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# To Investigate the Performance of Metal-Plastic Hybrid Grill Guard under Static and Dynamic Loading Conditions and Stress Scenarios by FEA and Experimentation

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**ABSTRACT:** This study investigates the performance of a metal-plastic hybrid grill guard subjected to static and dynamic loading conditions and various stress scenarios. The increasing demand for lightweight, durable, and cost-effective vehicle components has driven the exploration of hybrid materials that combine the strength of metals with the lightweight properties of plastics. A comprehensive evaluation of the hybrid grill guard's structural integrity is conducted through Finite Element Analysis (FEA) and experimental testing. The study begins with material characterization and the development of a CAD model for the grill guard, followed by static and dynamic simulations using FEA to analyze stress distribution, deformation, and failure criteria under different loading conditions. Experimental validation is performed to corroborate the numerical findings, involving load application and real-world impact scenarios to assess the guard's performance. Key parameters such as weight reduction, energy absorption, and durability are evaluated, providing insights into the suitability of hybrid materials in automotive applications. The results highlight the effectiveness of metal-plastic hybrid structures in achieving an optimal balance between strength and weight, offering a sustainable alternative to traditional metal grill guards. The findings contribute to the advancement of hybrid material technology and its potential applications in automotive safety and lightweight design.

**KEYWORDS:** Metal-plastic hybrid, Grill guard, Finite Element Analysis (FEA)

## I. INTRODUCTION

The automotive industry has undergone remarkable transformations over the decades, particularly in the design and functionality of front-end modules. These structures serve multiple purposes, including aerodynamic efficiency, structural integrity, and passenger safety. Among the various components of the front-end module, the grille guard plays a significant role in protecting the vehicle and its occupants during impacts while also contributing to aesthetics and ventilation efficiency. In modern vehicles, where lightweighting and energy absorption have become critical considerations, hybrid materials such as metal-plastic combinations are emerging as innovative solutions. This study investigates the performance of a metal-plastic hybrid grille guard under static and dynamic loading conditions, focusing on stress distribution through Finite Element Analysis (FEA) and experimental validation.

Front-end modules (FEMs) have evolved significantly since the early days of automotive design. Initially, vehicles featured simple structural frameworks, often built from robust steel or cast iron. These early FEMs were heavy but provided adequate protection for the rudimentary speeds and safety standards of the era. Over time, as vehicle speeds increased and crash safety became paramount, FEMs transformed into highly engineered systems integrating various components such as radiators, headlights, bumpers, and grille guards.

The introduction of plastics and composites in the mid-20th century revolutionized the automotive industry, offering lightweight alternatives to metal while maintaining strength and flexibility. Today, modern FEMs are modular assemblies often constructed from a combination of metals, polymers, and composite materials. These assemblies balance weight reduction, cost-effectiveness, and crashworthiness, making them integral to vehicle safety systems.

The grille guard, a prominent feature of the front-end module, was initially designed for utilitarian purposes, especially in off-road and commercial vehicles. Early grille guards were primarily fabricated from steel, providing robust protection against debris, wildlife, and minor collisions. Over the years, their role expanded to include aesthetic appeal, brand identity, and aerodynamic contributions. [1], [2]

In passenger vehicles, grille guards serve as a secondary safety layer, absorbing impact forces and reducing the severity of collisions. They also shield critical front-end components, such as radiators and air conditioning condensers, from damage. The evolution of grille guard design has been influenced by advancements in material science, leading to the adoption of lightweight materials like aluminum alloys, high-strength steel, and thermoplastics.

Hybrid grille guards, combining the rigidity of metals and the flexibility of plastics, have emerged as innovative solutions for addressing the conflicting requirements of strength, weight, and energy absorption. These designs capitalize on the superior mechanical properties of metals and the damping characteristics of plastics, offering an optimal balance for modern vehicles.

