Design Verification of a New Bonnet Design

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Abstract - *The bonnet of a vehicle plays a major role in influencing the behaviour of vehicle during collision and in mitigating pedestrian injuries in case of a vehicle-pedestrian collision. The severity of a head injury, in case of a collision between a pedestrian and the vehicle, greatly depends upon the energy absorbing capacity and the rigidity of the bonnet structure. Also, during an impact of the vehicle with a large, and rigid, object such as a tree, or a pillar, the ability of the bonnet structure to remain attached to the main vehicle body can significantly reduce the possibility of collateral damage for nearby individuals. Consequently, a rigorous design verification procedure is necessary before a proposed bonnet design can be accepted for production. In this study, we have subjected a new bonnet design to standard design verification in order to evaluate its safety and soundness of design. Finite element analysis has been used for simulating various loading scenarios on to the bonnet and the results from the simulations have been compared with the results from corresponding physical tests and subsequently, the performance of the given design has been evaluated. The loading scenarios include adult head-form impact test, frontal pillar impact test, oil canning resistance, etc.*

Key Words: bonnet design; design verification; head-form impact; pillar impact; vibration; oil canning; CAE

1. INTRODUCTION

The bonnet structure of a vehicle shows significant participation during any frontal impact of the vehicle, whether it is with large and fixed objects such as pillars, trees, walls, or whether it is with a pedestrian. Consequently, the bonnet plays a considerable role in determining the outcome of any frontal collision. Consequently, stringent regulations govern the design of the bonnet system of any vehicle. This, along with the ever increasing performance oriented demands of the vehicle, means that the design of the bonnet structure of the vehicle is of utmost importance.

The bonnet becomes a target for the pedestrian's head during any frontal vehicle-pedestrian collision. Consequently, the rigidity of the bonnet structure, and its ability to absorb energy from the impact gradually, will determine the severity of any head injuries that the pedestrian may suffer. It is desired that the bonnet must absorb energy in such a manner that the accelerations produced during the impact are well within the physiologically tolerable range of the human head. The most widely accepted method for gauging the severity of the pedestrian's head injury is the Head Injury Criterion (HIC). In case of a collision with an adult human, the value of HIC must be within 1000. It is also desired that the bonnet must prevent the contact between the head and the rigid, and hard, components underneath it in order to minimize the potential head injuries and also prevent the possibility of damage to the important components such as the engine, etc.

Another important aspect of the bonnet structure, during a collision with any large and rigid object, is its ability to remain attached to the main body of the vehicle in order to minimize the possibility of any collateral harm that might occur to the individuals in the vicinity off the collision. This characteristic assumes great importance during high speed frontal impacts such as collisions between two vehicles, or that between a vehicle and a tree, etc. Consequently, the strength of the bonnet structure, especially near its hinges is of great importance.

Being a primarily sheet metal component, the structure is vulnerable to vibrations. The source of the vibrations could be the engine-generated vibrations, the vibrations due to the unevenness in the surface of the road, and the aerodynamic interactions of the bonnet surface when the vehicle is in motion. Excessive vibrations impact the passengers' ride comfort, and also make the structure susceptible to fatigue failure. Too many vibrations can also affect the functioning of the locking mechanism of the bonnet, considerably risking the likelihood of unlocking, and opening up, of the bonnet while the vehicle is in motion. Because of the ongoing efforts to reduce the weight of the vehicle, in order to aid its performance and meet the strict emission norms, the thickness of the bonnet sheet is being reduced to its lowest possible values. This would considerably increase the severity of the vibrations that the structure is subjected to. Hence, determining the fundamental frequencies of the bonnet structure and its behaviour at those frequencies is necessary.

In this paper, a new bonnet structure design (of a vehicle, which is not yet under production) has been put through various loading scenarios as a part of its design verification process. The finite element analysis based simulation, including meshing and other pre-processing, solution of the equations, and the post-processing has been carried out in ANSYS 2019. The outputs from the simulations have been compared with the results from corresponding physical tests. The objective is to verify the performance of the new design and explore avenues for optimization.

2. BRIEF DESCRIPTION OF THE DESIGN

The structure is made of carbon steel (AISI 1008). This grade of steel is popular for its use in sheet metal components of vehicles due to its suitable properties.

The details of the relevant mechanical, and physical, properties of the material have been given in table. The bonnet sheet has a thickness of 1 mm. Its largest width is 141 cm and largest length is 110 cm. The bonnet design has been shown in figure 1.

