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PERFORMANCE OF AN AUTOMOTIVE BUMPER FROM LALLOH *(Corchorus triden L.)* PLANT FIBRE REINFORCED EPOXY COMPOSITE UNDER MODIFIED DYNATUP MODEL 8150 TEST

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ABSTRACT

The work presented here is the production of an automotive Bumper from Lalloh plant (Corchorus tridenL.) fibre reinforced epoxy composite and its performance evaluation using the drop weight test method. An impact test was carried out on the bumper using a test rig modeled after the Dynatup Model 8150 drop weight test set up. Two test variants were used that is, with the bumper completely restraint and the bumper restraint at two-points. The bumper damage were assessed using a set of criteria as outlined by the Insurance Institute for Highway Safety (IIHS). Results obtained showed that the bumper performed satisfactorily under the completely restraint condition. However, there were, tears, distortion and delamination observed on the bumper after the two-point constraint test. Although the extent of the tear, distortion and delamination were minimal which did not result in the shattering of the bumper. This therefore showed that, the bumper was able to absorb the impact energy by confining the damage to itself, thereby protecting adjacent components.

Keywords: *Bumper, Plant Fibre, Composite, Epoxy, Impact Test, Drop Weight Test*

1. INTRODUCTION

Legislative changes inspired by ecological concerns seeks to compel automobiles of the future to travel on less fuel in order to discharge lower levels of pollutants into the atmosphere. Thus, much work is on-going to improve transportation related fuel efficiency[1]. This is with a view to lessen the impact of vehicle emissions on our environment and provide a cleaner atmosphere for the future generations as exemplified by the works of [2-5]. Current trend in automotive technology energy efficiency is intended to increase fuel efficiency and decrease emissions. One strategy for achieving this is through mass reduction of vehicle structural components, and the use of polymer and their composites have been at the forefront in achieving this [6,7]. Studies have shown that a 25% weight reduction in current US vehicles alone could save 750,000 barrels of oil per day, reduce the yearly domestic fuel consumption by 13% and prevent 101 million tons of CO_2 from being emitted into the atmosphere each year [2].

Polymers and their composites are attractive alternative for automotive component production due to their low cost, ease of processibility, good chemical resistance and low specific gravity. Low density translates to low fuel consumption and hence, less pollutants are discharged into the atmosphere. Polymer composites exhibits good resistance to denting and do not warp under cyclic conditions of temperature and humidity which is beneficial for automotive exterior panels production [8]. These applications include door panels, trims, grills and fascia [9]. Glass fibre is by far the predominant reinforcement in polymer composites for automotive and aircraft component production. However, the use of glass fibre reinforced polymers in automobiles exhibits some shortcomings such as their relatively high fibre density, difficulty to machine and poor recycling properties in addition to the potential hazards posed during processing and handling [10, 11]. These shortcomings have made plant fibre a viable substitute for reinforcement in polymer composite production especially in the automotive

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and earospace industries where weight related properties are of concern [12, 13]. This interest in plant fibre is motivated by the properties that cannot be achieved using glass fibre, such as economics, weight reduction, natural carbon dioxide balance, no observed health risks during processing and handling, biodegradability, improved passenger and pedestrian safety in the event of accident [14, 15, 16, 17]. Plant fibres are also said to have significant processing advantages over the synthetic mineral fibres [18]. Therefore, fibres from plants are currently being sought after to replace the synthetic mineral fibres such as E-glass fibre for composite production for automotive components [19]. These includes, the dash board, door wallet, body liners, grills, and bumper fascia.

An automotive bumper is a sheild which spans the width of the vehicle mounted on the front and rear of a perssenger car intended to absorb crash energy at low velocity impact. The bumper system typically consists of a fascia, bumper beam made of steel, aluminum, or fibre reinforced thermoplastic or thermosetting polymer and some form of impact absorber made of different materials and configurations [20, 21].

