A Study on Fracture Phenomena of Windshield by Impact-pressure of Passenger-side Air-bag

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ABSTRACT

Recently, auto-mobile air-bag system are usually used. But on the other hand, a lot of safety problems of the air-bag system for the passengers have been reported. In this study, the fracture behavior of windshield by impact pressure of a passenger side air-bag and the fracture mechanism are analyzed. Especially the fracture phenomena of plastic interlayer (called P.V.B) in windshield is analyzed experimentally, by the simplify barrier test. Further more, the effect of pre-crack in glass on the fracture of windshield is analyzed. These studies are performed for the symmetrical laminated glass with two same thickness glasses and the asymmetrical laminated glass reducing thickness of inside glass. The obtained results are as follows;

1) Adhesive strength between glass and P.V.B affects the fracture resistance of laminated glass against air-bag pressure.
2) When a windshield has pre-crack on the surface, probability of P.V.B tear increases.

NOMENCLATURE

P.V.B Poly- vinyl Butyral
JIS Japanese Industrial Standard
SRS Supplemental Restraint System
MBH Mean Break Height
H.I.C Head Injury Criterion
SEM Scanning Electron Microscope

1 INTRODUCTION

It was worthy of notice that the windshield puncture by a passenger side air-bag attacking. This study tried to find out the mechanism of problem and learn about a better windshield concept against air-bag system. Now the productive front windshields were passed the safety regulations. But there is few consideration about the relationship between air-bag and windshield. The passenger side air-bag possibly hits the windshield violently and it might hurt its safety performances. And further more, recently it is necessary to reduce the weight of vehicle in the world and the most effective way of glass weight reduction is thickness reduction. So near future windshield will become thinner than current thickness. Along with the current JIS safety standard for glass, it was necessary to improve SRS air-bag system to solve this problem. But of course it might always be taken account of a better interaction between air-bag and windshield for the automotive glazing development, that was the reason of this study.

2 SUBJECT OF STUDY

Following three cases were major causes of windshield puncture by passenger side air-bag systems.

1) Puncture caused by attack of a lid
2) Puncture caused by impact of deployed air-bag
3) Puncture caused by attack of deployed air-bag with dummy or human body

In this study, the case 3 was judged to be the most serious windshield puncture. Because there was a possibility of air-bag tear by glass edge or release of dummy from inside the cabin to outside, in the worst case. Windshield breakage and P.V.B tear occur depending upon circumstances. Therefore the worst puncture case 3 was focused .

3 BEGINNING OF PROBLEM

In 1994 or 1995, Japanese automotive-manufacturers had a concern about serious windshield puncture in the barrier test for sub-compact cars. Since it was difficult for the sub-compact car to have a large space in the engine room to absorb the impact energy, the effect against windshield was heavy. This concern was the hint for our investigation. The fracture mechanism of windshield was observed in barrier tests based on the information and specimens from automotive-manufacturers. It was analyzed how the windshield was broken and how the P.V.B was torn in the crash.

4 OBSERVATION OF FRACTURE SURFACE

In the analysis of the broken windshield Used in car test, there was a peculiarity in the fracture surface of P.V.B (Figure 1-2). In the comparison of this remarkable patterns with the typical P.V.B fracture surface pattern in the ball drop test, there were quite similar to the surface pattern in radial crack (Figure 3). And the surface pattern in concentric circles crack that occur after radial crack is right-angled stripes (Figure 4). This difference of fracture surface pattern was evaluated in the view of P.V.B tearing mechanism as the delay of P.V.B tear from glass break. That is to say, when the crack propagation in glass and P.V.B interlayer tear occurred together, the surface pattern became vertical stripes. And when P.V.B tear occurred after glass break and the P.V.B could expand, the surface pattern became horizontal stripes.

