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EXPERIMENTAL EVALUATION OF USED CARS FOR FRONTAL COLLISION COMPATIBILITY

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ABSTRACT–This research investigates injury values and vehicle deformation for vehicle frontal crash compatibility. To investigate compatibility in an individual case, it is possible to impact two vehicles and evaluate the injury values and deformations in both vehicles. In this study, four tests were conducted to evaluate compatibility. A large and mini vehicle were subjected to a frontal car-to-car crash test at a speed of 48.3 km/h with an offset of 40%. An inclination car-to-car crash test using the large and small vehicle were conducted at 30 km/h at a 30° angle. The results of the 48.3 km/h, car-to-car frontal crash revealed extremely high injury values on the chest and upper leg of the Hybrid III 50% driver dummy with seatbelt in the mini vehicle compared to the large vehicle. For the 30 km/h, car-to-car inclination crash, however, injury values in the small vehicle were 1.5 times higher compared to the large vehicle.

KEY WORDS : Crash compatibility , HIC (Head Injury Criterion), Standard curb weight, AIS (Abbreviated Injury Scale)

1. INTRODUCTION

Many of today's crash tests impact the vehicle into a rigid or offset deformable barrier, even with the development of crash tests for safety assurance during stages of the design verification process where actual crash tests are conducted (Mizuno *et al.*, 2003). These rigid barrier crash tests are very effective in evaluating the safety performance of the vehicle's chassis in terms of repetitive tests and convenience. However, the single-bearing rigid barrier crash test is limited in the actual realization of evaluation factors for car-to-car crash accidents that occur in real life (O'Neill and Kyrycheonko, 2004; Yuichi and Chinmoy, 2001), thus leading to challenges of the results. This point has led to securing car-to-car crash compatibility caused by a vehicle structure mismatch. In fact, the research on the dangers that the car's passenger is exposed to in a small vehicle caused by a weight mismatch with a large vehicle has been inadequate to say the least (Koji *et al.*, 2003). This paper is focused on securing not only the vehicle's crash worthiness, but also the reciprocal crash compatibility, resulting in an automobile design that achieves crash compatibility of the chassis in a high-speed accident. Frontal crash tests with a large vehicle colliding with a mini vehicle (car-to-car, 48.3 km/h 40% offset), and between a large and small vehicle with different geometrical structures in an inclination (car-to-car, 30 km/h 30° angle) crash test have been conducted to analyze the damaged parts of the car and dummy injury characteristics.

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2. HUMAN INJURY EVALUATION METHOD

The most typical factors of evaluating the characteristics of human injury are HIC (Head Injury Criterion), chest acceleration, compressive force of each upper leg, etc, with HIC being expressed as follows (Park, 1999): a is resultant acceleration of the head ($g = 9.81\ m/s^2$). t_1 and t_2 are any two points not more than a 36 millisecond time interval for HIC criterion.

$$HIC=\left[\frac{1}{(t_2-t_1)}\int_{t_1}^{t_2} a(t)dt\right]^{2.5}(t_2-t_1) \tag{1}$$

The potentialities of head and chest injury, as well as a compound (head and chest) injury potentiality of AIS≥4, can be directly calculated by applying the injury risk as follows (Park, 1999):

$$p_{head}=\{1+\exp[5.02-0.00351\times HIC]\}^{-1} \tag{2}$$

$$p_{chest}=\{1+\exp[5.55-0.0693\times CHEST\ G]\}^{-1} \tag{3}$$

Table 1. Experimental conditions for car-to-car crash test.

