iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH
IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 9 Issue: XI Month of publication: November 2021

DOI: https://doi.org/10.22214/ijraset.2021.38803

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.429
Volume 9 Issue XI Nov 2021- Available at www.ijraset.com

Topology Optimization of Vehicle B-Pillar

Manas Metar
Undergraduate from University of Wolverhampton

Abstract: Weight reduction techniques have been practiced by automobile manufacturers for the purpose of long range, less fuel consumption and achieving higher speeds. Due to the numerous set objectives that must be met, especially with respect to of car safety, automotive chassis design for vehicle weight reduction is a difficult task. In passenger classed vehicles using a monocoque chassis for vehicle construction has been a great solution for reducing overall wight of the vehicle body yet the structure is more stiffened and sturdier. However, some parts such as A-pillar, B-pillar, roof structure, floor pan can be further optimized to reduce more weight without affecting the strength needed for respective purposes. In this paper, the main focus is on reducing weight of the B-pillar. The B-pillar of a passenger car has been optimized using topology optimization and optimum weight reduction has been done. The modelling and simulation are done using SOLIDWORKS 3D software. The B-pillar in this study has been subjected to a static load of 140 KN. Further by providing goals and constraints the optimization was caried out. The results of Finite Element Analysis (FEA) of the original model are explained. The Topology Optimization resulted in reducing 53% of the original weight of the B-pillar.

Keywords: Structural optimization techniques, weight reduction techniques, weight reduction technologies, need for weight reduction, Topology optimization, B-pillar design, structural optimization of B-pillar, Topology optimization of B-pillar.

I. INTRODUCTION

Nowadays, automotive industry has leaned towards creating light weight and environment-friendly vehicles. Reducing overall weight of a vehicle is a great strategy to reduce fuel consumption. When the mass of the vehicle is reduced, the inertial forces that are encountered by engine during acceleration are also reduced thus reducing the required work. Automotive engineers are indulged in using different methods to improve vehicle performance. Optimization techniques for weight reduction such as using design or structural optimizations like Topology optimization as well as replacing existing materials with light weight composite materials in some components etc. are not uncommon these days. One of the common methods used is to optimize the chassis parts, which in turn reduces overall weight of the vehicle body. Automakers have been using monocoque chassis due to its structural advantages. It does not require external frame and components of the chassis are attached to the body of the vehicle. Using monocoque chassis results in a lighter weight vehicle. This can be further optimized to get even less amount of weight. The parts of monocoque chassis such as floor pan, pillars, roof panel/structure may be optimized with using different materials for its structural advantages with making them lighter. Another technique to optimize these parts is structural optimization. Topology optimization becomes very convenient and useful optimization technique in such areas. Topology optimization is a type of structural optimization which removes unnecessary material from a component or from a given design space without changing the original strength required for its purpose. The presented study focuses on reducing weight of B-pillar of passenger vehicle. Topology optimization is carried out on B-pillar design under static loading conditions which is intended to have lesser weight at the end. The current design and optimization have been done using SOLIDWORKS 3D software.

II. VEHICLE B-PILLAR

In a vehicle, the B pillar is an important load-bearing component. It is situated between the front and rear door of the car. A B-pillar in a vehicle acts as a support structure for the vehicle roof. It is also known as center pillar and sometimes referred as posts. It is made up of steel and characterized by thin walled, closed structure. The pillar provides safety to the vehicle’s passengers in an event of a side impact or rollover. Figure 2 shows where the B-pillar is situated and its structure is shown

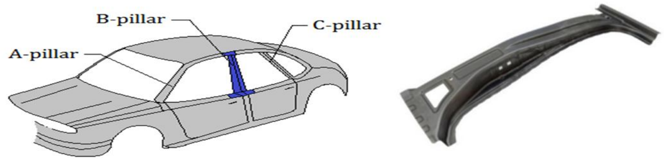


Figure 1: B-Pillar of a car

B-pillars are on the either side of a vehicle and also purposed for latching of front doors and mounting hinges for the rear doors. The structure is welded to the vehicle’s floor pan from the bottom and at the roof rail from the top.

