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Finite element analysis of bumper beam with thickness variation based on natural fibre composite material

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Abstract

Composite material consists of several materials. Currently, composite materials, such as bumper beams, have been widely applied in the automotive field. Natural fibres that are more environmentally friendly are one of the factors for making composite materials, one of which is coconut fiber bamboo fiber with epoxy matrix which has been done by previous researchers. In this study, finite element analysis was carried out, namely, von Misses stress, deformation, safety factor, and comparison of bumper weight between bumper beam steel weight. The results of the analysis obtained the highest Von misses stress at a thickness of 3 mm bumper beam of 7.0908 Mpa. The results of the study on the deformation obtained by the 3 mm bumper beam is 1.0575 mm. The results of the safety factor analysis obtained on the bumper beam thickness of 6 mm and 9 mm are 15,000 safety factors. The results of the study of the weight comparison of the bumper beam at a thickness of 3 mm, 6 mm, and 9 mm can reduce the weight by 85.37%, 68.48%, and 52.82%.

Keywords

Finite element, Bumper beam, Material Composite

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Introduction

Technological developments encourage the use of new materials in the automotive sector, materials that have strong and lightweight properties such as composite materials [1]. Composite materials are formed from several materials that remain separate, but produce a new material with better properties than the constituent materials [2]. Light metal materials such as aluminium alloys or mild steel plates are generally the basic ingredients for making car bumpers [3]. Bumpers are automotive parts located at the rear and front of the vehicle, to ensure the safety of passengers in the event of a low-speed collision. The bumper beam is one of those contained in the car bumper system, which serves to absorb kinetic energy when a low-speed collision occurs [4]. The use of natural fibers in the manufacture of composites as a car bumper beam application can be a more environmentally friendly alternative [1].

However, nowadays natural fibers have been widely used as fillers in composites, including coconut, bamboo, pineapple, banana, and so on. Natural fiber composite materials in addition to having the advantage of being cheap, lightweight, and environmentally friendly, but also have the disadvantage of tensile strength and weight depending on the type of fiber to be used. Coconut coir fiber compared to glass fiber or carbon fiber, which is easy to obtain and more environmentally friendly [5]. According to the Indonesian Coir Industry Association (AISKI), Indonesia is one of the largest coconut producers in the world [6]. Gopinath [7] have conducted research in the manufacture of composites using coconut fiber as a filler, stating that it can increase the tensile and flexural strength of the composite [7].

The use of other natural fibers in the manufacture of composites, one of which is bamboo fiber, which bamboo plants have high enough strength, easy to find and environmentally friendly properties to be applied to composites [8]. Reynaldi Saputra., et al (2022) have conducted research on natural fiber composites, namely coconut coir fiber and bamboo fiber mixed with an epoxy matrix with 3 samples of volume fraction variation 5% coconut fiber: 15% bamboo fiber: 80% epoxy matrix, 10% coir fiber coconut: 10% bamboo fiber: 80% epoxy matrix, and 15% coconut coir fiber: 5% bamboo fiber: 80% epoxy matrix, where the tensile strength results are 58.61 Mpa, 35.37 Mpa, and 41 ,31 MPa. The modulus of elasticity values obtained are 1502.3 MPa, 801.72 MPa, and 983.31 MPa, where the density results of the composites are 1.092 g/cm^3, 1.062 g/cm^3, and 1.076 g/cm^3 respectively. The level of holocellulose (cellulose and hemicellulose) in bamboo is also high at 83.8%. High cellulose in bamboo fiber indicates a strong fiber, whiter pulp color, relatively resistant to chemicals in separation and purification and insoluble in neutral organic solvents and water [9].

According to previous research conducted by Ekhlas Aboud Osman Al-Bahadly (2013) stated that the epoxy matrix has good mechanical properties, namely the Young's modulus of 3-6 GPa, tensile strength reaches 35-100 MPa, tensile elongation 1-6%, density 1.2-1.4 g/cm^3, and has good thermal with temperature 140-220 ^{o}C [10]. Based on the description above, the author analyzes the use of bamboo fiber coconut fiber composites with an epoxy matrix as a car bumper beam application, which uses Ansys finite element analysis. The engineering data used in this analysis is based on previous research conducted by Reynaldi., et al. Ansys analysis uses an explicit dynamics analysis system. The analysis of the use of the bumper beam of this car uses the standard Economic Commissions for Europe (ECE) United Nations Agreement no. 42 of 1994, namely with a crash speed of 4 km/hour with variations in bumper thickness of 3 mm, 6 mm, and 9 mm.

Materials and Methods

Bumper beam analysis research using bamboo fiber coconut fiber composite material with an epoxy matrix, which is designed according to one of the MPV bumper beams in Indonesia.

Bumper beam design

The application of bamboo fiber coconut fiber composite with an epoxy matrix as a bumper beam is in accordance with one of the MPV car bumper beam designs in Indonesia. Figure 1 shows the front view of the MPV car, Figure 2 shows the bumper beam of the car that will be used as a reference for finite element analysis, and Figure 3 shows the support between the car and the bumper beam. The bumper beam that will be used as a reference for the finite element analysis has the specifications listed in Table 1. The bumper beam design is made in accordance with Figure 2 which is one of the bumper beams for MPV cars in Indonesia. The design of the impactor is in accordance with Figure 3. The thickness of the bumper beam in this study is 3 mm, 6 mm and 9 mm. Figure 4 shows the design of the bumper beam, Figure 5 shows the design of the pendulum and Figure 6 shows the design of the pendulum/impactor and bumper beam assembly. The bumper beam and pendulum/impactor designs were designed using Solidworks software.

