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Effect of endcap type in beltline outer using finite element analysis

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Abstract. Each vehicle has a different beltline outer (BLO) system mainly focuses at the endcap. The endcap at the BLO will tend to detach after the usage of 3 months. The BLO is important in terms of protecting the car from certain effects. Those effects are wind from inside of the car during high speed moving, and water infiltrate into cabin during heavy raining. The sound can affect the driver’s mood while driving and the infiltrated water will damage the electronic parts at the door panel. One common material used for BLO is thermoplastic olefin (TPO). The purpose of this research is to investigate the effect of air resistance angle towards the endcap of BLO. This study concerns on the resulting stress distributions and total displacement. BLO of Proton Perdana model was drafted using Solidwork 2013 software to develop the finite element model for the endcap thus run through Abaqus 6.12 simulation software. In conclusion, the results will be a guideline for other studies in improving the mechanical strength and durability of the endcap to hold its position at the BLO.

1. Introduction

Weatherstrip or known as Beltline Outer (BLO) is installed to a door of vehicle and makes a slide contact with the door glass. The term ‘slide contact’ indicates the situation that the weatherstrip having a seal lip therefore makes a contact with the door glass which is moving upwardly or downwardly [1].

BLO design always improved, but raindrops leaking and wind nuisance have become its main problems. These BLO inevitably affect the natural wind distribution flow along the BLO line and create gap underneath the mirror that allow water to leak in. The present invention relates to a weatherstrip...
which is capable of allowing water to drain from the space between the edge of the door and the seal lip portion of the weatherstrip. It also has high durability and maximal sealing characteristics to prevent from water between the window and the weatherstrip [2].

BLO locking mechanism and angle of air that act resistance on BLO do affect the deformation happened at the BLO, which causes overall positioning of endcap at BLO to deviate from its original condition. The present invention has the moulded main body that forms the exterior design part of the door and the vertical flange that forms the step cross-section section to ensure cross-sectional rigidity sufficient for attachment of an endcap to the end of the beltline moulding even when the seal lip and the clinch flange have been removed [3].

Automobile manufacturers demand studies on how BLO can be damaged and affect the comfort level to the driver or passenger. This study will concentrate on the effect of how the angle of air resistance can affect the deformation on BLO with the variable of BLO locking mechanism. The material used for the endcap mostly is thermoplastic olefin (TPO) which applied at Proton Perdana model.

Nowadays with the development of computing technology and grid generation techniques, an increasing number of researchers have adopted Finite Element Analysis (FEA) in their investigation of static structural analysis on the impact of beltline outer (BLO) at car. FEA is a powerful computational tool for analysing complicated structures like doors. If it is compared to experimental work, it saves much time and costs. Various types of tests are essentials for door design [4].

For this research, to simulate the deformation undergoes at the BLO profile, one mechanism crimping profile (from Proton Perdana model) and flow mean speed of 110 km/h was introduced, particularly at the endcap face where the air resistance flow which is converted to force. 110km/h was chose since it is the high speed of 110km/h, the aerodynamics streamline fully developed than the velocity of 90 km/h or lower [5]. It is also the maximum speed limit in any highway in Malaysia which is the best maximum force for the most drivers in Malaysia.

A research of estimating free-flow speed in South Dakota from posted speed limit signs at ten sites have shown that average free-flow speeds are highly linked to posted speed limits with correlation coefficients of +0.99, +1.00, and +1.00 for urban streets, multilane highways and freeways respectively [6]. At the inner side containing the locking profile of BLO, the fixed support condition is set. The BLO around the door trim panel are considered as three-dimensional steady-state and static structural analysis. The modelling of the endcap and BLO was done through Solidwork 2013 X64 Edition. Then the analysis was performed by the aid of Abaqus 6.12 software.

2. Design model

There are two parts in which to develop the 3D head model. First where the model is developed using CAD programs which is Solidwork. The second part is to develop the simulation in Abaqus software in which to analyse the effects of air resistance to the BLO model, specifically on the stress distribution and total deformation.

2.1. BLO and endcap design model

The numerical approach of FEA was used to simulate the stress distribution and deformation happen using ABAQUS software. This simulation starts with pre-processing, solving and post-processing. At first, the dimension was taken from the actual endcap and BLO part of Proton Perdana model. After dimensions have been taken, the part was drawn in Solidwork software. Figure 2 shows the part generated in Abaqus software exactly according to the dimension of the models imported from the Solidwork.
2.2. Material properties

Thermoplastic Olefin (TPO) is the actual material considered for the BLO. This material has excellent lubricity, abrasion resistance, heat resistance and weather ability. It is suitable because of having good mechanical properties, such rubber that has very high tensile strength, high stiffness, and toughness. They are light in weight, which have extraordinary corrosion resistance and the ability to withstand extreme temperatures. The material considered was assumed to be homogeneous, isotropic and linear elastic solids. Table 1 lists the different of material properties.

