FINITE ELEMENT SIMULATION OF THE CRASHWORTHINESS TEST OF NON-UNIFORM THICKNESS BLANK

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Declaration

I declare that this dissertation has not been previously accepted in substance for any degree and is not being concurrently submitted in candidature for any degree. I state that this dissertation is the result of my independent investigation / work, except where otherwise stated. I hereby give consent for my dissertation, if accepted, to be available for photocopying and understand that any reference to or quotation from my journal will receive an acknowledgement.

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Nomenclature

TRB	Tailor Rolled Blanks

Symbols

ρ	Density
ν	Poisson's ratio
E	Young Modulus

Abstrak

Keringanan kenderaan dan keselamatan penumpang adalah isu-isu yang biasa diketengahkan dalam pembuatan kereta. Badan kereta mempunyai berat kereta majoriti dan pada masa yang sama mesti kuat untuk melindungi penumpang apabila kemalangan berlaku. Kemalangan dari depan merupakan kamalangan yang paling serius di dunia dan selepas itu merupakan kemalangan dari sampingan. Walau bagaimanapun, ruang yang diperlukan bagi struktur kereta untuk menyerap tenaga apabila kemalangan dari sampingan berlaku adalah sangat kurang kalau berbanding dengan kemalangan dari depan. Oleh itu, penumpang dalam kemalangan dari sanpingan selalu mempunyai kecederaan yang lebih serius apabila berbanding dengan kemalangan dari hadapan. Oleh itu, dalam projek ini, tiang B digunakan sebagai kajian kes untuk mengkaji kesan mengurangkan ketebalan terhadap keselamatan penumpang dengan menggunakan simulasi. Ketebalan yang tidak seragam seperti Tailor Rolled Blanks (TRB) adalah penting dalam pembuatan tiang B untuk mencapai keringanan dan meningkatkan crashworthiness tiang B. Simulasi bengkokkan sisi dan langgaran paksi tiang B telah dijalankan dan ubah bentuk direkodkan. Kesan taburan ketebalan dan kedudukan zon peralihan pada crashworthiness tiang B telah diteroka dan keputusan telah menunjukkan bahawa bagaimana mereka mempengaruhi crashworthiness. Oleh itu, reka bentuk optimum ketebalan tiang B yang lebih ringan dan selamat untuk penumpang telah dipilih dan dijangka menyediakan data utama bagi reka bentuk struktur TRB.

Kata kunci: Tailor Rolled Blanks (TRB), zon ketebalan peralihan, bengkokkan sisi, langgaran paksi, simulasi unsur terhingga, crashworthiness

Abstract

Lightweight and safety of the passenger are the most common issues highlighted in manufacturing of a car. The car body denoted majority of the car weight and at the same time must strong and protect passenger from a crash. Front impact is the most serious impact in the world and after that is side impact. However, the space required for the car structure to absorb the energy from side impact is very less when compare to the frontal impact. Therefore, the passenger in the side impact accident often has the more serious worth when compare to the front impact. Hence, in this project, B-pillar is used as a case study to study the effect of reducing thickness to the safety of the passenger using simulation. Non-uniform thickness such as Tailor-rolled blanks (TRB) is important in manufacturing the B-pillar to achieve the lightweight and improve crashworthiness of the B-pillar. Lateral bending and axial crash simulation of B-pillar were conducted and the deformation was recorded. The effects of thickness distribution and the position of transition zone on the crashworthiness of B-pillar were explored and the results showed that how they influenced the crashworthiness. Therefore, the optimum thickness design of the B-pillar that is lighter and safe to the passenger is determined and is expected to provide some primary data for lightweight and crashworthiness design of TRB structure.

Keywords: Tailor Rolled Blanks (TRB), thickness transition zone, lateral bending, axial crashing, finite element simulation, crashworthiness

1.0 Introduction

The weight of vehicle always plays a significant role in designing the body of full vehicles. Recently, due to environment and safety factor, vehicle crashworthiness and lightweight need to be considered together when designing a car. Vehicle mass affects the energy consumption of the vehicle due to increase in resistance when driving. Reducing weight by 100kg of vehicle weight will leads to fuel saving of about 0.351/ 100km and 8.4g of CO_2/km with gasoline engines [1]. In order to reduce the automotive weight, high strength steel, aluminium alloy and others composite material are widely used to replace original mild steel [2]. However, it is hard to achieve these two performances at the same times as these two performances always conflict with each other. It is common for material with higher strength will have heavier weight. Hence, a material is used to reduce weight that is by using high strength steel (HSS) or ultra-high strength steel (UHSS). High strength steel has higher yield strength and failure strength than mild steel. It also can be used in automotive body to increase the impact energy absorbing capability and plastic deformation. Material replacement is normally more effective than structure modification. However, these types of material are not widely applied in automotive industry due to the high cost of these materials. But when we compare to the aluminium and magnesium, UHSS has better economy in its raw material and the cost to fabricate are cheaper [3].

UHSS is used in the automobile body structure which largely composed of uniform thickness thin-walled structural parts. Although those thin-walled structures can decrease the weight and improve the vehicle safety, but the main disadvantage of uniform thin-walled structured is such structure may not exert their maximum capability of crashworthiness [4].Therefore, a metal sheet with varying thickness is needed because it uses material more efficiently and also increases crash capacities [5]. In order to achieve this, some advanced manufacturing process, such as tailor welded blank (TWB) have been widely applied in the automotive industry. TWB are semi-finished parts that consist of at least two single sheets that are welded prior to the forming process [6]. The sheets can exhibit different mechanical properties, thicknesses or coatings. TWB contribute to lightweight design because no reinforcing blanks and less joining elements are necessary. The use TWB with low density and high strength leads to weight reduction. The use of tailor blanks will also improve crash behavior besides weight reduction. Of these components with variable material/thickness, the TWB structure consists of laser-welded sheet metals of different thickness and materials, combine the flexibility of material and thicknesses, already adopted in many vehicle components, such as B-pillar, inner part of door, and front-end structure. The main problem in TWB blanks is the discrete thickness sections of TWB may lead to stress concentration and cause fatigue failure. A new rolling process, which called tailor rolled blanks (TRB) is invented to overcome the defects. When compare TRB with TWB, TRB varies the blank thickness with a continuous thickness transition, which will cause that have better formability and greater weight reduction. In TRB, any thickness transition is possible, there is an exact adaption to the load in the application. TRB also show better surface quality due to they do not contain a weld seam [7].