Ansys modeling

The bumper beam model that has been made with a solidworks CAD design is then exported to the finite element analysis ansys into the explicit dynamics system Figure 7 shows the project schematic in ansys.

Figure 1. Front view of car type MPV [11]

Figure 2. Bumper beam [11]

Figure 3. Bumper beam fix support [11]

Table 1. Specifications of bumper beam [12]

Bumper Specifications	Metric
Length	100 cm
Wide	12 cm
Material	Steel
Thickness	0,3 cm
Weight	6,806 kg
Distance between bumper and vehicle engine	90 mm

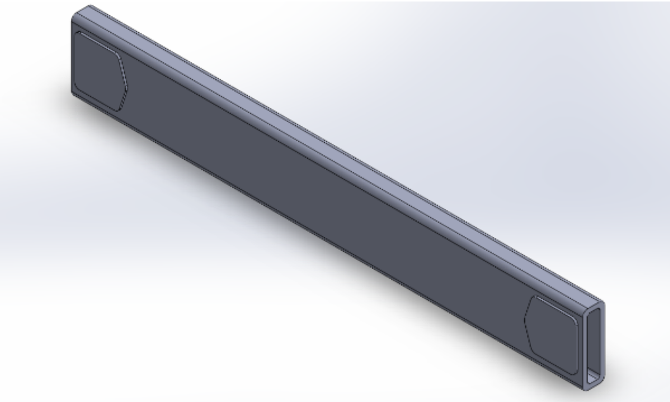

Figure 4. Bumper beam design

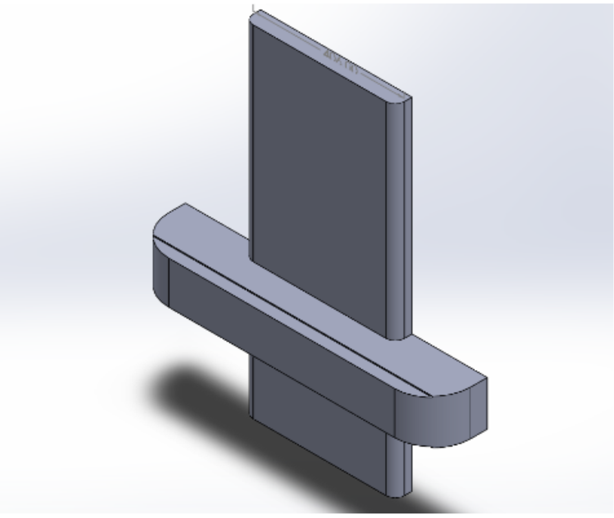

Figure 5. Impactor design

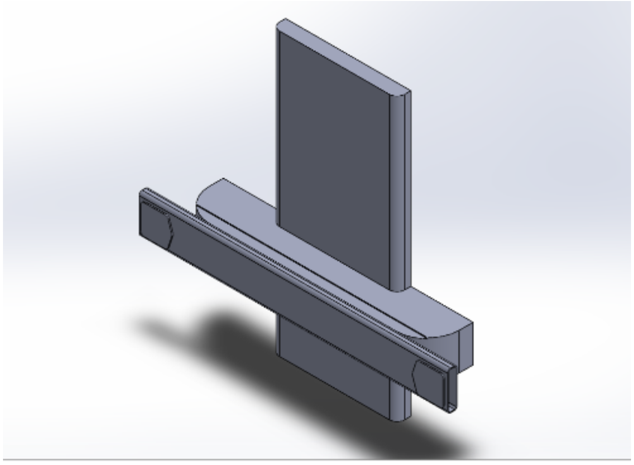

Figure 6. Assembly between impactor and bumper beam

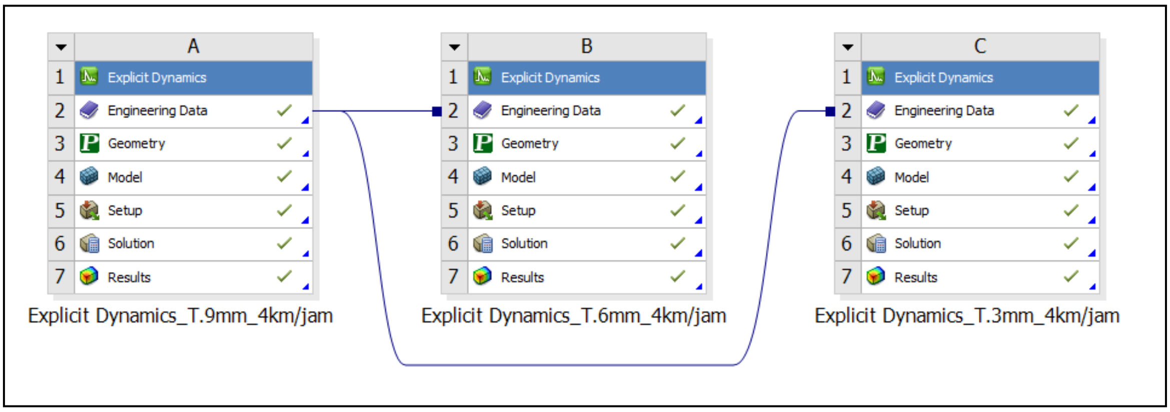

Figure 7. Project schematic ansys

Engineering data verification

In the study of the failure analysis of the bumper beam in the use of bamboo fiber coconut fiber composite material with an epoxy matrix, based on static tests on the finite element ansys software explicit dynamics system, the material data for previous studies were determined on the engineering data menu. The following is a table of mechanical properties of bamboo fiber coconut fiber composite material with the results of mechanical tensile tests at a volume fraction of 5% coconut fiber: 15% bamboo fiber: 80% matrix because it has high tensile strength, yield strength and modulus of elasticity values. Table 2 shows the specifications of the mechanical properties of composite materials.

