

Design and Analysis of Honeycomb Rear Door Map Pocket by Application of Finite Element Method

Pramod Ram Wadate^{1,*}, Deepak Dhondge², Rahul Bachute³ and Pritee Purohit⁴

Abstract

In modern automobiles, the door trim plays a vital role in both functionality and occupant safety. It integrates various convenience features such as armrests, power window switches, and map pockets, while also contributing to crash energy absorption during side impacts. In such collisions, the occupant's body typically contacts the door trim, making its design and material selection critical for minimizing injury through controlled deformation and energy dissipation. This research focuses on enhancing the crashworthiness of a rear door map pocket by analysing its response to impact using simulation and experimental methods. A 3D model of the map pocket is developed using SolidWorks and evaluated through Finite Element Analysis (FEA) in ANSYS Workbench 21, using a falling steel ball impact scenario as per industry standards. To improve energy absorption and reduce reactive forces, the conventional material is replaced with 3D-printed ABS featuring a honeycomb structure. Denting (compression) tests on a Universal Testing Machine (UTM) were used for experimental validation, followed by a comparative analysis of simulation and experimental outcomes to assess performance. The findings aim to guide the development of safer, lightweight automotive components, with recommendations for future improvements.

Keywords: Hexagonal core structures, composite structures, trapezoidal core structures, finite element analysis, automotive

INTRODUCTION

Side-impact collisions are among the most critical and dangerous types of traffic accidents, often resulting in severe injuries or fatalities. Global data indicates that side impacts account for nearly 30% of all vehicle collisions and approximately 35% of associated deaths. Unlike front and rear zones, the sides of a vehicle offer limited space for energy absorption, placing occupants perilously close to the impact zone. During a side collision, significant deformation can occur around the door area, intruding into the occupant space and heightening the risk of injury. This makes it imperative to

establish robust design criteria that anticipate worst-case impact scenarios to enhance occupant safety.

In recent years, considerable research has focused on improving side-impact crashworthiness through structural enhancements and occupant protection systems. With the advent of Computer-Aided Engineering (CAE), predictive simulations have become a standard practice in the automotive industry, particularly during the vehicle development phase. Finite Element Analysis (FEA) allows for a detailed evaluation of side impact performance, considering factors such as intrusion levels, impact speed, occupant position, structural strength, deformable padding, and the

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availability of side airbags and restraints. The door trim plays a crucial role in this context, acting as both a structural and functional component. Its assembly typically involves three major subsystems: the body-in-white (BIW), the plastic door trim, and the connections between them. Each subsystem must be accurately modeled to replicate real-world impact behaviour. Special attention is given to components like the armrest, map pocket, and lower substrate, which must meet stringent requirements for strength and durability while maintaining minimal thickness—often less than 2 mm. These components not only contribute to occupant comfort but also serve as critical elements in protecting passengers during side impacts.

Figure 1 shows the schematic of car door plane to understand fundamental. Map pockets can be found in various places within a vehicle, such as: Doors: Easily accessible for quick storage, Seats: Convenient for passengers to keep their belongings close and Centre console: Ideal for larger items or shared belongings.

This study focuses on evaluating and enhancing the crashworthiness of the door trim, particularly the rear map pocket, by employing advanced modelling techniques and material optimization strategies to ensure both lightweight design and superior impact performance.

Problem Statement

The map pocket, originally designed for storing paper maps, has evolved into a multifunctional storage space in modern vehicles, catering to the diverse needs of drivers and passengers. However, in certain crash scenarios, it poses a safety concern—loose items or the structure of the map pocket itself may lead to limb entrapment or obstruct occupant movement, thereby increasing the risk of injury and complicating emergency escape. This highlights the need for a safer, impact-optimized map pocket design.

By addressing these issues, car manufacturers can significantly enhance passenger safety and reduce the potential for injury during a crash

Objectives

1. The primary objective of integrating honeycomb structures into car door map pockets during a crash is to enhance passenger safety by mitigating the risk of injury from flying debris and structural failure.
2. Design and FEA simulation will be performed on rear door map pocket.

LITERATURE REVIEW

An extensive literature survey conducted towards the sustainable development of honeycomb rear door map pocket by application of finite element method.