The function of a bumper is to absorb crash energy and deliver momentum without significant damage to the bumper itself and the vehicle's front or rear ends during low velocity collision. In the early years of the history of bumpers, these were simple metallic beams that were attached to the front and rear of the car. However, in line with automotive trends, the production of automotive bumpers have also submitted itself to modern technology advancements with emphsis on vehicle performance, strength and styling. Although bumper systems should play an important role in energy management during vehicle accident [22], they are not typically designed to be structural components that would significantly contribute to overall vehicle crashworthiness or occupant protection during front or rear collisions.They are designed to protect the hood, trunk, grille, fuel, exhaust and cooling systems as well as safety related equipment such as parking lights, headlamps and taillights in low speed collisions[23, 24, 25]. According to the American Iron and Steel Institute (AISI), new technologies permit the bumper design to absorb about 15% of the crash energy under high speed[25].

Contemporary trends in bumper design is aimed at reducing its weight, cost of repair or replacement after low-speed collisions and to better protect pedestrians during low-speed collisions. There is significant interest around the world in introducing requirements to limit the injuries to pedestrians and to improve fuel efficiencies. To meet these emerging requirements, manufacturers attempt to design bumpers that are light in weight and offer supperior aerodynamic profile while not compromising service requirements [25].

There are basically four ways by which bumpers performance are evaluated world wide [26]. These tests have been developed by different agencies and organizations in Europe, America and Asia and are based upon the pendulum impact, drop weight or car-into-barrier crash test performed at different speeds depending upon the countrys' regulations. Although each of these test programs has its strengths and weaknesses, a limitation common to all four is the inability to test for the possibility of bumper mismatch (override and underride) during collision [25, 26]. The aim of this work was to produce an automotive bumper for the UniBen Eco marathon car from Lalloh Plant (*Corchorus tridenL.*) fibre reinforced epoxy composites and assess its performance by subjecting it to drop weight impact test. To achieve this, a test rig was designed and produced modeled after the Dynatup drop weight test apparatus Model 8150.

2. METHODOLOGY

2.1 Lalloh Plant (*Corchorus triden L.*) Fibre Harvesting and Processing

The mature plant was harvested as soon as the leaves began to whither. This was done by pulling it off the ground manually and then plucking off the remaining leaves and branches with a sharp knife. The stems were then cut into pieces of about 20cm each and were slit open. The barks containing the fibre bundles were then peeled off by hand [27] and were then sun-dried after which they were subjected to chemical retting and scouring processes.

300g of the peeled plant bark were retted by immersing in 400ml capacity beaker containing 5% solution of Ammonium Oxalate and heated to 100^{o}C on a heating mantle for 30 minutes. The retted fibres were then removed and rinsed in overflowing tap water until neutral pH was attained. The rinsed fibre were then oven dried at 55^{o}C overnight [28]. The dried fibres were further subjected to alkalization by completely immersing in 2% NaOH solution and heated to 100^{o}C for 30 minutes. The scoured fibre was then removed and thoroughly rinsed in overflowing tap water until neutral pH was attained and subsequently oven dried at 55°C overnight[28]. In both cases it was ensured that the fibres were completely submerged while heating is sustained to avoid oxidation.

2.2 Fibre Mat Preparation

The retted, scoured and dried fibres (Figure 1a) were separeted by manual combing to remove small hairlet fibres and to achieve consistency. The fibre filaments were then cut into lengths of 25mm (Figure 1b) and 300g of the fibre samples were measured out for the preparation of the fibre mat of 1680x280x1.5mm size. To prepare the mat, the chopped strands were mixed with 2.5g of epoxy and were placed randomly oriented in a compression mould by hackling with hand. The mould was closed and a load of 50N was applied and allowed to cure at room temperature for three hours. After curing the mats were ejected from the mould (Figure 1c), trimmed and stored away in plastic air tight bags ready for subsequent composite bumper casting. In all three fibre mats were prepared for the bumper production.

2.3 Automotive Bumper Production

The automotive bumper for The Shell EcoMarathon car of the University of Benin, was produced using contact moulding process. The steps involved pattern production, mould production, fibre mat production, mould preparation and final bumper casting and curing.