Meshing

Meshing is the process of dividing the model in the bumper and impactor design into small elements. The selection of meshing in this study is used in accordance with the default standards owned by the finite element ansys software. The details of meshing selection are shown in Figure 8 and Figure 9 shows the meshing between the pendulum and the bumper.

Fix support

The next step is to determine the fixed support on the bumper beam, the support given to the bumper beam is considered a rigid geometry. The location of the support is determined based on the geometry of the pendulum that is applied to the bumper beam. Figure 10 shows the location of the support on the bumper beam.

Velocity

Velocity is the determination of the impactor speed when it hits the bumper beam. The speed of the impactor complies with the ECE regulation 42 standard, which is 4 km/h. Figure 11 shows the velocity of 4 km/h.

Table 2. Specification of composite material properties [12]

Properties	Metric
Ultimate Tensile Strength	58,613 MPa
Yield Strength	58,602 MPa
Young's Modulus	1502,3 MPa
Poission Ratio (typical of epoxy) [13]	0,35
Density	1,092 g/cm3

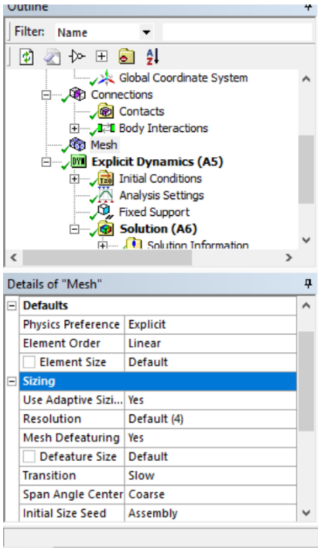

Figure 8. Selection details on meshing.

