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Design and development of honeycomb structure based side door impact beam

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ABSTRACT:

In the automotive industry, vehicle safety is paramount, and side door impact beams play a crucial role in protecting occupants during lateral collisions. This study presents the design and development of a honeycomb structure-based side door impact beam, aimed at enhancing energy absorption properties while minimizing weight. Utilizing a three-point bending analysis, we evaluate the mechanical performance of the proposed beam design in comparison to traditional solid and composite structures. Initially design will crated with the assistance of solid works 2022 then Finite Element Analysis (FEA) was employed to simulate the three-point bending test, allowing for the assessment of deformation, stress distribution, and failure modes. Then experimental 3 point bending test will be performed on universal testing machine. This innovative approach not only meets the regulatory safety standards but also contributes to weight reduction in vehicle design, thereby enhancing fuel efficiency and overall vehicle performance. The findings of this research pave the way for future advancements in vehicle safety technologies, emphasizing the importance of material selection and structural optimization in automotive engineering.

Keywords: honeycomb structure, side door impact beam, Three- point bending test.

1. Introduction:

Side impact collision accidents happen every day in various countries are mostly dangerous stage condition leads to death. Moreover, the space required of the side impact is less than the frontal impact. Side impact collision is directly impacted by the structure of a vehicle which affects the occupant. The vehicle structure which absorbs the impact energy from the side impact which passes the limited injuries to the occupant from the accident and side impact beam should resist from the crash impact forces, absorb the energy which minimizes the impact to the passenger compartment

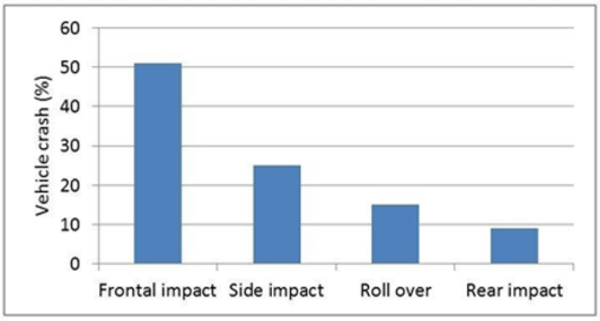


Figure 1. Percentage of the crash in different impacts

A side-impact door beam is a structural component in a vehicle's door designed to enhance the door's capability to repel impact during a side collision. It's designed to cover passengers from side impacts by absorbing the maximum quantum of impact energy and reducing the depth of door intrusion through an elasto - plastic distortion. Anti-intrusion shafts are mounted within the internal door depression of a vehicle at the external aeroplane and fixed to front and hinder door supports. These shafts are generally made of high- strength sword or other accoutrements that can absorb and distribute the force of a side impact, helping to cover the inhabitants inside the vehicle. In the event of a side collision, the side- impact door ray helps to help the door from collapsing inward towards the inhabitants, reducing the threat of injury. This added underpinning also helps to maintain the structural integrity of the vehicle, minimizing damage and perfecting overall safety.

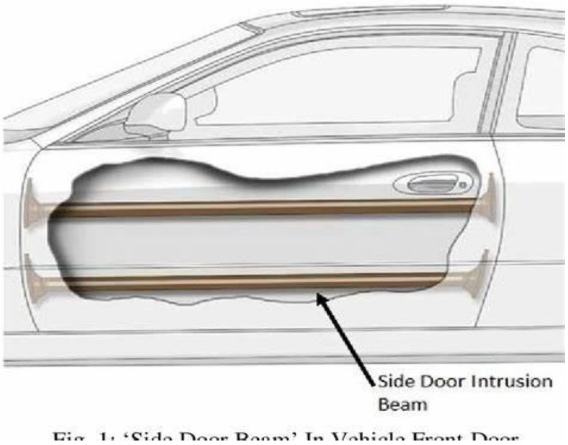


Figure 2 – side door impact beam

1.1 Crashworthiness :

Crashworthiness is a vehicle's capability to shield its inhabitants during a collision. This conception includes several factors similar as the vehicle's structural integrity, material strength, and design principles. By fastening on crashworthiness, automotive masterminds work towards creating vehicles that can effectively absorb and disperse crash energy, thereby perfecting passenger safety. Automotive safety has come a consummate consideration in vehicle design, particularly concerning side impacts. The side door impact ray plays a critical part in conserving passenger safety by absorbing and distributing the energy of an impact. Traditional designs frequently use solid accoutrements that may not offer the stylish trade- off between strength and weight. Recent advancements in accoutrements and structural design have led to the