Test vehicle	Test vehicle weight (kg)	Crash speed (km/h)	Engine displacement (cc) Front sidemember height (mm)	Remarks
Large Car	1,513	48.31	1,997 cc, 460 mm	48.3 km/h 40% offset (1,997 year, seat belt)
Mini Car	896	48.37	799 cc, 420 mm	
Large Car	1,490	30.13	1,997 cc, 440 mm	30 km/h 30° angle (1,996 year, seat belt)
Small Car	1,115	30.37	1,495 cc, 420 mm	

3. TEST APPARATUS AND METHOD

This crash test utilized a speed actuator apparatus, steering motor, guide cable transmitter, radio remote control, etc. (collectively known as the Electronically Controlled Vehicle System) to evaluate the compatibility in a multi-bearing car-to-car crash test. Test vehicles were positioned 100m apart with a crash error tolerance of ± 1%. Each vehicle's power switch was set in the "ON" position for auto drive, and the vehicle weight was the standard curb weight plus the driver's 75 kg. Hybrid III 50% male dummies were positioned in the driver's seat, with accelerometers (750 g, 7.357 m/sec square) to measure injury rate and load cells attached to the dummy's head, chest, thorax, upper leg, upper neck, etc. A high-speed camera (Frame rate: 3,000 fps, resolution: 512 × 480) was installed to measure the amount of car deformation and the behavior of the dummy at impact. Test conditions were shown as Table 1. 48.3 km/h with a tolerance of ± 1 km/h at a 40% frontal offset between the large and mini vehicle, and 30 km/h 30° angle inclination between the large and small car.

Figure 1. shows the car-to-car crash test materials for data collection.

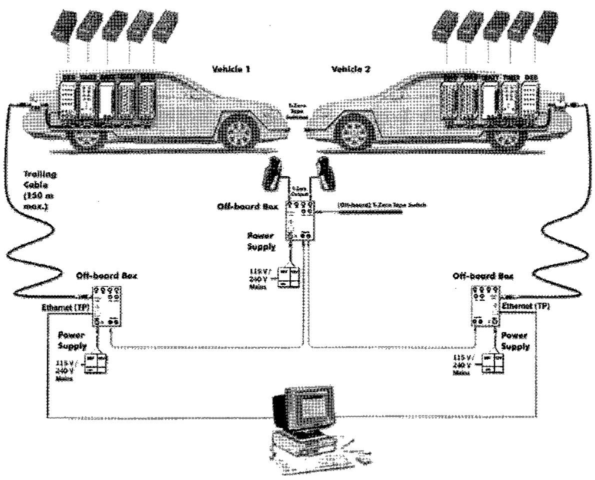
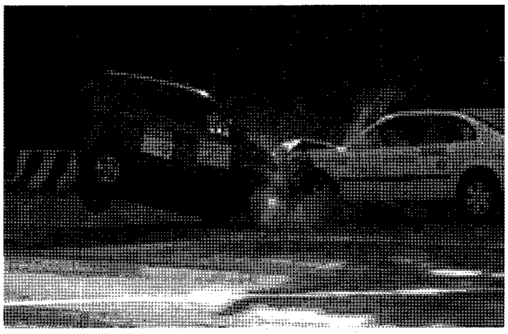


Figure 1. Car-to-car crash test with on-board boxes configuration diagram.

4. TEST RESULTS AND STUDIES

Car-to-car frontal and inclination crash tests were conducted as shown in Figure 2 and 3, between large and mini vehicles, and large and small vehicles, respectively.

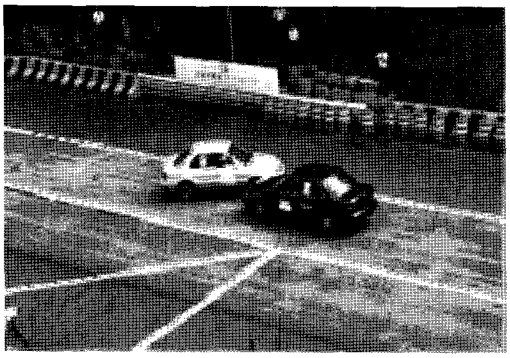
The results of the frontal crash showed extremely high injury values on the chest and upper leg of the person in the mini vehicle compared to the large vehicle; the same injury value was 1.5 times higher for the inclination crash in the small vehicle compared to the large vehicle, however.



