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# A NEW MINIMAL PART BREAKUP BODY-IN-WHITE DESIGN APPROACH AND OPTIMIZED MATERIAL MAP STRENGTH ASSESSMENT

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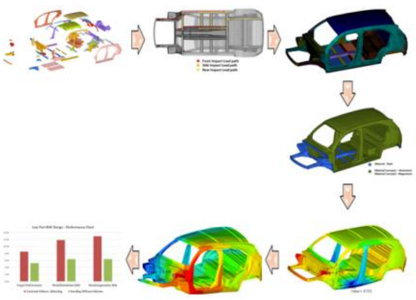
## Graphical abstract



## Abstract

Body-in-White (BIW) is the Car Body without additional subsystems. Automakers are trying hard to reduce the mass of the vehicle body. The efficient option is to use multi materials and minimal number of parts in the BIW, in order to meet the stiffness requirements considering different load cases. Bending Analysis and Torsion Stiffness Analysis was performed to understand and assess the structural performance of the BIW. This paper presents the new BIW architecture with minimal number of parts, with an effective load path for the Structural and Crash load cases. Structural bending and torsion stiffness of the BIW were performed to evaluate the stiffness of the BIW to meet the passenger segment car. The methodology of using different materials for upper and under body has been investigated with the alternatives as Aluminium and Magnesium. BIW was analysed with Steel under body and Magnesium or Aluminium upper body. The Torsion stiffness of Steel/Magnesium BIW was found to be better than Steel/Aluminium BIW. The design concept with Steel underbody and Magnesium upper body was giving lighter weight design with better structural stiffness as compared to the Steel/Aluminium body. This approach of modifying the materials for the upper body of the BIW can be considered as lightweight solutions in other Conceptual BIW designs.

*Keywords*: Body-in-white (BIW), bending, torsion, stiffness

## 1.0 INTRODUCTION

The automotive stream is striving in tandem towards the reduction of mass and fuel consumption, and meeting better emission norms. About 10-12% of mass reduction on the GVW will lead to 7-9% increase in fuel economy. For achieving a lighter BIW, the design needs to have optimal mass that meets the structural stiffness targets [9]. Since the BIW stiffness defines the competitiveness of the structure, its evaluation is critical. For studying the BIW structural performance at the conceptual BIW development stage, there is a need to perform Modal Analysis, along with Bending and Torsion Stiffness evaluation [1, 8]. Experimentation of BIW using the test rig at the conceptual stage is an expensive process [3]. So, Industries prefer to use Finite Element Analysis software like Nastran, Optistruct etc., to analyse the Stiffness and Frequency performance [10]. In this paper, the minimal part breakup BIW design with multi materials was analysed to determine the Bending and Torsion Stiffness. BIW with combinations of Steel and Aluminium or Magnesium were considered. Comparisons of structural performance and mass savings with material combinations on the Minimal part BIW design were carried out. This work is limited to BIW stiffness for Bending and Torsion. Though there were so many literatures on the BIW part design and the topology optimization, [13, 14] the opportunity of alternative upper body material has not been researched in detail. This paper analyses in detail, the BIW Bending and torsion stiffness performance with the BIW upper body material alternatives. This paper also explains the possibility of the use of minimal parts in the BIW design, yet maintaining the stiffness targets.

## 2.0 METHODOLOGY

### 2.1 Low Part Break-Up BIW Architecture

The BIW architecture [4, 11] with a focus on multi-disciplinary loads was designed at conceptual stage. In general, BIW constitutes of nearly 300-350 components. In this Advanced BIW architecture, the entire body was designed with only 58 parts. This is a significant reduction in the total number of parts in any BIW. Figure 1 shows the BIW design in an exploded view showing all the parts in the design.