From the laminated glass quality stand point, it would be better to prevent that glass and P.V.B from breaking

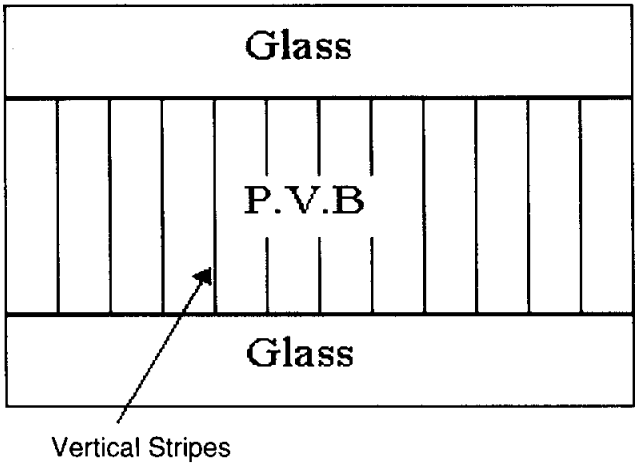

Figure 2 : The image of Surface Pattern

Figure 3 : Fracture Surface of Radial Crack by SEM

Figure 1 : Fracture Surface of Windshield by SEM

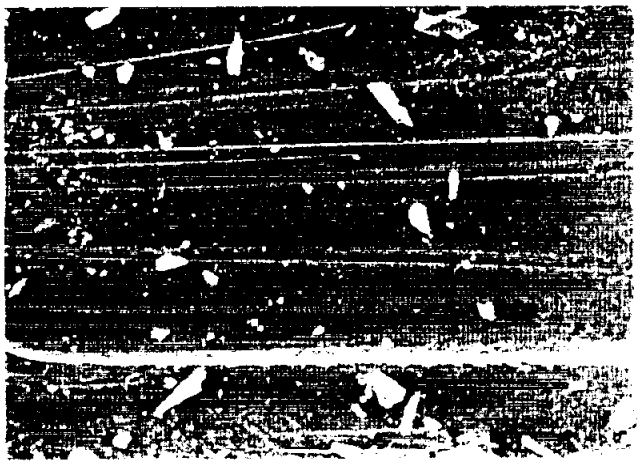

Figure 4 : Fracture Surface of Concentrated Circle Crack by SEM

together for proving the safety performance of windshield satisfactory. Then it was necessary for safety to give a chance of expansion to P.V.B which was tough against tensile stress, in breakage phenomena. This matter was thought in relation to adhesion extent between glass and P.V.B as follows;

1) The case of high adhesion; P.V.B sticks to adhered glass and break together with glass.
2) The case of low adhesion; P.V.B be peeled off around cracks and tears little by little along with expansion.

In the result of ball drop test, the case of low adhesion got higher value of MBH (Diagram 1). And it means strong against impact. It was considered that the mechanism described above was the one of direction to raise the resistance of laminated glass.

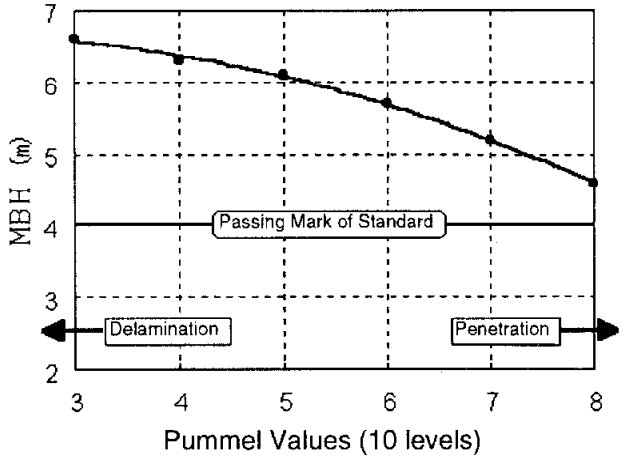

Diagram 1 : Relationship between Film Adhesion Level and MBH

But it would be better keep the current adhesion extent in the volume production and not be lowered. Because if it was lowered the adhesion of laminated glass, it possibly causes a problem of separation between glass and P.V.B. The current adhesion level in the production was in a good balance among all control items and if it was set the adhesion out of proper range, perhaps it would be caused another problems.

5 SIMPLIFY TEST-1

The ball drop test is one of the method to estimate impact strength, but it was not confident with the correspondence between this test and the problem of air-bag. Then it was started the primary study of relationship between windshield and air-bag to search for a new method of the impact test which was an approximation of real car crash. It was necessary to develop the new dynamic estimation method of glass fracture to solve this air-bag problem.

