International Journal of Infrastructure Research and Management
Vol. 10 (2), December 2022, pp. 1-11

STRUCTURAL ANALYSIS FOR AUTOMOTIVE A-PILLAR

Nursherida Jalaluddin
Infrastructure University Kuala Lumpur, MALAYSIA

ABSTRACT

Car body design in view of structural strength and light weighting is a challenging task due to all the performance targets that must be satisfied such as vehicle safety and ride quality. An increasing pressure on vehicle manufacturers internationally and also several countries are mandating to reduce vehicle emissions. Thus, light weight strengthening solutions are required to increase roof strengths while minimising structural mass. In this paper, material replacement along with multidisciplinary design optimisation strategy is proposed to develop a lightweight A-Pillar vehicle structure that satisfies the crashworthiness criteria while minimising weight. Through finite element simulations, a Federal Motor Vehicle Safety Standard (FMVSS 216), Roof Crush Resistance test and by the Insurance Institute for Highway Safety (IIHS) was conducted at the A-Pillar model structure. All the tests set up, simulation test constraints and procedure will be based on the standard. Then all the models will be rated, using the specific strength or strength to weight ratio calculations to determine the best model among all the model that had been tested. The wall thicknesses of two parts are which is inner and outer layer of A-Pillar were considered as the design variables. The benefits of the new proposed material (mild steel, aluminium and high strength steel) include reduced mass and hence more efficiency. All the three materials had passed the FMVSS 216 test requirement as the total deformation was not more than 127mm under a force of 1.5 times the weight of vehicle,12.21 kN, was applied so that the test device moves in a downward direction perpendicular to the lower surface of the test device at a rate of not more than 13mm per second. Total deformation for mild steel (MATS 100039MAT2_16800) get the highest value and Aluminium (A6060) gets the lowest value under the FMVSS216 test. This shows that Aluminium (A6060) have higher energy absorption compared with the existing material. The improved A-Pillar with the new proposed material was able to secure a substantial margin of the survival zone as well as to meet the requirement specified by standard.

Keywords:
A-Pillar, FMVSS 216, Total Deformation, Equivalent Stress, Weight Reduction & Structure Strength Rating.

BACKGROUND STUDY

The A-pillar is an important load carrying component of any automobile body. It is a primary support structure for the roof and is typically a thin-walled, spot-welded, closed-section structure made from high strength steels. This is a structural member as the sides of the windshield on which doors will be mounted. This research study will cover the structural analysis of the A-Pillar with different type of materials. The paper deals with the modal analysis of an A-pillar which is Proton Gen 2 that will be the benchmark model. The dimensions of the A-pillar are taken from the drawing or references whichever is available. The 3D model is prepared and then meshing is done in ANSYS and structural analysis is carried out on A-pillar to determine the natural frequencies and mode shapes of a structure. Post-processing is done using ANSYS software. The A-pillar design's acceptance is done from the results obtained in analysis on different type of materials. The analysis results and strength to weight ratio calculation will show the different results from which best material is selected based.

PROBLEM STATEMENT

Current benchmark model material is mild steel which is a conventional material used widely in automotive industry. A study by Cheah (2010), shows that current material of automotive body chassis which is mild steel are material that have low strength to weight ratio (SWR) or strength rating value and had more fuel consumption to be compared to other materials like aluminium, high strength steel and composite materials. (Cheah, 2010). Vehicle weight and size reduction is one known strategy to improve fuel economy in vehicles, and presents an opportunity to reduce fuel use from the transportation sector. By reducing the mass of the vehicle, the inertial forces that the engine has to overcome when accelerating are less, and the work or energy required to move the vehicle is thus lowered. A general rule of thumb is that for every 10% reduction in vehicle weight, the fuel consumption of vehicles is reduced by 5-7%. The strength to weight ratio value can be increased as it has high strength with less weight of material (Cheah, 2010).

