Governor’s School of Engineering and Technology Research Paper
Quality Engineering in a Major Manufacturing Facility

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ABSTRACT

Packaging protects a product from the point the manufacturer creates the good until the consumer purchases it. The goal of this project was to test Silver Line’s windows to ensure that they meet ISTA standards; if the windows do not meet these standards, a new package must be implemented. The current package that Silver Line utilizes does not protect their windows enough. The new designs do not meet the ISTA standards completely, even though they are three times stronger. Ultimately, the window itself must be strengthened, especially during the welding process.

INTRODUCTION

Often taken for granted, packaging is an essential part of the modern world; it exists everywhere and is a major element of not only the manufacturing world, but also the world of consumers and retailers. Proper packaging is the key to ensure quality products to consumers. An ideal package is cost-efficient, durable, environmentally friendly, easily assembled, and aesthetically pleasing.

This project was taken on, in the perspective of a Quality Engineer; they ensure that a factory runs smoothly and optimizes production, safety, assembly, and all other critical aspects of the workplace. In conjunction with Silver Line, a major manufacturer of windows, the factory in North Brunswick, New Jersey was examined. The fabrication of a window was traced, starting from cutting the proper size glass all the way to packaging and storing the final product. Furthermore, the final process of packaging the window was meticulously studied.

The focus of this project was to secure and optimize Silver Line’s production process. Moreover, the packaging was studied closely, as the package protects the final product until the consumer receives the glass window, a fragile and delicate item, packaged with extra protection. The product can not show any defects, and the appearance has to be perfectly preserved from the time when it leaves the manufacturing plant to when it arrives either at Home Depot or directly at customers’ homes.

Although Silver Line has a marginal defect error of 1.3%, there was room for improvement. At the same time, the room for improvement does not necessarily warrant extra work to eliminate the error margin. The cost of improved packaging outweighs the benefits of the extra windows sold that are now without defect.

The modern manufacturing world has experienced the rise of an environmentally conscious attitude. Silver Line is known for embracing environmental concerns in recent years, so when contemplating new ideas and processes, this fact had to be present in every new idea
presented. Most importantly, is the aspect of “user-friendly” products. All packaged items need to be easily opened by the customer, and easy to assemble in the factory. The project group toured the facility to find issues or places for improvement in the manufacturing process. Silver Line being the major manufacturing company that it is, the process that they employ has been tested and tried for many years. The Silver Line process as a whole is seemingly very efficient and workable. Only minor errors in the process were to be found in this age old process design.

Some of the basic problems we found included problems with pallet loading, corner weld strength, and lack of manuals. While observing the logistics area of the factory it was seen that the heavier and larger windows were often placed above the smaller and lighter windows. This configuration of the windows could lead to unwanted damage due to pressures not being placed on the windows most able to bear the load. A simple remedy would be to leave notes on the walls of the shipping area reminding the workers to place larger windows lower stacking the smaller windows on top.

Since the group was working with Mr. Won Jong Rhee, a packaging engineer, the group also decided to take a focus on the packaging quality aspect of the Silver Line process by doing testing on a sample of their windows. Three different sizes of windows were delivered to Mr. Rhee’s packaging facility (See Appendix Fig. 1). The smallest size of window was chosen for testing because it could easily fit on the MTS Shock Testing Machine (See Appendix Fig. 2). After testing of the windows in corner drop mode and flat drop mode the windows did not satisfy ISTA (International Safe Transit Association) standards which required a drop height of 24 inches in free fall.

The plastic that is used to wrap both stock and custom windows is Low-Density Polyethylene 1.65 Mil (0.00165 inches). They use B-flute cardboard, a single layer thin cardboard, and have two categories of shipping: custom and stock. Stock windows are packaged with more cardboard, covering the entire left and right sides of the window. The custom windows are packaged with cardboard corners, varying in design depending on the fragility and dimension of that particular window.

In the packaging engineering laboratory at Rutgers, two packaging tests were performed. We had to comprehend what needed to be tested, how to test it, and what the results mean for the research.

BACKGROUND

Figure 3.1 Silver Line Building Products LLC, North Brunswick, NJ [4].

Silver Line Building Products is a vinyl window and door manufacturing company that was started in 1947. Silver Line sells its products to a diverse range of customers. In 2006 Silver Line Building
Products was absorbed by Andersen Windows and Doors Company, becoming a part of the Andersen Family. The Andersen Family controls a majority of the United States window supply and includes other manufacturing groups such as American Craftsman.