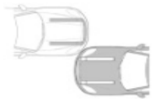
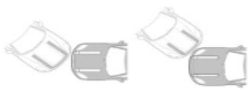
Collision type	Collision configuration	Example
Frontal	Large overlap – axial loading of both longitudinals	
	Moderate overlap – axial loading of one longitudinal	
	Small overlap – axial loading outboard of longitudinals	
	Frontal oblique – oblique loading of both or only one longitudinal	
Lateral	Lateral oblique – oblique loading of the passenger compartment region	
	Lateral 90° – perpendicular loading of the compartment region	

Figure 3 - Collision configuration classification for crashworthiness

emergence of honeycomb structures, known for their excellent energy- immersion characteristics, feather light nature, and structural effectiveness cover the inhabitants in survivable crashes. Also, in the automotive assiduity, crashworthiness connotes a measure of the vehicle's structural capability to plastically distort and yet maintain a sufficient survival space for its inhabitants in crashes involving reasonable retardation loads. Restraint systems and inhabitant packaging can give fresh protection to reduce severe injuries and losses. Crashworthiness evaluation is caught on by a combination of tests and logical styles. Vehicle crashworthiness and inhabitant safety remain among the most important and grueling design considerations in the automotive assiduity. Beforehand in the history of vehicle structural developments, vehicle bodies were manufactured from wood, and the thing of crashworthiness was to avoid vehicle distortions as much as possible. Over the times, the body structures evolved to include progressive crush zones to absorb part of the crash kinetic energy by plastic distortions. At present, vehicle bodies are manufactured primarily of stamped sword panels and assembled using colourful fastening ways. Contrivers produce vehicles to give inhabitant protection by maintaining integrity of the passenger cube and by contemporaneously controlling the crash retardation palpitation to fall below the upper limit of mortal forbearance. A crash retardation palpitation with an early peak in time and a gradational decay is more salutary for protection of a subdued inhabitant. Thus, the thing of crashworthiness is an optimized vehicle structure that can absorb the crash energy by controlled vehicle distortions while maintaining acceptable space so that the residual crash energy can be managed by the restraint systems to minimize crash loads transfer to the vehicle inhabitants. Real world vehicle collisions are unique dynamic events where the vehicle may collide with another vehicle of analogous or different shape, stiffness and mass; or it may collide with another stationary object similar as a tree, mileage pole or ground abutment. Generally, for the purpose of body development, safety experts classify vehicle collisions as anterior, side, hinder or rollover crashes. Further, the vehicle may witness a single impact or multiple impacts. Also, vehicle crashes do over a wide range of pets, persisting for a bit of an alternate, similar as when a vehicle hits a tree, or for many seconds as in rollover events. These factors illustrate some of the complex tasks involved in the design of vehicle structures to satisfy crashworthiness constraints for all collision scripts. Accident reconstruction and analysis of motor vehicle crashes give important information regarding the safety performance of vehicle in the business terrain. These styles don't give sufficient quantitative information necessary for vehicle design, similar as retardation palpitation, inhabitant kinematics or inhabitant loads. So, design masterminds calculate on a combination of standard laboratory tests, proving ground evaluations, and analysis to achieve safety objects. Presently vehicle crashworthiness is estimated in four distinct modes anterior, side, hinder and rollover crashes.

