Analysis of Crash Impact of Composites Stay-shaped Bumper using FEM Method

Byeong-Sam Kim*, Whanju Lee

Abstract—**The Bumper crash analysis encourages vehicle manufacturers to produce effective bumper systems that feature tall energy absorbing beams and crash boxes that are fitted at common heights and can effectively protect the vehicle in low speed crashes. The bumper systems should also have wide beams that protect the corners of the vehicle in low speed crashes (16 km/s). The analysis based on the RCAR(Research Council for Automobile Repairs) safety standards is done using a rigid wall impact with multiple materials. The finite element code is used for this study are LS-Dyna@. In this paper, the vehicle collision that occurred on the bumper-stay displacement according to energy absorbed that the amount of energy an integral measurement of the shape and bumper-stay beam depending on the amount of energy being applied to the difference between the finite element methods was used. The Stay shaped bumper structures exhibit bigger collision energy absorption capabilities of panel due to plastic deformation and the distribution of loading to the core region than metals.**

Keywords— Stay shaped bumper, FEM, Crush box, Bumper systems.

I. Introduction

A sandwich composite is usually composed of stay shaped bumpers faceplates and a core, usually either a honeycomb or a metal shaped. The constituents assume distinct functions to assure the structural integrity of the sandwich. In general, the core bears all the shearing stresses. It thus has to be stiff enough to keep the faceplates separated, it has to exhibit a high resistance to shear deformation so that the laminates don't slide over one another during bending and in order to prevent wrinkling of the faceplates, the core needs to be stiff enough to keep the laminates nearly flat.

The vehicle's crash analysis was used to the body structural analysis and occupant passenger behavior analysis. Analysis of the body structure has the kinetic energy of the body resulting from the absence of skeletal body collision energy can be transformed through a body that has a lot to absorb crash energy is delivered to passengers is to reduce the crash energy[1]. In contrast, the seat of the occupant behavior analysis, seat belts, such as airbag restraint systems through the passenger has a purpose, trying to reduce the injury value. In this paper, safety tools of passenger injury, but at less cost reduction has been much research. When the cause of vehicle crashes, the passengers inside the vehicle and the vehicle must be able to afford the same rate changes and can be free from injury. If the passengers inside the vehicle can move freely without restraint from the vehicle during a collision with the passenger's velocity relative to the speed of the car has a large value is formed inside the vehicle and the resulting severe clashing in some part by slowing the fatal injury. However, in the passenger seat belt is to be bound by the movement that causes the deceleration of the body more time can be extended and passengers also can shrink the size of the damage that will be less. By using composite materials, bumper structure will lead to a weight loss of vehicle weight, lower fuel consumption and pollutant emissions of greenhouse gases, and high resistance to impact and corrosion.

II. Stay Shaped bumper model

A. Characterization of Impact Resistance

In order to protect the passengers during an impact, a structure based on strength and stiffness is far from optimal. The structure should rather collapse in a well-defined deformation zone and keep the force well below the dangerous accelerations. However, since the amount of absorbed energy equals the area under the load-deflection curve, the two criteria mentioned above are somewhat contradictory. This shows that it's not enough to know how much energy is absorbed, but also how it is absorbed, i.e. how the inertial load is transferred from the impact point to the panel supports. However, most of the research done so far on the characterization of the crash resistance of different materials has been based solely on energy absorption. In the following chapter are described some parameters proposed in a previous work [2] as a tool for a more adequate comparison of different panels. The need of additional data required the design of an "*ad-hoc*" ball-drop impact tester, which is described reference [3].

B. RCAR Standards

The automobile bumper weight can be reduced by the use of composite and high- strength metallic stay sheet of a thin material. In creating the finite element model, the 2D shell

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element, shell model, is used to mesh the car bumper surface. RCAR standards. The material of the bumper surface is ABS, and the materials of the impact ball-towing hook are steel. RCAR(Research Council for Automobile Repairs), is an international organization that works towards reducing insurance costs by improving automotive damage ability, repair ability, safety and security by low-speed offset car crash standards test. This test vehicle speed shall be 16 km/h within a one-meter distance from the barrier. The barrier offset of the test vehicle is 40 %. The barrier is skewed in a 10 degrees barrier angle and has a radius of 150 mm as shown in Fig. 1[4],[5].

