The Fletcher-Terry Company, LLC

The Principles of Glass Cutting

A comprehensive technical guide to successful glass scoring and cutting techniques.

Introduction

As a process line engineer, you know that keeping your glass production line up and running efficiently and producing the highest level yields is a daily challenge.

Fletcher-Terry's The Principles of Glass Cutting technical document is aimed at examining, evaluating and providing effective methods for maintaining one of the key process elements for quality glass cutting. It examines all the critical components of glass cutting - wheels, axles, pillar post and inserts. It also presents the variables that affect the final results, such as:

- Cutting Force
- Cutting Wheel Diameter
- Cutting Wheel Angle
- Cutting Speed
- Cutting Fluids and others

A cutting application guide is provided and concludes with a number of cause and effect scenarios of recording operating parameters.

About Fletcher

Since 1868, Fletcher-Terry has revolutionized advanced cutting solutions for numerous global industries. Fletcher's innovations has rewarded the company with over 90 patents including the "original" glass cutting wheel, the first vertical glass cutting machine and the "wide-track" all carbide cutting wheel. Today, with a distribution network to 60 countries worldwide, we are proud to serve the glass production and fabrication industries, sign & graphic, picture framing and retail hardware, while continuing to provide advanced cutting methods and outstanding global customer service support.

Staying one step ahead of your material cutting, scoring and trimming needs has made us a global leader in the industries we serve.

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Is there room for improvement?

How is your glass cutting process affecting the overall quality of your product and your true cost to manufacture it?

Most people find it advantageous to increase quality and lower manufacturing costs. Do you? If so, please read on and determine if your glass cutting process can improve, most times without additional cost to you.

Many shared concerns associated with poor glass cutting practices are as follows:

- Edge failure once the glass is installed in its final application
- Breakage in the quenching process, when tempering glass
- Surface scratches
- Seaming belts and grinding wheels wear more quickly
- Inferior edge quality
- Decreased edge strength
- Increased rework

The above-mentioned concerns ultimately lead to the following:

Higher manufacturing costs

Lower product quality

Decreased yields

Increase in machinery downtime

So, how do you evaluate your glass cutting process and determine where opportunities for improvement exist? Let's start with the existing components used in the cutting head such as the pillar post, wheel holding insert (if applicable) and the axle.

First, it's important to insure that the inside diameter where the pillar post is inserted isn't worn or damaged thus allowing side-to-side movement of the pillar post. If side-to-side movement exists, it will affect the angle at which the cutting wheel is introduced to the top surface of the glass. If the pillar post is inserted into a radial bearing, it's important to insure that the bearing rotates freely so that the cutting wheel will be aligned properly. If it isn't aligned, it will scrape across the glass rather than roll across the glass and the result will be poor score quality, poor fissure quality, poor break out and poor edge quality *(see Figure 1)*.

If the pillar post accepts the cutting wheel directly into a slot, it's critical that the width of the slot does not allow for excessive side-to-side movement, even when new. As the pillar post ages, it's critical that each time the cutting wheel is changed, one evaluates it to insure that the cutting wheel rotates freely but doesn't have excessive side-to-side movement *(see Figure 2)*.

If the wheel moves side-to-side, it will affect the angle at which the cutting wheel is introduced to the top surface of the glass, especially when cutting shapes. With the wheel tilted, one side of the wheel angle will act as though it is sharper than the intended angle, causing subsurface fractures and glass flaking on that side *(see figure 3)*.

This condition will negatively impact fissure quality, break-out, edge quality and the strength of the glass edge. In addition, the overall life and performance of the cutting wheel will not be maximized.

If a quick change insert is used to hold the cutting wheel, and this assembly is then inserted into a pillar post, it's critical that the inside diameter of the pillar post that accepts the assembly doesn't allow it to move side-to-side. The wheel slot in the insert must also be evaluated each time the cutting wheel is changed to insure that the wheel rotates freely but doesn't have excessive side to-side movement *(see Figure 4)*

As in the situation mentioned above, this side-to-side movement affects the angle at which the cutting wheel is introduced to the top surface of the glass. When an axle is worn, one can expect different results under different circumstances *(see Figure 5)*.

