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Numerical and experimental approach of various sectioned new concept of the crash-boxes to determine the reliability and crashworthiness of the vehicles during frontal impacts

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ABSTRACT

Overview on vehicle collisions shows us a perspective to evaluate the impact behavior of the vehicles and occupant safety. To decrease the deformations of the vehicle body and occupant injuries, many products have been developed already. The mentioned safety measures can be defined via active and passive security systems. This study is about, passive safety systems used naming “the crash-box” for vehicles during accidents, are investigated experimentally to reduce the shock effects of the frontal impacts. For crash-boxes square, circular or other standard closed sections are preferred regularly due to ease of the production. For this research, open section crash-boxes are studied. Up to the manufacturing restrictions one of the designs in four, is preferred. The new concept of crash-box is, assembling the specimens in front of the chassis and just behind front bumper, instead of using it like regular crash-boxes. Cross-section type of w shape, steel, sheet-metal crash-boxes are manufactured as a shock absorber unit. Height of 2.88m drop test setup was used for the experiments. Considering the limitations of the test setup, one eighth of a real accident scenario for a 1200kg vehicle can be processed with this experimental system. The impact tests are handled with 150kg drop weight and one crash-box unit as an accepted collision scale. To understand the most appropriate thickness for the absorbers is decided between 2mm, 1.5mm, 1mm and 0.8mm thick samples. Finally, 1mm thick St37 w shape cross-sectional sheet metal crash-box is strong enough to absorb the impact energy of the frontal collisions.

Keywords: Vehicle Reliability, Impact, Shock Energy, Crash-box, Occupant Safety

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INTRODUCTION

Due to the advancement of vehicle technologies with the comfort and speed, accidents have also increased concerning the human factors. During collisions even sophisticated safety procedures, injuries and sometimes fatalities are inevitable. One of the most important problem of vehicles collision is frontal impact for decades [1-8]. Thus, manufacturers and establishments (Euro NCAP etc.) have been trying to facilitate rules and create different type of prevention systems.

Recent studies indicate about features; inside the chassis and under the hood staying in front of the driver like protection bars to decrease the collision effects and prevent the passengers. This safety system defined as a crash-box [9-11]. Crash box is a system converting the kinetic energy caused by the collision, via deforming itself in plastic region of the material and absorbing the impact energy and shock waves of the accident and is expected to be collapsed with absorbing crash energy prior to the other body parts so that the damage of the main cabin frame is minimized, and passengers have saved their lives. Crash-box or thin walled safety structure is designed for absorbing approximately 50% of kinetic energy of vehicles during frontal impact collision [12-14]. Widely known cross section of energy absorbers is mainly utilized as a rectangular/square shape. Previous studies indicated to understand impact behavior of rectangular/shape under static or dynamic axial loading. The most significant design parameters for the crash-box can be described as energy absorption efficiency and light weight [15,16]. Shock absorbing capability advances gradually by using pre-notched crash-boxes; otherwise in non-notched samples observed deformation is materialized in an uncontrolled way. Yet, because of the additional manufacturing processes for the notching, it is increasing the costs of the production. Considering the effective, simple and economic way, non-notched samples have been preferred for this study.

Instead of regular shapes known as rectangular or circular cross sections [17,18], different geometries like W folded crash-boxes are selected for this research. W shaped design could make many fold ways [19-21], but up to the manufacturing ability and limitations, one of the designs are accepted.

The manufactured specimens could not be carried out in the form of actual vehicle crash tests due to real collisions, laboratory conditions and material availability. Instead, the tests were accomplished using the drop test setup. The data obtained from the current test setup were analyzed and evaluated by the experimental approach. Considering the deformations of the different thicknesses of crash-boxes, 1mm thick specimen gain enough amount of the shock energy of the impact scenarios.

MATERIAL AND TESTING

Experimental study of the impact procedures is handled via drop test module at laboratory facilities in Sakarya University, Turkey. While the real accidents are very difficult to simulate in the laboratory conditions, some parts of the collisions are partially imitable to actualize the daily life incidents. In this perspective frontal crash case will be evaluated with a drop test approximation.

2.1. Experimental Setup

The drop test module (Figure 1) is able hold 150 kg and drop it from 2.88m height. Because of the sample height is 300mm, it can reach a crash-box contact maximum speed of 24.6024km/h measured by the speed sensor.

