a slight dip or bend in the wall or small air bubbles on the surface), and heavy amount of warping (there is separation from the sidewall or other immediately distinct disruption to the integrity damage to more than). See table 3 for the definition of each category.

The inlay was examined for structural warping. The PETE film on the inlay should be flat and smooth and without any fold or bends to the film or the antenna. The character of each inlay was analyzed and recorded as the amount of damage as follows: none, light damage (small amount of bending or rippling effect in the inlay) and heavy amount of damage (the integrity of the inlay is warped and/or large fold or rip in the PETE). Also complete dislodging of the microchip would qualify as heavy damage to the inlay. Table 3-3 displays the amount of damage that would place an item in each category.

Table 3-3. The damage ranking for inlay and sidewall damage.

Category	Amount of Damage
None	=0
Light	<25%
Heavy	>25%

The location of the tag was also measured, to identify if the tag had shifted during molding. If the tag was still within the original range of placement, it was considered as not having shifted during molding. If the tag had shifted, the direction was recorded as having moved north (N), south (S), east(E) or west (W). The amount of shift that had taken place was recorded as well.

CHAPTER 4
RESULTS

Container Weight Measurements

Weight measurements for each sample container were taken in order to determine the effects of the introduction of an RFID inlay on filling of the mold. Tables 4-1, 4-2, 4-3 contain the results for the container weight measurement alone. The weights for each respective inlay type and the additional weight of the IML label were removed from the result in order to display a representation of the amount of plastic used in the filling process of injection molding and allow for easy comparison to the standard container. Each tag type is represented in a single table. This was performed to display the data to promote easy comparison between single and double sided tags, and also adhesive type versus adhesive type. Table 4-4 displays the weight measurements for the IPL container with and without the IML film weight. The measurement was taken with IML and then the standardized film weight was removed from the container. The film weight was removed in order to determine the core plastic weight. The core plastic weight is important for the determination of the affect to the filling phase of the plastic during injection molding. If the filling cycle was affected due to the inlay addition (for example, the injection of the plastic could have been reduced or limited because of flow issues from the addition of the inlay), the plastic weights of the sample containers would be noticeably different. Note, as seen in chapter 3, the amount subtracted from the IPL container was less than that subtracted from the sample containers, due to the standardized container containing only the sidewall film. The sample containers were molded with an additional bottom label whose weight was measured in the same way as the sidewall labels. The three tag categories displayed results averaging from 47.4-47.7 g. These results are all higher than the IPL standard container of 46.5 g, but not a large notable difference in the weights; only a 2.8% increase in the weight.

Table 4-1: Button tag weight measurements with the IML film and inlay weights removed from the number.

Button Tag		
Glue Type 1	Single Sided	Double Sided
1	47.71	47.60
2	47.61	47.53
3	47.73	47.53
4	47.69	47.53
5	47.76	47.78
Average	47.70	47.59
Std Dev	0.05	0.11
Glue Type 2	Single Sided	Double Sided
1	47.72	47.60
2	47.78	47.53
3	47.67	47.53
4	47.82	47.54
5	47.78	47.77
Average	47.75	47.59
Std Dev	0.06	0.10

Table 4-2. Disk tag weight measurements with the IML film and inlay weights removed from the number.

Disk Tag		
Glue Type 1	Single Sided	Double Sided
1	47.68	47.68
2	47.69	47.42
3	47.72	47.81
4	47.67	47.75
5	47.78	47.74
Average	47.71	47.68
Std Dev	0.04	0.15
Glue Type 2	Single Sided	Double Sided
1	47.83	47.68
2	47.78	47.42
3	47.75	47.81
4	47.78	47.75
5	47.82	47.63
Average	47.79	47.66
Std Dev	0.03	0.15

Table 4-3. Satellite tag weight measurements with the IML film and inlay weights removed from the number.

Glue Type 1	Single Sided	Double Sided
1	47.41	47.43
2	47.42	47.42
3	47.40	47.46
4	47.44	47.40
5	47.39	47.36
Average	47.41	47.42
Std Dev	0.02	0.04

Glue Type 2	Single Sided	Double Sided
1	47.69	47.52
2	47.69	47.53
3	47.69	47.54
4	47.67	47.61
5	47.71	47.61
Average	47.69	47.56
Std Dev	0.02	0.05

Table 4-4. IPL standard container weight (with and without IML film)

IPL Container	w/o IML
49.97	46.52

Adhesive Results: RFID Functionality and Shift

Data from tables 8 and 9 display the relationship of each tag type to adhesive type and application method based on RFID functionality. This data can be considered as part result of the adhesive and should be therefore analyzed as part inlay results and part adhesive results. It was noted that there was a higher number of successful RFID readable tags in adhesive type 1.

See figures 4-1 through 4-3 (below) for the results of the shift for each tag based on amount shift (mm) and adhesive type with application method. This data was measured to compare the holding power of the adhesives, and to determine if the method was suitable. As seen in chapter 3, the tags were measured based amount of shift that occurred out of the box allocated for placement of the tags. The tags were measured based on amount of movement north, south, east or west. The button tag exhibited results of over half of inlays applied with adhesive 1 shifting under 10mm. The tags applied with adhesive 2 exhibited a smaller amount of movement all under 10mm, with the exception of one large outlier of 30mm that was applied on both sides. The disk tag exhibited a large number of samples with movement under 5mm for both types of adhesive and application method, with the exception of the double sided inlay with adhesive 1. This series of tags displayed only one tag with a single millimeter of shift and is the series, for all tag types, that exhibited the least amount of shift. Of the three types of tags, the satellite tag exhibited the most movement for all adhesive types. The satellite tag displayed shift under 10mm for most tags, with one outlier displaying 20mm of shift.

RFID Readability Results

The tags were tested for functionality once returned from IPL (Quebec, Canada) and found to be either functional or nonfunctional. The result for the RFID inlay functionality, are as follows: 10 samples had either completely broken or failed tags for RFID readability out of the original 60 tags tested. See tables 4-5 and 4-6 for the listed results.

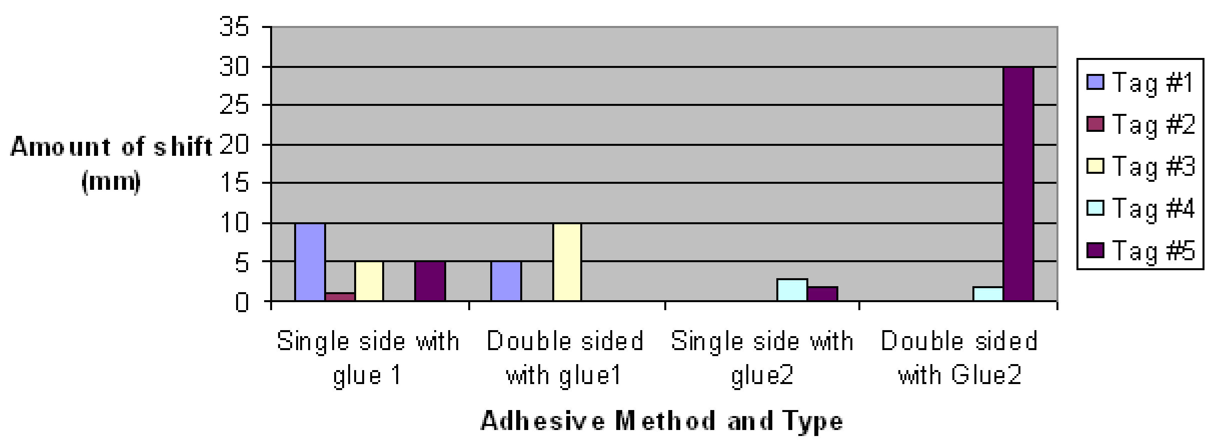


Figure 4-1: The measurements of the amount of shift for the button tag.