The rolling gap of TRB can be varied, which leads to a continuous thickness variation in the workplace. To produce TRB, the cost of does not depend on the number of thickness transition, but the flexible rolling process itself is very elaborate since the roll gap is adjusted online. The adjustment of the roll gap is done online by measuring the sheet thickness [8]. The thickness of the sheet can be set by an integrated algorithm by using a closed loop control. The most economic transition slope for TRB is a thickness different of 1mm over a length of 100mm [9]. The forming behavior of tailor rolled blanks can be tested by using deep drawing tests. The longer the transition regions will cause less wrinkling in the test [10]. By using TRB, the maximum drawing depth of deep drawing can be increased when comparing with the uniform thickness blanks [11]. There are few studies about the crushing behaviors of TRB structures. For example, one of them is study about the effect of different functionally graded wall thickness on the crashworthiness of square tube [12], another one compares the energy absorption characteristics of FGT tubes when different force applied on it [13]. Figure 1 show the tailored rolled blank process for longitudinal thickness transition.

This paper aimed to study the crashworthiness characteristics of TRB structures with different thickness transition under lateral bending and axial crashing by using ANSYS software.

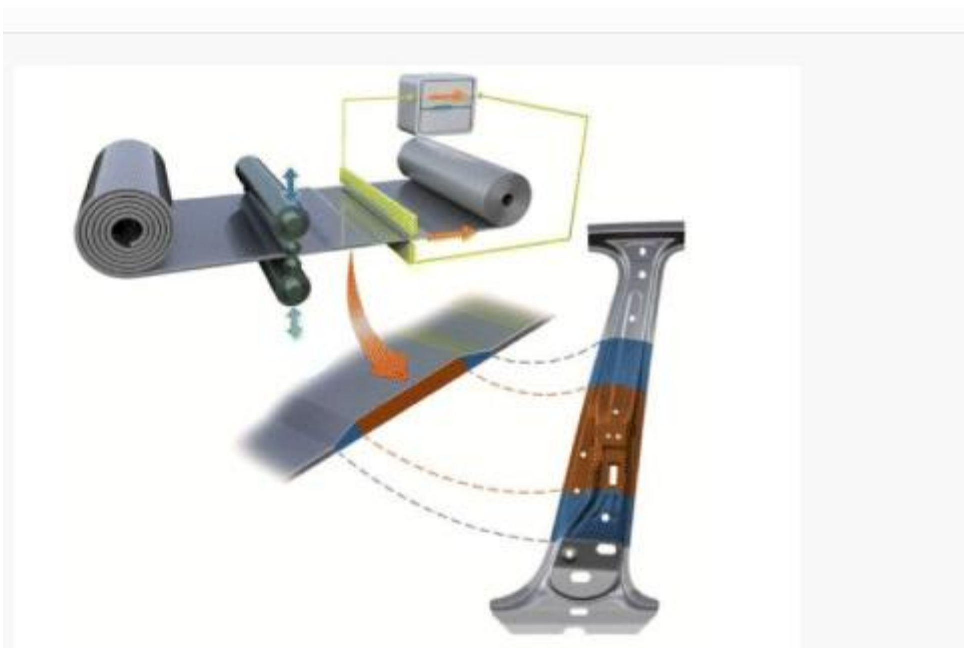


Figure 1: Tailor Rolled Blank (TRB) process for longitudinal thickness transitions [14]

2.0 Methodology

B-pillar is the most significant energy absorption component when side impact happens and its crash modes and energy absorbing capability can greatly influence the side part of the full vehicle crashworthiness and safety of passengers. Crushing force should be low in the beginning of a crushing event to reduce the deceleration and avoid passengers' injuries or death. But at the end of the crash event, a high force would be expected to enhance energy absorption. The TRB structure due to the high cost, it is difficult to do the real impact test of the vehicle level. Hence, ANSYS simulation is used in the test of crashworthiness.

TRB structure is divided into 3 functional zones during the longitudinal direction, that is zone A, zone B and zone C. These three zones have the same thickness distribution along the longitudinal direction of the TRB structure and are known as constant thickness zone (CTZ). Between these three zones, there is a segment with continuous varying thickness along the longitudinal direction of TRB structure and it is called thickness transition zone (TTZ). Zone A and zone C are designed to maximize the structure weight reduction belong to lightweight zone so it has the lowest thickness. It is called as thin zone. Zone B is designed to resist bending collapse and absorb the collision to transfer it to plastic deformation energy so it has the highest thickness. It is called thick zone [15]. Figure 2 shows that the 3 functional zones of TRB structure.

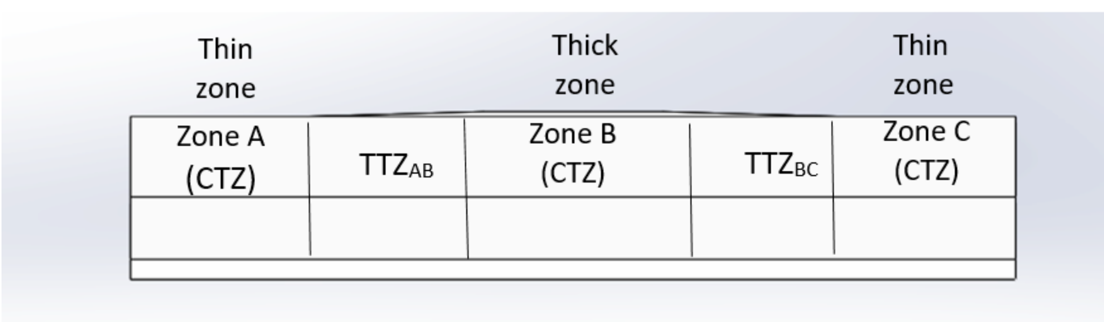


Figure 2: Three functional zones of TRB structure

2.1 Part Modeling

In order to do the simulation, the model, B-pillar is needed. The model can either get from reverse engineering or construct it using available CAD software. Although reverse engineering will get the exact dimension and shape of the part, but the original B-pillar only used uniform blanks when manufactured the part. Furthermore, it is time consuming and it is a waste due to only a part of B-pillar is used in the simulation. Hence, the method of constructing CAD file of B-pillar is selected and the dimension of B-pillar is measured by using typical measuring equipment such as micrometer, vernier caliper and etc. The CAD software used to construct the model is Solidworks due to it can construct the 3D model and more user friendly. The total length L of the TRB structure is 200mm and 3 TRB structures with different thickness. Figure 3 shows that the simplified middle part of the B-pillar with different thicknesses. In the Figure 3, t_1 is the thickness at the thick zone, t_2 is the thickness at the thin zone while l_1 is the length of the transition zone. The detailed dimensions of those three specimens are summarized in Table 1.