1.3 Conditions of Crashworthiness

The vehicle structure should be sufficiently stiff in bending and torsion for proper lift and running. It should minimize high frequency fore- posterior climate that give rise to harshness. In addition, the structure should yield a retardation palpitation that satisfies the ensuing conditions for a range of inhabitant sizes, periods, and crash pets for both genders

• Deformable, yet stiff, frontal structure with crumple zones to absorb the crash kinetic energy performing from anterior collisions by plastic distortion and help intrusion into the inhabitant cube, especially in case of neutralize crashes and collisions with narrow objects similar as trees. Short vehicle front ends, driven by baptizing considerations, present a gruelling task to the crash worthiness mastermind.

• Deformable hinder structure to maintain integrity of the hinder passenger cube and cover the energy tank.

• Duly designed side structures and doors to minimize intrusion in side impact and help doors from opening due to crash loads.

• Strong roof structure for rollover protection. Duly designed restraint systems that work in harmony with the vehicle structure to give the inhabitant with optimal lift down and protection in different interior spaces and trims.

• Accommodate colourful lattice designs for different power train locales and drive configurations.

Crashworthiness Models Conditions

The models should satisfy at a minimum the following overall conditions .

• Delicacy – the model should be suitable to yield nicely accurate prognostications of the essential features being sought

• Speed – the model should be executable with a reasonable reversal time, not to exceed 12 hours anyhow of its size, to allow for duplications and parameter studies

• Robustness – small variations in model parameters should n't yield large model responses

• Development time – the model could be erected in a nicely short period of time, not to exceed two week

Safety norms

1.4 National Highway Safety Administration (NHTSA)

The transportation of the US Department of National Highway Safety Administration (NHTSA) established the Highway Safety Act in 1970. NHTSA performs the safety program of National Traffic and Motor Vehicle Safety Act in 1966. The safety conditions of the Motor Vehicle to the manufactures and corridor of vehicles. In 1972 the NHTSA performs the colourful programs of Motor Vehicle Information and Cost Savings Act are reused from the title of 49 outlines in Chapter 301. The safety standard pretensions of the NHTSA to help injuries from the impact and profitable cost will be reduced from crashes of the vehicle. The safety standard sets the pretensions of achieving the acceptance and execute the norms for the machine manufacturers and mindfulness program for the government safety standard. NHTSA safety standard continuously probing and probing the new safety norms for the machine which reduce the injuries from the collision. This safety standard helps the association and government maintain to minimize the threat from the crapulous motorists and set the norms for child safety seat and seat belts. Developing the safety norms of anti-theft motorcars and researches the motorist's gets and Road safety to introduce the safety norms to the machine companies and passenger safety which helps to reduce the injury from the collision.

1.5 Federal Motor Vehicle Safety Standard (FMVSS 214)

Federal Motor Vehicle Safety Standard 214 is established in 1990 to cover the passenger in a dynamic test which simulates at an angle of crash impact. This standard is most important to the safety norms by means of National Highway Traffic Safety Administration (NHTSA). 16 The losses of side impact have 33 for passenger auto inhabitant so this safety standard used to drop the injuries to the passenger if the auto side door is struck with another auto collision

After many years research, they developed the passenger car which reduces the injuries and manufactured the vehicle with less harmed from the side impact during the struct from another vehicle which collision on the side door. The NHTSA standard is developed by the United States and international community researched together for the safety standard [5]. 1.3.3 Insurance Institute for Highway Safety, Side Impact Test Protocol The Insurance Institute for Highway safety test is most critical to the vehicle which leads to injuring the occupant serious level, so it is good using the side impact protection occupant can survive from the collision with injuries. It is same as Federal Motor Vehicle Safety Standard (FMVSS 214) crash test but in this procedure, wheels are aligned in the moving deformable barrier (MDB) on longitudinal axis of the cart is zero degree which allows for 90-degree impact on the vehicle at the velocity of 50 kmph (31 mph).