Vehicle safety has become a cornerstone of automotive engineering, driven by regulatory requirements and consumer expectations. Front-end protection systems are critical to mitigating the effects of frontal collisions, which account for a significant proportion of traffic accidents. The grille guard plays a pivotal role in absorbing impact energy and minimizing injuries to pedestrians and vehicle occupants.[2],[4],[12]

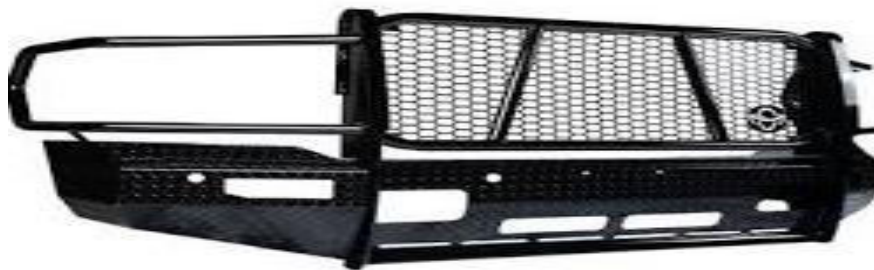


Figure 1: Image indicating Grille Guards of cars front end structure

## II. OBJECTIVES

- To perform the structural analysis on the grille guard metal component under different loading conditions and stress scenarios by FEA analysis.
- To perform the structural analysis of metal-plastic hybrid components under different loading conditions and stress scenarios by FEA and experimentation.
- To perform structural analysis for various plastic shapes filled in the component and compare structures for more strength of the component.

## III. SIGNIFICANCE

This research aligns with the growing emphasis on sustainability and safety in the automotive industry. The use of hybrid materials not only addresses the challenge of lightweighting but also enhances crashworthiness, making vehicles safer and more efficient. By investigating the performance of metal-plastic hybrid grille guards, this study contributes to the development of next-generation automotive safety solutions.

Moreover, the integration of FEA and experimental methodologies provides a comprehensive approach to design validation, ensuring that the hybrid grille guard meets both performance and regulatory standards. The findings of this study have the potential to influence future designs of grille guards and front-end modules, promoting innovation in automotive engineering.[6],[7]

## IV. METHODOLOGY OVERVIEW

The research methodology comprises two primary components: computational analysis using FEA and experimental testing. In the FEA phase, a detailed 3D model of component of the grille guard is developed, incorporating the

material properties of metal and plastic components. Static and dynamic simulations are performed to evaluate stress, strain, and deformation under various loading conditions.

In the experimental phase, physical prototypes of the hybrid grille guard are subjected to static loading tests using UTM. The results are compared with the FEA simulations to validate the computational model.

**Material Selection**

For this study, a square tube configuration was chosen to create the metal-plastic hybrid component, utilizing Mild Steel (MS) and Acrylonitrile Butadiene Styrene (ABS). Mild Steel, known for its high strength, ductility, and toughness, provides the necessary structural rigidity, with properties such as tensile strength of 400–550 MPa and density of 7830 Kg/m<sup>3</sup>. ABS plastic, with its lightweight nature, excellent impact resistance, and good fatigue durability, offers a tensile strength of 40–50 MPa and density of 1040 Kg/m<sup>3</sup>. This combination was selected to balance weight reduction, energy absorption, and structural strength, meeting both safety and performance requirements.

Table 1: Properties of Material

Material	Modulus of Elasticity	Tensile Strength	Elongation at Break	Density	Shore Hardness
Steel	205MPa	440 MPa	15%	7830 Kg/m <sup>3</sup>	126
ABS Plastic	1790-3200MPa	29.8-49MPa	10-15%	1040 Kg/m <sup>3</sup>	100

**Design**

The component was designed using CATIA, incorporating a honeycomb plastic structure [6] for the ABS section. The honeycomb geometry optimizes strength-to-weight ratio, enhancing impact resistance and energy absorption. Detailed drafting was developed to ensure precise fabrication, integrating the design seamlessly with the MS square tube [5],[7] for a robust metal-plastic hybrid assembly.