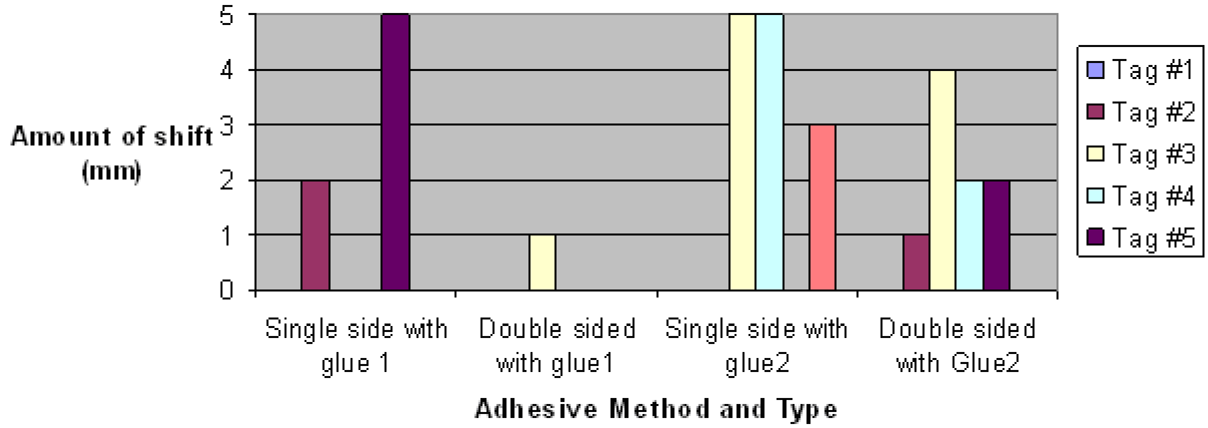


Figure 4-2: The measurements of the amount of shift for the disk tag.

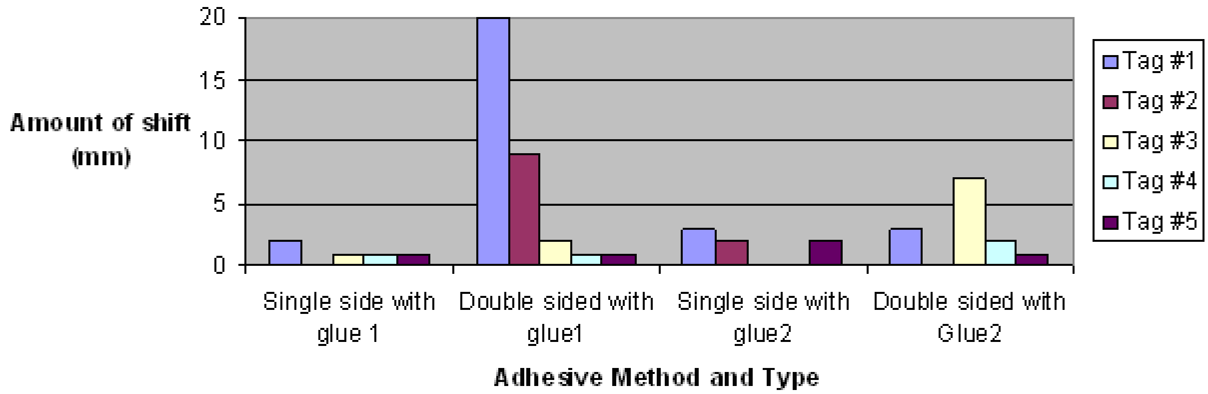


Figure 4-3: The measurements of the amount of shift for the satellite tag.

Tag Type 1: The Button Tag

Nonfunctional tags

One of the tags with adhesive type one did not work, and this was a tag applied with the two layers of adhesive. For adhesive type two, one of each gluing method did not work.

Functional tags

Four tags were functioning, in both the adhesive type one and two, that were applied with the double layered adhesive. Four tags with adhesive type two for the single layer adhesive method were also working. In addition, for adhesive type one, all five tags applied with the single layer of adhesive method functioned.

Tag Type Two: The Disk Tag

Nonfunctional tags

For adhesive type one there was one double layer of adhesive tag and no single layer tags found to be malfunctioning. For adhesive type two there was also only one tag of double layer found to be unreadable. In addition, no single layered tags malfunctioned.

Functional tags

There were four double layer tags of each adhesive type working. There were all five tags of each adhesive type of single layer tags functioning.

Tags Type 3: The Satellite Tag

Nonfunctional tags

For adhesive type one there was one double layer of adhesive tag and two single layer tags found to be malfunctioning. For adhesive type two there was also only one tag of double layer found to be unreadable. In addition, one single layered tag malfunctioned.

Functional tags

For adhesive type one there was four double layer of adhesive tags and three single layer tags found to be functioning. For adhesive type two, there was also four tags of each layering method functioning.

Table 4-5: Adhesive type 1 results for RFID functionality.

	Adhesive only between film and tag (single layer)		Adhesive on both sides of RFID tag (double layer adhesive)	
Tag Type	Functional	Nonfunctional	Functional	Nonfunctional
1	5	0	4	1
2	5	0	4	1
3	3	2	4	1

Table 4-6: Adhesive type 2 results for RFID functionality.

	Adhesive only between film and tag (single layer)		Adhesive on both sides of RFID tag (double layer adhesive)	
Tag Type	Functional	Nonfunctional	Functional	Nonfunctional
1	4	1	4	1
2	5	0	4	1
3	4	1	4	1

Inlay Performance Results

The results of the inlay performance in the mold are displayed in tables 4-7 through 4-12. The tables are separated by tag types and adhesive layering method (single side with adhesive or both sides of the inlay covered with adhesive). There are some trends in inlay performance that can be seen in tables 4-7 through 4-12. Heavy damage to the inlay will often occur where there is some damage to the sidewall as well. Tags with RFID no longer functioning always had damage to the inlay, however, the tag may have no other sign of damage (sidewall or shifting). Furthermore, there was no distinct trend with respect to weight of the container.

Table 4-7: Results for tags in type 1 (button tag) performance in the mold for both types of adhesive when applied to a single side of the inlay.

Button Tag: Adhesive applied to one side									
Adhesive 1					Adhesive 2				
Tag #	Weight (g)	Sidewall Damage	Inlay Damage	Shift (mm and direction)	Tag #	Weight (g)	Sidewall Damage	Inlay Damage	Shift (mm and direction)
1	51.71	Heavy	Heavy	10mm S	1	51.72	Light	Light	None
2	51.61	Heavy	Heavy	1mm S	2	51.78	None	Heavy	None
3	51.72	Heavy	Heavy	5mm W	3	51.67	Light	Heavy	None
4	51.69	None	None	None	4	51.82	Light	Light	3mm N
5	51.76	Light	Light	5mm S	5 RFID Broken	51.78	Light	Heavy	2mm S

Table 4-8. Results for tags in type 1 (button tag) performance in the mold for both types of adhesive when applied to a both sides of the inlay.

