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Torsional Rigidity Optimization on Tailgate and Lift Gate of the Vehicles

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Abstract

The upward tailgate of the vehicles is connected to the vehicle body with hinges and opened with the help of two dampers placed on the fifth doors. Pulling is applied in the corner areas of the tailgate to close the tailgate. During this process, the tailgate tries to stretch from one side. This stretch amount is should meet the torsional stiffness targets set by automotive companies. Torsional stiffness target values are important because proportional to the life of the door. The most impact on torsional rigidity is the door inner sheet thickness and hinge bracket designs. The designs made according to the gap between outer and inner sheet panel, and according to their sections they can be grouped in three different ways; L Design, Z Design and Bridge Type Design. There are torsional stiffness targets within the norms of the companies. These target values may vary even if the vehicle is commercial and passenger. Therefore, Z design can be used on hinge brackets of some vehicles while L design of five doors of some vehicles is used. In this paper, how to design the hinge bracket, which is the most important part of the fifth doors opening condition and the effects of design changes on torsional stiffness values will be examined comparatively.

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Highlights

Fifth doors, Torsional stiffness, Hinge brackets, Hinges, Torsional Rigidity, Tailgate, Lift Gate

Araçların Yukarı Açılan Beşinci Kapılarında Torsiyonel Rijitlik Optimizasyonu

Özet

Araçların yukarı açılan bagaj kapakları menteşeler ile araç gövdesine bağlanmakta ve üzerine yerleştirilen iki adet amortisör yardımı ile açılmaktadır. Bagaj kapağını kapatmak için bagajın köşe bölgelerinde çekme işlemi uygulanır. Bu işlem sırasında bagaj kapağı tek taraftan esnemeye çalışır. Bu esneme miktarının otomotiv firmaları tarafında belirlenen torsiyonel rijitlik hedeflerini sağlaması gerekmektedir. Torsiyonellik rjitlik hedef değerlerinin ciddi anlamda önem arz etmesinin sebebi, kapının ömrü ile orantılı olmasıdır. Torsionel rijitliğe en çok etki eden faktörler kapı iç sacı kalınlığı ve menteşe destek bracketi tasarımlarıdır. Dış sac ve iç sac birleştiği zaman arasında kalan boşluğa göre yapılan tasarımlar kesit olarak L design – Z design – köprü tipi design olmak üç farklı şekilde yapılabilir. Bu makalede araçların yukarı açılan beşinci kapılarında en önemli parça olan menteşe destek braketinin ne şekilde tasarlanması gerektiği ve yapılan tasarım değişikliklerinin torsiyonel rijitlik değerlerine etkisi karşılaştırmalı olarak incelenmiştir.

Anahtar Kelimeler

Beşinci Kapı, Torsiyonel Rijitlik, Menteşe Braketleri, Menteşeler, Bagaj Kapağı

Öne Çıkanlar

Beşinci Kapı, Torsiyonel Rijitlik, Menteşe Braketleri, Menteşeler, Bagaj Kapağı

1. Introduction

Movable parts of the vehicle body, which are doors, bonnets and hoods, must satisfy superior quality and structural performance due to the customer needs, comfort and safety regulations, Dudescu, C. and Pop, M. (2009). There are numerous studies on improving the mentioned performances of these components. In their study, Song, S.-I., and Park, G.-J. (2006) used multi-disciplinary optimization methods on side impact, natural frequency and stiffness in order to achieve a lightweight design with tailor blank door structure. Halilović, J. & Nasić, E. & Kovacevic, D. (2018) performed shape optimization analyses on a bonnet hinge bracket and after sixteen different designs, stiffness targets achieved. Shrivastava, R. & Dhole, A. & Raval, C. (2019) studied on the correlation of the door slam test which is a crucial requirement of the development phase and they have reached consistent results with experimental tests.

Among the vehicle doors, one of the crucial components is the tailgate. Because of the direct usage of the customer beside beauty and safety requirements, tailgates need good performance on quality aspect. Thavamani, S. & Devaradjene, G. & Yogeshkumar, K. (2014) studied on reducing the closing efforts of a tailgate, by dimensional analyses on BIW (Body-In-White) and sub-component levels. Yang, Y. & Jeon, E.S. (2016) implemented topology optimization on tailgate hinges of a pickup truck cargo. They have improved the performance of the conventional hinges to satisfy the strength requirements which are needed for reliable customer usage during loading and unloading.