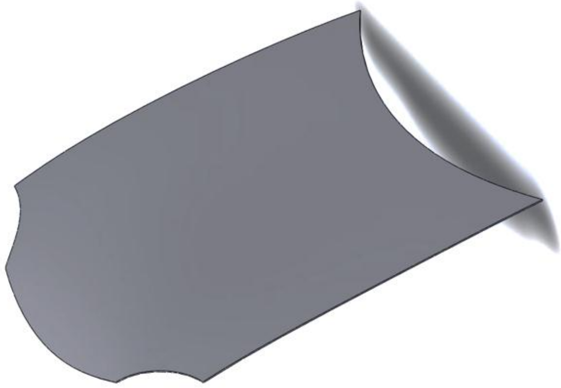

Fig - 1: Design of the bonnet

Table -1: Properties of AISI 1008

Properties of the material used in bonnet	
Ultimate Tensile Strength	430 MPa
Tensile Yield Strength	310 MPa
Fatigue Strength	230 MPa
Young's Modulus	210 MPa
Poisson's Ratio	0.28

3. MESHING, LOAD CASES, AND BOUNDARY CONDITIONS

The mesh for the structure was generated using Hypermesh. The element chosen for creating the finite element model of the bonnet structure is Quad shell element. Initially, the element size for the meshing that was chosen was the default element size with the element length equal to approximately 83 mm. The condition of convergence was decided such that the convergence was said to have been achieved when the error in the consecutive results was less than 1%. Accordingly, a nominal element length of around 24 mm was observed to be providing satisfactorily accurate results.

The rear hinges and the latching point of the bonnet have been provided with a fixed support. The edges of the bonnet structure, which rest on the frame of the vehicle, have been simply supported.

4. ANALYSIS AND OBSREVATIONS

The design has been subjected to the following four load cases:
1. Adult Head-form Impact Test
2. Frontal Pillar Impact Test
3. Dent Resistance
4. Modal Analysis
The load cases, and the resulting observations have been elaborated below.

4.1 Load Case 1: Adult Head-Form Impact Test

During a frontal collision with a pedestrian, it is commonly observed that the head of the pedestrian tends to hit the bonnet of the vehicle. How the bonnet structure will behave under such an impact greatly influences the severity of the head injuries of the pedestrian. Consequently, it is necessary that the deformation of the bonnet be limited within a prescribed limit in order to prevent the impact of the pedestrian's head with the hard under-bonnet components while also protecting these from any serious damage.

In this test, an adult head-form impactor, weighing around 4.5 kg impacts the mid-point of the bonnet at an angle of 30 degrees with the vertical axis at a velocity of 11 m/s. The design of the head-form impactor, and the loading conditions are in accordance with the Global-NCAP norms. The rear hinges and the latching point of the bonnet have been provided with a fixed support. The edges of the bonnet structure, which rest on the frame of the vehicle, have been simply supported. It is desired that the maximum deformation must be less than 80 mm.

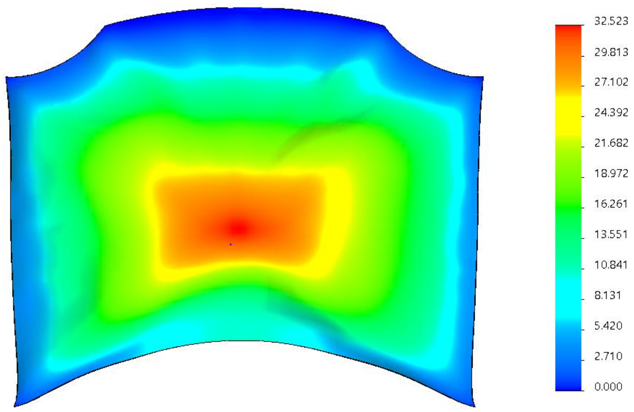

Fig - 2: Deformation due to adult head-form impact

Table-2: Maximum total deformation due to adult head-form impact

Comparison of Analysis Results with Permissible Limits	
Maximum deformation observed in the analysis	Permissible maximum deformation
32.5 mm	80 mm

The maximum deformation occurs near the central region of the bonnet and its magnitude is less than the permissible limit for the given design. The performance of the design, with respect to this loading condition, is thus satisfactory.

4.2 Load Case 2: Frontal Pillar Impact Test

In case of a head-on collision with large and rigid objects such as pillars, trees, etc. the bonnet forms an important part of the frontal crash zone. Its behaviour under collision is therefore important for attenuating any passenger, and collateral, injuries. The bonnet must maintain its integrity and remain attached to the vehicle even after the collision so as to ensure that either it, or the vehicle components underneath it, do not separate from the vehicle frame and injure anyone in the vicinity of the collision.

In this test, the bonnet, travelling at a velocity of around 40 kmph, hits a cast iron pillar of diameter 180 mm. The pillar is fixed to the ground at its base. The rear hinges and the latching point of the bonnet have been provided with a fixed support. The edges of the bonnet structure, which rest on the frame of the vehicle, have been simply supported. For satisfactory performance, the regions near the rear hinges of the bonnet must not be subjected to stresses beyond the ultimate tensile strength of the bonnet material (which is 430 MPa).

