Experimental Study of the Possibility of Using of External Inversion Crash Box on Sloped Crash Barrier

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ABSTRACT

A new crash box system in the vehicle frontal crash is considering by energy absorbing of the pre-inverted pipe, which is a useful compression force based on the external inversion phenomenon. As a result of the application of the pre-inverted pipe, this paper describes the benefits of the uniform energy absorbing and the space utilization of the crash box systems with 3 thicknesses of pipes during the frontal collision.

INTRODUCTION

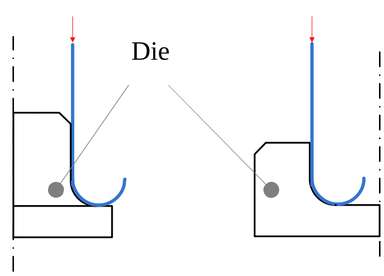
The most of the physical phenomena to absorb crash energy were the local buckling and overall buckling of the crash boxes, frontal side members and other structural parts on the vehicle during a frontal collision. The phenomenon on the crash box and side member during a frontal collision is primarily accordion-like deformation. It is regarded as the ideal design. And it has a deformed region about 70% of the total length of the crash boxes.
The previous researches of the external inversion of pipe were conducted by Guist et al in 1966 [1], Al-Hassani et al in 1972 [2], and Rosa in 2003 [3]. The external pipe research conducted by Guist1) was to invent the test machine to develop the landing system of the space ship for NASA. Al-Hanssani2) used the various dies to invert the pipe for the internal and external inversion. And the validation research of external inversion of thin-walled tubes using the inversion die between the physical tests and theoretical investigation was conducted by Rosa et al [3].

In this study this paper reports the results of the compression tests of the pipes which is 80 mm in outer diameter and the thicknesses are 1, 1.6 and 2 mm with external inversion. And it is compared to the results of the simple compression tests of the pipe which is same size with the accordion-like deformation. The external inversion phenomenon on pipe type crash box allows for uniform energy absorption and gives us the advantage of space utilization during the frontal collisions.

Static and Dynamic Compression Tests

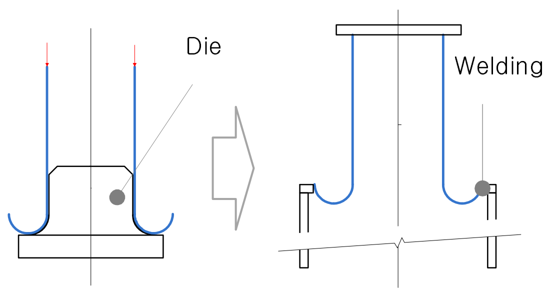
Crash Box with Pre-Inverted Pipe

The longitudinal compression of pipe on the die which is useful to external inversion or internal inversion are necessary a certain level of force to change the shape of thin-walled tube. Figure 1 shows the sectional shape of the pipe during the static compression tests of external inversion and internal inversion. Figure 1-(a) represents the phenomenon of external inversion which the inner surface of pipe is inverted into outer surface along the expanded slope of die. Figure 1-(b) also represents the phenomenon of internal inversion. The outer surface of pipe is inverted into inner surface along the reduced slope of die.



a) External Inversion (b) Internal Inversion
Figure 1. Inversion of pipe

Fabrication of Pre-Inverted of Pipe The test specimen of crash box was consist of pipe pre-inverted. Figure 2 represents the fabrication process of the external inversion of pipe and the installation of pipe into the side member. The space between the outer surface of die and the inner surface of pipe is 0.125 mm used in the research conducted by Al-Hassani et al [1]. And the pre-inverted pipe was installed into the side member with TIG welding.