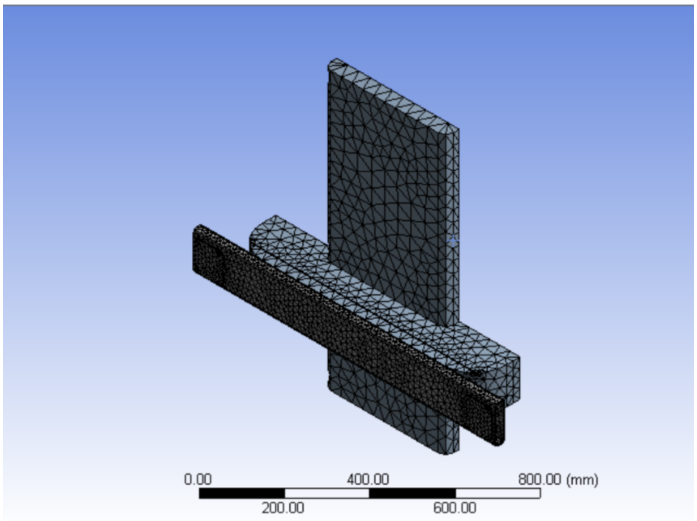

Figure 9. Meshing between pendulum and bumper

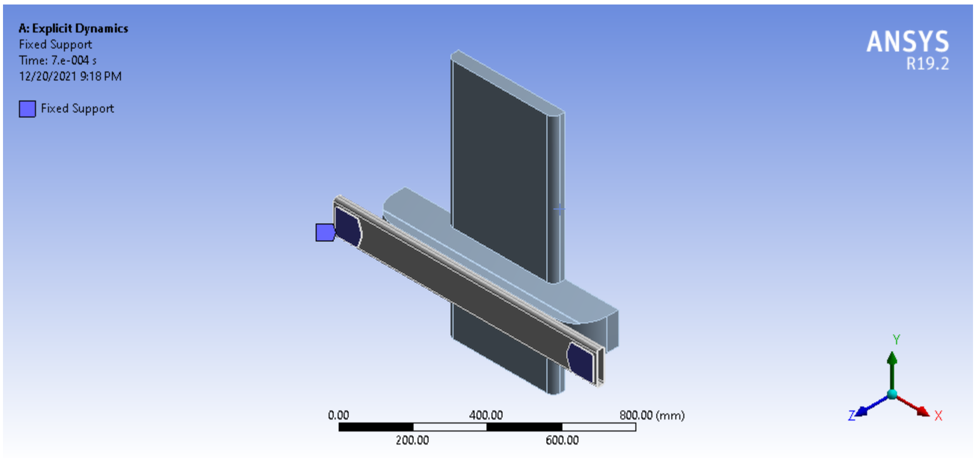

Figure 10. Fixed support

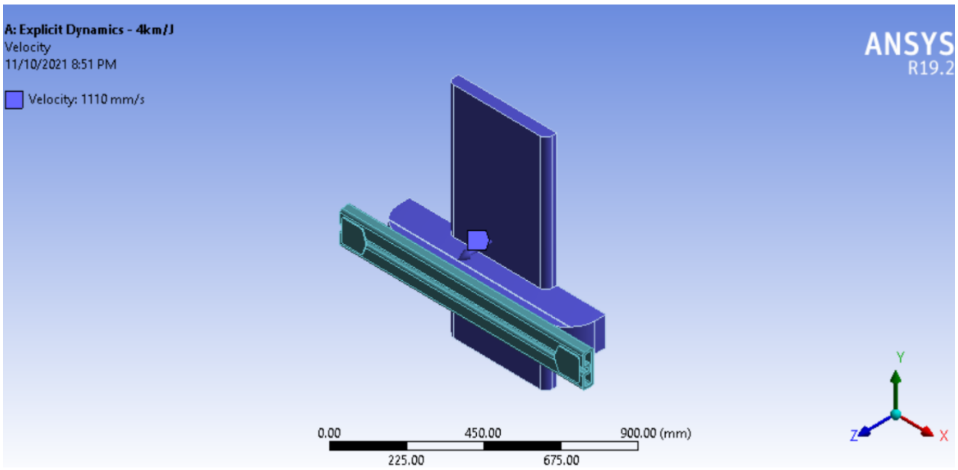

Figure 11. Determination of velocity 4 km/hour.

Results And Discussion

The results and discussion in this study concerns the results of the simulation analysis of the failure of the bumper beam of the car against the impactor, in which the specifications and engineering data are in accordance with those shown in Table 1 and Table 2.

Von misses stress

Von misses stress is a finite element analysis to see the yield level of a material to the loading conditions from the tensile test results based on previous tests conducted by Reynaldi, et al. A material is said to fail if the von misses stress exceeds the yield strength of the material. Von misses stress in this study was designed with a bumper thickness of 3 mm, 6 mm, and 9 mm, with a speed of 4 km/hour in each thickness.

The results of the analysis of the bumper beam thickness of 3mm

The results of the von misses stress on the bumper beam with a thickness of 3 mm based on this finite element analysis with a speed of 4 km/h in a row have a maximum stress of 7.0908 MPa and a minimum value of 0.011567 MPa. Figure 12 shows the results of von misses stress at a speed of 4 km/h.

The results of the analysis of the bumper beam thickness of 6mm

The results of von misses stress on the research of a bumper beam with a thickness of 6 mm based on this finite element analysis with a speed of 4 km/h in a row has a maximum stress of 5.8394 MPa and a minimum value of 0.0063442 MPa. Figure 13 shows the results of von misses stress at a speed of 4 km/h.

The results of the analysis of the bumper beam thickness of 9mm

The results of von misses stress on a bumper beam with a thickness of 9 mm based on this finite element analysis with a speed of 4 km/hour in a row has a maximum stress of 4.1104 MPa and a minimum value of 0.0063442 MPa. Figure 14 shows the results of von misses stress at a speed of 4 km/h.

Overall results of von misses stress analysis

Figure 15 shows the results of the von Mises stress analysis of finite element at a speed of 4 km/hour with a bumper thickness of 3 mm, 6 mm, and 9 mm, respectively. Based on Figure 15, the results of the analysis of the finite element bumper beam, the value of von misses stress at a thickness of 3 mm, 6 mm, and 9 mm with a speed of 4 km/h, the highest value of von misses stress at a bumper thickness of 3 mm is 7.0908 MPa and the lowest value is von misses. stress on the thickness of the bumper 9 mm is 4.1104 Mpa. Increasing the thickness of the bumper can increase the area to receive the load, so that the value of von misses stress that occurs decreases. Composites made of coconut fiber, bamboo fibers and an epoxy matrix can be used or tested further because the overall value of von misses stress is below the yield strength of the composite material, which is 58.602 Mpa.

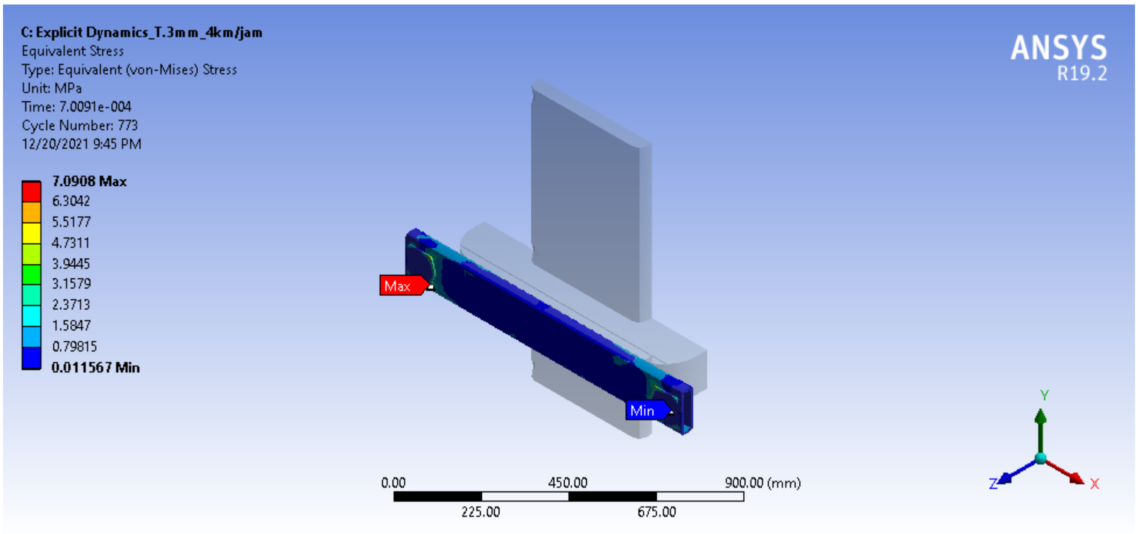

Figure 12. Result of von mises stress 3mm thickness of the bumper.

