Abstract

In this research project, we used the concepts of quality engineering to find the optimal temperature at which to extrude durable, high quality vinyl window frames. Sponsored by Silver Line Windows and Doors, we were able to apply quality principles in an actual setting. In order to find this temperature, we used a variety of tests such as the Drop Dart test, the Heat Resistance Test, the Weight Per Foot Test, and the Shadow System Test, on samples of vinyl frames created at various temperatures. We observed that vinyl frames extruded at 375 degrees Fahrenheit performed the best of all samples on the Drop Dart Test and the Weight Per Foot Test. We therefore recommend that Silver Line Windows create all of their windows at 375 degrees Fahrenheit.

1 Introduction

Quality engineering in any manufacturing facility is crucial to the outcome of the products made by the business. This type of engineering is very important because businesses want to make high quality products in the most cost and energy efficient way possible. For our project, we observed and fixed problems in the vinyl window making process at Silver Line Windows and Doors in order to ensure the quality of Silver Line’s windows, especially when they are exposed to harsh environmental conditions. We also wished to make Silver Line’s window-making process more efficient. Silver Line’s general process for a window is comprised of extrusion, welding, and glass precision. Extrusion is how the vinyl is shaped from a raw material. Welding is how the vinyl is used to create the actual shape of the window. The glass precision is a parallel process with the vinyl that culminates simultaneously to combine the frame and the glass. Extrusion is an important element in the process because it dictates the shape and strength of the vinyl frame. This is an operation in which the powder melts into a liquid, then changes shape and solidifies. This operation makes the parts of the frame before they are welded together. During extrusion, many variables determine the overall quality of the vinyl. These variables include the melting point of the vinyl and also the powder quality. There are strict quality tests to ensure the efficiency and strength of the vinyl from the extrusion process, so as to ensure the window will not fracture or leak once installed[1]. Our project measured the quality of each vinyl sample based on its performance on the quality tests in order to minimize the defects in the extrusion process and maximize the quality of every vinyl window.

2 The Making and Breaking of Window Frames

2.1 Window Making Process

On the macro scale at Silver Line Windows, the process of making a vinyl window begins with the raw material: vinyl in its powder form, being sent to the extruder. In the extruder, the vinyl powder is melted into a liquid form, then it is forced through a specific shape or die to become a molded frame. While most frames are transported to a storage area, a select few of the vinyl frames are sent to the quality test area. If a frame passes the tests, it is sent to the storage
area, but if it fails, the frame as well as other frames created in the same batch are sent to the grinder to convert the frames back to their powder form for reuse. After storage, the vinyl is sent through a machine where holes are punched into the vinyl to serve as a draining system. Next, the vinyl is welded together in a process known as fusion welding so that the vinyl forms a window frame. Afterwards, all excess materials are cleaned off of the frame, preparing it for the next step. In the glazing process, the frame is coated with a liquid which makes the frame water-proof. Simultaneously, the glass goes through its own process. The glass is purchased and then templated. The glass is then cut accordingly and cleaned. Spacers are added between two pieces of glass to act as insulators. Next, a gas is injected into the glass to increase the energy efficiency of the window. Finally, the window is sealed. Once both of these processes are complete, the vinyl and glass meet up and are married together (see Figure 1) [1]. The process that we specifically looked at in this window process was extrusion.

2.2 The Extrusion Process

The extrusion process consists of nine steps. First, the vinyl powder (consisting of TiO2, lubricants, PVC, impact modifiers, and stabilizers) is poured into a hopper, a container which dispenses the vinyl to the rest of the system. Second, the vinyl powder falls into a barrel containing two screws rotating at a high velocity. These screws heat the vinyl powder, ensuring that it melts into a molten form, and increasing the output of the heat chamber. While the screws liquify the powder, excess gases are removed from the barrel to guarantee a homogenous mixture. Next, the liquid is forced through a die, which forms the vinyl into its final shape. Then, the vinyl is cooled and solidified by a series of calibration tables that use water to regulate the vinyl's temperature. Finally, the vinyl is pulled out of the extruder, cut at a specific length, and is then either sent to a storage area or tested (see Figure 2)[7]. This process is relevant to our project because the vinyl samples used in the quality tests are produced at this part of the window making process.