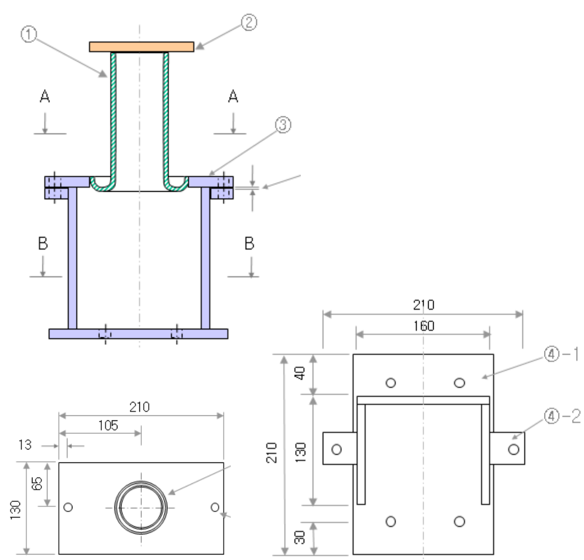


(a) Pre Inversion (b) Installation

Figure 2. Installation of pre inverted pipe

Test Specimen of Crash Box

Figure 3 represents the configuration of the crash box as test specimen. The pre inverted crash box is installed on side member with TIG welding. A thin plate is welded on the crash box. In the B-B section of figure 3 one side of the side member is opened to take the pictures during tests.



(a) Section A-A (b) Section B-B

Figure 3. Assembling of the crash box

Tensile Test of the Material The pipe for this research was tested to get the material characteristics using the universal test machine. Figure 4 shows the setup of the tensile test according to the KS B 0801 standard. The thickness of specimen was 1 mm. The dimension of it was 12.5 mm of width, 50 mm of reference distance, and 75 mm of parallel section. Figure 5 shows the characteristics of test specimen in the tensile condition. The yield stress, σ_y, was calculated according to the offset standard of metallic material tensile test method of KS B 0802. The calculated yield stress was 546 MPa and the maximum tensile stress, σ_b, was 570 MPa. In this research the calculated flow stress, σ_p, is 558 MPa of the average between 546 to 570 MPa.

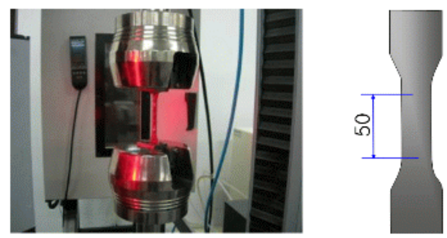


Figure 4. Tensile Test of test specimen

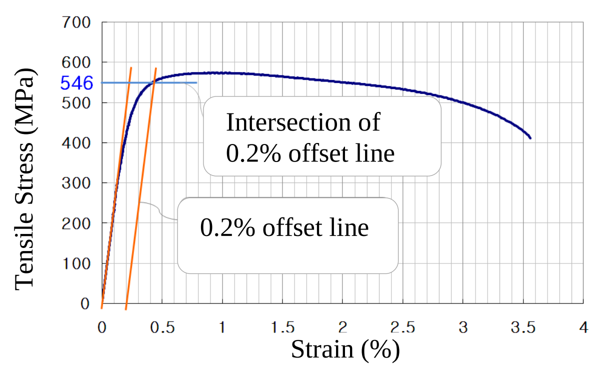


Figure 5. Characteristics of test specimen

Table 1.
Tensile test result of specimen

Thickness	Young's Modulus	Yield Stress(σ_y)	Tensile(σ_B)
1.0t	234.8 GPa	546 MPa	570 MPa

Static Compression Test of Pre External Inversion Crash Box

The static compression tests using the universal test machine were conducted to compare the energy absorption performance of crash box with same material under the different test conditions. Three pipes are compressed in different test conditions of simple compression, simple compression on 10-degree slope, and pre-external inversion respectively. The compression rate of the static compression tests were 10 mm a minute.

Comparison between simple compression and pre external inversion of pipe

Figure 6 shows the deformed pipes during the test. The pipes of the simple compression and the pre-external inversion were symmetric and the pipe of the simple compression on 10-degree slope was asymmetric during the static test.

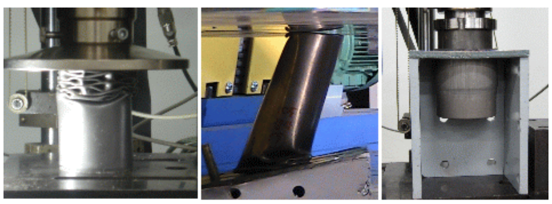


Figure 6. Static compression test of simple pipes and pre external inverted pipe

Figure 7 shows the compression force compared to the displacement of pipes in the different compression conditions. The compression force level of the simple compression of pipe was fluctuated the range between 60 kN and 20 kN. The simple pipe on 10 degree of slope surface was slipped and not compressed properly. The pre-external inverted pipe was compressed with flat shape of the compression force during the plastic deformation.