During customer usage, tailgate is exposed to different loadings such as bending, sinking and torsional loads. Thus, stiffness becomes a vital performance criterion in tailgate design. Ngai, A., & Arnold, M.E. (2015) analyzed a composite tailgate to under different structural loads such as: latch, torsional and bending loads in order to achieve both performance and weight reduction targets. Including bending, torsional, lateral and vertical load cases, Ma, F. & Wang, G. & Yang, M. & Yongfeng, P. & Zhao, Y. (2019) conducted a multi-step optimization study on a SUV tailgate. With changing the material from metal to CFRP (Carbon Fiber Reinforced Polymer) they have both improved the stiffness and reduced the weight of the component. In their study Foss, P., Mentzer CC, Franklin DW. (2004) analyzed a thermoplastic composite SUV (Sport Utility Vehicle) liftgate. In their study they have found that small deformations in hinge area causes crucial displacements on the bottom of the liftgate.

2. Material and Method

The tailgate is formed by the joining of two assemblies which are the outer sheet assembly and the inner sheet assembly, as shown in Figure 1. The inner sheet assembly is created by welding the hinge bracket, latch bracket, shock absorber mounting bracket to the inner panel sheet. The hinge brackets on the inner panel sheet shown in Figure 1 have the greatest impact on torsional rigidity. In this paper, several hinge brackets design which are active parts of the tailgates on torsional rigidity test evaluated by means of finite element analyses.

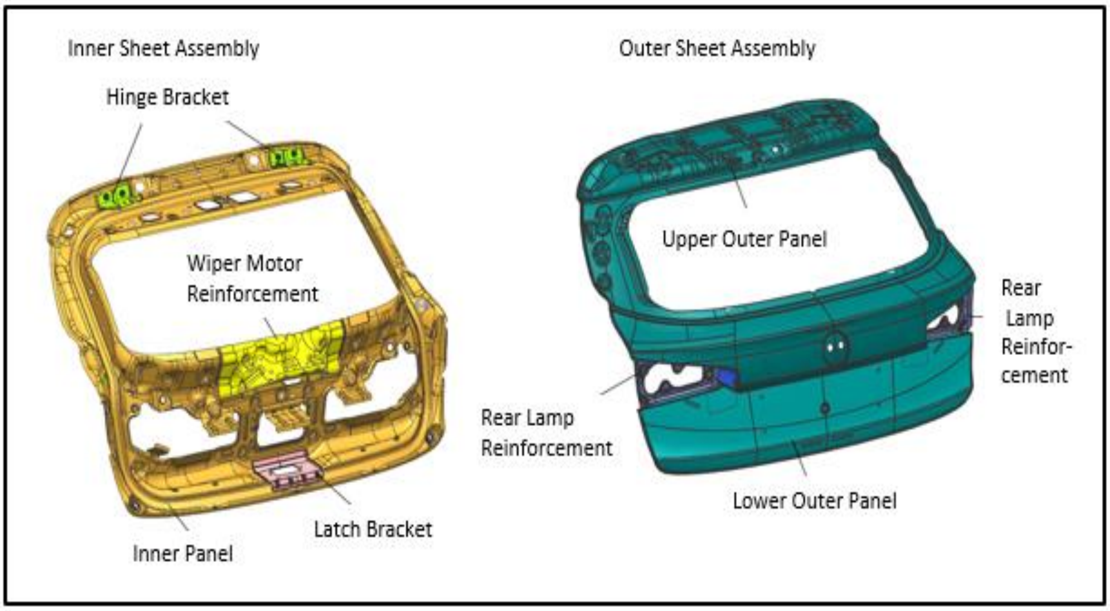

Figure 1. Existing door structures – inner and outer sheet assembly pictures

Finite element model (FEM) is created in Hypermesh software and updated for all five versions. All the metal components shown in Figure 1 are included in the FEM model. Components of the assembly meshed using 2D (two-dimensional shape) shell elements with average size of 7 mm and the components are joined by 1D spot welding elements. The finite element model also includes hinges and adhesives which are meshed as

3D(three –dimensional shape) hexa elements and bolts are modelled with rigid elements. The completed model has 102147 elements. Since the analyses conducted on Abaqus software, FEM model is converted to Abaqus format. Non-linear elastic material properties are used for sheet metal parts. Elastic properties of the sheets are shown in Table 1.