![Figure 1: The window making process.](image)
2.3 Problems with the Extrusion Process

There are a couple of problems with the extrusion process. If the vinyl powder abrades the screws or other parts of the extrusion chamber, the resulting vinyl piece may have an unpleasant-looking gray tint, a trait known as pinking. Pinking is easily remedied by changing the temperature of the heating chambers or by replacing the old extrusion chamber screws with new ones [3]. Also, vinyl expands when exposed to hot temperatures and condenses when exposed to cold temperatures. According to the East Row Historic District, vinyl expands seven times as much as glass at equal, high temperatures. In addition, the long-term durability of vinyl has yet to be tested, since vinyl windows have only been widely installed since the 1980s [2]. Unfortunately, samples of these windows have begun to show symptoms of aging, especially yellowing when exposed to sunlight. To hide this problem, some window companies give a blue tint to their vinyl frames. However, makers of higher-quality windows simply use a higher-quality vinyl powder, making the vinyl frames more resistant to aging as well as being a pure white color [6].

2.4 Melting Temperature

The most important factor to control in the extrusion process is the melting temperature of the vinyl. Most companies extrude vinyl at 360 degrees, so we decided to collect samples at temperatures above and below this value [1]. In order to obtain samples extruded at different temperatures, we adjusted the temperature of the heat chamber on the extruder’s control panel and measured the actual temperature of the extruded vinyl using a laser-based digital thermometer. It was difficult to obtain samples at the same temperature intervals due to the many heating sections in the heat chamber, so we extruded vinyl frames at 350, 360, 365, 375, and 390 degrees Fahrenheit. If the melting temperature is too high or the length of time that the vinyl is in the drill chamber is too long, the individual chemicals in the vinyl compound could start to degrade. On the other hand, if the melting temperature is too low, the resulting vinyl frame could suffer from poor physical properties such as a dull surface, a poor fusion of its chemical compounds, and reduced weatherability. To prevent such problems, there are a variety of quality tests which are performed by window industries, such as Silver Line Windows, and approved by the AAMA (American Architectural Manufacturers Association), a third party that oversees the quality of Silver Line’s Products. The AAMA checks the tests twice a year to affirm the testing machines are valid [1].

3 Determining the Optimal Temperature of the Vinyl

We used an extrusion process line to find the optimal temperature to extrude vinyl. For five hours we took the powder vinyl and put it through the extruder at different temperatures to create various vinyl samples. Then, we took the samples through a series of AAMA-approved tests which demonstrated to us the best temperature at which to extrude vinyl. The AAMA-approved tests in order of importance are the
Drop Dart test, Heat Resistance test, the Weight Per Foot test, and the Romidot Shadow test[4].

3.1 Drop Dart Test

The most important test that performed was the Drop Dart Test. In this test, we measured the impact resistance of the vinyl frame by raising a metal impactor to marked heights and allowing it to fall on the vinyl frame. We repeated this process until the frame was pierced. We then recorded if the vinyl’s piercing was ductile or brittle. A ductile piercing in a frame would only cause the frame to tear. On the other hand, a brittle frame, which could be shattered, would be unfavorable to a customer because it would be less durable than a frame which could only have a ductile piercing. The results were given in inch-pound per thousandths of an inch of thickness, if necessary (see Figure 3)[p. 4-1 and 4-2][3].

Figure 3: A diagram of the Drop Dart device.

3.2 Heat Resistance Test

In the Heat Resistance Test, we tested the vinyl frames at extreme temperatures. We placed the vinyl in an oven at 300 degrees Fahrenheit for a half hour to simulate the intensity of the sun on the vinyl for 10 years. We then visually checked the vinyl for any warping or brittleness that would indicate any stress related changes by studying the change in color, the new formation of the vinyl, and by comparing the new formation to a sample of vinyl that was not put in the oven[1].

3.3 The Weight Per Foot Test

In order to perform this test, we obtained samples of vinyl frames, cut them into one-foot lengths, and placed them individually on a scale. We then recorded the weight of the frame and compared this weight with the frame’s target weight on Silverline’s database[1] (See Figure 4).

3.4 The Romidot Shadow Test

We used the Shadow System test to measure the adherence of the vinyl samples to the design of the frame created by the engineers. In this test, we placed a cross section of the profile into a scanner where a picture was taken, and an outline of the picture was shown on a computer screen. The outline was matched up with the engineers original diagram. The computer showed the engineers’ diagram in red, places that were out of tolerance in the vinyl profile in yellow, and places that were in tolerance in green[1].

4 Results

4.1 Results of the Drop Dart Test

The results show that the 375 degree sample took the most impact energy, the physical force applied to the sample. All of the samples passed the test as their impact energies were all well above the 1.2 inch-pound per mill impact energy minimum set by the AAMA. The test revealed a trend: as the samples were made at higher temperatures, the strength of the vinyl’s frame raised accordingly until it reached the 390 degree sample. Instead of being the best sample, at this temperature, this sample turned brittle and glasslike, passing the test with a lower impact energy than all other samples (see Figure 4).

