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Some Investigations on Identifications of Defect in Windshields

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Abstract : *Glass is a versatile material with more than hundreds of applications, including windshields. Glass has a long history and was first made more than 7,000 years ago in Egypt, as early as 3,000 B.C. Glass is found in a natural state as a by-product of volcanic activity. Today, glass is manufactured from a variety of ceramic materials (main components are oxides). The main product categories are flat or float glass, container glass, cut glass, fiber glass, optical glass, and specialty glass.*

The main aim of this paper is to investigate the snags and defect in windshields manufacturing process. Different tools like literature and industrial survey, data collection, exhaustive brainstorming and analysis are used to identify and rectify the observed defect in glass windshields. During analysis it is observed that the most significant defects are delamination and an optical distortion due to SAG bending.

Keywords - *Windshield, Defects, De-lamination.*

I. INTRODUCTION

Glass is a versatile material with hundreds of applications, including windshields. Glass has a long history and was first made more than 7,000 years ago in Egypt, as early as 3,000 B.C. Glass is found in a natural state as a by-product of volcanic activity. Today, glass is manufactured from a variety of ceramic materials (main components are oxides). The main product categories are flat or float glass, container glass, cut glass, fiber glass, optical glass, and specialty glass.

Automotive windshields fall into the flat glass category. There are more than 80 companies worldwide which produce automotive glass, including windshields. Major producers in the United States include PPG, Guardian Industries Corp., and Libby-Owens Ford. According to the Department of Commerce, 25 percent of flat glass production is consumed by the automotive industry (including windows) at a total value of approximately $483 million. In Japan, 30 percent of flat glass goes to the automotive industry, valued at around $190 billion in 1989. Major Japanese flat glass manufacturers include Asahi Glass Co., Central Glass Co., and Nippon Sheet Glass Co. Little growth is expected for the flat glass industry overall in both countries. Germany has a more positive outlook, with high growth rates expected from the automotive industry. Glass windshields first appeared around 1905 with the invention of safety glass-glass tempered to make it especially hard and resistant to shattering. This type of windshield was popular well into the middle of the century, but it was eventually replaced by windshields made of laminated glass-a multilayer unit consisting of a plastic layer surrounded by two sheets of glass. In many countries, including the U.S., auto windshields are required by law made of laminated glass. Laminated glass can bend slightly under impact and is less likely to shatter than normal safety glass. This quality reduces the risk of injury to the automobile's passengers [1].

The windshield of an automobile such as car, bus etc., is its front glass. Apart from providing a good vision area to the driver, it is designed to provide a good resistance against unauthorized entry into the vehicle. Another important function of the windshield is to protect the passengers suffering from various injuries during an accident. But it has been reported that windshield is the most frequent vehicle source for head injuries of the passenger in accident cases of a vehicle [2]. In another report the International Harmonized Research Activities (IHRA) pedestrian safety working groups have found out that the windshield is the leading source of head injury for adult pedestrian during a vehicle pedestrian collision [3]. Thus the windshield of a vehicle is a critical component that requires a detailed analysis based on the type of loads acting on it. In early vehicles flat annealed glass sheets have been used as windshields which possess relatively low strength and involve high risk since it would break into large fragments with sharp edges in case of a collision . This could lead to severe injuries or loss of life to both pedestrian as well as passenger. This can be attributed to the brittleness of glass.

Breakage of glass could also happen due to static fatigue, which is a typical property of glass due to progressive growth of cracks initiated by micro defects in the surface under the combined effect of mechanical stresses and environmental humidity. Later developments lead to the introduction of temper hardening process of the glass and this has resulted in an increase in strength and splitting of the glass into a great number of fragments without sharp edges. Curved glass sheets have been developed at a later stage both by simple gravity effect and using press molding without compromising on the optical performance of the glass [4]. The most important goal in the design practice is to study and predict the glass durability in the conditions of standard use.

The most effective development in the design of windshield has been the use of laminated windshield glass. It is globally accepted and is used in almost all passenger cars at present. Laminated windshield glass is made up of two sheets of float glass with a Poly-Vinyl-Butryl (PVB) interlayer pressed together at a high pressure and temperature. The PVB interlayer is a visco elastic material. The energy absorbing properties of laminated glass is obtained through a combination of the energy dissipation as a consequence of the fracture behavior of the glass and the visco elastic deformation of the PVB interlayer. In short time dynamics, the elastic behavior for small deformations of the composite is determined by the glass layers. For large deformations the brittle glass cannot withstand large strains and hence the PVB interlayer plays a dominant role. The torsional stiffness of the vehicle body is also increased by the use of bonded laminated windshield glass [5].