Button Tag: Adhesive applied to both sides									
Adhesive 1					Adhesive 2				
Tag #	Weight (g)	Sidewall Damage	Inlay Damage	Shift (mm and direction)	Tag #	Weight (g)	Sidewall Damage	Inlay Damage	Shift (mm and direction)
1	51.61	None	None	5mm S	1	51.61	None	Light	None
2	51.53	None	None	None	2	51.53	None	Heavy	None
3	51.54	Light	Light	10mm W 2mm S	3	51.54	Light	Light	None
4	51.54	None	Light	None	4	51.55	Light	Heavy	2mm S
5 RFID Broken	51.79	Light	Light	None	5 RFID Broken	51.78	None	Light	30mm N

Table 4-9. Results for tags in type 2 (disk tag) performance in the mold for both types of adhesive when applied to a single side of the inlay.

Disk Tag: Adhesive applied to one side									
Adhesive 1					Adhesive 2				
Tag #	Weight (g)	Sidewall Damage	Inlay Damage	Shift (mm and direction)	Tag #	Weight (g)	Sidewall Damage	Inlay Damage	Shift (mm and direction)
1	51.74	Heavy	Heavy	2mm N 2mm E	1	51.89	Light	Heavy	None
2	51.75	Light	Light	None	2	51.84	None	Heavy	5mm N
3	51.78	Light	Heavy	None	3	51.81	Light	Light	5mm N
4	51.73	Light	Heavy	5mm N	4	51.84	Light	Light	None
5	51.84	Light	Light	None	5	51.88	Light	Light	3mm N

Table 4-10. Results for tags in type 2 (disk tag) performance in the mold for both types of adhesive when applied to both sides of the inlay.

Disk Tag: Adhesive applied to both sides									
Adhesive 1					Adhesive 2				
Tag #	Weight (g)	Sidewall Damage	Inlay Damage	Shift (mm and direction)	Tag #	Weight (g)	Sidewall Damage	Inlay Damage	Shift (mm and direction)
1	51.75	Light	None	None	1	51.75	None	Heavy	1mm N
2	51.74	None	None	1mm N	2	51.74	Heavy	Light	4mm S
3	51.78	Light	Light	None	3	51.78	Light	Heavy	2mm N
4	51.72	Light	None	None	4	51.72	Light	Heavy	2mm S
5 RFID broken	51.71	Light	Heavy (chip removed)	None	5 RFID broken	51.60	Light	Heavy (chip removed)	None

Table 4-11. Results for tags in type 3 (satellite tag) performance in the mold for both types of adhesive when applied to a single side of the inlay.

Satellite Tag: Adhesive applied to one side									
Adhesive 1					Adhesive 2				
Tag #	Weight (g)	Sidewall Damage	Inlay Damage	Shift (mm and direction)	Tag #	Weight (g)	Sidewall Damage	Inlay Damage	Shift (mm and direction)
1	51.63	Heavy	Heavy	2mm W	1	51.91	Light	Heavy	3mm S
2	51.64	Heavy	Heavy	None	2	51.90	Heavy	Heavy	2mm S
3	51.62	Heavy	Heavy	1mm N	3	51.91	Light	Heavy	None
4 RFID broken	51.66	Heavy	Heavy	1mm N	4	51.89	Heavy	Heavy	None
5 RFID broken	51.61	Heavy	Heavy	1mm N	5 RFID broken	51.93	Light	Heavy	2mm S (½ tag only)

Table 4-12 Results for tags in type 3 (satellite tag) performance in the mold for both types of adhesive when applied to both sides of the inlay.

Satellite Tag: Adhesive applied to both sides									
Adhesive 1					Adhesive 2				
Tag #	Weight (g)	Sidewall Damage	Inlay Damage	Shift (mm and direction)	Tag #	Weight (g)	Sidewall Damage	Inlay Damage	Shift (mm and direction)
1	51.75	Heavy	None	20mm S	1	51.83	Heavy	Heavy	3mm S
2	51.74	Heavy	None	9mm N	2	51.85	Light	Light	None
3	51.78	Heavy	None	2mm W	3	51.85	Light	Heavy	7mm S
4	51.72	Heavy	Light	1mm S	4	51.93	Light	Heavy	2mm S
5 RFID broken	51.68	Heavy	Light	1mm N	5 RFID broken	51.93	Heavy	Heavy	1mm S

Figures 4-4 through 4-6 further display the results for the sidewall and inlay damage for focused comparison between the three inlay types.

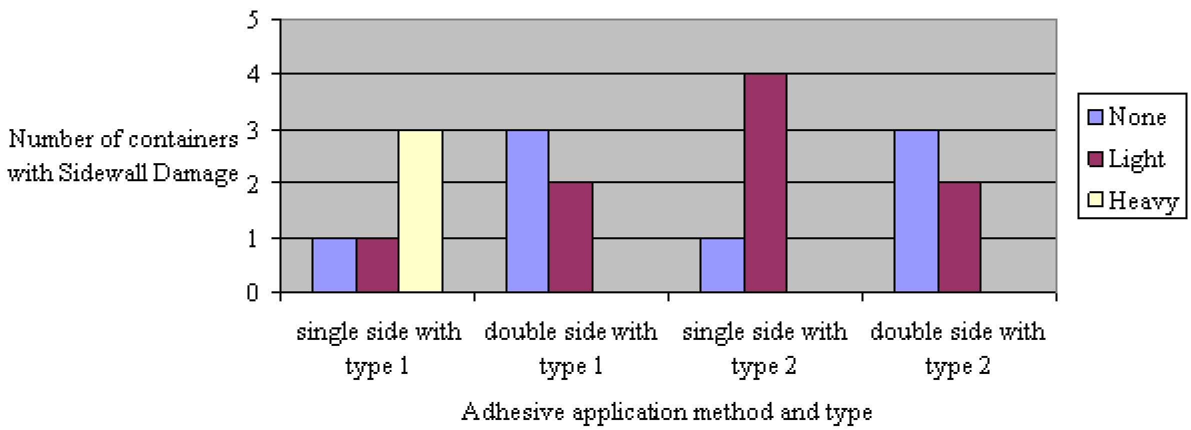


Figure 4-4: Displays the button tag sidewall damage for each sample container.

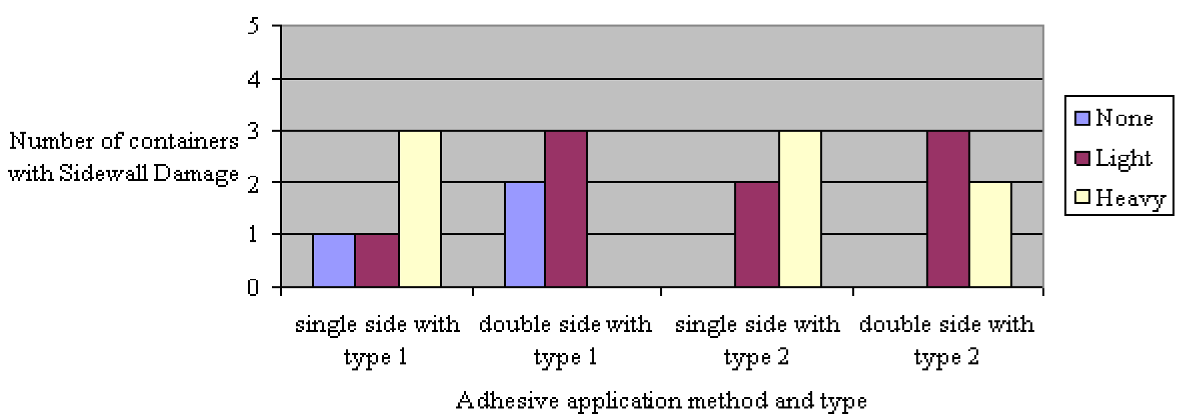


Figure 4-5: Displays the disk tag inlay damage for each sample container.