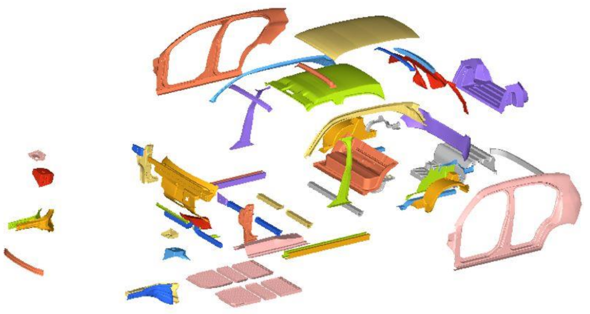


**Figure 1** Exploded View of the Low Part Break-Up BIW

In this paper, there is a new BIW design approach that has been discussed, considering all the BIW stiffness load cases [12]. Figure 2 and Figure 3 show the load path planned in the BIW design for the Front, Side and Rear Impact analysis. The Front Rails were connected to the Hinge Pillar and the rocker in the Front Compartment. Two cross members connect the LH and the RH side of the vehicle body. These load paths are designed to ensure that there is distribution of the energy during the frontal crash events [5, 13]. Four cross members run on the floor between the LH and the RH. They were all designed in a way to reduce the severity of the occupant space reduction during the Side Impact and side pole Impacts. Rear rails were designed to overlap with the Rocker rear cross member in the region between the Centre tunnel reinforcement and the Rocker. Energy from Rear impact load cases could be distributed to these members, thereby improving the energy absorption during the Rear Crash Impact. All the load carrying members like Front rails, Hinge Pillar, Centre Floor, Cross members and the Rear Rails were modelled with steel. Remaining parts like Honeycomb floor, Body side, B-Pillar roof rails, Rear floor lower/upper, Reinforcements, Roof outer/inner, Roof bow, Rear closeout etc. were modelled with Aluminium or Magnesium [6].

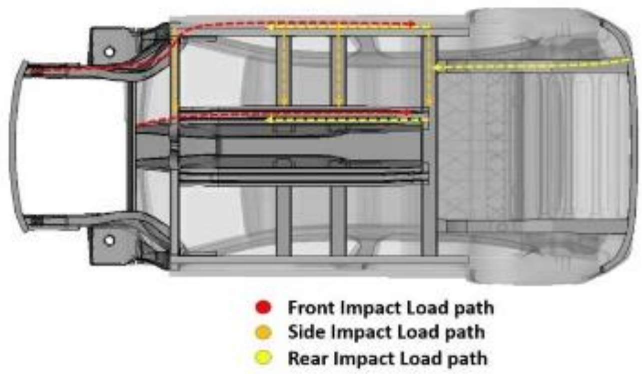


**Figure 2** Load Path - Front

**Figure 3** Load Path – Front, Side and Rear

### 2.2 FE Model of the BIW Architecture

The Finite Element model of the BIW was modelled using Hypermesh. Since the BIW has minimal parts this will lead to significant reduction in the assembly time. The importance of the BIW stiffness in the vehicle is to ensure a stable structure to mount all the subsystems together.

BIW needs to also act as a safety compartment and protect the occupant during the crash events. Bending and Torsion is a combination of vehicle asymmetric loads. Members like side frame or rocker were carefully designed owing to their significance on the Bending stiffness. The FE Model of the BIW has a count of 758902 elements and element size in the range of 7-10mm. The metal parts in the BIW were meshed with shell elements and connected by spot welds and adhesives. Spot welds were defined with Hex/RBE3 ACM Spot welds using Hypermesh for Optistruct solver. Windshield was also modelled as a shell element, and adhesives were used to connect with the BIW. The reference baseline mass of BIW is 262Kgs with Bending and Torsion Stiffness of 5.2KN/mm and 8.5KNm/deg were considered as the target stiffness performance [2]. Since the BIW architecture is Conceptual, manufacturability will be considered only in the future part of the work. The FE model mass of the Steel/Aluminium BIW and Steel/Magnesium BIW was 185.6Kgs and 170Kgs respectively.

## 2.3 BIW Finite Element Model Validity Checks

Finite element mesh model was checked for the quality checks like Warpage, Aspect ratio, Element Jacobian, Element's normal orientations, minimum/maximum quadrilateral element angles, and minimum/maximum triangular element angles. Mesh Element Size Convergence Checks were performed to check the Mesh size validity of the Finite Element model of the BIW as shown in Figure 4 and 5. Mesh sizes varying from 5mm to 20mm were analysed and the corresponding Bending and Torsion stiffness analysis displacement values were extracted. Induced displacement in the initial analysis to check the mesh convergence was carried out. The difference in displacement values from the analysis were minor for a mesh size of 7mm to 10mm. Based on this the mesh size of 7-10mm was selected for further analysis.

