



SIDE IMPACT ON B-PILLAR OF VEHICLE AND MATERIAL OPTIMIZATION

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Abstract: The automotive B-pillar is one of the most critical structural members in a vehicle body, playing a significant role in occupant protection during side-impact collisions. The present work focuses on the crashworthiness analysis and optimization of an automotive B-pillar using finite element analysis techniques. A detailed B-pillar model was developed and meshed using HyperMesh, while impact simulations were performed using LS-DYNA under dynamic loading conditions.

Initially, a baseline B-pillar model was analyzed to evaluate its structural response in terms of displacement, stress, strain, and energy absorption. To improve crash performance and reduce structural weight, a systematic optimization approach was adopted. The study involved material substitution using steel DP1000 steel, aluminium alloy, and carbon fiber reinforced polymer (CFRP), followed by thickness reduction and slot introduction in low-stress regions. Further design modifications were implemented to enhance stiffness and control deformation.

The study highlights the effectiveness of finite element analysis as a cost-effective tool for evaluating and optimizing automotive safety components. The findings provide valuable insights for the development of lightweight and high-performance B-pillar structures capable of meeting modern vehicle safety requirements.

1.INTRODUCTION

The global automotive sector continues to face simultaneous pressure for improved occupant safety, lower emissions, and reduced lifecycle cost. Structural lightweighting remains one of the most effective strategies for improving fuel economy in internal combustion vehicles and extending driving range in battery electric vehicles. However, mass reduction cannot compromise crashworthiness, particularly in side-impact scenarios where available crush space is limited. Within the body-in-white architecture, the B-pillar is one of the most safety-critical members because it transfers impact loads between the roof rail, rocker, floor, and door ring.

Recent side-impact protocols from regulatory and consumer agencies have increased the demand for robust pillar designs with lower cabin intrusion. As a result, researchers have investigated advanced high-strength steels, hot-stamped boron steels, aluminum alloys, fiber-reinforced polymers, and hybrid multi-material architectures. Parallel progress in explicit finite element methods has enabled rapid evaluation of crash behavior, optimization, and virtual certification.

This review critically evaluates recent progress in B-pillar crashworthiness and lightweight optimization, identifies unresolved engineering barriers, and proposes future research directions. Automotive safety structures are designed to manage collision loads while minimizing passenger compartment intrusion. Among these structures, the B-pillar plays a central role during side impact crashes. It transfers load from the roof rail to rocker panel and contributes to door retention, roof strength, and body stiffness. With growing demand for reduced vehicle mass and improved fuel economy or EV range, optimizing B-pillar structures has become an active research area.

1.1 ROLE OF B-PILLAR IN VEHICLE SAFETY

THE B-PILLAR SUPPORTS THE SIDE BODY OPENING, IMPROVES TORSIONAL RIGIDITY, AND PROTECTS OCCUPANTS DURING LATERAL INTRUSION EVENTS. IT IS HEAVILY LOADED DURING POLE TESTS AND SIDE BARRIER IMPACTS. A WELL-DESIGNED B-PILLAR DELAYS CABIN INTRUSION AND REDISTRIBUTES IMPACT ENERGY.

2. LITERATURE REVIEW SUMMARY

This section presents an extensive literature survey related to B-pillar design, crashworthiness improvement, and material optimization using Finite Element Analysis (FEA). Research papers were reviewed to identify current trends, methodologies, and gaps.

Yang et al. [1] proposed a lightweight design approach for automotive B-pillars utilizing Tailor Rolled Blank (TRB) technology, in which the sheet thickness is varied along the component length to achieve weight optimization. The study aimed to reduce structural mass while preserving crashworthiness during side-impact events. Finite element simulations were conducted to assess deformation patterns, stress distribution, and intrusion behavior. The findings indicated that the TRB-based design provided a considerable reduction in weight with only a minor effect on structural performance. However, the investigation was restricted to steel-based materials and did not consider alternative lightweight materials such as aluminum alloys or composite structures.

