◎ 논 문

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티어심 파손 강도를 고려한 동승석 에어백 도어시스템의 최적 설계

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Optimal Design of Passenger Airbag Door System Considering the Tearseam Failure Strength

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Key Words: Operating window(기능창), Invisible passenger airbag(보이지 않는 동승석 에어백), Airbag deployment(에어백 전개), Head impact performance(머리 충격 성능), Failure criteria of tearseam(티어심 파손 기준)

ABSTRACT

Invisible passenger airbag door system of hard panel types must be designed with a weakened area such that the side airbag will deploy through the instrument panel as like intended manner, with no flying debris at any required operating temperature. At the same time, there must be no cracking or sharp edges in the head impact test. If the advanced airbag with the big difference between high and low deployment pressure ranges are applied to hard panel types of invisible passenger airbag (IPAB) door system, it becomes more difficult to optimize the tearseam strength for satisfying deployment and head impact performance simultaneously. It was introduced the 'Operating Window' idea from quality engineering to design the hard panel types of IPAB door system applied to the advanced airbag for optimal deployment and head impact performance. Zigzab airbag folding and 'n' type PAB mounting bracket were selected.

1. Introduction

Advanced airbag, which sense various crash conditions and regulate airbag pressure to minimize occupant injury, use the dual-stage inflator. While diminution of the inflator energy is considered to reduce the airbag risk of airbag deployment related injury in out of position (OOP), its protective effect in severe crashes increases as well. The occupant size,belt or unbelted condition, impact speed can be considered to define which deployment pressure to be chosen by comparing occupant injury at each case. But the lower contact pressure conditions to the airbag door, especially at low temperature of first stage, make it difficult to apply the hard panel types of invisible passenger airbag (IPAB) door to the advanced airbag. That's because not only the plastic consisting of the tearseam becomes more brittle and tough but also the IPAB door systems have to satisfy the following conditions simultaneously.[1]

For the airbag deployment, the airbag door must open in a predicted manner at a specified temperature and there must be no fragmentation during airbag deployment.[2] And then, for head impact test (ECE 21.01) for instrument panel requires that, when the

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instrument panel area that is within the head impact area is impacted by a 6.8 kg mass and 165 mm diameter head form at a relative velocity of 24.2 km/h, the head form deceleration shall not exceed 80 g continuously for more than 3 milliseconds and there must be no sharp edges.[(3)]

During airbag deployment, the tearseam strength is smaller−the−better to be easily torn out and airbag deployment pressure must be as high as the tearseam could be easily torn out. But at head impact test, the tearseam strength is larger−the−better to endure without crack. So the failure strength of the tearseam has to be within such a range that satisfies above conditions together. However the hard panel types of IPAB door make the range small because of the high brittleness and failure strength of plastic consisting of tearseam at low temperature. When using the advanced airbag producing low deployment pressure at first stage, the range becomes much smaller because the tearseam has to be weak enough to open the airbag door. If the tearseam was designed to be torn easily at low deployment pressure, it could be fragile at head impact condition. When applying the hard panel IPAB door system with the styling and cost advantages, the safety range as stated above must be large enough not to occur unintended tearing.

In this study, it is suggested the hard panel types of IPAB door design for the optimal deployment and head impact performance. The idea called the ‘Operating Window’ from quality engineering was introduced to optimize the design factors for deployment and head impact performance.[(4)] The impact performance and temperature dependence of the plastic parts were considered. And it was also used the different failure criteria for the failure modes, either ductile or brittle. In order to calculate the accurate distributions of the contact−pressure between the airbag door and the fabric, it was modeled the airbag after specified folding patterns using OASYS/PRIMER. It was possible to cut the developing time and reduce the prototyping cost through the design optimization.[(5)] Head impact was analyzed using LS−DYNA.

2. Invisible passenger airbag door system

Invisible passenger airbag door system in this study, which consists of an airbag, airbag housing, door plate, reaction plate, chute and IP door cover as shown in Fig. 1. The pressure from filling the airbag with gas causes the door to open along tearseam, thereby releasing the airbag. The door−plate hinge which is sandwiched between chute and airbag−housing is extended and bent back. The assembly of airbag door is made up of the reaction plate, door plate and IP door cover, held together by rivet. The passenger side airbag mounting bracket attaches an airbag housing to the cowl cross bar, which supports the reaction of the airbag housing. The chute is attached to the IP with vibration welding, and provides a rigid structural airbag surrounding to prevent the bell mouth effect.

