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CRASH ANALYSIS OF THE COIR/PSEUDO STEM PLANTAIN (CPS) HYBRID FIBER REINFORCED POLYESTER COMPOSITE AS CAR BUMPERS USING MIDASNFX

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ABSTRACT: *This research conducts crash analysis of the Coir/Pseudo Stem Plantain (CPS) hybrid fibers reinforced polyester composites as car bumpers using midasNFX. The hybrid of Coir and plantain pseudo stem fibers were used as reinforcement for CPS hybrid fibers reinforced polyester composites. The samples were formed using the control factors of volume fraction, coupling agent and coir/plantain fiber ratio. The optimum values were established for CPS hybrid fibers reinforced polyester resin composites. In accordance with the Research Council for Automobile Repairs (RCAR) standard of low-speed crash test using midasNFX, the maximum Von Mises stress, percentage of highly stressed part, displacement and the rate of deformation of front and rear CPS car bumper materials were conducted and analyzed. From finite element analysis, CPS materials for front car bumper which are of better damageability and repairability than that of rear car bumpers have the highest Von Mises stress of front bumper is 1.24742 x 10^6 N/m^2 at the smallest part of 0.4%, highest displacement is 0.046571m at the 79.3% part of the bumper, and the maximum deformation is 0.022m at 0.0052sec.*

KEYWORDS: Car bumper, Coir/plantain fiber ratio, Coir/pseudo Stem plantain hybrid fibers, Damageability, Low-speed crash test, MidasNFX, Repairability,

INTRODUCTION

Composites can be tailored to suit different requirements; which may include desirable properties in corrosive environment, higher strength at a lower weight, and lower life-cycle costs; thereby leading to good combination in mechanical and thermal properties, and insulating protection [1]. These qualities give composites an edge over conventional materials [2].

Natural fiber based composite demand is most appreciated in automotive industry. Using the automotive industry as stepping stone towards other markets, each natural fiber based composite has found other applications, depending on the specific properties of the fiber [3]. Composites have been adopted slowly in the automobile industries due to their higher costs; but fiber reinforced composites have been mostly used in high end sports cars, and they have started gaining ground in traditional vehicles [4]. In the same way; aerospace, marine and sporting goods are taking advantage of fiber reinforced composites [5].

To overcome shortcomings associated with natural fibers, fiber treatment should be undertaken before the fibers will be used in polymer composites forming [6]. Hydrophilic nature of the natural fibers due to the presence of pendant hydroxyl and polar groups in various constituents can lead to poor adhesion between fibers and hydrophobic matrix polymers [7].

The mechanical, thermal, damping properties are better enhanced using the hybrid fiber reinforced composites than single-fiber reinforced composites; and the hybrid fiber composites are replacing wood, wood fiber composites and conventional materials, and also used for many application [8]. can withstand Higher loads can be more withstood by the hybrid fibers reinforced composites than that of single-fiber reinforcements in the same condition based on the reinforcement direction, and the surrounding matrix keeping them in the desired location and orientation and also acting as a load transfer medium. The interest in the development of new composite materials came as a result of environmental issues even with addition of more than one reinforcement that are natural fibers at low-cost, and environment-friendly for an alternative to synthetic fibers [9]. Recently, the polymer matrix composites of natural fibrous or non-fibrous (particulate) reinforcing phase are being widely used for different applications like automobile parts, aircraft parts, household appliances and construction materials [10].

It has been discovered that natural fiber composites have good stiffness but most times the composites do not reach their optimal strength going by the research on the potential of natural fiber as reinforcement for composites [11]. The full economic and technical potential of any composite manufacturing process can be achieved only when the optimum parameters combination are considered in the formulation process. One of the most important optimization processes is design of experiments [12]. The approach enables a comprehensive understanding of the individual and combined effects of factors from a minimum number of simulation trials. This technique is a multi-step process that follows a certain sequence for the experiments to yield an improved composites performance [13].