Lilehkoohi et al. [2] investigated the crash performance of vehicle side structures, particularly the B-pillar and side door, under pole side-impact loading conditions. The research focused on evaluating the influence of thickness variation on intrusion resistance and energy absorption capability. Numerical simulations revealed that increasing the B-pillar thickness enhanced impact energy absorption and reduced structural deformation, thereby improving occupant protection. Nevertheless, the increased thickness contributed to higher structural weight, and the study did not explore material substitution or optimization techniques for mass reduction.

Cao et al. [3] presented a reliability-based optimization methodology for automotive B-pillars subjected to side-impact loading. The objective was to improve crash performance consistency by considering uncertainties in manufacturing processes and material properties. Through the integration of probabilistic analysis and finite element simulations, the study demonstrated improved structural reliability and reduced variation in deformation responses. Despite these advantages, the research primarily focused on conventional steel materials and did not investigate lightweight alternatives or mass optimization.

Ikpe et al. [4] performed a design optimization study on an automotive B-pillar using computer-aided design and finite element analysis tools. The primary objective was to minimize stress concentration and deformation while maintaining adequate structural strength during impact events. Various geometric modifications were evaluated, and the optimized design exhibited improved load distribution and lower stress levels. However, the investigation concentrated mainly on geometric optimization and did not include material replacement or hybrid material concepts.

Sun et al. [5] conducted a multi-objective optimization study aimed at improving crashworthiness while simultaneously reducing structural weight. Advanced computational optimization techniques coupled with finite element analysis were employed to maximize energy absorption efficiency and minimize mass. The

optimized structures achieved superior crash performance with reduced weight. However, the research was not specifically focused on B-pillars and did not incorporate practical design modifications such as reinforcements or slot configurations.

Ibrahim et al. [6] developed and analyzed a composite B-pillar model to investigate the potential of composite materials for automotive safety applications. The study focused on evaluating crashworthiness characteristics and weight reduction capabilities through finite element simulations. Results showed that composite B-pillars possessed significantly higher specific energy absorption compared to conventional steel structures, making them attractive for lightweight vehicle design. Nevertheless, challenges associated with manufacturing complexity, production cost, and large-scale implementation were not comprehensively addressed.

Zhuang et al. [7] examined occupant protection during side-impact collisions by focusing on the reinforcement of automotive B-pillars. The study aimed to reduce passenger compartment intrusion and improve overall crash safety. Numerical analyses demonstrated that strategically reinforced B-pillars effectively minimized deformation and enhanced occupant protection. However, limited attention was given to lightweight design strategies and material optimization.

Pan et al. [8] introduced a metamodel-based optimization framework for B-pillar design using surrogate modeling techniques. The objective was to decrease computational expense while enabling multiple design iterations during the optimization process. By combining response surface methodology with finite element analysis, the researchers achieved substantial reductions in simulation time while maintaining prediction accuracy. The study, however, did not incorporate multi-material configurations or practical manufacturing considerations.

Wang et al. [9] investigated the effect of geometric and thickness-related design parameters on B-pillar crash performance. Finite element simulations were used to evaluate structural stiffness, load transfer mechanisms, and intrusion behavior under side-impact loading. The results indicated that optimized geometric configurations significantly improved load distribution and reduced deformation. Despite these improvements, the study did not address advanced lightweight materials or mass reduction techniques.

Zhang et al. [10] carried out a combined numerical and experimental investigation to validate the crash performance of automotive side structures. The primary goal was to establish the accuracy and reliability of finite element models used in crash simulations. Experimental results showed strong correlation with numerical predictions, confirming the effectiveness of simulation-based approaches. However, the work considered only a limited number of design variations and did not focus on structural optimization.

Li et al. [11] explored the application of aluminum alloys in automotive B-pillars to achieve vehicle lightweighting. Through finite element simulations, the crash performance of aluminum structures was compared with conventional steel designs. The results demonstrated significant weight savings, although a slight reduction in structural stiffness was observed. The study highlighted the trade-off between weight reduction and crash performance when adopting lightweight metallic materials.

Zhang et al. [12] investigated a multi-material B-pillar design with the objective of reducing structural weight while maintaining crashworthiness under side-impact conditions. Various material combinations

involving high-strength steel, aluminum alloys, and hybrid configurations were evaluated using finite element analysis. The results revealed that hybrid material concepts offered an effective compromise between mass reduction and structural strength, producing lower deformation than aluminum designs while remaining lighter than fully steel structures. However, manufacturing feasibility and cost considerations were not extensively discussed.