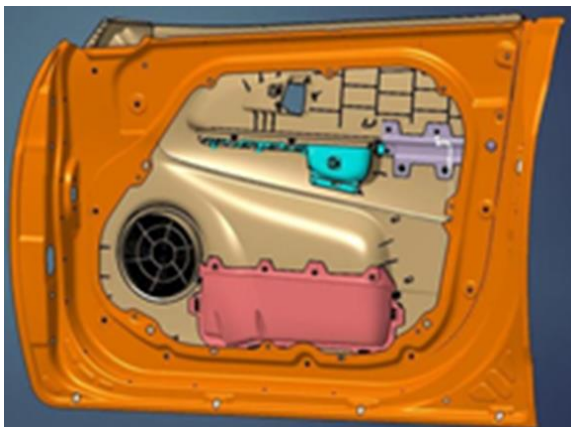


Figure 1. Schematic diagram of car door panel.

M.Y. Yuhazri et. al [1] emphasis on recycling in the automotive industry has driven increased use Incorporation of natural fibers into composite materials. This study investigated the use of non-woven and hybrid woven/non-woven kenaf fibers were utilized in the fabrication of a car door map pocket for the PROTON Saga FL. The manufacturing process employed the hand lay-up technique combined with vacuum bagging. The manufacturing process employed the hand lay-up technique combined with vacuum bagging. L2 HN-W/W sample showed superior performance in terms of light weight, tensile strength, and flexural strength compared to polypropylene (PP). The incorporation of woven kenaf fabric notably enhanced the mechanical properties, and the study also discussed future research possibilities.

M.Y. Yuhazri et. al [2] conducted studies have highlighted the growing interest in natural fibre composites to improve fuel efficiency and reduce environmental impact in the automotive sector. Kenaf fibers have shown promise as a sustainable alternative to petroleum-based materials. Experimental investigations using non-woven and woven kenaf fabrics for automotive components, such as car door map pockets, demonstrated improved tensile and flexural strength, along with weight reduction.

Hybrid composites combining both fabric types have been identified as optimal configurations, supporting the potential of kenaf fibres in eco-friendly automotive applications. Recent developments in Aeronautics, Aeronautical engineering, and Power generation sectors have increased the desire for lightweight, multifunctional, and heat-resistant structural materials. To address this, a hierarchical honeycomb structure design is proposed by replacing the side walls of conventional pores with Voronoi lattices. Using a centroidal Voronoi tessellation (CVT) algorithm, a digital model is created to generate the primary honeycomb layout, followed by structural optimization through a modified bidirectional evolutionary structural optimization method. This approach enables precise control of pore size and material distribution, and its effectiveness is validated through three case studies, supporting its potential in additive manufacturing of advanced hierarchical structures by Yuan Liu et. al [3]. Gouri Ghongade et. al [4] examines the impact of Structural enhancement of circular-core honeycomb panels under axial compression using Abaqus-CAE and furnace-brazed steel specimens. Despite a slight weight increase, reinforcements enhanced load-carrying capacity by 44%, with 10 mm cell diameter showing the best performance and validating the numerical model.

Shubham Upreti et. al [5] investigated the self-resonant frequency of of a honeycomb Trapezoidal core structures using carbon/glass fibre face sheets and an Aluminium 5052 hexagonal core, analyzed via ANSYS. Natural frequencies were evaluated for varying face sheet thicknesses (0.5 mm to 2.5 mm) under static loading. Results showed that natural frequency increased and converged with greater face sheet thickness, while deformation and Von Mises stress decreased accordingly. Hossein Mohammadi [6] studied honeycomb structures, inspired by nature, offer excellent energy absorption and are widely used to enhance crashworthiness in vehicles. Advanced designs like graded, hierarchical, and sandwich panels significantly improve impact performance while reducing weight and emissions. Lukas Utzig et. al enhanced the squeak and rattle noises inside vehicles are increasingly critical as overall cabin noise decreases. This study uses vibroacoustic measurements and a 3D finite element model with the Harmonic Balance Method to predict and assess squeak noise audibility, showing good agreement between simulation and experimental results.