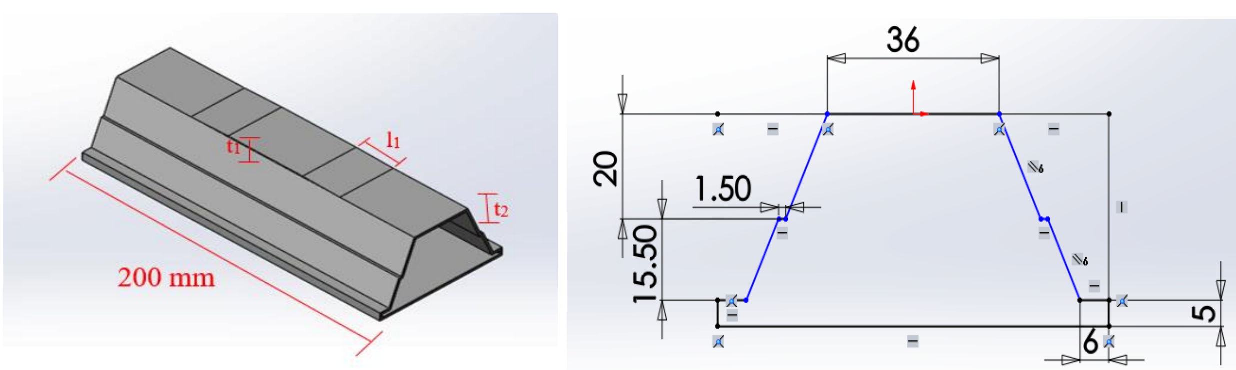


Figure 3: Description of the dimensions and the simplified middle part of the B-pillar with different thickness

Table 1: The remaining detail dimensions

Specimens	Dimensions (mm)			Weight (kg)
	t_1	t_2	l_1	
TRB 1	1.5	2.1	25	0.514
TRB 2	1.5	2.7	40	0.528
TRB 3	2.1	2.7	25	0.707

2.2 Material Properties

The model is simulated using FE analysis code LS-DYNA in ANSYS. The material used in the simulation is Ultra High Strength Steel 600 (UHSS 600) which is mostly use in the vehicle structural components such as crash energy absorber. The Young's Modulus (E), Poisson's ratio (v) and density (ρ)of UHSS are 210GPa, 0.32 and 7.83×10^3 kg/m^3 respectively.

2.3 Mesh Convergence Test

In finite element analysis (FEA), finite element size (mesh density) will determine the accuracy of the results and required computing time. According to FEA theory, FE models with fine mesh (small element size) will get the highly accurate results but may take longer computing time. On the other hand, FE models with coarse mesh (larger mesh size) may get the less accurate results but smaller computing time. Hence, in generating FEA models, the most important is to choose appropriate element size to obtain the accurate results while save as much computing time as possible [16]. In this paper, the mesh convergence test is conducted to determine the optimum mesh size of TRB structure with accurate results and low computing time.

2.4 Finite Element Simulation

There are two simulation conditions carried out in this study, which are lateral bending and axial crashing models.

2.4.1 Lateral bending

In lateral bending test, the diameter of the fixed support is 15mm, and have a length of 160mm. For crushing simulation, a cylindrical punch with diameter of 15mm is used and the location is on the mid-span of the specimen.

The support and punch without deformation are modelled as rigid body. In the crash, a constant velocity of 17 m/s is assigned to the punch, while the support is fixed. 60km/h is converted to 17m/s, as it is the speed limit in town area in Malaysia. Hence, 17m/s is chosen as the velocity in simulation to determine the deformation of B-pillar under maximum crashing speed. There is a friction coefficient of 0.2 is set between the punch, support and TRB structure. [15]Figure 4 shows that set up of lateral bending test.

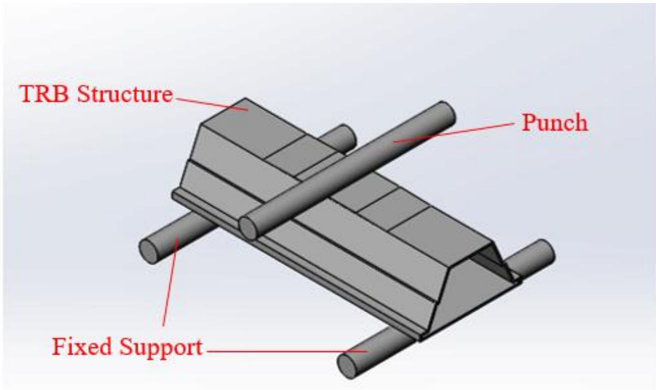


Figure 4: Set up of Lateral bending test

2.4.2 Axial crashing

For the axial crash, the two platens are taken as the rigid wall, the top platen is act as a moveable and the bottom platen is fixed. The specimen was crushed gradually by applying a constant velocity, V=5mm/s on a top platens, as shown in Figure 5. There is a friction coefficient of 0.2 is set between the punch, support and TRB structure. [17]

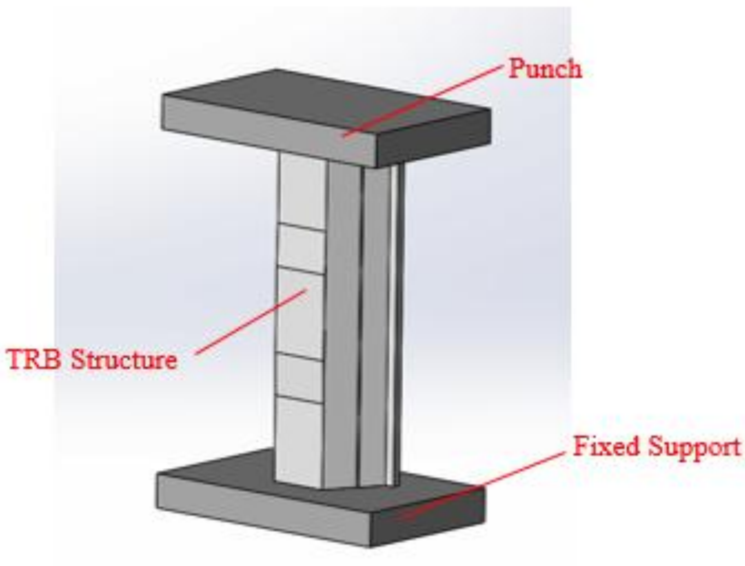


Figure 5 : Set up of axial crashing test

3.0 Result and Discussion

3.1 Mesh Convergence Test

Figure 6 shows that the results of mesh convergence test. From the results, optimum number of element nodes number of 507379 or mesh size of 1.5mm is chosen as the optimum number of element nodes. This is because the difference of deformation is not mush by using the mesh size smaller than 1.5mm but the computing time consumed is much more longer. For example, the smaller mesh size such as 1.3mm can get a 94.235 mm deformation which is larger than 93.912 mm in 1.5mm mesh size, but the computing time is approximately 864 minutes which is much more longer than 536 minutes in 1.5 mesh size.