Table-3: Maximum value of von Mises Stresses due to Frontal Pillar Impact

Comparison of Analysis Results with Permissible Limits	
Maximum von Mises stresses observed near the rear hinges	Permissible value of von Mises stresses for the rear hinges
412 MPa	430 MPa (ultimate strength of the material)

The stresses induced in the region near the hinges are well below the ultimate strength of the material, indicating that the bonnet will remain attached to the vehicle frame in the event of such a collision. The design, thus, has performed satisfactorily in this test.

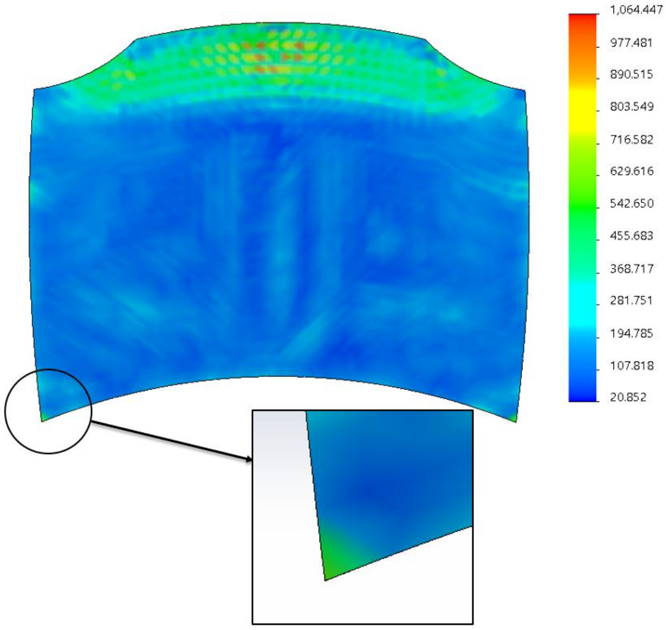

Fig - 3: Distribution of von Mises stresses in the bonnet

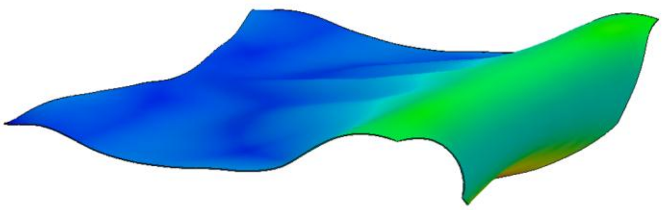

Fig - 4: Deformation due to the frontal pillar impact

4.3 Load Case 3: Dent Resistance

During the normal operation of the bonnet, it is frequently subjected to forces of relatively small magnitude during its handling and other occasions. This involves scenarios such as placing small objects on top of the bonnet, pressing against it with your hands, leaning against it, etc. It is necessary that bonnet does not under permanent deformations and the stresses induced in it remain within the elastic limit of the material.

In this test, a static load of 100 N acts vertically downward at the centre of the bonnet. The rear hinges and the latching point of the bonnet have been provided with a fixed support. The edges of the bonnet structure, which rest on the frame of the vehicle, have been simply supported. The design must be strong enough to limit the magnitude of the maximum deformation within a permissible value and ensure that the stresses in any part of the bonnet do not exceed the elastic limit of the material.

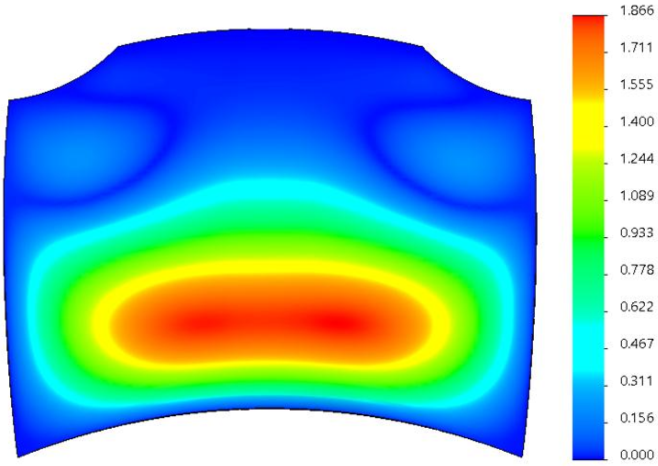

Fig - 5: Total deformation due to 100 N force

The analysis shows that the deformation, experienced by the bonnet, is well within the permissible limit. The stresses acting the bonnet are also within the safety limits. The performance of the design, with respect to this loading condition, is thus satisfactory.