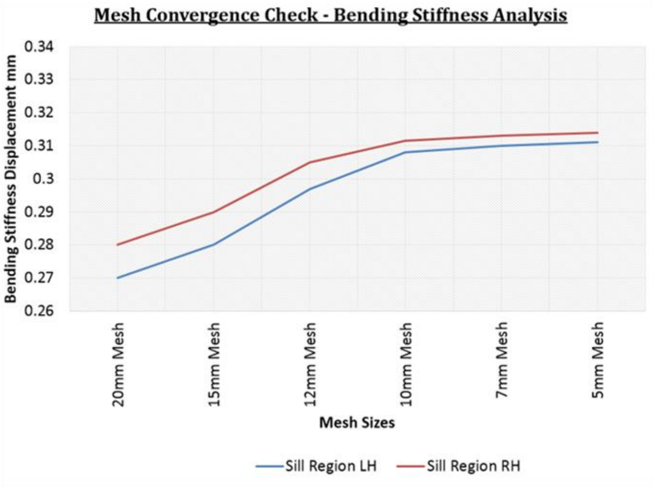


**Figure 4** Mesh Convergence - Bending Stiffness Analysis

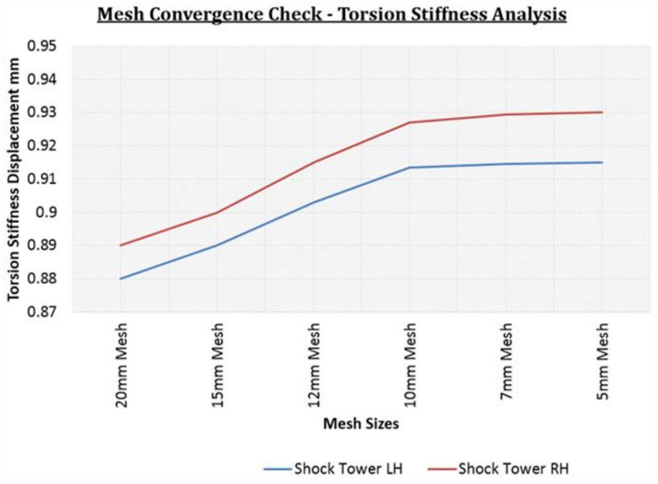


**Figure 5** Mesh Convergence - Torsion Stiffness Analysis

## 2.4 BIW Material Architecture

Two concepts of the low part breakup BIW were analysed to identify its performance value for the Bending and Torsion Stiffness Load cases as shown. The first concept is a Steel Load Path with Aluminium Upper Body and Floor and the second one is Steel load path with Magnesium Underbody and Floors. Structural stiffness on both these designs will be compared. Figure 6 shows the material concepts in the BIW.

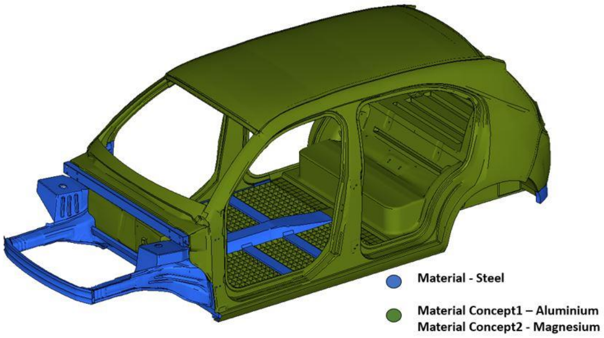


**Figure 6** BIW material concepts

## 2.5 FEA Setup for Bending Stiffness Analysis on the Body-In-White

Bending stiffness will define the vehicle competency on retaining the vehicle subsystems in the correct locations. Structural Bending stiffness is arrived from the ratio of force applied to the maximum deflection of the rocker [1]. The boundary conditions are defined as shown in Figure 7. 1,2,3 indicates the boundary conditions of constraining all the Translational degrees of freedom about X, Y, Z axes and 1,2 indicates constraining of all the translational degree of freedom about X and Y axes.

For performing the Bending Stiffness analysis, the BIW will be constrained with minimum boundary conditions ensuring that there is no unconnected degree of freedom in BIW. The BIW was considered to be in its mounted conditions at the Front Shock Tower and the Rear Spring Mounting location. 1000N Force was applied at the Rocker region near the B-Pillar. Bending stiffness will result from the ratio of the Load Applied and the maximum deflection along the Rocker.