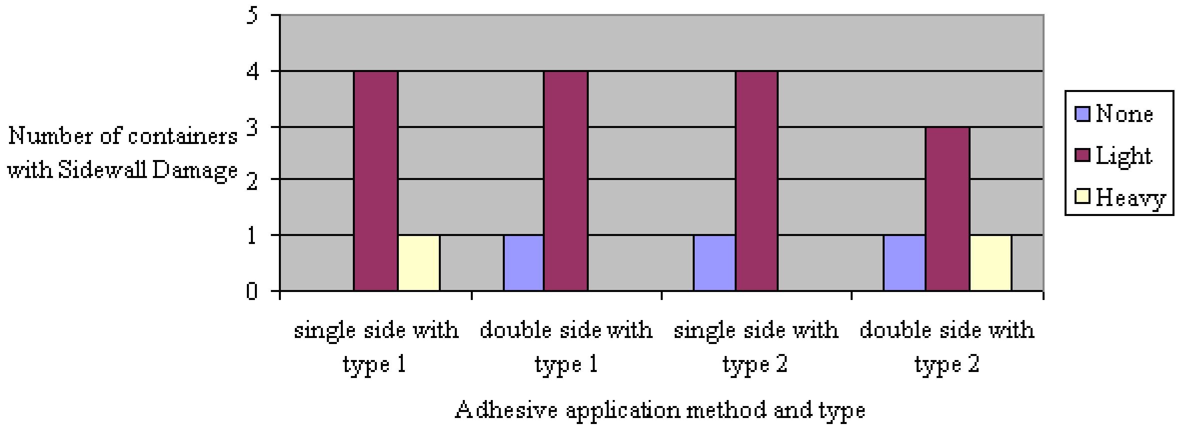


Figure 4-6: Displays the disk tag sidewall damage for each sample container.

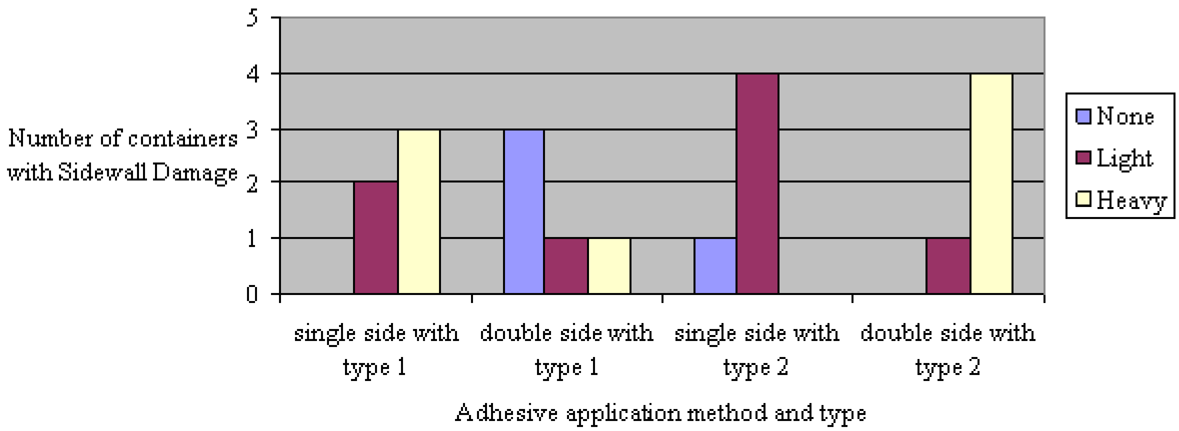


Figure 4-7: Displays the disk tag inlay damage for each sample container.

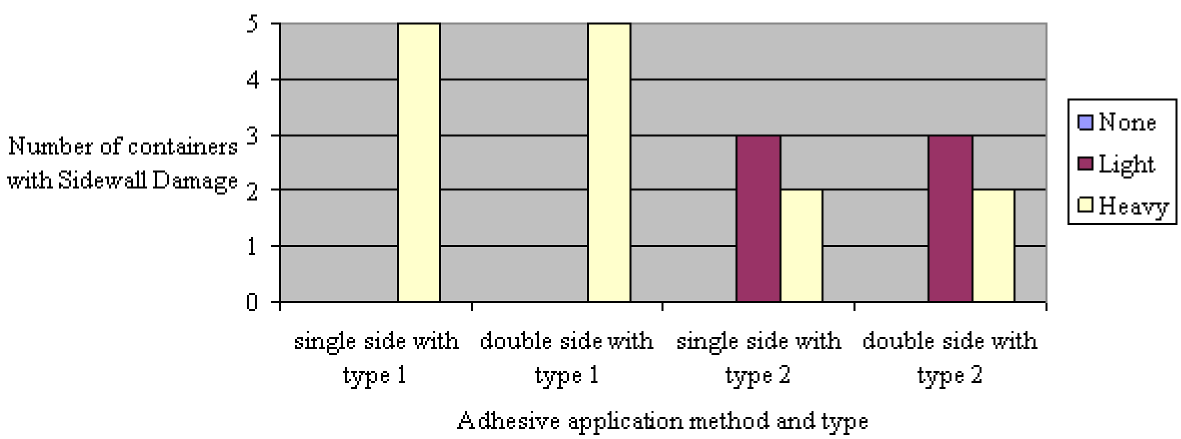


Figure 4-8: Displays the satellite tag sidewall damage for each sample container.

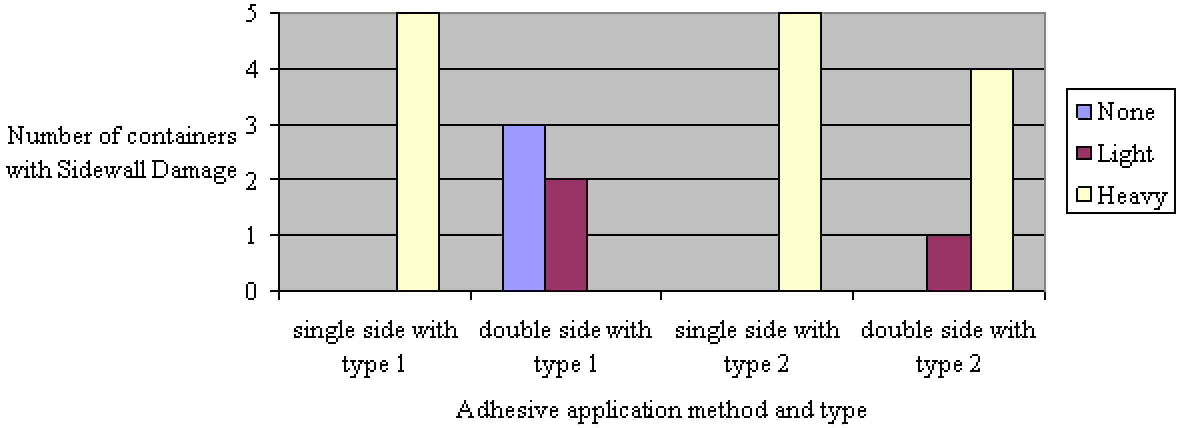


Figure 4-9: Displays the satellite tag inlay damage for each sample container.