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.429
Volume 9 Issue XI Nov 2021- Available at www.ijraset.com

III. NEED for WEIGHT REDUCTION

Dangerous emissions from vehicles have had a negative effect on the atmosphere as well as on human health for decades. Many government agencies have imposed stringent regulations on car producers in order to keep toxic emissions under allowable limits as a result of the transportation sector's air pollution. Uncompromising regulations have been placed by government agencies and harsh fines on automakers are also applied, putting enormous pressure on them to investigate various approaches and technologies that can help reduce vehicular emissions. Reduced vehicle weight is a common technique used by automakers and OEMs, as it can dramatically decrease vehicle's fuel consumption and carbon emissions. A car with less weight will use less fuel because it will have to fight less inertia, which reduces the amount of force needed to drive it.

IV. OPTIMIZATION THEORY

Topology optimization has been widely used in applications of engineering product designs including aerospace, mechanical, civil engineering, material science and biomechanics. Though it is new, it is an increasingly growing area of study. Engineers use this method at the concept level of design process. It takes 3D design space and optimizes the material layout to achieve the most efficient design. The goal of using this method is to minimize the mass of a component without compromising its strength. While generating a topological optimization, the material chooses the quickest path from the load to the constraint, which produces mathematically the most effective shape. The final product is usually difficult to manufacture as the design may attain any shape within design space. The user has to define the loading conditions and manufacturing constraints to the design space which helps in figuring out the material needed for developing the load path. Topology optimization first initiates with regular Finite Element Analysis (FEA) mesh of the design space which shows stress distribution through design space. Each and every element sends back its stress level and strain energy and those elements which does not have or have less stress and strain energy is removed from the mesh by topology optimizer. An example of how the optimization results is shown below in Figure 3.

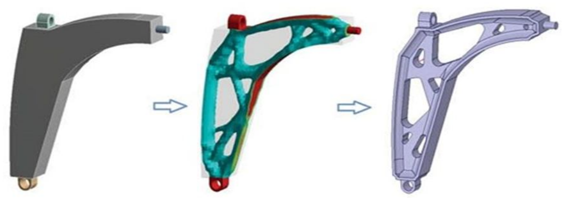


Figure 2: Topology optimization example

Architects and engineers have been using various methods to develop optimal structures and sculptures in the twentieth century. While this resulted in efficient and aesthetic forms of the structures it had limitation of reaching optimum form of the structure. Applying topology optimization was never a standard procedure, developments lead to finding the optimum structures. Changes in computer hardware and software technology has caused decreased time to test and present the product and have changed the approach towards topology formation structures.

To generate topology optimization, following steps are usually followed:

1) Creation of finite element model
2) Providing design goals or objective
3) Defining design area
4) Defining design constraints
5) Defining manufacturing constraints (if necessary)
6) Solving the model

Objective function of optimization process could be presented as

$$\mathrm{Min}(C(x)) = \left(u(x)\right)^T f(x) = u(x)^T K(x)\, u(x)$$

Where,
C = compliance
f = Global load vector containing nodal forces
u = Global displacement vector
K = Global stiffness matrix

V. OBJECTIVES

The objectives of the presented research are:

A. To understand the applications of structural topology optimization.

To perform topology optimization, wide research on topology optimization has to be carried out to understand its uses and applications.

B. To study the loads carried by the B-pillar and materials used.

To optimize and perform FEA on the B-pillar, its functions and load bearing capacities have to understand.

C. To make 3D model of the B-pillar.

A 3D FEA model is needed to be created for analysis and optimization. This structure will provide the design space for topology optimization.

D. To apply Topology optimization on the provided design space.

While applying topology optimization, it is important to understand the purpose of design and manufacturing constraints and apply it on the design space.

E. To reduce the weight of original model.

The main goal of this project is to reduce weight of the B-pillar.

VI. EXISTING TECHNOLOGIES

Weight reduction of a component or the whole vehicle body, it has always been a challenging and never-ending task. Even though strategies such as replacing materials and structural optimizations are widely used some weight reduction technologies are explained below.