Hence, finite element module (FEM) is utilized for analysis of stress and deformation within the car bumpers as isotropic materials. The limiting values of load that structural elements of car bumpers can sustain without suffering damage, failure or compromise function are assessed.

MATERIALS AND METHODS

Chemical Treatment

Alkaline treatment is a process that depolymerizes cellulose, removes a certain amount of wax, oils and lignin on the external surface of the fiber cell wall and exposes the short length crystallites [14][15]. Coupling agents are mostly applied in order to decrease hydrophilic nature of fibers and increase compatibility between fiber and matrix [16].

This study considered and used the following materials; namely, the hybrid of coir and PS plantain fibers as the reinforcement; aqueous sodium hydroxide (NaOH) and Maleic anhydride (MAH) for fiber chemical treatments; and polyester resin as the matrix [17].

In this study, 5% of aqueous sodium hydroxide (NAOH) was applied for treating coir and PS plantain fibers in 2 hours at room temperature. Afterward, the alkali treated fibers were dried at room temperature, and were later esterified with maleic anhydride (MAH) solution of 0.1%, 0.25% and 0.5% concentrations. The esterified fibers were left for 45 minutes for condensation and chemical bonding of maleic anhydride and fibers under agitation. Excess coupling agents were removed by washing the treated fibers. After esterification of Coir and Pseudo stem plantain fiber; the fibers were chopped at the same length of 10mm for reinforcement of composite samples [17].

Figure 1: Treated coir fiber [17]

Figure 2: Treated PS plantain fiber [17]

Composite Design and Preparation Technique

The experimental process variables (control factors) considered in this study as concern the hybrid arrangement of Coir/Pseudo stem plantain (CPS) fibers are Volume fraction (%), Coupling agent (%w/v) and Fiber ratio (-).

From the known density of fibers (Table 1), volume fraction, and the volume of composite specimen; the mass of the fiber for the specified volume fraction in producing a particular composite specimen can be determined for that same specified volume fraction as stipulated by [18].

Table 1: Densities of reinforcing fibers

Fibers	Densities (g/cm^3)	Sources
Coir fiber	1.2	[19]
Pseudo Stem Plantain fiber	0.354151	[20]

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The most important stage in the design of experiment used in this study is the selection of the control factors. The control factors (process parameters) of hybrid fibers and their three levels for preparing specimens are shown in Table 2.

The parameters affecting the process and the levels at which they should be varied as proposed by Taguchi was organized by the experimental design using orthogonal arrays. This arrangement allows for the collection of the required data to determine which factor most affect product quality with a minimum amount of experimentation, thereby saving time and resources [21].

Chukwunyelu, et al. [18] gives a well detailed of the value of quality characteristics using different levels of control factors as in Table 2; and Table 3 which shows Taguchi DOE orthogonal array that will be implemented in Design matrix for the larger the better signal to noise (S/N) ratio.

Table 2: Control factors and their levels for the preparation of specimen

Control Factors	**Levels**		
	1	**2**	**3**
Coupling Agent (%w/v)	0.1	0.25	0.5
Volume Fraction (%)	10	30	50
Fiber Ratio (coir/plantain)	30/70	50/50	70/30

Table 3: Taguchi standard Orthogonal array L9 (3^3) [18, 22].

Specimen	**Coupling Agent**	**Volume Fraction**	**Fiber Ratio**
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2

2.3 Preparation of Composites

The coir/pseudo stem plantain hybrid fiber reinforced composite specimens were prepared using the Hand Lay-up process which is an open molding method of placing the reinforcement manually before applying matrix. For tensile test in accordance to ASTM D638 Type I [18, 22]; the chopped fibers reinforcement, as recommended by Ashby et al. [23], were placed in a randomly oriented and discontinuous manner.