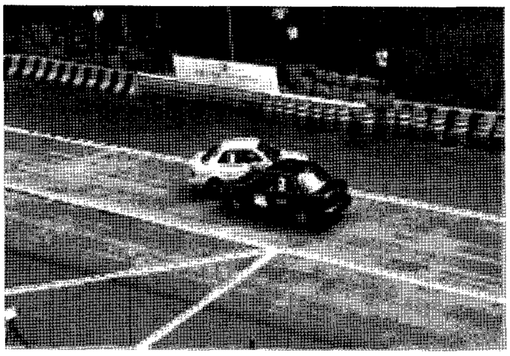
(a) Car-to-car frontal crash test between large and mini vehicles

(b) Car-to-car frontal crash test between large and mini vehicles

Figure 2. Car–to-car frontal crash test at 48.3 km/h with a 40% offset between large and mini vehicles, with ECV.



(a) Car-to-car inclination crash test between large and small vehicles



(b) Car-to-car inclination crash test between large and small vehicles

Figure 3. Car-to-car inclination crash test at conditions of 30 km/h and a 30° angle between large and small vehicles, with ECV.

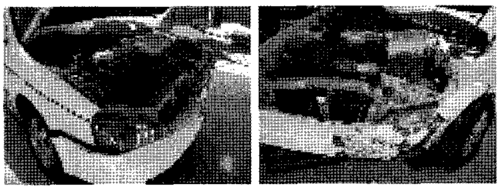
4.1. Analysis of Vehicle Deformation Characteristics

On the 48.3 km/h 40% offset car-to-car crashed large vehicle, there was significant damage to the front side member, cowl panel, dash panel, front pillar, side sill panel, airbag, etc. shown in Table 2, while the passenger area showed moderate conditions. In the case of the mini vehicle, extensive damage was found in the engine compartment, passenger area, as well as severe deformation on the entire body panel. Most importantly, the driver's side, where the impact actually occurred, was found to have experienced damage considered fatal to the driver. This demonstrates the fact that the mini vehicle has a lower structural stiffness and is unable to absorb as much of the total impact energy as the large vehicle (Kim and Heo, 2003; Kim *et al.*, 2005). Despite the larger early movement energy of the large vehicle because of its heavier weight, most of the resulting impact energy is absorbed by the mini vehicle (Lim *et al.*, 2005). Considering these findings, the maximum value of the reciprocal impact energy depends greatly on the comparatively lower structural stiffness and front end geometry of the mini vehicle (Kim *et al.*, 2003).

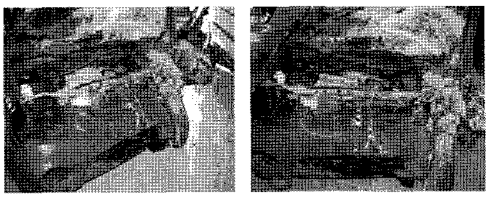
Table 2. Damaged parts of car-to-car crash test vehicle.

Car parts	Damaged contents				Remarks
	48.3 km/h 40% offset		30 km/h 30° angle		
	Large car	Mini car	Large car	Small car	
Front side member	X	X	X	X	X: Damaged part
Hood	X	X	–	X	
Radiator	X	X	–	–	
Condenser	X	X	–	–	
Front panel	X	X	X	X	
Sub-frame	X	X	-	X	
Engine assembly	–	X	–	–	
Front pillar	–	X	–	X	
Center pillar	–	X	–	X	
Roof panel	–	X	–	–	

These results indicate that a design capable of distributing the continuous impact load and preventing bulging can secure the safety of the vehicle, prevent the transition of the impact energy into the passenger area during car-to-car crashes between vehicles of different geometrical structures, and improve the performance of the car during a frontal crash by constraining the sudden change of impact load (Kang and Huh, 2000), thereby securing the compatibility of a mini vehicle. The large and small vehicle 30 km/h 30° inclination crash test



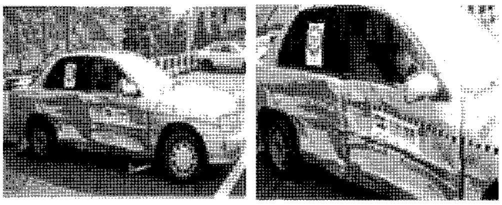
(a) After crash test of a large car



(b) After crash test of a mini car

Figure 4. Damaged type of test vehicle at 48.3 km/h with a 40% offset car-to-car crash test.