Du et al. [13] performed a multi-objective optimization study on the lower section of an automotive B-pillar. Sensitivity analysis was utilized to identify critical joints and structural regions affecting stiffness and crashworthiness. The optimization process successfully enhanced both rigidity and impact performance. Nevertheless, the investigation was limited to the lower section of the B-pillar, and the behavior of the complete component under realistic side-impact scenarios requires further evaluation.

Li et al. [14] studied the crashworthiness optimization of variable-stiffness B-pillars reinforced with continuous carbon-fiber composites. The research demonstrated that variable stiffness tailoring significantly improved specific energy absorption while achieving considerable mass reduction compared to conventional steel structures. Although the results were promising, challenges related to joining techniques, insert design, manufacturing feasibility, and production cost remain important areas for future investigation.

Swami and Jadhav [15] examined the reinforcement of automotive B-pillars using composite materials and evaluated their bending strength through experimental and numerical methods. Their findings indicated that composite reinforcements could substantially improve structural performance and contribute to enhanced side-impact resistance. The study also emphasized the importance of accurate material modeling for reliable simulation results. However, comprehensive dynamic crash testing and lifecycle cost analysis were not included, highlighting opportunities for future research.

2.1 Gap Identification

While several studies have explored the application of advanced materials, limited attention has been paid to structural redesign of the B-pillar for combined benefits of strength and weight reduction. Most works focus on steel or aluminum alone, without hybrid or composite integration. This research addresses the gap by combining material evaluation with geometric optimization.

2.3 Problem Definition

To analyze and optimize the B-pillar of a vehicle under side impact using FEA, comparing different materials and introducing design modifications for weight reduction while ensuring compliance with safety performance criteria.

2.4 Objectives

The main objectives of project work are as follows,

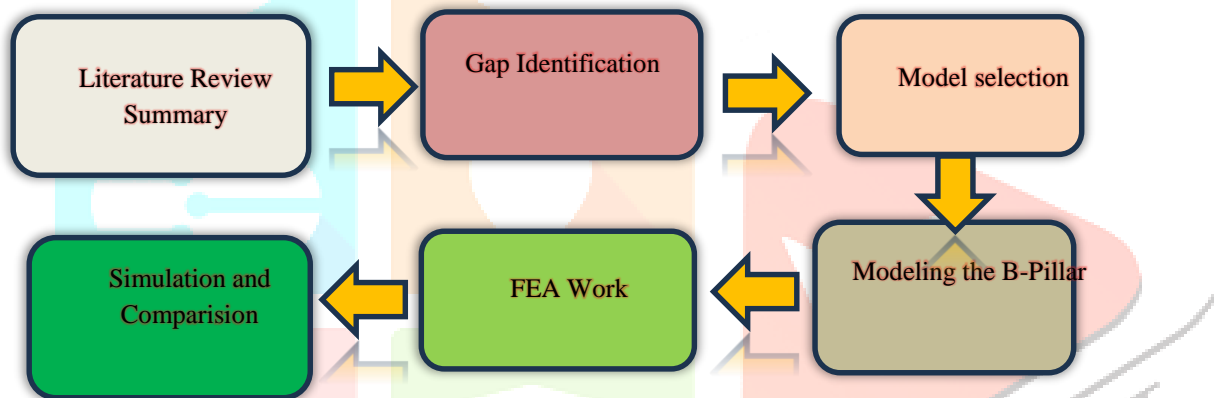
- To evaluate the crashworthiness performance of the automobile B-pillar under side impact loading conditions using numerical simulation and finite element analysis (FEA).
- To investigate the influence of different materials (e.g., high-strength steels, aluminum alloys, and advanced composites) on the deformation behavior, and weight of the B-pillar.

