Simulation and Failure Analysis of Car Bumper Made of Pineapple Leaf Fiber Reinforced Composite

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Abstract. The bumper car made of the Pineapple Leaf Fiber Reinforced Composite (PLFRC) is possible to be produced with the advantage of easy to get, and cheap. Pineapple leaf fiber has chosen as a natural fiber, which the maximum of the strength of 368 MPa. The objective of this study was to determine the maximum capability of front car bumpers using Pineapple Leaf Fiber Reinforced Composite materials through the process of simulating stress analysis with Solidworks 2014 software. The aim also to know the distribution of loads that occur on the front car bumper and predict the critical point position on the design of the bumper. The result will use to develop the alternative lightweight, cheap and environmentally friendly materials in general and the development of the use of pineapple fiber for automotive purposes in particular. Simulations and failure analysis have been conducted and showed an increased impact speed in line with increased displacement, strain, and stress that occur on the surface of the bumper. The bumper can withstand collisions at a speed of less than 70 kph.

1. Introduction
In line with the intensively using of green technology, the focus of researchers and developers of an alternative material comes back to research on the mechanical properties of natural fiber-reinforced composites. In general, composite is reinforced with fiberglass, which is relatively expensive and harmful to the environment. There are some advantages to using a natural fiber, among which are: a) natural fibers are biodegradable (capable of being broken down by bacteria/microorganisms); b) natural fiber, one of which pineapple leaf fiber has low production cost, low density, and low energy consumption. According to Kaewpirom and Worrarat [1] amidst the rapidly evolving material science, natural fibers seem to be a remarkable material, which can be used as a viable replacement of synthetic fibers as well as abundant resource and inexpensive. Natural fiber reinforced composites have a specific tensile strength of 250-650 MPa smaller than 2850 MPa for carbon fiber reinforced composites [2]. However, natural fibers have advantages, especially cheaper, lighter and better environmentally [3]. Natural fiber reinforced composites form a new class of materials science that has good potential in the future as a substitute for wood-based materials in a wide range of applications [4]. However, resistance to poor water absorption makes the use of natural fiber reinforced composites less attractive.

Car bumpers are made of lightweight metals such as aluminium alloys or thin steel plates. Nowadays, as further technological developments, car bumpers are made of fiber reinforced composites (most use synthetic fibers) [3]. However, in recent years the price of aluminium and plastic materials continues to increase, so the demand for a replacement material with similar properties and low price also increases. Natural fibers are chosen because they have advantages with biodegradable and low prices. Natural fiber reinforced composites in addition to having low-cost, lightweight and eco-friendly advantages also have drawbacks where the specific tensile strength and weight depend on the type of fiber, the type of webbing, and the process of preparing the natural fibers. Arbintarso [5] suggested that pineapple fiber has the highest mechanical properties compared to coconut fiber fibers and Roselle fibers.

The objective of this study was to determine the maximum capability of front car bumpers using natural fiber composite materials through the process of simulating stress analysis with Solidworks 2014 software and to know the distribution of loads that occur on the car bumper and predict the critical point position on the design of the bumper. The result will use to develop the alternative lightweight, cheap and environmentally friendly materials in general and the development of the use of natural fiber (pineapple fiber) for automotive purposes in particular.