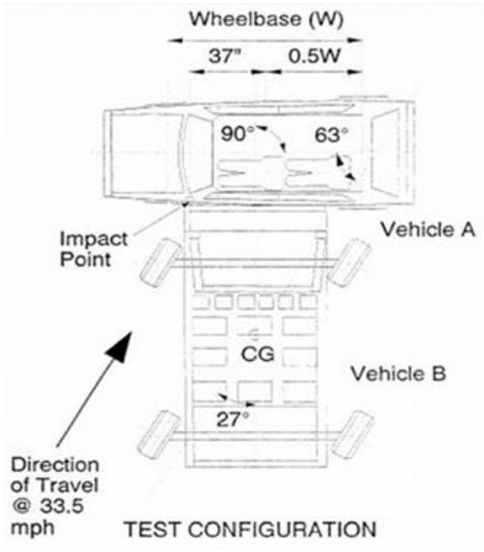


Figure 4. FMVSS 214 Test Configuration

The moving deformable barrier which has a total mass of 1500 kg and impact velocity of 50km/hr at the angle of impact is 90 degrees to the vehicle which cause damage to the occupant at the serious condition. The objective of the safety standard to test the vehicle it is suitable for the occupants which increase the regulation to reduce the side impact, prevent from the damage, avoided injuries in the collision.

Euro – NCAP side impact test Euro – NCAP side impact test evaluating the research at the carriage of 950 kg (Aluminium foam in frontal part) impacts at the displacement of 50km/hr hit against the vehicle at the stationary condition with dummies as driver and passenger in the seats. In the side impact test which the car is fixed on the carriage against a pole and moves against to the stationary fixed pole with the speed of 29km/hr. In this test, they added dummies in driver's seat which directed towards the pole near to the driver's head with the diameter of 254 mm during the impact which enters into the car cabin which affects the occupant so evaluate the research in Human head injury criteria (HIC).

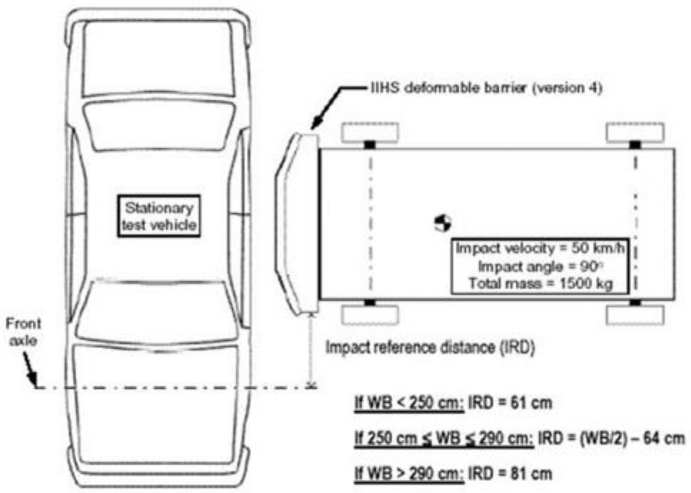


Figure 5. IIHS Test Configuration

Side impact beam is attached on the car side door parts which protect passengers in a collision with side obstacle. There is no separate beam standard test or regulation test for the side impact beam testing.

After finished the car production model are tested and fitted the side impact to test in this condition. The research should be determined in the experimental or computational method to analysed the result of the side impact test with intersecting of the safety bags, occupant head and passenger of the rear seat moving is analysed in dynamic condition

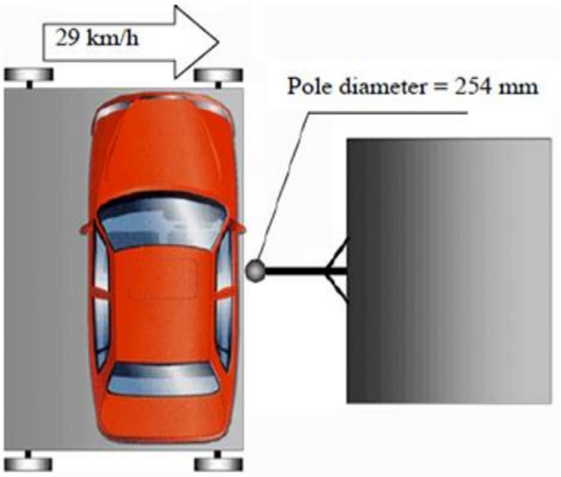


Figure 6. Test of a side impact to the pole according to Euro-NCAP

2 . Crash data :