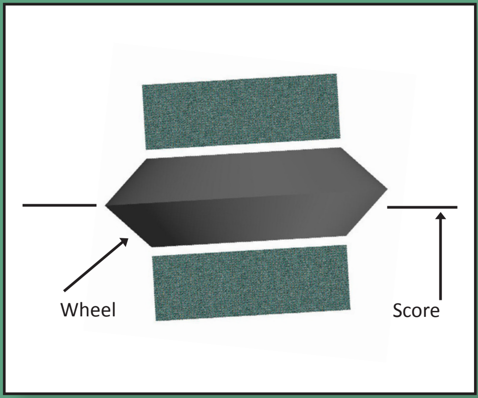

Figure 1

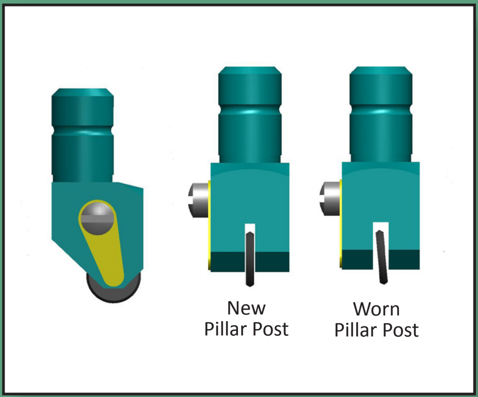

Figure 2

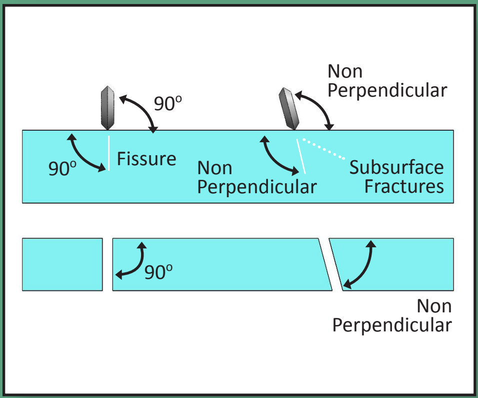

Figure 3

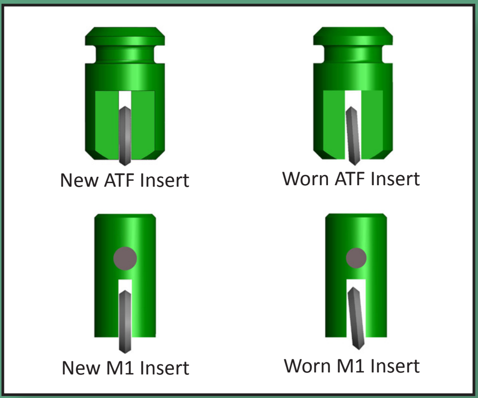

Figure 4

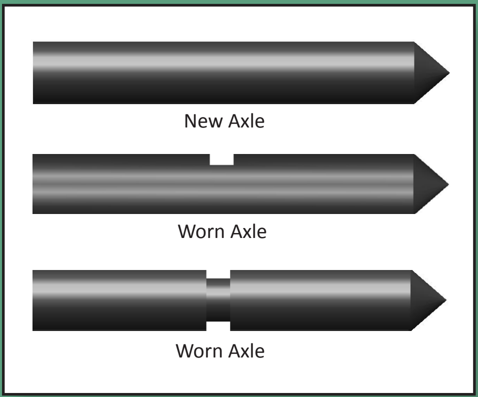

Figure 5

If the wheel slot in the pillar post or quick change insert isn't worn, and the axle is, the cutting wheel will not rotate as freely as possible. This condition may cause an interrupted score line (skipping) which can cause break-out and edge quality issues. If both the axle and wheel slot are worn, one can expect glass particles on the score line with break-out and edge quality issues.

There is no rule stating that these components need to be changed after a certain number of hours of operation or after a certain number of linear feet of glass are cut. An accepted industry practice is to review each of these components every time a cutting wheel is changed and if the wheel has too much side-to-side movement or if the axle is too worn, it must be replaced. One of the most common mistakes is not changing the cutting wheel frequently enough. As a cutting wheel is used, the very tip of the wheel starts to wear and the profile changes. At some point, the break-out of the glass will become more difficult and rather than increasing cutting force, one should change the cutting wheel. This should be done because as the tip wears and cutting force is added, the quality of the fissure is slowly deteriorating. This condition will negatively affect the quality of the score-line, ease of break-out, edge quality, as well as the quality of the finished product. By the time you've determined that one of these components is causing poor quality, you're likely to have added considerable value to the glass by means of cutting, grinding, seaming, washing, coating or assembling the glass into a finished component. The fact remains that the cost of replacing these components is little when compared to the cost associated with the scrap glass that has been created or the negative impact on your company should defective products reach your customer.

The desired results of our glass cutting process.

Now that we're sure our pillar post, quick change insert and axle aren't worn, let's understand the criteria that we want our glass cutting process to include:

- **A score-line on the top surface of the glass that's free of glass particles.**

When evaluating the score quality, it's important to wipe the cutting fluid from the glass so that the true quality of the score line can be seen. The ideal score line is very light and is free of glass particles *(see Figures 6a & 6b)*.

If the score-line is too heavy, one can see the subsurface fractures just below the surface with a 10x magnifying lens *(see Figures 7a & b)*.

The two primary contributing factors of glass particles are excessive cutting force and the cutting wheel angle being too sharp for the application. A piece of glass that has subsurface fractures has very poor edge strength and will cause considerable problems, especially in a tempering process, unless they're removed by grinding or seaming. One can remove these subsurface fractures with grinding or seaming, however, if an excessive amount of glass must be removed, additional subsurface fracturing can be created. In addition, the glass particles can cause scratching on the top surface of the glass, especially on coated glass.