2.4 Pattern Production

A pattern was first produced from scrapped automobile body part with exisiting profile and curves suitable for the UnibenEco marathon car as shown in Figure 2(a). The pattern was then used to produce the mould from polyester resin and non-wooven glass fibre mat by the hand-lay-up mould process. This was done by first polishing the surface of the pattern with wax until a highly polished surface is attained. Then, a release agent was applied on the pattern surfaces and allowed to become tacky after which a thin coat of already formulated polyester resin was applied on the tacky release agent. A predetermined size of the glass mat was laid on the pattern and with the aid of a hand brush, the polyester resin formulation was applied on it while ensuring that the mat conforms to the contour of the pattern. More resin was then applied and with the aid of a hand roller and brush, the resin was squeezed into the mat to ensure total impregnation and to eliminate air entrapment. Additional layers of the glass mat were then laid with more resin applied until the desired thickness was attained. The cast mould was then left to set over night, after which it was ejected trimmed, cleaned and stored away securely as shown in Figure 2(b).

In order to cast the bumper, the surface of the mould was polished manually with wax to near mirror quality and a coat of release agent was applied on the polished surface and allowed for 15minutes to become tacky as show in Figure 2(c). Commercial grade epoxy resin and hardener were formulated in the ratio of 3:2 by volume and throughly mixed to ensure homogeneity while being careful that air entrapment is minimized to the bearest.

The first layer of the plant fibre mat (Figure 1c) was laid in the mould and the formulated epoxy was applied and with the aid of the hand roller and brush to properly impregnate the fibre mat and eliminate entrapment of air. Sucessive layers of the plant fibre mats and resin were applied in stages until the desired thickness was attained. The cast product was then left to set for five hours, after which it was ejected from the mould and subsequently trimmed and polished (see Figure 2(d)).

(a) (b) (c)

Figure 1: Lalloh Plant Fibre (a) – extracted, retted, scoured and dried fibres, (b)-Chopped fibre strands, (c) – Fibre Mats

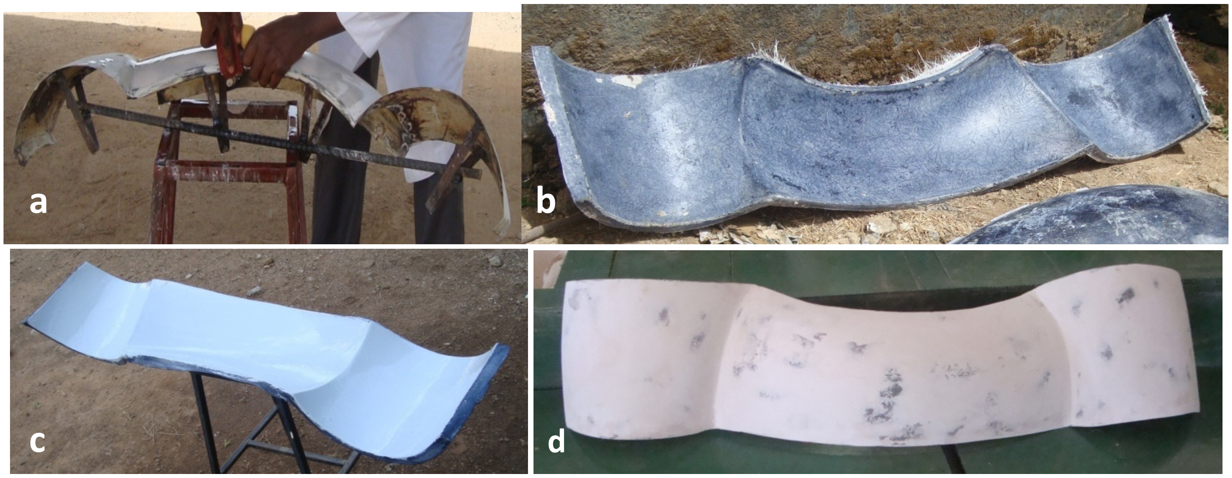

Figure 2 (a – d): Bumper Production Steps

2.5 Automotive Bumper Test

A modified form of the the drop Weight Impact System, modeled after the Dynatup Model 8150 test set up was adopted for the test of the bumper.The procedure was developed byInstron Laboratory Test Equipment Manufacturer in accordance to ASTM D-3029. The test involved an impact drop weight that would produce a momentum equivalent to that of the passenger car to be tested at a test speed of 8km/hr. as recommended by Research Council of Automotive Repairs [29].

A test rig was designed and constructed for the drop weight impact test of the bumper. A schematic diagram of the test rig is shown in Figure 3. The rig consists of two wooden boxes, the impact test load box (A) and bumper test box (B). The impact test load box is suspended via a pulley and guided by two vertical rails. During the test, the test load was raised manually to a height of 2.4malong the guide rails and released to impact on the bumper in the test box.