The interlayer provides three beneficial properties to laminated windshield. Firstly the interlayer helps to distribute impact forces across a greater area of the glass thus increasing the impact resistance of the windshield. Secondly the PVB layer is so designed as to keep the glass layers together thereby reducing the extent of damage and preserving almost full visibility in practice except through cracked lines in case of breakage of glass. Finally the visco elastic interlayer undergoes plastic deformation during impact, absorbing energy and reducing penetration by the impactor as well as reducing the energy of the impact that is transmitted to impactor. In order to study the behavior of the glass both static as well as impact analysis are necessary for the determination of stress field and for the prediction of failure pattern. The windshield behavior should be investigated during normal working condition as well as during a sudden impact such as the one occurring during a vehicle pedestrian collision.

As per literature and industrial survey it is seen that the current trend for automotive glass designers is to require complex shapes, deep bends, and large cross curvature for car windscreens. The primary objective of this paper is to optimize, within the linear elasticity model, the sag bending process which is commonly used to manufacture car windscreens. There are two basic strategies employed by glass manufacturers. The first method is the so-called gravity bending and the second method is the so-called press bending. In gravity or sag bending, two pieces of flat preprocessed glass are placed on an optimally curved steel mould which are then passed through a furnace and gradually heated to a suitable temperature (around 500oC–650oC). At this stage, the glass sags under its own weight until it comes into contact with the mould. This forming process can conveniently be simulated computationally. De-lamination or Reprocess is major defects happening with laminated glass, if the process is not executed properly. Most prominent of such problems is reprocess or de-lamination. This happens mainly due to the poor bonding between the glass and PVB sheet. The objective of this study is to investigate, how to reduce the reprocess of laminated glass manufacturing.

II. PROBLEM FORMULATION AND OBJECTIVE

Windshield manufacturers are facing challenges as the vehicle designers and carmakers are driven to improve safety, aerodynamic efficiency, driving comfort, and aesthetics. In practice this means introduction of increasing windshield sizes, reduced thickness to gain component weight loss, decreasing installation angles, complex surface geometry, coatings for reduced Infrared (IR) radiation and acoustic inter-layers for sound insulation. Simultaneously the original equipment manufacturer (OEM) and Automotive Replacement Glass (ARG) quality requirements are increasing. These developments possess a challenge to the heat treatment processes and especially for the sag bending process as high optical quality in both transmission and reflection optics are compulsory requirement for auto windshield today. Design of the bending process heating configuration according to bending trial results is the most complicated and time-consuming tasks of a bending technician working with new model introduction and quality defects. This paper reviews the requirements design trends and quality requirements set for sag bending process controls and introduces key parameters to be controlled to enable production of superior optical quality. Hence in this paper we intend to localize and classify the defects that are originated while manufacturing the glass that forms the windshield. Reprocess are major defects happening with laminated glass, if the process is not executed properly. Most prominent of such problems is re-process. This happens mainly due to the poor bonding between the glass and PVB sheet. The objective of this study is to investigate snags and defect in windshields and how to reduce these defects of laminated glass manufacturing.

III. IDENTIFICATION OF SNAGS AND DEFECT IN WINDSHIELDS

Table 1 summarizes the internal as well as external defects induced during the manufacture of windshields which leads to defects like reprocess (de-lamination).

Table: 1 Causes of De-Lamination

Sr. No.	Factor/Defect
1	Recipe
2	Heaters at pocket location-Failures
3	Loading at Furnace- Mainly mismatch
4	CC variation
5	CC on sides
6	Glass not seating on bottom corners
7	Gap between inner and outer glass after bending
8	Effect of absence of baffles
9	Direct heaters
10	Tool height
11	Roller distance
12	Roller diameter
13	Radiator position (Length and Weight)
14	Radiator type
15	Smooth opening and closing of tools
16	Waviness at articulation
17	Pillar side radiator: Gap between band and radiator
18	Twist in tools
19	Deformation in tools inside the furnace
20	Tool weight
21	Steps in articulation point
22	Worn out stoppers
23	Stopper (Roller) height w.r.to. glass
24	Cycle time
25	Autoclave cycle

4.2 Finding out Root Cause of Defect in Windshields.

The complex nature of lamination defects; individual processing conditions, and different raw materials create a situation where the only working solutions are individually adjusted processing parameters. During industrial survey it is observed that the majority of windscreen production related cases included findings relating to lamination defects. As per our experience the producers too often overlook the processing or material conditions that contribute to reduced lamination process performance. The lamination process is in key-role in complete windshield production unit performance and its results and quality are directly linked with bending and pre-processing activities.