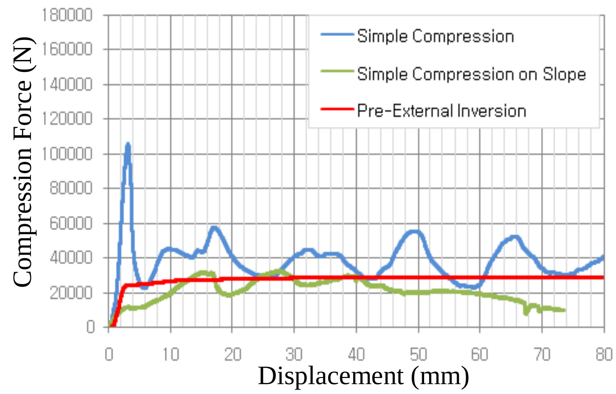


Figure 7. Test graph of static compression test of simple and pre external inversion pipes

Table 2 describes the results of the energy absorption of the pipes under the three different test conditions. The absorption energy of pipes pre-inverted was 61.3% when that of simple compression is based. The pipe on the slope condition was slipped and not reached to the compression force of simple compression.

Table 2.
Test result of static compression test of simple and pre external inversion pipes (1t, 50 mm deformation and based on simple compression)

Test Conditions	Section Area(mm^2)	Average Force(N)	Energy(J)	%
Simple Compression	248.2	41,382.7	2,069.1	100.0%
Slope	248.2	23,084.2	1,154.2	55.8%
Pre Inverted	248.2	25,377.2	1,268.9	61.3%

Comparison between rectangular section crash box and pre external inversion of pipe

The static compression tests were also conducted to compare the energy absorption performance of crash boxes between pre-external inversion of pipe and conventional rectangular. Figure 8 shows the test setup of these tests. The rectangular crash box was mounted and compressed on universal test machine guiding vertically.

Figure 8. Static compression test of pre external inversion pipes and rectangular section crash box

Figure 9 shows the compression force on time history of the crash boxes of pre-external inverted pipe type and rectangular type. The compression force level of the crash boxes of the pre-external inverted pipe type were flat shape within the certain levels during the static test. But the compression force of the rectangular crash box was fluctuated the range between 30 kN and 100 kN.

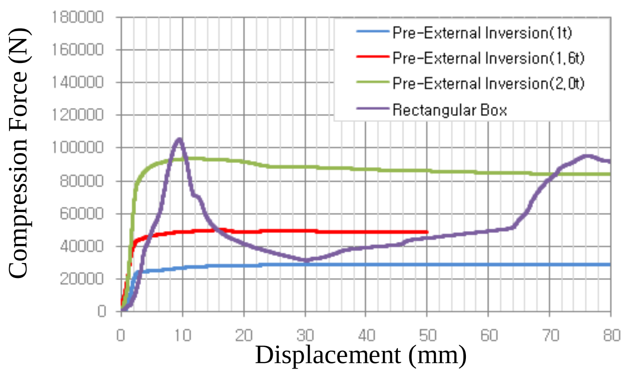


Figure 9. Test graph of Static compression test of rectangular section crash box and pre external inversion pipes

Table 3.
Test result of Static compression test of rectangular section crash box and pre external inversion pipes (50 mm deformation and based on simple compression)

Test Specimen	Section Area(mm^2)	Average Force(N)	Energy(J)	%
Pipe 1.0t	248.2	25,377.2	1,268.9	60.2%
Pipe 1.6t	394.1	46,254.1	2,312.7	109.8%
Pipe 2.0t	490.1	84,074.7	4,203.7	199.5%
Rectangular 1.6/2.0t	629.6	42,136.2	2,106.8	100.0%

Dynamic Comparison Tests with Moving Crash Barrier

The crash tests using the moving barrier were conducted to verify the energy absorption performance of crash box with pre inverted pipe material in the dynamic condition.
The weight of the moving barrier was set to 1400 kg before the test. One of the crash box was installed on the mid of the front surface of the moving barrier firmly. The load cell was installed between the crash box and the moving barrier to measure the compression force. Three axis accelerometers are also installed on C.G. of the moving barrier to measure the deceleration during the crash test. And these accelerations were used to calculating the displacement of the moving barrier. The moving barrier was guided in rails and travelled into the concrete crash barrier with a speed of 16 kilometers an hour.