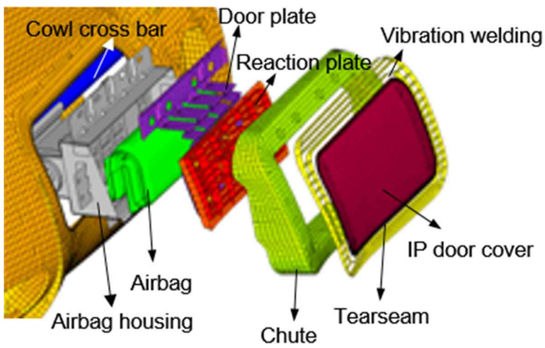


Fig. 1 IPAB door system components

3. Simulation of head impact

In the head impact simulation, the finite element model consisted of the IPAB door system and the hemispherical head form that were modeled using shell elements.[(6~7)] The rigid 165 mm diameter hemispherical head form of mass 6.8 kg was provided an initial velocity of 24.2 km/h in direction normal to the airbag door's surface at the #1 ~ #6 location of impact as shown in Fig. 2. The decelerations of the head form were compared at each locations and whether the tearseam failed or not was monitored. When the head form was impacted at #2, the deceleration was the highest and the tearseam was torn out as shown in Fig. 3. The airbag begins to break through tearseam near #2. Therefore the 50mm region of the tearseam near #2 was selected for the target section for optimization. Fig. 4 shows a view of FE model used in the head impact analysis for optimizing and the deformed section of the model at maximum head form intrusion. The energy absorption of the IPAB door system against head impact makes an effect on the failure of the tearseam.