- To perform parametric design optimization of the B-pillar geometry and cross-sectional configuration to achieve an optimal balance between strength, stiffness, and weight reduction.
- To compare the crash performance of baseline and optimized B-pillar designs in term of intrusion resistance, specific energy absorption, and safety standards compliance

3.METHODOLOGY-

The project methodology follows a systematic workflow beginning from CAD modeling to result validation. The process includes steps such as model preparation, meshing, boundary condition application, and impact analysis in LS-DYNA. A simplified flow is as follows:

1. CAD modeling of B-pillar using CATIA V5
2. Import geometry to HyperMesh for meshing
3. Define material properties for steel, aluminum, and composite
4. Set up impact boundary conditions in LS-DYNA
5. Run side impact simulation and post-process results in HyperView



4.MODELING OF B-PILLAR

4.1Preprocessing

4.1.1Meshing- Meshing is a critical step in finite element analysis as it directly affects the accuracy and stability of the simulation. In this project, meshing was carried out using HyperMesh pre-processing software. The global element size of 5 mm is selected for the B-pillar model to achieve a balance between simulation accuracy and computational efficiency. In automotive structural and crash analysis, the mesh size must be fine enough to accurately capture stress distribution, deformation behavior, and energy absorption characteristics, especially in critical regions of the B-pillar subjected to impact loading.

| Sr. No. | Parameters of Mesh Quality | |
|---------|------------------------------|-----|
| 1 | Minimum Length(mm) | 2 |
| 2 | Maximum Length (mm) | 8 |
| 3 | Aspect ratio | 5 |
| 4 | Warpage of element in degree | 15 |
| 5 | Skew in degree of element | 40 |
| 6 | Jacobian of element | 0.6 |
| 7 | Minimum Quad Angle | 40 |
| 8 | Maximum Quad Angle | 145 |

4.1.2 Constraints

The base of the B-pillar was fixed to simulate its attachment to the vehicle body.

- All degrees of freedom restricted:

Translation: X, Y, Z

Rotation: RX, RY, RZ

LS-DYNA Keyword:

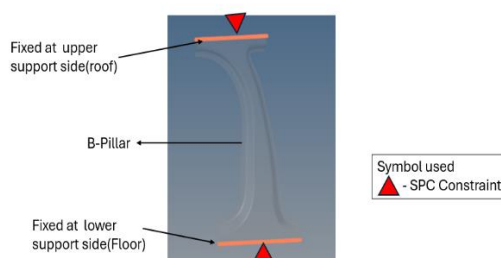
*BOUNDARY_SPC_SET

This ensures:

No rigid body motion

Stable simulation

In this model we fix the model at upper position where its getting lock to roof and in lower side where it was mounted and fixed to panel. Fig 5.2 shows the constrain applied on pillar where it fixed.

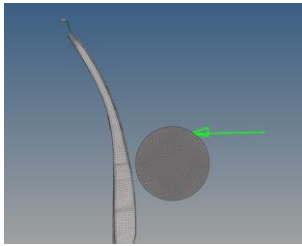


4.1.3 Load Application

Impact loading was applied using initial velocity.

The Diameter of imactor is 250 mm, and Velocity of imactor is 32kmph. Impactor is impacted on B-pillar Y negative direction at location mention in image. In the below figure 5.3 shows the impact location which is mention and find out the deformation, stresses and displacement. Using Impactor material is steel(rigid)

and its diameter 250 mm and its velocity is 32kmph impact to the Car B-Pillar area. after the Impact checking the displacement of B -pillar .



4.1.4Contact Defination

CONTACT_AUTOMATIC_SURFACE_TO_SURFACE

Parameters: Master and Slave selection:

Master- In this model we selected rigid impactor as master

Who transfer the force is selected as master

Slave- - In this model we selected B-pillar as slave

Who displace and on whom it goes impacted is selected as slave

This contact Contact ensures: Proper force transfer and Realistic deformation

4.2Postprocessing-

After completed the deck for impact analysis will run on LS-Dyna solver for specified run time.

4.3Postprocessing-

For postprocessing used software is hyperview. After completed the run their result stress and strain and displacement are checked and compare it with base model for weight reduction percentage and displacement.