Lamination defects are typically within the top 5 waste (scrap) reasons in production of laminated windshields. Defect known as “bubbles”, name relating to is shape and appearance, is the most common lamination defects. Air is key-factor in creation of the bubble defect. Bubbles, teardrops and worms all are an indication of excess residual air between the laminate. This lamination defect is controversial: the bubbles do not appear every time when a little air is left between the laminate or when gapping between the glass pairs is monitored. The defect seems to arise when excess residual air remains between the laminate and few contributing factors are existent. The fact that there are various lamination and autoclaving process parameters, conditions of pre-processing and equally bending that affect to the process performance and especially air removal makes the elimination difficult.

IV. RESULTS AND DISCUSSION

4.1 De-Lamination

De-lamination issues with laminated glass made using PVB inter layers fall into two main categories:

1. Sunburst de-laminations
2. Edge de-lamination

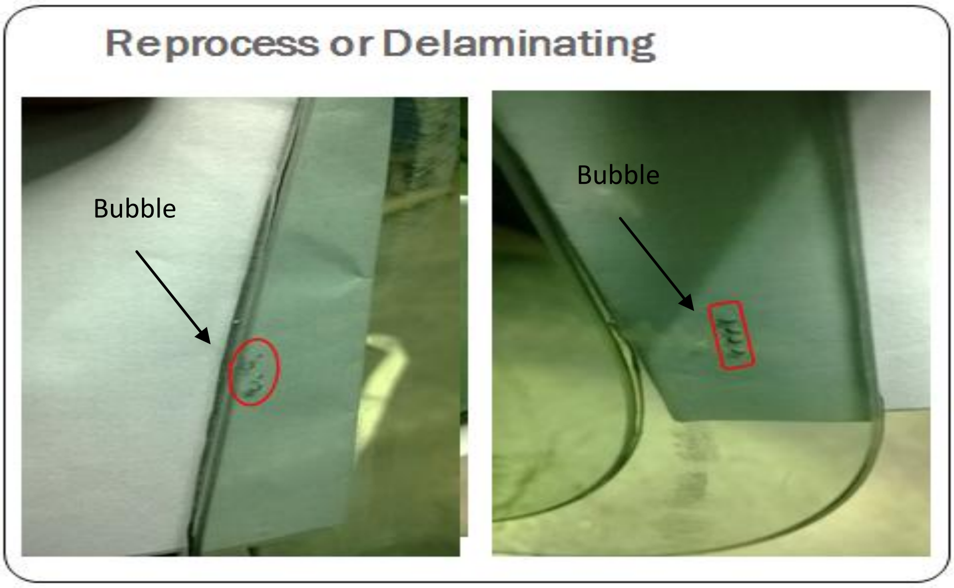

Figure 5.1: De-lamination defect

'Sunburst' de-laminations (see Figure 5.1) in some projects have undoubtedly caused concern in the glazing industry. This type of de-lamination is generally the result of poor manufacturing processes, which impart stresses at locations at the edges of laminated glass, often combined with thinning of the PVB. Optical distortion is also normally evident at these locations. The most common cause of this type of localized de-lamination is the use of clamping devices on the edges of laminated tempered glass during the autoclaving of the laminated glass. While the quality of the glass may appear to be satisfactory at time of dispatch of the glass from the factory gradual release over time of the stresses imparted to the glass at the locations that were clamped may result in 'sunburst' de-laminations.

Lamination defects are typically within the top 5 waste (scrap) reasons in production of laminated windshields. Defect known as "bubbles", name relating to is shape and appearance, is the most common lamination defects mainly due to closing and opening of the tool. Air is key-factor in creation of the bubble defect. Bubbles, teardrops and worms all are an indication of excess residual air between the laminate. This lamination defect is controversial: the bubbles do not appear every time when a little air is left between the laminate or when gapping between the glass pairs is monitored. The defect seems to arise when excess residual air remains between the laminate and few contributing factors are existent. The fact that there are various lamination and autoclaving process parameters, conditions of pre-processing and equally bending that affect to the process performance and especially air removal makes the elimination difficult.