(a) After crash test of a large car



(b) After crash test of a small car

Figure 5. Damaged type of test vehicle at 30 km/h with a 30 angle car-to-car crash test.

showed no significant movement in the large car, but a 75° spin and a 5-meter slip in the case of the small car. The front bumper and front panel were slightly damaged on the large car, but the small car showed greatest damage on the side, including the front bumper, front panel, rear door, sidestep panel, front pillar, center pillar, etc. Figure 4 and 5. show the extent of damage to the test vehicles after the car-to-car crash test.

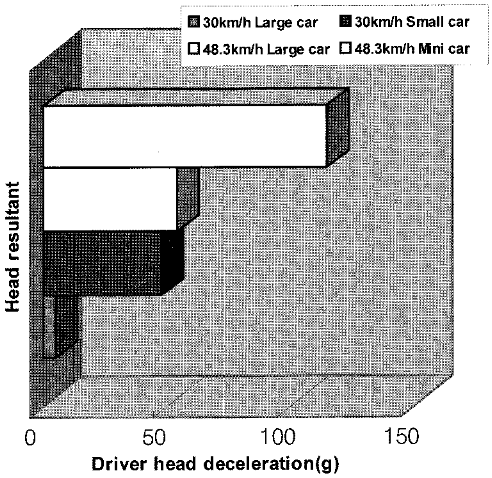
4.2. Analysis of Human Injury Characteristics

By analyzing the HIC, chest acceleration (G), and maximum femur load (kN) values of the Hybrid III 50% male dummy placed in the test vehicles, Figure 6. reveals the mini vehicle "passenger" sustained fatal injuries to the upper leg from direct contact with the crash pad. During the 48.3 km/h and 40% offset car-to-car frontal crash test, chest acceleration, and maximum femur load showed a significant difference compared to the 30 km/h 30° inclination car to car crash test.

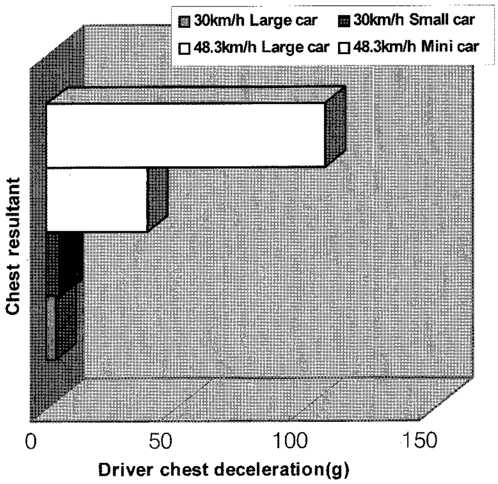
Analyzing the chest acceleration (G) and injury probability (AIS4) for each of the car-to-car crash tests reveals a less than 5% injury probability for both the large and small vehicles at the 30 km/h 30° inclination crash test as shown in Figure 7. and less than 10% injury probability on the large vehicle at the 48.3 km/h 40% offset frontal crash test. However, the mini vehicle showed an 80% injury probability, which is considered fatal to the dummy body.

In car-to-car crashes, frontal or offset crashes have a higher probability of harming the dummy body than inclination crashes.

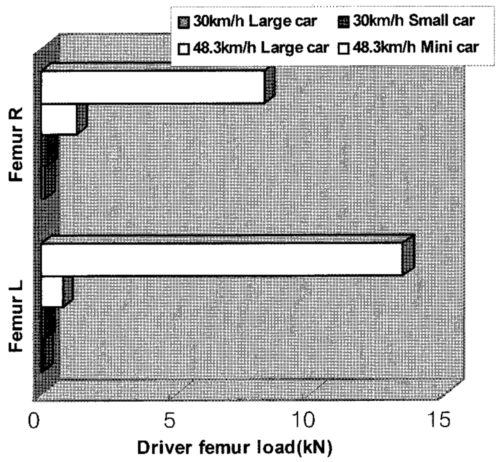
In the car-to-car frontal crash test at 48.3 km/h with a 40% offset between the large and mini vehicle, the HIC value was satisfied with the Korea motor vehicle safety



(a) Driver head deceleration for Hybrid III 50% male



(b) Driver chest deceleration for Hybrid III 50% male



(c) Driver femur force for Hybrid III 50% male

Figure 6. Injury Comparison of Head (G), chest (G) and femur load (kN) for Hybrid III 50% male driver in the test vehicle.

