Performance Simulation of Bio-Reinforced Composite Car Door Panel using Finite Element Analysis

1st Nanang Fatchurrohman
Department of Industrial Engineering
Faculty of Engineering
Universitas Putra Indonesia YPTK
Padang, Indonesia
n.fatchurrohman@gmail.com

2nd Hew Xiao Jun,
Faculty of Manufacturing and Mechatronic Engineering Technology
Universiti Malaysia Pahang
Pahang, Malaysia
xiaojun1803@gmail.com

3rd Rifki Muhida
Department of Industrial Engineering
Faculty of Engineering
Universitas Putra Indonesia YPTK
Padang, Indonesia
rifkimuhida@gmail.com

4th Muhammad Ilham Adelino
Department of Industrial Engineering
Faculty of Engineering
Universitas Putra Indonesia YPTK
Padang, Indonesia
ilhamadelino@gmail.com

2021 International Conference on Computer Science and Engineering (IC2SE) | 978-1-6654-0046-6/21/$31.00 ©2021 IEEE | DOI: 10.1109/IC2SE52832.2021.9791880

***Abstract*— Interior car door panel serves as an interface between the interior of the car and the inner workings of the door, and between vehicle occupants and the door. They are expected to meet a variety of design specifications regarding safety, aesthetics, and functionality. The objective of this study is to compare the current acrylonitrile butadiene styrene (ABS) car door panel material with polylactic acid (PLA) reinforced kenaf fiber bio-reinforced composite material. The objective is to suggest a recommendation to car manufacturers on the performance of bio-reinforced composites as a new material for the car door panel. Finite Element Analysis (FEA) was conducted to simulate the performance and the results were obtained by determining stress and deformation. The results show that PL It shows that PLA-kenaf composite can absorb higher maximum von-Mises stress (214.13 MPa) if compared to ABS (211.26 MPa). The PLA-kenaf composites also show lower maximum total deformation (12.012 mm) if compared to ABS (42.501 mm). From the analysis, it can be concluded that PLA-kenaf composite has better performance than ABS, therefore has the potential to replace the current material used for car door panels.**

Keywords—product development, automotive component, car door panel, ABS, bio-reinforced composite, FEA

I. BACKGROUND OF STUDY

The door panel serves as an interface between the interior of the car and the inner workings of the door, and between vehicle occupants and the door. They are expected to meet a variety of design specifications regarding safety, aesthetics, and functionality. In general, a car door can be opened and closed to provide access to the opening or closing to secure [1]. They are typically hinged partitions or sometimes attached by other mechanisms like tracks as sliding doors. These doors can be either opened manually or powered electronically. The powered car doors can be usually found on minivans and luxury cars.

An earlier study [2] details out there are two sides of a car door namely the interior side and exterior side of the door. The exterior side of the car door is typically exposed to the vehicle's exterior and colored with a decorative design appearance, while the interior side of the car door contributes to the overall functionality and ergonomics of the car ride. The interior side of the car door is also known as the car door panel. The interior car door panel is normally made up of a variety of materials. Those materials can be produced by vinyl and leather or sometimes can be made by cloth and fabric. The choice of the material for the car door panel is always intended to match the styles and materials used in the car's inner body equipment such as dashboard, seats, carpet, and others.

Dissimilar to the materials used for the exterior side of the car door, the interior car door panel needs to consider both aesthetic appeal and coziness [3]. Their overall function is associated with the ergonomics of the ride, such as armrests, door lock system, window control system, various switches, and compartments for small items and bottles [1,3].

A comprehensive review from previous research [4] reported that the safety of the car passengers can be enhanced by optimizing the interior car door panel's properties and design parameters. These design parameters include the elastic modulus and thickness of the interior car door panels. Moreover, the selection of appropriate material and thickness of car door panels can improve the car safety performance in a side collision [5].

Previous work [6] suggested that the selection of materials is significant because the materials used in vehicles serve as a structural reinforcement to absorb impact energy from transferring to the passengers. The effect of different properties of various materials will directly influence the vehicle crashworthiness. Hence, it can be concluded that the vehicle crashworthiness would be advantageous from materials with high energy absorption [7].