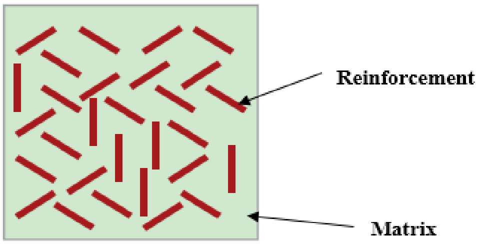


Figure 3: Fiber pattern in matrix for Composite Specimens forming [23]

Figure 4: Tensile Test specimen [18].

Figure 5: Fractured Tensile Test Specimen [18].

2.4 Estimation of optimum response based on optimum setting

The optimum response is estimated using the optimum control factor setting from the main effects plots; by employing the response table in Chukwunyelu et al.[18] for signal-to-noise (S/N) ratio and the response table for mean [24-25].

For proper stress analysis of the two categories of CPS car bumpers in FEA, some physical properties play very important role. They are: Poisson ratio, Shear modulus and Density of the optimized CPS hybrid fiber reinforced polyester composites (Table 4).

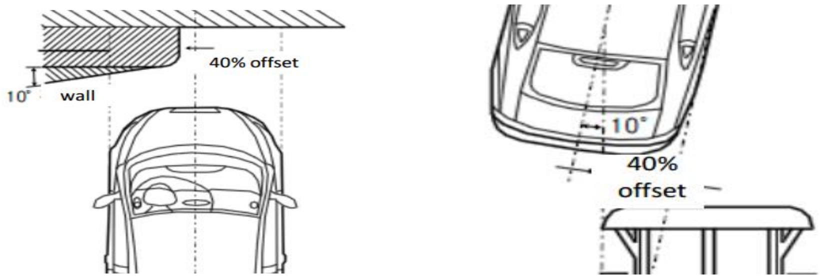
Poisson Ratio, v, is the ratio of transverse or lateral contraction strain to axial or longitudinal extension strain in the direction of stretching force. Tensile deformation is a positive value of Poisson ratio while compressive deformation is a negative value of Poisson ratio. It is positive in this study because the tensile properties of the materials were conducted.
Shear Modulus, G, is the ratio of shear stress to shear strain. It is also known as the Modulus of rigidity.Density, $\tilde{\rho}$ is mainly determined by the atomic weight and is influenced to a lesser degree by the atomic size.

Table 4: Properties of optimized CPS hybrid fiber reinforced polyester composite (car bumper)

Material Properties	CPS
Ultimate Tensile Strength (N/m^2)	75.498 x 10^6
Young's Modulus (N/m^2)	6.690 x 10^6
Poisson's Ratio	0.314
Shear Modulus (N/m^2)	2.550 x 10^6
Density (kg/m^3)	2450

2.5 RCAR Testing Standard

The Research Council for Automobile Repairs (RCAR) is an international organization that has adopted RCAR test as a standard for conducting low speed crash control tests. RCAR works towards improving automobile safety, security, damageability, and repairability [26-27]. Damageability represents the level of external shock that a vehicle can endure, and repairability represents the possible restoration of damaged vehicle.



(a) Front (b) Rear

Figure 6: Scheme of RCAR tests [27]

1) Front low-speed test

- Front collision with an angle of 10˚
- Collision speed: 15 ~ 16km/h

2) Rear low-speed test

- Rear-end collision on a wall inclined with an angle of 10˚
- Collision speed: 15 ~ 16km / h,
- Moving wall weight: 1,400 kg [27].

A simplified model where the overall vehicle weight of 1119kg was applied to the center point of the mass. Considering the worst condition, collision velocity and the total kinetic energy were set to 16 km/hour and 11.1KJ respectively [27].

RESULTS AND DISCUSSIONS

In finite element method, certain assumptions are used in modeling materials. Some of the assumptions used in the FEA include the following:

- ❖ Fibers are uniform in properties
- ❖ Fibers are not porous.
- ❖ The material properties for all the constituents are assumed to be isotropic.
- ❖ Inter phase bonding is maintained between fibers and matrix.
- ❖ Perfect bonding between fiber and matrix and no slippage occurs.
- ❖ The arrangement of fibers is not unidirectional [20].