1.1. Front car bumper model
The main purpose of front car bumper systems is to protect the engine and radiator, to absorb energy at the start of a collision and to guide the remaining impact forces into the rest of the body structure [6]. The front bumper system protects the vehicle in a low-speed crash (at ≤ 8 km/h (kph) ~ ECE R-42 Europe standard) which indicates without damage of functionally relevant parts and only minimal or no plastic deformation of any other vehicle component. The modern design front car bumper consists of plastic fascia, a propylene foam or a honeycomb energy absorber and a reinforcing bumper beam. The energy absorber is placed between the plastic fascia and reinforcing bumper beam [6]. This modern design also improves pedestrian protection (leg impact) as shown in Figure 1.a. The fascia is a non-structural component that reduces the air resistance, while the energy absorber dissipates part of the kinetic energy during the collision and the bumper beam is a structural component, which absorbs the low impact energy by bending resistance [7]. The traditional design only used bumper beam without fascia and energy absorber is seldom used today. A visible metallic transverse beam was chosen to decorate the front or rear end of the vehicle and will act as the primary energy absorber in a collision [6]. The Isuzu Elf NKR 55 Microbus adopts the traditional bumper design with adding an energy absorber as shown in Figure 1.b. This design is chosen because of simple, compact and inexpensive. According to the speed and the acceleration of the car, the total impact energy at 40 kph is 825 J [8] that the load is distributed throughout the bumper.
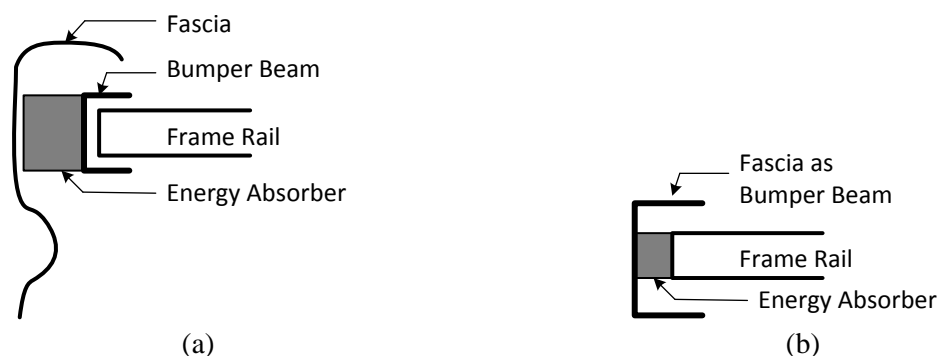

(a)   (b)

Figure 1. a) Common modern front car bumper design [6] and b) Front car bumper of Isuzu [9].

1.2. Pineapple leaf fiber reinforced composites

Pineapple is a perennial herbaceous plant with 1-2 m for height and width belongs to family Bromelia-ceae [10]. It is chiefly cultivated in coastal and tropical regions, mainly for its fruits purpose. In Indonesia, one of the big pineapple industry is PT. Great Giant Pineapple with produced 200,000 Ton per year in 2015. It is cultivated on about 81,510 acres in Lampung Province of Sumatra, Indonesia [11] and is continuously increasing its production. PALF has high specific strength and stiffness; it is hydrophilic due to high cellulose content [12], as shown in Table 1.

Table 1. Physical and mechanical strength of pineapple leaves fiber [12].

Density (g/cm^3)	Tensile Strength (MPa)	Young's Modulus (GPa)	Elongation At break (%)	Diameter (μm)	Microfibril Angle
1.520	170-1627	6.21-82.51	1.6-3	20-80	-
1.526	170-413	6.26-62.10	1.6-3	30-60	-
1.440	413-1627	34.50-82.51	1.6	1.56-80	8-15
1.070	126.6-1627	4.40-82.50	1.6-2.2	20-80	14
1.523	413	4.20	3.0-4.0	50	14

The disadvantage of PALF as fiber on reinforced composite is the lower degree of compatibility with hydrophobic polymers due to its hygroscopic nature. The existence of natural waxy substance on the surface of fiber layer provides low surface tension, which does not allow a strong bond with polymer matrix [12]. Santosh Kumar et al. [13] obtained the maximum tensile, and flexural strength of pineapple leaf fiber reinforced composites as 65.95 MPa and 121.83 MPa at 30% volume ratio, respectively.

2. Experimental Setup

Solidworks 2014 was used in making car bumper design and the simulations. Using Surfacing feature to make the 3D model and Drop Test and Static Analysis for the simulations. Drop Test is a test of the strength/reliability of an object, where the object is dropped from a certain height. Drop Test simulation is chosen because the condition is similar when a car has a collision with a wall (the target is motionless). The Drop Test simulation uses the velocity of impact that depends on some parameters, such as gravity magnitude, velocity magnitude and target stiffness (in this simulation using target rigid as shown in Figure 2.a). The simulation runs at speeds of 40 kph, 70 kph, 100 kph, and 130 kph.
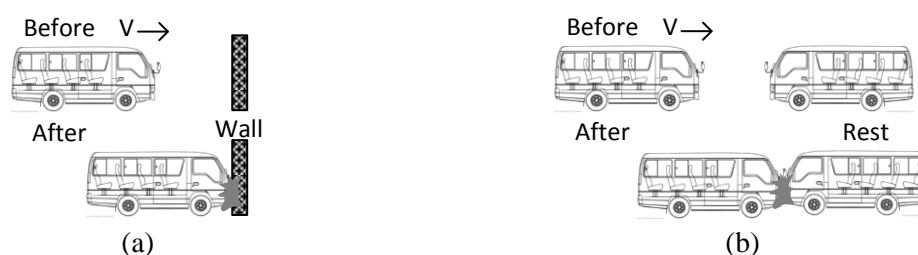

(a)   (b)

Figure 2. a) Drop Test illustration, and b) Static Analysis illustration (car figure is property of [9]).