The workings of the Silver Line North Brunswick manufacturing plant were examined. Silver Line windows have three major components: the vinyl frame, the glass and the packaging. The process begins with the vinyl extrusion machines which takes the raw materials, mixes them, and delivers various lengths of vinyl that are stored temporarily. These vinyl extrusions are stored until needed, which at that point the vinyl is moved from storage racks to the cutting floor where the proper lengths of vinyl are partitioned from the longer extrusions. The cut pieces are then properly prepared for fusing into the frames. Once the frames are fused they are stored until the glass is placed into the center.

Meanwhile, the glass is being fashioned in another part of the factory floor. The glass is cut from large sheets using an optimization machine that makes the cuts for glass based on the pieces required by the types of order filled in with the company. After cutting, the pieces are taken to be connected with a pair to form a glass sandwich with argon gas in the middle. This glass sandwich is brought to be connected with the frame at a different part of the factory. Once the pieces are connected the window is taken and packaged by putting four corner covers and a plastic shrink film over the window. The purpose of this packaging is to protect the product from drop damage and dirt particles.

A quality and packaging engineering approach was taken for this task by looking for areas of improvement in the Silver Line process. Silver Line, being an established organization already has an effective process in place, yet it was our opportunity to examine this process and provide what feedback could be given. The group specifically looked for sources of inefficiency in the processes that were inspected. As quality engineers the process was scrutinized to see if it was optimized without compromising the safety of the workers.

Also, Silver Line’s packaging was inspected by testing their designs. This project focused on packaging engineering as it pertains to the Silver Line manufacturing process. In this regard, the group tried to optimize the effectiveness of the packaging design. When looking at the packaging design, parameters such as fragility, heat and humidity resistance, and cost effectiveness must be considered. These constraints were checked with respect to ISTA guidelines.

**EXPERIMENT**

For packaged products 150 pounds or less, the ISTA 1 Series Non-Simulation Integrity Performance Test Procedure for the Shock test had certain requirements. The experiment used drop testing to certify the viability of the Silver Line windows. The window chosen for testing was the small window of weight 22.95 pounds and as such is required to withstand a free fall drop height of 24 inches. The product needed to be analyzed prior to testing in order to account for any pre-existing damages or defects. There is a certain degree of subjectivity when deciding what constitutes damage or defect. At the start of the test a check must be administered to see if the product can be tested and at the end to see if damages from the execution of the test have rendered the sample useless. Once establishing what the standards are for damage caused breakage, this standard must be held constant throughout the rest of testing.
The MTS Shock Machine used has approximately a 2.89 times stronger impact than a free fall drop height. Due to this proportionality the height that the window must be dropped from on the shock machine is eight inches. The Shock test method dropped the windows in two different package orientations: flat and corner, which are practical locations on the window that are prone to damage. This damage could occur in the manufacturing process or in transit to the buyers.

The machine itself is made up of a solid steel block, or seismic base, and two cylinders that are placed on top of the block that will be taking the impact of the fall. There are “rubber-like” pads on top of these cylinders, made of elastomer. There are two larger cylinders on the side of the drop platform that guide the movements of the test subject. Pulleys that are controlled hydraulically regulate the movement of the drop platform up and down the guide pillars. A rectangular bar connected to the two taller cylinders, is used to hold the package in place and ensure that it is dropped at the correct height. For corner testing, there is a strap involved so the window will not move or be damaged before the drop test. There is an infrared sensor that detects the impact time and rebound time of the drop, which is displayed on two screens near the operating buttons.

The corner packaging consisted of “cardboard,” or as known in the packaging world: corrugated fiberboard container (CFC). A specific type of CFC used was B-Flute. B-Flute is a single wall that contains three main pieces: top linerboard, the corrugating medium, and the bottom linerboard. Cornstarch acts as the adhesive for the three pieces. The corner cap has one slit on both the front and back side so the vinyl part of the window frame that protrudes out slides into that slit, to reinforce the protection being provided by the CFC. One fault found with the corner packaging design was there is a gap between the top of the frame and the side, so there is no protection for the piece of corner that is flat, which can turn into a big issue. The entire package is also wrapped in 1.65 Mil Low-Density Polyethylene Film. This film is used primarily for protecting the aesthetic value of the bare window.

The packaging design created consisted of single wall C-Flute corrugated fiberboard container, which is different than the B-Flute type Silver Line is currently using. C-Flute is stronger, thicker, and is more popularly used in manufacturing plants. This new design also completely covers the corner of the bare window, as the previous design did not protect the flat side of the corner.

While on the tour at the manufacturing plant, the group saw some errors were preventable. For instance, when the window was being packaged, it was put through a plastic wrapping machine called AR-PAC. The window is inserted in a machine called AR-PAC, where the plastic film is cut according to the window dimensions and heated to activate the shrink wrap. They currently own three different models of the machine: 88 inch, 80 inch, and 62 inch rolls. The excess plastic is properly recycled by Silver Line but is still a source of waste.