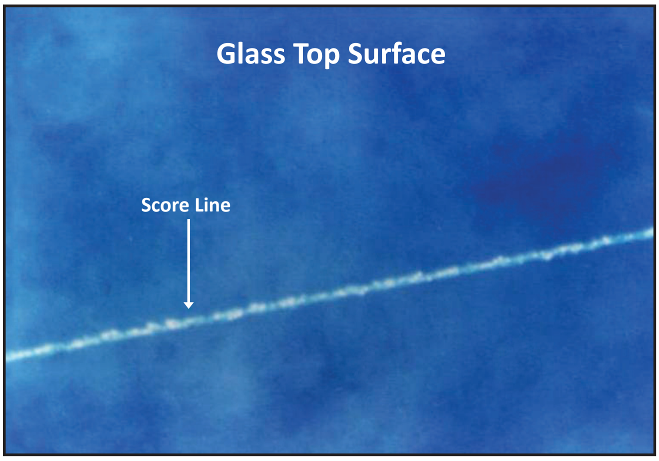

Figure 6A

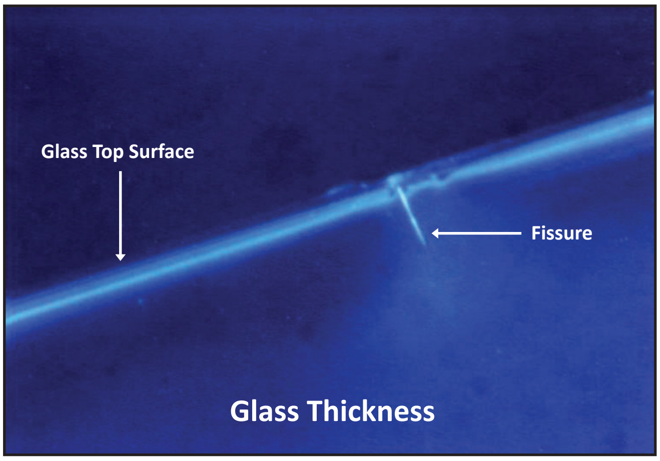

Figure 6B

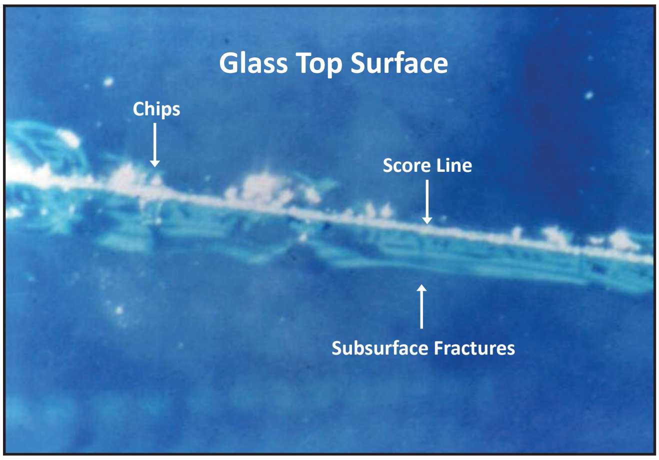

Figure 7A

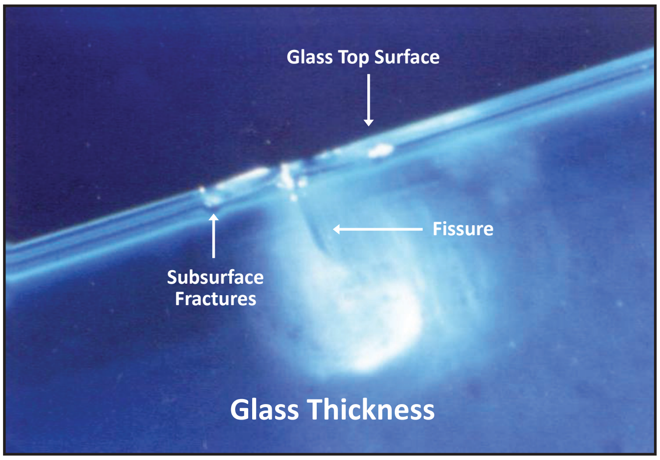

Figure 7B

♦ **Fissure depth that's appropriate for the given application.**

One of the most critical parts of the process to maintain. When cutting straight lines, the depth of the fissure should be equal to 5% to 10% of the total glass thickness. When cutting parts with small radii, such as automotive glass, the depth of the fissure should be equal to 15% to 20% of the total glass thickness. When cutting parts with larger radii, such as round top windows, the depth of the fissure should be equal to 10% to 15% of the total glass thickness *(see Figure 8)*.

These percentages are to be used as a guideline only. If acceptable score quality, break-out and edge quality can be obtained by using a lower percentage, one should do so. Fissure depth can be measured by taking a piece of glass approximately 1" wide and putting the eyepiece of a 10x magnifying lens that has a measuring scale against the edge. The actual fissure is easier to see if this is done near an outside window or with bright overhead lighting.