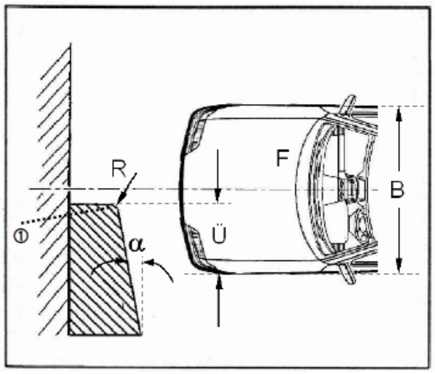

Fig. 1. Scheme of RCAR standards test

In case of front bumper, the impact absorption performance is improved so as to be suitable for low-speed 16 km/h, 40% offset collision, and the crush box type is improved by applying the split type supply and the crush box type. As shown, the past bumper of the passenger car was designed to meet the 2.5 mile certification standard, but the 8 mile bumper was applied to improve the shock absorption as shown in Fig. 2.

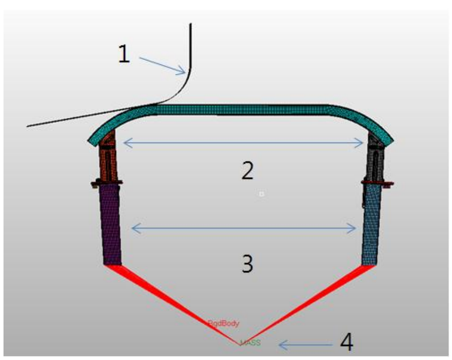

Fig. 2. Bumper test condition on RCAR standards

C. Impact Simulation by FEM

Experimental crashworthiness testing is, by its very nature, destructive. As such, even if testing could be conducted on a reduced scale or on a selected component basis, it is likely that a wholly experimental approach to the design and validation of a crashworthy structure would be prohibitively expensive. Finite element techniques which are capable of predicting the behaviour of the system under loading are therefore of great interest to crashworthiness engineers [3].

The front bumpers are fixed on the front and on the back side of a vehicle for the protection. The bumpers are designed and shaped in order to deform it and absorb the force during a collision. The bumper structure consists of three parts: a bumper cover, crash box and a bumper rail frame in Fig. 3.

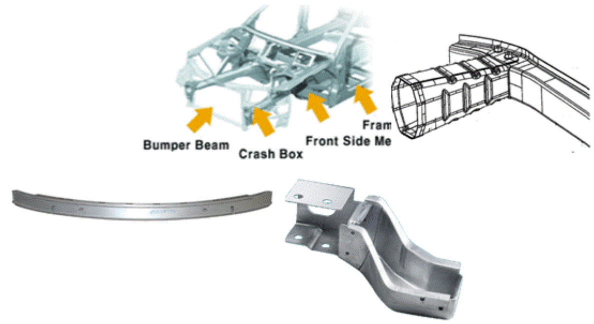

Fig. 3. Scheme of front bumper system compenents (bumper beam, crash box, and frame)

III. FEM ANALYSIS

A. Finite Elements Model

The finite element analysis is the simulation of a physical system (geometry and loading environment) by a mathematical approximation of the real system. Using simple, interrelated building blocks called elements; a real system with infinite unknowns is approximated with a finite number of unknowns. This discretisation of a structure allows the modeling of complex problems. The solutions are calculated only for a finite number of points called nodes, which define the corners of the elements. The impact problem can be solved with a transient dynamic analysis which is a technique used to determine the dynamic response of a structure under the action of any general time-dependent loads. This analysis is used to determine time-varying displacements, strains, stresses and forces in a structure as it responds to any combination of static, transient and harmonic loads. The basic equation of motion solved by transient dynamic analysis is:

$$[M]\{\ddot{u}\}+[C]\{\dot{u}\}+[K]\{u\}=\{F(t)\} \tag{1}$$

Where [M] is the mass matrix and [C] the damping matrix

B. Implicit and Explicit Integration Schemes

There exist two possibilities to solve these equations: by implicit or explicit integration. The implicit integration mode in Abaqus[6] and LS-Dyna [7] is based on the "Newmark method" where as the explicit integration uses the "central difference method". The basic difference lies in the fact that for implicit integration the displacement vector at time (t+Δt), i.e. $\{u\}^{t+\Delta t}$, is calculated by using the equilibrium equation (1) at time (t+Δt) where as in the explicit method the same solution is calculated by using the equilibrium conditions at time t. This implies that in explicit integration the stiffness matrix [K] doesn't have to be factorised to find the solution $\{u\}^{t+\Delta t}$. However, this method is only conditionally stable which means that the integration time step Δt needs to be smaller than a critical time Δt_{cr} in order to achieve a stable solution.