Static Analysis is a testing method to figure out the maximum ability of material to receive a moving load in a state condition. The results of the Static Analysis will be used to review a design of front car bumper and see the possible damage when the bumper -in the rest condition- was hit by another car (Figure 2.b.). The location of fixed points, the location of loading and determine the amount of force are a parameter that will be used to Static Analysis simulation.

Figure 3. Blueprint of Isuzu Elf NKR 55 Microbus [9].

Front car bumper was designed from the Isuzu Elf NKR 55 Microbus car blueprint [9], as shown in Figure 3. The failure that occurs in the bumper is analyzed with variable speed of the car, and the critical loading test is manifested through graphics by using striking colors for critical points where composites fail over material capabilities.

3. Results and Discussion
In the simulated static test, the Isuzu Elf NKR 55 Microbus vehicle scenario is in rest condition and hit by the same vehicle (mass and dimension) in the middle of the front vehicle. The simulation of the drop test is similar to the case of the static test, but in this case, the Isuzu Elf vehicle NKR 55 Microbus accelerates and hit a strong and heavy wall (motionless). The determination of force based on the mass, speed and time, by converting the force value ($F = (mV)/t$ …(1)) both for static and drop test, time (t) is expected to occur for 1 second. The simulation results for the static test can be seen in Table 2. Emphasis the observed properties are the displacement (mm), the maximum strain that will occur, and the maximum stress (MPa) occurring in the bumper. The results of the simulation drop test can be seen in Table 3.

Table 2. Static test simulation results.

Velocity (V) (kph)	Force (F) (kN)	Displacement (max) (mm)	Strain (max)	Stress (max) (MPa)
40	57,11	8,59	0,018	75,10
70	99,94	15,04	0,031	131,42
100	142,78	21,48	0,045	187,74
130	185,61	27,92	0,058	244,06

Table 3. Drop test simulation results.

Impact Velocity (V) (kph)	Displacement (max) (mm)	Strain (max)	Stress (max) (MPa)
40	6,03	0,007	69,71
70	10,54	0,012	129,09
100	15,10	0,016	189,54
130	19,70	0,021	244,72

Figure 4 shows the location of the critical stress (the area that has the highest potential damage when subjected to force) on the car bumper. The maximum stress value (indicated in red) is 75.10 MPa for speed 40 kph (Figure 4.a), and increase as the speed increases. Figure 5. Shows the location of the highest strain value on the car bumper shown in red, with a value of 0.018 for speed 40 kph at Figure 5.a, and also increases as the speed increases. The location of the critical displacement of the car bumper shown in red with its maximum displacement value is 8.59 mm at a speed of 40 kph as shown in Figure 6.a and increase as the speed increases. Davoodi et al. [8] found the energy absorption is 77 J and