The impact velocities were measured by the velocity sensor just before the contact of the crash-box and steel plate. To understand the absorbing capability, four distinct specimen thicknesses are selected considering previous studies for different cross sections [22]. Deciding which thickness is the most appropriate for the absorbers, 2mm, 1.5mm, 1mm and 0.8mm thick sheet metal boxes crashed respectively via drop test experiments.

Up to the calculations, the experiments represents eight crash-box mounted in front of a 1200kg vehicle, 4 by 4 symmetrically in a 24.5km/h impact scenario.

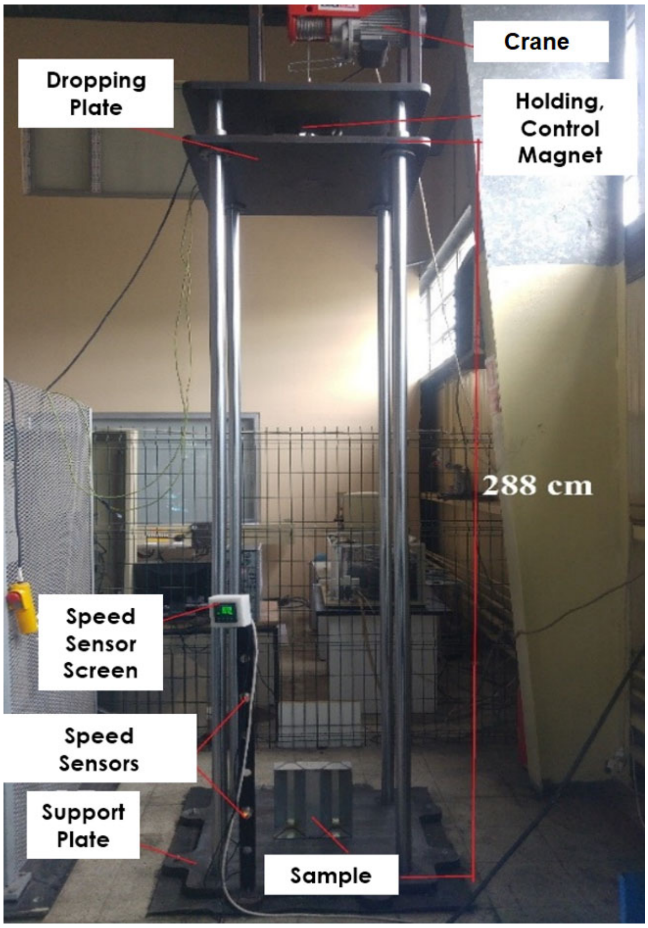

Figure 1. Drop Test Setup

2.2. Material Properties

When creating a description for the safety precautions of the accidents, companies usually try to facilitate economical methods to reduce the deformations and injuries of the occupants. Sometimes this way is enough, nevertheless unfortunately not enough for all. Protective systems should be developed and the system should not much expensive for the mass production. Regarding the automobile industry St-37 mild steel sheet-metal material was applied to the W shaped cross-sectional designs just because the St-37 material is financially suitable for the manufacturers.

Just because the regular shapes had been studied before for decades, different profiles were designed to demonstrate the behavior of the W shaped folded crash boxes. The designs can be seen in Figure 2. With the limitations of the manufacturer, the most convenient design 4 was selected as a crash-box during the frontal impact scenario of the vehicle.