Lightweight design plays a key role in automotive development through structural optimization and the use of low-density materials. This study investigates PP/elastomer/talc (PP+EPDM-TD) blends with varying talc content (5%, 10%, 20%) to develop lightweight door panel materials. Among them, the 10% talc blend (PP+EPDM-TD10) was found optimal, balancing stiffness, shrinkage, and cost while meeting lightweight design goals by Shupeng Li et. al [7]. Woonsang Baek et. al [8] elaborates interior trim panels of car doors can generate irritating noise due to assembly defects, affecting driver comfort. This study proposes an in-process inspection system using a pneumatic pusher and strategically placed microphones to detect such noise. By applying noise source localization and time

difference of arrival analysis, the system accurately identifies faulty panels, demonstrating effective noise detection during production. Sound quality significantly influences vehicle purchase decisions, with Buzz, Squeak, and Rattle (BSR) issues commonly affecting perceived quality. This study presents a shape optimization-based methodology to reduce rattle noise in door trim and audio speaker assemblies. Unlike the traditional "find and cure" approach, the proposed method addresses BSR during the design phase, enhancing overall NVH performance by Omkar S Bhosale et. al [9].

The reviewed literature highlights the growing emphasis on addressing NVH issues, particularly BSR, as a key aspect of vehicle quality and customer satisfaction [10–13]. Advanced methodologies, such as shape optimization and in-process inspection systems, offer promising solutions to detect and reduce rattle noise during the early design and development stages. These proactive approaches not only improve sound quality but also align with the automotive industry's goal of achieving right-first-time designs. Continued research in this area is essential to further enhance occupant comfort and vehicle refinement [14–16].

Material Properties

The honeycomb rear door map pocket in automobiles is often made using polymer materials due to their lightweight, durable, and moldable nature. When a honeycomb structure is integrated, it provides enhanced strength-to-weight ratio, stiffness and energy absorption capabilities, which are crucial for vehicle interiors. Table 1 represents the detailed overview of the polymer materials typically used and their material properties and characteristics relevant to a honeycomb rear door map pocket.

Polypropylene is the material of choice for honeycomb rear door map pockets due to its ideal combination of lightweight design, mechanical reliability, manufacturing efficiency, and environmental compatibility, aligning with modern automotive design and sustainability goals. The defined suitable materials having specific testing property under compression loading conditions and mentioned in Table 2.

DESIGN and ANALYSIS

The study focuses on the design and analysis of automotive interior components, specifically targeting the reduction of rattle noise in door trim and audio speaker assemblies. A shape optimization approach is employed during the design phase to enhance structural integrity and minimize noise generation. Finite Element Analysis (FEA) is used to evaluate the dynamic behaviour of the components under operational conditions, enabling identification of critical areas prone to Buzz, Squeak, and Rattle (BSR). The integrated design and analysis methodology ensures improved sound quality, structural performance, and compliance with NVH standards. The fundamental geometry of rear door map pocket is shown in Figure 2.

Table 1. Material Properties and Characteristics [17].

Property	Polypropylene (PP)	ABS	Polycarbonate (PC)	PC/ABS Blend	TPO
Density (g/cm ³)	0.90–0.91	1.04–1.07	1.20–1.22	1.10–1.20	0.90–1.05
Tensile Strength (MPa)	25–40	40–50	55–75	40–60	10–30
Flexural Modulus (MPa)	1000–1500	2000–2500	2100–2400	1700–2300	800–1200
Impact Strength	Moderate	Good	Excellent	Excellent	Good
Thermal Resistance (°C)	100–110	~85–100	125–135	~110–125	~100–110
Moldability	Excellent	Good	Moderate	Good	Excellent
Recyclability	High	Moderate	Moderate	Moderate	High

Table 2. Polypropylene Material Properties [18].

Property	Density	Young's Modulus	Poisson's Ratio	Bulk Modulus	Shear Modulus	Yield Strength	Tangent Modulus
Values	900kgm ³	1700MPa	0.43	4047.6MPa	594.41MPa	31.6MPa	566MPa

Grid division, a crucial component of finite element analysis, best captures the concept of finite elements. and mesh model with the element size of 4mm is represented in Figure 3. The quality of the mesh not only influences the efficiency of model analysis but also has a direct impact on the accuracy of the results. Therefore, based on the available hardware, an appropriate meshing strategy should be selected to optimize computation time without compromising the accuracy of the analysis.

Boundary Conditions

Finite Element Analysis or structural simulations, defining appropriate boundary conditions is critical to evaluate the performance of the honeycomb rear door map pocket under real-world conditions. Figure 4 represents the static structural boundary conditions as per the specific requirements and to satisfy the defined goal. Table 3 represents the summary of boundary conditions considered for this analysis.

Table 3. Summary of boundary conditions.