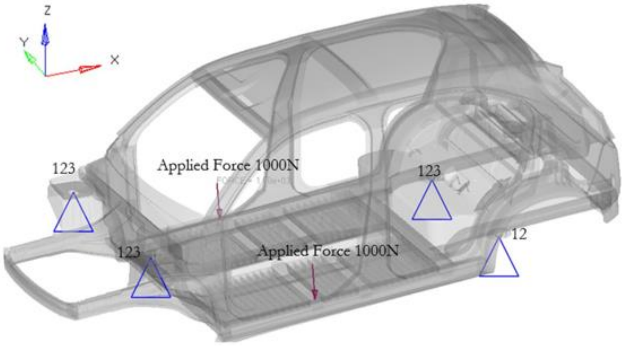


**Figure 7** Bending Load Case Details

### 2.6 FEA Setup for Torsion Stiffness Analysis on the Body-In-White

Torsion stiffness will dictate vehicle competency and a low Torsion stiffness can affect other disciplines like NVH and dynamic stiffness performance as well. The BIW was constrained with minimal Boundary conditions without over constraining. The BIW was considered to be in vertical axis in the middle of the front bumper and the rear spring mount. The Torsion stiffness is the stiffness of the BIW for the twist load conditions [1, 3]. In the Figure 8, the numbers 1,2,3 indicate the boundary conditions for constraining all the translational degrees of freedom about X, Y and Z axes respectively and 3 indicates constraining the translational degree of freedom about Z axis.

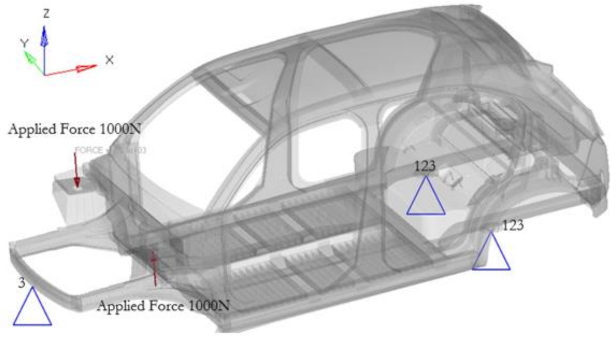


**Figure 8** Torsion Load Case Details

Force of about 1000N is applied in the opposite direction on the Vertical axis in the shock tower mount. This will induce a static moment on the Front Shock Tower with the Rear spring mounts constrained in all translations [7].

## 3.0 RESULTS AND DISCUSSIONS

### 3.1 FEA Simulation Results – Validation

The finite element analysis was validated for the simulation accuracy by extracting the mounting point reaction forces from both Bending and Torsion Stiffness Analysis. From the analysis, it has been determined that the reaction forces were equal to the total applied force. This confirms the simulation's validity for Bending Stiffness analysis. Similarly, the sum of the reaction forces for Torsion load case is equal to zero. In the Torsion stiffness load case, the applied loads were in equal and opposite directions at the Front LH/RH shock tower mounts, and the reaction sum was zero. This confirms the accuracy of the Bending and Torsion analysis.

### 3.2 FEA Simulation Results – Bending Stiffness Analysis

Bending stiffness of the BIW is the resistance to deflection in the event of bending which happens due to symmetric loads. In other words, the Bending stiffness can be considered as the difference in pitch angle between rear and front part of the BIW. When the vehicle gets accelerated, the body bends and the load transfer occurs. It is applicable during both acceleration and deceleration of the vehicle.

The maximum induced average displacement was 0.314mm for the Steel/AL BIW design and 0.312mm for the Steel/Mg BIW design as shown in Figure 9 and 10. The Bending Stiffness of the BIW, when applied with 1000N force on LH and RH is 6.36KN/mm and 6.40KN/mm as tabulated in Table 1. The stiffness of the BIW is meeting the Target Stiffness [2]. The Bending Stiffness performance is 22% higher than the target values on both Steel/Al design and Steel/Mg model.