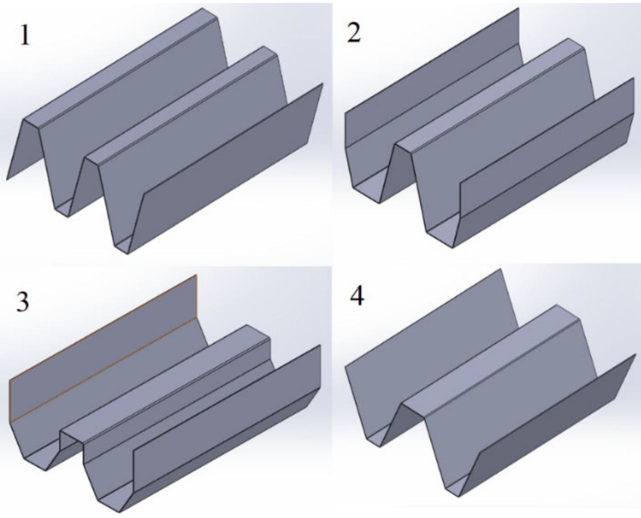

Figure 2. The designs of the W shaped crash boxes

The dimensions and perimeter of the columns are designed up to the recent studies and appropriate space imagined between the chassis and the frontal bumper of the daily used vehicles. When the height is 304mm, width and depth are 260mm and 90mm respectively. The height and the perimeter of the samples are considered by the effects of the collisions during frontal impacts of the vehicles to absorb enough amount of the shock energy. And also the thicknesses are decided up to the availability of the sheet metal market as 0.8mm, 1mm, 1.5mm and 2mm. The dimensions of the design 4 is given in Figure 3.

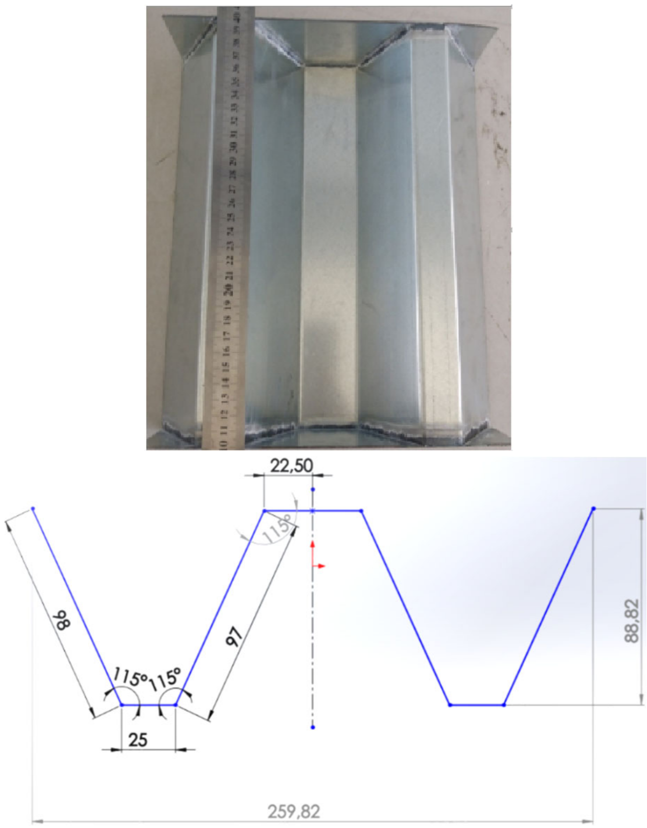

Figure 3. Dimensions of the W cross section

2.3. Experiments

The main idea in the impact shock absorbers like crash boxes is to deform enough to absorb sufficient amount of destructive energy. But if the specimens deform all the way in a large deformation scale, there will be no space to fold on itself and protect the vehicle anymore. Thus, initially the optimum thickness should be evaluated between very large deformations and not enough deformable behavior of the crash-boxes. During the tests the folding mechanism usually starts from the bottom side, opposite of the initial contact region as a reaction attitude.

2mm thick specimen: Initially a little more buckling seen at the left side. Folding deformations are determined above from the right side of the column is 69mm, left side is 79mm and the center is 75mm. After the impact test the average height became 279mm. This sample is so rigid and is not able to absorb harmful shock energy. The crash-box will transfer the shock wave directly to the vehicle. The impact deformation of the 2mm thick specimen can be seen on Figure 4.

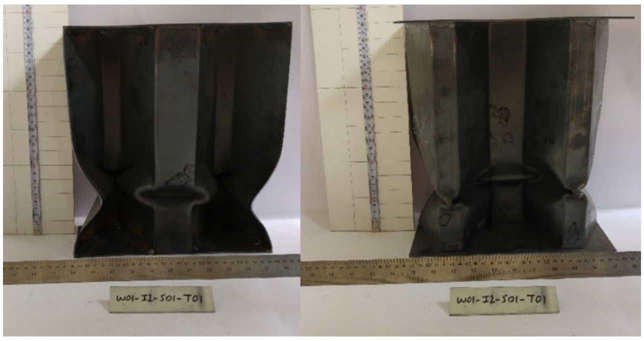

Figure 4. The impact deformation of the 2mm thick specimen

1.5mm thick specimen: As seen in the Figure 5, buckling at left side is more than the right. After first fold reached to the bottom, second fold at right is 33mm above from the bottom, and for the left is 29mm above. Defined plastic deformation at right column is 14mm, at left 16mm and at middle 15mm. Right column decreased to 247mm, and left decreased to 243mm. 1.5mm thick plate sample crash-box is not able to absorb enough energy because of rigidity.