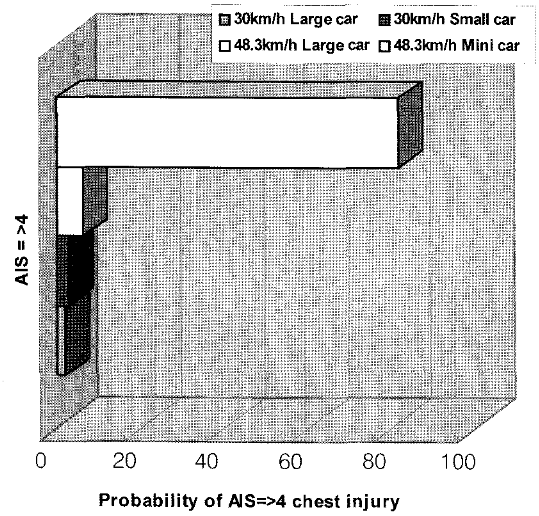


Figure 7. Risk of AIS4 injury (%) to chest regions in frontal car-to-car crashes.

standards, although the head injury value in the mini vehicle (751.9) was 2 times higher than in the large vehicle (359.8). The chest acceleration value (3 ms-A,g) in the mini vehicle is extremely high compared with large vehicle. The compressive force of each upper leg (kN) for the dummy in the mini vehicle is extremely high, which represents a fatal injury resulting from a direct impact of the dummy's femoral region with the vehicle's crash pad and seat.

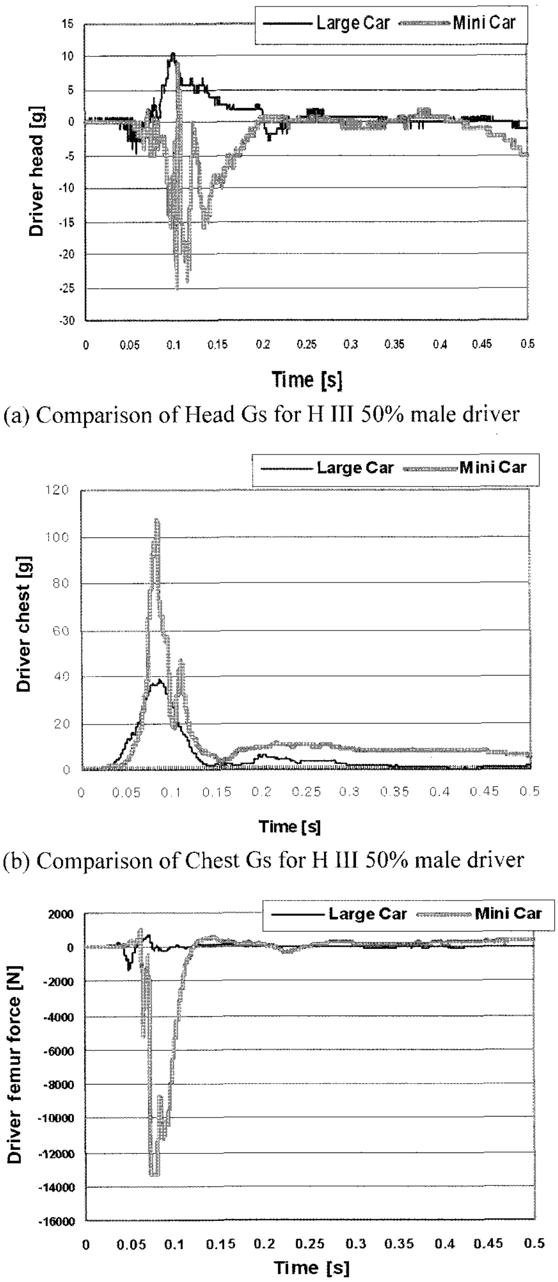
In the inclination crash test at 30 km/h and at a 30° angle between the large and small vehicles, all injury level was low, however, the injury value in the small vehicle was 1.5 times higher than the large vehicle. Figures 8 and 9 show the injury data of Hybrid III 50% male dummy.