A. Volkswagen-led European Super Light Car

It was a multi-material approach adopted to reduce CO2 emissions and fuel consumption. Energy absorption, structural integrity, stiffness, formability, surface quality, and cost were all considered when choosing materials for various parts of the body structure. The result of final weight and material distribution was characterized on the basis of computerized simulations and other related factors were taken into account.

B. Heat Activated Smart Materials

Chevrolet and General Motors have tried using a shape memory alloy wire which will open the hatch vent as the car's boot is lifted. When an electric current is applied to the form memory alloy wire, it contracts, which in turn the vent will be opened by the lever arm.

Due to this the pressure inside lowers and makes it easier to close the trunk lid. When the hatch is closed and no electric current is passing, the alloy wire will take its original form.

To keep the cabin at a comfortable temperature, this setting closes the vent. As compared to the heavy motors usually applicable for the same or similar purpose, using the low-cost smart material can compromise 1.1 pounds of total weight of the vehicle. On average, a car may contain 200 movable motorized parts which can be replaced with such materials, will result in more weight reduction.

C. Quick Plastic Forming Process for Aluminium Component Production

Steel parts such as trunk lids and door inners can be replaced with aluminium to minimize vehicle weight. However, the current capabilities of manufacturing processes to form complex shapes from aluminium are very minimal. In order to address this issue, General VTP and Kaiser Aluminum partnered with motors to create a Fast Plastic Forming process which was able to produce aluminium closure panels in mass quantity. Automotive trunk doors with complex shapes have been successfully introduced using this technology.

VII. LITERATURE REVIEW

An intensive research of topology optimization has been carried out. The study focuses on applying topology optimization on engineering structures and presents different methodologies including used ones and new. A brief introduction of topology optimization is provided and related studies are also classified. The literature reviewed by the researcher shows applications and methodologies of topology in various specific areas.[1] The removal of materials and making chassis lighter is the main objective of research. Advantages of light-weighting the chassis are explained. Research has been carried out by using topology optimization on automotive break pedal. The model was designed in CATIA V5 software and optimization was performed using Altair Optistruct software. The process was carried under linear static stress analysis. The final product had 22% less mass than the original one. another FEA analysis was carried out for validation of structural integrity of optimized break pedal. The results show that design achieved less weight without sacrificing the performance requirements.[2] This paper presents a comparison of different types of meshes and different sizes of elements affecting topology optimization. For this study, an automotive B-pillar is considered. In sizes 20, 10 and 7mm, the meshes from brick components, tetrahedral elements, and their combinations are compared. In addition, the output from different solvers used in Siemens NX 12 software are compared. [3] A wide research has been presented for optimization of vehicle front structure. The main objective of the study was to find the optimum structure for beams and rods in front structure to achieve higher stiffness and improve ride and handling. This is done by performing topology optimization. The optimization was performed in Optistruct software. A theory on different structural optimization techniques is presented. Methodologies for topology optimization are also explained. [4] In this study an automotive B-pillar is optimized after analyzing through Finite Element Analysis (FEA). The Hypermesh and CATIA V5 software are used for the FEA. The initial analysis showed max von mises stress as 1646MPa while displacement magnitude was 5.9mm. This B-pillar was reinforced using steel plates. The optimized B-pillar had lower mass than the original one. Hence, it was concluded that using the method presented, in an event of side impact the severe damage to the vehicle and passengers could be avoided.[5] Because of the growing demand for lightweight components, topology optimization has become increasingly important. In this paper, for topologically optimizing stiffness of a structure a general mathematical formulation is presented when the structure is subjected to mixed boundary conditions, along with some imperative manufacturing constraints. Using ANSYS software and TOSCA in batch-process mode, a technique is applied to assess the optimum configuration of operational structural components. Smoothing the topologically optimized surfaces leads to CAD viable architecture. The geometry of the most stressed areas has also been improved.[6] The use of topological optimization in the design of a mechanical forging press is the subject of this paper. For a long time, this sector has been without major development improvements around the world. Topological optimization is used to reduce the weight of the forging press while increasing the stiffness of the entire process. As an example, a mechanical press with a nominal force of 80 MN is used. Two separate crossbeams and two preloaded columns make up the press's frame. The article discusses the use of optimization methods for welded and casted press frames. The welded steel frame is undergoing remodeling and verification. Tosca, NX Nastran, and Frustum are three optimization methods (FEM codes) used for optimization. Upper and lower crossbeams are mainly focused. The whole assembly is considered as simulation model.[7] Stresses must be considered in order to achieve an optimum design of any vehicle's structure. There are two big challenges in topology optimization problems which are based on the stress. A substantially majority number of constraints must be considered as stress is a local variable. The computational time and cost, when either of the optimization and sensitivity analysis faced with the traditional topology optimization problem, increases as a result of this problem. As stress is nonlinear when considering structure's design parameters, a shift restriction is needed during the optimization process. General stress parameters are used to estimate local stresses in this study. Topology optimization problems are solved using the density approach. This investigation makes use of three numerical instances. The findings presents that a minimum stress design is possible and that a optimum stiffness design is not always the same as a minimum stress design.[8] A technique for reducing the weight of an automobile hood substructure is discussed in this paper. The methodology entails a loop of various optimization techniques, such as topology, topometry, scale, and topography, as well as constant model re-designing. The mass has been reduced while respecting manufacturing constraints, without violating the output goals expected by Ferrari internal regulation.[9] The main goal of this research is weight reduction of an automotive chassis design. The suggested design approach is used twice: first to address a chassis for spider vehicles, and then to address a chassis for coupe vehicles. The two chassis are discussed and compared, along with some intermediate results. The technique has been shown to be successful for the creation of new and efficient automotive chassis layouts.[10] In this research a methodology is presented using different optimization techniques for automotive chassis design. To achieve the best chassis configuration, FEM analyses are combined with topology, topometry, and size optimizations. The technique is used in the creation of a high-performance vehicle chassis with a rear-central engine. The aim of the optimization process is to reduce chassis weight while keeping structural performance constraints in line with Ferrari standards.