You may have to turn your head to obtain the best lighting for which to see the fissure. One can calculate the fissure depth by dividing the actual fissure depth by the glass thickness. Remove the zero and move the decimal point two places to the right. The number that appears is the fissure depth, as a percentage of the overall glass thickness. It's more important to measure fissure depth at times when you're having break-out and edge quality issues to help determine if these problems are related to incorrect fissure depth, method of break-out or other factors.

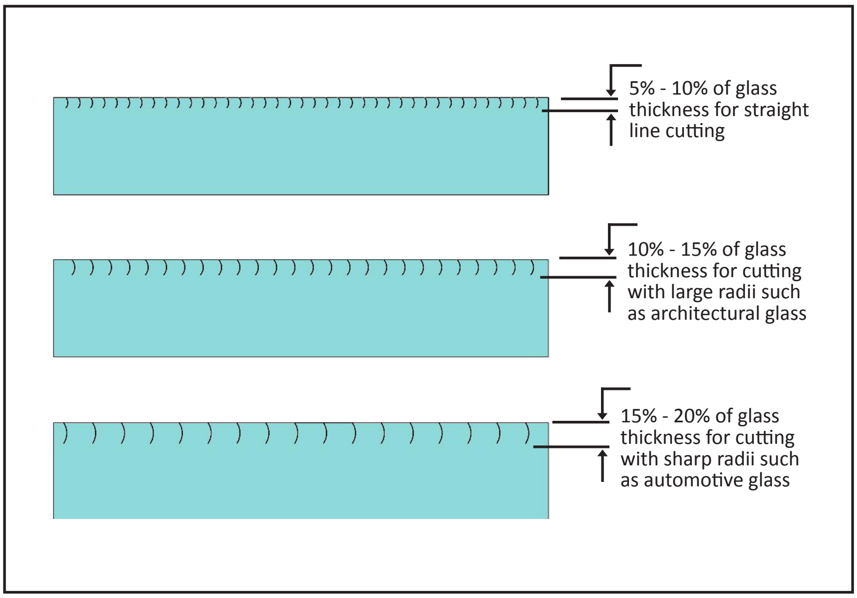

Figure 8

♦ Easy break-out of the glass.

Assuming that one is using acceptable break-out techniques and that positioning and timing is not an issue, the quality and depth of the fissure are primary contributing factors in how easily the glass will break-out. Additional factors are the amount of time between when the glass was scored and when it is broken, along with the type and amount of cutting fluid used.

♦ Acceptable edge quality.

When the edge of the glass is evaluated, one should see a fissure that is uniform in depth and beneath it the edge should be clear and free of blemishes. The edge of the glass should be perpendicular to the surface of the glass. If a particular cutting wheel selection requires too much cutting force, the edge will have sharks teeth. If the fissure is not deep enough, you may see vertical lines on the glass edge and flared edges that aren't perpendicular *(see Figure 9)*. If the break-out is not symmetrical the edges may not be perpendicular.

Variables that affect results.

♦ Cutting force.

Cutting force works in conjunction with the cutting wheel diameter and angle. Therefore, once the correct cutting wheel diameter and angle are selected for the specific application, cutting force is generated so that a fissure of the proper depth is created. If too little force is applied the fissure will not be deep enough, break-out will be difficult and edges may not be perpendicular. If too much force is applied the score line may have glass particles on it and the edge of the glass may have sharks teeth *(see Figure 10)*.

Cutting force is the easiest factor to change when break-out becomes difficult, however, most times it's not the correct factor to change. Often this change negatively affects other parts of the process.

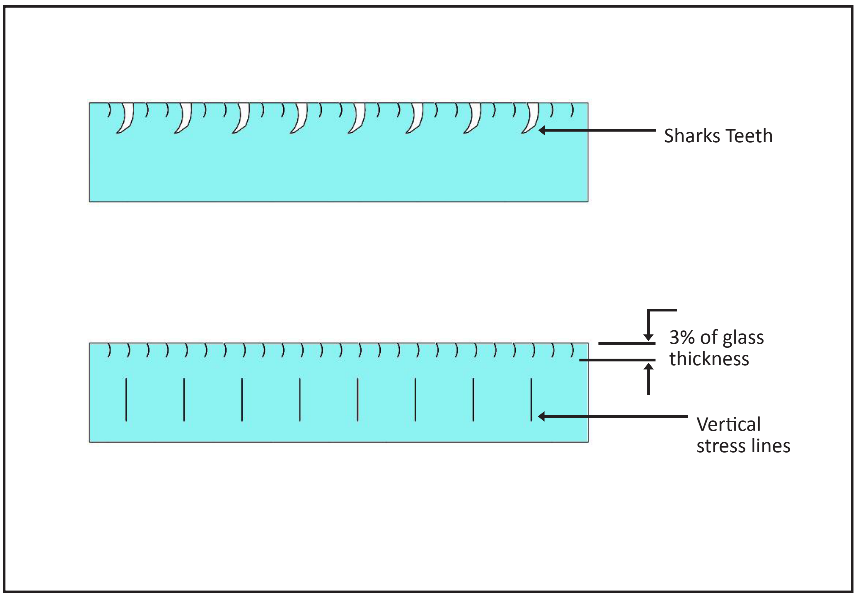

Figure 9

♦ Cutting wheel diameter.