Figures 4-10 through 4-12 are images taken from sample containers. The pictures show some of the damage and shifting that occurs in the mold. Detailed description of sidewall and inlay damages for each tag is presented in appendix A.

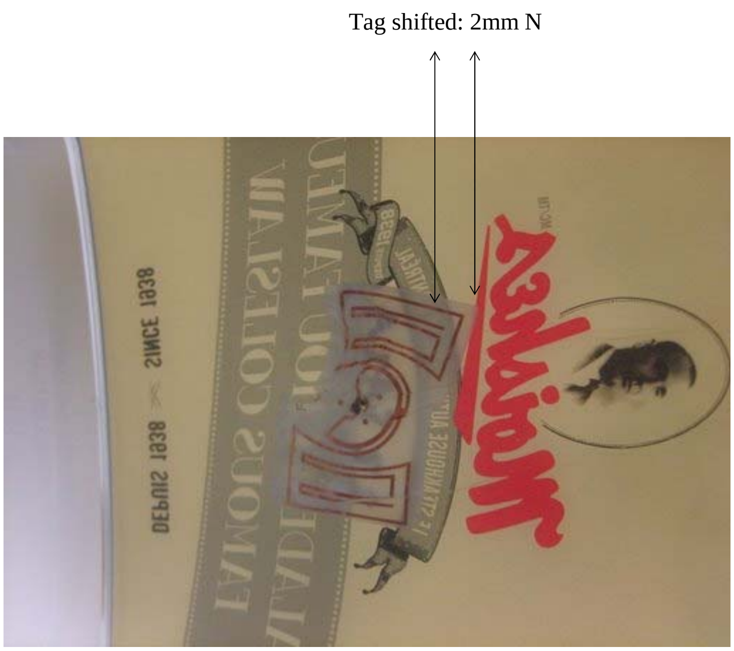


Figure 4-10: Displays a picture of a satellite tag (tag type 3).The warping and shift movement that occurs. This inlay was a functioning inlay and it shows the warping that took place to tags in this category.

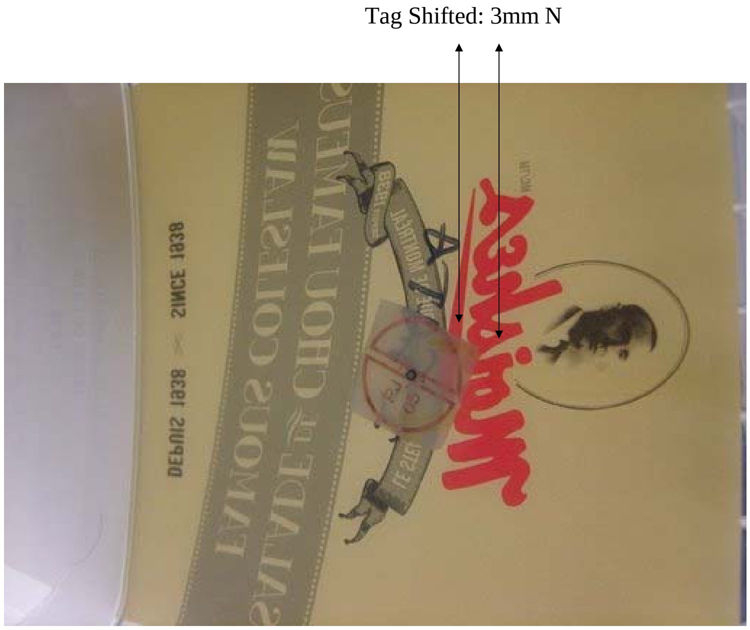


Figure 4-11: Shows a disk tag (tag type 2)The tag has no major warping damage to the antenna but has shifted slightly.

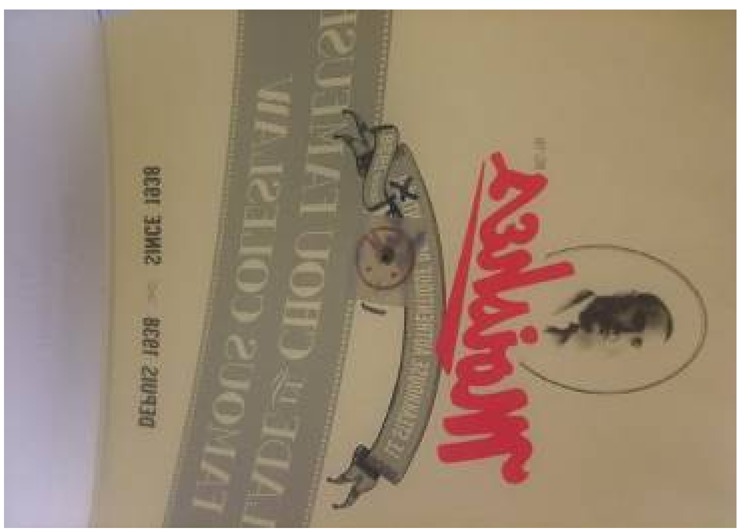


Figure 4-12: Displays a button tag (tag type 1). This has no physical damage from the forces that are present in the mold.

CHAPTER 5
DISCUSSION

Effect of Inlay on Plastic Filling Process

The weight of each sample container was measured and recorded, the data was then manipulated by removal of the IML film and inlay weights in order to display the main remaining polypropylene matrix numbers alone. The measurement of the standard IPL container (46.52 g w/o the IML) was compared to those of the 60 samples to determine the effect of the inlay on mold filling. The averages for the three styles were all above the IPL container weight (the highest only 2.8% higher). This implies that while there is a consistent theme of an increased weight in amount of injected plastic, it is negligible. This is due in part to the fact that the standard deviation of the IML film weight is approximately .05 g. The remaining contributing factors to the elevated weight potentially arise from the allowance of inlay weight variation and other similar influencing factors. Therefore it can be concluded that while there might be a slight tendency for higher measurement in weights, it is most likely not contributed to by the filling process of the mold. This conclusion is very favorable to the structure of the plastic in the container. If the container was not being formed using the total amount of plastic it was designed to have, the structure and integrity of the plastic would have been compromised due to a forced reduction in thickness throughout the whole container (Yao et al., 2002). Tables 4-7 display the container weight for each sample.

Holding Tags in the Mold

Analysis of Shift

The results show that the disk tag was the tag that performed the most consistently, as well as performing the most favorably, for the amount of shift in molding conditions. The button tag is closely following the disk tag, and the satellite tag performed the least favorably as can be seen in figures 4-1 through 4-3. In the instance of the button tag, the results were concluded to be a symptom of the shear stress overcoming the adhesive ability to bond the PETE surface to the PP on the chip. The shear forces present in the mold are acting at the highest point in the center of the mold (Rosato et al., 2002). With the placement being used, the chip is facing the part of the mold with the highest shear forces are being exhibited. When comparing the inlay structures, the thickness of the button tag is very similar to that of the disk tag and the satellite tag. The surface area, however, is much smaller. Consequently, rather than aiding the button tag, the proportionately smaller disturbance area in the mold proves itself to be a disadvantage (rather than the expected advantage) due to the shared thickness parameters without the added surface area covered with adhesive to aid the holding capabilities. Thus the same (as with the other tags) shear forces focusing on the very center, and pivotal point, of the tag are overcoming the surface area of the adhesive present. However, if an inlay could be found that has the same surface area but a smaller thickness over the chip, it would most likely perform at a much higher rating than the disk tag, rather than following it closely. The results of the satellite tag where concluded to be resulting from a surface area that is too large. The satellite tag performed least favorably throughout the whole experiment, as expected, due to the large surface area causing too much of a disturbance in the mold and adversely affecting the end results.