The results show that the technique presented can be used to obtain the structure's general trusses configuration and thickness distribution in a wide range of situations.[11] The research is based on generating topology optimization algorithm for solving problems occurred in aerospace engineering. Two problems are given the priority in this study. The design optimization was carried on aircraft landing gear and the engine mount of aircraft. The paper concludes that using topology optimization one can attain a structure having minimum weight in aerospace designs. The airworthiness standards are ensured referring to the Federal Aviation Regulations.[12] The purpose of this work was to assess and equate existing mathematical solutions for structural topology optimization which already have advanced to the point of being implemented in industrial software. The numerical topology methods have been discussed including SIMP and ESO (SERA) method in detail.[13] Applying the geometry projection process, the structures made of discrete geometric components are topologically optimized and an Adaptive Mesh Refinement (AMR) technique is presented for the same optimization. They suggested a technique to dramatically optimize the mesh and decrease the number of elements by using a smoother mesh on geometric parts and a coarser mesh apart to them to increase the performance of the analysis and optimization. They have used topology optimization for designing the minimum-compliance and stress-constrained structures made out of bars and plates to evaluate the efficacy of the proposed AMR system.[14] With a generalised Cahn–Hilliard model, this paper describes a step field method for optimising multi-material structural topology. The weight composition of every phase of the material is treated as a design element, which is similar to the penalization process with isotropic material. However, using the Cahn–Hilliard principle, a variational approach is used to describe a model which is thermodynamic in nature, that deals with the bulk and interface energies of the phases, as well as the elastic strain energy of the structure. As a consequence, a phase transition problem was created by transforming the structural optimization problem. The solution to this problem was nonlinear parabolic partial differential equations. The generalised Cahn–Hilliard model regularises the ill-posed topology optimization problem and allows for topology changes due to phase separation and coarsening. They have used a strong multigrid algorithm for numerical solution of Cahn-Hiliard equations that is extended to include four material phases. They have shown how to reduce the mean compliance of multimaterial structures using many 2-D and 3-D instances.[15] The aim of this project is to incorporate reliability analysis into problems of topology optimization. Reliability-Based Topology Optimization is the name of the modern paradigm, which incorporates reliability constraints into a deterministic topology optimization formulation (RBTO). The value of this integration is demonstrated by a number of applications. In comparison to deterministic topology optimization, the RBTO model produces a different topology. It was also discovered that the RBTO model produces more stable structures than deterministic topology optimization for the same weight.[16] A discussion about how topology optimization of continuum structure has been done. To solve this problem in the past, a set of rules have to be followed. To parametrize a design space, design patches, which are fixed in the optimization process and which are similar to finite element discretization, are used. Whether or not the material is present in the design patches, the structural structure is decided. A large number of optimization variables are generated during the process since several design patches are required for the approximation of the structural layout. Furthermore, the findings obtained are often only usable as a conceptual design due to a lack of clarity and smoothness. Adaptive strategies, which cause optimization variables to decrease in number and produce smooth performance, are implemented to address these flaws. The first section discusses the topology optimization by using pure mesh refinement. As that approach still produced poor outcome, a fresh method was introduced adapting each design cycle's successful design space in relation to the current material distribution. Using this technique will reduce the count of design variables as well as it will produce smooth results. Though, it may also be used in conjunction with traditional shape optimization.[17] In this research paper the researcher has studied different loads acting on a truck’s chassis. In particular this research is based on weight load, brake load and centrifugal load that a vehicle undergoes. He has used topology optimization to reduce weight of the chassis. ANSYS workbench program was used to perform the proposed study. He achieved a 14% reduction in mass without changing the characteristics according to loads. [18]