OBJECTIVES

i. To improve the structure strength rating value of commercialized automotive A-Pillar and decrease the weight of automotive A-Pillar structure.
ii. To analyse the automotive A-Pillar structure based on its material type and thickness of the structure.

LITERATURE REVIEW

A monocoque chassis is a single piece of framework that gives shape to the car. A one-piece chassis is built by welding several pieces together. Figure 1 shows a monocoque chassis (Wan, 2000). Monocoques chassis consist of front bumper beam, side members, A-pillar, B-pillar, floor platform and roof. The design of A-Pillar from local car manufacturer was chosen as the benchmark model to improved in terms of the structure strength rating with the new proposed material. Material can play an important factor in achieving the expected output. Producing the lightweight material car body design in view of structural performance and light weighting is a challenging task due to all the performance targets that must be satisfied such as vehicle safety and ride quality (Meschtscherjakov 2014). The applications of lightweight materials not only bring the potential for carmakers to reduce the car weight but also simultaneously satisfy the new regulations of fuel economy and emissions. A few lightweight materials have been introduced in automotive industry such as aluminium and composite materials. The growing interest in reducing fuel consumption has encouraged auto industry to come up with various techniques for obtaining a lighter design. One of the common techniques to achieve this demand is material replacement. This technique allows engineers to design a car body structure without compromising the safety and crashworthiness behaviours. The minimum load that the new designed A-Pillar need to withstand is 1.5 times to the total weight of the car and the displacement of plate must be less than 5 inches after the load been applied to it (Meschtscherjakov, 2014).

Figure 1: Monocoque Chassis *(Mark Wan,2000).*

The new designed A-Pillar need to meet the requirement of FMVSS 216 standard (U.S. Department of Transportation National Highway Traffic Safety Administration, 2006) Kashir Naik, run an analysis on the A-Pillar by applying axial load at the top surface of the structure and define the maximum load and deflection it can withstand (Naik & Patil, 2018). A-pillar CAD model using CATIA V5 is shown in Figure 2.

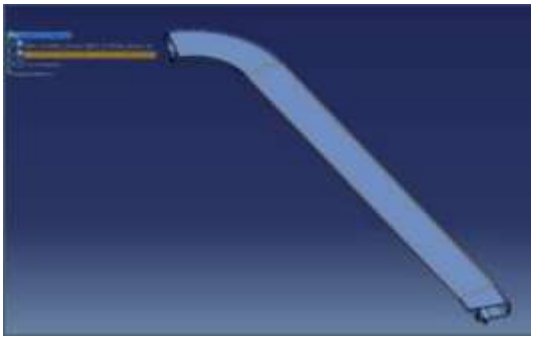

Figure 2: A-pillar CAD model using CATIA V5 *(Naik* & Patil*, 2018)*

In mechanical engineering, some machine components and automotive parts can behave differently due to the design of machine elements, manufacturing processes, and selection of materials (Salem & Nursherida, 2019). The material selection is the most important steps in engineering field. The construction sector and automotive sector must adopt environmentally sound planning and design practices to create a safe and sustainable environment design or construction waste materials resulting from development, reconstruction, destruction involving excavation, civil and building construction, road work, automotive safety, clearing of sites and demolition (Mohamed Eliwa & Mohamad Ayob, 2020). Secondly, design stage also plays important roles in designing any mechanical components. According to Wong (2019), lack of design or incorrect design caused due to manufacture error – Improper design may cause connection problems during installation (Wong & Siti Nur Aliaa Roslan, 2019). Boundary conditions and contact interface will be set up based on the FMVSS 216 test requirement. The result will show the value of total deformation, equivalent stress, equivalent strain and weight of all the model.

According to the United States Environmental Protection Agency (EPA), the average new U.S. vehicle weight has been increasing steadily at a rate of 1.2% per annum over the past two decades, levelling off at around 1,730 kg in recent years (EPA 2009, EPA 2010). Based on research findings from Davis (2009), the model assumes that the median vehicle lifetime remains at 16.9 years for cars, and 15.5 years for light trucks, including SUVs (Davis et al., 2009). Figure 3 shows the material production energy intensity of steel vs. lighter-weight automotive materials (UChicago Argonne LLC, 2007).