The overall success of the two smaller tags does indicate that, when dealing with injection molding, the smaller the disturbance in the mold yields a higher rating for the performance overall. It shows that it is imperative to have a tag that is small, in both size and thickness, in order to have a not only a functioning tag, but to have a tag that maintains its physical structure and yield a marketable and functioning product. This result was also escalated in this study as a result of dealing with two incompatible polymers. The satellite tag, even with adhesive to help increase compatibility proved to be too large to yield a tag that was completely uncompromised. The tag was successful in functionality, but was largely unsuccessful in surviving physical warping to tag structure and is a result of the turbulence and the higher shear rate placed upon the tag due to the larger surface area and perhaps the antenna design. Where both smaller tags faced similar pressures, it was at a reduced rate because of the smaller surface area causing obstruction in the mold and was displayed in a reduced amount of warping to the tags. However, the surface area should not be considered without the thickness measurements taken into account.

Comparison of Adhesive Type and Method

Based on RFID performance

The results of RFID readability can be seen in tables 8 and 9. The results of adhesive performance based on RFID capabilities were noted to display a difference in the damages observed for the different adhesive application methods. The single side application method, for both types of adhesives, performed with higher successful tags overall. The disk and button tag types had 100% success with adhesive type 1, and only the disk tag had 100% with adhesive type 2. Using these results, it can be concluded that adhesive type 1 is the most successful overall with the single side application method.

Based on Structural Performance Factors

Figures 4-5, 4-7, and 4-9 display the results for inlay and sidewall damage. The adhesive type differences and performance examination yielded a visible pattern for the three inlay types. It was noted that the inlays applied on both sides with adhesive type 1 perform best with respect to inlay damage. This is opposite to the RFID read performance which yielded better results with single application method using adhesive type 1. This was concluded to be a result of the added adhesive of double sided coverage aiding in maintenance of the structure of the inlay during molding but is a consequently larger disturbance to the mold. The sidewall damage, seen in figures 4-4, 4-66, and 4-8 displays no such clearly evident pattern.

Effects of Injection Molding on Inlay Functionality

Analysis of RFID Readability

RFID inlays are very sensitive to microchip damage, if the microchip suffers too much impact, or the placement on the contacts of the inlay antenna is altered, it will no longer function correctly (Clampitt, 2006). If the antenna on the inlay is too damaged, or severed for any reason, the resulting effect is a very large decrease in the distance that the tag can be activated and read by the transmitting and receiving antennas (Lahiri, 2006). Thus, it can be concluded that damage to inlay antenna, or microchip, during molding was the reason the ten inlays were no longer functioning.

It was hypothesized that the majority of the occurrence of severely damaged inlays would be located in the tag type 3 due to the large surface area from which to experience turbulent conditions. Severe damage is characterized by crippling of the tag to the point that it will not read. However, the results, as seen in tables 8 and 9,not only display a smaller of amount of severe damage than originally expected, but an almost even distribution of severe damage across the three tag types. This is a result of the movement of the plastic through the mold in some instances overpowering the microchip bonds and causing its complete removal due to the shear stress present in the mold from the plastic.

There were efforts taken to remove the likelihood of electrostatics causing inlay failure. The inlay was placed on the inside of the label with microchip on the absolute inside, thus possibly sheltering the chip from some of the damaging static. It is unfortunately impossible to test whether there was static damage to the inlays that were rendered useless (that were not damaged from chip removal) and it was concluded that due to the warped nature of the malfunctioning tags that the damage was from the forces faced in molding and not from static. The high success rate of functioning inlays also indicates that the microchips did not suffer from close proximity of the static.

Analysis of Inlay and Sidewall Performance

Figures 4-4 through 4-9 show the sidewall damage for the button, disk and satellite tags. It may be observed that while button tag has a better overall rating for sidewall damage, it is less consistent than the disk tag performance. It can also be concluded that, for performance, the button tags with adhesive applied to both sides of the inlay performed at a better rate than those that contained adhesive applied to a single side for all adhesive types. The satellite tag performed the least favorably with respect to both sidewall and inlay damage. The button tag performed the most favorably, closely followed by the disk tag in both instances. When analyzing the performances for both sidewall and inlay damage, it was noted that in most instances there was a small correlation between inlay damage and sidewall damage it is, however, not consistent throughout the samples.

Part of this warping could be an added result of the surface layer difference between the tags. Coinciding with the larger surface area of PETE, the larger tag also has a larger area of metal antenna. This creates a surface that has more ridges and is much less uniform than one that has a smaller antenna with less metal and structure to it, and it results in a greater shear force across the majority of the inlay antenna that would not be solely directed at the microchip. It is suggested that the antenna design and structure are, other than the incompatibility of the polymers and surface area, a major contributor to the warping and shear force affect seen in the physical warping of the inlays. The circular antennas have the added advantage of the lower surface area and a reduced antenna size which creates the radius of the antenna and travels back to the microchip in two locations. Creating a more uniform surface that has much less area to face the shearing force of the turbulence in the mold. Resulting in a lower percent of movement and warping in the inlay. The warping affects and a clearer picture of the antenna shape and style can be seen in the figures 4-10 through 4-12.

CHAPTER 6
FUTURE WORK

The suggested future work of this project is separated by time scales of items, first referencing items that can be considered for immediate action and then moving to items that should be considered farther in the future as the RFID technology continues to develop.

Firstly, it is suggested that this process be repeated using polypropylene inlays. Currently it is impossible to create RFID inlays using polypropylene due to the properties of the film itself, however there is testing be done to attempt creation of such an inlay. Utilizing a polypropylene inlay would reduce or eliminate some of the issues due to the incompatibility and insolubility of PETE and PP. Secondly, it is suggested that the experiment also be attempted using thinner inlays. While the current experiment yielded product that was suitable for the market, using thinner inlays would help to further reduce some of the issues that were seen in the experiment.

Furthermore, it is suggested that this study be done focusing on one or two of the parameters used in the study. With each set of samples run by IPL, a large amount of time was required to reset the injection molder and then to run the samples on the machine used. The large amount of time that was taken to dedicate a machine to the tests also came with high costs for each of these runs. Therefore, it was impossible to focus the work of this study on more specific parameters due to the costs and machine time limitations. Thus, this study was focused on many parameters and a smaller sampling in order to establish a broad view of the work. Further work should be considered, allowing a focused study on one or two parameters with a large sampling for a more statistically viable method for each parameter.

Additionally, testing RFID inlays in conjunction with biosensors embedded into packaging should be considered. Knowing a product is expired by date alone is a useful piece of information. However, even more useful would be to know when a product has expired before this date has passed. To have some indication when a food borne illness is present would also of even further value. This type of predictor could become immensely welcome in the market place due to the recent outbreaks of illness and contaminated products. Therefore, it is suggested that exploration into creating a smart package combining RFID inlays and biosensors would present a uniquely valuable packaging system that would represent the start of a new age in packaging; a package that can alert the consumer when there is something wrong and the product is either contaminated or has expired. To take the above idea further, to bring the technology to the shelf and make the shelf an intelligent piece of equipment would revolutionize the food retail industry. It is suggested to move RFID antennas and readers to the retail shelf and apply the technology by having shelves that alert the retail store personnel to the fact of food expiration. The shelf could also alert personnel if a food container is containing food borne illness causing pathogens are present and thus cause a recall reducing the possibility of consumption. The future of RFID is almost unlimited in its applications.