Table 1. Elastic material properties

Sheet Metal Material Properties	Density (g/cm3)	E/Gpa	μ
	7.85	210	0.3

This study relates only with torsional stiffness. Similarly, to [9,11], tailgate is mounted horizontally on three rigid plates which are the hinges and lock and stabilus. Door is allowed to rotate along hinges with CONN3D2 hinge elements in order to represent the BIW mount. At the point on the fixed part of hinge, the model is constrained with single point constraint (SPC) in all degree of freedoms. The lock point is fixed in only in translational degree of freedoms. 50 N force is applied on the bottom corner of the lower outer panel. The deformation is measured from the projection of the loading point on inner panel. Boundary and loading conditions are shown in Figure 2.

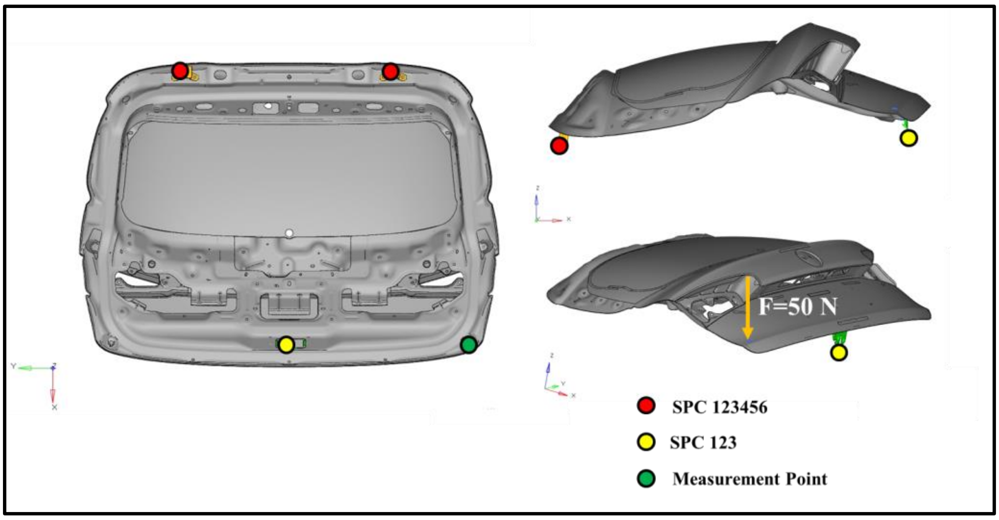

Figure 2. Boundary and loading conditions

2.1. Hinge Brackets Design Optimizations

The hinge brackets to be placed in this area have limited design shapes. The designs made according to the gap between outer and inner sheet panel and according to their sections they can be grouped in three different ways; L Design, Z Design and Bridge Type Design. Under these three main headings, Z and bridge type designs can be made with sealant and screw connections to the outer sheet panel as shown in table 2.

Besides, in order to examine the thickness effect of any selected design, an analysis was made by increasing the thickness of the same design. Thickness variability is not applied for each design based on time and cost. The reason why, it is made in only one model is that the effect from thickness variability is calculated as a percentage for that design and if desired, it is intended to provide a prediction for thickness changes in other designs. In addition, the effect of surface expansion was analyzed by increasing the surface area of the selected second design as much as possible.

Table 2. Types of hinge bracket designs

Types of Hinge Bracket Designs	
L Hinge Bracket Design	
Bridge Type Hinge Bracket	
	With Adhesive
	Extended Area With Adhesive
	With Screw
Z Type Hinge Bracket	
	Z (mm)
	(Z+0,4) mm

2.1.1. L Hinge Bracket Design

Simple and cost-effective L-shaped designs are shown in Figure 3. However, this design is not used in cases where it cannot be reached to targetted torsional stiffness value of the tailgate. Although, it has low values in terms of cost and investment. It is necessary to achieve the target.

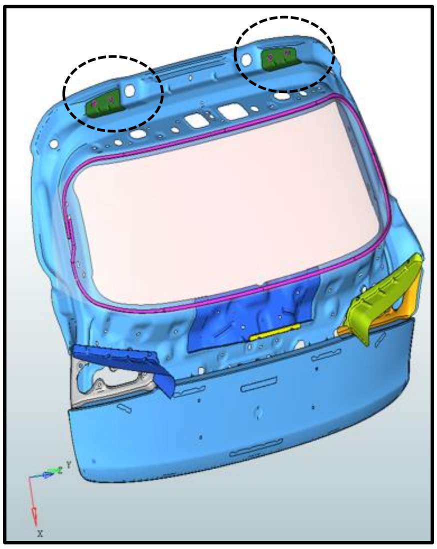

Figure 3. L Hinge bracket design

2.1.2. Bridge Type Hinge Bracket with Adhesive

The bracket design shown in Figure 4 extends from the surface of the hinge to the outer panel glass frame and in contact with the C type adhesive on the outer sheet metal.

