Efficiency of 8500 Silver Line Windows Process

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Abstract

As the quality engineering team, our project looked into the Silver Line Window Manufacturing Company's processes and ways to make it more efficient. We looked into the fusion welding process, specifically the 8500 line, a procedure to combine the sashes and the frames for double-hung windows. Due to its measured inconsistencies and weaker weld output than the other lines in the factory, we investigated possible problems in the line and presented feasible solutions to these problems. To start, we conducted experiments including time trials, heat measurements, and break tests for different size pieces of vinyl in order to see where the variations in strength surfaced most frequently. By analyzing our data, we were able to come to the conclusion that pieces cut over the target length were the reason that the process was inconsistent. In addition, there was a deficiency of statistical data available and a lack of inspection points along the line. Our solution was to make the target length of the pieces slightly shorter to provide sturdier welds and increase checkpoints to eliminate the weaker outliers.

1 Introduction

In the window making process, vinyl is extruded, cut, and welded together. Then a precut piece of glass is inserted into the frame. While all processes inevitably produce waste and contain several variables, we observed that this particular process of welding vinyl pieces is not being monitored enough and is causing a crucial part of the window to be produced with insufficient quality. The variability of the window length coupled with an insufficient inspection process causes unidentified weak welds to end up in finalized windows. To make sure that the length was the deciding factor in weld strength, we conducted various tests to eliminate the temperature of the plates, the heating rate of the machine, and the time the piece is in the machine as variables in the process.

Silver Line Windows adheres to mandated tolerances in which their pieces must fall within $^{1}/_{16}$" of their target length. We discovered several issues with this tolerance. First, the pieces that fall on these limits of $^{1}/_{16}$" over the target produce welds that were tested to be weaker than those of vinyl pieces of the right size. When a piece's length falls over the 1/16" tolerance level and is put into the machine, a cold weld is produced. A cold weld happens when the excess vinyl is melted during the heating process, and then does not align correctly with the other piece. In addition to misalignment, the melted vinyl is pushed out of the way forcing two cold pieces of vinyl together, thus resulting in a very weak weld.

While it is clear that these pieces on the upper limits are not nearly as structurally sound, it is not as easy to notice these weak welds after fusion. Due to the fact that these pieces of vinyl still fuse together, a worker cannot detect a deficiency in strength as long as the two pieces are bonded. It is this fact, along with a lack of checkpoints that allows many weak frames to turn into a customer's window.

The standard break test is a test that places one end of the vinyl corner into a clamp and attaches the other end of the vinyl to a spring scale. A worker pulls on the spring scale until the vinyl breaks and then records the measurement of the force that was required to break the weld. Although it is one of the crucial checkpoints in the process because it measures the strength of the weld, it is only performed whenever deemed necessary. On average, it is done no more than once a week. The other checkpoint is in the cutting section. Only one piece of vinyl per batch, which depending on the order size can range from around twenty to one-hundred windows, is measured to make sure it falls within the mandated tolerance of 1/16". This means that there is a high possibility that many of the pieces in a batch fall outside of the tolerance level without ever being noticed.

The main problem in going about our research was that we encountered a lack of statistics documenting existing problems with the process and common reoccurring defects. We ran into the dilemma of having to come up with new tests, get new data, work around missing statistics, and try to track vinyl pieces through the process. It is not a problem that we had to conduct these tests for our data since we had ample time, but it may be a problem for Silver Line in the future if they do not have any records documenting its process's faults. Since each window has four pieces that all contain the same sticker, each piece of that window is virtually seen as the same piece. There is no way other than looking closely at each individual piece of the frame to determine which piece will be the top, bottom, left, or right side of the frame. This inability to follow certain pieces made it hard to keep track of which pieces were over or under the target length. It also provided no way to keep track of defective pieces.

Since many of the defective frames that are produced in the process pass through unnoticed, we had to take a different approach than just observing the final product. We tracked individual pieces and looked the process as a whole instead of analyzing past records to find a problem.