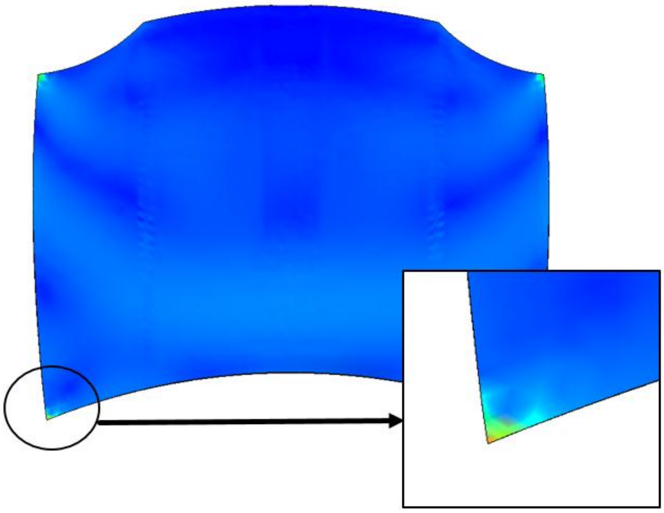

Fig - 6: Distribution of von Mises stresses due to 100 N force

Table -4: Deformation and von Mises stresses due to 100 N force

Comparison of Analysis Results with Permissible Limits		
Results from analysis		Permissible limits
Maximum total deformation	1.9 mm	4 mm
Maximum von Mises stresses	103 MPa	310 MPa (elastic limit of material)

4.4 Load Case 4: Modal Analysis

Being composed primarily of sheet metal components, the bonnet structure is liable to vibrate violently if it is excited at its natural frequencies. This may cause fatigue failure near the points of attachment such as the hinges and the latching mechanism. It is therefore necessary that the behaviour of the bonnet when it is vibrated at its natural frequencies, and the consequent stresses induced, be determined.

The first three natural frequencies of the design have been determined and the their mode shapes, and stresses induced, have been observed. It is desired that the stresses induced in the structure be within the fatigue limit of the material.

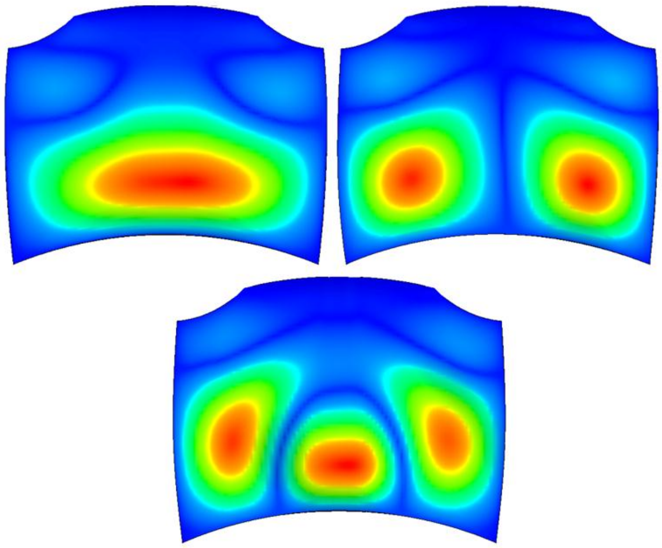

Fig - 7: Mode shapes due to vibration at the first 3 natural frequencies

Table -5: First 3 natural frequencies and Maximum value of von Mises stresses due to vibration at these frequencies

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First fundamental frequency			
Frequency	268 Hz	Maximum value of von Mises stress	8.7 MPa
Second fundamental frequency			
Frequency	448 Hz	Maximum value of von Mises stress	9.1 MPa
Third fundamental frequency			
Frequency	523 Hz	Maximum value of von Mises stress	8.5 MPa
Fatigue limit of the material : 230 MPa			

From the analysis (Fig - 7), it can be observed that the design is stiff enough and strong enough to ensure that the stresses remain below the fatigue limit when the structure is vibrated at its natural frequencies. The design is thus safe with respect to this loading scenario.

5. CONCLUSIONS FROM THE ANALYSIS

The objective of this analysis was to ensure that the new design of bonnet performs satisfactorily under a variety of loading conditions and thus can function satisfactorily during its normal operation. With this objective in mind, the design had been subjected to a variety of loading conditions which involved impact loads, static loading, and vibration. During the analysis, it has been observed that the design is capable of sustaining all the loading conditions with satisfactory performance. The deformations were well within limits for the load cases as were the stresses. Thus, with this design verification procedure, it can be concluded that the proposed design of the bonnet meets the various safety and quality parameters set forth by the various testing and standards organisations.

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