In implicit integration, the time step Δt can be much larger than Δt_{cr}, but the stiffness matrix [K] appears as a factor of our required solution $\{u\}^{t+\Delta t}$, thereby increasing the calculation time. The explicit integration method supplied by Abaqus through the *LS-Dyna*@ solver is said to "provide fast solutions for short-time, large deformation dynamics and complex contact/impact problems" [8]. This method seems therefore adapted to solve a three-dimensional impact problem.

It was found [9] that the impact load didn't correspond to the measured load carried by the cells supporting the panel since part of it was used for inertia effects. This relationship can be expressed in the following manner:

$$[P]_i = \{F_{Inertia}(t)\} + \{F_{celles}(t)\} \qquad (2)$$

The maximum moment of flexion is defined by:

$$[M]_{\max} = \frac{1}{2}\{P_{IMax}(t)\}/2 \qquad (3)$$

Where I is the span of the panel between supports

The following values were proposed to characterize the crashworthiness of sandwich panels, where ΔE is the energy difference of the dart between before and after the impact and s_{max} the maximum deflection or maximum (negative) dart displacement. Absorbing Energy and Moment Parameter:

C. RCAR Model

The overall shape modeling for the RCAR 3D simulation is shown in Fig.4, with front bumper (0.9t), rear beam (1.6t), each crush box RH, LH outside thickness (1.6t) and inside thickness (1.8t), and 26 parts files are assembled in the order of back plate (2t) and side member (1.6t). The angle of the barriers at the front of the front bumper is 10 °, the mass is 1400 Kg, which is the RCAR specification, the back plate and the side members are fixed to measure the force, the compression collapse occurs when the shape of the crush box changes And the force and displacement generated between the crush box and the back plate are measured.

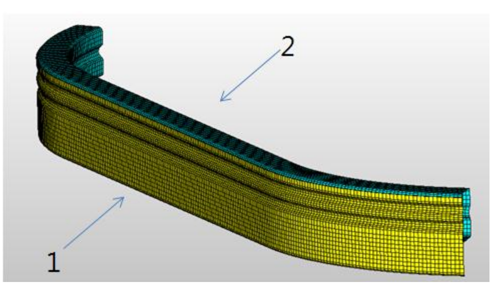

Fig. 4. Bumper test with front bumper (1) and Back beam (2)

The results of compare the in each case, differences of the front bumper for comparative analysis, each modeling is shown in Fig. 4. Each case carries out a comparative analysis by making three cases from a normal bumper with no grain pattern, a front bumper with a grain pattern, and a bumper with a grain pattern on both sides of the front bumper and back beam.

D. RCAR Analysis

The RCAR analysis was carried out at a low speed collision condition in which a front bumper with a mass of 1400 kg was collided with the barrier at a speed of 16 km/s as stipulated. The front bumper shape of three cases is prepared and the result data of three cases are compared and analyzed through the same type of crush box. At this time, the scale factor in the analysis is set to 1. As a standardized data for medium-sized vehicles, displacement from 80 to 100 mm from the crush box becomes a criterion that does not involve the radiator. In this paper, we compare the amount of energy absorbed by measuring the amount of energy from 80 to 100 for accuracy. Basically, the physical properties of steel were input. In order to prevent infiltration through the contact of the contact surface, the rigid relationship between the side member and the back plate and the master and slave relationship between the back plate and the crush box were prevented [10].

TABLE I: DIFFERENCE IN ENERGY ACCORDING TO F-D CHART BY CASE

	Case 1	Case 2	Case 3
Contact Force(KN)	109	119	121
Displacement(mm)	**Energy(J)**	**Energy(J)**	**Energy(J)**
80	5.1e+6	5.48e+6	5.49e+6
90	5.67e+6	6.05e+6	6.1e+6
95	6e+6	6.36e+6	6.43e+6
100	6.35e+6	6.686e+6	6.77e+6

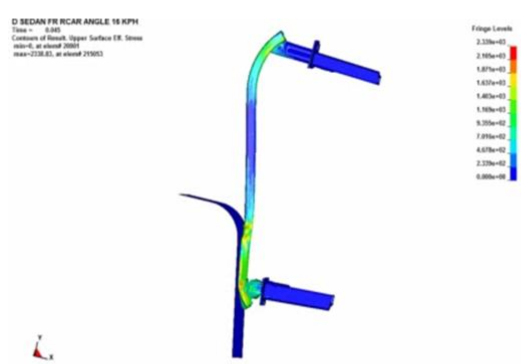

Fig. 5. Bumper FEM analysis with RCAR condition(15 km/h)