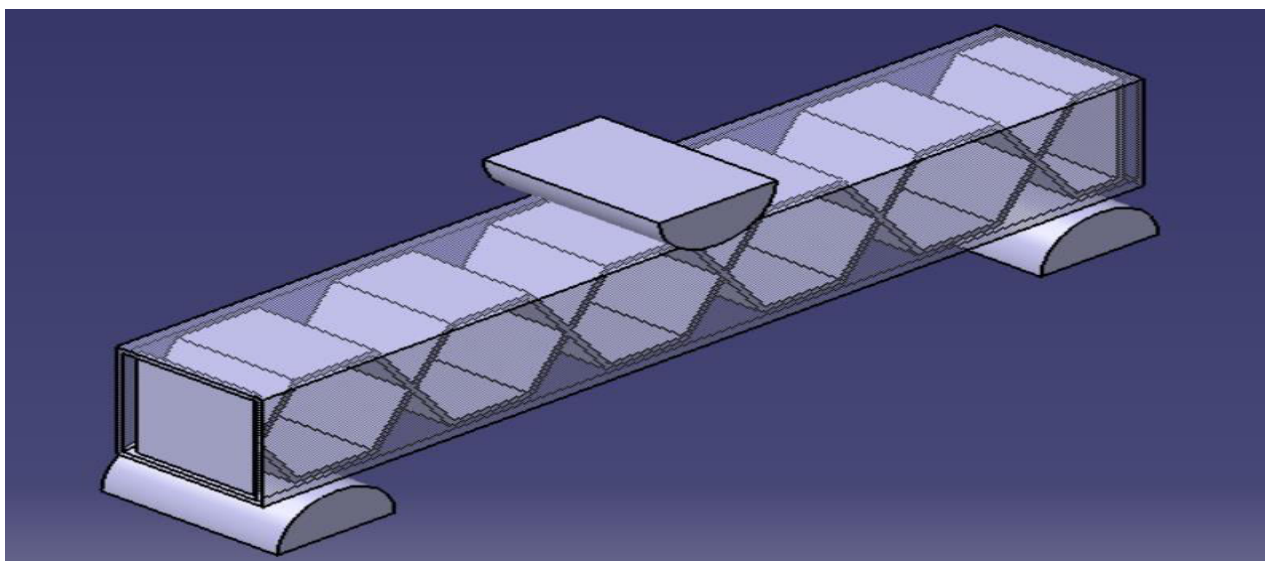


Figure 2: 3D model of Honeycomb Plastic Structure

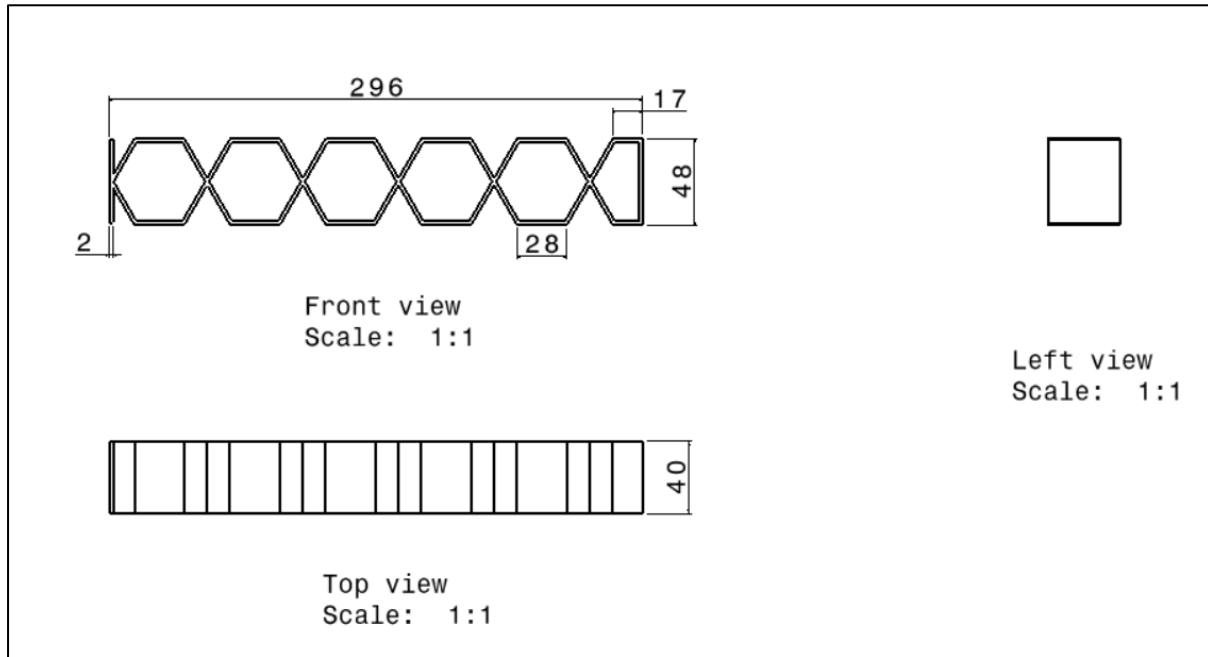


Figure 3: 2D drawing of Honeycomb Plastic Structure

### Finite Element Analysis

The analysis simulated static and dynamic loading conditions, focusing on stress distribution, deformation, and failure points. FEA helped optimize the design, ensuring structural integrity and effective energy absorption under real-world impact scenarios.