VIII. METHODOLOGY

The study was carried out by reviewing variety of literatures. A wide research of topology optimization on different components is carried out. The parts of monocoque chassis which could be topologically optimized for research are researched and the B-pillar which is chosen for the optimization is studied. The B-pillar loading conditions were understood as well. Also, how to use topology optimization tool in SOLIDWORKS 3D software was understood. A FEA model of B-pillar is designed as shown in Figure 4 using SOLDIWORKS 3D software. The topology study was carried out by providing design goals and constrains. Meshing of the design was obtained after meshing with different element sizes. The results from the study are discussed.

Figure 3: 3-D model of B-Pillar

Further details about topology optimization process are provided below.

A. *Material Selection*

Selecting a material for B-pillar has to be one of the most important tasks as B-pillar has to carry the load of the roof. In an event of a side impact the B-pillar should work as a stiffer component so as to provide maximum safety for the passengers. In this study, for the structure of B-pillar steel alloy has been used and its properties are shown in the following table.

Poisson’s Ratio	0.28
Mass Density	7700 kg/m^3
Tensile Strength	724 N/mm^2
Yield Strength	620 N/mm^2

B. *Loading Condition*

Topology optimization usually works under static loading conditions. Based upon Euro NCAP standards a static force of 140 KN is applied on the front face of the B-pillar. The Figure 5 shows the distributed load across the front face.

Figure 4: Load Distribution Area

C. *Fixing Constraint*

The B-pillar was constraint for providing rigid boundary conditions. Fixing constraint was used at the extended faces which restricts its movement in all six degrees of freedom. In the following figure blue arrows show where fixing constraint is applied.

Figure 5: Fixing Constraint

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.429
Volume 9 Issue XI Nov 2021- Available at www.ijraset.com

D. Study Goals

The study goals are applied to execute the main purpose of the optimization process. These include options such as "best stiffness to weight ratio", "minimize maximum displacement" and "minimize mass". The goal of the study was set to "best stiffness to weight ratio" as the main objective is to reduce the mass of the B-pillar without losing its stiffness. The weight reduction was constrained to 55% of the original model.

E. Meshing

Meshing is one of the important stages when performing finite element analysis for providing accurate results. Typically, the smaller the size of the mesh elements the more accurate is the result. The best mesh is selected after meshing the design with different sized elements. The mesh generated is a type of solid mesh with element sized at 1mm. In total 129583 elements were created and 42754 nodes were created. Following figure shows the meshed B-pillar.

Figure 6: Mesh Result

Now, that the settings for optimization are provided, the study is ready to run. The results of this run is a product of various iterations that occurred while optimizing the B-pillar.

IX. RESULTS

As described earlier, topology optimization process first creates a Finite Element Analysis of the design space. Hence, following results of von mises and displacement magnitude are obtained during the process.