E. Results of Bumper Analysis

The analysis of the low speed impact analysis according to the shape of the front bumper of the three cases was performed in Fig. 5. As shown in Table 1, the amount of energy up to 80 ~ 100 mm of universal displacement based on the medium-sized standard is measured, and the amount of energy can be obtained by integrating the F-D line. Energy represents the amount of energy delivered to the back plate through the front bumper and crush box during impact and case 3 shows the best energy absorption at the same displacement. Therefore, it was found that the energy absorption rate was increased with the presence of the grain pattern. The Fig. 6, Fig. 7 and Fig. 8 shows that the absorption rate of energy with or without the grain pattern is improved.

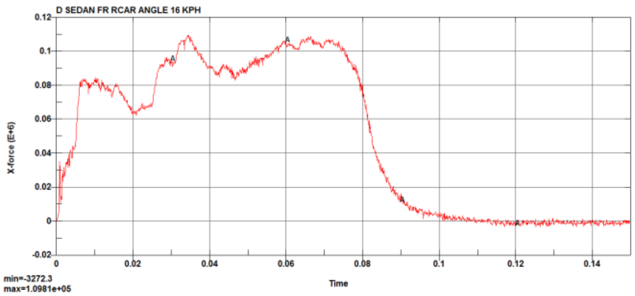

Fig. 6. .Absorption rate of energy bumper FEM analysis with case 1 (only Front bumper)

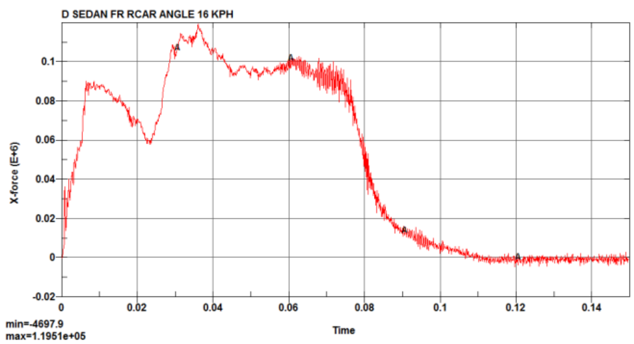

Fig. 7. Absorption rate of energy bumper FEM analysis with case 2 (Front bumper grain)

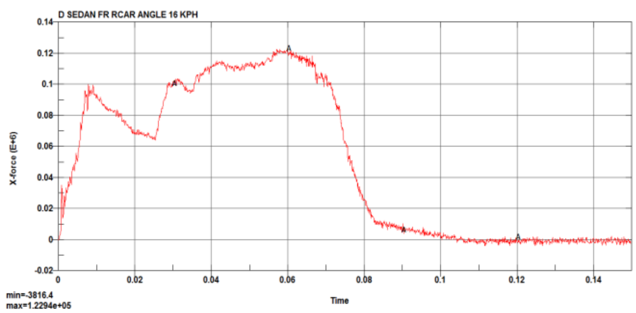

Fig. 8. Absorption rate of energy bumper FEM analysis with case 3 (Front bumper, back beam grain)

F. Crush Analysis

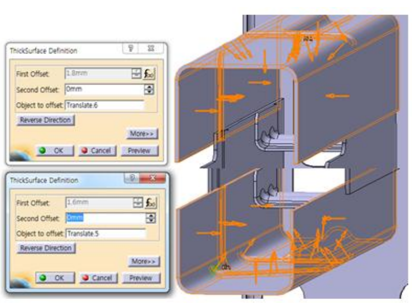

Fig. 9. Crush box in case 1 (INR 1.8t, OTR 1.6t)

Basically, the bumper crush box is a shock absorber in which the shape of each of the crush boxes OTR and INR is a crush box through welding. The impact force is transmitted to the vehicle body through the front bumper, the crush box and the side member serves as a perforation line to induce compression collapse so that the shape of the crush box can be folded well and absorbs energy. Each crush box OTR(outside thickness). and INR(inner side thickness) is 1.6t and 1.8t, shown in Fig. 9. The case 1, which is not formable by variable design through forming, case 2, OTR, INR, which exists only in crush box OTR Finally, case 3 in which foaming is present.