When finished windows are ready to be shipped, they are first are placed on a cart to be transported to the other side of the manufacturing plant. If a window were to be broken on that cart, those shards or tiny pieces of glass may not be seen or cleaned as quickly to prevent cutting the plastic on the packaged products. When reaching the shipping dock, the windows are piled on pallets, which then are piled on top of each other in the back of a shipping truck. The heavier pallets were not always on the
bottom of the piles, which can cause damage to the product.

RESULTS

The 23 7/8 inch by 37 7/8 inch by 3 3/4 inch window was selected to test. The machine used was the MTS Systems Corporation Shock Test Machine. The shock test is used to simulate the product in free fall as it drops on a certain face, edge, or corner. The shock test allows the performer to see if each specimen meets ISTA standards. It also reveals the weakest points of a product and its package.

There was a total of eight windows that fit the 23 3/4 inch by 37 1/4 inch by 3 1/4 inch dimensions. The package itself added 1/8 of an inch to the length and 1/8 of an inch to the height, and 1/2 inch to the width. The bare window weighed 21.95 pounds, and the packaging added one pound, adding up to 22.95 pounds for the packaged product. The first window had a preexisting crack on the bottom right side of the window so it was not testable. Also, there was an indentation on the white vinyl frame and excess glue from joining the screen to the window. The next window was tested at drop heights of 2, 4, 8, 12, and 16 inches. The impact and rebound times recorded for sixteen inches were used to calculate the change in velocity for the window. To obtain the total change in velocity the equation used was:

\[ V = \frac{1}{t_{\text{impact}}} + \frac{1}{t_{\text{rebound}}} \]

This equation uses the values read from the Infrared sensor on the machine. For the second window the impact time was 10.42 milliseconds and the rebound time was 17.56 milliseconds. For the equation for calculating the velocity all times had to be converted to seconds by dividing by 1000. The impact velocity was 95.97 inches/second and the rebound velocity was 56.95 inches/second, so the sum was 152.92 inches/second. After collecting data, the packaging was taken off and the actual window was tested on how well the product can protect itself against a flat impact. The window was dropped at 2, 4, 8, 12, and 16 inches. At sixteen inches, part of the frame cracked. The data from the twelve inch drop was used to calculate the change in velocity. The impact time recorded was 12.28 milliseconds and the rebound time was 27.43 milliseconds. The change in velocity was 117.89 inches/second. The rest of the windows were done bare, or without the packaging. The fact that the window from the last test broke at sixteen inches, the group decided to begin testing at twelve inches for the initial drop height. The third window’s corner broke at twelve inches, so the data was not usable. The fourth window’s corner also broke at an eight inch drop height. The fifth window had two corners broken at a drop height of six inches. The sixth window tested began at a 4 inch initial drop height, and was dropped at 5, 6, 8, 10, 12, 14, 16, and 18 inches. At 18 inches a visible defect in the corner frame lining was found. The data was used from the 16 inch drop, which was 10.44 milliseconds for impact and 17.18 milliseconds for rebound. This is because this is the height at which the package is still able to protect the product. The change in velocity was calculated to be 153.99 inches/second. The seventh window was tested with the packaging on, and instead of the flat drop test, we tested a specific corner. The corner tested was the front top right corner, or the 1-2-5 corner. The initial drop height was two inches, and glass from the window was broken.
The project needed to produce a new design, stronger and more efficient than the current package. The group conducted a corner drop test on the same front top corner, or the 1-2-5 corner. The initial drop height was 2 inches, and was tested at 4, 6, and 8 inches. At eight inches the corner covered by the package broke apart into two separate pieces. Meaning, the critical drop height was six inches, and the calculated velocity was 88.26 inches per seconds. From that number the free fall drop height at which the product would result in a defect calculated to be 10.09 inches. This height was higher and more efficient than the original B-Flute single-wall CFC corner, which would break at a 0.86 inch free fall drop height.

**ANALYSIS**

The data from the tests seemed scattered; however, this was due to the fact that the vinyl structure was different depending on what model the window was. Also, different windows had a stronger corner weld; these windows survived greater heights. The amount of time the welding process took could explain this variance in the windows. As seen in the figure below, the stronger frame is melted more than the weaker frame; the stronger frame did not break evenly while the weaker frame broke along the incomplete weld.

![Figure 6.1 Picture of triangular frame with stronger weld (left) and rectangular frame with weaker weld (right).](image)

The frame on the left shows the stronger window frame interior, and the frame on the right shows the weaker window frame. The difference is that the left frame is a triangular shape, which is stronger than the right, a rectangular shape, which allows for a better weld.