According to the previous study [8], natural fiber composites have arisen to become a choice of materials for automotive interior components, such as door panels, dashboards, seatbacks, and others. Automotive manufacturer, Toyota has used kenaf fiber for their five interior components in 27 car models. These kenaf fiber composites are typically made from kenaf reinforced polypropylene (PP) or kenaf reinforced polylactic acid (PLA). PLA and kenaf fiber are derived from plants hence they have higher bio-based contents and are continuously being developed. PLA-kenaf composite is classified under bio-composites group where they are sustainable solutions for developing high-strength based polymer composites, replacing traditional polymers and their composites [9-11]. Furthermore, bio-composites are safe for the environment and cost-effective [12-14]. Additionally, these composites are increasingly used in many applications [15].

The future material choice by automotive manufacturer, Ford would be sisal fiber reinforced polypropylene composite since it has already passed the crash and impact test requirements. The need for green materials has led to the increasing application of bio-composites made from natural polymers as matrix and natural fiber as reinforcement. They have the properties of eco-friendly, sustainable, and biodegradable [16,17].

Previous investigation reported natural fiber reinforced with synthetic polymer composites are used in car components by European car manufacturers in the past decade [18]. These natural fiber composites are replacing glass fiber and carbon fiber because of the winning parameters of natural fibers. These parameters are lower cost, weight reduction, low energy consumption, and recyclability.

Earlier work narrated the luxury automotive manufacturer used bio-composites as material for their car applications to eliminate environmental impacts and enhance biodegradability. They used jute-based composites, banana fiber-reinforced composites, and some other bio-composites for different car models [19].

II. EXPERIMENTAL METHOD

A. *Finite Element Analysis*

Finite Element Analysis (FEA) is an impressively great computational tool used for examining and analyzing numerous structures such as doors [20]. Prior work was done to characterize car door using FEA [21]. Static structural analysis was done to compare the performance of bamboo fiber material with existing materials of the internal door panel using FEA [22]. Also work related to bio-composites was done to study the behavior of bio-composites used to manufacture a car door handle [23]. Many researchers have applied finite element analysis to analyze bio-composites features [24].

It helps to save time and costs as compared to experimental tests. In the finite element method, numerous structure is decomposed into small simple elements [25]. These small elements have their behavior which can be outlined with a comparatively simple set of equations. The behaviors of these individual elements are then joined together to build the behavior of the whole structure with a large set of equations. FEA is applied using ANSYS simulation software. Three stages are involved; pre-processing stage include which type of analysis, material properties, select fine element size of mesh analysis, loads, and boundary condition is defined, then the; processing stage where the desired result is computed and solved; and the results are interpreted during the post-processing stage.

ANSYS is a finite element analysis software for exploring the performance of processes or products in virtual reality. This type of virtual reality product development is indicated as virtual prototyping. The users can simulate various structural analyses to optimize the product life. So when it comes to manufacturing, it can reduce the level of risk and the cost of invalid designs. ANSYS software provides the effects of design on the whole product behavior, such as strains, stresses, and reaction forces. The finite element analysis simulation is carried out by modeling a car door panel with appropriate dimension specifications and selected properties in the first place. Then, the car door model will be subjected to various structural analyses.

The car door panel is designed and modeled as a solid using CATIA software. The model was 700 mm in height with a cross-section of 843 mm x 356.35 mm. The car door model was shown in Fig. 1.

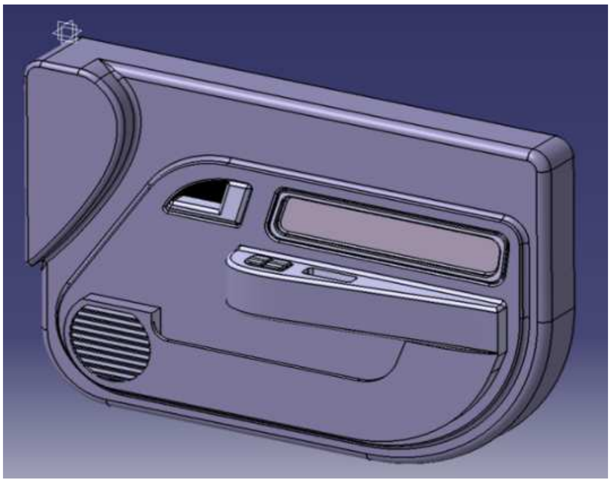

Fig.1 Car door panel modeling

B. *Materials*

The conventional material used for car door panels is Acrylonitrile-Butadiene-Styrene (ABS). ABS is mainly be used for structural applications because it is a low-cost engineering plastic. The material properties of ABS are shown in Table 1.