Fig. 11. No Crush Box Foaming analysis in Case 1

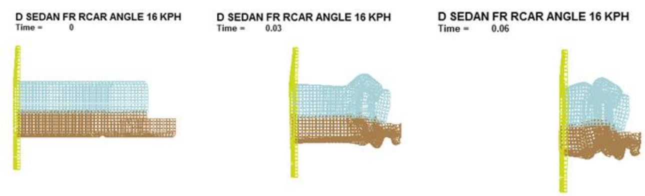

Fig. 12. OTR crush box foaming analysis in Case 2

Fig. 13. OTR, NTR crush box foaming analysis in case 3

These 3 cases variables for crush box forming were generated and analyzed at low speed. In the above test, as in the case of the bumper test, it is a test to hit the wall at a speed of 16 km / s. As a test to see the amount of energy absorbed by displacement with or without foaming, the same result as Fig 11, Fig 12 and Fig. 13 was obtained. In addition, the presence or absence of forming can be found by measuring the displacement every 0.03 seconds due to the shape change over time, and the displacement of the forming due to the compression collapse is shown in Table 2. In case 3, the displacement of 0.03 second was the least, but the first folding of 0.06 second collapsed and the displacement rapidly increased.

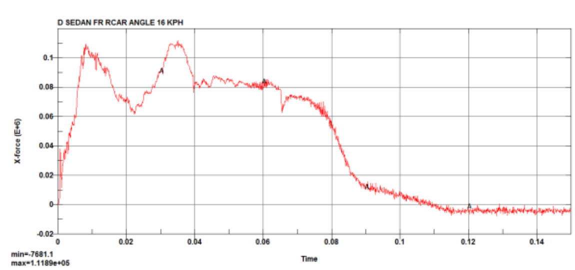

Fig. 14. Absorption energy in case 1(No Crush Box Foaming)

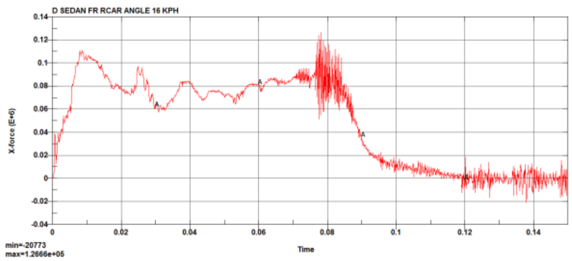

Fig. 15. Absorption energy in case 2(OTR crush box foaming)

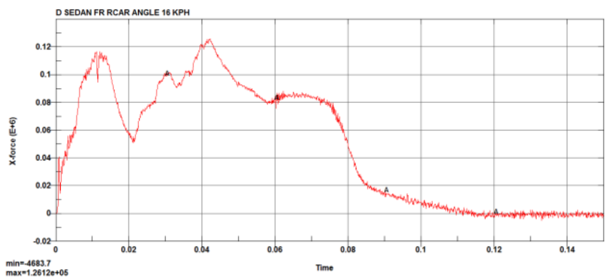

Fig. 16. Absorption energy in case 3(OTR, NTR crush box foaming)

In case 1 without forming, the amount of energy absorbed for 114KN absorbs significantly less when case 2 and case 3 are compared. In cases 2 and 3, only the crush box OTR forms, The crush box OTR and INR forming cases show that the energy absorption rate is higher than that of case 1, which has no foaming. As shows in Fig. 14, Fig 15 and Fig 16, the crush box formations induce compressive collapse at the foaming sites in cases 2 and 3, compared to case 1 where the shape changes indiscriminately at 0.03 sec. The presence or absence of foaming is meaningful in reducing the impact energy that absorbs energy and transmits energy to the body by folding the crush box well. This test is used to derive the results according to the presence or absence of foaming, It was clear.

TABLE 2: DISPLACEMENT OF THE FORMING IN EACH CASE

	Case 1	Case 2	Case 3
Contact Force(KN)	114	124	121
Displacement(mm)	**Energy(J)**	**Energy(J)**	**Energy(J)**
80	5.48e+6	6.17e+6	6.18e+6
85	5.81e+6	6.45e+6	6.56e+6
90	6.113e+6	6.76e+6	6.94e+6
95	6.42e+6	7.11e+6	7.36e+6
100	6.76e+6	7.051e+6	7.79e+6