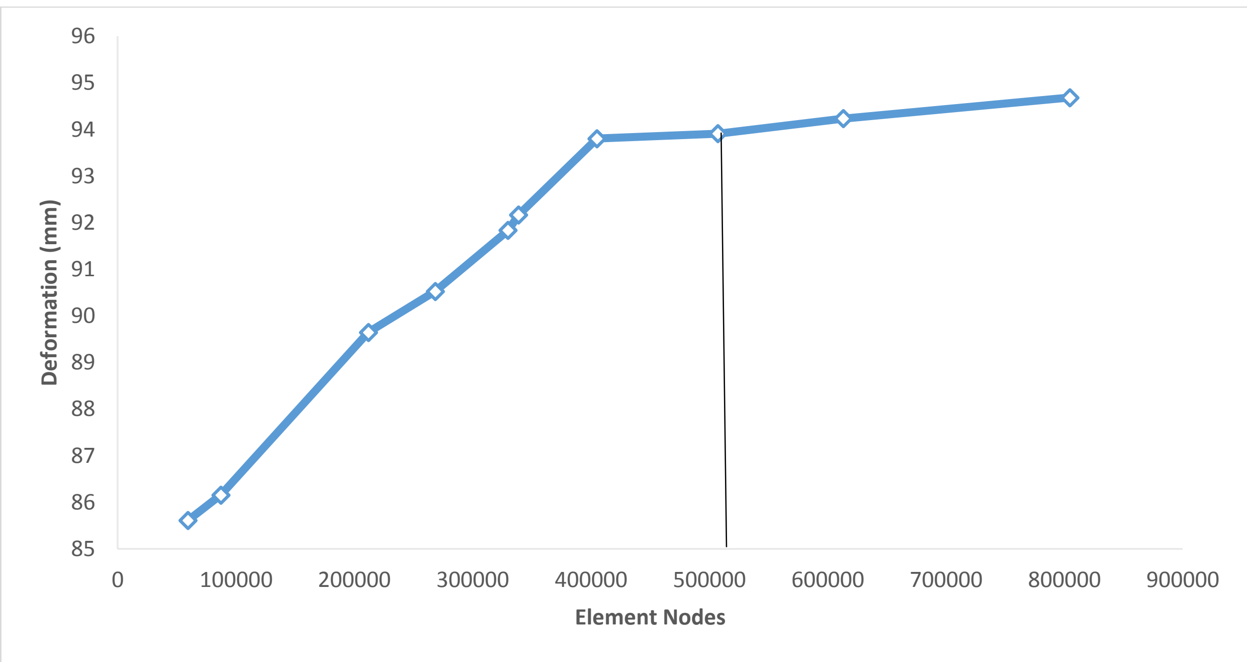


Figure 6: Deformation against Element Nodes

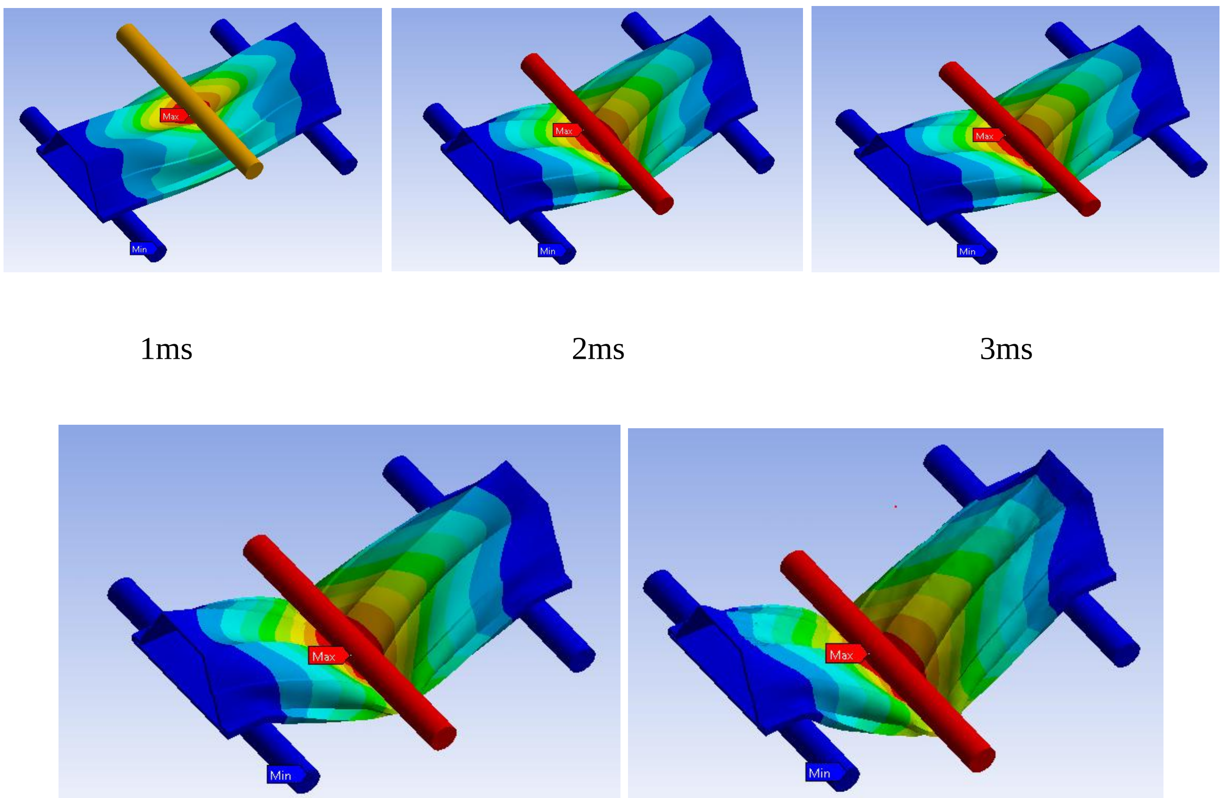
Figure 6 shows that the results of mesh convergence test. From the results, optimum number of element nodes number of 507379 or mesh size of 1.5mm is chosen as the optimum number of element nodes. This is because the difference of deformation is not mush by using the mesh size smaller than 1.5mm but the computing time consumed is much more longer. For example, the smaller mesh size such as 1.3mm can get a 94.235 mm deformation which is larger than 93.912 mm in 1.5mm mesh size, but the computing time is 864 minutes which is much more longer than 536 minutes in 1.5 mesh size.