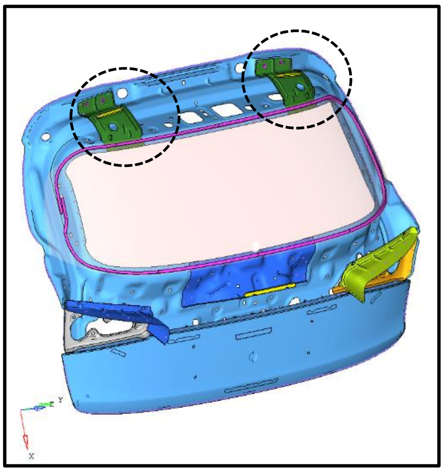

Figure 4. Bridge type hinge bracket which is assembled with adhesive to outer sheet metal

2.1.3. Surface Area Extended on Bridge Type Hinge Bracket with Adhesive

The bracket design shown in Figure 5 extends from the surface of the hinge to the outer panel glass frame and in contact with the C type adhesive on the outer sheet metal. The difference from the previous design is that the surface area is extended. Made to understand the effect of extending the surface area on torsional stiffness.

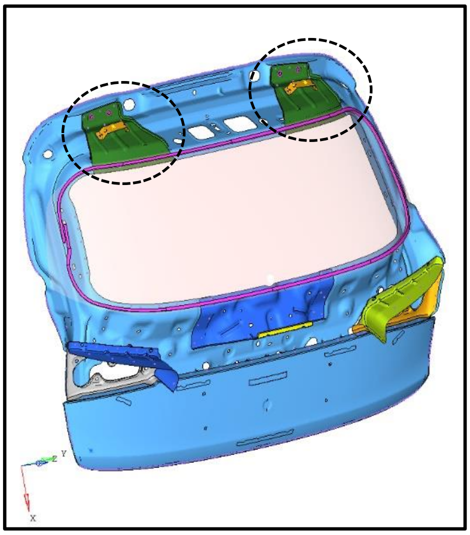

Figure 5. Surface area extended on bridge type hinge bracket which is assembled with adhesive to outer sheet metal

2.1.4. Bridge Type Hinge Bracket with Screw

In this bracket design, instead of the application of C type adhesive from the upper area is shown in figure 3, the connection was made with the bolt nut connection to the outer sheet metal. This design is shown in Figure 6.

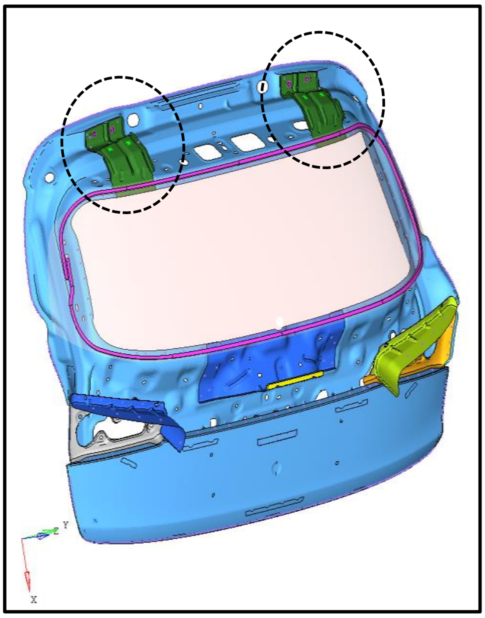

Figure 6. Bridge type hinge bracket which is assembled with screw to outer sheet metal

2.1.5. Z Type Hinge Bracket with Screw

The bracket design is shown in Figure 7. In this design, bolt nut connection is made to the outer sheet from the upper areas. The bracket extends to the inner panel glass zone. In addition, in this design, 2 different thickness analysis were made to check the effect of the thicknesses.