IV. RESULTS AND CONCLUSION

A. RESULTS

As a result of the above two analyzes, it was found that the amount of energy absorbed in the shape of the crush box was larger than that of the front bumper. Therefore, based on the existing data, the parameters are assigned to the crush box thickness and analyzed. In this results, we compared the conventional case 1(INR 1.8t, the OTR 1.6t) crush box and the crush box with two cases with variable. Case 2, designated as a variable, designated case 2 (1.8t ~2.3t) for INR (1.8t~2.1t) for case 3, (1.8t ~2.3t) INR 2.8t for OTR, and 2.6t for OTR. We compare the amount of shock absorption that occurs in the model with each variable and investigate the correlation according to the thickness. The thickness of the crush box was compared with that of the existing one. In the conventional crush box, INR and OTR are increased by 0.5mm each, and the results are shown in Table 2. The amount of displacement varies depending on the thickness, and the amount of force varies as shown in Fig. 14, Fig. 15, and Fig. 16. In case 2, there was no significant effect on displacement but there was a difference in external force. In case 3, there was a large difference in displacement and energy amount was greatly reduced.

Therefore, the thickness of the crush box specified by the variable has a great effect on reducing the external force acting as shows in Fig. 17, Fig 18 and Fig 19,. However, an indiscriminate increase in thickness can not sufficiently absorb the amount of energy during impact, so that the impact can be transmitted to the driver in the car, so that the thickness of 3 mm specified by the supplier is not exceeded.

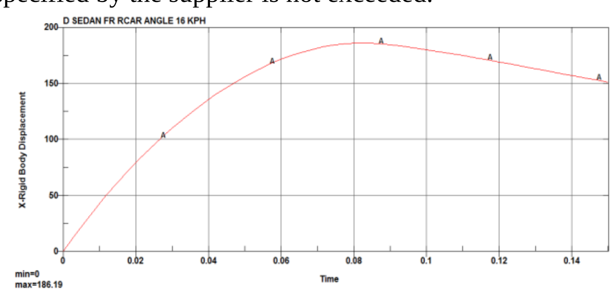

Fig. 17. Maximum displacement in each case(114kN, Case 1)

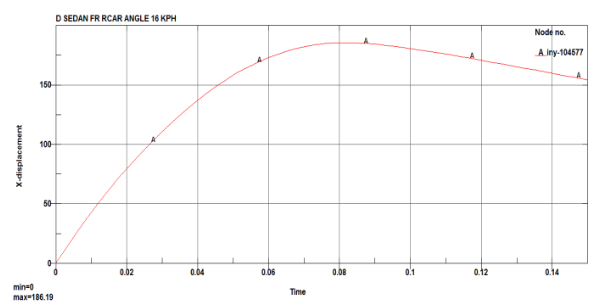

Fig. 18. Maximum displacement in each case(118kN, Case 2)

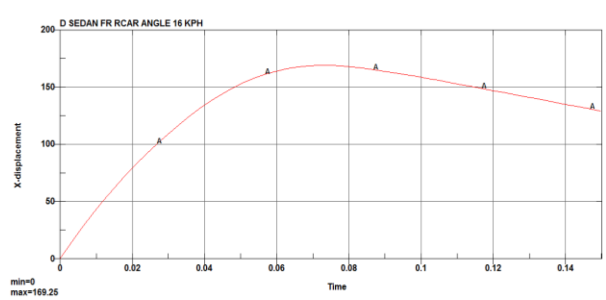

Fig. 19. Maximum displacement in each case(121kN, Case 3)

A. CONCLUSION

In this paper, we provide basic data on stress distribution, displacement, and energy occurring during collision by performing RCAR low - speed collision analysis. The model analysis of the bumper with grained pattern and the bumper with no pattern at the same low speed collision condition showed a sufficient difference in the amount of energy to measure and absorb 80-100 mm section. In addition, a clear difference was found by comparing the front bumper with the bumper with the grain pattern, the front, and the back beam bumper, respectively. It is proved that the analytical results are valid by comparing the overall measurements for a large section rather than a simple section.

From the modeling analysis according to the OTR and INR formations of the bumper crush box, the displacement difference according to the foaming was found at 0.03 0.06 0.09 due to the compressive collapse phenomenon occurring in the crush box at the time of collision. It was found that the fast compression collapse absorbs a large amount of energy in a small amount of time.

Through these RCAR low-speed crash tests, non-life insurance companies and automobile companies will continue to provide information on the repairability and impairment studies for future reductions in repair costs, As the information becomes more sophisticated as customers become more sophisticated, low-speed crash tests between companies with better results will be competitive in the automotive market.

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