Comparison the pipes of 1t, 1.6t and 2t

Figure 10 shows the test setup and the crash box of the pre and post-test. The crash boxes with thickness of 1 mm, 1.6 mm and 2 mm respectively were fully deformed into the inside of the side member during the tests.

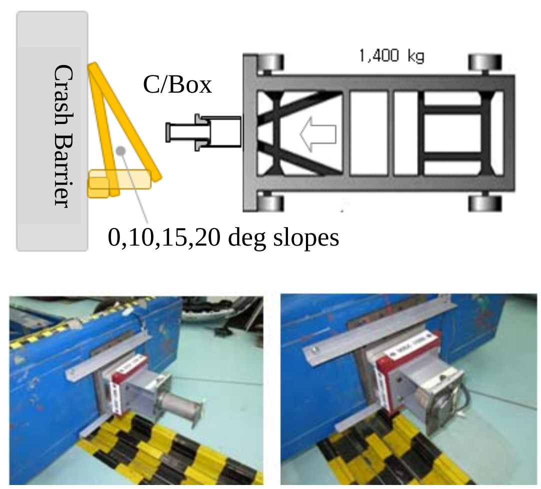


Figure 10. Dynamic test using the moving crash barrier

Figure 11 shows the compression force compared to the displacement of the crash boxes with the thickness of 1 mm, 1.6 mm, and 2 mm respectively in the 0-degree crash barrier conditions. The levels of compression force for the crash boxes with different thickness are flat within the certain levels during the moving barrier crash test.

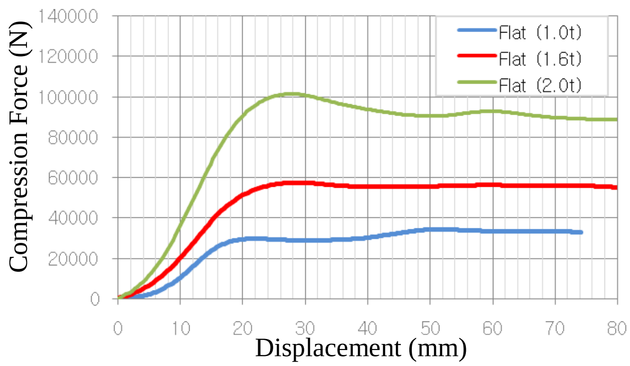


Figure 11. Graph of dynamic test using the moving crash barrier

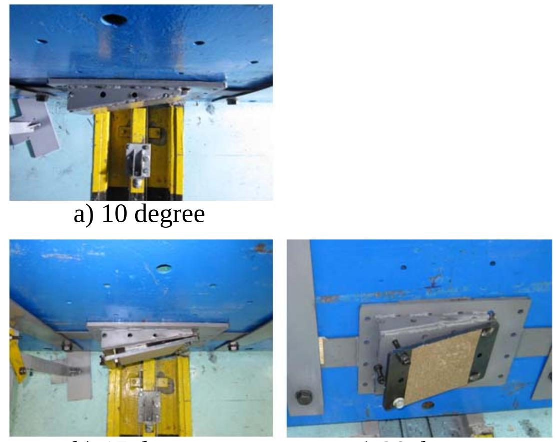
Table 4 describes the results of the energy absorption of the crash box with the different thicknesses of pipe material. The absorption energy of crash box with the thickness of 1 mm, 1.6 mm, and 2 mm respectively were increased 100%, 174.6%, and 301.2% gradually when that of 1.0t is based.