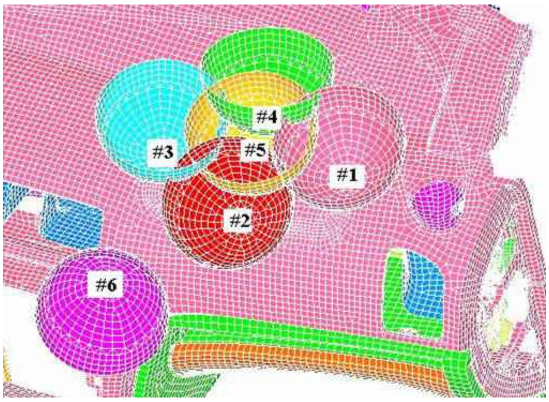


Fig. 2 Head form impact locations on the IPAB door

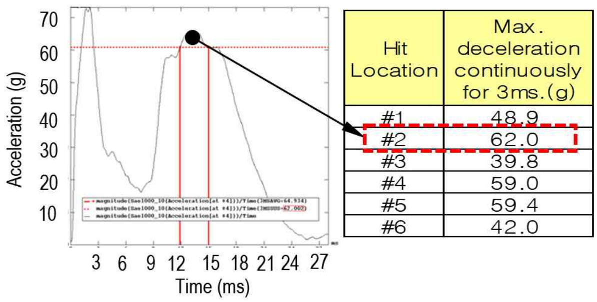


Fig. 3 Head form deceleration curve at #2 location

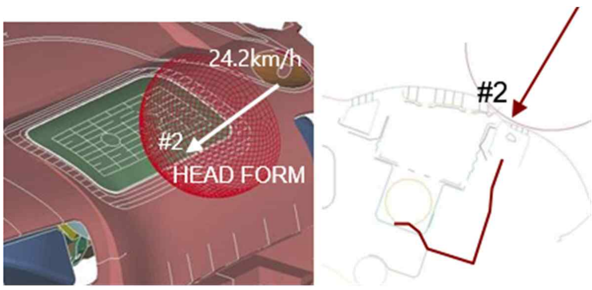


Fig. 4 Head form FE model used at #2

4. Advanced airbag modelling

Dual-stage inflators are widely considered to represent a major component of advanced airbag system. Fig. 5 shows dual-stage inflator used in this paper, which have two separate chambers for solid propellant. It can generally be ignited separately, with a time delay, or simultaneously, and is thereby capable of producing different pressure vs time histories. Depending on the ratio between the two chambers, these inflators are designated generally “X%:Y%”. It is shown the mass flow vs time history of single-stage and dual-stage (60%:40%, 70%:30%) inflators at −35°C as shown in Fig. 6. In this paper, the curve of 60%:40% at −35°C were used as the airbag input, because it's more difficult for the tearseam to tear out at the lower deployment pressure. For OOP to reduce the airbag-door risk related injury during airbag deployment, the top mount module and the minimized airbag door were considered. It was modeled airbag fabrics in the manner of two folding patterns, roll and zigzag as shown in Fig. 7.

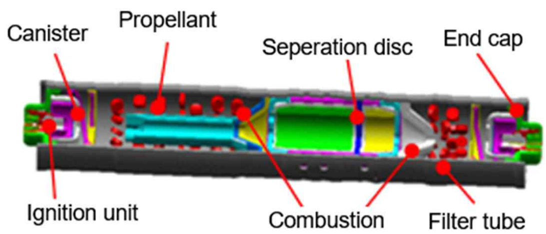


Fig. 5 Dual-stage propellant inflator

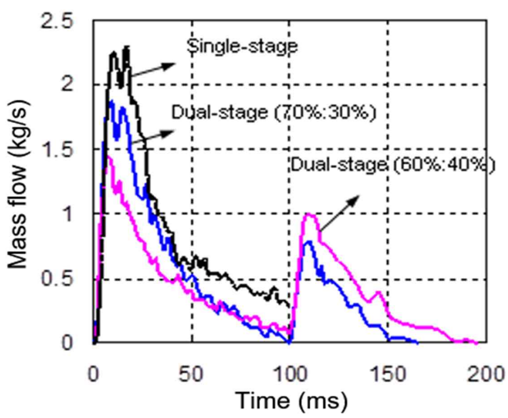


Fig. 6 Inflator mass flow-time curve

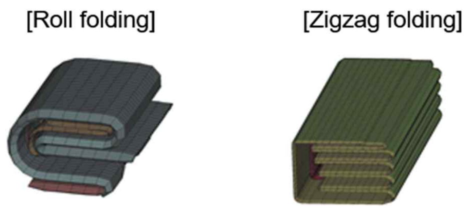


Fig. 7 Airbag folding patterns

5. Strain rate and temperature dependencies of material property

The mechanical properties of thermoplastic materials are strongly dependent on strain rate and temperature.(8) In such an impact analysis as airbag deployment or head impact analysis, it is very important to consider the effects of strain rate and temperature for the mechanical properties. During deployment or head impact, the door cover deforms and sometimes cracks along the tearseam rapidly at various service temperatures, so the strain rates on the tearseam are very high and different at each position.(9~11) In FE analysis, it was inputted the mechanical properties considering the different strain rates along the tearseam as shown in