3.2 Lateral bending

Figure 7 shows the deformation pattern of TRB 3 in 5ms. When comparing the deformation of TRB 1, TRB 2, and TRB 3, TRB 1 shows the highest deformation than the others two. This is due to the TRB 1 has the transition zone of 1.5-2.1mm which has lowest thickness transition zone in three models. When comparing TRB 2 and TRB 3, although TRB 2 and TRB 3 has the same thickness at the middle part of the B-pillar, but yet deformation of TRB 2 is higher than the TRB 3. This is due to TRB 2 has the lower minimum thickness when comparing TRB 3. The results of deformation of three TRB structures are shown in Figure 8. However, there is not much differences when comparing the deformation pattern of 3 models in the figure. It is because to the variation of thickness of 3 models is also not much.

From Figure 9, the stress graph show a fluctuation of data with the increase of time. This is due to the area of contact of the fixed load and the TRB keep changing with the increase of time. Higher stress is required to deform a material with higher thickness. Therefore, it is expected for the TRB 3 can withstand the highest stress at the end among three TRB structure. Due to the and the following is TRB 2 and TRB 1.

Strain is defined as the relative change in shape in shape or size of an object due to applied force. High strain rate is expected to influence the deformation and fracture properties. [18]From Figure 10, TRB 1 show the highest value of strain, and the TRB 3 has the lowest value of strain. This is because the material with lower thickness will deform more than the material with higher thickness and cause it to elongate more.