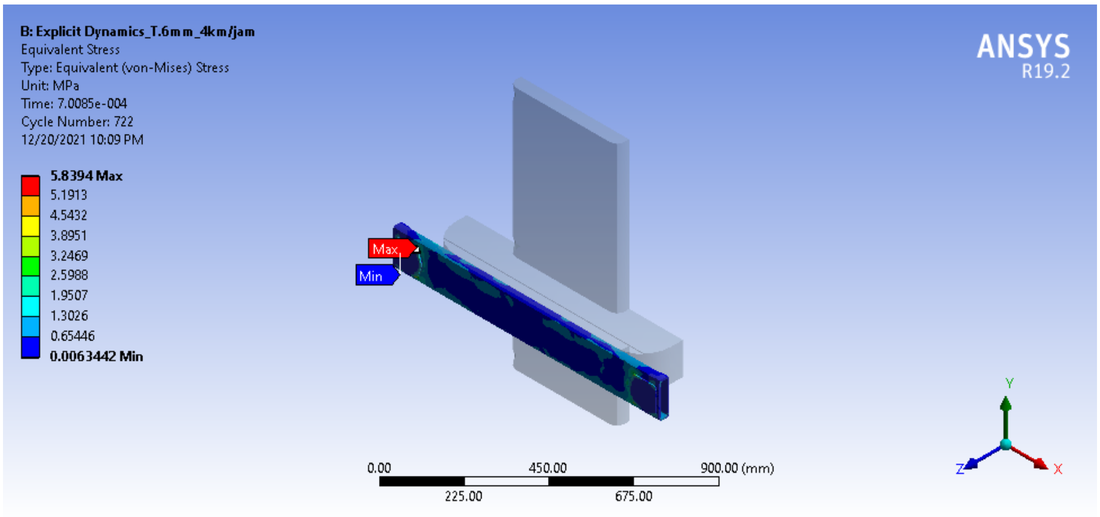

Figure 13. Result of von mises stress 6mm thickness of the bumper

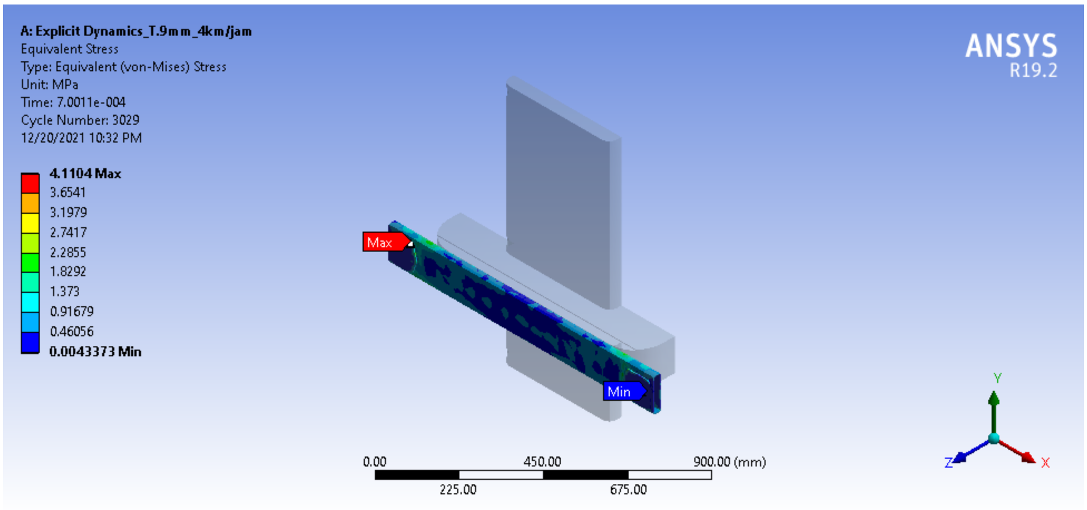

Figure 14. Result of von mises stress 9mm thickness of the bumper

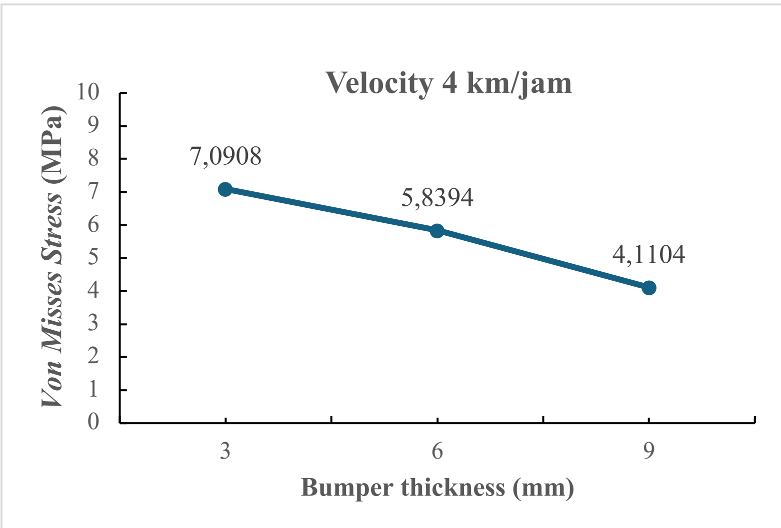

Figure 15. Keseluruhan hasil von misses stress finite element analysis

Deformation

Deformation is the change in length of a material caused by a collision between the bumper and the impactor. The deformation in this study was designed with a bumper thickness of 3 mm, 6 mm, and 9 mm, with a speed of 4 km/h in each of the variations in the thickness of the bumper analyzed.

1. The results of the analysis of the bumper beam thickness of 3mm

   The results of the deformation analysis on the bumper beam with a thickness of 3 mm based on this finite element with a speed of 4 km/h have a maximum deformation value of 1.0575 mm. Figure 16 shows the results of deformation with a speed of 4 km/h.

2. The results of the analysis of the bumper beam thickness of 6mm

   The results of the deformation analysis on the bumper beam with a thickness of 6 mm based on this finite element with a speed of 4 km/h have a maximum deformation value of 1.0322 mm. Figure 17 shows the results of deformation with a speed of 4 km/h.

3. The results of the analysis of the bumper beam thickness of 9mm

   The results of the deformation analysis on the 9 mm thick bumper beam based on this finite element with a speed of 4 km/h have a maximum deformation value of 1.0063 mm. Figure 18 shows the results of deformation with a speed of 4 km/h.

4. Overall results of the analysis deformation

   Figure 19 shows the results of the finite element deformation analysis at a speed of 4 km/h with a bumper thickness of 3 mm, 6 mm, and 9 mm, respectively. The highest deformation value at 3 mm bumper thickness is 1.0575 mm and the lowest deformation value at 9 mm bumper thickness is 1.0063 mm.

The value of the increase in length (deformation) for each variation of the thickness of the bumper at a speed of 4 km/h is 0.02 to 0.03 mm. The results of the analysis that have been carried out state that the difference in bumper thickness and speed can affect the deformation value of the bumper. When viewed from the distance between the bumper beam and the MPV car engine as shown in Table 1, which is 90 mm, the deformation in this study is categorized as safe which is lower than the allowable deformation. The greater the deformation that occurs, the softer the material will be. On the other hand, if the deformation that occurs is small, then the material is a strong material that is able to accept and withstand large forces [11].