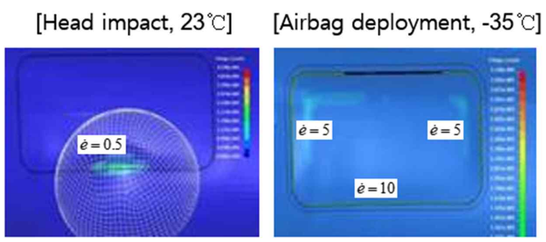


Fig. 8 Maximum strain rate distributions in the tearseam

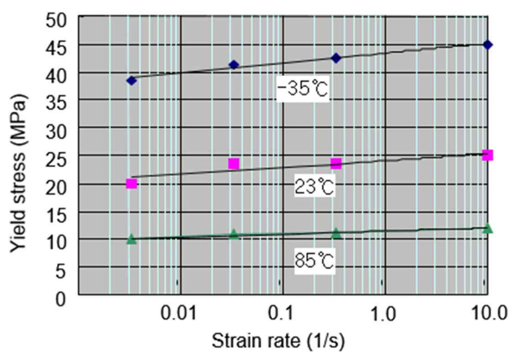


Fig. 9 Stress-strain curves at each temperature

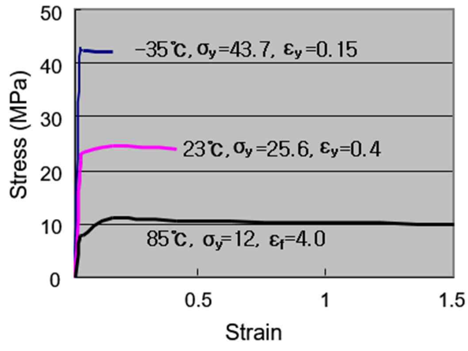


Fig. 10 Ture stress-true strain relationships at each temperature

Fig. 8. The tensile tests were carried out for IP material, rubber-toughened polypropylene (PPF). Fig. 9 shows the results of tensile tests at the varying ambient temperatures (−35°C, 23°C, 85°C). It shows that the yield stress is significantly dependent on not only strain rate but also ambient service temperature. This dependency must not be ignored. It shows the true stress-true strain relationships of PPF at the strain rate of 1(1/s) in Fig. 10. The failure strain is decreased and the tensile strength is increased when the ambient temperature becomes lower.(12~13)

6. Tearseam failure analysis

6.1. Tearseam modelling

Tearseam consists of a laser-scoring hole distributed at a regular distance. There are many types of the tearseam, depending on the pitch and depth arrangement. If the tearseam were solid modeled as it is, the computing cost would be increased excessively since the distance and depth of scoring hole are very fine. So, it was simplified the tearseam area just as the shell model and needed the alternative properties of the shell type tearseam model. To obtain the alternative properties as like the failure strength and strain of the tearseam, it was performed the tensile analysis for the simple tearseam model taken partially from tearseam area. Scoring details are proprietary information.(4,14~15) It is shown the simple specimen for tensile analysis

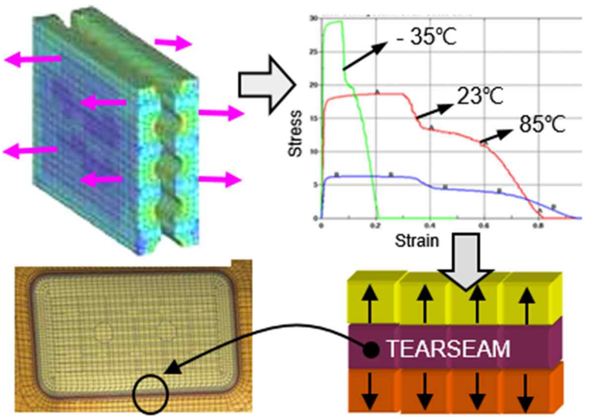


Fig. 11 Analysis model of tearseam

and the stress-strain curves at tensile of the tearseam model at the various temperatures in Fig. 11.

6.2. Tearseam failure criteria

To optimize design factors that affect the tearing of tearseam at deployment and head impact, it is necessary to measure the failure strength of tearseam precisely. It is the possibility of two different failure modes; ductile and brittle. In a ductile failure, the part fails in a slow, no catastrophic manner. In contrast, a brittle failure is characterized by a sudden and complete failure that, once initiated, requires no further energy to propagate. The failure mode of tearseam material is brittle at low temperature but ductile at normal and high temperature as shown in Fig. 10. Strain to failure criterion is used as the ductile failure criterion indicating when tearing is expected to occur. Brittle failure criteria have not yet been firmly established but maximum principal stress to failure had been used successfully. It shows the contour of stress and strain in the laser scoring section before rupture of tearseam in Fig. 12. Brittle failure at tearseam occurred when maximum principal stress is up to 50 MPa and ductile failure occurred when strain is up to 0.3.