The purposes of development were

1) the establishment of simplify air-bag test method for the glass.
2) various kinds of parameter tests using the equipment above.

The actual air-bag was used and dropped a steel impactor which weighs 15 or 20kg from maximum 12 meters high. And then it hit the glass over an air-bag with a round plastic impact head. This examination is related to the situation that a dummy of a passenger hits a deployed air-bag with its head over 30 km/h. Maximum speed of an impactor is 35 km/h and maximum energy of impact is about 1173 J (Figure 5).

In this experiment an air-bag is not deployed in the initial state, and it will be deployed just before the impact by the signal of the phototube. Internal pressure of an air-bag is similar to that of an actual car, 0.3 or 0.5 kg/cm2. And there are vent holes on the surface of a bag, so a bag deflates in the course of time like the actual air-bag systems.

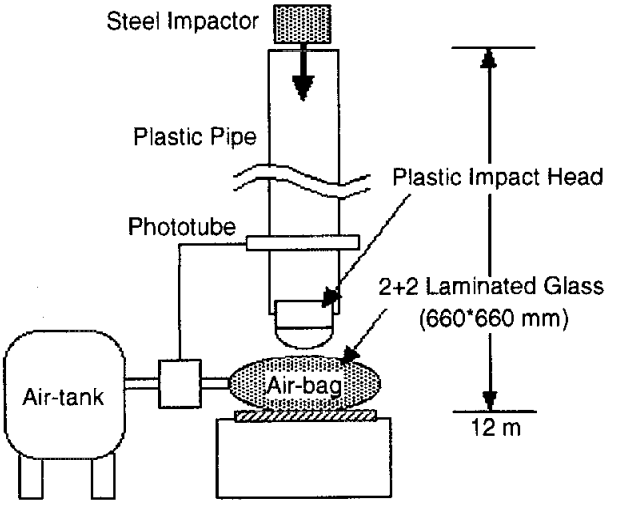

Figure 5 : The Equipment Image

5.1 TEST SPECIMEN

In this experiment flat laminated glass specimens were prepared. The thickness of glass was 2+2 and the specimen size was 660*660 mm. P.V.B thickness was 0.76 mm and moisture content was 0.58 wt% and pummel value was 5 or 6 out of 10.

5.2 NORMAL SPECIMEN TEST

At first normal glass specimens were used. "Normal" means it were processed nothing on specimens because "processed" specimens were used too as described later. And the strain gauges were set on the top of the impact head, measured strain which was loaded on the impactor instead of strain on the glass surface (Table 1). According to this results, it could reduce strain value on the impactor by using an air-bag and it meant H.I.C value of a dummy might also decreased. Furthermore, it gave suggestions that lower internal pressure made more reduction of impact energy.

Table 1 : Results of Normal Specimens

Internal Pressure of Air-bag	Number of Specimens	Maximum Strain on the Impactor	Others
No Air-bag	3	718.2 [με]	Easily Penetrated
0.03 [MPa]	7	315.2 [με]	2 tears on PVB
0.05 [MPa]	13	425.9 [με]	1 tears on PVB

On the other hand, it might be paid attention to glass, P.V.B tear occurred in the case air-bag expansion was failed and the impactor hit glass almost directly. therefore the conclusion that it is difficult to break P.V.B with the quite large impact energy like this tests when the air-bag system works actually.

5.3 CRACKED SPECIMEN TEST

It was difficult to find out P.V.B tear in the normal specimen test, then consequently it was noticed that there was a long crack from bottom to top of the windshield and P.V.B interlayer tore along this long crack in some cases (Figure 6). When and how this long crack appeared was not clear. But it was assumed that this crack had appeared before air-bag inflation and the dummy's attack. It is difficult to consider that two same cracks propagate both of outer and inner glass at same time. And one pre-crack in each specimens was prepared and tested two patterns type 1 & 2 (Figure 7). In this tests it could be found P.V.B tear 82% or more (Table 2).