TABLE I. MATERIAL PROPERTIES OF ABS

Material	Density (kg/m^3)	Tensile strength (MPa)	Young's modulus (GPa)	Poisson's ratio
ABS	1040	44	2.25	0.35

The new composite material used for car door panels is kenaf fiber reinforced with PLA composites. Polylactic acid (PLA) resin with a diameter of 5 μm was used as the matrix whereas kenaf fiber bundles were used as the reinforcement. The dimension of reinforcement is approximately 50 to 150 μm in diameter and 500 mm in length. These kenaf fibers occupied 40% of the volume content. Mechanical characteristics such as density, tensile strength, and Young's modulus are shown in Table 2.

In FEM, material properties were required to simulate the mechanical behavior of the model. The first step of static analysis started with entering the value of different material properties into ANSYS software.

TABLE II. MATERIAL PROPERTIES OF BIO-REINFORCED COMPOSITE

Material	**Density (kg/m^3)**	**Tensile strength (MPa)**	**Young's modulus (GPa)**	**Poisson's ratio**
PLA-kenaf (40%)	1350	82	8	0.32

After entering the values of different material properties, the second step is to import the assembled car door model to ANSYS workbench in STP format. In the next step, the mesh was generated with selected material and structural properties, this would help to define how the structure reacts to different loading conditions.

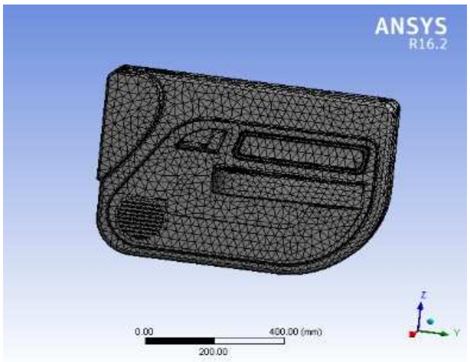

Fig.2 Meshed model of the car door panel

C. Boundary condition and load

The next stage of modeling was to locate the nodes at a certain density of the car door model and consider the anticipated stress levels of a specific area. The model was analyzed with static analysis under different loads and boundary conditions such as total deformation, equivalent stress, and maximum principal elastic strain. The selection of the area at which motions were captured as the boundary condition. For this simulation, the car deceleration was as high as 200 m/s^2. Then by considering the car's weight of 1425 kg this deceleration would generate a load of 285 kN. The car door panel's area under consideration was 0.30040305 m^2 and this would apply pressure of 0.949 MPa on the surface area of the panel. Fig. 3 presents the boundary condition and load applied to the model.

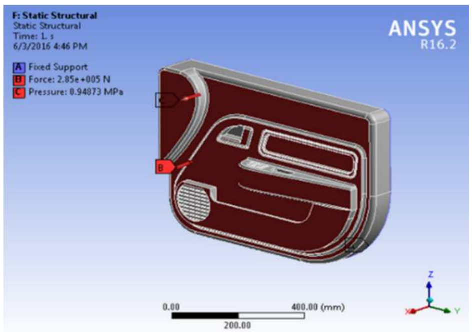

Fig.3 Application of boundary condition and load

III. RESULT AND DISCUSSIONS

This section describes the results of the study that were carried out based on Finite Element Analysis (FEA). It has been noticed that the stress concentration is located at the irregular surface of the car door panel. Hence, it can be predicted that failure is more likely to occur at the irregular surface of the car door panel. Fig. 4 shows von-Mises stress analysis result from the simulation when applying acrylonitrile butadiene styrene (ABS) as the material during static analysis. When there was an impact, the maximum von-Mises stress obtained by finite element analysis is 211.26 MPa. From this figure, it can be observed that the stress concentration is located at the irregular surface of the car door panel. It can be observed that failure is most likely to occur at the lower side of the car door panel as it has a higher stress concentration. Prior work had observed that stress concentration is located at the irregular surface of the car door panel [26]. Hence failure is most likely to occur at this location. A recent study supported that failure usually occurs at high stress concentration [27].

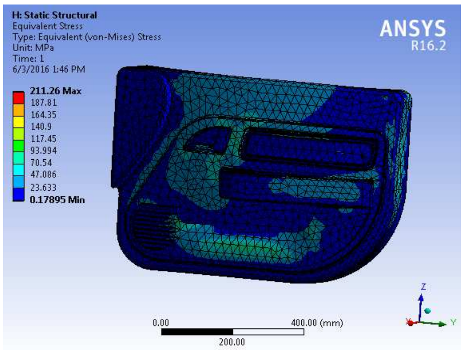

Fig.4.: Equivalent von-Mises stress distribution for ABS car door panel

Fig. 5 shows the results of total deformation when the car door panel was receiving an impact. The maximum deformation value recorded is 42.501 mm. This figure shows the displacement magnitude of the front surface of the car door panel after a force of 285 kN is applied on the front surface in the x-direction. From that, it can be observed that the deformation is likely to occur from the side to the center of the car door panel. Few prior works suggested that deformation is likely to occur from the side to the center of the car door panel. The failure of the car door panel can happen as the result of this deformation [28-30].