displacement is approximately 45 mm, larger than displacement results in this study. It means the pineapple fiber reinforced composite has energy absorber higher than 77 J and sufficient for pedestrian impact for low impact collision [8]. The energy absorbing performance is strongly affected by the geometry component [14], in this case, beam way profile or beam corner can serve as stress concentration zone or crack triggering point as shown in Figure 6.
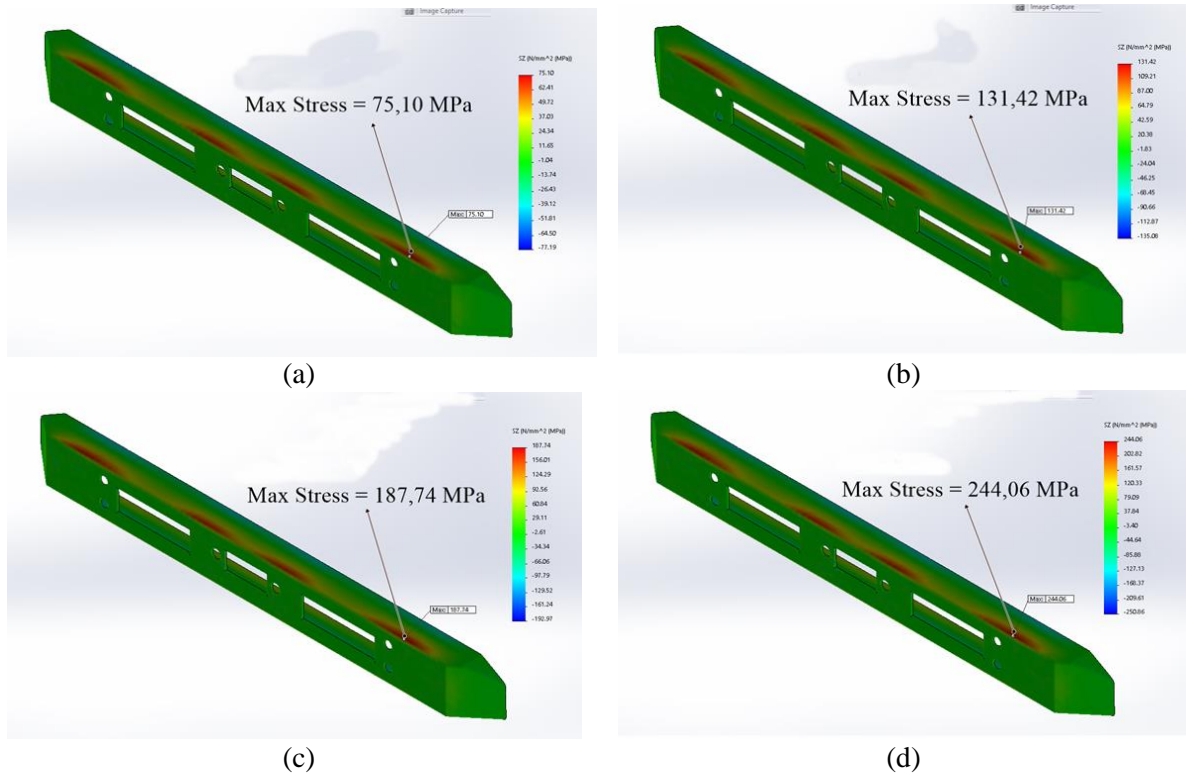

(a)　　　　　　　　　　　　　　　　　　　　　　　(b)

(c)　　　　　　　　　　　　　　　　　　　　　　　(d)

Figure 4. The location of critical stresses of the bumper at a) 40 kph, b) 70 kph, c) 100 kph, and d) 130 kph.

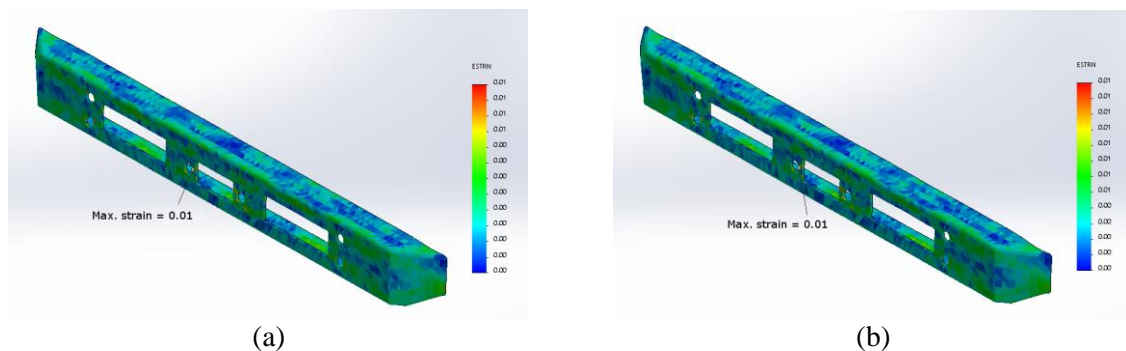(a)　　　　　　　　　　　　　　　　　　　　　　　(b)

Figure 5. The location of critical strains of the bumper at a) 40 kph, b) 70 kph, c) 100 kph, and d) 130 kph.