2 Background

As seen in Figure 1.1 in the appendix, Silver Line's window making process consists of five main steps: extruding the vinyl, cutting the glass, welding the window frame, assembling the window, and shipping the window to the customer.

The vinyl used to make the window frames and sashes starts from a powdery resin compound. This compound is either purchased from a manufacturer or obtained in recycled form from excess vinyl. The resin compound is then pressurized into a solid form and then pushed through the die, to give it its shape, thus creating the final vinyl product.

The glass process and the welding process occur simultaneously. The glass process begins with the glass being cut into the correct size and then cleaned. Meanwhile, the grids that hold the glass in place are inserted into the window and are then cleaned. After the glass and grid are stacked, a second piece of glass is laid on top and a spacer is inserted between the glass pieces to keep them separated with space for insulation between them.

While the glass process is occurring, the welding process is also under way at another station. A worker places vinyl pieces into the welding machine. A plate then enters between the vinyl pieces, heats up to approximately 475°F, and melts the edge of the two vinyl pieces. The plate, covered in a layer of Teflon-like material, then retracts and the vinyl pieces are forced together for about thirty seconds. Even though the retracted plate does cool down in the air, we measured that the difference in the time it took to increase from the cooled temperature of around 330-360 degrees back to the heating temperature of 475 degrees was insignificant. The machine then releases the newly formed frame from the corner clamps, and the window is nearly complete.

The glass process and the welding process then converge. The glass is placed into the frame and then insulated. Also, inert gases, such as argon and helium, are injected into the window to prevent condensation from forming inside the window. The window is then shipped off to the customer.

3 Experimental Design

In order to realize that the welding and cutting process had inaccuracies, we conducted multiple tests that ranged from time trials of the welding machine, heat measurements during the fusion process, and breaking strength tests of different lengths of vinyl.

While at Silver Line, we made 15 vinyl frames from beginning to end. Since 15 frames would give us 60 testable welds, this would provide enough data to reach conclusive results. In an effort to see if the length of the vinyl pieces affected the strength of the weld, we produced frames constructed from vinyl pieces whose lengths were at both ends of Silver Line's tolerance level as well as right on target with the tolerance level. Five vinyl frames were made at 1/16" under the target level, five were made at the target level, and five were made at 1/16" over the target level. For example, the target size that we looked at was 30 and 3/4" in height and 20 and 1/2" in width. This would make the window at the lower tolerance 30 and 11/16" by 20 and 7/16", and the window at the higher tolerance would be 30 and 13/16" by 20 and 9/16".

Although Silver Line provided us with the measurements of the vinyl pieces, we still measured the pieces to insure Silver Line's measurements were accurate. Even though many of the pieces were less than 1/32" off the target, they still fell well within the tolerance range, allowing us to effectively use the frames, knowing they were still less than and greater than the desired length.

While the machine was welding the window together, infrared guns were used to measure the temperature of the plates that heated the vinyl. The purpose of this test was to evaluate if the machine cooled down after consecutive uses or took too long to heat back up to the machine's prime temperature after cooling between uses. Two infrared guns were pointed at the same spot to create an average temperature. With this tolerance, we could determine the consistency of the temperature of the welding plates to see whether or not that would be a variable in the weld strength. After the frame was finished welding together, the weld of the frame was then smoothed down by a worker, and the process was repeated again.

During the heat measurements, we also conducted time trials. Again, the purpose was to see whether or not time was a variable in the strength of the welds. We observed whether the heating and fusion phase remained constant during the process and recorded the total time that the machine took to produce a frame. This information allowed us to determine whether inconsistencies in the machine could contribute to a variation in the temperature at which the vinyl was heated, and the amount of time spent heating and welding the vinyl.

After each of the 15 frames was welded together, we labeled each corner of the frame either top-left, top-right, bottom-left, or bottom-right depending upon the location. These labels proved useful later when we conducted break tests to determine the strength of the vinyl.