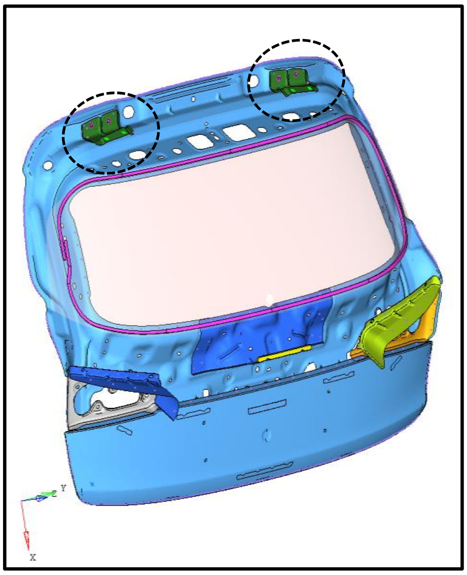

Figure 7. Z type hinge bracket which is assembled with screw to outer sheet metal

3. Results and Discussion

3.1. Analysis of L Hinge Bracket Design

The virtual analysis result of the L-type hinge bracket design is shown in Figure 8. According to the result of this analysis, comparison was made with the other analysis. According to the results of this Analysis, when the tailgate is installed and released as in figure 7, A mm is displaced due to the weight of the tailgate itself. In the direction shown in Figure 8, force F (N) is applied and displacement is measured from the place where the force is applied.

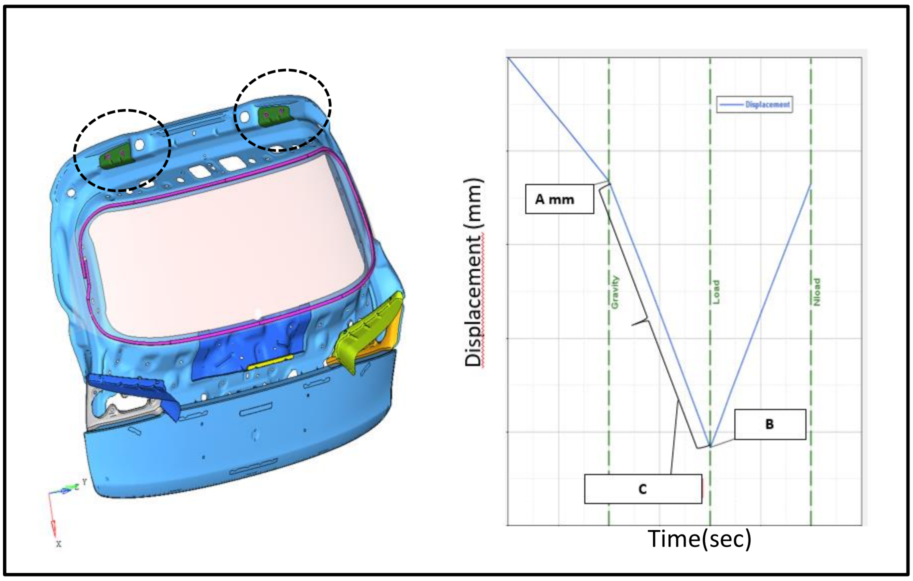

Figure 8. Analysis results of L hinge bracket design

3.2. Analysis of Bridge Type Hinge Bracket with Adhesive

The analysis results of bridge type hinge bracket which is assembled with adhesive to outer sheet metal is shown in Figure 9. According to the result of this analysis, the tailgate is installed and released as in figure 7 A-1,52 mm is displaced due to the weight of the tailgate itself. Due to the strengthening of the hinge bracket, a decrease of -1,52mm was achieved in the amount of collapse from weight of the tailgate itself. When the F (N) force is applied in the direction shown in Figure 7, and displacement is measured from the place where the force is applied, the B value is improved of -4.88mm compared to the base version. When the tailgate collapses from weight of itself is subtracted from the largest displacement when force is applied (Delta displacement), -3,36mm improvement is achieved compared to the base level. This value is the C value from the base level, the improving amount is C-3,36mm.