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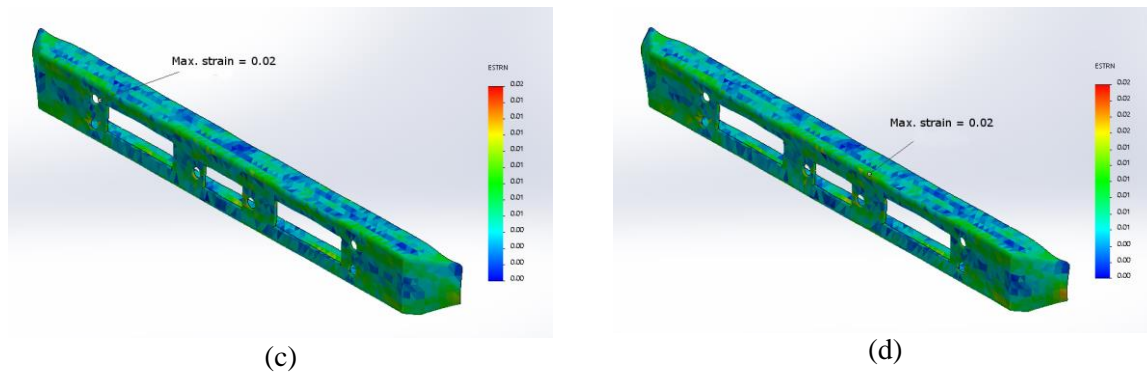<tr><td>(c)</td><td>(d)</td></tr>
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Figure 5 (Cont.). The location of critical strains of the bumper at a) 40 kph, b) 70 kph, c) 100 kph, and d) 130 kph.

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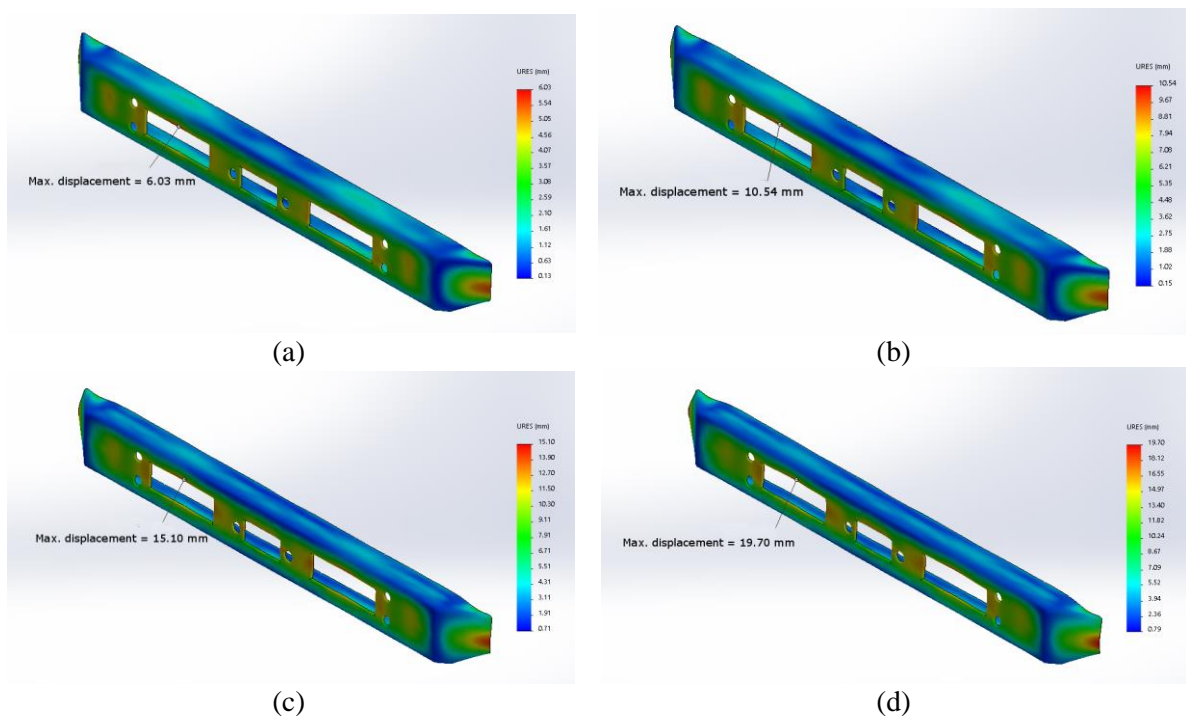<tr><td>(c)</td><td>(d)</td></tr>
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Figure 6. The location of max. displacements of the bumper at a) 40 kph, b) 70 kph, c) 100 kph, and d) 130 kph.