CHAPTER 7
CONCLUSION

The main objective of this work was to develop a method for embedding RFID inlays into injection molded food containers using IML technologies. This objective was accomplished by studying the mold filling process, the utilization of adhesive to bond the RFID inlay to the IML film, and finally studying the survival of the inlays under molding conditions.

The injection molding mold filling process was studied. Preliminary tests were run to study the effects of adding materials to a mold. Subsequently, it was determined that mold filling was very sensitive to additional materials with thicknesses in excess of 50% of the wall thickness. To study mold fill response to the thinner inlays, the weights of the sample containers were measured. The resulting effect to the mold was negligible.

The more difficult challenges faced in this study can be traced back to inlay surface area and incompatibility of the polymers causing a disturbance in the mold. The inlay surface area was examined using three different size inlays that were the smallest on the market at the time of the study. These inlays also offered the ability to read through liquids which not all tags options offer, thus allowing them to be very good for various food applications. Results showed that the two smallest inlays performed the best in the mold situation. The incompatibility of the polymers was overcome using two hot melt heat seal adhesives that, under the high temperatures of injection molding, work to bond the PETE to the PP. The incompatibility was, as result, no longer an issue for the mold filling process. Turbulence still played a key role in the destruction of a small percentage of the inlays, however the adhesive that was used help reduce the likelihood of the damage occurring. The results indicate that through utilization of hot melt adhesive, RFID inlays with a PETE substrate can be embedded into injection molded food container and yield a functioning RFID solution into a marketable food container.

To get higher performance out of an inlay, it would be advantageous to reduce the thickness of the inlay even further or to try using a polypropylene tag of similar surface area and thickness. The advantages of a smaller surface area could be increased if a thinner tag were present, furthering the reduction of a disturbance in the mold. The antenna design is critical, but inlay design should be taken into account as well. For further increase in performance of a tag in the injection molding process, the tag should be as thin as possible (while still ensuring that the creation of the inlay will still be high performing and effective) and create as little disturbance in the mold as possible.

APPENDIX:
RECORDED DAMAGE TO EACH INLAY

The following are detailed descriptions of the damage that each inlay faced during molding:

- Tag type 1 (button tag) Glue applied to one side of the inlay:
  - Glue 1
    - Tag #1:
      - Sidewall damage: Heavy damage to the sidewall, very large air bubble over more than half of the surface, sidewall angle dipping backwards where the inlay is located.
      - Inlay damage: Heavily damaged, inlay is bent in the upper right corner and the entire inlay is wrinkled and rippled.
    - Tag #2:
      - Sidewall damage: Heavy damage to the sidewall, very large air bubble covering more than half of the surface where the inlay is located and angle of the sidewall is dipping backward in the same location
      - Inlay damage: Heavily damaged, inlay is bent in 3 locations vertically and severely wrinkled.
    - Tag #3:
      - Sidewall damage: Heavy damage to the sidewall, air bubble is covering the whole surface where the inlay is located.
      - Inlay damage: Heavy damage, inlay is completely wrinkled.
    - Tag #4:
      - Sidewall damage: None
      - Inlay damage: None
    - Tag #5:
      - Sidewall damage: Light damage, there is a very small air bubble.

        - Inlay damage: Lightly damaged, the inlay is wrinkled in the middle of it which coincides with the sidewall damage.

    - Glue 2

        - Tag #1:

            - Sidewall damage: Lightly damaged, very minor dip in the angle where the inlay is located

            - Inlay damage: Light damage, very small wrinkle in the inlay through the top.

        - Tag #2:

            - Sidewall damage: None

            - Inlay damage: Heavy damage, almost folded completely in half across the horizontal.

        - Tag #3:

            - Sidewall damage: Lightly damaged, the inlay is causing the sidewall to bulge out where it is located.

            - Inlay damage: Heavy damage, the inlay is completely wrinkled.

        - Tag #4:

            - Sidewall damage: None

            - Inlay damage: None

        - Tag #5:

            - Sidewall damage: Light damage, there is a very minor dip in the angle to the sidewall where the inlay is located and there is 1 very small air bubble.

            - Inlay damage: Heavy damage, the inlay is completely wrinkled in and this tag was broken (no longer was capable of giving a RFID read).

- Tag type 1 (button tag) Glue applied to both sides of the inlay:

    - Glue 1

        - Tag #1:

        - Sidewall damage: None
        - Inlay damage: None
    - Tag #2:
        - Sidewall damage: None
        - Inlay damage: None
    - Tag #3:
        - Sidewall damage: Light damage, there are very small air bubble on the surface over the center of the inlay location.
        - Inlay damage: Light damage, the inlay is wrinkled in the upper left hand corner.
    - Tag #4:
        - Sidewall damage: Light amount of damage, the surface has small air bubbles over the surface where the inlay is located.
        - Inlay damage: Light damage, the inlay is slightly wrinkled in the outer edges.
    - Tag #5:
        - Sidewall damage: Light damage, the angle of the sidewall is slightly dipped backwards where the inlay is located.
        - Inlay damage: Light damage, the inlay is wrinkled in the left hand corner, this tag was however broken (RFID not functioning).
- Glue 2
    - Tag #1:
        - Sidewall damage: None
        - Inlay damage: Light damage, the inlay is wrinkled slightly on the outer edges.
    - Tag #2:
        - Sidewall damage: None

        - Inlay damage: Heavy damage, the inlay is folded in half horizontally.
    - Tag #3:
        - Sidewall damage: Light damage, there is a small dip backwards where the inlay is located.
        - Inlay damage: Light damage, there is a small wrinkle in the inlay where through the center where the dip in the surface is located.
    - Tag #4:
        - Sidewall damage: Light damage, there is a slight dip in the surface angle of the sidewall.
        - Inlay damage: Heavy damage, the inlay is folded vertically in the middle back upon itself, and it is wrinkled on both sides next to it.
    - Tag #5:
        - Sidewall damage: None
        - Inlay damage: Light damage, there is a small horizontal wrinkle through the center of the inlay. This inlay is also broken (RFID not functioning).

- Tag type 2 (disk tag) Glue applied to one side of the inlay:
  - Glue 1
    - Tag #1:
        - Sidewall damage: Heavy damage, inlay is causing the sidewall to bulge outward where it is located and there is an air bubble covering the top 25% of the tag.
        - Inlay damage: Heavy damage, the inlay is folded onto itself horizontally through the middle and wrinkled through the rest.
    - Tag #2:
        - Sidewall damage: Light damage, the sidewall is bumpy over 25% of the tag location.
        - Inlay damage: Light damage, 20% of the inlay is wrinkled horizontally through the middle.

- Tag #3:
  - Sidewall damage: Light damage, very small air bubble located over the tag.
  - Inlay damage: Heavy damage, the inlay is folded in half horizontally from the top.
- Tag #4:
  - Sidewall damage: Light damage, 2 small air bubbles across the top of the inlay location
  - Inlay damage: Heavy damage, half of the inlay is heavily wrinkled and warped out of shape.
- Tag #5:
  - Sidewall damage: Light damage, 1 small bubble at the top of the inlay location.
  - Inlay damage: Light damage, the top of the inlay is horizontally wrinkled.