7. Operating window method

The purpose of this study was to obtain the IPAB

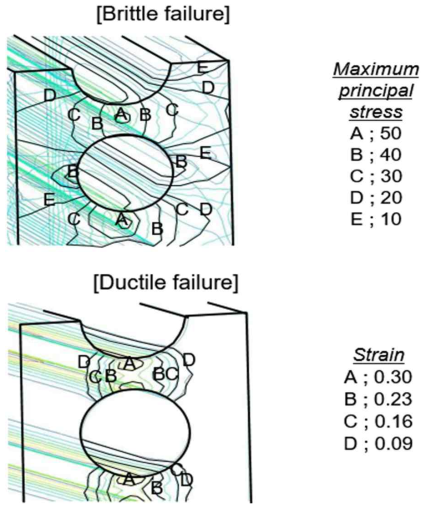


Fig. 12 Tearseam failure criteria

door system which would not experience failure mode during airbag deployment and head impact test. Failure mode included the cracked tearseam after head impact and the unintended airbag door opening during deploy-ment. It was used the idea of 'Operating Window', which means the range of working without failure, from quality engineering. The 'Operating Window' method is useful to optimize the system which has two contrary inputs and outputs. System diagram is shown in Fig. 13 and the output responses is shown in Fig. 14. It was selected for impluses of optimal FE analysis as likes;

X = Minimum impulse to tear the tearseam during deployment ($f_x \cdot t_f$) (smaller-the-better, at -35℃)

Z = Maximum impulse not to tear the tearseam at head impact ($f_z \cdot t_f$) (lager-the better, at 23℃)

In this study, the impulse is defined as the time integration of force to tear. The reason it is included the influence of time as well as force in the response is why the failure of the tearseam depends on the energy absorption of the structure in the IPAB door and a time term is related to energy absorption. By FE analysis, it was calculated the impulses at tearseam in condition of the deployment at low temperature and

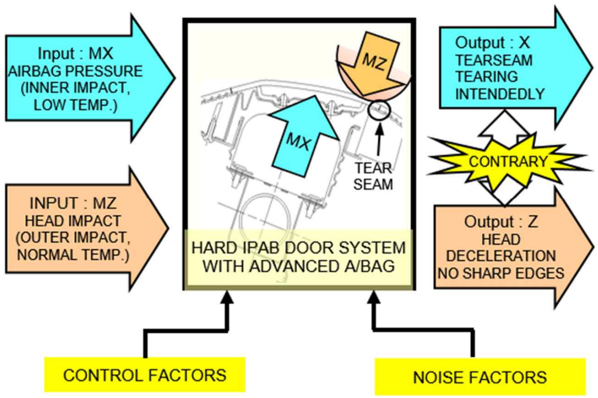


Fig. 13 System diagram of IPAB door

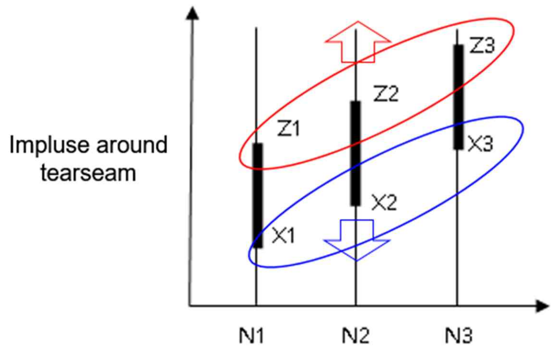


Fig. 15 Maximizing the operationg window for each of N1, N2, N3

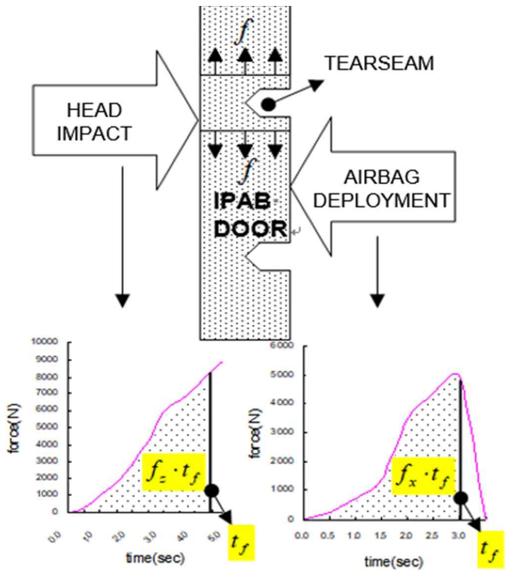


Fig. 14 IPAB system output responses

the head impact at normal temperature, since these conditions were severe. The operating window of the impulse between X and Z is the range in which the system functions well and larger−the−better. It means, the less X is, the better IPAB door open in airbag deployment, and the larger Z is, the more endurable the tearseam is without tearing in the head impact.