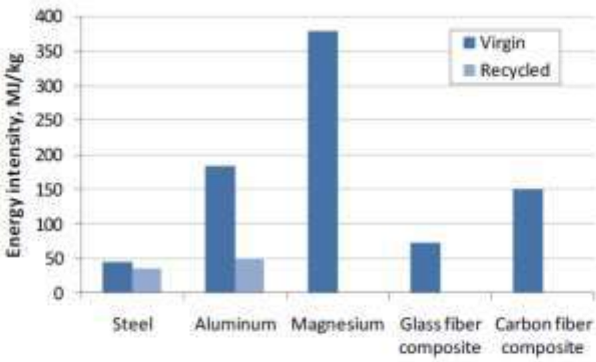

Figure 3: Material production energy intensity of steel vs. lighter-weight automotive materials (UChicago Argonne LLC, 2007, Knittel, 2009).

An older 2002 study from the National Research Council estimates that raising fuel economy targets by 20% by 2013 can lead to fuel savings of 10-15 billion gallons in 2015 (National Research Council (U.S.), 2002). Morrow et al., (2010) examined the greenhouse gas (GHG) emissions reductions arising from a scenario where the fuel economy standard is raised to 43.7 MPG by year 2030 (Morrow, et al., 2010). Based on the research from Smith (2002) and Geyer (2007), the life-cycle energy impact of vehicle weight reduction in the U.S. involved the fuel savings and vehicle light weighting only (Smith et al., 2007).

METHODOLOGY

The flowchart of the project as shown in Figure 4. Figure 5 shows the inner layer and outer layer of the A-pillar structure.

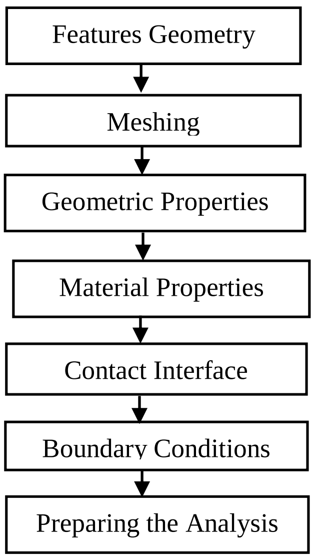

Figure 4: Flow chart of the project.

The area of analysis that will be focus is the structure strength of the A-Pillar, the highest load that the structure can withstand by different type of materials. Secondly, is to calculate the structure strength rating value of every type of materials. Then the results were compared.

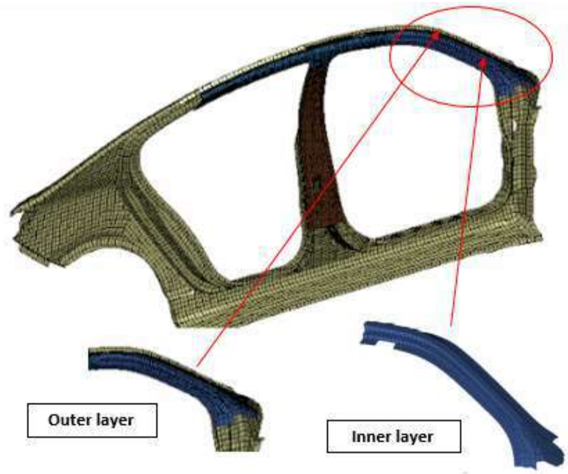

Figure 5: Inner layer and Outer layer for the A-Pillar structure

Table 1 shows the material properties of mild steel, aluminium and high strength steel that have been used in the A-pillar structure model. The material properties and thickness of the model also shown in Table 1 and Table 2. Table 3 shows the meshing details for the A-pillar structure model. The number of nodes are13441 and number of elements are 12704. Figure 6 shows the A-pillar test setup that follow requirement from FMVSS 216 standards.