1ms 2ms 3ms

4ms 5ms

Figure 7: Deformation pattern of TRB 3 in 5ms

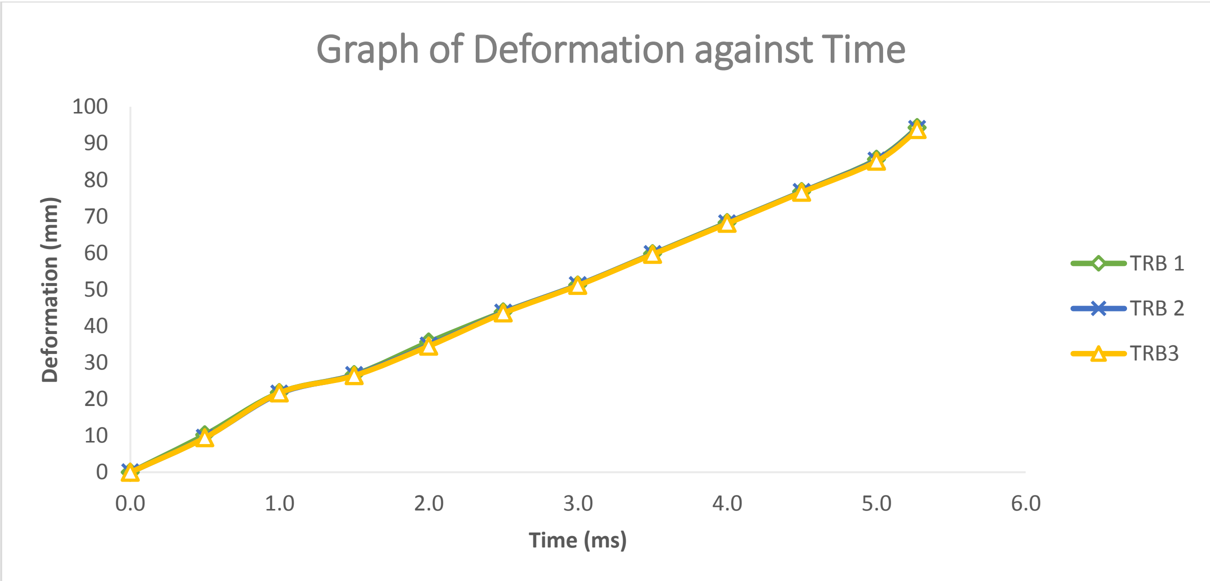


Figure 8: Deformation against time

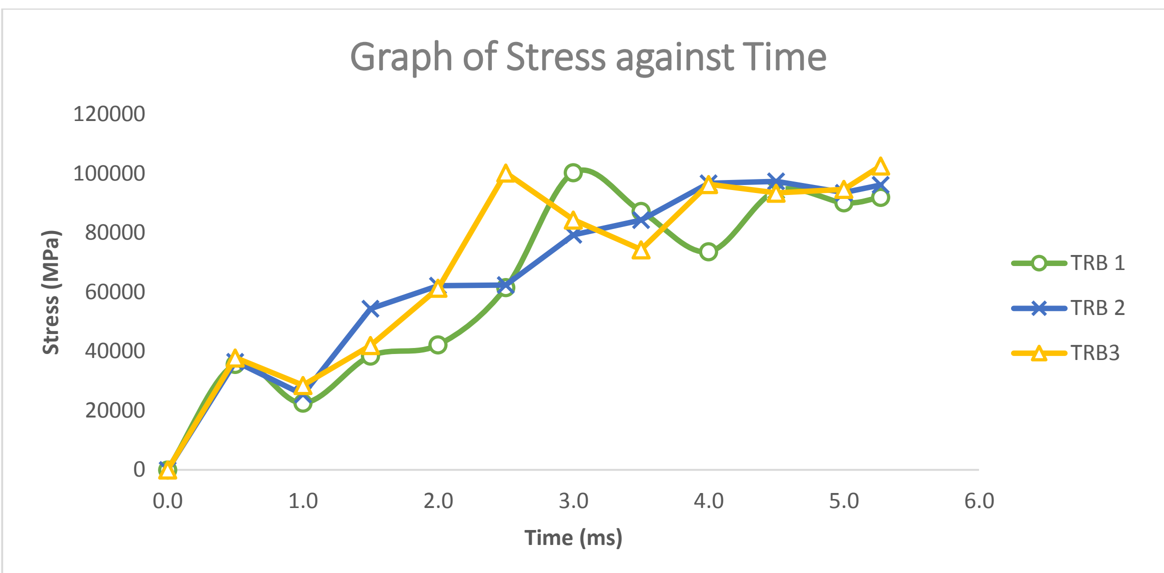


Figure 9: Stress against time

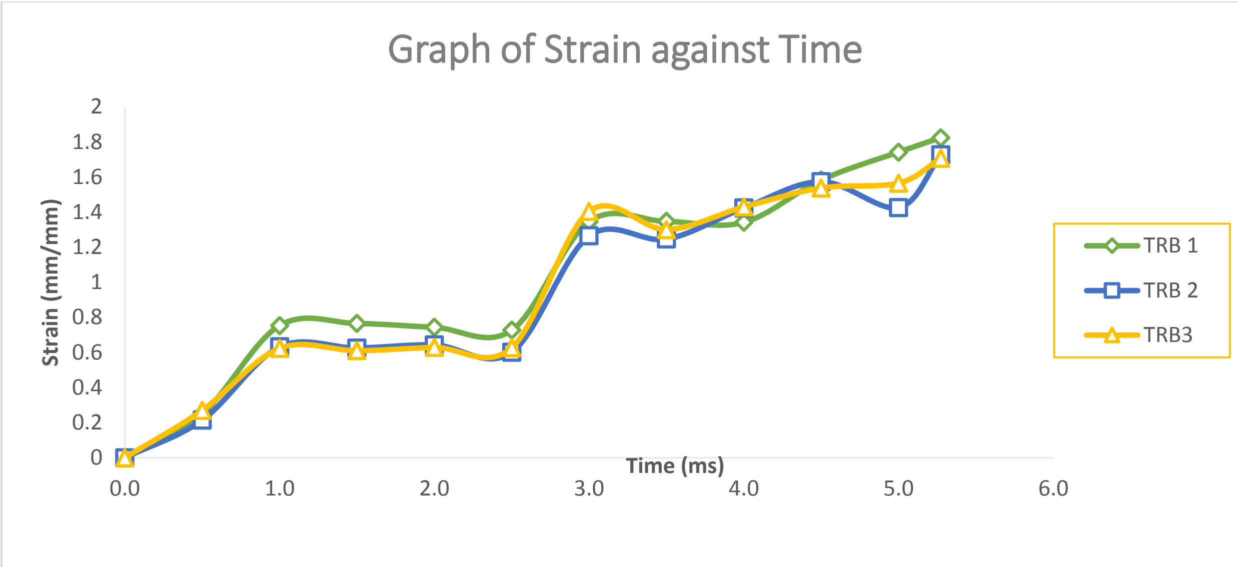


Figure 10: Strain against time

3.3 Axial crashing

Figure 11 shows that the deformation of axial crashing in 8ms. From Figure 12, the deformation of TRB 1 depicts the highest deformation than TRB 3 and TRB 2. The reason is same as the lateral bending test. TRB 1 has the transition zone of 1.5-2.1mm which has lowest thickness transition zone among three models. Structure with lower thickness transition zone will deform more than the structure with higher thickness transition zone when the force applied on it. Therefore, TRB 1 has the highest deformation while TRB 3 has the lowest deformation among three structures.

From Figure 13, the relationship between stress and time was plotted. The graph shows that the TRB 3 will withstand the highest deformation than TRB 1 and TRB. However, TRB 2 shows the unusual stress pattern than the other two TRB structures at the interval time of 3ms to 4ms. In the beginning of axial crash, the punch will reach the thickness of 1.5mm first. Hence the stress is almost same as the TRB 1. But at the middle part, the thickness is gradually increased from 1.5mm to 2.7mm. Hence the force required to crash the structure increase and cause the increase in stress.

From Figure 14, the strain condition also same like the strain condition of bending test, which is the material with lower thickness will deform more and elongate more than the material with higher thickness. Thus, TRB 3 has the lowest strain while TRB 1 has the highest strain among 3 structures.