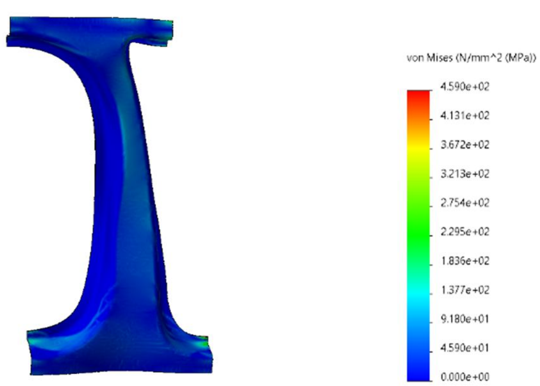


Figure 7: Von Mises Stress

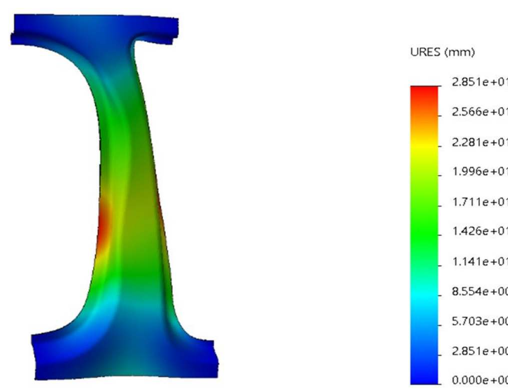


Figure 8: Displacement Magnitude

The results show maximum von mises stress of 459MPa and maximum displacement magnitude as 28.5 mm. Von mises stress shows maximum magnitude near the bottom fixed support and maximum displacement is seen at the side of the B-pillar. Further, the final material removal process brought result as shown in Figure 10. This result was again edited using smooth mesh function and the final product can be seen in Figure 11.

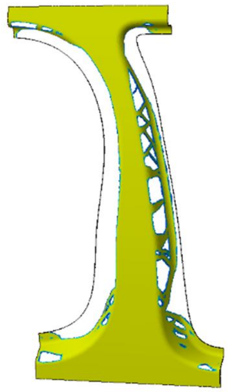


Figure 9: Optimized Model

Figure 10: Smoothed Mesh

The final product obtained had reduced mass of 53% than the original B-Pillar. The structure can be improved or covered using lightweight sheet metal and still have less weight than original.

X. CONCLUSION

In this research the approach towards topology optimization of vehicle B-pillar is presented. The B-pillar was designed and optimized using SOLIDWORKS software where the results obtained from the optimization process are presented. The paper presents a methodology to use the topology optimization tool and to perform topology optimization over a part subjected to static loading condition. The B-pillar designed was subjected to a static load of 140KN. The manufacturing and design constraints applied are shown. The design was meshed using solid meshing. It can be concluded that main objective of the study that is to reduce weight of the structure through topology optimization has been achieved. The final product achieved 53% less mass than that of initial product. This methodology can be used on other parts such as roof rails, pillars, floor pan to reduce the overall weight of the vehicle.