Figure 5. Drop test result for the 1.5mm thick specimen

0.8mm thick specimen: After the impact tests for the 0.8mm thick specimens, large deformations were determined. Opposite of the 2mm and 1.5mm thick samples, 0.8mm thick crash-boxes were not able to absorb enough energy considering that the all 0.8mm thick specimens deformed in an extra-large behavior. Two other specimens are behaved identically.

Figure 6. Drop test result for the 0.8mm thick specimen

Results up to this section shows that 2mm and 1.5mm thick samples are acted rigidly and not sufficient folding mechanism is detected. On the other hand, all of the three 0.8mm thick samples present extra-large deformation and this sample is not capable to withstand the impact forces.

According to the results to gain optimum thickness for the crash-box should be between 1.5mm and 0.8mm. Subsequently, 1mm thick easily obtainable St37 sheet metal is decided for the next experiment.

1mm thick specimen: The samples 0.5mm thinner than the previous one, thence the deformation result and mechanism is different. The increase of number of the folding mechanism represents an acceptable folding process for an efficient impact absorbing capability, besides the crash-box is not indicating large-deformation which is favorable. To depict the correlation between the numbering of the samples and specimen numbering in the Figure 7 subsequently the trial sample (W01_I1_S01_T01: specimen 1) which is not given, the specimen numbering starts from the number 2. After the first trial impact test, the second impact test (Figure 7-2) represents the gradually and acceptable folding deformation for absorbing enough energy. The results for the 2nd specimen shows that it absorbed the shock waves and energy during the deformation between 304mm to199mm. The drop test for the 3rd sample is carried out, and the result of the test is depicted in Figure 7-3. The outcome for the 3rd specimen demonstrate that absorbing the impact energy during deformation, is starting from 304mm to approximately 200mm. Impact test for the fourth specimen (Figure 7-4), the height of the crash-box decreased to, between 189mm to184mm. The second folding is not at the bottom like the 2nd and 3rd; it is on the top region of the crash-box. When the 5th specimen is examined in Figure 7-5, two folds were observed just above the lower surface. Just below the upper surface, folding starts in the two columns, but the plastic deformation of buckling in the right column is greater than in the left column. The result of 5th specimen was found to be 209mm on the right side from 300mm and 211mm on the left side. For the 6th and 7th (See Figure 7-6 and 7) specimens, the folding behaviors are close to 4th one. One fold at the bottom and the other fold at the top surface of the crash-box. Results of 6th specimen shows that the height decreased from 300mm to 187mm on the right side and from 300mm to 185mm on the left side. And the 7th specimen's height decreased from 300mm to 181mm on the right side and from 300mm to 182mm on the left side.

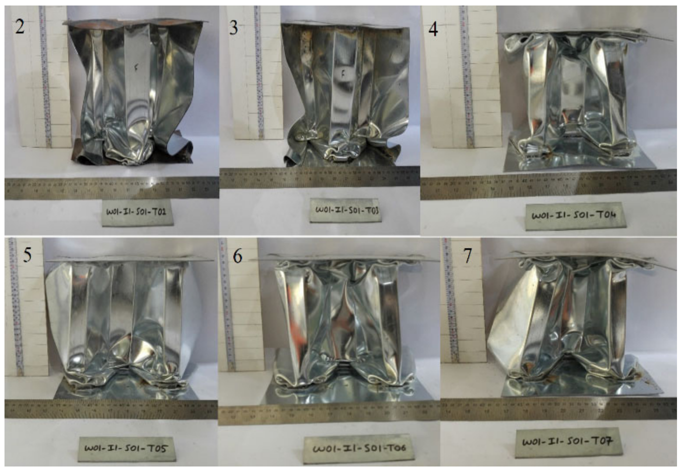

Figure 7. Drop test results of the 1mm thick specimen

When the all experiments are considered, the results at Table 1 should be investigated.