Table 1: Material Properties

Material	E (GPa)	υ	S_y (MPa)	ρ (kg/m^3)
Steel	206	0.3	168	7850
AA6060	69.6	0.33	134.84	2650
A606	210	0.3	310	7870

Table 2: Model Specification

Material	Mild Steel (MATS 100039MAT2_16800 (Model 1)		Aluminium (A6060) (Model 2)		High Strength Steels (A606) (Model 3)	
Thickness (mm)	Outer Layer	Inner Layer	Outer Layer	Inner Layer	Outer Layer	Inner Layer
	0.7	1.8	1.0	2.0	0.7	1.8

Table 3: Meshing Details

Element Types	**Shell**
Number of Nodes	**13441**
Number of Element	**12704**

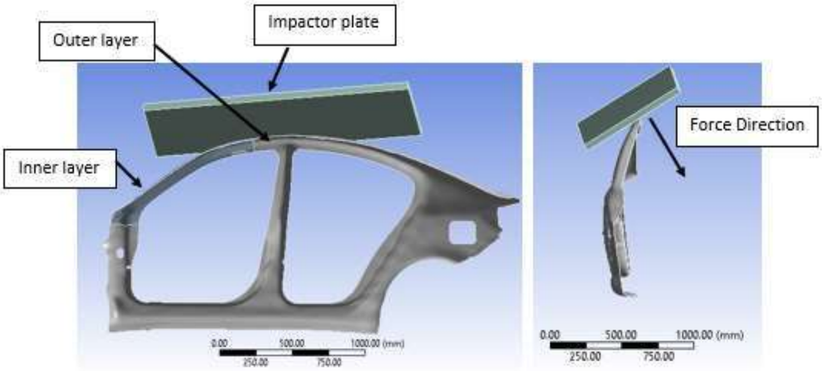

Figure 6: FMVSS 216 test set up.

RESULTS AND DISCUSSIONS

Figure 7 shows the deformation of the A-pillar. The maximum deformation value is 12.23mm. The simulation analysis crash events for the A-pillar are shown in Figure 8.

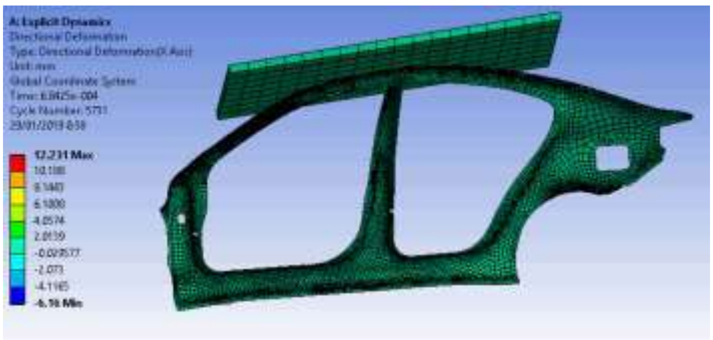

Figure 7: A-Pillar deformation

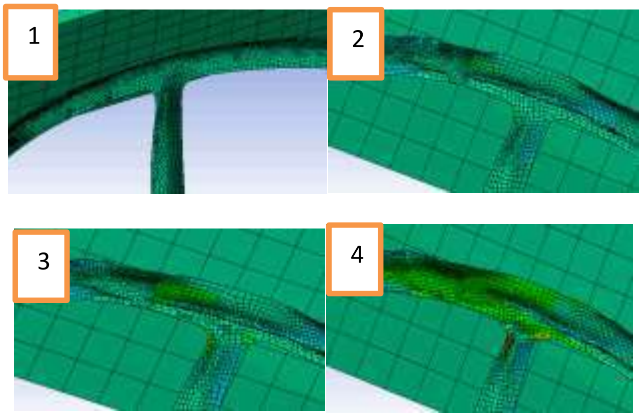

Figure 8: Simulation analysis crash event.