Safety factor

Safety factor is an important parameter to determine whether a construction is safe or not, where the safety factor is also the ratio between the allowable stress of the material and the stress that occurs. The safety factor in this study was designed with a bumper thickness of 3 mm, 6 mm, and 9 mm, with a speed of 4 km/hour for each variation of the thickness of the bumper.

The results of the analysis of the bumper beam thickness of 3mm

The results of the safety factor in the research of a bumper beam with a thickness of 3 mm based on this finite element with a speed of 4 km/h has a minimum safety factor of 13.42 safety factor. Figure 20 shows the results of the safety factor with a speed of 4 km/h.

The results of the analysis of the bumper beam thickness of 6mm

The results of the safety factor in the research of a bumper beam with a thickness of 6 mm based on this finite element with a speed of 4 km/h have a minimum safety factor of 15 safety factor. Figure 21 shows the results of the safety factor with a speed of 4 km/h.

The results of the analysis of the bumper beam thickness of 9mm

The results of the safety factor in the bumper beam research with a thickness of 9 mm based on this finite element with a speed of 4 km/h have a minimum safety factor of 15 safety factor. Figure 22 shows the results of the safety factor with a speed of 4 km/h.

Overall result of safety factor analysis

Figure 23 shows the results of the safety factor analysis of the finite element at a speed of 4 km/h with a bumper thickness of 3 mm, 6 mm, and 9 mm, respectively. The highest value of safety factor at bumper thickness of 6 mm and 9 mm is 15,000 safety factor and the lowest value of safety factor at 3 mm bumper thickness is 13,420 safety factor. Increasing the thickness of the bumper and the lower the speed of the pendulum against the bumper can increase the value of the safety factor of the bumper. A construction is declared safe and can be tested further because the resulting minimum safety factor value is above the value of 3 (three) safety factors. The construction of a material is declared unsafe if the safety factor value is less than 3 (three), the value is based on the standards listed in the automotive safety factor [14].