Condition Type	Location	Purpose
Fixed Constraints	Mounting holes/edges	Prevent movement (simulate real mounts)
Static Load	Inner face of pocket	Simulate load of stored objects
Point Load	Wall or corner	Simulate user pressing or sharp object
Distributed Load	Entire inner surface	Even pressure from stored items
Contact Constraint	Between pocket and door/trim	Simulate assembly or support
Thermal Condition	Whole pocket surface	Simulate in-cabin temperature range
Impact Load (Optional)	Inner or outer surface	Simulate crash or dynamic event

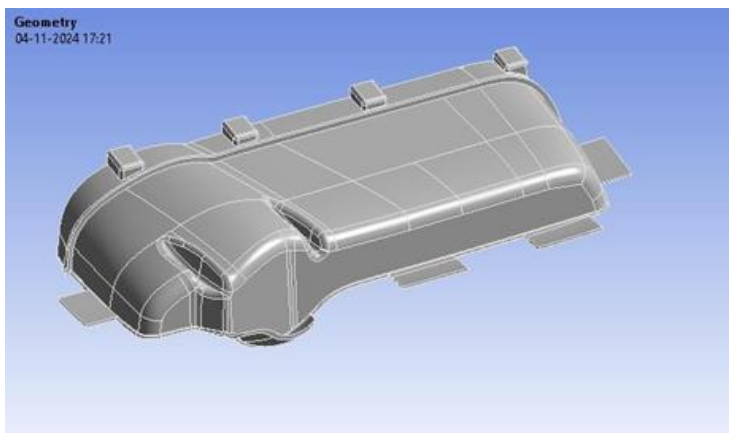


Figure 2. Geometry of rear door map pocket.

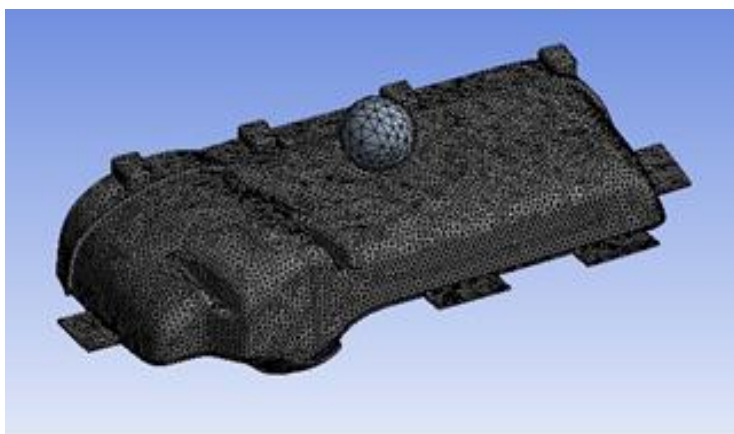


Figure 3. Mesh model with element size of 4mm.

FEA ANALYSIS

Finite Element Analysis (FEA) performed for rear door map pocket to simulate the reaction force in FEA & experimental investigation of forces by utilization of universal testing machine to achieve the desired objectives of this paper.

To understand the Von-Mises, structural static analysis is conducted and shown in Figure 6. It can reveal from Figure 5 that the maximum and minimum equivalent stresses recorded are 40.425 Mpa and 2.500 MPa respectively.

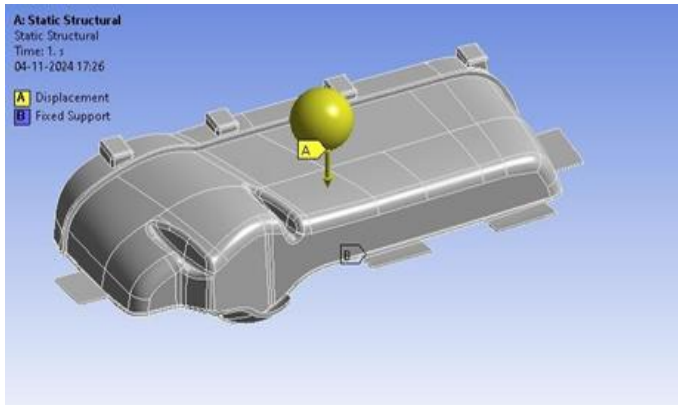


Figure 4. Static structural boundary conditions.

Tabular Data					
	Steps	Time [s]	<input checked="" type="checkbox"/> X [mm]	<input checked="" type="checkbox"/> Y [mm]	<input checked="" type="checkbox"/> Z [mm]
1	1	0.	= 0.	0.	= 0.
2	1	1.	0.	3.	0.
3	2	2.	= 0.	6.	= 0.
4	3	3.	= 0.	9.	= 0.
5	4	4.	= 0.	12.	= 0.
6	5	5.	= 0.	15.	= 0.