Figure 4. Drop Dart Test Data
4.2 Results of the Heat Resistance Test

Every test passed in the heat resistance test.

4.3 Results of the Weight Per Foot Test

The results of the Weight Per Foot Test show that all samples were lighter than the target weight, which was 0.864 pounds. For example, the sample extruded at 350 degrees weighed eleven percent less than the target weight, meaning that the sample failed the test. Likewise, the 360 and 365 degree samples also failed. However, the 375 and 390 degree samples were within ten percent of their target weight, so they passed the test. Since the 375 degree sample had the least deviation from the target weight, the Weight Per Foot Test suggests that this temperature is the best temperature at which to extrude vinyl [1](see Figure 5).

![Figure 5. Weight Per Foot Test Data](image)

4.4 Results of the Romidot Shadow Test

All sample tests failed the Romidot Shadow Test. Figure 6. Romidot Shadow Test Data

![Figure 6. Romidot Shadow Test Data](image)

5 Discussion and Recommendations

By varying sample temperatures, we were able to obtain an optimal temperature of 375 degrees Fahrenheit, which gave the best performance through our most important tests. The most important of the testing procedures was the Drop Dart test, since the data gathered from this test allowed us to determine the resistance of the frame to sudden impacts, an important feature of any window frame. Next in importance was the Heat Resistance test because we observed how the frame acted under intense sun conditions: how much the frame warped and if the frame became brittle. The next important test was the Weight Per Foot Test because we found the optimal amount of torque needed for the screws in the extrusion machines to melt the powder efficiently and not the durability of the frame. Finally, the test of least importance was the Shadow System test, since this test was only used to observe a frame’s cross section’s resemblance to the engineers’ original plans.

The Drop Dart test at sample temperature 390 degrees informed us of the potential problems of having the extrusion temperature too high. The sample at degrees showed a brittle failure, meaning that a higher extrusion temperature did not necessarily produce a better frame. This was a highly important test because we needed to know how durable the window frame was to sudden impacts, an essential safety feature of any window.

The Heat Resistance Test was second in importance because it was important to know how the vinyl would react to the sun over time when the vinyl was installed in a household.

Third in importance was the Weight Per Foot Test, which was used to determine whether a frame was too light or too heavy. This test was important to perform because Silverline must comply with certain standards which state that for a frame to be in tolerance, the frame must not weigh ten percent less than a certain target weight, nor must it weigh ten percent more than this target weight. A frame that is lighter than the target weight means that this frame is more prone to break or deform when installed in a customer’s home. However, a frame that is too heavy means that too much material has been used in this frame, wasting this material.

The Romidot Shadow test was last in importance, but was also very crucial because the vinyl pieces needed to be close to the perfect shape to make a durable frame. All samples failed the Romidot Shadow Test because the inside of each sample was
always out of tolerance. However, Steve Drexler informed us that this was not important, since the more-important outsides of the samples were always in tolerance[1].

Based on the data we collected, we recommend that the temperature should be 375 degrees because of its overwhelming performance on the most critical tests. It is the best temperature because if the temperature is higher than 375 degrees, the vinyl begins to degrade. If the temperature is lower than degrees the vinyl shows poor physical properties such as a dull extrusion surface, a poor fusion of the chemicals, and reduced weatherability [p. 2-8][3]. In order for Silver Line to adjust its extruders to this temperature, we recommend that the extruder operators use the extruder control panel to change all die and heat chamber temperatures to 375 degrees and to then check the temperature of the extruded frames using a laser-based digital thermometer.

6 Conclusion

The process of extrusion is one that requires precision and a product of the highest quality. We therefore performed the Drop Dart, Heat Resistance, Weight Per Foot, and Romidot Shadow Tests in order to ensure the quality of Silver Line’s windows when exposed to harsh environmental conditions as well as the efficiency of the extrusion process. After reaching our results, we know that both the right materials and the proper extruding temperature are needed in order to create a high-quality frame. Performance of the frames during testing helped us to separate the high-quality frames from the low-quality frames and produced insight on what extruding temperature was most desirable. To continue testing the quality of the extrusion process, we would test the quality of the vinyl powder by varying the pellet sizes. Next, we would adjust the angle and size of the extrusion chamber screws to gain perspective of the screws importance during extrusion. Finally, we would test cooling times of the vinyl in order to find the most desirable cooling time.

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References