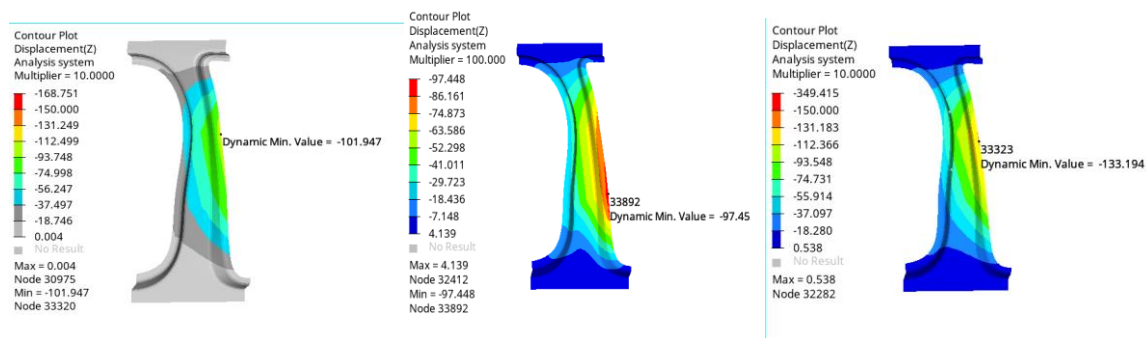
5.RESULTS AND DISCUSSION

5.1 Analysis Iteration For Material Comparision

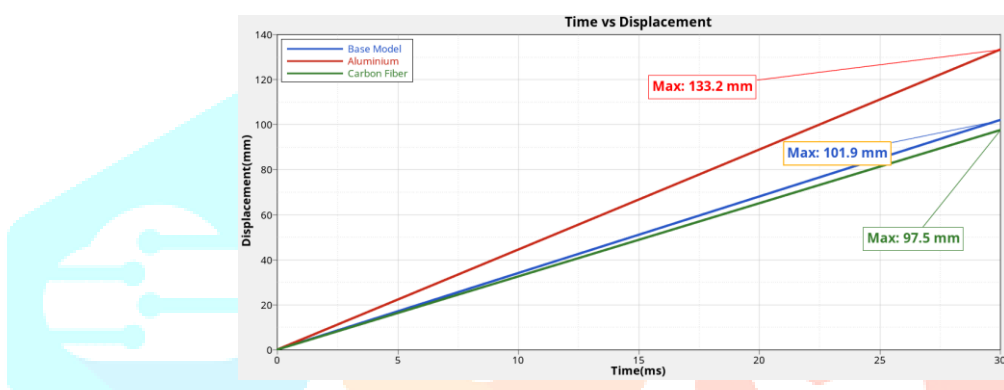
Material Data for Analysis

| Material Name | Density | Young’s Modulus | Poission’s Ratio |
|---------------|---------|-----------------|------------------|
| DP600 | 7.5E-9 | 21000 | 0.33 |
| Carbon Fiber | 1.5E-9 | 45000 | 0.3 |
| Aluminium | 2.7E-9 | 70000 | 0.33 |

5.1.1 Result and Discussion For material comparison



AS fig Show the Displacement plot for each material we observe that maximum displacement for base model is 101.94, for Carbon fiber material is 97.45 and for aluminium material 133.19 and their graphical representation as shown in below fig. full details are also represented in table below.



| Case | Material | Final Displacement(mm) | Stress | Strain | Total Weight | Reduction |
|------|--------------|------------------------|--------|--------|--------------|-----------|
| I | DP600 | 101.94 | 580 | 0.075 | 8.50 | 0% |
| II | Carbon Fiber | 97.45 | 920 | 0.06 | 8.50 | 0% |
| III | Aluminium | 133.19 | 580 | 0.09 | 3.10 | 63% |

The simulation results for the B-pillar under side impact loading demonstrate the influence of material selection and structural modification on crash performance parameters such as displacement, stress, strain, and weight. In the material comparison study, DP600 steel exhibits a displacement of 101.94 mm with a stress of 580 MPa and strain of 0.075, indicating a balanced combination of strength and absorption. Carbon fiber shows superior stiffness with the lowest displacement of 97.45 mm and strain of 0.06, despite experiencing the highest stress of 920 MPa, reflecting its high load-carrying capacity and resistance to deformation. In contrast, aluminium results in the highest displacement of 133.19 mm and strain of 0.09 at the same stress level as DP600, due to its lower stiffness, but achieves a significant weight reduction of 63%, highlighting its lightweight advantage