Figure 5. Boundary conditions.

A: Static Structural
 Equivalent Stress
 Type: Equivalent (von-Mises) Stress
 Unit: MPa
 Time: 5
 Custom Obsolete
 Max: 40.425
 Min: 1.4225e-10
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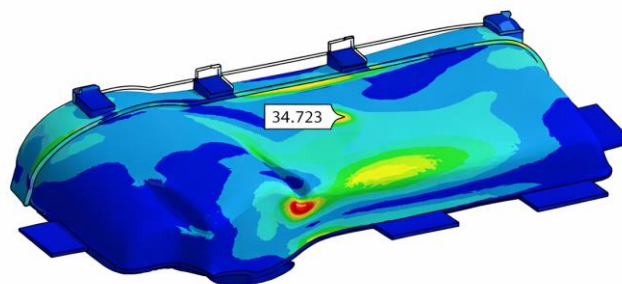
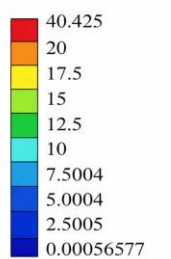


Figure 6. Equivalent stress of rear door map pock.

Force Reaction

The analysis of the rear door map pocket's mounting design revealed that the reaction forces in X, Y, Z axis recorded are $-2.692 \times 10^{-2} \text{N}$, -1.379N , 14.972N . Total reaction force obtained 97.631N which represent support loads are crucial for verifying the adequacy of fasteners, clips or bonding interfaces. The simulation results showed that the reaction forces were primarily concentrated at the clip attachment points, balancing the external load. The force distribution was uneven, with higher loads at lower clips bearing more structural responsibility. Understanding force reactions is essential for fasteners and welds to safely handle loads during vehicle operation.

RESULTS

Total Deformation

The total deformation plot represents the overall displacement of the rear door map pocket structure under the applied load conditions. This includes both elastic and potential plastic deformation depending on the material behavior and boundary conditions defined during the analysis.

For this simulation, a static load of 97.631N was applied vertically to simulate the weight of items typically stored in the map pocket. The pocket is assumed to be rigidly mounted to the inner door panel at defined fixing points, which were constrained in all degrees of freedom.

The analysis revealed the following:

1. Maximum total deformation occurred at the central bottom region of the map pocket, which is the farthest point from the mounting constraints. The peak deformation was measured as 16.475 mm and shown in Figure 7.
2. The deformation is within acceptable limits and does not affect the functionality or aesthetic integrity of the map pocket. The deformation pattern indicates a typical cantilever-type bending behavior due to the overhanging geometry of the pocket relative to its mounting base.

Overall, the structure demonstrates sufficient stiffness under normal loading conditions with no excessive deflection that could lead to material fatigue or user dissatisfaction.

Finite Element Analysis (FEA) performed for rear door map pocket to simulate the reaction force in FEA & experimental investigation of forces by utilization of universal testing machine to achieve the desired objectives of this paper.

B: POLYETHYLENE

Total Deformation

Type: Total Deformation

Unit: mm

Time: 5

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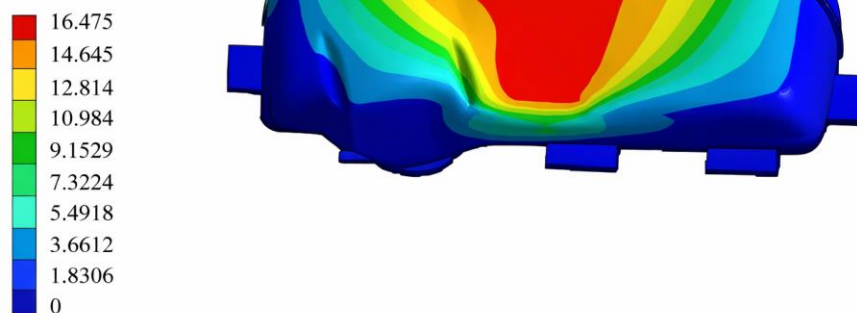


Figure 7. Total deformation rear door map pocket.

It can reveal from Figure 8 that the maximum and minimum equivalent stresses recorded are 590.22Mpa and 65.58MPa respectively. Stress has crossed yield which leads to failure of component to determine reaction force.