Break tests were performed on each corner of each frame to find the amount of force needed to break the weld. Once the corner was broken, we recorded the results so that we could later make the correlation between the length of the vinyl piece and the strength of the weld.

One thing that we noticed while at Silver Line in observing the process was the expertise of the workers. Any question that we had about the process was easily answered by the men and women on the line. While all of the employees were able to give us the correct technical answers, the workers on the line knew the machines down to their specific behavior. This greatly helped when it came to understanding the process and creating efficient tests to conduct.

4 Results

After conducting these time, heat, length, and strength tests, we were able to come to concise results that dealt with what factors affected the weld strength. Our data led us to determine that the length of the vinyl and the inaccuracy in cutting the vinyl pieces are the contributing factors to a weak weld, while time and heat are constants in the process. In addition to this, we were able to notice the knowledge of the workers in their respective aspects of the process. This knowledge translated into concrete ways that the employees' observations and ideas could turn into feasible solutions and improvements for the entire window-making process.

While the frames were being welded, we conducted both time trials and heat measurements. As can be seen from our time and heat measurements in Figure 1.2, the time of heating and the time of fusion both remained constant, eliminating this as a variable that could contribute to varied weld strength. The time of heating remained at a constant 25.6 seconds, and the time of fusion remained at 29.7 seconds.

Figure 1.2

Heating and Time Test			
Number	Heat (°F)	Time of Heating (sec)	Time of Fusion (sec)
1	472	25.6	29.7
2	487	25.6	29.7
3	484	25.6	29.7
4	481	25.6	29.7
5	468	25.6	29.7
6	483	25.6	29.7
7	478	25.6	29.7
8	482	25.6	29.7
9	482	25.6	29.7
10	482	25.6	29.7
11	459	25.6	29.7
12	462	25.6	29.7
13	463	25.6	29.7
14	466	25.6	29.7
Average	474.93	25.6	29.7

This chart shows the heat of the plate during welding, the time of heating and fusion during the welding, and how all of them remain consistent after consecutive tests.

Considering the rate that the heating plates increase temperature from around 300-350 degrees when they cool to the heating temperature of approximately 480 degrees, we could conclude that consecutive welds and the plates cooling in the air was not significant in weld strength. We then concentrated on the heat of the plates during the weld. These temperatures remained remarkably consistent, only ranging from 459-487 degrees. This range also took into account multiple frames being welded at the same time. With the time, the quick heating rate, and the plate temperature remaining consistent, these factors proved to be insignificant with regards to the final weld strength.

Due to the accuracy and stability of the angle cutting machine, the only variable left to test was the length of the pieces. After measuring the length and calculating the average, we realized that although pieces are commonly cut around 1/32" off of the target range, the standard deviation in the process is so minimal that this variation is not problematic. This deviation and range can be seen in Figure 1.3 in the appendix. It is also insignificant considering the mandated tolerance in the industry for a piece's length is 1/16".

Since the majority of pieces fell well within this range and the deviation was so small, we were able to reject the idea that Silver Line's tolerance would have to change, as well as reject the idea that the cutting machines were excessively inconsistent.

The most surprising results came during the break strength test. As shown in Figure 1.4, we found that frames made from pieces of vinyl under the target length were consistently stronger in all four corners, and reported equal defective welds as the target length frames. Although the standard deviation in the weld strength was less for the target length frames, the average break strength was greater for the frames of shorter vinyl. In all cases, the top right and top left corners were significantly stronger than the bottom corners due to the fact that there was severely less surface area connecting the bottom welds than the top welds.

While the shorter pieces came back with higher weld strengths, the opposite was found for pieces of greater length. The pieces of greater length had the highest standard deviation, ranging up to a variation of eleven pounds of force off the mean, the widest control limits, which indicate the extent to which the data will still represent an efficient process, and the smallest weld strength.

What this data told us was that just like in the case of a cold weld for long pieces, there was still excess vinyl that had to be melted for target length pieces, thus preventing it from welding immediately. For this reason, the shorter vinyl pieces proved to be optimal since there was no excess vinyl to be melted, allowing it to begin bonding right away.