Two test variants were used for the test, one with complete restraint and the other with the bumper restraint at two points. In both test variants, the same test load and falling height was used. After which the bumper was retrieved for damage assessment.

2.6 Bumper Drop Weight Impact Load Determination

The following procedure was used to arrive at the impact drop weight test load falling from a height of 2.4m given a vehicle mass of 205kg (Shell Eco Marathon car)[30].

The following test conditions were specified to be:

Vehicle mass (M) = 205kg
Speed at impact (V) = 8km/hr.[29]
Height of free fall (h_t) = 2.4m

Thus, let the momentum at impact=MV (1)

Therefore, let test mass be M_t such that for M_t falling from a height of 2.4m, the velocity, V_t at the end off all is obtained from energy conservation condition by equating potential energy to kinetic energy from which V_t was calculated to be 6.86m/s from equation 2;

$$V_t = \sqrt{(2gh_1)} \qquad (2)$$

Here, g is the acceleration due to gravity (9.81m/s^2) and h_t is the test height (2.4m)

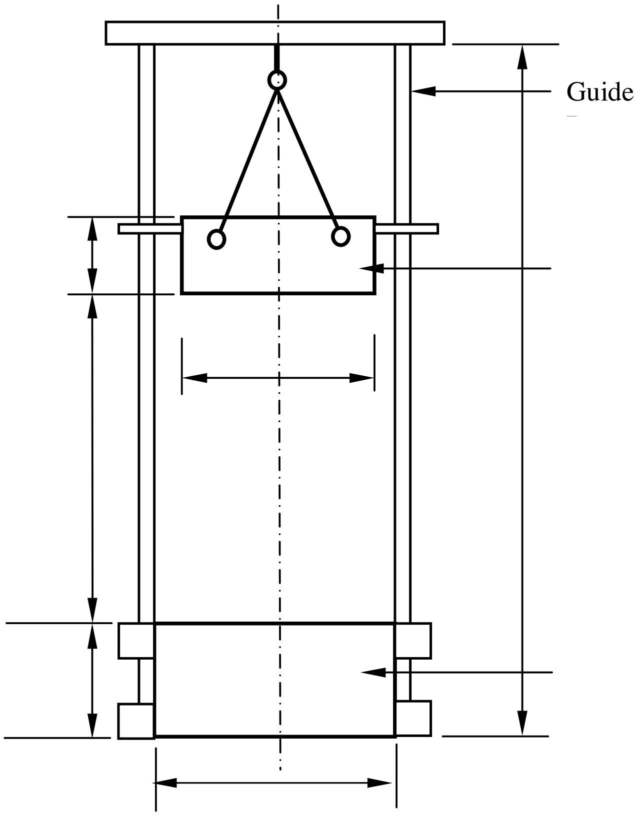

Figure3: Schematic Diagram of Bumper Drop Weight Impact Test Rig

Now, momentum at impact = $M_t V_t$ (3)

$$= 6.86M_t \quad (4)$$

Equating equations (1) and (3)

$$M_tV_t = MV$$

$$\text{Therefore, Mt} = \frac{MV}{V_t} \quad (5)$$

Hence, the value of M_t was obtained to be 66.34kg from equation (5).

3. RESULTS AND DISCUSSIONS

3.1 Bumper Damage Assessment

The damage assessment criteria for bumpers as outlined by the International Institute for Highway Safety (IIHS) [31] for damages which may occur in low-speed collision (typically 8km/hr.) was used for the assessment. The outline served as a guide for the assessment from which inferences were drawn on the level of damage sustained on the bumper after impact. Result of the test with complete restraint showed that the bumper performed satisfactorily since there were no damage, cracks, dents or scratches on it. However, in the case of test with two-point restraint, tears, distortion and delamination of the bumper were observed. Although the extent of the tear, distortion and delamination were minimal which did not result in the shattering of the bumper. This therefore shows that, the bumper was able to absorb the impact energy by confining the damage to itself, thereby protecting adjacent components. Detailed assessment of the bumper using the damage assessment criteria set by IIHS [31] is presented in Table 1.