5. CONCLUSIONS

This research conducted car-to-car crash tests in conditions matching high accident probability, focusing on the deformation of the vehicle and human injury characteristics in crashes between two vehicles with different geometrical structures. Analysis of the test results has lead to the following conclusions.

(1) The mini car, which satisfied with the Korea motor vehicle safety standards for rigid barrier crash tests, caused a head injury value that was 2 times higher than the large vehicle due to the mismatch of the geometrical structure. The chest injury level and compressive force of each upper leg were extremely high compared to the large vehicle.

(2) In the inclination crash test at 30 km/h at a 30° angle between the large and small vehicles, all injury levels were low; note, however, that the injury value in the small vehicle was 1.5 times higher compared to the large vehicle.

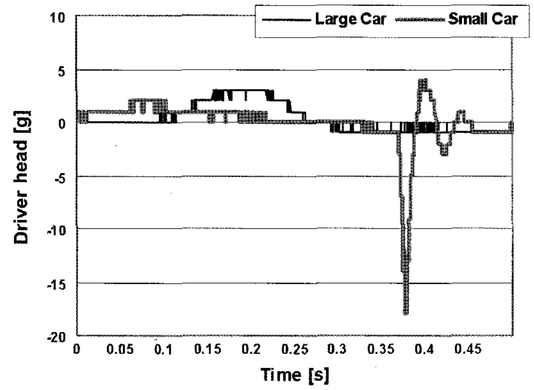


(a) Comparison of Head Gs for H III 50% male driver

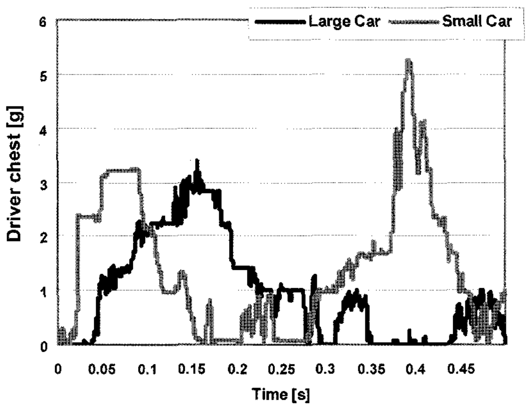
(b) Comparison of Chest Gs for H III 50% male driver

Figure 8. Injury measurement comparison for a Hybrid III 50% male dummy in the driver's seat in a car-to-car crash test at 48.3 km/h 40% offset.

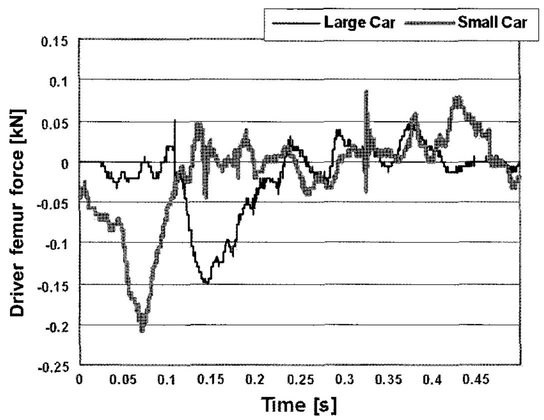
(3) Analyzing the chest acceleration (G) and injury probability (AIS4) for each of the car-to-car crash tests revealed a less than 5% injury probability in both the large and small vehicles during the 30 km/h 30° inclination crash test and less than 10% injury prob-



(a) Comparison of Head Gs for H III 50% male driver



(b) Comparison of Chest Gs for HIII 50% male driver



(c) Comparison of femur load for H III 50% male driver

Figure 9. Injury measurement comparison for Hybrid III 50% male dummy in the driver's seat in a car-to-car crash test at 30 km/h at a 30° angle.

ability in the large vehicle at 48.3 km/h with a 40% offset frontal crash. However, the small vehicle demonstrated an 80% injury probability, proving to be fatal to the human body.

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