- Glue 2
  - Tag #1:
    - Sidewall damage: Light damage, small air bubble covering the left side of the inlay location.
    - Inlay damage: Heavy damage, inlay is folded horizontally through the middle, and the right upper corner is folded down.
  - Tag #2:
    - Sidewall damage: None
    - Inlay damage: Heavy damage, the inlay is folded down horizontally in half.
  - Tag #3:
    - Sidewall damage: Light damage, small air bubble present on the bottom of the inlay location.
    - Inlay damage: Light damage, inlay slightly wrinkled throughout the middle.

        - Tag #4:
            - Sidewall damage: Light damage, small air bubble and slight dip to the angle of the sidewall where inlay is located.
            - Inlay damage: Light damage, inlay is wrinkled through the middle.
        - Tag #5:
            - Sidewall damage: Light damage, small air bubble in the lower left hand corner of the inlay.
            - Inlay damage: Light damage, inlay is slightly wrinkled in the upper left hand corner.
- Tag type 2 (disk tag) Glue applied to both sides of the inlay:
    - Glue 1
        - Tag #1:
            - Sidewall damage: Light damage, small air bubble and slight outward bulging of the sidewall over location where inlay present.
            - Inlay damage: None
        - Tag #2:
            - Sidewall damage: None
            - Inlay damage: None
        - Tag #3:
            - Sidewall damage: Light damage, slight dip inward in sidewall angle.
            - Inlay damage: Light damage, the upper left hand corner is wrinkled.
        - Tag #4:
            - Sidewall damage: Light damage, slight inward dip in the sidewall angle.
            - Inlay damage: None
        - Tag #5:

            - Sidewall damage: Light damage, inward dip and small air bubble where inlay is located.

            - Inlay damage: Heavy damage, inlay slightly wrinkled but microchip is completely removed and RFID no longer functioning.

    - Glue 2

        - Tag #1:

            - Sidewall damage: None

            - Inlay damage: Heavy damage, upper right corner of inlay is folded down and inlay is heavily wrinkled.

        - Tag #2:

            - Sidewall damage: Heavy damage, IML film is causing an air bubble from top of container to the bottom that is approximately 20 mm thick and 15mm to the left of the inlay.

            - Inlay damage: Light damage, inlay slightly vertically wrinkled across the middle.

        - Tag #3:

            - Sidewall damage: Light damage, small bulge outward over inlay location.

            - Inlay damage: Heavy damage, inlay completely wrinkled.

        - Tag #4:

            - Sidewall damage: Light damage, small bulge where inlay located.

            - Inlay damage: Light damage, inlay wrinkled across top left corner.

        - Tag #5:

            - Sidewall damage: Light damage, small air bubble located over middle of inlay.

            - Inlay damage: Heavy damage, microchip is completely removed and inlay is wrinkled and folded over in all the corners, RFID no longer functioning (no longer reading/broken).

- Tag type 3 (satellite tag) Glue applied to one side of the inlay:

- Glue 1
    - Tag #1:
        - Sidewall damage: Heavy damage, large air bubble completely covering the inlay location.
        - Inlay damage: Heavy damage, inlay is completely wrinkled.
    - Tag #2:
        - Sidewall damage: Heavy damage, large air bubble completely covering the inlay location.
        - Inlay damage: Heavy damage, inlay is completely wrinkled.
    - Tag #3:
        - Sidewall damage: Heavy damage, large air bubble completely covering the inlay location.
        - Inlay damage: Heavy damage, inlay is completely wrinkled.
    - Tag #4:
        - Sidewall damage: Heavy damage, large air bubble completely covering the inlay location.
        - Inlay damage: Heavy damage, inlay is completely wrinkled and RFID microchip was removed. RFID capabilities no longer functioning.
    - Tag #5:
        - Sidewall damage: Heavy damage, large air bubble completely covering the inlay location.
        - Inlay damage: Heavy damage, inlay is completely wrinkled and RFID microchip was removed. RFID capabilities no longer functioning.
- Glue 2
    - Tag #1:
        - Sidewall damage: Light damage, sidewall dipping backward where inlay is located.

            - Inlay damage: Heavy damage, inlay is completely wrinkled and warped.

        - Tag #2:

            - Sidewall damage: Heavy damage, large air bubble completely covering the location where inlay present.

            - Inlay damage: Heavy damage, inlay completely wrinkled.

        - Tag #3:

            - Sidewall damage: Light damage, sidewall angle dipping backward where inlay is located.

            - Inlay damage: Heavy damage, inlay completely wrinkled.

        - Tag #4:

            - Sidewall damage: Heavy damage, large air bubble over inlay location.

            - Inlay damage: Heavy damage, top 50% of inlay completely wrinkled.

        - Tag #5:

            - Sidewall damage: Light damage, small dip where inlay is located on sidewall surface.

            - Inlay damage: Heavy damage, inlay completely wrinkled and RFID capabilities no longer functioning.

- Tag type 3 (satellite tag) Glue applied to both sides of the inlay:

    - Glue 1

        - Tag #1:

            - Sidewall damage: Heavy damage, large air bubble covering location of inlay completely and sidewall dipping backward at the same location.

            - Inlay damage: None

        - Tag #2:

        - Sidewall damage: Heavy damage, IML film graphics are warped and location of inlay is bulging outward.
        - Inlay damage: None
    - Tag #3:
        - Sidewall damage: Heavy damage, IML film graphics are warped and location of inlay is bulging outward.
        - Inlay damage: None
    - Tag #4:
        - Sidewall damage: Heavy damage, IML film graphics are warped and location of inlay is bulging outward and large air bubble is present over inlay.
        - Inlay damage: Light damage, inlay displays minor wrinkling around corners.
    - Tag #5:
        - Sidewall damage: Heavy damage, large air bubble completely covering inlay location.
        - Inlay damage: Light damage, inlay is wrinkled through horizontal middle location. RFID capabilities are no longer functioning.
- Glue 2
    - Tag #1:
        - Sidewall damage: Heavy damage, air bubble completely covering location of the inlay.
        - Inlay damage: Heavy damage, whole inlay is completely wrinkled and warped.
    - Tag #2:
        - Sidewall damage: Light damage, small air bubble on left side of inlay location.
        - Inlay damage: Light damage, inlay wrinkled on left 20%.
    - Tag #3:

        - Sidewall damage: Light damage, small air bubbles are located over right side of inlay location.

        - Inlay damage: Heavy damage, inlay is completely wrinkled.

    - Tag #4:

        - Sidewall damage: Light damage, small air bubbles are located over the right side of inlay area.

        - Inlay damage: Heavy damage, inlay is completely wrinkled over 75% (from the right side).

    - Tag #5:

        - Sidewall damage: Heavy damage, large air bubble completely covering inlay location and dip in angle of sidewall.

        - Inlay damage: Heavy damage, inlay is completely wrinkled and RFID chip is removed. RFID capabilities no longer functioning.

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BIOGRAPHICAL SKETCH

Alexis has a bachelor's degree in packaging science from the University of Florida, as well as earning the Master of Science degree in agricultural and biological engineering.

In the third year of her bachelor's degree, she created the packaging science club. She was president for the first year and is still an active member today. Alexis was also a very active member of the Graduate Student Council. She took part in this organization as a department representative and participated in various committees. During the course of her graduate studies, Alexis assisted in multiple projects other than those discussed in this paper and also worked as a teaching assistant for the principles of packaging and package decoration courses. Also during the two years in graduate school, Alexis ran and managed her own 15 acre horse boarding facility located in Newberry, Florida.