**Table 1.** Material properties used in Finite Element Model

| Material          | Thermoplastic Olefin (TPO) |
|-------------------|----------------------------|
| Young’s Modulus   | 3000                       |
| Poisson Ratio     | 0.49                       |
| Density (kg/m³)   | 880                        |
| Yield Stress (MPa)| 45.84                      |

3. Methodology

3.1 Loading and boundary condition

In this study, the endcap and BLO were considered respectively. This work was performed on distributed loading of concentrated force which is air resistance of 110 km/h. The loads which is the air resistance is converted to force, \( F_w \) (wind Force) by using formula of

\[
F_w = 0.5 \rho C_d v^2 A
\]

where \( A \) is the surface area of car frontal area, \( C_d \) is the value of drag coefficient, \( \rho \) is the density of air and \( v \) is the wind velocity.

Loads are assumed to be happened at the tip of the BLO which is at the endcap. The force which is air resistance 110 km/h, is converted by using the above formula. The air resistance 110 km/h converted to force in Newton equivalent to 412.94 N. The force was applied at the endcap part that contact with the air resistance. There will be 10 angle values for the force to be applied. First is at 0˚ from the x axis then anticlockwise to 90˚ with a value of 10˚ for each increment. This is to analyze at which angle the deformation and the Von Mises Stress happened to be at maximum level. Table 2 shows the force value obtained for 0 to 90 degree angle rotating anticlockwise starting from the x-axis.
Table 2. Force Distribution of Proton Perdana BLO

| Angle (°) | Resultant Force, $F_w$ = 412.94 (N) |
|-----------|----------------------------------|
|           | $F_x = F_w \cos (\theta)$ | $F_y = F_w \sin (\theta)$ |
| 0         | 412.94             | 0                   |
| 10        | 406.67             | 71.71               |
| 20        | 388.037            | 141.23              |
| 30        | 357.62             | 206.47              |
| 40        | 316.33             | 265.43              |
| 50        | 265.43             | 316.33              |
| 60        | 206.47             | 357.62              |
| 70        | 141.23             | 388.037             |
| 80        | 71.71              | 406.67              |
| 90        | 0                  | 412.94              |

Figure 3 shows how the Perdana BLO loading is applied in real case and Abaqus software: (a) Force applied at Proton Perdana endcap with angle in real case, (b) Yellow arrow (Concentrated Force) and Purple arrow (Pressure) both indicate the force air resistance being applied in Abaqus.

![Figure 3](image1.png)

(a)  (b)

Figure 3. Loading applied on Perdana BLO for (a) real case and (b) abaqus software

Boundary condition is also applied to indicate the fixed support for this model. The fixed support was represented as the locking mechanism between the BLO and endcap. This meets the objective of the research to find which locking mechanisms provide better durability to the model. Figure 4 shows how the Perdana BLO boundary condition is applied in real case and Abaqus software: (a) Boundary condition applied at Proton Perdana endcap in real case, (b) The orange mark indicates the fixed support region Perdana BLO being applied in Abaqus.

![Figure 4](image2.png)

(a)  (b)

Figure 4. Boundary condition and fixed support on Perdana BLO for (a) real case and (b) Abaqus.
3.2 Meshing
In this study, the meshing is defined with approximate global size which value is 2. Meanwhile, the local size used is 5. This stage involves the element shape which tetrahedron is considered. The mesh controls also used the default algorithm set to 1.050. This is to monitor and ensure the stability of the simulation. About 9786 elements and 3794 nodes were generated. Figure 5 shows how the meshing is setup and generated for Perdana BLO.

![Figure 5. Meshing of Proton Perdana BLO](image)

4. Result and discussion

4.1 Von Mises Stress distribution in Proton Perdana BLO
Figure 6 shows the distribution of Von Mises Stress in Proton Perdana BLO.

| Angle (°) | Interior view | Exterior view |
|-----------|---------------|---------------|
| 0         |               |               |
| 30        |               |               |
| 60        |               |               |
| 90        |               |               |

![Figure 6. Proton Perdana Von Mises Distribution](image)
Figure 7 shows the graph obtained for Perdana BLO Von Mises Stress with respect to the degree of angle.