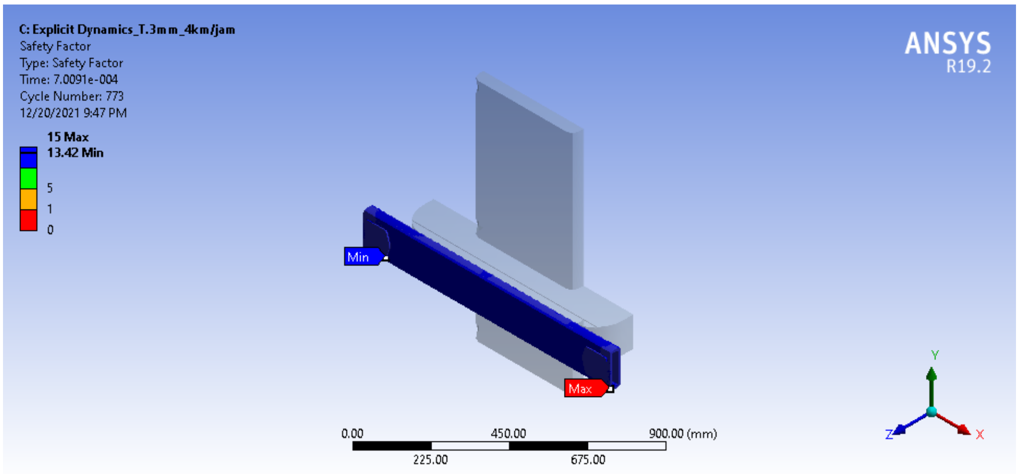

Figure 20. The results of the safety factor bumper thickness of 3mm

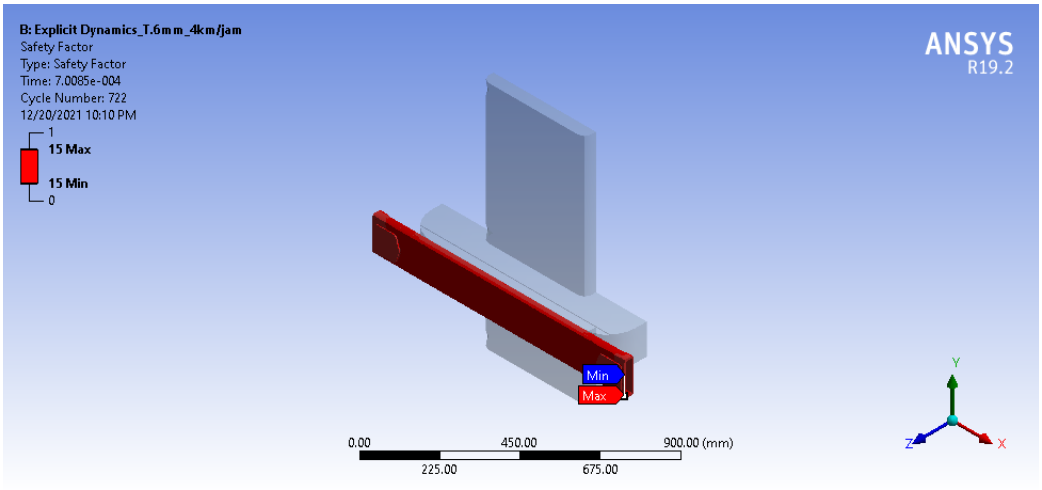

Figure 21. The results of the safety factor bumper thickness of 6mm

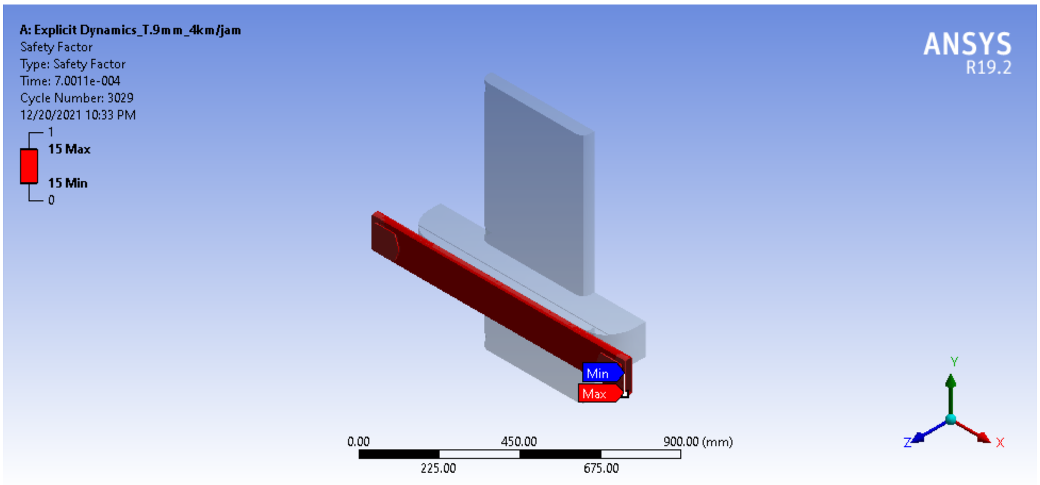

Figure 22. The results of the safety factor bumper thickness of 9mm

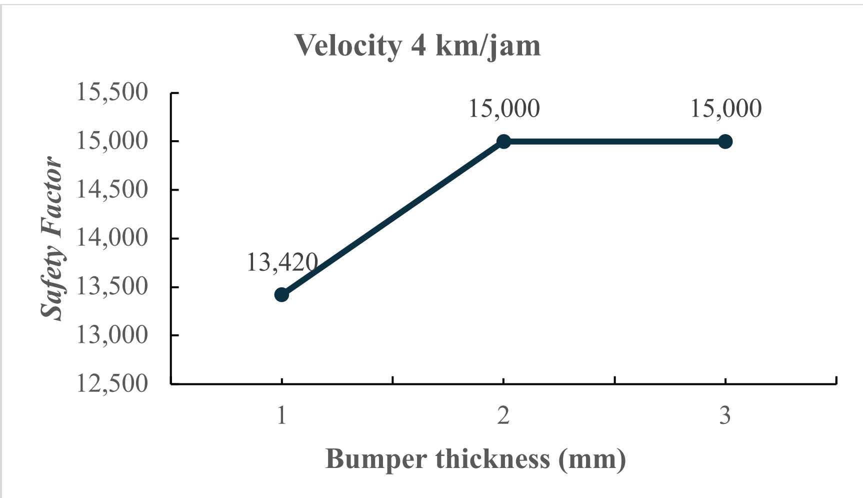

Figure 23. Keseluruhan hasil safety factor finite element analysis.