Table 2: Properties of MS Material used

Properties of Outline Row 4: STEEL 4340			
	A	B	C
1	Property	Value	Unit
2	Material Field Variables	Table	
3	Density	7830	kg m <sup>-3</sup>
4	Specific Heat, C <sub>p</sub>	477	J kg <sup>-1</sup> C <sup>-1</sup>
5	Johnson Cook Strength		
14	Bulk Modulus	1.59E+11	Pa
15	Shear Modulus	8.18E+10	Pa

Table 3: Properties of ABS Material used

Properties of Outline Row 3: ABS			
	A	B	C
1	Property	Value	Unit
2	Material Field Variables	Table	
3	Density	1040	kg m <sup>-3</sup>
4	Isotropic Elasticity		
5	Derive from	Young's Modulus and Poisso...	
6	Young's Modulus	2390	MPa
7	Poisson's Ratio	0.399	
8	Bulk Modulus	3.9439E+09	Pa
9	Shear Modulus	8.5418E+08	Pa
10	Bilinear Isotropic Hardening		
11	Yield Strength	45	MPa
12	Tangent Modulus	700	MPa

For dynamic loading in FEA, the boundary conditions align with the NCAP Global Test standards. The velocity of impact for a stationary object is set at 17.77 m/s, replicating real-world collision scenarios. This velocity ensures accurate simulation of stress distribution and energy absorption during frontal impact conditions. [5],[10]