![Von Mises Graph](image)

**Figure 7.** Graph of Von Mises Stress respect to angle

From this analysis, the load of air resistance is set at 412.94 N. This value is equivalent to 110 km/h of a car speed. This result show that the variation of the stress distribution for the Proton Perdana model which is at the speed of 110km/h. According to the formula of air resistance, the value for the force at Proton Perdana with the speed of 110 km/h is 412.94N. The difference is mostly due to the frontal area of the car and the drag force coefficient, $C_d$ which are the parameters in obtaining the air resistance force value. Figure 6 shows the maximum value of the Von Mises Stress at Proton Perdana is 2.87 MPa. The grey colour represent the maximum stress. Grey colour ranging from 0.025 Mpa until 2.87 MPa. The grey colour is seen at the tip of the endcap which concentrated force and pressure have been applied. There are two regions where the endcap are mostly mark with grey colour. The grey colour is at the both tip side of the endcap. This is due to the position of the region. This is the position where most concentrated force and pressure is been applied since it is located facing outside of the car. The interior region especially at the flocking part is mostly blue in colour since the region is not exposed to the air resistance. It is also obvious with the inclination of angle, the Von Mises Stress value is also increasing. However, the yield stress for TPO is 45.84 Mpa which indicate the system is still safe as the maximum Von Mises Stress for this Proton Perdana is at 2.87 Mpa. The Von Mises graph shows the value is decreasing from 0° to 10° but later gradually increasing until the angle of 90°.

For comparison, the maximum value of Von Mises for Perdana is 2.87 Mpa. For yielding stress, the value for TPO is 45.84 Mpa. From automotive view, the grey colour is at the critical region since it is located to the most outside which the water tends to infiltrate in. the stress distribution shows a little bit increasing in Von Mises Stress. The higher value of Von Mises Stress will result at much more deformation happen at the endcap. In prolonged time, the Perdana endcap will have higher chances to go for failure. This is obvious when the tip of endcap which is critical region have a high value. From the mechanical view, the endcap for both model is not fail or can delay the risk at BLO because the value of yield strength TPO is 45.84 MPa which is considered has long survivorship of the model.
4.2 Deformation magnitude distribution in Proton Perdana BLO
Figure 8 shows the deformation magnitude in Proton Perdana BLO.

| Angle (°) | Interior view | Exterior view |
|----------|---------------|---------------|
| 0        | ![Image](image1.png) | ![Image](image2.png) |
| 30       | ![Image](image3.png) | ![Image](image4.png) |
| 60       | ![Image](image5.png) | ![Image](image6.png) |
| 90       | ![Image](image7.png) | ![Image](image8.png) |

**Figure 8.** Proton Perdana deformation distribution

Figure 9 show the graph obtained for Perdana BLO displacement magnitude with respect to the degree of angle.

**Figure 9.** Graph of displacement magnitude respect to angle

Next aspect analyzed is the deformation that happened at the endcap. From the graph, it is shown that the displacement magnitude is increasing with the increment of the degree of angle. The maximum magnitude for Proton Perdana stand at 0.0092 mm. The highest deformation happened for Perdana model when the angle of 90° of air resistance is being applied. Most of the grey colour represent highest magnitude occurred at the BLO instead of the endcap. This happen due to force of the air resistance that contact with the endcap has been transferred directly to the BLO. The BLO that attached to the door car absorb the force, which causes the most deformation magnitude happen at that region. Besides, the
flocking region also has a large grey surface area since the flocking contact directly to the window glass. The blue region is mostly at the fixed support mechanism since it is lock with screw and crimping mechanism. This shows that deformation is minor at the fixed support region.

![Deformation Graph](image)

**Figure 10.** Graph of displacement magnitude respect to angle

5. Conclusion
In nutshell, deformation magnitude gave clearer picture that this material provides the expected least deformation at max 0.0092 mm which will lengthen the gripping endurance during high speed of the vehicle. Moreover, value indicated by Von Mises stress was also affected in this study. Proton Perdana has a maximum stress 2.87 MPa and deformation when the angle of air resistance is at 90°. In term of mechanical strength and durability of the endcap to hold its position at the BLO, this model is working effectively. The main reason is that the maximum stress generated was still far from their yielding stress properties which is 45.84 MPa. However, for a longer time the BLO of Proton Perdana model is suspected cannot maintain as the deformation magnitude will tend to increase and affect the stability of the locking mechanism. Further experiment and simulation research can be implemented to study this issue.

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