7.1. Noise factors of IPAB door system

IPAB door system was required to deliver its intended function over the car life, it was very important the noises of laser scoring process be identified. The variable processing factors of laser scoring yield the irregular depth and radius of scoring hole. The followings are the group of noises that could affect the IPAB door function.

N1: Noise factor which tend to produce the tearing failure mode in head impact test. Over scored hole (remaining depth: 0.12 mm, diameter: 0.4 mm).

N2: Standard operating condition (remaining depth: 0.15 mm, diameter: 0.35 mm).

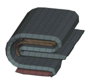
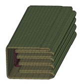
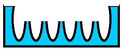
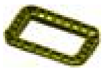
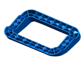
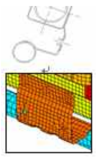
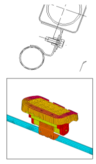
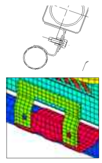
N3: Noise factor which tend to produce the irregular and late tearing failure mode in deployment test. Under scored hole (remaining depth: 0.18 mm, diameter: 0.3 mm).

The objective is not only to maximize a window under a given condition, but to maximize the window over all conditions as represented by the levels of noise as shown in Fig. 15.

7.2. Control factors and levels of IPAB door

It is listed the control factors and their levels in Table 1. The design variables which affect the deformation and failure of tearseam were selected as the control factors. To use an L18 orthogonal array, one control factor at 2 levels, 7 control factors at 3 levels were

Table 1 Control factors and levels of IPAB door

Control factors	1 level	2 level	3 level
A. airbag folding pattern	 roll	 zigzag	–
B. laser scoring pitch (mm)	0.50	0.55	0.60
C. laser scoring arrangement	 cut between hole	 Long–long	 Long–short
D. chute thickness (mm)	2.0	2.5	3.0
E. chute rib type	 1EA(2.0t)	 2EA(2.0t)	 2EA(2.5t)
F. door plate thickness (mm)	1.0	1.2	1.4
G. PAB mounting bracket thickness (mm)	1.0	1.4	2.0
H. PAB mounting bracket shape			

assigned. The compound noise factor was assigned to the outer array. To determine the optimum combination of control factors where X was minimized and Z was maximized, FE analysis was conducted. The S/N ratio for the operating window is the sum of smaller–the–better S/N(X) and larger–the–better S/N(Z) as shown in Equation (1). So the largest S/N ratio maximizes the operating window. The results of S/N ratio are shown in Table 2.

S/N (Operating Window)
= S/N(X, smaller–the–better) + S/N(Z, larger–the–better)

$$= 10\log\frac{1}{\frac{1}{n}\sum X_i^2} + 10\log\frac{1}{\frac{1}{n}\sum\frac{1}{Z_i^2}} \quad (1)$$

Table 2 L18 orthogonal array and S/N ratio result

	A	B	C	D	E	F	G	H	X			Z			S/N
									N1	N2	N3	N1	N2	N3	
1	1	1	1	1	1	1	1	1	5.2	6.5	7.8	16.4	20.5	24.6	9.51
2	1	1	2	2	2	2	2	2	5.6	6.6	7.9	15.2	19.0	22.8	8.60
3	1	1	3	3	3	3	3	3	5.0	6.6	7.9	17.0	21.0	24.1	9.64
4	1	2	1	1	2	2	3	3	5.5	6.9	9.5	18.0	22.5	27.0	9.20
5	1	2	2	2	3	3	1	1	5.0	6.3	7.6	18.2	22.8	29.0	10.80
6	1	2	3	3	1	1	2	2	6.0	7.0	8.4	20.0	25.0	30.0	10.45
7	1	3	1	2	1	3	2	3	7.2	9.0	10.8	22.0	26.0	31.2	8.97
8	1	3	2	3	2	1	3	1	7.4	9.2	10.0	21.1	26.4	37.0	9.32
9	1	3	3	1	3	2	1	2	8.4	10.5	12.6	21.0	26.2	31.4	7.47
10	2	1	1	3	3	2	2	1	4.0	5.0	6.0	16.8	21.0	26.0	12.05
11	2	1	2	1	1	3	3	2	4.5	5.1	6.1	15.6	19.5	23.4	10.99
12	2	1	3	2	2	1	1	3	4.1	5.1	6.4	18.0	20.0	24.0	11.67
13	2	2	1	2	3	1	3	2	4.5	5.6	6.7	18.4	23.0	27.6	11.80
14	2	2	2	3	1	2	1	3	4.2	5.3	6.3	19.6	24.5	29.4	12.91
15	2	2	3	1	2	3	2	1	5.4	6.0	7.5	17.6	22.0	28.0	10.52
16	2	3	1	3	2	3	1	2	6.8	8.5	10.2	20.0	25.0	30.0	8.90
17	2	3	2	1	3	1	2	3	6.4	8.0	9.9	23.7	26.4	34.0	10.36
18	2	3	3	2	1	2	3	1	8.0	9.5	11.4	16.8	21.0	25.2	6.32