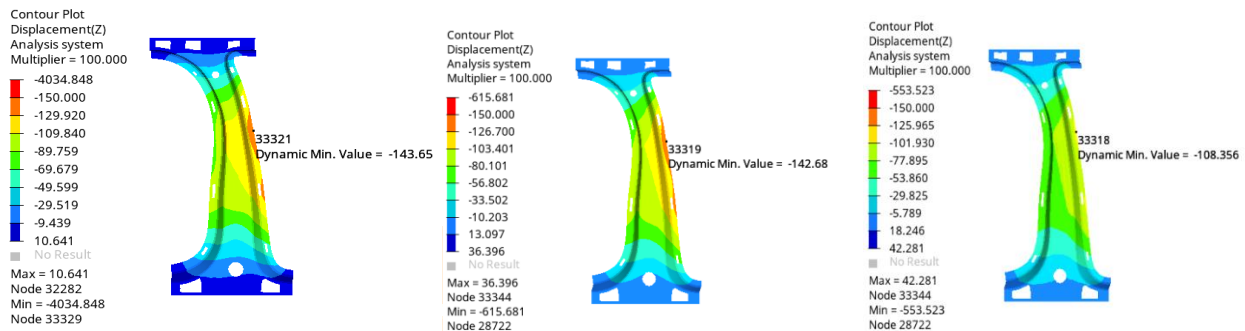
5.2 Analysis Iteration for weight Reduction

Iteration I- Thickness reduced – In this case thickness of B-Pillar is reduced to 1.5 mm from 2 mm

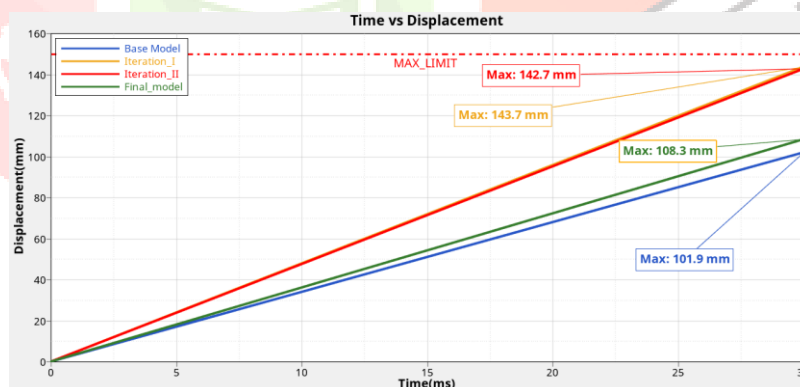
Iteration II- Slot Generated - In this case some slots are created in B-pillar for removing extra material in some regions.

Iteration III- Final Optimized model, where shape in impacted position is changed for better strength

Result and discussion for weight optimization Iterations.-



AS fig Show the Displacement plot for each iteration, we observe that maximum displacement for Iteration I is 143.65, for Iteration II is 142.68 and for final optimized model is 108.35 and their graphical representation as shown in below fig. full details are also represented in table below.



| Case | Material | Thickness (mm) | Final Displacement (mm) | Strain | Total weight | Reduction % |
|---------------------|----------|----------------|-------------------------|--------|--------------|-------------|
| Base Model | DP600 | 2.0 | 101.94 | 0.075 | 8.50 | 0% |
| Thickness Reduction | DP600 | 1.5 | 143.65 | 0.11 | 7.65 | 10% |
| Slot Design | DP600 | 1.5 | 142.68 | 0.11 | 7.10 | 16% |
| Design Modification | DP600 | 1.5 | 108.35 | 0.11 | 7.10 | 16 % |