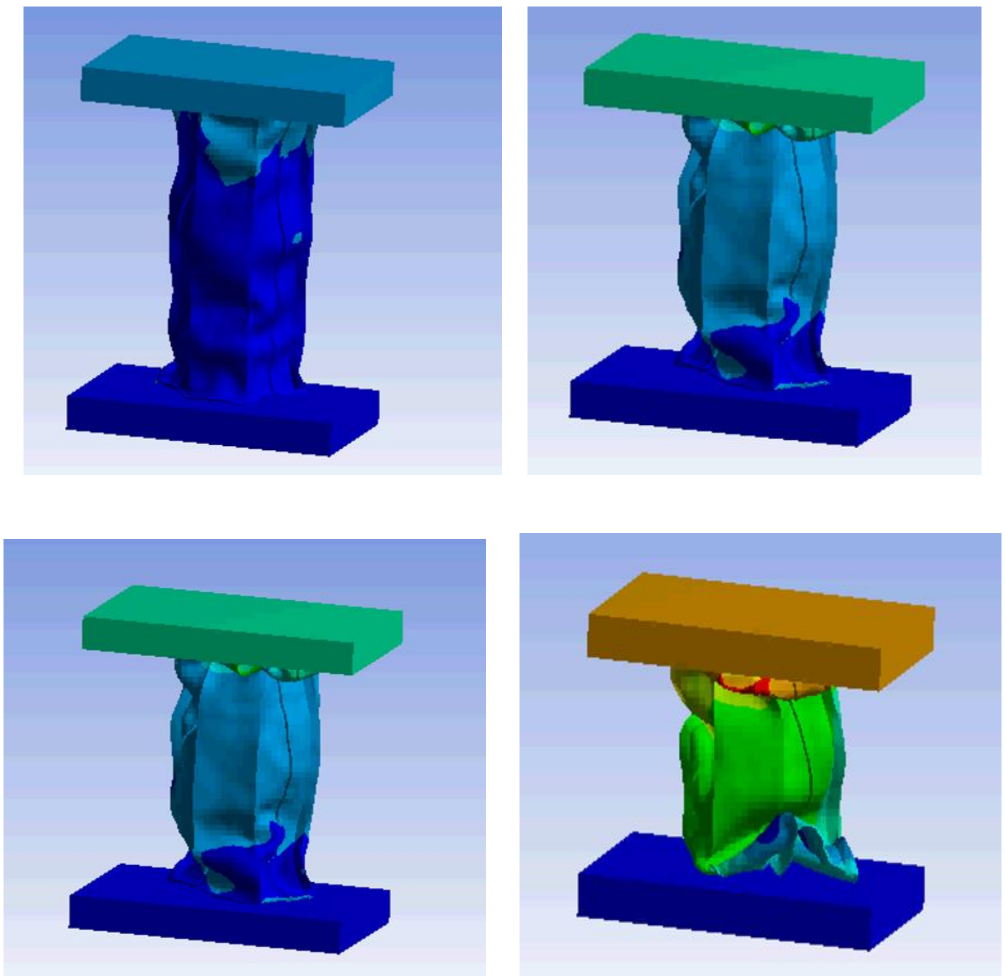


Figure 11: Deformation of axial crashing in 8ms

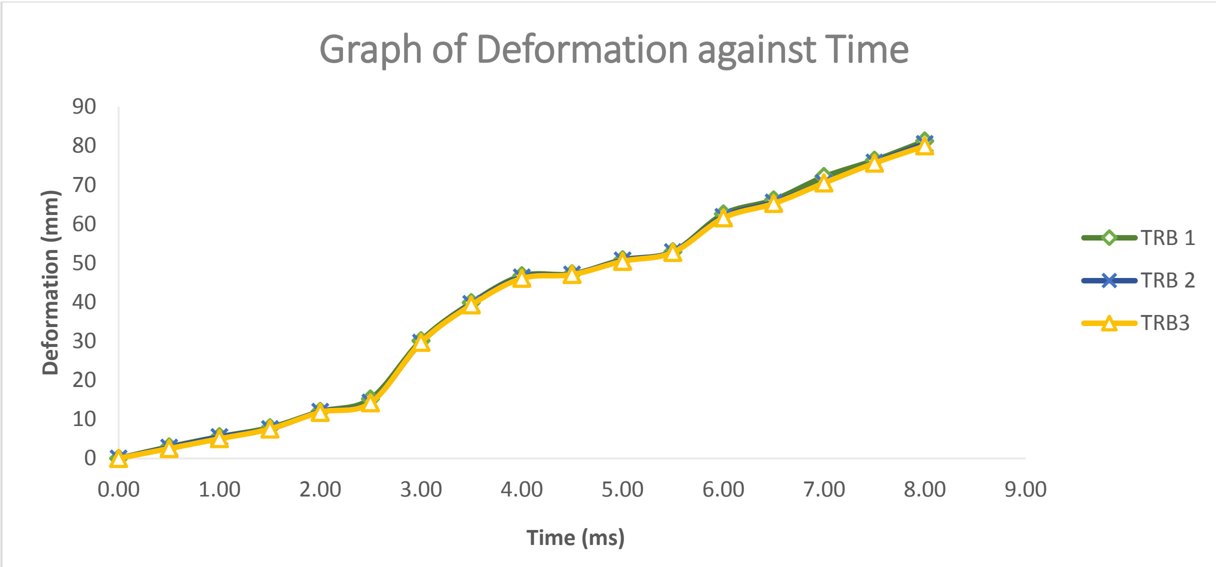


Figure 12: Result of deformation against time

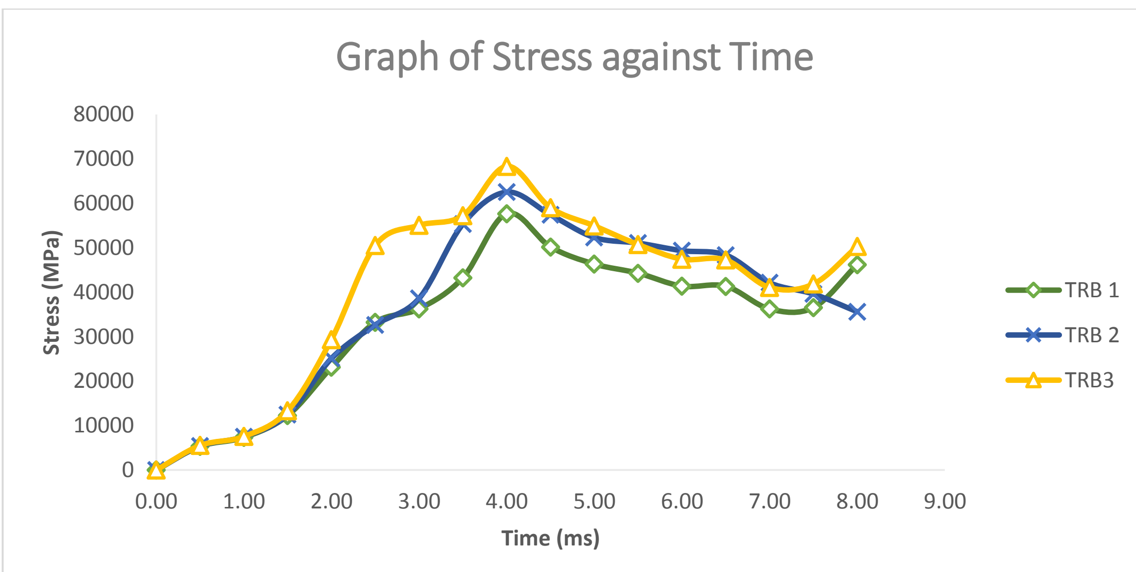


Figure 13: Result of stress against time

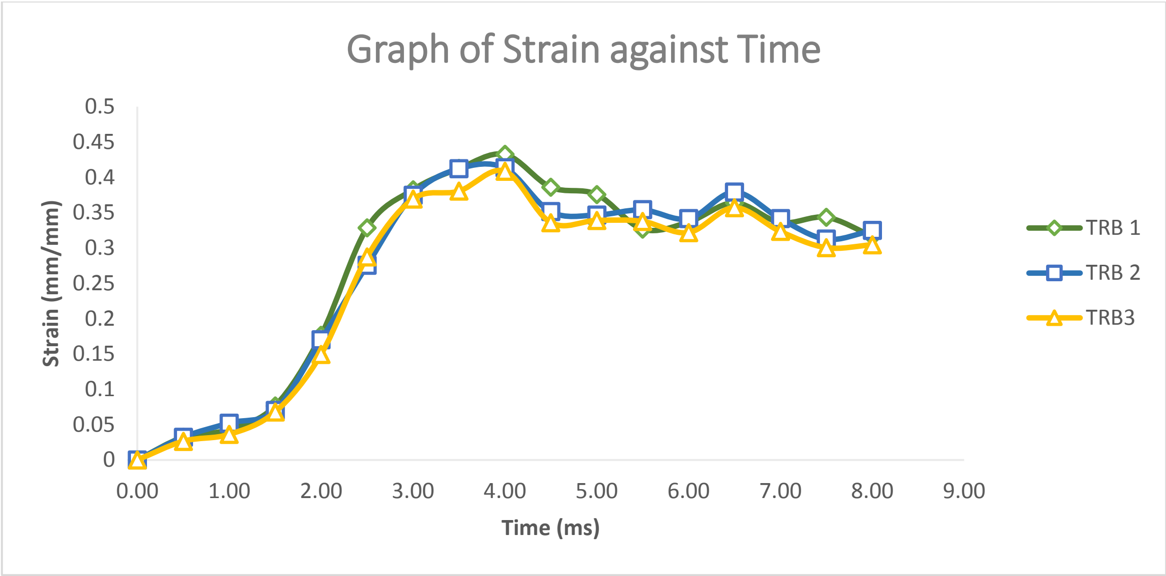


Figure 14: Result of strain against time

3.4 Maximum Safety Deformation

Car safety plays an important role to protect passengers when the crash happened. Therefore, the B-pillar is designed to allow maximum energy absorption during impact. In this work, the maximum deformation of the B-pillar is determined by using the lateral bending test of TRB 3. TRB 3 is chosen because of it has the highest thickness among three TRB structures. Figure 15 shows the maximum safety deformation of B-pillar from front seat centerline. The maximum safety deformation should be 125mm from front seat centerline. The distance of the B-pillar of the car to the front seat center centerline is 295mm measured by measuring instrument. Hence, the calculation of the maximum deformation can be calculated as follow:

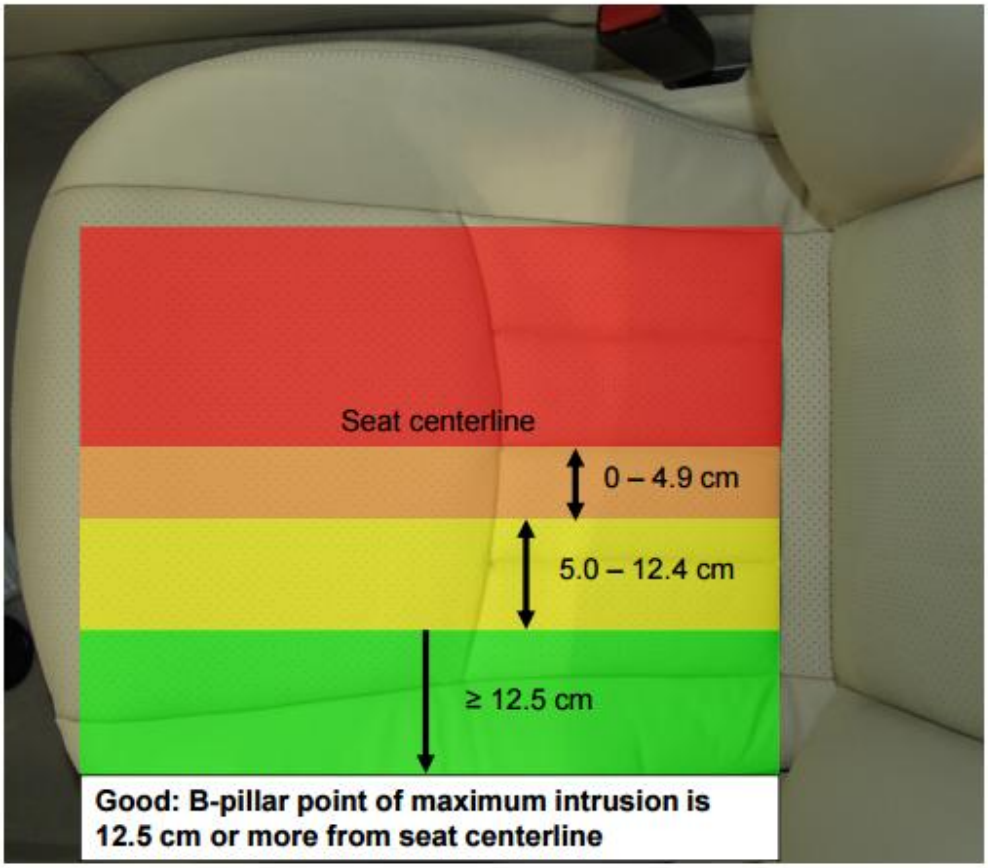


Figure 15: B-pillar maximum safety deformation [19]

Maximum safety deformation of B-pillar

= (Distance from B-pillar to the front seat centerline - Maximum safety deformation B-pillar from seat centerline)

= 295mm - 125mm

= 170mm