Figure 1.4 – Weld Strength

Frame Number	Top-Left	Top-Right	Bottom-Left	Bottom Right
1.1	44.5	34.5	17.5	14
1.2	31	38	13	15
1.3	27	28.5	13	16.5
1.4	44.5	32.5	16	
1.5	33	37	13	12
Line 1 Average	36	34.1	14.5	14.4
Standard Deviation	8.05	3.80	2.12	1.89
Upper Limit	46.0	38.82	17.13	17.38
Lower Limit	26.0	29.38	11.87	11.37

Figure 1.4 – Weld Strength (continued)

Frame Number	Top-Left	Top-Right	Bottom-Left	Bottom Right
2.1	40	39	17	13
2.2	48.5	31.5	18.5	20
2.3	32.5	38.5	15	21.5
2.4	28	28	19	17
2.5		41.5	17.5	31.5
Line 2 Average	37.25	34.22	16.8	17.18
Standard Deviation	8.99	5.69	1.56	6.90
Upper Limit	51.55	41.28	18.73	25.75
Lower Limit	22.95	27.16	14.87	8.60
3.1	35	33	9.5	13
3.2	15	31	15.5	13
3.3	39.5	32		26
3.4	45	37	10.5	22.5
3.5	31.5	38	17.5	15
Line 3 Average	33.2	34.2	13.25	17.9
Standard Deviation	11.36	3.11	3.86	5.98
Upper Limit	47.30	38.07	19.39	25.33
Lower Limit	19.10	30.33	7.11	10.47

Mistrial
Bad Weld

This chart shows that while the target length (line 1) has the least standard deviation, the shorter frames (line 2) produced the strongest welds, and the longer welds (line 3) produced the weakest welds.

5 Conclusion

From the data collected in our experiments, we came to conclusions about the source of the problem and thought of feasible solutions to improve Silver Line's window-making process. We presented both physical, tangible solutions as well as new systems that will improve the efficiency of the process.

In addition to tweaking the cutting process, our approach involves implementing more inspection stations, giving workers check sheets to keep valuable statistics, and applying an employee feedback system to utilize first-hand knowledge. While it is not the most direct route to immediate results, it is the most plausible way to increase future production on the welding/fusion line, the 8500 line, while saving money, increasing the workers' contribution, and improving the product.

In combining the results of the strength test and length test, we came to the conclusion that cutting the vinyl pieces consistently was not a problem, and that pieces slightly shorter than the target provided the strongest welds. Our suggestion to Silver Line is to cut all vinyl pieces 1/32" shorter than the assigned size. With this change in place, the size of the vinyl pieces will shift slightly downward to the size that creates stronger welds, and will shift away from being too long, where it is seen that the weld becomes significantly weaker. Instead of the system now where the vinyl piece varies from 1/16" over the target and 1/16" under the target, it would vary from 3/32" under the original target to 1/32" over the original target. This would mean that they could keep their mandated tolerance in use, but shift the whole length of the vinyl pieces to the observed stronger length, rather than risk long pieces that result in weak welds. By cutting these pieces 1/32" shorter, it would eventually save Silver Line Windows money as well.

We calculated that it is cheaper for them to re-extrude their excess vinyl rather than buying the raw materials. Although it is such a minute quality to cut off of the end of the vinyl, it would make a significant difference considering Silver Line as a company makes from five to six million windows a year.

We came across many obstacles in retrieving the necessary data. Data such as the number of defects that occur on the line, the major types of defects, and the results of their inspections would be beneficial to any quality attempt and especially to the company implementing them. This realization led us to think of ways to record data on the line and store it to simplify efficiency efforts in the future. The way that we propose to do this is to equip every machine operator with a check sheet like the one in Figure 1.5 (in the appendix), that highlights the defects that could go wrong during their specific process. If an inspection were to go wrong or a noticeable defect were to occur, the worker on the line would make a note or a simple mark on the check sheet indicating a defect, and at the end of the day these sheets would be stored. The data could be compiled to get an overall idea of the number, type, and frequency of the defects, and then stored for later usage. In that case, if a quality engineer were to come in the future, they would have easily accessible records of what the key problems on the line are. While this would not replace their task, it would help give them certain sections of the process that they know to pay particular attention to.