Bumper weight ratio

The use of composite materials as a car bumper application can reduce the weight of the bumper. Table 3 shows the comparison of the weight of the bumper against the use of steel and coconut fiber composites with an epoxy matrix with a volume fraction of 5% coconut fiber: 15% bamboo fiber: 80% matrix. Based on Table 3 shows the weight value of the bumper with steel material is heavier than the coconut fiber composite material with epoxy matrix with a volume fraction of 5% coconut coir fiber: 15% bamboo fiber: 80% matrix. The highest weight obtained on the composite material bumper is 9 mm thick and weighs 3,211 kg, while the lowest weight on the composite material bumper is 3 mm thick and weighs 0.996 kg. When compared with the bumper steel specifications listed in Table 1 which is 6.806 kg, then the thickness of 3 mm, 6 mm and 9 mm is able to reduce weight by 85.37%, 68.48% and 52.82%, respectively.

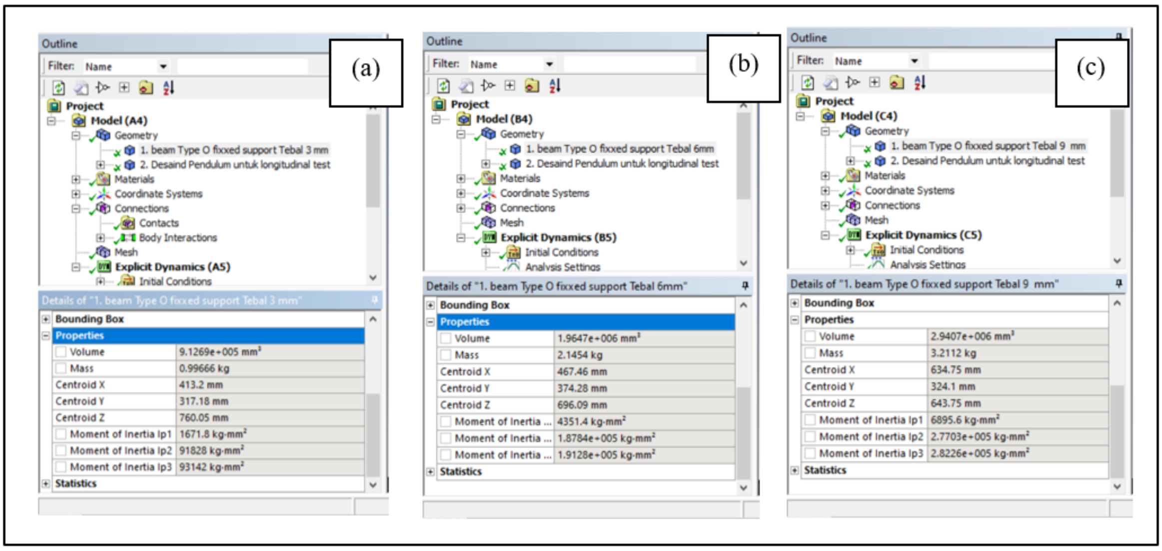

Figure 23. Bumper weight of bamboo fiber coconut fiber composite bumper with epoxy matrix. (a). 3 mm thick bumper, (b). bumper thickness of 6 mm, and (c). 9mm thick bumper.

Table 3. Comparison of steel and composite materials to the weight of the bumper.

Bumper weight comparison			
The weight of the bumper material is 3 mm thick steel (kg)	Bumper thickness (mm)	Composite material bumper weight (kg)	weight ratio percentage (%)
6,806	3	0.996	85.37%
6,806	6	2.145	68.48%
6,806	9	3.211	52.82%

Conclusion

The conclusion of this study is the use of composites with a volume fraction of 5% coconut coir fiber: 15% bamboo fiber: 80% matrix. The value of von misses stress in the analysis of the 3 mm bumper beam is 7.0908 MPa and the lowest value of von misses stress on the thickness of the 9 mm bumper beam is 4.1104 MPa. The results of the analysis of the highest deformation value at 3 mm bumper thickness is 1.0575 mm and the lowest deformation value at 9 mm bumper thickness is 1.0063 mm. From the results of the analysis of the bumper beam, the highest safety factor at a bumper thickness of 6 mm and 9 mm is 15,000 safety factor and the lowest value of safety factor at a bumper thickness of 3 mm is 13,420 safety factor. The results of the ansys analysis showed that the highest bumper beam weight was obtained on the composite material bumper, which was 9 mm thick and weighed 3,211 kg, while the lowest weight for the composite bumper material was 3 mm thick and weighed 0.996 kg. When compared with the bumper steel specifications listed in table 1, which is 6.806 kg, then from a thickness of 3 mm, 6 mm and 9 mm, respectively, it can reduce weight by 85.37%, 68.48% and 52.82%

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