Total Deformation

Graph for total deformation versus time is shown in Figure 9. It shows that the mild steel has the maximum value of the total deformation. Aluminium gives the lowest value of total deformation. Thus, the most suitable material to absorb the energy is aluminium. Table 4 show the total deformation results for mild steel, aluminium and high strength steel.

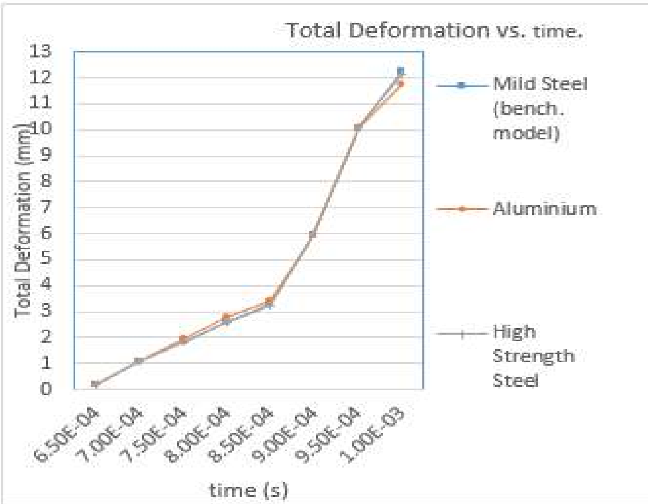

Figure 9: Graph for Total Deformation vs. Time

Material	Mild Steel (conventional material)	Aluminium (A6060)	High Strength Steel (A606)
Total Deformation (mm)	12.231	11.752	12.121

Table 4: Total Deformation result.

From the test, all the three materials are able to reach the targets. The part must not deform more than 127mm. If it deformed more than 127mm then the vehicle fails under this test and the vehicle will not pass successfully. As been shown in the result test, all three materials not deformed more than 127 mm which is 12.231mm for mild steel, 11.752mm for aluminium and 12.121mm for high strength steel. This shows that aluminium has the lowest deformation under the same force indicating that it has the strongest structure compared to the other two.

Equivalent Stress

Figure 10 shows stress versus time chart of A-pillar finite element analysis results.

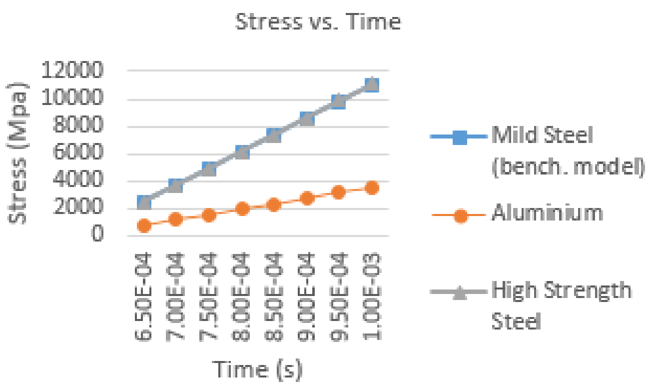

Figure 10: Stress vs. Time chart.

Table 5: Equivalent Stress Result

Material	Mild Steel (conventional material)	Aluminium (A6060)	High Strength Steel (A606)
Equivalent Stress (mm)	11042	3545.5	11087

Determining whether an isotropic and ductile metal will yield when subjected to a complex loading condition. This is accomplished by calculating the von Mises stress and comparing it to the material's yield stress, which constitutes the von Mises Yield Criterion. The objective is to develop a yield criterion for ductile metals that works for any complex 3D loading condition, regardless of the mix of normal and shear stresses. Three types of material will be tested. Result shows that high strength steel have the highest value of stress. This may be due to higher hardness strength to be compared to others.

Weight Reduction

One of the main objectives is to reduce the weight of the A-Pillar vehicle structure. The conventional material weight was compared with the improved material by using the ANSYS software which it calculated based on the density of the material and volume of the structures. Table 6 shows structure weight with different materials.