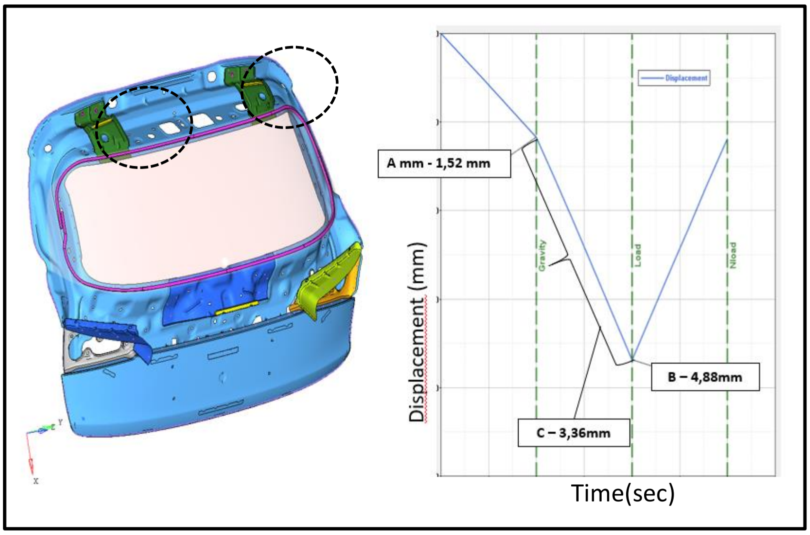

Figure 9. Analysis results of bridge type hinge bracket with adhesive

3. 3. Analysis of Surface Area Extended on Bridge Type Hinge Bracket with Adhesive

The analysis results of bridge type hinge bracket which is assembled with adhesive to outer sheet metal with extended surface area design is shown in Figure 10. According to the result of this analysis, the tailgate is installed and released as in figure 7. A-2,3 mm is displaced due to the weight of the tailgate itself. Due to the strengthening of the hinge bracket, a decrease of -2,3mm was achieved in the amount of collapse from weight of the tailgate itself. When the F (N) force is applied in the direction shown in Figure 7, and displacement is measured from the place where the force is applied, the B value is improved of -7,49mm compared to the base version. When the tailgate collapses from weight of itself is subtracted from the largest displacement when force is applied (Delta displacement), -5,19mm improvement is achieved compared to the base level. This value is the C value from the base level, the improving amount is C-5,19mm.

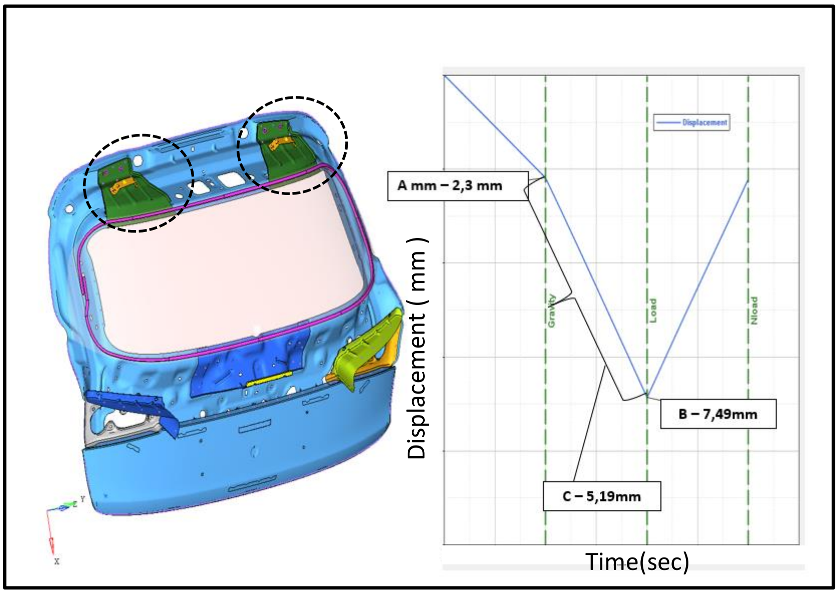

Figure 10. Analysis results of surface area extended on bridge type hinge bracket with adhesive

3.4. Analysis of Bridge Type Hinge Bracket with Screw

The analysis results of bridge type hinge bracket which is assembled with screw to outer sheet metal is shown in Figure 11. According to the result of this analysis, the tailgate is installed and released as in figure 7, A-3,1 mm is displaced due to the weight of the tailgate itself. Due to the strengthening of the hinge bracket, a decrease of -3,1mm was achieved in the amount of collapse from weight of the tailgate itself. When the F (N) force is applied in the direction shown in Figure 7, and displacement is measured from the place where the force is applied, the B value is improved of -9,64mm compared to the base version. When the tailgate collapses from weight of itself is subtracted from the largest displacement when force is applied (Delta displacement), -6,54mm improvement is achieved compared to the base level. This value is the C value from the base level, the improving amount is C-6,54mm.