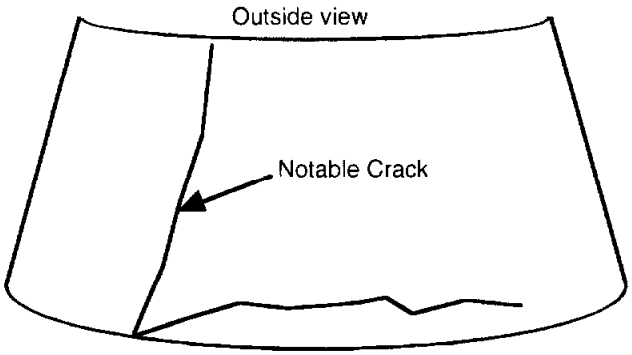

Figure 6 : The Long Crack in The Windshield

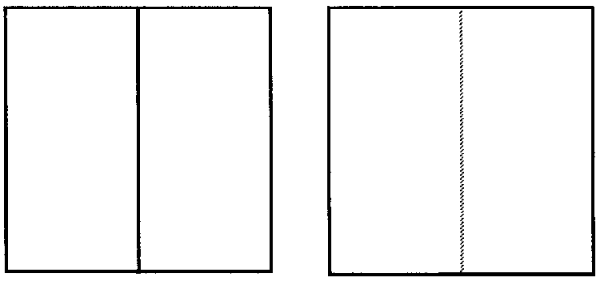

Figure 7 : Types of Pre-cracked Specimens

Table 2 : Results of Pre-cracked Specimens

Specimen	Internal Pressure of Air-bag	Number of Specimens	Maximum Strain on the Impactor	Number of PVB tear
Type 1	0.03 [MPa]	5	236.9 [με]	4
	0.05 [MPa]	4	280.2 [με]	4
Type 2	0.03 [MPa]	4	219.7 [με]	3
	0.05 [MPa]	4	305.4 [με]	3

6 SIMPLIFY TEST-2

In the study above, the effect of pre-crack against P.V.B penetration was evident.[1] The next stage of study was the expansion to asymmetrical laminated glass. The needs of thinner glass is increased to reduce weight of vehicles and one of the most effective way is reducing thickness of inner glass. New Air-gun type simplify equipment was established to compare symmetrical with asymmetrical laminated glass. This equipment was compact and easy to use. It was consisted of a compressor, an air-tank and 4500 mm steel pipe. Maximum energy of impact was about 850 J (Figure 8).

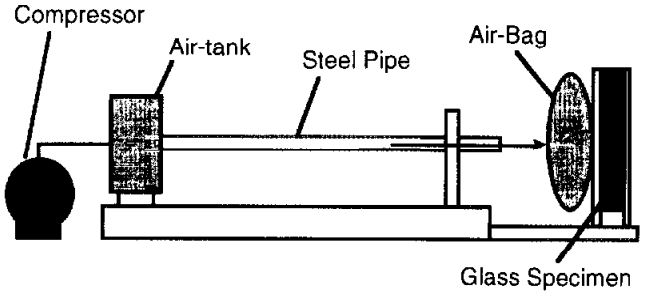

Figure 8 : The Air-gun Type Equipment Image

6.1 TEST SPECIMEN

In this experiment flat laminated glass specimens were prepared too. The thickness of glass was symmetrical 2+2 and asymmetrical 2+1.6 mm. The specimen size was 500*500 mm. P.V.B thickness was 0.38 mm, it's half of simplify test-1. 1 normal (crack free) type and 3 types of pre-cracked specimens were prepared in each thickness (Figure 9).