The rigid walls for both front and rear low-speed collision tests were slanted towards the bumper at 40% offset according to RCAR standards. The bumper has a thickness of 5mm. The wall and bumper were made to crash with each other at a velocity of 15km/h.

The damageability of the bumper materials (CPS hybrid fiber reinforced composites) which depends on the ability the front and rear bumper to withstand the force of collision and absorb crash energy, and the repairability which determines the possible restoration of damaged materials were measured.

Front Bumper

The front low-speed collision test on CPS bumper material was simulated in accordance with the RCAR standard. It was observed that small part of the front bumper has the highest stress caused by the crash energy. The highest Von mises stress, from Figures 7 and 8, is $1.24742x10^6$ N/m^2 at the smallest part of 0.4% of the front bumper. The greatest part of the CPS front bumper is least stressed. This is an indication that the level of damageability is high having the small part of the front bumper absorb the crash energy at collision thereby limiting the displacement and deformation of the front bumper.

Figure 7: Front view of Von Mises stress for Front Bumper (CPS)

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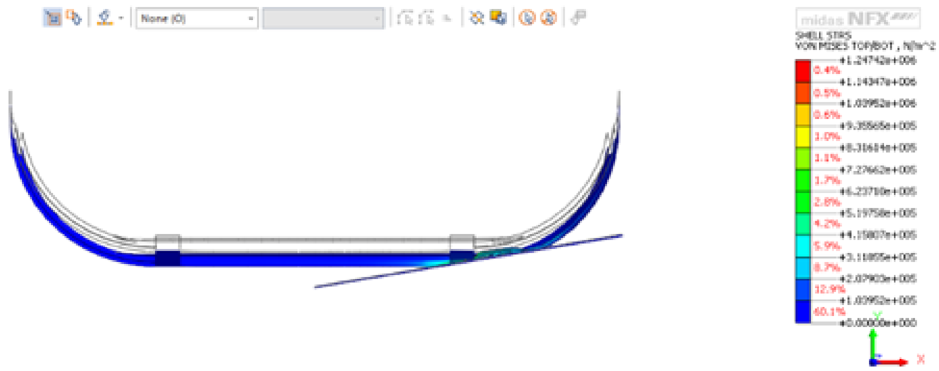

Figure 8: Top view of Von Mises stress for Front Bumper (CPS)

The rate at which the front bumper experience stress at collision was not spontaneous as depicted in Figure 9. The stress-time curve indicates the rate at which the force of collision between the rigid wall and car bumper causes stress on the bumper. The front bumper withstood the force of collision up to 0.0040sec, and absorbed the crash energy before experience stress, in so doing limiting the physical displacement, deformation and damage to front bumper structure

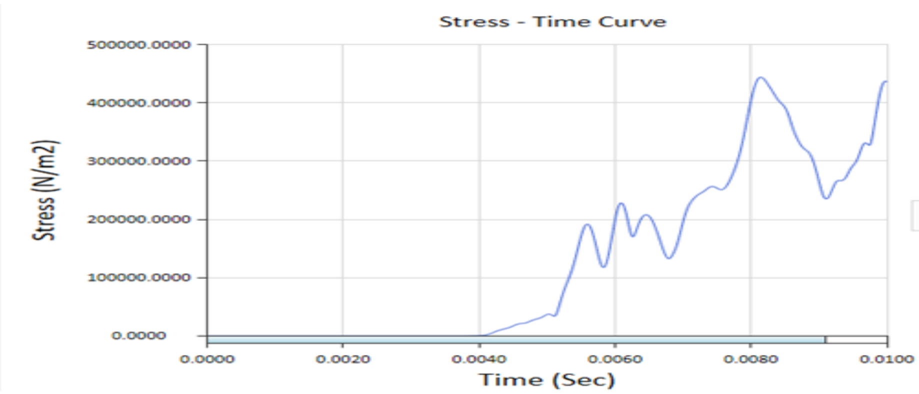

Figure 9: Stress-Time curve for Front Bumper (CPS)

From Figure 10, it observed that the highest displacement of CPS front bumper material is 0.046571m at the 79.3% part of the bumper which also signifies high damageability of the front bumper.