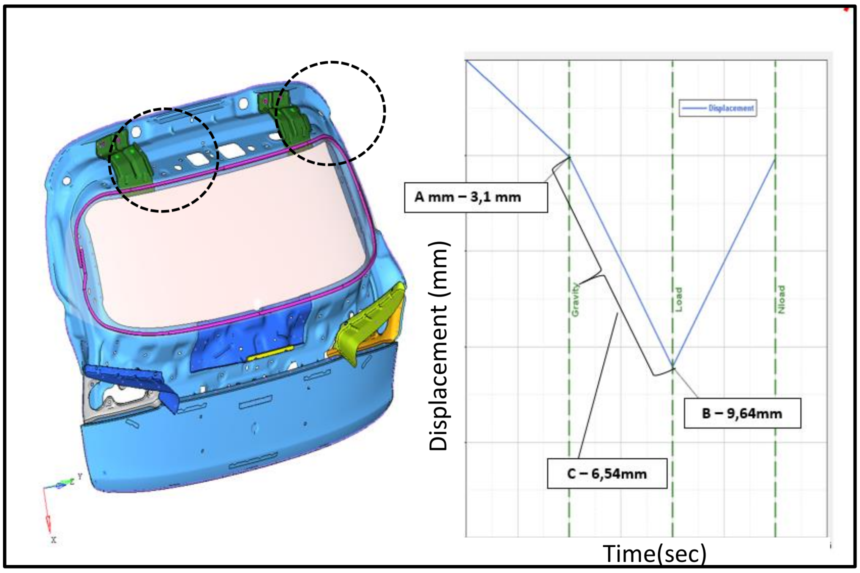

Figure 11. Analysis results of bridge type hinge bracket with screw

3.5. Analysis of Z Type Hinge Bracket with Screw

In this analysis, virtual analysis was performed for two different thickness and the effect of thickness was examined.

3.5.1. Analysis of Z Type Hinge Bracket with Screw (Z) mm

The analysis results of bridge type hinge bracket which is assembled with screw to outer sheet metal is shown in Figure 12. According to the result of this analysis, the tailgate is installed and released as in figure 7, A-2,07 mm is displaced due to the weight of the tailgate itself. Due to the strengthening of the hinge bracket, a decrease of -2,07mm was achieved in the amount of collapse from weight of the tailgate itself. When the F (N) force is applied in the direction shown in Figure 7, and displacement is measured from the place where the force is applied, the B value is improved of -6,44mm compared to the base version. When the tailgate collapses from weight of itself is subtracted from the largest displacement when force is applied (Delta displacement), -4,37mm improvement is achieved compared to the base level. This value is the C value from the base level, the improving amount is C-4,37mm.

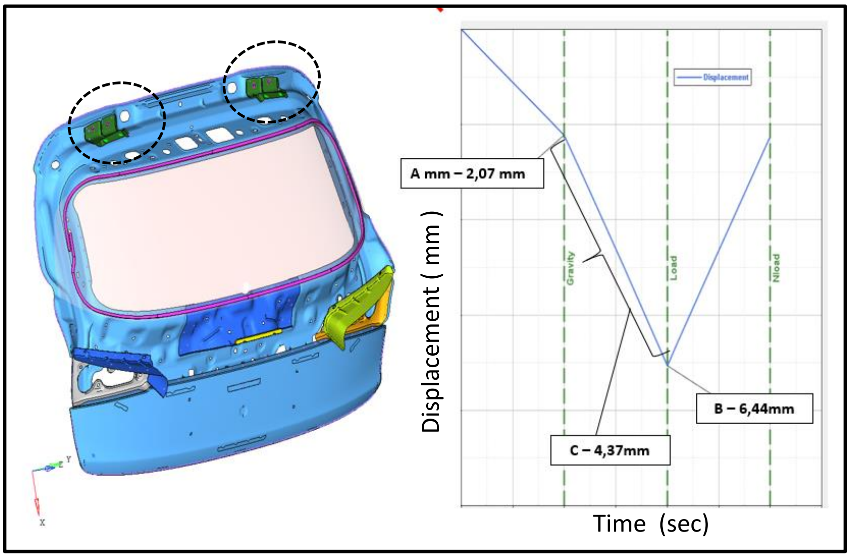

Figure 12. Analysis results of Z type hinge bracket with screw (Z) mm

3.5.2. Analysis of Z Type Hinge Bracket with Screw (Z+0,4) mm

The analysis results of bridge type hinge bracket which is assembled with screw to outer sheet metal is shown in Figure 13. According to the result of this analysis, the tailgate is installed and released as in figure 7, A-2,47 mm is displaced due to the weight of the tailgate itself. Due to the strengthening of the hinge bracket, a decrease of -2,47mm was achieved in the amount of collapse from weight of the tailgate itself. When the F (N) force is applied in the direction shown in Figure 7, and displacement is measured from the place where the force is applied, the B value is improved of -7,7mm compared to the base version. When the tailgate collapses from weight of itself is subtracted from the largest displacement when force is applied (Delta displacement), -5,23mm improvement is achieved compared to the base level. This value is the C value from the base level, the improving amount is C-5,23mm.