In the present day-day injuries take place every hour around the world and most of these are very unstable. The side-impact crash is the second most severe crash scenario after frontal impact. It may be found that the frontal impact is higher than the side-impact. However, the space required for any structure in the event of a side-impact to absorb strength can be very less than the frontal-impact. The occupant injuries inside the side-impact crash are severe while compared with the frontal crash. Different crashes concerned are the rollover and rear impact. Many researchers have executed a significant study on frontal and side impact crash evaluation and have been a success in decreasing the risk of the injuries sustained by the occupant. The commission has observed an ambitious road safety program which targets to reduce road deaths in Europe between 2011 and 2020. The program sets out a mixture of initiatives, at the European and countrywide stage, specializing in improving automobile safety, the protection of infrastructure and road customers' behaviour.

2.1 Injury pattern of side impact protection

Intrusion most usually will increase the threat of chest, stomach and pelvic injuries. Door panel intrusion remains the most considerable contributor to occupant injuries. Earlier than the implementation of the side impact standard, it turned into probably that the lower door panel could interfere and result in pelvic fracture

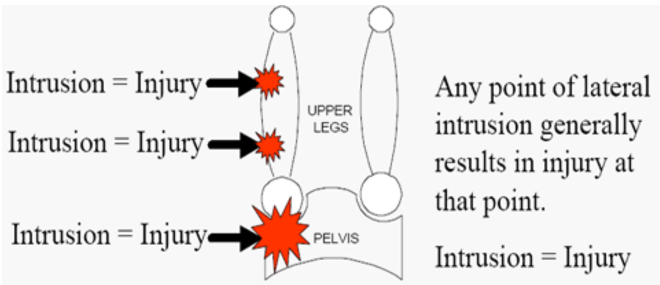


Figure 7 - Injury Pattern in Side Impact

2.3 Theoretical Background

Side impact vehicle injuries are most risky accidents to the occupant higher than the frontal crashes. Side impact crashes are directly impacted by the automobile structure which affects the occupant due to the fact there may be no large area required for the deformation to save you the occupant from the collusion. The car structure which absorbs the impact power from the aspect effect which passes the restricted injuries to the occupant from the coincidence and aspect impact beam has to withstand from the crash impact forces, absorb the strength which reduces the effect to the passenger compartment. Side effect car injuries end in critical accidents to the passenger because of time loss of aspect air bags and plenty of coincidence cases the sufferer will do the mistakes to have an effect on the collision with the side of the cars. 3.1 Side-Impact Beam Vehicle side doors are the most imported components of the frame because this element has to conform to a lot of requirements and specifications. The gap between the door and the occupant may be very less in a side impact when in comparison to the frontal impact. The protection member referred to as the side impact beam is generally located inside the door and this is answerable for offering high stage of safety for the occupant in the event of side impact by another car. For the structural analysis of the side door impact beam, Finite element method becomes used considering it is the maximum widely used computational method within the automotive industry.

3. Types of crash test investigation :

3.1 Quasi-Static testing :

In quasi-static testing, the test specimen is overwhelmed at a consistent velocity. Quasi static tests won't be a real simulation of the crash situation because, in a real crash situation, the structure is subjected to a decrease in crushing speed from an initial impact speed finally to relaxation.
The following are some advantages of quasi-static testing:
• Quasi-static tests are easy and smooth to manipulate.
• To observe the crushing method, impact tests require a very high-priced device, because the complete process occurs in a split second. Therefore, quasi-static tests are used to study the failure mechanisms in composites, by using a selection of suitable crush speeds. The following is the main drawback of quasi-static testing.
• Quasi-static tests won't be a real simulation of the actual crash situations since certain materials are strain rate sensitive.