Force Reaction

The analysis of the rear door map pocket's mounting design revealed that the reaction forces in X, Y, Z axis recorded are 290.51N, -93.605N, 139.21N, Total reaction force obtained 1440.4N for the applied displacement. which represents that it becomes necessary to improve reaction force by replacing existing material with honeycomb structure. The force reaction in rear door map pocket is shown in Figure 9.

Existing Scale Down Model of Honeycomb Map Pocket

The existing material consideration for the analysis is ABS. Below mentioned are material properties and FEA analysis to understand the characteristically performance of the map pocket.

B: Polyethylene

Equivalent Stress

Type: Equivalent (von-Mises) Stress

Unit: MPa

Time: 5

Custom

Max: 590.22

Min: 0.00018662

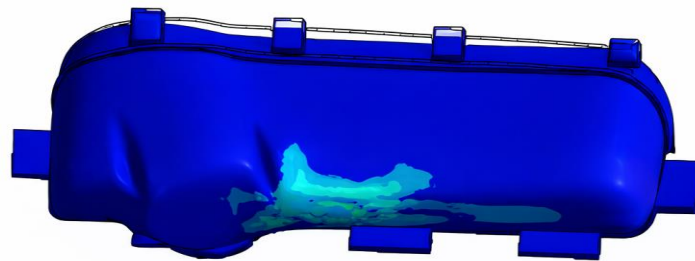
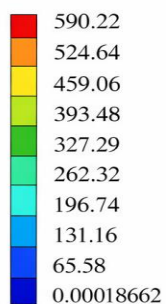


Figure 8. Equivalent Stress of Rear Door Map Pocket

B: Polyethylene

Force Reaction

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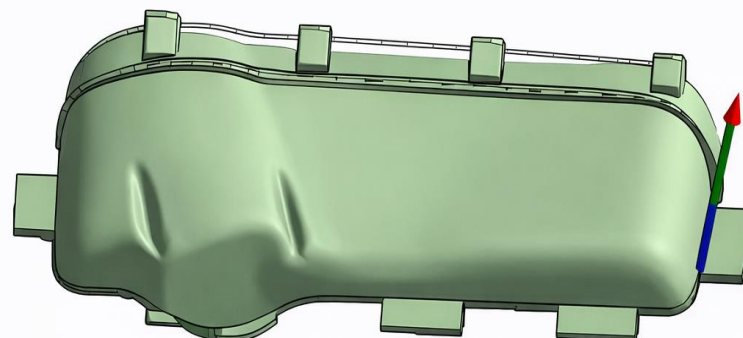


Figure 9. Force reaction in rear door map pocket.

Material Properties

Table 4 represents the fundamental properties of ABS.

EXPERIMENTAL ANALYSIS

A Universal Testing Machine (UTM) is employed to assess both the tensile and compressive strength of various materials. It is capable of testing a wide range of specimens, from rigid materials like metals and concrete to flexible ones such as rubber and textiles. This versatility makes the UTM suitable for use across nearly all manufacturing industries. As a multifunctional and essential testing device, the UTM can evaluate key material properties, including tensile strength, elasticity, compressive strength, yield strength, elastic and plastic deformation, bending behaviour, and strain hardening, which are responsible for understanding and utilization of defined property of material for sustainable applications.

Figure 10 represents the load versus displacement (deformation) for honeycomb map pocket. It can be revealed that, with increase in the load the deformation increases hence, there is direct relationship with load and deformation. The maximum force reaction of 2010 N is taken by the honeycomb map pocket under compression loading.

The force reaction represents the values of 1955.7N for finite element analysis and 2010N for universal testing machines and mentioned in Table 5. Hence it can be revealed that there is an excellent correlation between theoretical and practical analysis.

Table 4. ABS material properties.