Table 1. Experimental results of the drop tests

Specimens	Velocity (m/s)	Absorbed Energy (J)	Mean Deformation (mm)	Deformation
W01-I2-S01-T01 (2mm thick)	6,815	3072	25	Not Enough (Rigid)
W01-I1.5-S01-T01 (1.5mm thick)	6,821	3119	57	Not Enough (Rigid)
W01-I1-S01-T01 (1mm thick-**trial sample**)	6,79	3164	98	Acceptable
W01-I1-S01-T02 (1mm thick)	6,827	3202	101	
W01-I1-S01-T03 (1mm thick)	6,809	3189	99	
W01-I1-S01-T04 (1mm thick)	6,811	3204	111	
W01-I1-S01-T05 (1mm thick)	6,814	3173	91	
W01-I1-S01-T06 (1mm thick)	6,834	3209	115	
W01-I1-S01-T07 (1mm thick)	6,825	3226	118	
W01-I0,8-S01-T01 (0.8mm thick)	**Error**	**Error**	245	Large-Def.
W01-I0,8-S01-T01 (0.8mm thick)	6,741	3343	256	
W01-I0,8-S01-T01 (0.8mm thick)	6,88	3447	230	

After comparing the results, 1mm thick St37 W shaped crash-box absorbers exhibit better results to eliminate the shock effects of the frontal collision scenario. For the further studies, 1.2mm thick samples will be added to the W shaped cross sections expanding with regular sections thickness of 1mm to compare the different shapes acts. After deciding the best shape and thickness the height optimization will take place for a superior crash-box design. To improve the experiments, accelerometer is going to be included while the numerical approximation of explicit dynamics procedures will be conducted with LS-DYNA software.

CONCLUSION

According to the experimental study of the frontal impact simulations via drop test setup is admissible to describe the direct collisions as expected. Although crash-box developments spread on spacious studies, there are still sufficient amount of undiscovered areas exist. To saturate some part of not defined areas of the impact absorbing field, this study has accomplished using not regular shapes.

Instead of using standard cross-sections, w cross-section open form crash-boxes are preferred to see the mechanical behavior of the new concept. And also for the further studies, the W shaped cross sections will be investigated via comparing with the standard cross sections.

Thickness optimization of the crash-box has been processed by the experiments. The impact absorbing capability of the 2mm and 1.5mm thick crash boxes is not appropriate because of the rigid and not enough deformable behavior.

When 0.8mm thick boxes are investigated the mechanical strength was found so week to absorb enough impact energy, considering all samples have large-deformations.

According to the results to gain optimum thickness for the crash-box should be between 1.5mm and 0.8mm. Hereby, 1mm thick easily obtainable St37 sheet metal is capable to absorb enough impact energy by folding two times on itself while the rigid ones just fold once and the soft samples fold all the way.

Finally, repeated 1mm thick specimen experiments, verify the absorbing ability during many drop tests. And also the results for the new design of crash-box concept are promising.

REFERENCES

[1] S. Boria, J. Obradovic, and G. Belingardi, "Experimental and numerical investigations of the impact behaviour of composite frontal crash structures," *Composites Part B: Engineering*, vol. 79, pp. 20–27, 2015.

[2] K. Solabannawar, S.I. Bekinal, "To simulate and study the behaviour of vehicle front structure through tox joints in frontal collision," *International Research Journal of Engineering and Technology (IRJET)*", vol. 03, no. 7, pp. 1702-1707, 2016.

[3] A. Ghadianlou, S.B. Abdullah, and A. Agarwal, "Crashworthiness design of vehicle side door beams under low-speed pole side impacts," *Thin-Walled Structures*, vol. 67, pp. 25-33, 2013.

[4] N. Tanlak, "Cross-sectional shape optimization of thin-walled columns enduring oblique impact loads," *Thin-Walled Structures*, vol. 107, pp. 65-72, 2016.