When selecting the appropriate cutting wheel diameter, one needs to consider glass thickness and whether straight or radii cuts are being made. Thin glass requires a fissure of minimal depth, therefore, a smaller diameter cutting wheel is appropriate. The smaller diameter cutting wheel has a shorter footprint on the glass requiring less cutting force to penetrate the glass and create the proper fissure depth without causing sharks teeth on the glass edge *(see Figure 11)*.

Thicker glass requires a fissure of greater depth, which is achieved by increasing the amount of cutting force. To compensate for this increased cutting force, a larger diameter cutting wheel or a blunter cutting wheel angle can be chosen thus providing an edge free of sharks teeth and a score-line free of glass particles. Because a smaller diameter wheel has a shorter footprint, it will travel around a sharp radii more smoothly, thus providing a higher quality fissure with improved break-out and edge quality. If too large a diameter cutting wheel is used when cutting small radii, the leading and trailing edge of the wheel will scrape at the glass causing glass particles to appear on the score-line. This condition will negatively affect break-out and edge quality.

♦ Cutting wheel angle.

Glass thickness and whether you're making straight cuts or radii cuts are the primary considerations when selecting the appropriate cutting wheel angle. As mentioned above, thin glass requires a fissure of minimal depth, therefore, a sharper wheel angle is appropriate. The wheel produces a narrower footprint on the glass, thereby, requiring less cutting force to penetrate the glass and create the proper fissure depth without causing sharks teeth on the glass edge *(see Figure 11)*. Thicker glass requires a fissure of greater depth, which is achieved by increasing the amount of cutting force. To compensate for this increased cutting force a blunter cutting wheel angle can be chosen, thus providing an edge free of sharks teeth and a score-line free of glass particles. When cutting radii, the fissure depth (as a percentage of the overall glass thickness) needs to be more than when making straight cuts in order for the glass to break-out appropriately. This depth is achieved by increasing the amount of cutting force. To compensate for this increased cutting force, a blunter cutting wheel angle can be chosen, thus providing an edge free of sharks teeth and a score-line free of glass particles.

♦ Speed of the cutting wheel.

Speed is generally not a variable that one can adjust too liberally, however, it's important to realize what affect speed has on the glass cutting process. Basically speed acts like cutting force. Typically your operating parameters are set to yield a certain score quality, ease of break-out and edge quality using a certain cutting wheel diameter and angle with a certain amount of cutting force with the cutting wheel traveling at a certain speed. If only the cutting wheel speed is increased, the fissure depth will increase and you may start to see particles of glass on the score-line much as if the cutting force was increased *(see Figure 12)*. When cutting smaller radii, the cutting head typically slows prior to entering the radii and in order to maintain the appropriate fissure depth and ease of breakout, one typically increases the cutting force. As the cutting head exits the radii, the speed increases and cutting force is usually decreased. Other variables that affect the criteria that we expect from our glass cutting process are as follows:

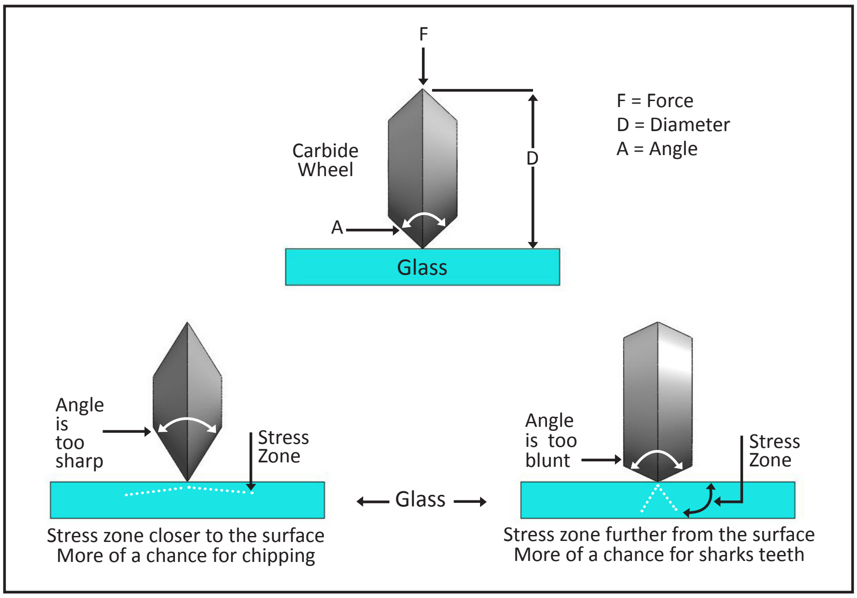

Figure 10

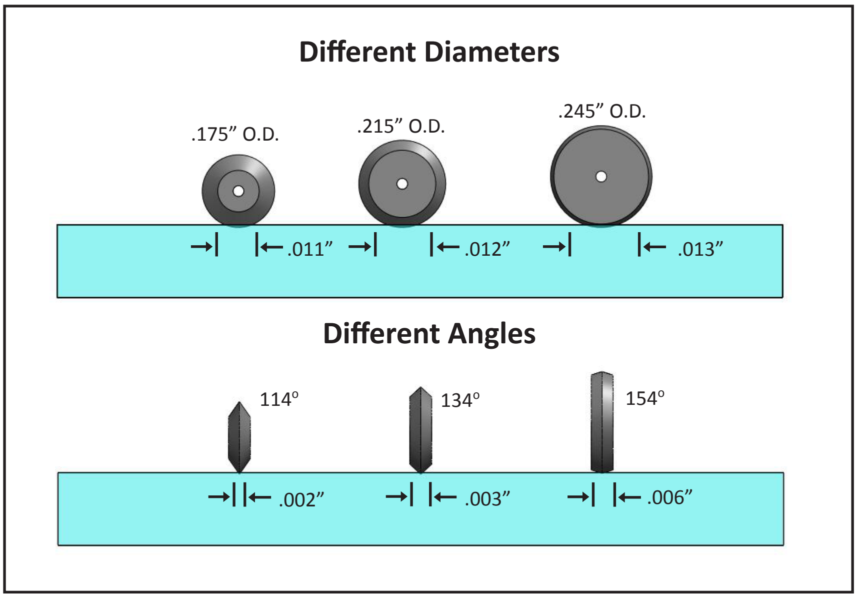

Figure 11

♦ Cleanliness of the glass.

If there is an excessive amount of dust or glass separation media on the cutting surface it may cause the cutting wheel to skip. If this happens the score-line may be interrupted or be of poor quality in which case break-out and edge quality may be negatively affected. The most effective solution to this problem is to clean the glass prior to cutting. Depending upon the amount of dust or glass separation media another possibility is to use a cutting wheel with a coarse grind finish on the angle.

♦ Temperature of the glass.

The main temperature related issues are cold glass and variance in temperature within a certain piece of glass.