From the simulation, the results show that the 93.804mm is the maximum deformation of TRB 3. However, the results are not accurate because when the punch is continued to move down, the TRB is supposed continue to deform. This is most probably due to the improper set up of the simulation. The improper set up cause too much imbalance in the system. Even though the program tries hard to make changes to overcome the imbalances, it hasn't been able to do so and stops. Figure 16 shows that the maximum deformation of B-pillar by simulation.

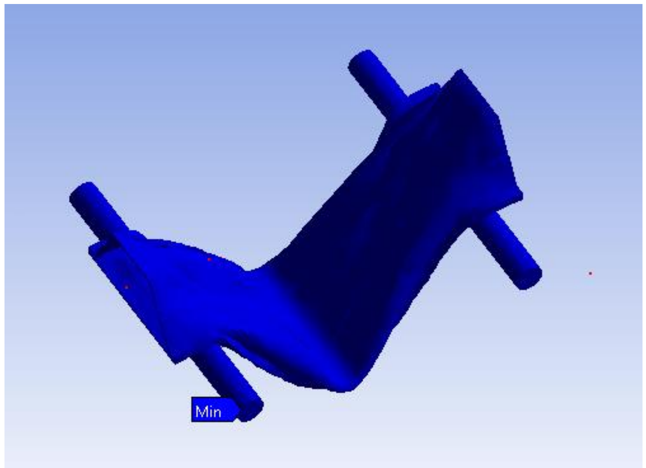


Figure 16: Maximum deformation of b-pillar by simulation.

4.0 Conclusion and Recommendation for Future Works

Tailor Rolled Blank technology is very beneficial for the sake of passenger safety for manufacturing of the car body. To investigate the crashworthiness of TRB, finite element (FE) modeling method is used in the explicit non-linear FE code LS-DYNA. From the simulation, it is recommended that the TRB with thickness 2.1-2.7mm is the best to resist deformation while the TRB 1 with thickness 1.5-2.1mm is the worst to resists deformation. However, when the lightweight is taken into consideration, TRB 1 with the weight of 0.514kg is lighter than TRB 3 with the weight of 0.707kg. If TRB 1 is used in vehicle, the body weight of the vehicle can be reduced and cause less fuel consumption. Therefore, the lightweight and crashworthiness is equally important and should be taken into consideration when designing a car. Therefore, future work need to be conducted to obtain the optimum design which is highly safe to the passenger and at the same time it light for the sake of the environment.

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