3.2 Impact testing :

The crushing velocity decreases from the initial impact velocity to relaxation because the specimen absorbs the energy. The following is the main advantage of impact testing
• It is a real simulation of the crash situation because it takes into consideration the stress rate sensitivity of materials. The following is the main drawback of impact testing.
• In impact testing, the crushing method takes place in a fraction of a second. Consequently, it is encouraged that crushing is studied with high-speed camera.

3.3 Dynamic Collision test (FMVSS 214) :

In this test process, a deformable barrier set up on a sled impacts a vehicle side door angularly. This is, all four wheels of the barrier-sledge are inclined at an angle of 27° in the front, an aluminium honeycomb barrier is fixed, and this is at the peak of the bumper in order that the real simulation of the crash is simulated. Inside the automobile, a US-side impact Dummy is placed in the front seat and this dummy measures the injury ranges sustained.
Composite test procedure (CTP) for automobile side impact testing the terminology should suggest, this test method is not most effective for a composite. This test begins with the displacement of the barrier into the side of the vehicle until the internal door is in contact with the dummy. At this point, the barrier face is half on this position until the internal wall of the door is loaded using the frame forms. Enough force-deflection information is received for the computer model.

4. Literature review :

1) Kiran C. More et al. [1] This study examines the design of a side door intrusion beam for automotive Body In White (BIW) to reduce passenger injuries in car accidents. The research focuses on analyzing the static and dynamic behavior of different profiles, gauges, and materials in case of side impacts. The study uses FEA software to determine force reaction and energy absorption capacity, and the Taguchi method is used to optimize design parameters. The optimal design with optimal energy absorption capacity and resistance force is validated through experimental tests and full vehicle side impact simulations.

2) Hossein Mohammad et.al. (2) Crashworthiness refers to a vehicle's ability to protect occupants from serious injuries in collisions. The design of lightweight energy absorption components is crucial for enhancing safety and reducing fuel consumption and gas emissions. Honeycomb structures, known for their excellent mechanical performance, have gained attention in automobiles and railway vehicles. This work introduces crashworthiness criteria and nature-bioinspired cellular structures, discusses advanced honeycomb design classifications like graded, hierarchical, and sandwich panel-based structures, and highlights the importance of potential design in enhancing crashworthiness and future challenges.

3) Madasamy Panneerselvam et. al. (3) The project focuses on dynamic analysis of an automotive door beam impacted by a ram. The Finite Element Method (FEM) is used for this analysis, with a finite element basic model developed in hypermesh 12.0. The goal is to collect animation results, force-displacement plots, and stresses at 6 inch ram travel. The stresses in the beam should be less than the ultimate stress of the material used. Phase II involves simulating the door beam in a complete vehicle with different design and material composition. Energy-time and force displacement plots provide insights into the beam's energy absorption and load carrying capacity. Two design improvements have been suggested, resulting in improved load carrying capacity.

4) Vinay Papaiya et. al. (4) The automobile industry is increasingly seeking fuel-efficient vehicles due to their lower energy consumption and lower pollution emissions. Fiber-reinforcement composite materials, with their higher strength-to-weight ratio, have been found to be effective in improving fuel efficiency while maintaining safety standards. A research paper examined the use of carbon-aramid fiber-reinforced composite impact beams for passenger car side door impact protection. However, the study found defects in the fabrication process, resulting in reduced load-bearing capacity and energy absorption. The beam was unsuccessful in three-point bending tests using an I cross-section design.

5) **S Eržen et. al. (5**) The paper discusses the use of Fiber Reinforced Plastics (FRP) in the automotive industry, highlighting its impact on car weight reduction and gas emissions. It presents a local design solution for reducing passenger car weight using a Twintex® side door impact beam. The Finite Element Method (FEM) was used to analyze the beam's behavior under loading, determining its impact energy absorption capacity. The study found that the Twintex® composite has adequate load-carrying capacities and absorbs more strain energy than steel. However, the composite increases beam dimensions but achieves a 10% weight reduction compared to steel.