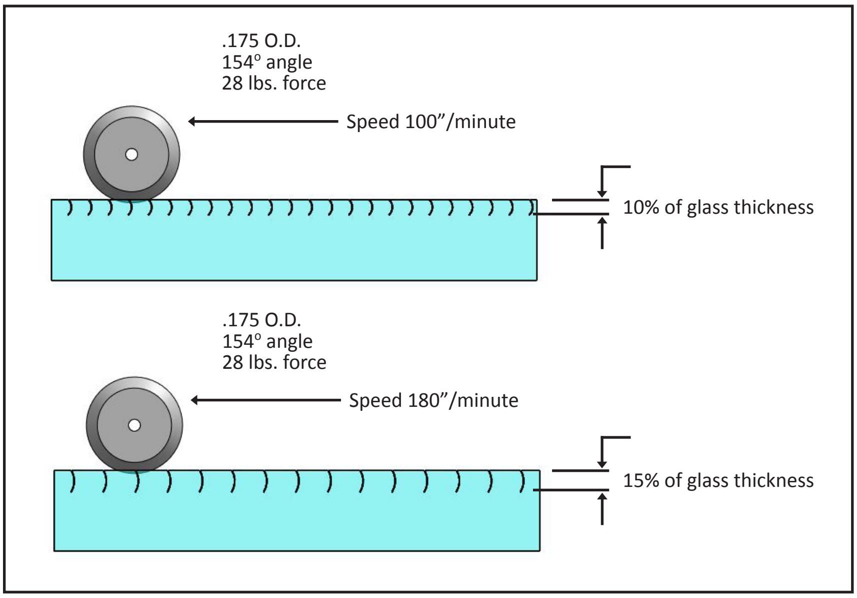

Figure 12

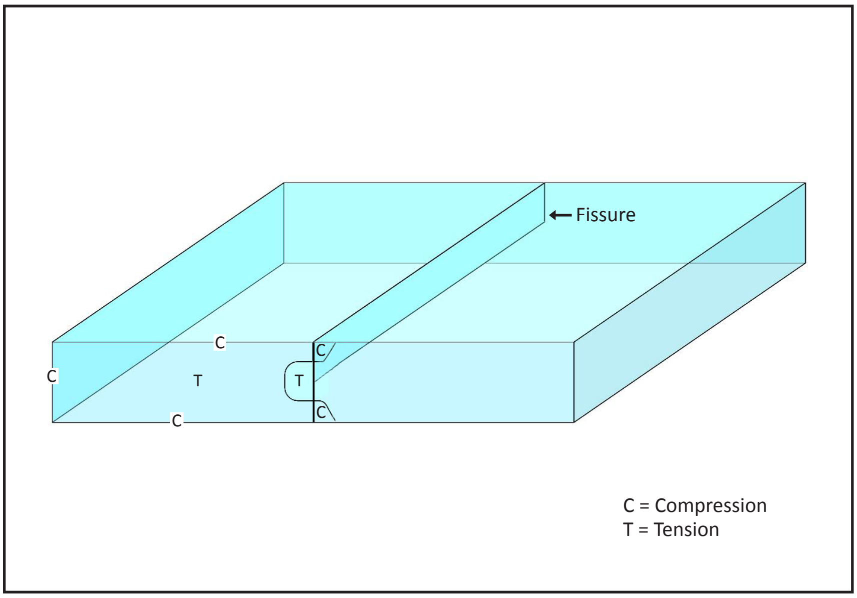

Figure 13

Generally speaking, cold glass reacts differently than glass that’s at ambient room temperature with the result being less predictability in the break-out process. It’s difficult to state a specific temperature at which you will notice a difference, but those companies in colder climates or where dramatic seasonal changes occur, are the most likely candidates to experience this situation. In those situations where glass is brought in from an unheated outside storage facility it’s a good idea to allow 48 to 72 hours for the glass to come up to ambient room temperature. Another idea is to install a glass washer prior to the cutting table. These ideas will also decrease the possibility of a variance in temperature within each piece of glass which, is another situation that can make break-out unpredictable.

♦ Anneal of the glass.

During the production of float glass, the glass ribbon travels through the “lehr” where the glass is gradually cooled in a controlled way in order to control the internal stresses, which could cause breakage. If this process doesn’t control those stresses adequately, the scoring and break-out process for a glass fabricator may be less predictable. This is not to say that all cutting-related issues are caused by the annealing of the glass, however, it’s important to understand the importance of the annealing process. Because the glass cools on the outside first, layers of compression and tension are created in the glass. The cutting wheel penetrates the top layer of compression, approximately .0007”, at which time the combination of the cutting wheels angle and diameter along with the cutting force and speed of the wheel creates a fissure in the glass *(see Figure 13)*.

♦ Cutting fluid.

Cutting fluid will help improve the quality of the score-line and aid the break-out process. It also lubricates the axle allowing for smoother rotation of the cutting wheel. If you're using cutting fluid as part of your process, it's important to have an uninterrupted flow to the cutting wheel to insure consistency of score quality and break-out. Even with cutting fluid, it's critical that the correct cutting wheel selection for the application is made and that the correct cutting force is used. Many cutting fluids are available on the market and some are better suited for certain applications. Please contact your cutting fluid supplier for specific information.

Guidelines for cutting applications.

The following tables provide a guideline for cutting wheel diameter and angle selection for different applications. The actual cutting wheel diameter and angle required to produce a score-line free of glass particles, acceptable break-out and acceptable edge quality may vary depending upon operator, machine condition, type of glass, temperature of glass and the speed of the cutting head.

Cutting Wheel Selection Guide for Shape Cutting
(ie. Automotive Glass Fabrication; 1⁄4" - 4" Radii)
Recommended Cutting Wheel Diameter and Range of Wheel Angles

Glass Thickness	.140" diameter	5/32" diameter	.175" diameter	.215" diameter
1.6 mm	140° - 148°	140° - 145°	140° - 145°	140° - 145°
2 mm	145° - 150°	145° - 150°	145° - 150°	145° - 150°
3 mm	150° - 156°	150° - 156°	150° - 156°	150° - 156°
4 mm	152° - 158°	152° - 158°	152° - 158°	152° - 158°
5 mm	154° - 160°	154° - 160°	154° - 160°	154° - 160°
6 mm	156° - 162°	156° - 162°	156° - 162°	156° - 162°

Cutting Wheel Selection Guide for Shape Cutting
(ie. Shapes With 5” + Radii)
Recommended Cutting Wheel Diameter and Range of Wheel Angles

Glass Thickness	.140” diameter	5/32” diameter	.175” diameter	215” diameter	7/32”/.228” diameter
1.6 mm	125° - 135°	125° - 130°	125° - 130°	125° - 130°	125° - 130°
2 mm	130° - 140°	130° - 140°	130° - 140°	130° - 140°	130° - 140°
3 - 5 mm	135° - 145°	135° - 145°	135° - 145°	135° - 145°	135° - 145°
6 - 8 mm	152° - 160°	152° - 160°	152° - 160°	152° - 160°	152° - 160°
10 - 12 mm		154° - 162°	154° - 162°	154° - 162°	154° - 162°
15 - 19 mm			158° - 162°	158° - 162°	158° - 162°

Cutting Wheel Selection Guide for Straight Line Cutting
(ie. Float Line or Rectangular Windows)
Recommended Cutting Wheel Diameter and Range of Wheel Angles

Glass Thickness	.140” diameter	5/32” diameter	.175” diameter	.215” diameter	7/32”/.228” diameter	.245” diameter	.500” diameter
1.6 mm	120° - 130°	120° - 130°	120° - 130°	115° - 125°	115° - 125°		
2 - 2.8 mm	130° - 140°	130° - 140°	130° - 140°	120° - 130°	115° - 125°	115° - 125°	
3 - 5 mm	140° - 150°	140° - 150°	140° - 150°	130° - 140°	125° - 135°	125° - 135°	
6 - 8 mm	150° - 160°	150° - 155°	150° - 155°	140° - 150°	135° - 145°	135° - 145°	
10 - 12 mm	155° - 160°	155° - 160°	150° - 160°	150° - 160°	145° - 155°	145° - 155°	140° - 150°
15 - 19 mm		155° - 165°	155° - 165°	155° - 165°	145° - 155°	145° - 155°	145° - 155°

Evaluating the criteria.