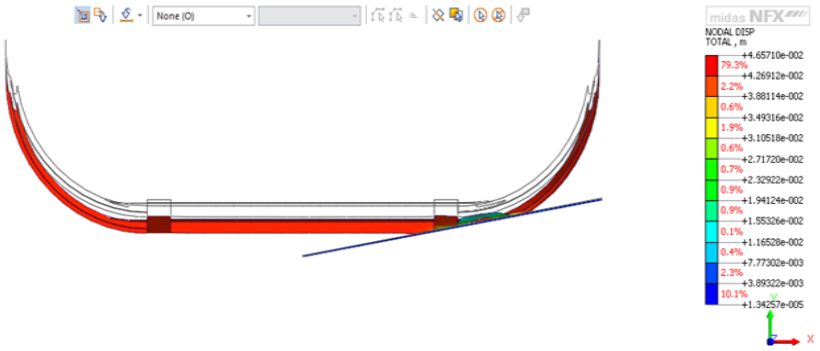

Figure 10: Top view of Displacement for Front Bumper (CPS)

The rate of deformation of the CPS front bumper, as depicted in Figure 11, was steady and proportional. The rate of deformation started changing at 0.0042sec when the deformation reached 0.018m. The maximum deformation of the CPS front bumper is 0.022m at 0.0052sec.

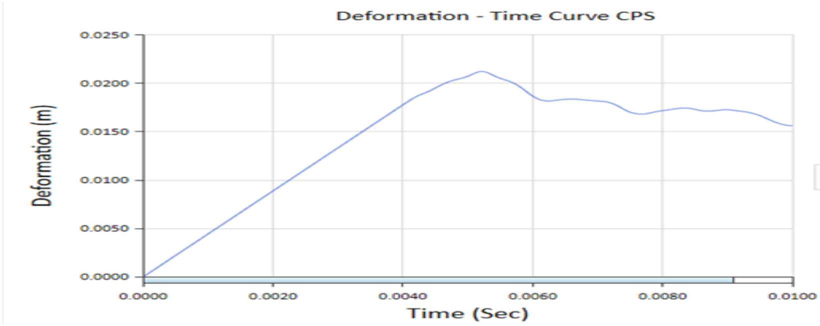

Figure 11: Deformation-Time curve for Front Bumper (CPS)

Rear Bumper

The rear low-speed collision test on CPS bumper material was also simulated in accordance with the RCAR standard. The small part of the rear bumper has the highest stress caused by the crash energy. The highest Von mises stress, from Figures 12 and 13, is 7.22047x10^{6} N/m^{2} at the smallest part of 1.0% of the rear bumper. The greatest part of the CPS front bumper is least stressed. This is an indication that the level of damageability is high having the small part of the rear bumper absorb the crash energy at collision thereby limiting the displacement and deformation of the rear bumper.

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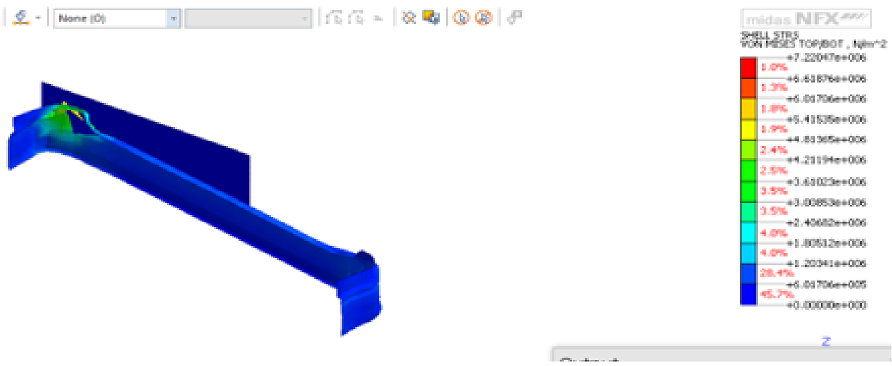