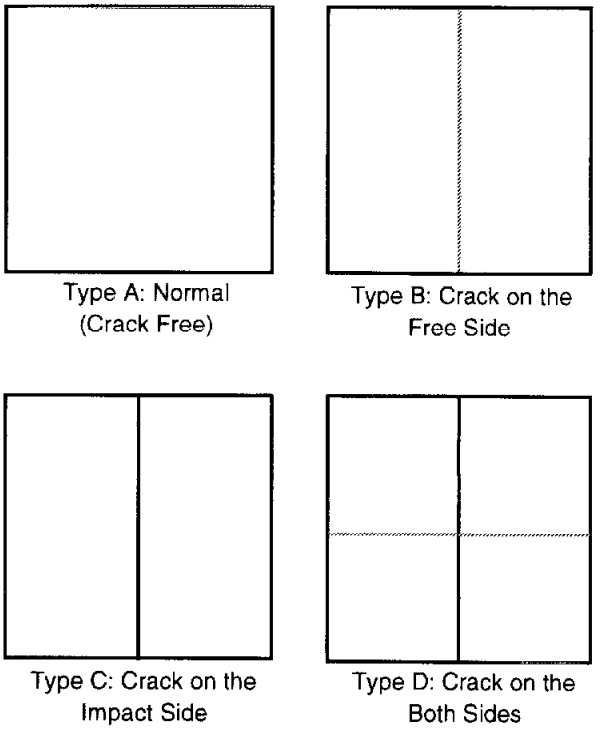

Figure 9 : Types of Specimens

6.2 TEST RESULT

In this experiment asymmetrical thinner specimen was weaker than symmetrical one in type A & B. But in type C & D specimens the order was reversed, penetration energy of asymmetrical laminated glass was higher than symmetrical one (Diagram 2). Each type of specimen had typical fracture pattern (Figure 10) and penetration pattern (Figure 11).