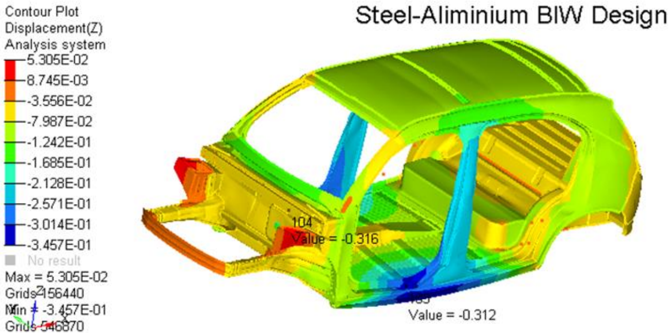


**Figure 9** Steel-AL BIW Bending Stiffness Result

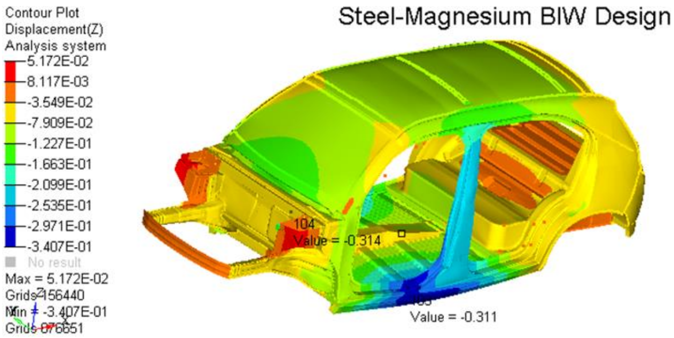


**Figure 10** Steel-Mg BIW Bending Stiffness Result

### 3.3 FEA Simulation Results – Torsion Stiffness Analysis

Considering a car riding on bump or a pothole, the force acting upwards will have a reaction opposite on the other side of the vehicle. This condition will induce the Torsion load on the vehicle. Figure 11 and 12 shows the analysis results.

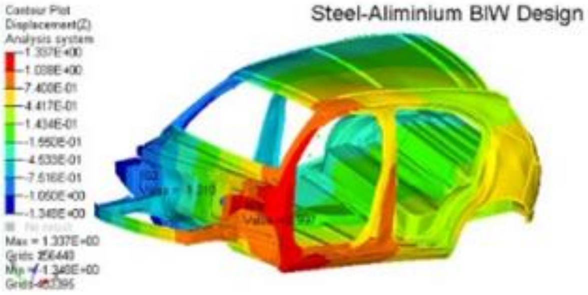


**Figure 11** Steel-AL BIW – Torsion Stiffness Result

Torsion stiffness is a key aspect in any vehicle design. Torsion stiffness is the resistance to the deformation of the body during the event of twist due to asymmetric loads. Suspension kinematics, compliance, ride handling, steering etc. were all influenced by the Torsional stiffness of the BIW. The Torsion stiffness of the BIW for the applied force of 1000N in opposite directions on the LH and RH of the Shock tower mount has induced an average displacement of 1.0035mm and 0.9225mm for the Steel/Al and Steel/Mg BIW design.

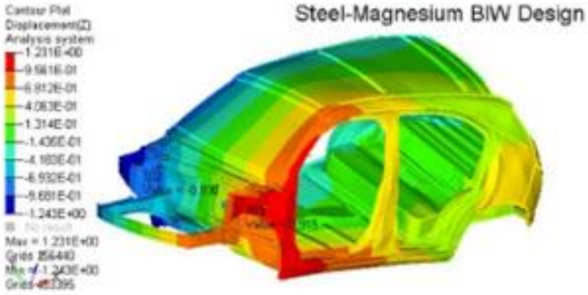


**Figure 12** Steel-Mg BIW – Torsion Stiffness Result

The Torsion stiffness of the BIW when applied with 1000N in opposite vertical directions on the shock tower is 11.86KN and 12.91KN for the Steel/Aluminium and Steel/Magnesium Body as tabulated in Table 2. The performance for Torsion stiffness is 40% and 51% better than the target model for the Steel/AL BIW and the Steel/Mg BIW design respectively. Steel/Mg BIW design has an 8.8% higher Torsion stiffness value as compared to the Steel/AL BIW design.

**Table 1** Bending stiffness Results

| Model Details | Z-Disp. Rocker LH (mm) | Z Disp. Rocker RH (mm) | Avg. Z Displacement (mm) | Total Force (N) | No. of Occupants | Total Load (N) | Bending Stiffness KN/mm | Target Stiffness KN/mm |
|---|---|---|---|---|---|---|---|---|
| Steel, Aluminum BIW | 0.312 | 0.316 | 0.314 | 2000 | 1 | 2000 | 6.37 | 5.2 |
| Steel, Magnesium BIW | 0.311 | 0.314 | 0.3125 | 2000 | 1 | 2000 | 6.40 | 5.2 |

**Table 2** Torsion stiffness Results

| Model Details | Avg. Z Disp. (mm) | Force Applied (N) | Moment Arm (mm) | Twist (Radians) | Twist (Deg) | Torque (Nmm) | Torque (KNm) | Torque Stiffness KN/mm | Target Stiffness KNm/deg |
|---|---|---|---|---|---|---|---|---|---|
| Steel, Aluminum BIW | 1.0035 | 1000 | 1168 | 0.001718 | 0.098452 | 1168000 | 1.168 | 11.86 | 8.5 |
| Steel, Magnesium BIW | 0.9225 | 1000 | 1168 | 0.00158 | 0.090506 | 1168000 | 1.168 | 12.91 | 8.5 |

## 4.0 CONCLUSION

The BIW architecture with minimal number of parts meet the structural competency for Bending and Torsion stiffness. The Conceptual BIW architecture has an increased structural performance of nearly 22% on Bending stiffness for both Steel/Al BIW and Steel/Mg BIW. The Torsion stiffness performance was found to be 40% and 51% higher than the target values in the Steel/Al BIW and the Steel/Mg BIW respectively as shown in Figure13.