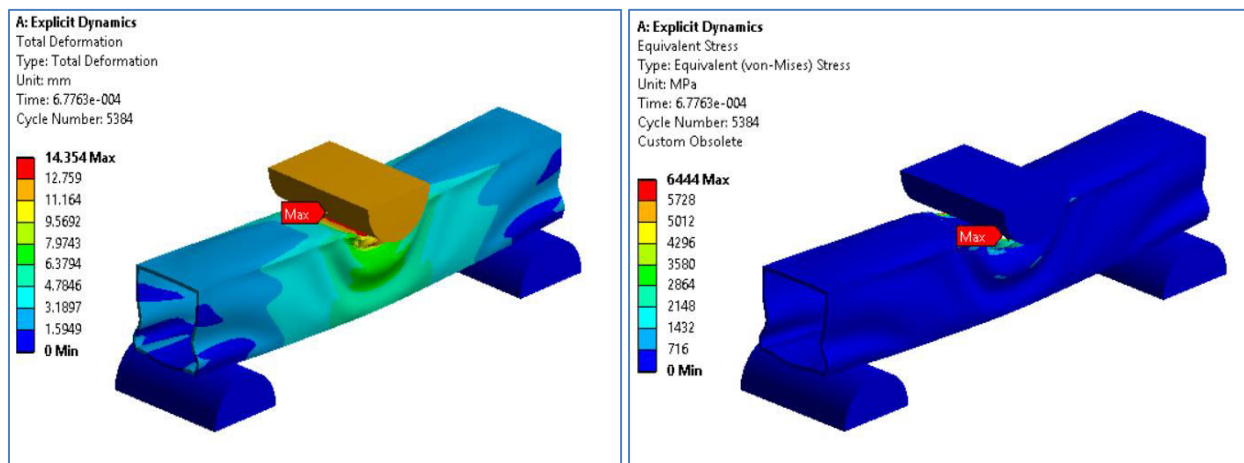


Figure 4: FEA results of existing grille guard component

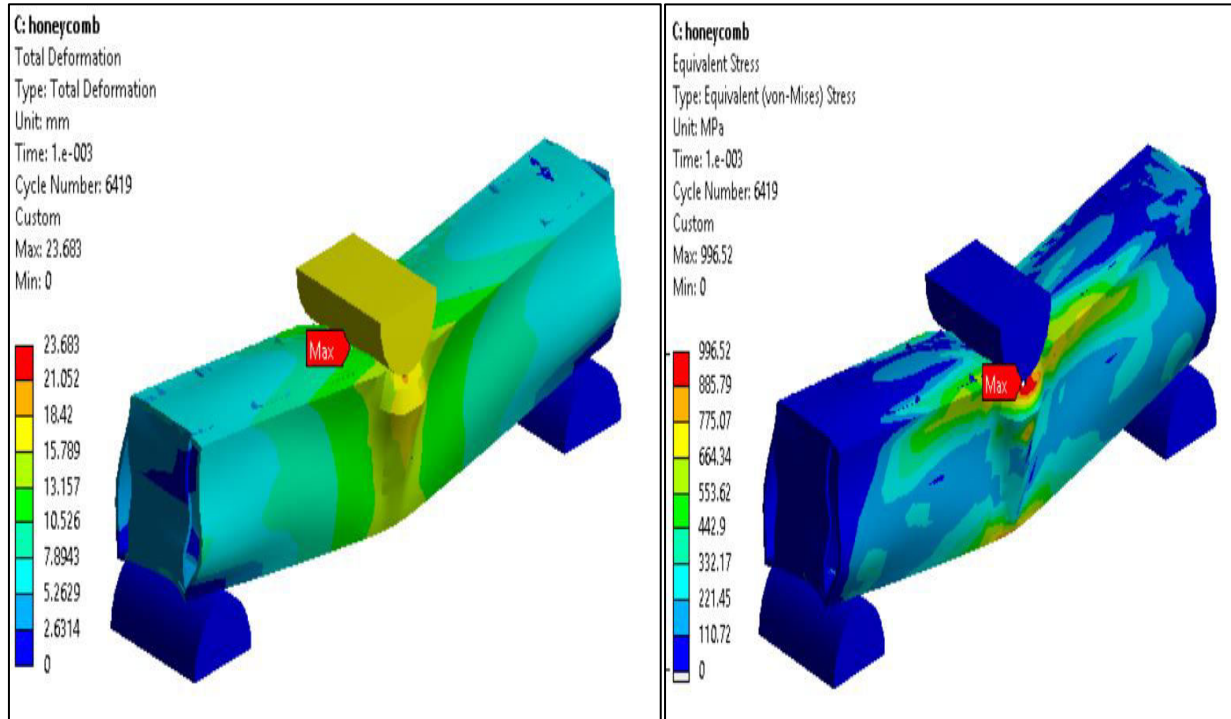


Figure 5: FEA results of hybrid grille guard

Under dynamic loading, the performance of the metal-plastic hybrid grille guard is enhanced compared to existing grille guard designs. The combination of Mild Steel (MS) for structural rigidity and ABS plastic for energy absorption offers improved impact resistance, reduced weight, and superior energy dissipation. This hybrid design effectively minimizes stress concentrations and deformation during collisions, outperforming traditional all-metal components in crashworthiness and overall safety.