IN THE DESIGN ITERATION STUDY USING DP600, THE BASE MODEL WITH 2.0 MM THICKNESS SHOWS A DISPLACEMENT OF 101.94 MM AND STRAIN OF 0.075. REDUCING THE THICKNESS TO 1.5 MM INCREASES DISPLACEMENT TO 143.65 MM AND STRAIN TO 0.11, INDICATING REDUCED STRUCTURAL STIFFNESS, WHILE ACHIEVING A 10% WEIGHT REDUCTION. THE INTRODUCTION OF A SLOT MAINTAINS SIMILAR DEFORMATION BEHAVIOR (142.68 MM DISPLACEMENT), CONFIRMING THAT STIFFNESS LOSS PERSISTS DESPITE GEOMETRIC MODIFICATION. HOWEVER, THE FINAL OPTIMIZED MODEL REDUCES DISPLACEMENT TO 108.35 MM WHILE MAINTAINING THE SAME STRAIN LEVEL AND ACHIEVING A 16% WEIGHT REDUCTION, DEMONSTRATING THAT GEOMETRIC REFINEMENT CAN EFFECTIVELY IMPROVE LOAD DISTRIBUTION AND PARTIALLY RESTORE STIFFNESS. OVERALL, THE RESULTS INDICATE THAT CARBON FIBER PROVIDES THE BEST DEFORMATION RESISTANCE, ALUMINIUM OFFERS MAXIMUM WEIGHT REDUCTION WITH HIGHER DEFORMATION, AND OPTIMIZED DP600 DESIGN ACHIEVES A BALANCE BETWEEN STRUCTURAL INTEGRITY AND WEIGHT EFFICIENCY SUITABLE FOR CRASHWORTHINESS APPLICATIONS

6 CONCLUSION

THE FINITE ELEMENT ANALYSIS OF THE B-PILLAR WAS SUCCESSFULLY CARRIED OUT USING LS-DYNA. THE STUDY FOCUSED ON EVALUATING THE STRUCTURAL PERFORMANCE OF THE B-PILLAR UNDER IMPACT LOADING CONDITIONS.

A BASE MODEL WAS FIRST ANALYZED TO ESTABLISH A REFERENCE. FURTHER MODIFICATIONS WERE PERFORMED BY CHANGING MATERIALS, REDUCING THICKNESS, INTRODUCING SLOTS, AND MODIFYING THE DESIGN. BASE MODEL GIVES THE ALMOST SAME RESULT AS REFERENCE STUDIED MODEL. DISPLACEMENT IS 101.9 MM

MATERIAL CHANGE SHOWED THAT CARBON FIBER PROVIDE BETTER RESISTANCE TO DEFORMATION, AND ALUMINIUM IS LIGHT IN WEIGHT BUT IT DEFLECTS MORE. ALUMINIUM DEFLECTION IS 133.2 MM BUT CARBON FIBER DEFLECTION WAS 97.5 MM

THICKNESS REDUCTION HELPED IN REDUCING THE OVERALL WEIGHT OF THE STRUCTURE. SLOT INTRODUCTION WAS USED TO REMOVE EXCESS MATERIAL FROM THE STRUCTURE. DESIGN MODIFICATION TECHNIQUES SUCH AS REINFORCEMENT IMPROVED THE STIFFNESS OF THE B-PILLAR. FOR SLOT INTRODUCTION ALMOST 16% WEIGHT IS REDUCED FROM MODEL BUT DISPLACEMENT IS MORE. FOR SLOT DISPLACEMENT GOING 142.7 AND FOR THICKNESS REDUCTION TO 1.5 MM DISPLACEMENT GOES TO 143.7MM.

THE FINAL OPTIMIZED MODEL MAINTAINED STRUCTURAL STRENGTH WHILE REDUCING WEIGHT. THE DISPLACEMENT VALUES WERE WITHIN ACCEPTABLE LIMITS, ENSURING SAFETY REQUIREMENTS WERE

SATISFIED. AT THIS MODEL WE ARE ABLE TO REDUCE DISPLACEMENT NEARBY BASE MODEL IT COMES TO 108.35 MM.

OVERALL, THE STUDY DEMONSTRATES THAT PROPER MATERIAL SELECTION, THICKNESS OPTIMIZATION, AND STRUCTURAL MODIFICATION CAN SIGNIFICANTLY IMPROVE THE PERFORMANCE OF THE B-PILLAR.

7 FUTURE SCOPE

Further improvements can be made by using advanced methods and detailed analysis. Advanced composite materials can be used with accurate material models to improve performance. Full vehicle crash simulation can be performed instead of component level analysis. Optimization techniques such as topology optimization can be applied for better weight reduction.

Experimental validation can be carried out to compare simulation results with real world conditions. Multi layer composite structures and hybrid materials can also be studied for improved structural performance.

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