Table 4.
Test result of dynamic test with pre-inverted crash box using the moving crash barrier (70 mm deformation and based on 0 degree)

Test Conditions	Section Area(mm^2)	Average Force(N)	Energy(J)	%
1.0t	248.2	26,795.9	1,875.7	100.0%
1.6t	394.1	46,777.3	3,274.4	174.6%
2.0t	490.1	80,716.5	5,650.2	301.2%

Comparison the oblique conditions, 0, 10, 15, and 20 degrees

The dynamic moving barrier tests were conducted on the 0, 10, 15, and 20 degree of rigid slope surfaces using the crash boxes with 1.6 mm thickness of pipe material. Figure 12 shows the slope surface of the moving barrier test.



a) 10 degree

b) 15 degree

c) 20 degree

Figure 12. Dynamic test for oblique conditions

Figure 13 shows the compression force compared to the displacement of the moving barrier tests in the slope surface conditions. The compression forces among the 0, 10, and 15 degree of slope surfaces are similar each other and reduced in 20 degree of the slope surface.

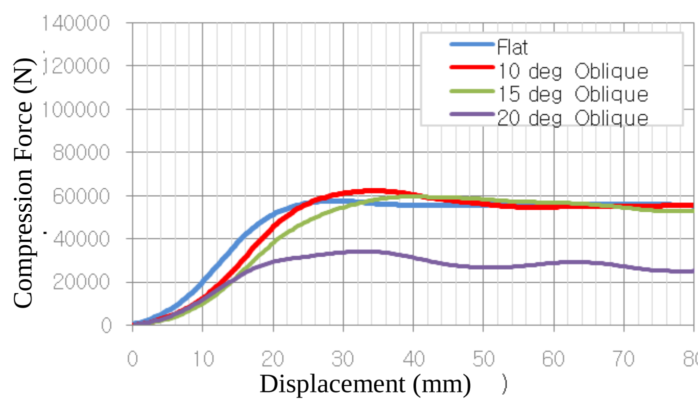


Figure 13. Graph of dynamic test for oblique conditions

Table 5 describes the results of the energy absorption of the crash boxes with pipe material of 1.6 mm thickness in the slope conditions. The absorption energy values of crash box in 0, 10, 15, and 20 degree slope surfaces were reduced 100%, 99.4%, 95.3% and 54.0% gradually when that of 0 degree is based.

Table 5.
Test results of dynamic test for oblique conditions (70 mm deformation and based on 0 degree)

Test Conditions	Section Area(mm^2)	Average Force(N)	Energy(J)	%
Flat	394.1	46,777.3	3,274.4	100.0%
10 deg	394.1	46,518.1	3,256.3	99.4%
15 deg	394.1	44,587.4	3,121.1	95.3%
20 deg	394.1	25,240.6	1,766.8	54.0%

Calculation of Compression Force

The required force for the compression of the pre inverted pipe material was calculated. The average diameter and the thickness of pipe is 79 mm and 1 mm each. The flow stress (σ_p) of the pre inverted pipe through tensile test is 558 MPa.

To calculate the compression force(P) it was used the equation suggested by Guist et al [1] in 1966.

$$P\ (N) = \pi\ D\ t\ \sigma_p\ \sqrt{(2\ t / D)} = 4.44\ \sigma_p\ t^{3/2}\ D^{1/2}$$

where D is diameter and t is thickness of pipe material.

The calculated compression force was compared to that of the test on the Table 6.

Table 6.
Comparison of compression force between calculation and test

Diameter of Pipe	Force of Compression (N)			Remark
	Test	Calculation	%	
79 mm	24,694	22,035	10.8	

The calculated compression force is 10.8% lower than that of the test. The cause of this difference is assumed to only using of the plastic deformation energy in the equation of Guist et al [1]. It is possible to use in early stage of the vehicle engineering design to predict the crash performance.

CONCLUSIONS

The following conclusions were obtained from the static compression tests and the dynamic moving barrier tests with the crash box using the pre inverted pipe material.

With the application of the pre inverted crash box, it was possible to improve the space utilization efficiency of the crumble zone in the frontal collision.

As results of pre inverted pipe application with various thicknesses, it was also possible to control the level of the crash energy for the different size of the vehicles.

With the benefit of the external inversion of pipe material, it was also possible to have the consistent compression force of crash box in the 15-degree slope conditions.

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