From these observations, the group suggests that Silver Line to raises the welding plate temperature or hold the plates together for a longer period of time. This experiment showed that this could give the windows a greater advantage in strength of the frame and protection against damage. Also, the corner test with the original packaging broke at a two inch drop height, indicating that the packaging material on the corners does not protect the product very well. The new packaging design withstood the impact until eight inches, which is a very big difference and could save the company wasted money. The two differences in the design is switching from B-Flute corrugated fiberboard container to C-Flute, and the new one is folded specially to ensure the corners can get maximum protection. The group strongly believes this is a very realistic and easily adaptable idea for the Silver Line window manufacturing plant. The design would be pre-cut and flat, the workers would fold them at the plant, along with applying an adhesive.

The data from all the tests concluded that with the packaging is sufficient when dealing with flat drops, but when it comes to corner drops, there needs to be something done to improve this design. It is costing the company money both by remaking broken window orders for free and losing those unsatisfied customers. And, even with the new design, it does not fully follow the ISTA requirements for a package.
with a weight heavier than twenty pounds. Only adding more cushioning, which most likely would be a “foam” material, such as polyethylene or polystyrene would work to withstand the twenty four inch free fall requirement of the ISTA standards.

During the tours, the group had some suggestions that if possibly implemented by Silver Line, it could help with the safety of workers, and increase the protection for the windows. If a rubber mat was on all the carts transporting the already packaged windows, it could be beneficial in the fact it will be safer for workers moving and handling the packages, and will help lessen the stress placed on the bottom side of the packaged window. Also, if there were friendly reminders, a sign or poster of some sort, to help the workers loading the shipping trucks to keep the heavier pallets towards the bottom and the lighter pallets on top. It could dramatically help the amount of compression and stress these windows feel before arriving to the customer.

Silver Line is an energy star and green company, and they strongly believe in no waste by recycling all excess plastic, cardboard, and vinyl scraps. On the plastic wrapping, there is a sticker that reminds the customer to immediately unwrap the window upon arrival, but there is no reminder to recycle the packaging materials after the window is unwrapped. The group designed a new cover for the installation manual that includes a reminder to please recycle the cardboard corners and plastic film.

CONCLUSION

The new designs that were tested were significantly stronger than Silver Line’s existing package. In terms of the flat drop test, the new design reduced the margin of breakage; more windows survived the ISTA standards and could withstand even higher drop heights. Furthermore, the new designs performed better for the corner drop test. The designs did not meet the ISTA standard of 24 inches; however, there was a 200% increase in performance, as the new design tripled the surviving drop height.

The fact that the new designs did not meet the ISTA standards for the corner drop test reveals that the product itself - in this case the windows - need to be strengthened. Even with a double layered corrugated fiberboard corner and an inch of polyethylene cushioning, the windows did not survive a 24 inch drop; in order for the package to meet this standard, the product’s corner itself must be strengthened. The welding process must be improved; the time that the vinyl comes in contact with the heated metal plates can be increased for a more durable weld.

Ultimately, the single wall corrugated fiberboard is the recommended design because it is the greatest compromise between strength and cost. Although the double wall corrugated fiberboard with the polyethylene cushioning protects the window more than the single wall corrugated fiberboard, the results showed only a 1 or 2 inch difference. However, the single wall corrugated fiberboard is much cheaper and easier to assemble and recycle, making it the optimized choice for future windows.

ACKNOWLEDGMENTS

Our research group would like to thank the Governor’s School of Engineering and Technology for this unique opportunity to experience an important field of engineering. We would also like to thank the people involved in this program that assisted us directly or indirectly with this project specifically Jean Patrick Antoine, Joshua Binder, Adrien Perkins, and Stoyan Lazarov.
Our group also greatly appreciates the support and cooperation of the Silver Line Company in volunteering their time to help this project come to fruition. Special thanks to the people most involved in helping us at the North Brunswick Silver Line factory including Alejandro Nino, Scott Steurer, and Robert Amariti.

We would like to thank Rutgers University for providing the students with a quality learning experience and dedicated professors who took the time to mentor us.

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Lastly, we would like to thank our family for supporting our endeavors at the NJ Governor’s School for Engineering and Technology.

WORKS CITED


### APPENDIX

**Fig. 1 Dimensions and weights of the window samples provided by Silver Line**

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<thead>
<tr>
<th>Dimensions</th>
<th>Small (3)</th>
<th>Medium (1)</th>
<th>Large (2)</th>
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<td><strong>With Packaging</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>L (in)</td>
<td>23 7/8</td>
<td>28</td>
<td>32 3/4</td>
</tr>
<tr>
<td>W (in)</td>
<td>3 3/4</td>
<td>4 1/8</td>
<td>4 1/4</td>
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**Fig. 2 MTS Shock Testing Machine**