The "Bubble"-defect appears in different sizes and locations. Typically the defect appears as "bubble"-areas in the very edges of the glass, while also larger individual bubbles appear: both in edges as well more towards to the middle section. Larger "bubbles" appearing in the very edge of glass can be commonly fixed with re-autoclave cycle adding clips that help sealing the glass edges. There are drawbacks in this curing method: The re-autoclaving cycle creates work flow against normal, increases production costs, but also some re-worked parts have tendency to introduce worm-like de-lamination's a while after –re-autoclaving. Furthermore using clips is controversial as the pressure applied with the clips is potentially altering the thickness of the laminate and introducing stresses. However larger bubbles in the inner parts of the glass, typically between the glass corner and mould hinge line can be impossible to fix. Typical lamination defects are visible right after autoclaving, but the residual air can unify to rise to worm-like de-lamination caused by residual air left between the glass sheets, phenomenon described as super-saturation. Typical sign of poor edge seal after autoclaving - can be fixed but with a manufacturing cost and potential delayed defect issues

4.2 Causes for formation of Bubbles

There are several conditions in each processing stage that can affect the lamination performance.

- **Pre-Processing**

1. Cutting size variations will cause severe difficulties in positioning of the glass pair in the lamination. Default in positioning of glass pairs in PVB assembly will cause unwanted gapping between the glass sheets.
2. Extensive amount of separating powder will cause minor surface variations in the glass pair's inner surfaces reducing adhesion of the PVB and glass.
3. Poor washing water characteristics can affect the adhesion. Therefore the hardness of the water is monitored. For example Salts can cause large deviations where adhesion may even drop by several pummel units.
4. Gapping between glass pairs created during bending process is also potentially increasing the risk of defects. Gapping between the glass sheets created due to temperature difference between the glass sheets or mould issues will contribute to creation of appearing bubbles. The in-house tolerances for acceptable gapping vary from 0.3 mm to 0.5 mm. Gapping affect is very product dependent, however gapping even large as 0,8 can perform well without any bubbles. Therefore recognition of maximum gapping together with another shape related key parameter will be give better indication of the probabilities.

4.3 Inner and outer glass miss match causing gapping

- Tin and airside orientation of the float glass affects the adhesion levels. Therefore the affect/relationship to PVB adhesion is important and has to be acknowledged by the manufacturers in their glass pair setup. The decided standard orientation is to be maintained always!

4.4 Closing weight of tool

- For deep bending external force is required up to 14.5 kg. When the amount of applied external exceeds 14.5kg, result in bubble formation in laminated glass which leads to de-lamination.
- Design of experiment (DOE) trial was conducted for 02 parameters to check effectiveness on Reprocess on both moulds A and B.
- Tools number 5,6,10 and 11 selected for DOE.

TABLE 5.1 OPENING AND CLOSING WEIGHT

Mould number	Opening Weight	Mould Weight	% Reprocess	% Pocket
11A	17.5	33.78	20.00%	0.00%
10A	14.5	33.78	0.00%	0.00%
6A	17.5	32.38	40.00%	0.00%
5A	14.5	32.38	12.50%	0.00%
11B	14.5	33.78	0.00%	0.00%
5B	17.5	32.38	66.70%	0.00%
10B	17.5	33.78	20.00%	0.00%
6B	14.5	32.38	0.00%	0.00%

TABLE 5.2 DATA COLLECTION

Mould no.	Sub parts	Quantity checked	Sum	% Reprocess
5	A	8	1	12.50%
	B	6	4	66.67%
6	A	5	2	40.00%
	B	8	0	0.00%
10	A	8	0	0.00%
	B	5	1	20.00%
11	A	5	1	20.00%
	B	8	0	0.00%