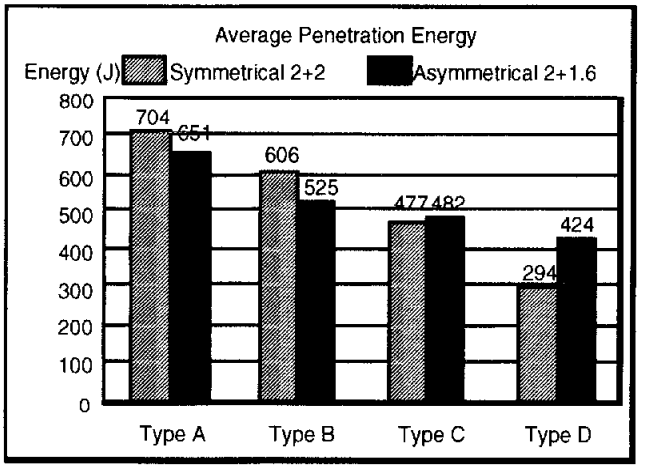

Diagram 2 : Penetration Energy

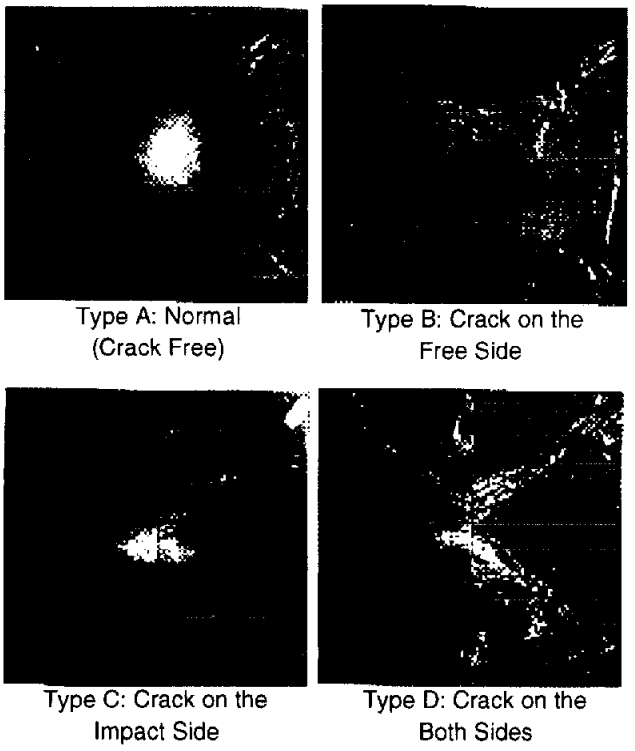

Figure 10 : Fracture Pattern of Glass

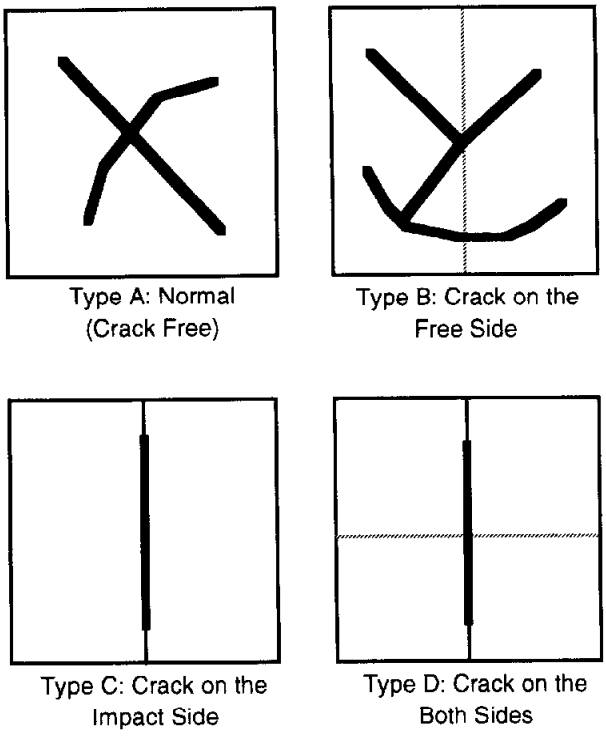

Figure 11 : Penetration Pattern of P.V.B

7 INVESTIGATION

The mechanism of this "reversed" result could be considered as follows;

1) P.V.B was broken by edge of inner glass.
2) If there was pre-crack on inner (impact side) glass, the pressure was easy to concentrate to initial glass edge.
3) If there was not any crack on inner glass, the pressure was dispersed to many glass edge.
4) 2.0 mm thickness glass edge could push P.V.B membrane stronger than 1.6 mm thickness one (Figure 12).

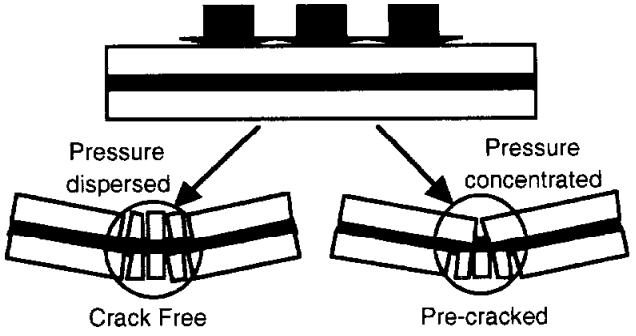

Figure 12 : Mechanism of Penetration

8 CONCLUSION

In this study it was analyzed the phenomena of windshield break in the barrier test, especially the case of P.V.B tear by mechanical and chemical approaches. It was tested the effect of pre-crack by using 2 simplify equipments. According to this study, the process from the crash to the windshield penetration was assumed (Figure 13) .

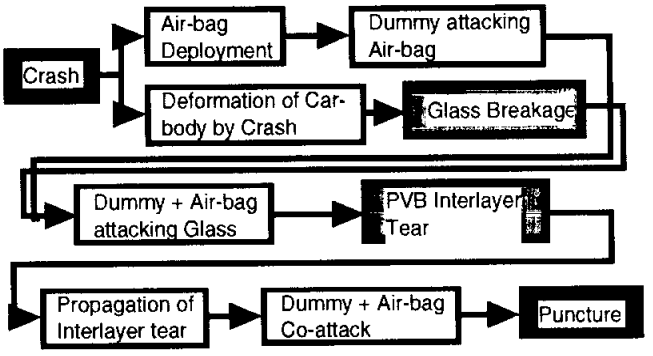

Figure 13 : The process of the windshield puncture

The most important points were concluded as follows;

1) Adhesion between glass and P.V.B influenced the penetration resistance of laminated glass.
2) If a windshield had pre-crack in surface, probability of P.V.B tear increased.
3) If There were pre-crack on inner glass, asymmetrical laminated glass could be stronger than symmetrical one against air-bag impact.[2]

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[1] Oda, J. and Mori, T., *On Impact Fracture of Automobile Windshield Glass and Airbag*, Transactions of the JSME, Vol. 63, No. 615, A, pp112-117, Nov 1997

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