7.2. Optimized levels of control factors

The operating window is maximized by selecting factors levels with highest S/N ratio. It is shown the response table for S/N is shown in Table 3. The IPAB door system designed with selected factor levels means that tearseam could be easily torn during deployment and endurable in head impact. Table 4 shows the prediction and confirmation for optimum case and it is gotten the S/N ratio that meant the possibility of satisfying the deployment and head impact performance simultaneously. Then the confirmation deployment and head impact tests were conducted and compared with FE analysis as shown in Fig. 16. Although the deployment pressure with dual stage inflator (60%:40%)

Table 3 Highest S/N ratio result for control factors

	A	B	C	D	E	F	G	H
1	9.33	10.41	10.07	9.68	9.86	10.52	10.21	9.76
2	10.61	10.95	10.50	9.70	9.70	9.43	10.16	9.70
3		8.56	9.35	10.55	10.35	9.97	9.54	10.46
△	1.29	2.39	1.15	0.87	0.65	1.09	0.67	0.76

Table 4 Prediction and confirmation for optimum case

	A	B	C	D	E	F	G	H	PREDICTION	CONFIRMATION
EXISTING	1	1	1	1	1	1	1	1	10.04	9.95
OPTIMUM	2	2	2	3	3	1	1	3	14.35	14.2
GAIN									4.31	4.25

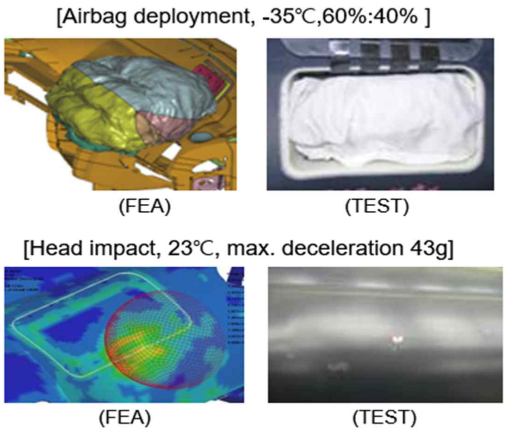


Fig. 16 Confirmation of FE analysis and test results

was comparative low, airbag deployed through the instrument panel in the predicted and balanced manner. And, there aren't only cracking or sharp edges but also the head deceleration became lower (43 g) in the head impact test.

8. Conclusion

To optimize the hard type IPAB door system, 'Operating Window' was used and successful confirmed with only a few tests. It was obtained the design factors that enhanced the possibility to deploy well for the inner airbag pressure and endure for the outer head impact. As a result, it was possible to apply the advanced airbag, which deployed with lower pressure at low temperature, to the hard types of IPAB door systems. The key factors of optimal design are as follows;

1) For airbag folding pattern, zigzag type was selected. That's why unfolding of the zigzag airbag lead to distribute the pressure on an airbag door fast and uniformly.
2) For laser scoring pitch and arrangement, the long-long type of middle pitch was selected because the strength of tearseam was neither strong nor weak. It was the most influent factor to affect the tearing.
3) For PAB mounting bracket, 3 level of PAB mounting bracket ('n' type) was selected. That's why it had the configuration to absorb the energy well in the head impact. And it was strong enough to support the reaction against airbag deployment.

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