6) Oğuz Can Karahan et. al. (6) this study investigates the bending behavior of dual-phase steel tubes used as door impact beams in crash cases. Using DP500 and DPG00 steel grades, three-point bending tests are performed, and force-stroke curves and spring back values are obtained experimentally. Finite element analyses using the Hill 48 plasticity model are performed, and force-stroke curves, spring back, and product forms are compared with experimental results. The results show that force-stroke curves and product forms are highly compatible with experimental results, but the amount of pingback values in finite element analyses is higher than experimental.

7) Meiqin Liang et.al. (7) This study investigates the stress distribution and bending resistance of hollow beams using a finite element model based on Abaqus. The results show that the beam meets design requirements, with a bending resistance of 4.26 kN and a maximum stress of 378.6 MPa at 1 mm indenter displacement. As the indenter displacement increases to 10 mm, the bending resistance increases to 9.04 kN and the maximum stress reaches 636.4 MPa. Stress concentration is observed on the upper and lower sides of the cross-section, with lower stress in the middle region. The study suggests that modelling and simulation are a feasible approach for studying bending deformation of hollow beams, providing abundant measurement data without size limitations.

8) M. A. Shaharuzaman et. al. (8) This paper discusses the conceptual design stage in the product development process of natural fibre composites for side-door impact beams. It uses the integrated Theory of Inventive Problem Solving (TRIZ)-Biomimetics method and VIKOR method to generate design concepts inspired by nature and select the best design for the composite side-door impact beam. Eight design concepts were generated using TRIZ Biomimetics, and their performance and weight criteria were analyzed using ANSYS software. The VIKOR method was used to compare the performance, weight, and cost criteria. The paper demonstrates that the integrated methods can help researchers and engineers develop designs inspired by nature and select the best design concept.

9) M. A. Shaharuzaman et. al. (9) This paper explores the development of side door impact beams for passenger cars, designed to protect occupants during side impact collisions. The beams are categorized into three shapes: tubular beam, panel, and belt, and are made from alloys, composites, and metal/composites hybrids. The selection of materials affects the beam's strength, stiffness, and weight. The study also examines the connection of the beam to the door to analyze failures during collisions. The paper concludes based on previous studies' data.

10) M. A. Shaharuzaman et.al. (10) This study aims to develop new bio-inspired design concepts for composite side-door impact beams in passenger vehicles. The integrated Theory of Inventive Principle – Function Oriented Search (TRIZ-FOS) and Biomimetics method are used to generate design concepts. The study focuses on three nature technologies: toucan beak, pomelo peel, and hedgehog spine. The TRIZ-FOS method generates five design concepts based on these technologies, and the FEA analysis method compares their strength, deformation, energy absorption, and weight. The integrated method helps engineers generate nature technology ideas and obtain performance data for the generated designs before proceeding to the next step in product development.

11) Zhu Haitao et.al. (11) The research focuses on developing a side deformation barrier for SUVs with Chinese characteristics. By extracting typical SUV parameters, honeycomb aluminium barrier and trolley development objectives are defined. The barrier trolley's dynamic load-cell wall test evaluates honeycomb aluminium calibration performance. A new verification method is developed based on body structure deformation and crash load force height distribution. The new barrier meets design specifications, is stable in deformation modes, and can characterize SUV appearance and stiffness.

12) Mayank Chandak et.al. (12) The safety rating of a vehicle is crucial for minimizing post-crash injuries. Crashworthiness is determined through static and dynamic tests. Side crashes are a leading cause of fatal injuries. Side door strength depends on door components like latch, striker, hinge, and door beam. The side door beam significantly contributes to lateral stiffness and limits intrusion into the passenger compartment. This paper uses ANSYS to study the effect of intrusion beam materials and orientation on side door strength and weight. The simulation study is cost-effective and time-saving.

5. Conclusion:

The design and development of a honeycomb structure-based side door impact beam have demonstrated significant advancements in vehicle safety, weight reduction, and material efficiency. This innovative approach combines the inherent strengths of honeycomb geometry—such as high energy absorption characteristics and lightweight nature—with the traditional requirements of automotive safety components.

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