The red color indicates the maximum displacement and the blue color indicates the minimum displacement during deformation.

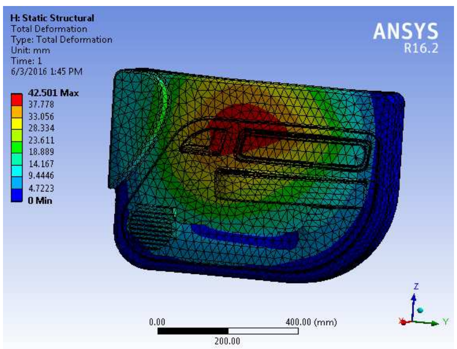

Fig.5 Total deformation obtained for ABS car door panel

The pictorial representation of the equivalent von-Mises stress for PLA-kenaf composite is given in Fig. 6. When the car door panel received an impact. the maximum von-Mises stress obtained is 214.13 MPa. This new composite material has higher maximum stress when compared to the ABS. This indicates that there is an improvement in the strength of the car door panel of PLA-kenaf composite over ABS conventional car door material.

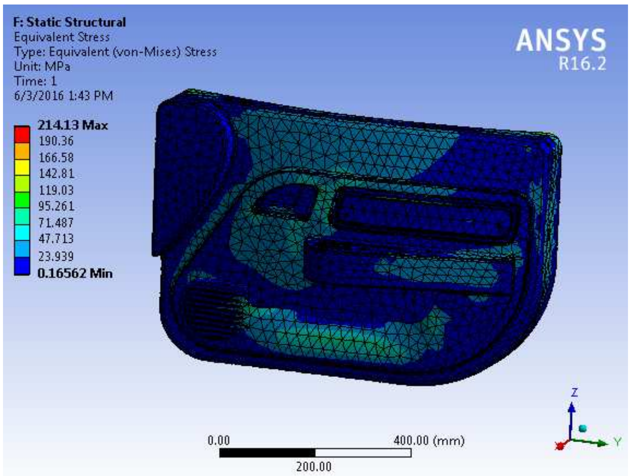

Fig.6 Equivalent von-Mises stress distribution for PLA-kenaf composite.

The impact caused maximum total deformation of 12.012 mm of the PLA-kenaf composite (Fig. 7). The maximum deformation of this new material was reduced by 28.3% if compared to the ABS. The decrement of displacement value is because the PLA-kenaf composite has higher stiffness and higher tensile strength if compared to the ABS. Having these properties means that PLA-kenaf composite can absorb higher impact force hence the deformation is reduced. This also means that the new material is potentially safer if a side impact occurred due to an accident.

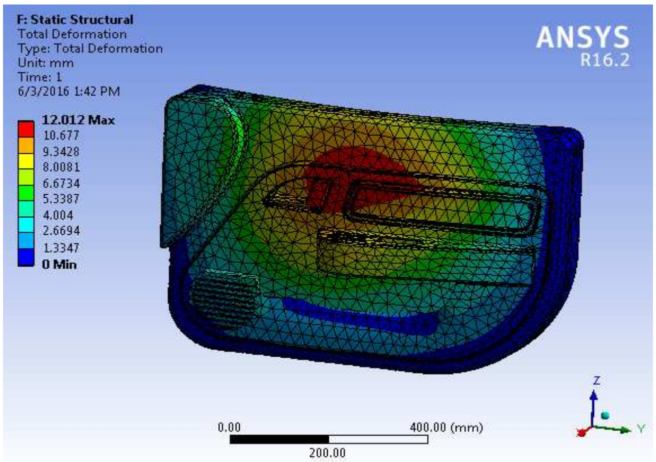

Fig.7 Total deformation obtained for PLA-kenaf composite

The FEA results presented in Fig. 4-7 is summarized in Table 3. It shows that PLA-kenaf composite can absorb higher maximum von-Mises stress if compared to ABS. This indicates that PLA-kenaf car door panel can withstand higher collision impact compared to ABS car door panel. The PLA-kenaf composites also show lower maximum total deformation if compared to ABS. This shows that the PLA-kenaf car door panel would deform less due to collision impact compared to ABS car door panel.