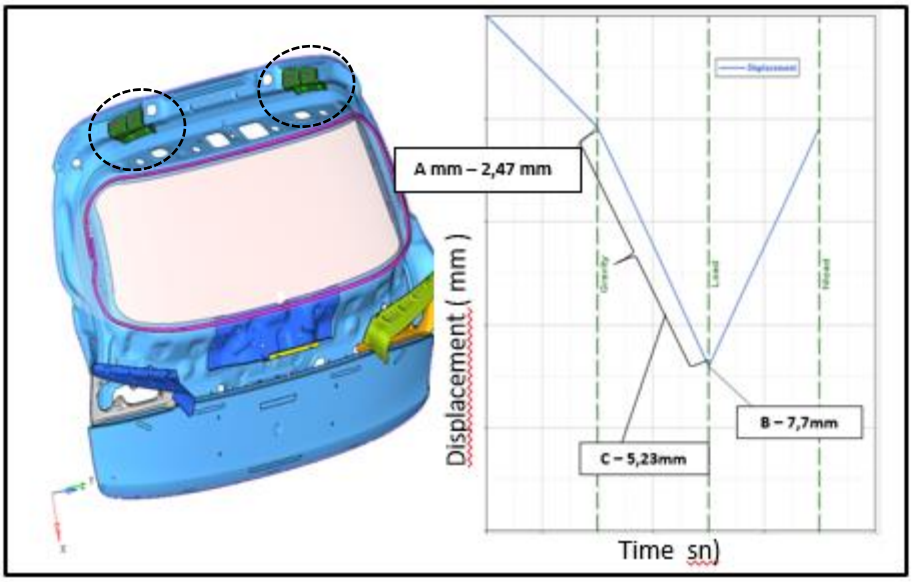

Figure 13. Analysis results of z type hinge bracket with screw (Z+0,4) mm

4. Conclusion

The results of the five different bracket design and two different thickness design made from number 1 is shown in Table 3. The table contains the summary status and brief descriptions of the items described above.

In terms of the amount of collapse from the weight of the tailgate; compared to the simple L type Hinge bracket referenced, the bridge type hinge bracket which is assembled with screw to outer sheet metal improved by 3,1mm and gave the best result.

In terms of total displacement after applying force; compared to the simple L type Hinge bracket referenced, the bridge type hinge bracket which is assembled with screw to outer sheet metal improved by 9,6mm and gave the best result.

In terms of tailgate collapses from weight of itself is subtracted from the largest displacement when force is applied (Delta Displacement); compared to the simple L type Hinge bracket referenced, the bridge type hinge bracket which is assembled with screw to outer sheet metal improved by -6,54mm and gave the best result.

Although, the best result has been the design of the bridge type hinge bracket which is assembled with screw to outer sheet metal, the cost in the automotive industry is importance. It should be noted that each door architecture has its own specific torsional stiffness results. After the analysis results of the first designs come at the design stage, the optimum design should be selected in terms of reaching the target value set in the norm. In order to reach the optimum design, the design examples specified in the table below will help.

Table 3. Comparison of analysis of bracket designs

Types of Hinge Bracket Designs	Displacement Due to The Weight of The Tailgate Itself	Total Displacement After Applying Force	Tailgate collapses from weight of itself is subtracted from the largest displacement when force is applied (Delta Displacement)
L Hinge Bracket Design	A	B	C
Bridge type hinge bracket with adhesive	A - 1,52mm	B - 4,88mm	C – 3,36mm
Surface Area Extended on Bridge Type Hinge Bracket with Adhesive	A – 2,3mm	B – 7,49mm	C – 5,19mm
Bridge type hinge bracket with Screw	A – 3,1mm	B – 9,64mm	C – 6,54mm
Z Type Hinge Bracket with Screw Design (Z) mm	A – 2,07mm	B – 6,44mm	C – 4,37mm
Z Type Hinge Bracket with Screw (Z+0,4) mm	A – 2,47mm	B – 7,7mm	C – 5,23mm

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