[5] N.N. Hussain, S.P. Regalla and Y.V.D. Rao, "Low velocity Impact Characterization of Glass Fibre Reinforced Plastics for Application of Crash Box," *Materialstoday: Proceedings*, vol. 4 (2 PartA), pp. 3252-3262 2011.

[6] J.A.C. Ambrósio, "Contact and impact models for vehicle crashworthiness simulation," *International Journal of Crashworthiness 8*, vol. 8, no. 1, pp. 73-86, 2003.

[7] Y. Nakazawa, K. Tamura, M. Yoshida, K. Takagi and M. Kano, "Development of Crash-box for passenger car with high capability for energy absorption," *CIMNE 2005 VIII International Conference on Computational Plasticity*, 2005.

[8] G. Belingardi, A.T. Beyene, E.G. Koricho and B. Martorana, "Alternative lightweight materials and component manufacturing technologies for vehicle frontal bumper beam," *Composite Structures*, vol. 112, pp. 1-10, 2014.

[9] C. Zhou, Y. Zhou and B. Wang, "Crashworthiness design for trapezoid origami crash boxes," *Thin-Walled Structures*, vol. 117, pp. 257-267, 2017.

[10] G. Belingardi, A.T. Beyene, E.G. Koricho and B. Martorana, "Crashworthiness of integrated crash-box and bumper beam made by die- forming composite," *16th European Conf. on Composite Materials*, 2014.

[11] H. Chul, K. Dong, K. Shin, J.J. Lee and J.B. Kwon, "Crashworthiness of aluminum/CFRP square hollow section

beam under axial impact loading for crash box application," *Composite Structures*, vol. 112, pp. 1-10 2014.

[12] G. Suna, T. Panga, C. Xua, G. Zhenga and J. Songc, "Energy absorption mechanics for variable thickness thin-walled structures," *Thin-Walled Structures*, vol. 118, no. 1, pp. 214-218, 2017.

[13] F. Tarlochan, F. Samer, A.M.S. Hamouda, S. Ramesh and K. Khalid, "Design of thin wall structures for energy absorption applications: Enhancement of crashworthiness due to axial and oblique impact forces, *Thin-Walled Structures*, vol. 71, pp. 7-17, 2013.

[14] A.A.A. Alghamdi, "Collapsible impact energy absorbers: An overview," *Thin-Walled Structures*, vol. 39, pp. 189-213, 2001.

[15] T. Wierzbicki, W. Abramowicz, "Collapsible impact energy absorbers: An overview," *Thin-Walled Structures*, vol. 50, pp. 727-734, 1983.

[16] S.A. Meguid, Y.P, ". Hou, Crush behaviour of foam-filled thin-walled conical frusta: analytical, numerical and experimental studies," *Acta Mechanical*, vol. 227, pp. 3391–3406, 2016.

[17] Y. Zhou, F. Lan and J. Chen, "Crashworthiness research on S-shaped front rails made of steel–aluminium hybrid materials," *Thin-Walled Structures*, vol. 49, pp. 291-297 2011.

[18] N. Tanlak, F.O. Sonmez and M. Senaltun, "Shape optimization of bumper beams under high-velocity impact loads," *Engineering Structures*, vol. 95, pp. 49-60, 2015.

[19] H. Ozera, Y. Canb and M. Yazıcıa, "Investigation of the Crash Boxes Light Weighting with Syntactic Foams by the Finite Element Analysis," *Acta Phys. Pol. A*, vol. 132, pp. 734-737, 2017.

[20] U. Ozsaraca, S. Isika, F. Varolb, "M.E. Unata, C. Ozdemira and S. Aslanlara, Investigation of Tensile Properties of Aluminium 6082-T6 Alloys Joined by Cold Metal Transfer Method by Using Different Working Time," *Acta Phys. Pol. A*, vol. 132, pp. 705-707, 2017.

[21] M. Urbanek and D. Blaszkiewicz, "FEM Based Improvement of CAD for Non-Conventional Railway Track," *Acta Phys. Pol. A*, vol. 128, pp. 241-242, 2015.

[22] I. K. Yilmazcoban, Omer Adanur, "Experimental Crash-Box Optimizations for The Frontal Impact Scenario of a Vehicle to Decrease The Shock Effects of Collisions," ICCESEN 2017 *4th International Conference on Computational and Experimental Science and Engineering*, pp. 387, 2017.