Property	Density	Young's Modulus	Poisson's Ratio	Bulk Modulus	Shear Modulus	Yield Strength	Tangent Modulus
Values	1080kgm ³	2060MPa	0.45	6866MPa	7103MPa	3800MPa	8900MPa

Table 5. Force reactions

Parameter	Honeycomb MAP Pocket (FEA)	Honeycomb MAP Pocket (UTM)
Force Reaction	1955.7 N	2010 N

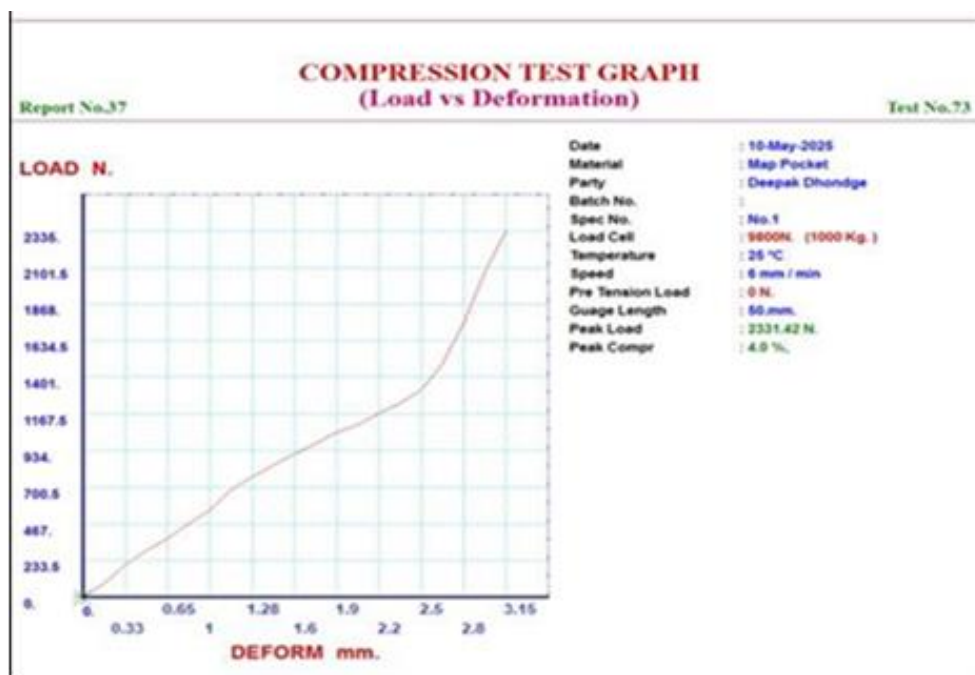


Figure 10. Load with deformation during compression test.

CONCLUSIONS

The design and analysis of a honeycomb-structured rear door map pocket have demonstrated the viability of developing a lightweight yet mechanically robust automotive interior component. By exploiting the high strength-to-weight ratio inherent to honeycomb geometries, the study validates the potential for replacing conventional solid or ribbed map pocket designs with a more efficient structural alternative.

This study involved static structural analyses to evaluate stress distribution and reaction forces under realistic loading conditions. The baseline model (solid/ribbed design) exhibited a maximum reaction force of 1440 N, confirming its capacity to withstand typical operational loads within expected material performance limits.

Subsequently, the honeycomb-enhanced model was subjected to an identical loading scenario. The analysis revealed a slightly increased maximum reaction force of 1955 N, indicating an improvement in load-bearing capacity. This enhancement is attributed to the optimized internal structure that promotes efficient stress distribution while reducing material usage. Moreover, the numerical results from FEA correlated well with experimental data, particularly in terms of the force reaction values observed for the honeycomb model. This congruence between simulation and physical validation reinforces the accuracy of the modelling approach and supports the structural feasibility of the honeycomb design in real-world applications.

The results indicate a good correlation between the FEA prediction and the experimental measurement of the force reaction for the honeycomb map pocket.

The outcomes of this study substantiate that a honeycomb-structured rear door map pocket not only meets but exceeds the structural requirements of its traditional counterpart. The implementation of such a design can contribute significantly to mass reduction strategies in vehicle interiors, aligning with broader automotive goals for fuel efficiency and sustainability. Further studies involving dynamic and fatigue analyses are recommended to comprehensively evaluate long-term durability under variable service conditions.

FUTURE SCOPE

The scope of a project focused on the Design, Analysis, and Prototyping of a Honeycomb Structure for a Rear Door Map Pocket typically involves several key phases: concept development, structural analysis, material selection, prototype creation, and testing. Here's a breakdown of each phase: improving emission performance.

The scope of the project is as mentioned below:

- Design of a remote mounted reed valve in Crankcase Ventilation system and analyse its design including mounting bracketry using FEA.
- Development of prototypes and its validation on engine test bed as well as on vehicle.

ACKNOWLEDGEMENTS

Ethical Approval

Not applicable. This study does not involve human participants or animals.

Conflict of Interest

The authors declare no conflict of interest related to this study.

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