Glass with a coating applied to the surface is extremely commonplace in today’s market. These different coatings, many of which have different thickness and hardness values, may require different operating parameters than non-coated glass. In order to obtain a score-line free of glass particles, easy break-out and acceptable edge quality, one may need to use a wheel angle that is 5° to 10° sharper and use slightly less cutting force than what’s used for cutting non-coated glass.

Now it's time to "read" the glass and determine if the current operating parameters (cutting wheel diameter, angle and cutting force) are producing a score-line free of glass particles, easy breakout and acceptable edge quality. After review of this criteria, if you determine there is no opportunity for improvement, you should be congratulated and move on to the next challenge in your process. If, however, there appears to be room for improvement, one should use a certain methodology as part of the improvement process.

The methodology starts with reading the glass, evaluating certain criteria and documenting your findings. Then, utilizing certain tools, you can start to consider which tool to adjust in order to make the necessary improvement. Consider changing Force first because it is the easiest tool to change. Angle is the second tool to consider changing as there are generally several angles within the possible range. Diameter is the third tool to consider as there are generally two primary diameters that will provide the best results. Speed is the last tool to consider changing as it's generally the tool with the least flexibility and is more time consuming to change. As with any problem-solving exercise, it's recommended that one variable at a time is changed so that its affect can be measured and understood. The chart below will, hopefully, help you understand this part of the methodology:

Criteria:	***Evaluate Criteria For:***	***Tools:***
Quality of score-line	*Are glass particles present or is it a clean score-line?*	**Force** applied to the cutting wheel
Ease of break-out	*Is break-out easy or difficult?*	**Angle** of cutting wheel
Edge quality	Are edges perpendicular or are they flared? Are there sharks teeth or vertical lines?	**Diameter** of the cutting wheel
Fissure depth	Measure and quantify as a percentage of the overall glass thickness and know what your target range is for your application.	**Speed** of the cutting wheel

It is helpful to record your current operating parameters, along with the actual findings of the criteria that is evaluated. For example:

Operating Parameters:
Glass thickness: 2.3 mm
Diameter of cutting wheel: .245"
Angle of cutting wheel: 134°
Force applied to cutting wheel: 28 pounds

Actual Conditions:
Quality of score-line: Glass particles everywhere
Ease of break-out: Easy
Edge quality: Sharks teeth
Fissure depth: 18%
(for this review target depth is 15% - 20%.)

To save time and unnecessary steps, before actually changing a tool, ask yourself, “If I change a certain tool, how will it affect the criteria I’m evaluating?” Then determine if the affect will be positive and you can move forward or if it will be negative. If negative, you may still move forward, if by altering another tool it will have a positive affect. For example, with the above-mentioned Operating Parameters and Actual Conditions we want to eliminate the glass particles on the score-line and the sharks teeth on the edge of the glass. The proper methodology is as follows:

Adjustment: Reduce the cutting force

Intended Affect: Eliminate glass particles on the score-line and sharks teeth

Theoretical Affect/Positive/Negative/Results

Positive: Excessive cutting force can cause glass particles and sharks teeth. Reducing cutting force will decrease the fissure depth making break-out harder, however, fissure depth is currently 18% and above the mid range target depth. Break-out is very easy so fissure depth can perhaps decrease slightly.

Results: Break-out is difficult; the sharks teeth are gone; there are still some glass particles on the score-line. We’ll have to make another change, but cutting force cannot be increased or decreased because the score quality and ease of breakout will be negatively affected.

Adjustment: Try a blunter wheel angle

Intended Affect: Eliminate glass particles on the score-line and improve break-out

Theoretical Affect/Positive/Negative/Results

Negative: If the wheel angle is too sharp, it can cause glass particles on the score-line, therefore, using a blunter wheel angle makes sense. A blunter wheel angle has a wider footprint with more surface area, therefore, it will act as though less cutting force has been applied. This will negatively affect the break-out, however, while this is negative, if the glass however, while this is negative, if the glass particles are eliminated from the score-line, cutting force can be increased to increase the fissure depth and improve break-out.

Results: Break-out is difficult; fissure depth is 13%; the score-line is free of glass particles. Cutting force can be increased as there are no glass particles on the score-line. By doing so, the fissure depth will increase and break-out will improve.

Adjustment: Increase the cutting force

Intended Affect: Increase the fissure depth and improve the break-out

Theoretical Affect/Positive/Negative/Results

Positive: By increasing the cutting force, our fissure depth will increase, which should make break-out easier.

Results: Score line is still clean; break-out is easy; edge quality is good; fissure depth is 16%. The problem has been solved.

This back and forth thought and adjustment process is sometimes necessary before the optimal operating parameters are discovered.

*Following the recommendations in this document is intended to provide you with guidelines and methods for controlling your glass cutting operation. Please contact **Fletcher-Terry** for an in-house process analysis.*

The Fletcher-Terry Company, LLC

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