Figure 12: Front view of Von Mises stress for Rear Bumper (CPS)

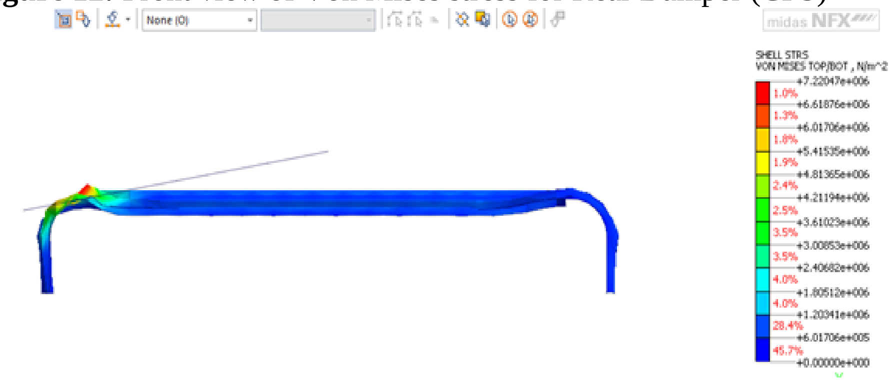

Figure 13: Top view of Von Mises stress for Rear Bumper (CPS)

The rate at which the rear bumper experience stress at collision was spontaneous but not proportional as shown in Figure 14. The stress-time curve indicates the rate at which the rear bumper experience stress as it collides with the fixed rigid wall. At collision, the rear bumper started absorbing the crash energy and experiencing stress, in so doing limiting the physical displacement, deformation and damage to rear bumper structure.

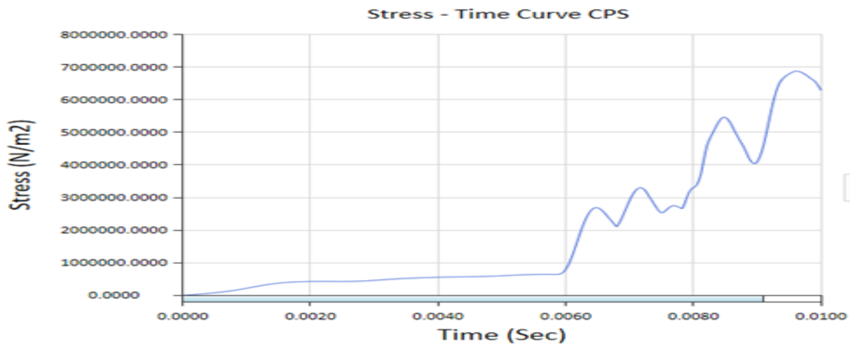

Figure 14: Stress-Time curve for Rear Bumper (CPS)

From Figures 15 and 16, it observed that the highest displacement of CPS rear bumper material is 0.05891m at the 0.2% part of the bumper which also signifies high damageability of the rear bumper.

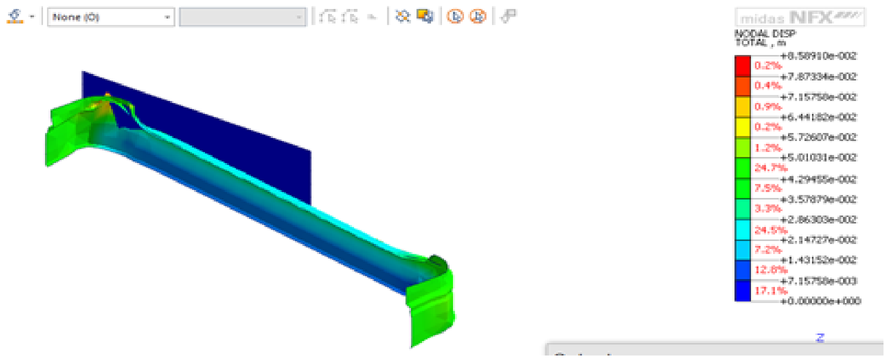

Figure 15: Front view of Displacement for Rear Bumper (CPS)