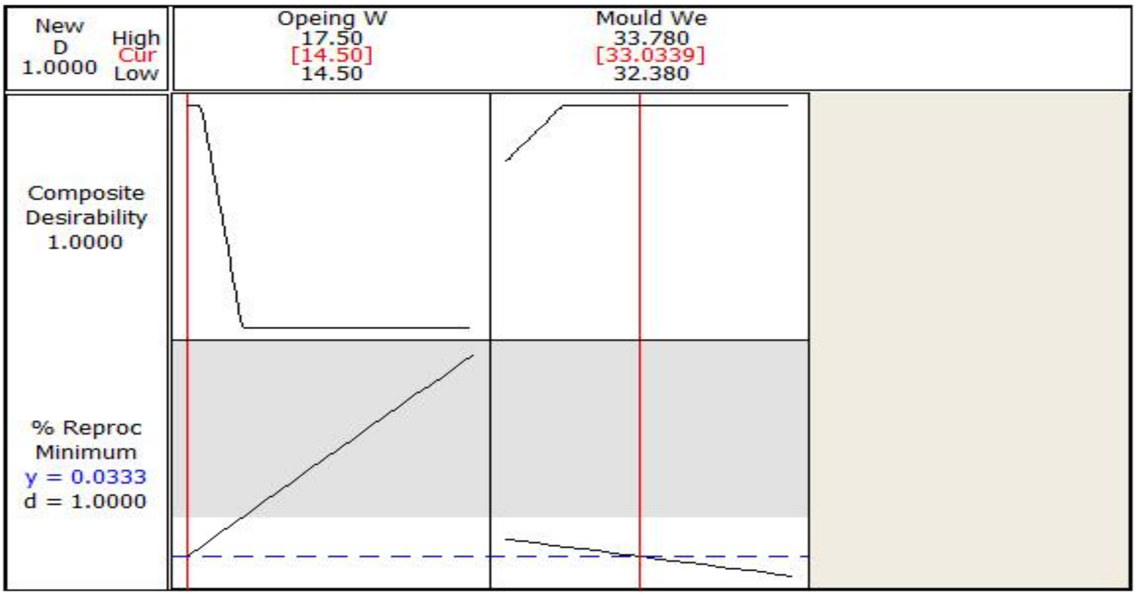

Figure 5.3 Optimization plot for DOE

From Figure 5.3 following observation are obtained.

- Result of reduction in Force required to open tool is significant
- Optimization plot for considered 02 parameters is as shown Figure5.3.
- Reduction in Opening force shows improvement in Reprocess.
- But as lowest weight taken for trial was 14.5Kg, additional trial taken to reduce it further to 12.7Kg and 12.9Kg
- Result of Reduction in force shows further Improvement

4.5 Methods to Prevent Bubble Defect

Start with perfecting the pre-processing activities whilst creating FMEA, Standard Operating Procedure and others work with; cutting size, washing water quality control, bending process controls and quality. Follow to lamination activities controlling and measuring all the actions carefully: Releasing the PVB, careful positioning at assembly, sufficient cold-vacuum, controlled heating in hot-vacuum, correct actions with vacuum ring assembly and disassembly, and finally perform perfectly adjusted autoclave process with correct heating and pressure curves. When all production activities are well documented and instructed, staff performs according to production instructions and process parameters are repeated to perfection the identification of all variations is considerably easier.

V. CONCLUSION

The primary objective of this work was to investigate the snags and defect in windshields manufacturing process. This objective is achieved with the help of extensiveliterature survey, industrial survey, data collection, exhaustive brainstorming and analysis. During analysis it is observed that the most significant defects are de-lamination and an optical distortion due to SAG bending. During trials it is seen that for when the amount of applied external exceeds 14.5kg, result in bubble formation in laminated glass which leads to de-lamination. As furnace cycle time varies from 61.5 sec to 63.7 sec there is increase in Reprocess from average 18% to 32.45%. Hence the optimized cycle time can be taken as 61.0 to 61.5 sec. Although reduced optical quality can be caused by sub-par float glass quality especially with thinner glass, imperfections in pre-processing as well as lamination process, it can be concluded that majority of the experienced optical flaws in transmission and reflection optics are related to the challenge posed by the modern windshield design due to the special requirements the design features create to the sag bending process in particular. In addition to this the market quality requirements are increasing and these tightening quality requirements on key quality aspects, such as optical quality, are also a source of additional performance pressures to level and improvement of manufacturing quality. Single most important factor producing superior optical quality is the correct design heat distribution (heating element configuration) that will form the required shape, inefficient time, with optimal quality, and finally repeats this continuously cycle after cycle.

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