Our last suggestion had to do with increasing communication between the employees and the managers. This idea was adopted from the Kaizen philosophy, which incorporated the employee's ideas and suggestions into the business process. Since the employees work in the factory every day at the same machine, it is clear that they have an exceptional understanding of the ways the machines behave. The idea of adopting Kaizen is a way to utilize this knowledge that the workers gain everyday and convert it into realistic solutions to improve the problems that they see most. Not only will this strategy provide some kind of incentive for the workers, but it will boost morale as well, possibly increasing production. The other possible result is to save money by finding cheap and easy solutions to problems that would not be discovered without the employee input.

By implementing the above recommendations, Silver Line will not only make the welds of their windows stronger, but will also set them up for better success in the future.

6 Acknowledgements

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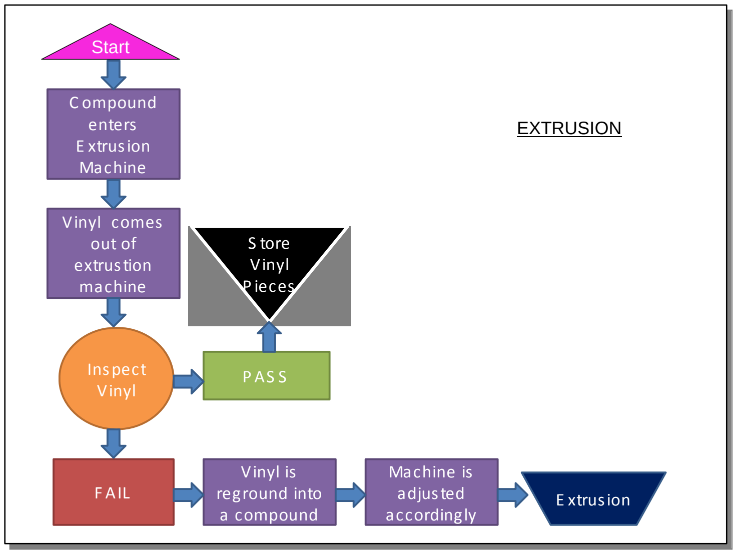
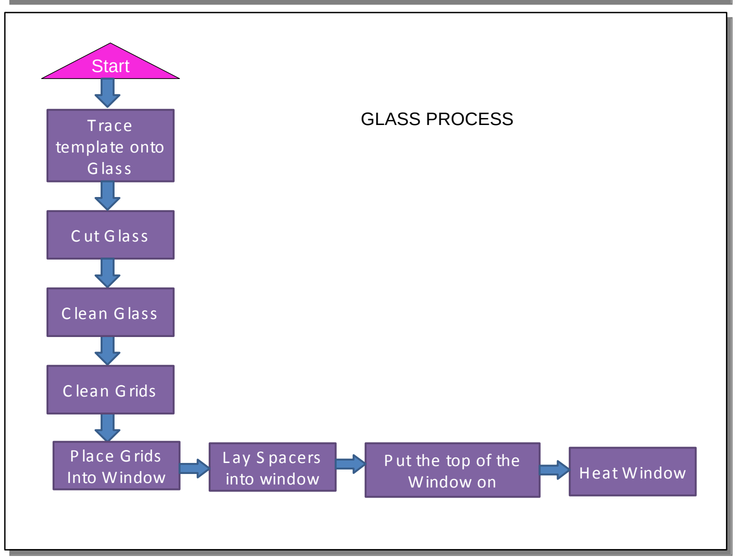
Appendix