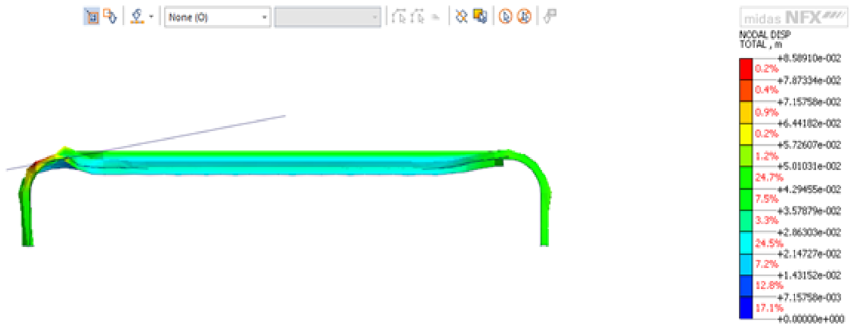

Figure 16: Top view of Displacement for Rear Bumper (CPS)

The rate of deformation of the CPS rear bumper, as depicted in Fig. 17, was not steady and proportional. The maximum deformation of the CPS rear bumper is 0.0670m at 0.0097sec.

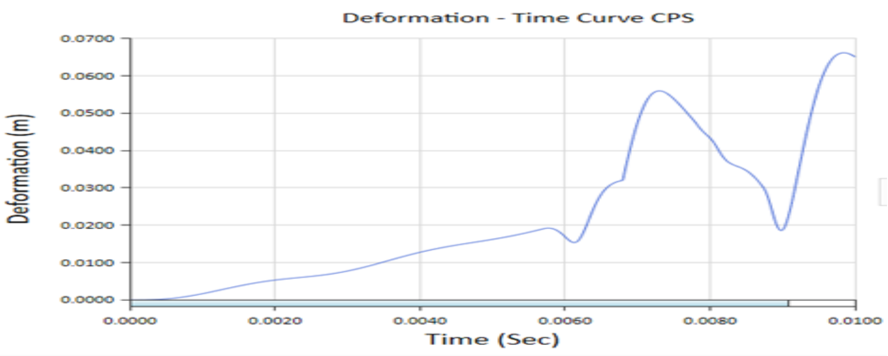

Figure 17: Deformation-Time curve for Rear Bumper (CPS)

The optimized CPS materials for front and rear car bumper also exhibit good crash behavior in the front and rear low-speed collision tests as recommended by RCAR. The maximum Von Mises stresses experienced by the front and rear bumper materials are less than the ultimate tensile strength of CPS composite material. Hence, CPS materials for front and rear car bumper have high damageability, which enable the bumpers to also have the capacity to withstand the force of collision and thereby limiting the displacement and deformation of the bumpers. The front and rear car bumpers of CPS material also have high repairability where the repair of the CPS bumper materials in terms of physical sense and cost is possible.

CONCLUSION

The highest Von Mises stress of front CPS bumper, 1.24742 x 10^6 N/m^2 at the smallest part of 0.4%, is much less than that of rear CPS bumper which is 7.22047 x 10^6 N/m^2 at the smallest part of 1.0%. The rate at which the front bumper experience stress at collision was also not spontaneous while the rate at which the rear bumper experience stress at collision was spontaneous but not proportional.

It is also observed that the highest displacement of CPS front bumper material is 0.046571m at the 79.3% part of the bumper while that of CPS rear is 0.05891m at the 0.2% part of the bumper. The maximum deformation of the CPS front bumper is 0.022m at 0.0052sec while the maximum deformation of the CPS rear bumper is 0.0670m at 0.0097sec

Hence, CPS materials for front car bumper have better damageability and repairability than that of rear car bumper.

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