**Performance under static loading and experimentation using UTM**

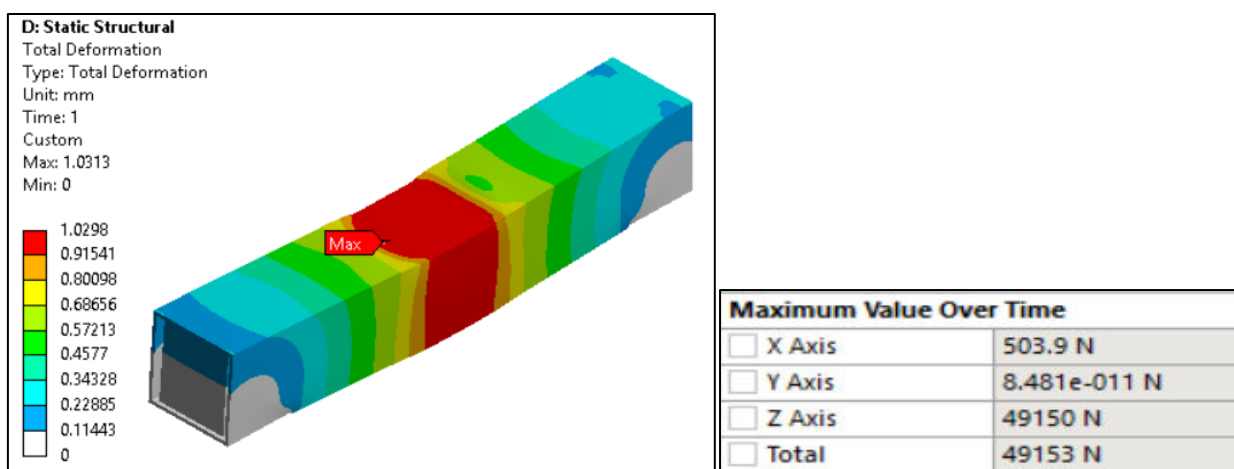


Figure 6: FEA of metal plastic under static loading

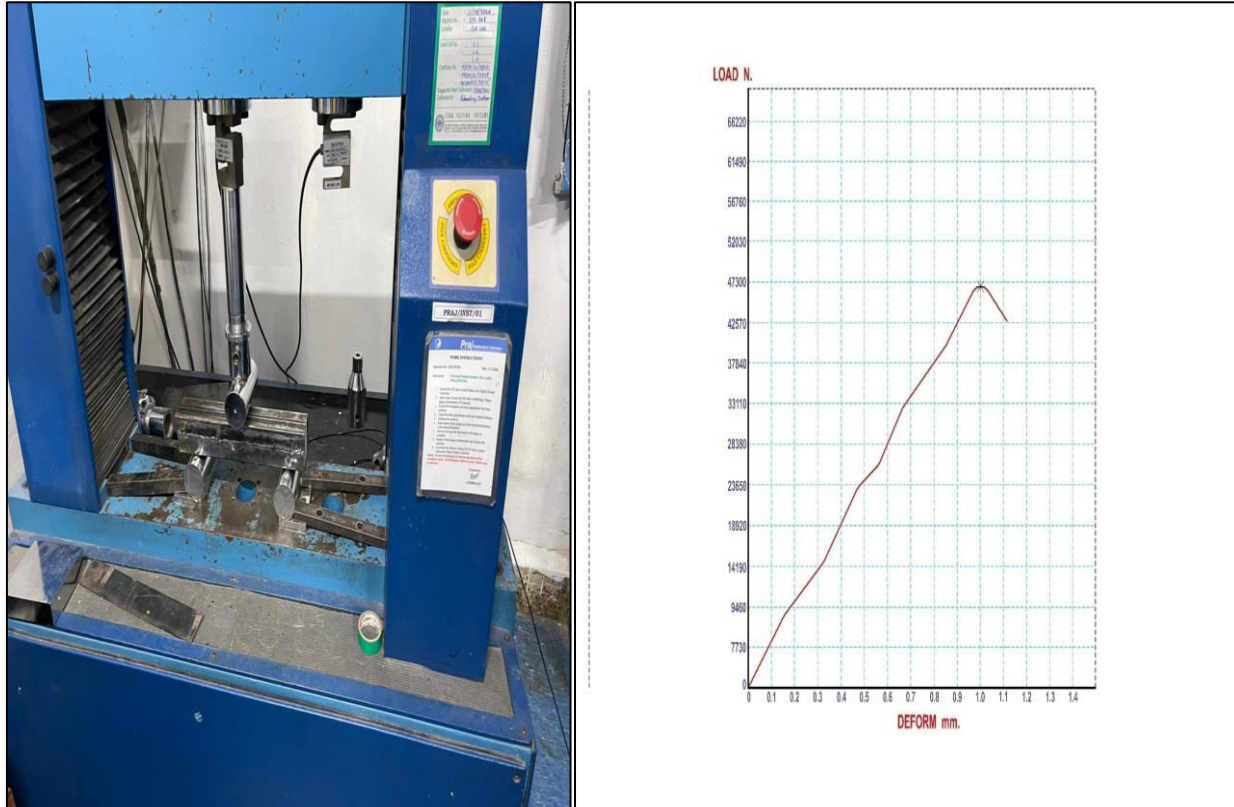


Figure 7: Experimentation of metal plastic hybrid component to validate the FEA

Table 4: Comparison of test results

SR NO	VALIDATION TYPES	REACTION FORCE (N)
1	FEA	49153
2	EXPERIMENTAL	47300

[6],[7]

## V. CONCLUSION

The performance of grille guards is crucial to ensuring vehicle safety and mitigating collision effects. The shift towards metal-plastic hybrid designs represents a significant advancement in automotive engineering, combining the strengths of different materials to achieve superior performance. This study investigates the behavior of such a hybrid grille guard under static and dynamic loading conditions, contributing valuable insights to the field of front-end module design.

The combined analysis of experimental and software data revealed 47300N reaction force of experimentation and 49153N reaction force of FEA. The consistency between the experimental and software results strengthens the validity of our conclusion and lends credibility to our research outcome.

By integrating computational simulations with experimental testing, the research not only validates the performance of the hybrid grille guard but also highlights the potential of hybrid materials for cost-effectiveness and lightweights in modern automotive applications.



The idea of high strength for the various cross section rod (rectangular) of grille guard structures which was earlier restricted to only circular rods is now possible. So changing circular to rectangular cross sectioned rods wherever aesthetic comes into picture is possible.

The outcomes of this study will inform future design strategies, advancing the safety, efficiency, and sustainability of vehicles.

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