TABLE III. SUMMARY OF FEA RESULTS

Material	Maximum von-Mises stress (MPa)	Maximum total deformation (mm)
ABS	211.26	42.501
PLA-kenaf (40%)	214.13	12.012

IV. CONCLUSION

From various analyses, it is to be concluded that PLA reinforced kenaf composite is the preferred material that can be used as the material for car door panels. PLA reinforced kenaf composite possesses the highest von-Mises stress value and the lower deformation, which suits the best among the comparison. Based on the finite element analysis (FEA) using ANSYS software, it is concluded that the selected material, PLA reinforced kenaf fiber composite had higher performance if compared to ABS as the current material for car panels. PLA reinforced kenaf fiber composite material improves the safety of passengers as well as enhances the end-of-life vehicle recycling factor. Thus, the selected bio-polymer reinforced with natural fiber composite material can be recommended to the automotive industry.

V. ACKNOWLEDGEMENTS

This research is being conducted and was supported by funding from Lembaga Penelitian dan Pengabdian kepada Masyarakat (LPPM), Universitas Putra Indonesia YPTK Padang, Surat Perjanjian Penelitian No: 38/UPI-YPTK/LPPM/KP/PDP/I/2021.

REFERENCES

[1] M.U. Rosli, M.K.A. Ariffin, S.M. Sapuan, S.Sulaiman, “Integrated AHP-TRIZ innovation method for automotive door panel design”, International Journal of Engineering and Technology, vol. 5, no. 3, pp. 3158–3167, July 2013.

[2] M. Raghuveer, and G.S. Prakash, “Design and impact analysis of a car door”, International Journal of Modern Engineering Research, vol. 4, no. 9, pp. 1–8, September 2014.

[3] S. Abercrombie, A philosophy of interior design, 1st Ed. London: Routledge, 2018.

[4] B. Zhang, J. Yang, Z. Zhong,”Optimisation of vehicle side interior panels for occupant safety in side impact”, International Journal of Crashworthiness, vol. 15, no. 6, pp. 617–623, December 2010.

[5] L.H.M Junaida, and N. Sakundarini, “Material Selection for Lightweight Design of Vehicle Component”, in Recent Trends in Manufacturing and Materials Towards Industry 4.0, Singapore: Springer, 2021, pp. 1001-1015.

[6] Y.Y. Tay, C.S. Lim, H.M. Lankarani, “A finite element analysis of high-energy absorption cellular materials in enhancing passive safety of road vehicles in side-impact accidents”, International Journal of Crashworthiness, vol. 19, no. 3, pp. 288–300, March 2014.

[7] D. Gao, X. Li, H. Chen, “Application of improved particle swarm optimization in vehicle crashworthiness”, Mathematical problems in Engineering, 2019, pp. 1-10, March 2019.

[8] B.A. Ahmed Ali, S.M. Sapuan, E.S. Zainudin, M. Othman, “Java based expert system for selection of natural fibre composite materials”, Journal of Food, Agriculture and Environment, vol. 11, no. 3-4, pp. 1871–1877, October 2013.

[9] V. A. Prabu, R. D. J. Johnson, and S. Vigneshwaran, “Mechanical performance of nanocomposites and biomass-based composite materials and its applications: an overview,” in Handbook of Nanomaterials and Nanocomposites for Energy and Environmental Applications, Springer International Publishing, Geneva, Switzerland, 2020.

[10] S. Vigneshwaran, R. Sundarakannan, K. M. John, R. D. J. Johnson, K. A. Prasath, S. Ajith, V. Arumugaprabu, M. Uthayakumar, “Recent advancement in the natural fiber polymer composites: a comprehensive review,” Journal of Cleaner Production, vol. 277, December 2020.

[11] A. K. Mohanty, S. Vivekanandhan, J. Pin, M. Misra, “Composites from renewable and sustainable resources: Challenges and innovations,” Science, vol. 362, no. 6414, pp. 536-542, November 2018.

[12] M. R. A. Karim, D. Tahir, E. U. Haq, A. Hussain, M. S. Malik, “Natural fibres as promising environmental-friendly reinforcements for polymer composites,” Polymers and Polymer Composites, vol. 29, no. 4, pp 277-300, May 2021.

[13] M. Y. Khalid, A. Al Rashid, Z. U. Arif, W. Ahmed, H. Arshad, A. A. Zaidi, “Natural fiber reinforced composites: Sustainable materials for emerging applications,” Results in Engineering, vol. 11, pp.100263, September 2021.