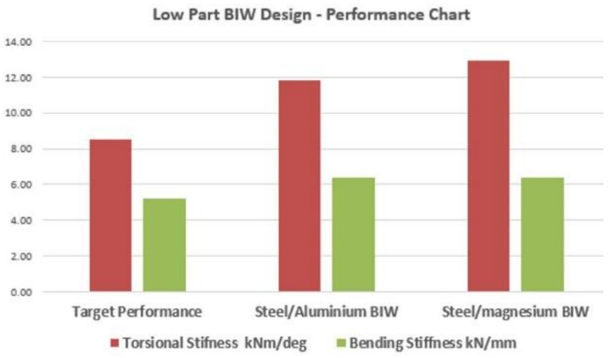


**Figure 13** BIW performance Comparison

This methodology of having less number of parts can be implemented in conventional BIW designs and it could lead to potential mass reduction on materials and manufacturing process. Magnesium material can be a better option as compared to Aluminium for a potential swap with BIW upper body components to achieve mass reduction in the BIW design without compromising the structural performance. The design concept of having the front rails directly connecting to the hinge pillar and Rocker can be considered as a load path suggestion in the conceptual design stage. This methodology of replacing the materials for the upper body with lighter materials can be used for all the conventional BIW designs and using this concept, mass reduction could be achieved. Since the BIW is in the initial stages of design, there is a potential scope for more mass savings upon performing further optimization in the BIW design. Further Topology optimization, Multi Materials Concepts and Design of Experiments based structural performance optimization is the future scope work on the BIW Design.

## References

[1] Zhang, Q. 2013. A Simulation Analysis and Optimization of Mode and Stiffness of BIW, SAE-China. *Proceedings of the FISITA2012 World Automotive Congress*. Springer-Verlag berlin Heidelberg.

[2] Boeman, R.G. 2002. Development of a Cost Competitive, Composite Intensive, Body-in-White. SAE Inc 2002. 1: 1905-19128. 2002-01-1905.

[3] Ramsai, R. 2015 Methodology To Measure BIW Torsional Stiffness And Study To Identify And Optimize Critical Panels. SAE 2015-26-0224.

[4] Conklin, J. 2015. BIW Design and CAE. SAE 2015-01-0408.

[5] Chen, H. 2015. Vehicle Front Structure Energy Absorbing Optimization in Frontal Impact. *The Open Mechanical Engineering Journal*. 9: 168-172.

[6] Khani, M. 2014. Design of Lightweight Magnesium Car Body Structure Under Crash And Vibration Constraints. *Journal of Magnesium and Alloys*. 99-108.

[7] Deshmukh. Case Study on Sandwich Steel Applications in Automotive BIW for NVH Improvements. International *Journal of Mechanical and Civil Engineering*. 2278-1684, PP:01-06.

[8] Nusholtz, S. 2004, Vehicle Mass, Stiffness And Their Relationship. SAE Paper Number 05-0413.

[9] Peterson, G. 2013. Cost-Effectiveness of a Lightweight BIW Design for 2020-2025: An Assessment of a Midsize Crossover Utility Vehicle Body Structure. SAE International. 2013-01-0667.

[10] Karan, R.K. 2013. Test Set-Up of BIW (BIW) Stiffness Measurements. SAE International. 2013-01-1439.

[11] Deleene, J. 2010. Extraction of Static Car Body Stiffness from Dynamic Measurements. SAE International. 2010-01-0228.

[12] Aziz, N. 2015, Crash Analysis of Racing Car Nose Subjected to Full Frontal Impact. *Jurnal Teknologi*. 75(8).

[13] Christensen, J. 2011. Lightweight Hybrid Electrical Vehicle Structural Topology Optimisation Investigation Focusing On Crashworthiness. *Int. J. Vehicle Structures & Systems.* 3(2): 113-122.

[14] Rajasekaran, M., Hari Ram, V. and Subramanian, M. 2016. Multi-Objective Optimization of Material Layout for Body-In-White using Design of Experiments. *Int. J. Vehicle Structures & Systems*. 8(1): 17-22.