Table 6: Structure weight with different materials

Material	Mild Steel (Conventional material)		Aluminium (A6060)		High Strength Steel (A606)	
Part	Main Layer	Inner Layer	Main Layer	Inner Layer	Main Layer	Inner Layer
Weight (kg)	10.374	2.1561	3.5682	0.74158	10.401	2.1616
Total Weight (kg)	12.53		4.3094		14.5626	
Weight Reduction (%)	-		65.6		-24	

Structure Strength Rating

The structure strength is the structure maximum stress (force per unit area at failure) divided by its density. Equation (1) shows the formula for the strength of the structure. The SI unit for specific strength is Pa m^3/kg, or N•m/kg, which is equivalent to m^2/s^2, nevertheless the latter form is infrequently used. This calculation will show which material is the best and rate it based on the calculation results. Table 7 shows the result of the structure strength.

$$\text{Structure Strength} = \frac{Stress\ (force\ per\ unit\ area\ at\ failure)}{Density} \tag{1}$$

Table 7: Structure Strength Result.

Material	Mild Steel (Conventional material)	Aluminium (A6060)	High Strength Steel (A606)
Structure Strength (Mpa $\frac{m^3}{kg}$)	635919887.9	656579677.3	637964186.2

From the result, it shows that Aluminium has the highest value of specific strength which can be concluded that it is the best materials to be compared to the conventional material and another improved material.

CONCLUSIONS

From the result obtained, it can be concluded that:

i. All the three materials had passed the FMVSS 216 test requirement as the total deformation was not more than 127mm under a force of 1.5 times the weight of vehicle,12.21 kN, was applied so that the test device moves in a downward direction perpendicular to the lower surface of the test device at a rate of not more than 13mm per second.
ii. Total deformation for mild steel (MATS 100039MAT2_16800) got the highest value and Aluminium (A6060) gets the lowest value under the FMVSS216 test. This shows that Aluminium (A6060) have higher absorption energy which mean aluminium have better toughness and amount of energy per unit volume that a material can absorb before rupturing.
iii. The result of equivalent elastic strain showed that High Strength Steel obtained the highest value, due to its higher hardness strength to be compared to others
iv. ANSYS software had calculated the weight of the structure as well based on the density and volume of the structure. Aluminium (A6060) was the lightest material and it had reduce weight of the structure until 65.6% of the conventional material.
v. The rate of the material structure were determined by using the structure strength rating. It was a material's strength (force per unit area at failure) divided by its density. Aluminium (A6060) shows the highest value of structure strength rating value which indicate that it is the best material structure as to be compared to others.
vi. Based on the simulation results, the objectives of the study have been achieved where the weight of the structure has been reduced without decreasing the strength of the structure.

RECOMENDATIONS

Further recommendation for this study is to do the FMVSS216 simulation run on the same structure by using the composite materials. Composites are being considered to make lighter, safer and more fuel-efficient vehicles. Based on the author knowledge during the engineering materials subject, the strength and stiffness factors are why composites are currently used in aerospace applications, which also require a material that is extremely light. A composite is composed of a high-performance fiber (such as carbon or glass) in a matrix material (epoxy polymer) that when combined provides enhanced properties compared with the individual materials by themselves. Carbon-fiber composites weight about one-fifth as much as steel but are as good or better in terms of stiffness and strength. Second is the structure itself can be improve as well by adding some rib at the inner layer especially at the contact force area. This will reduce the total deformation and increase the structure strength as well.

AUTHOR BIOGRAPHY

Nursherida, Dr. was born on 29th May 1983, in Kuala Pilah, Negeri Sembilan. She obtained a Second Class Upper Honours Degree, Bachelor of Engineering (Mechanical Engineering), 2006, Master of Science (Mechanical Engineering), 2011 and Ph.D in Mechanical Engineering, 2017 from Universiti Putra Malaysia (UPM), Selangor, Malaysia. She has extensive teaching experience in Mechanical Engineering field and Automotive for almost 10 years in IUKL, UNISEL and UniKL MIDI.

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