[14] A. Lotfi, H. Li, D. V. Dao, G. Prusty, “Natural fiber–reinforced composites: A review on material, manufacturing, and machinability,” Journal of Thermoplastic Composite Materials, vol. 34, no. 2, pp. 238-284, February 2021.

[15] M. Liu, A. Thygesen, J. Summerscales, A. S. Meyer, “Targeted pre-treatment of hemp bast fibres for optimal performance in biocomposite materials: A review,” Industrial crops and products, vol. 108, pp. 660-683, December 2017.

[16] M. R. Sanjay, P. Madhu, M. Jawaid, P. Senthamaraikannan, S. Senthil, S. Pradeep, “Characterization and properties of natural fiber polymer composites: A comprehensive review,” Journal of Cleaner Production, vol. 172, pp. 566-581, January 2018.

[17] M. Syduzzaman, M. A. Al Faruque, K. Bilisik, M. Naebe, “Plant-based natural fibre reinforced composites: A review on fabrication, properties and applications,” vol. 10, no. 10, pp. 973, October 2020

[18] O. Faruk, A.K. Bledzki, H. Fink, M. Sain, “Progress report on natural fiber reinforced composites”, Macromolecular Materials and Engineering, vol. 299, no. 1, pp. 9–26, January 2014.

[19] K. Shaker, Y. Nawab, M. Jabbar, “Bio-composites: Eco-friendly substitute of glass fiber composites” in Handbook of nanomaterials and nanocomposites for energy and environmental applications, Cham: Springer, 2020, pp. 1-25.

[20] S. Darwish, H.M.A. Hussein, A. Gemeal, “Numerical study of automotive doors”, International Journal of Engineering and Technology, vol. 12, no. 04, pp. 82–92, August 2012.

[21] V. Gheorghe, M. L. Scutaru, V. B. Ungureanu, E. Chircan, and M. Ulea, “New Design of Composite Structures Used in Automotive Engineering,” Symmetry, vol. 13, no. 3, p. 383, Feb. 2021.

[22] R. V. Deshmukh, T. Y. Badgujar, “Vibration analysis of composite internal door panel of a car using FFT analyzer,” AIP Conference Proceedings, vol. 2327, no. 1, pp. 020032, Feb. 2021.

[23] H. Oliver-Ortega, F. Julian, F. X. Espinach, Q. Tarrés, M. Ardanuy, P. Mutjé, “Research on the use of lignocellulosic fibers reinforced bio-polyamide 11 with composites for automotive parts: Car door handle case study,” Journal of cleaner production, vol. 226, pp. 64-73, Jul. 2019.

[24] M. Alhijazi, Q. Zeeshan, Z. Qin, B. Safaei, M. Asmael, “Finite element analysis of natural fibers composites: a review,” Nanotechnology Reviews, vol. 9, no. 1, pp. 853-875, Jan. 2020.

[25] L. Liu, J. Zhang, C. Song, K. He, A.A. Saputra, W. Gao, “Automatic scaled boundary finite element method for three-dimensional elastoplastic analysis”, International Journal of Mechanical Sciences, vol. 171, pp. 105374, April 2020.

[26] P. K. Mallick, “Designing lightweight vehicle body,” in Materials, Design and Manufacturing for Lightweight Vehicles, Woodhead Publishing: Materials, 2021, pp. 405-432.

[27] W. Song, M. Xiuying, M. Qiang, “Simulation and Optimization of Automobile Back Door Lock,” in Recent Developments in Intelligent Computing, Communication and Devices, Springer: Proceedings of ICCD, 2019, pp. 482-487.Computing, Communication and Devices, Springer: Proceedings of ICCD, 2019, pp. 482-487.

[28] J. Skiera, C. Crosby, C. Bare, M. Paradiso, G. Campbell, “Passenger vehicle dynamic response and characterization of side structure during low-to moderate-speed side impacts,” SAE International Journal of Advances and Current Practices in Mobility, vol. 1, no. 3, pp. 918-950, 2019.

[29] D. Struble, J. Struble, “Calculating Vehicle Side Structure Stiffness from Crash Test Data: Effects of Impactor Characteristics,” SAE Technical Paper 2020-01-0640, 2020

[30] C. R. Long, S. C. K. Y. Yuen, G. N. Nurick, “Analysis of a car door subjected to side pole impact,” Latin American Journal of Solids and Structures, vol. 16, no. 8, 2019.