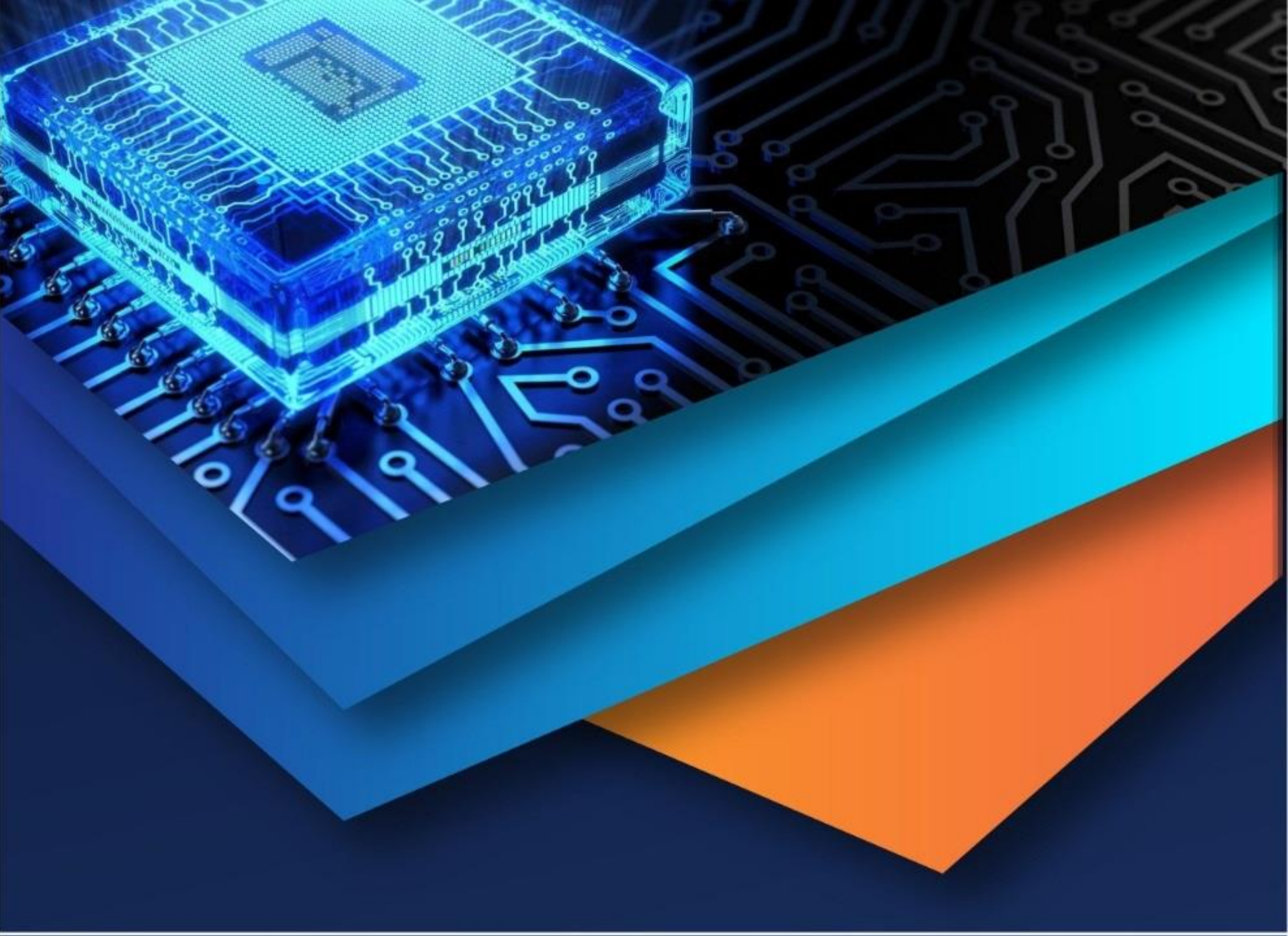
XI. FUTURE SCOPE

As it can be seen that topology optimization at the design phase of manufacturing any component could lead to a lighter weight component, the presented study would be beneficial in future. In future where battery powered cars would be leading the automotive industry the goal will remain the same that is achieving higher driving distance. It is very useful for solar and electric cars as it will provide them with additional driving range. The rising use of additive engineering could use this method and find it beneficial as it is almost possible for complex structures to be made by using 3D printing technology.