Figure 7.a. shows the comparison of the maximum stress values generated in the static and drop test simulations. There were no significant differences between the two test results. Figure 7.b. shows the comparison of the maximum strain values generated in the static and drop test simulations. In the static test, the strain tends to increase along with the increase of the speed of the vehicle, while at the drop test, no signification occurs with the increase of collision velocity.
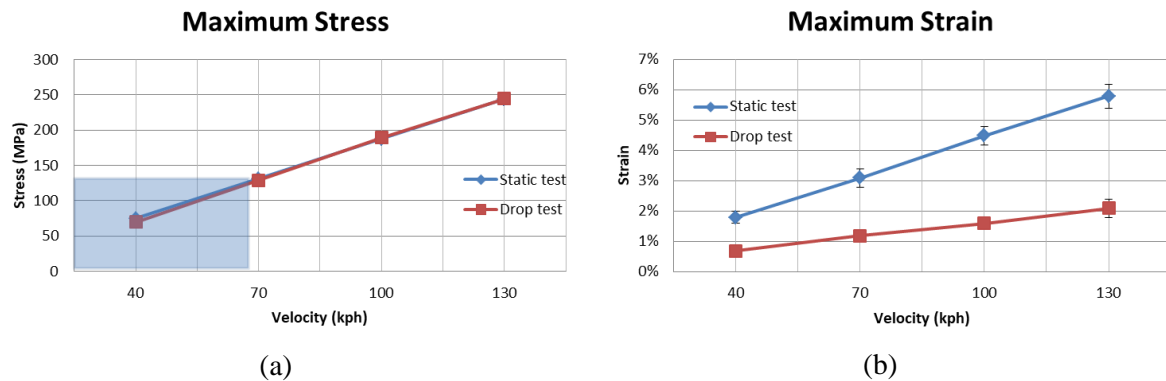
Maximum Stress

Maximum Strain

(a)

(b)

Figure 7. Graph of maximum stresses and strains versus velocity.

Figure 8 shows the maximum displacement values generated in the static analysis and drop test simulations. The maximum displacement value in the static test is higher than the drop test; the momentum that occurs in the simulation influences this. The momentum of static test and drop test are (e)> 1 and e = 1, respectively. In case of small low-velocity impact, only the bumper beam should be involved and should behave fully elastic (e = 1) [14].
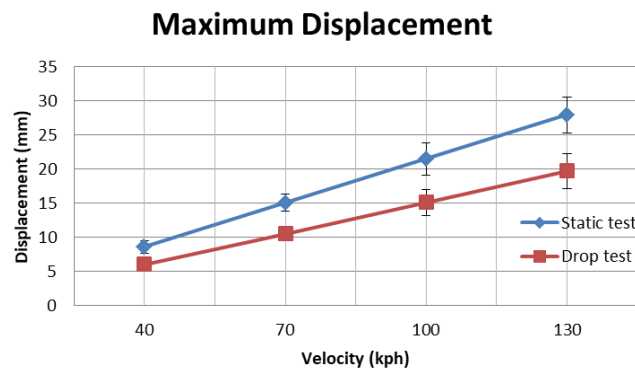
Maximum Displacement

Figure 8. Maximum displacement versus velocity.

Based on data of pineapple leaf fiber-reinforced composite capability of ~ 120 MPa/m [5] as seen in Figure 7.a. as gray block area, and it can be concluded front car bumper using pineapple leaf fiber composite able to withstand impact with speed 40 kph but less than 70 kph. This simulation result needs to be improved by the optimization method as Liu et al. [15] did that using modified particle swarm optimizer. This algorithm was used to accomplish the optimization procedure considering the static strength conditions and dynamic impact the bumper system.

4. Conclusions

Increasing collision speed increases the displacement, strain, and stress. There are significant differences in the displacement and strain results between static analysis and drop test, but not for stress results. Bumpers with pineapple leaf fiber-reinforced composites can withstand collisions at speed less than 70 kph.

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