Figure 1.1
Flow Chart





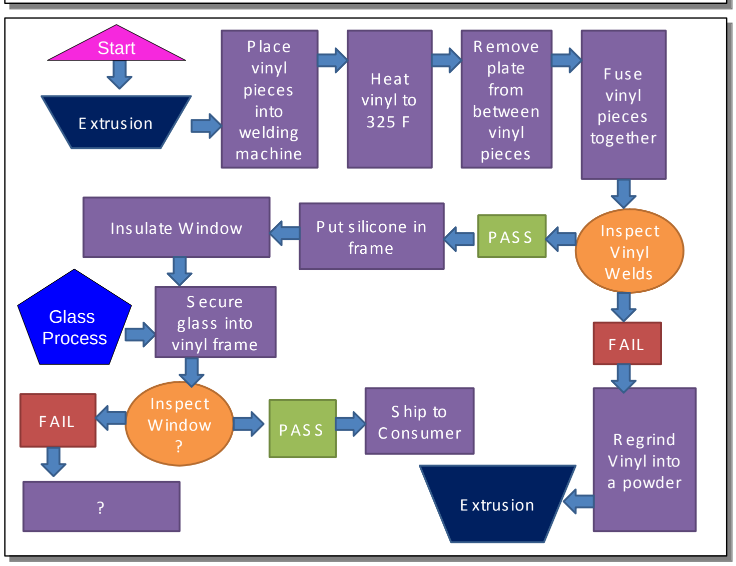


Figure 1.3
Length

Measured	1.1	1.2	1.3	1.4	1.5	Average	Stdev	Target
Left	30 3/4	30 3/4	30 11/16	30 3/4	30 3/4	30 3/4	0	30 3/4
Right	30 13/16	30 3/4	30 3/4	30 3/4	30 3/4	30 3/4	0	30 3/4
Top	20 5/16	20 1/4	20 1/4	20 5/16	20 5/16	20 2/7	0	20 1/4
Bottom	20 1/2	20 1/2	20 17/32	20 17/32	20 17/32	20 3/8	0	20 1/2
Measured	2.1	2.2	2.3	2.4	2.5	Average	stdev	Target
Left	30 11/16	30 11/16	30 11/16	30 11/16	30 11/16	30 2/3	0	30 11/16
Right	30 11/16	30 3/4	30 11/16	30 11/16	30 11/16	30 2/3	0	30 11/16
Top	20 1/8	20 3/8	20 1/8	20 3.5/16	20 3/8	20 1/5	1/7	20 3/16
Bottom	20 7/16	20 7/16	20 13/32	20 7/16	20 7/16	20 1/2	0	20 7/16
Measured	3.1	3.2	3.3	3.4	3.5	Average	stdev	Target
Left	31 11/16	31 3/4	31 11/16	31 11/16	31 11/16	31 2/3	0	31 11/16
Right	31 11/16	31 11/16	31 11/16	31 11/16	31 11/16	31 2/3	0	31 11/16
Top	20 5/16	20 5/16	20 11/32	20 11/32	20 3/8	20 1/3	0	20 5/16
Bottom	20 9/16	20 9/16	20 17/32	20 17/32	20 1/2	20 1/2	0	20 9/16

Although several pieces are cut around 1/16” off the target length, the standard deviation is in almost all cases 0, meaning pieces will usually be very close to the target.

Figure1.5
This is a sample check sheet that a worker can use to track defects throughout the day.

	Defect	Frequency (min)						Number of Defects
		0-5	5-10	10-15	15-20	20-25	25-30	
Cutting process	Wrong Angle							
	Too Short							
	Too Long							
Welding Process	Not Enough Heat							
	Wore Down Paper							
	Paper stuck to Vinyl							
	Breaks along Weld							
	Wrong Piece put in							
	outside Contaminate							
	Too Much Humidity							
	Wrong Angle							
	Too Short							
	Too Long							
Extrusion Process	Weak Vinyl							
	Wrong Dimensions							
	Total							