REFERENCES

[1] A. Kentli, “Topology Optimization Applications on Engineering Structures,” Truss Fram. - Recent Adv. New Perspect., Dec. 2019, doi: 10.5772/intechopen.90474.
[2] M. N. Sudin, “Topology Optimization in Automotive Brake Pedal Redesign,” Int. J. Eng. Technol. IJET, vol. 6, pp. 398–402, Feb. 2014.
[3] Z. Chval, K. Raz, and Í. Almeida Aguiar, “Topology Optimization of B-pillar with Respect to Mesh Type and Size,” IOP Conf. Ser. Mater. Sci. Eng., vol. 776, p. 012025, Apr. 2020, doi: 10.1088/1757-899X/776/1/012025.
[4] S. (S)" "Lövgren, “Topology Optimization of Vehicle Body Structure,” p. 56.
[5] Department of Mechanical Engineering, Coventry University, West Midlands, UK, A. E. Ikpe, I. B. Owunna, Department of Mechanical Engineering, Coventry University, West Midlands, UK, P. Satope, and Department of Mechanical Engineering, Coventry University, West Midlands, UK, “Design optimization of a B-pillar for crashworthiness of vehicle side impact,” J. Mech. Eng. Sci., vol. 11, no. 2, pp. 2693–2710, Jun. 2017, doi: 10.15282/jmes.11.2.2017.11.0245.
[6] W. Saleem, M. Aurangzeb Khan, and S. R. Ch, “Formulation and Execution of Structural Topology Optimization for Practical Design Solutions,” J. Optim. Theory Appl., vol. 152, no. 2, pp. 517–536, Feb. 2012, doi: 10.1007/s10957-011-9894-3.
[7] K. Raz and M. Cechura, “USAGE OF TOPOLOGICAL OPTIMIZATION IN DESIGN OF MECHANICAL FORGING PRESSES,” MM Sci. J., vol. 2018, no. 04, pp. 2581–2584, Nov. 2018, doi: 10.17973/MMSJ.2018_11_201877.
[8] R. J. Yang and C. J. Chen, “Stress-based topology optimization,” Struct. Optim., vol. 12, no. 2–3, pp. 98–105, Oct. 1996, doi: 10.1007/BF01196941
[9] D. Costi, E. Torricelli, L. Splendi, and M. Pettazzoni, “Optimization Methodology for an Automotive Hood Substructure (Inner Panel),” p. 4, 2011.
[10] M. Cavazzuti, D. Costi, A. Baldini, and P. Moruzzi, Automotive Chassis Topology Optimization: a Comparison Between Spider and Coupé Designs.
[11] M. Cavazzuti, A. Baldini, E. Bertocchi, D. Costi, E. Torricelli, and P. Moruzzi, “High performance automotive chassis design: a topology optimization based approach,” Struct. Multidiscip. Optim., vol. 44, no. 1, pp. 45–56, Jul. 2011, doi: 10.1007/s00158-010-0578-7.
[12] D. J. Munk, D. J. Auld, G. P. Steven, and G. A. Vio, “On the benefits of applying topology optimization to structural design of aircraft components,” Struct. Multidiscip. Optim., vol. 60, no. 3, pp. 1245–1266, Sep. 2019, doi: 10.1007/s00158-019-02250-6.

[13] G. I. N. Rozvany, “A critical review of established methods of structural topology optimization,” Struct. Multidiscip. Optim., vol. 37, no. 3, pp. 217–237, Jan. 2009, doi: 10.1007/s00158-007-0217-0.
[14] S. Zhang, A. L. Gain, and J. A. Norato, “Adaptive mesh refinement for topology optimization with discrete geometric components,” Comput. Methods Appl. Mech. Eng., vol. 364, p. 112930, Jun. 2020, doi: 10.1016/j.cma.2020.112930.
[15] S. Zhou and M. Y. Wang, “Multimaterial structural topology optimization with a generalized Cahn–Hilliard model of multiphase transition,” Struct. Multidiscip. Optim., vol. 33, no. 2, pp. 89–111, Dec. 2006, doi: 10.1007/s00158-006-0035-9.
[16] G. Kharmanda, N. Olhoff, A. Mohamed, and M. Lemaire, “Reliability-based topology optimization,” Struct. Multidiscip. Optim., vol. 26, no. 5, pp. 295–307, Mar. 2004, doi: 10.1007/s00158-003-0322-7.
[17] K. Maute and E. Ramm, “Adaptive topology optimization,” Struct. Optim., vol. 10, no. 2, pp. 100–112, Oct. 1995, doi: 10.1007/BF01743537.
[18] M. hanifi Doğru, “Çoklu Yükleme Koşulları Altında Kamyon Şasisinin Topoloji Optimizasyonu,” El-Cezeri Fen Ve Mühendis. Derg., Sep. 2019, doi: 10.31202/ecjse.612531.



10.22214/IJRASET

INDEX COPERNICUS

45.98

IMPACT FACTOR: 7.129

TOGETHER WE REACH THE GOAL

IMPACT FACTOR: 7.429

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Call : 08813907089 (24*7 Support on Whatsapp)