Table 1: Bumper Impact Test Assessment

SN	Damage Assessment Criteria	Bumper with complete restraint	Bumper with two-point restraint
1	Damage is to the external bumper surfaces	There was no visible damage to the external surfaces of the bumper. The surface remained clean and free of any dent or scratches (see Figure 4(a)).	There was visible damage to the external surfaces of the bumper as shown in Figure 4(b). The damage includes scratches, dents and tears as indicated by arrows A, B and C
2	Localized dents or deformation are no more than 3/8 inch (0.95 cm) deep	Localized dents or deformation were absent on the bumper surface after the test (see Figure 4(a)).	Localized dents or deformation observed on the bumper surface after the test were not up to 0.95cm (see Figure 4(b)).
3	Overall bumper distortion or displacement is no more than 3/4 inch (1.9 cm) from the original contour, and there is no breakage of fasteners	The original contour and alignment of the bumper were maintained after the test with no distortion or displacement.	There was no overall distortion of the bumper; however, the left wing of the bumper was distorted from its initial contour as shown in Figure 4.40. In addition, the two fasteners meant to fasten the bumper to the chassis frame were completely removed from their original position during the test as indicated as X on Figure 5.
4	Larger localized dents, deformation, or distortion than indicated above if, in the opinion of the appraisers, the bumpers would meet the criteria after repairs to underlying damage such as replacement of reinforcement bars or foam absorbers	No localized dents, deformation or distortion.	There were no reinforcement bars in the initial design, however, the bumper brackets were completely displaced and will have to be replaced
5	ears or holes that penetrate completely through the cover material if they are no more than 1 cm in length or diameter and do not occur in critical areas such as openings for fasteners that secure the cover	There were no tears or holes on all the surfaces of the bumper after the test.	There were no penetrating holes on all the surfaces of the bumper after the test, however, tears of more than 1cm were observed on two locations as shown one of which occurred at a critical area marked X in Figure 6
6	Gouging or cracking partially into the cover material if its length or diameter is no more than 2 cm and is not located in critical areas	There were no gouging or cracking into the cover material of the bumper (see Figure 4(a))	There were visible cracks into the bumper material of the bumper (see Figure4(b)) which were more than 2cm in length although not located in critical areas
7	External paint or finish scuffing, delamination, wrinkling, and the like	The bumper was not painted as such paint or finish scuffling and wrinkling	There were tears and cracks into the material of the bumper although the material did not

SN	Damage Assessment Criteria	Bumper with complete restraint	Bumper with two-point restraint
	if there are no tears or holes completely through or cracks or gouges part way into the material as described above	cannot be reported. However, there were no tears, holes, cracks nor gouges on the material of the bumper	part ways, but the cracks and tears went through the material of the bumper as shown in Figure 7.
8	Colour lightening of moulded-in-colour (unpainted) covers	Colour lightening was observed as indicated by arrow in Figure 8(a)	Colour lightening was observed as indicated by the circles in Figure 8(b)

Figure 4(a): Bumper surface after impact test with complete restraints

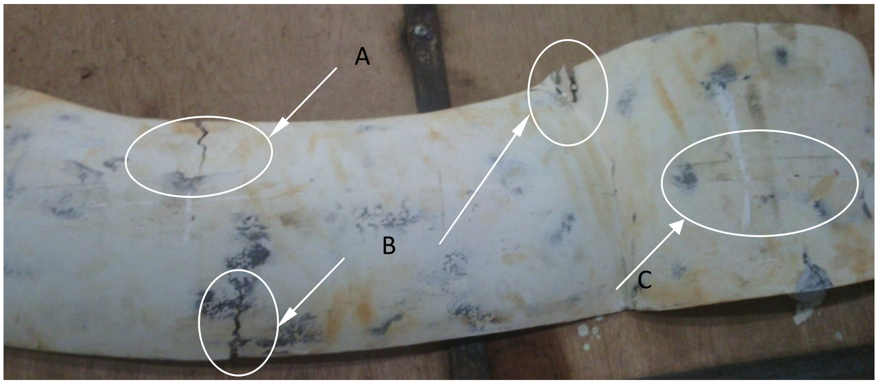

Figure 4(b): Bumper surface after Impact Test with Two-Point Restraints

Figure 5: Bumper Displacement and positions of broken off fasteners

Figure 6: Crashed bumper showing tears more than 1cm

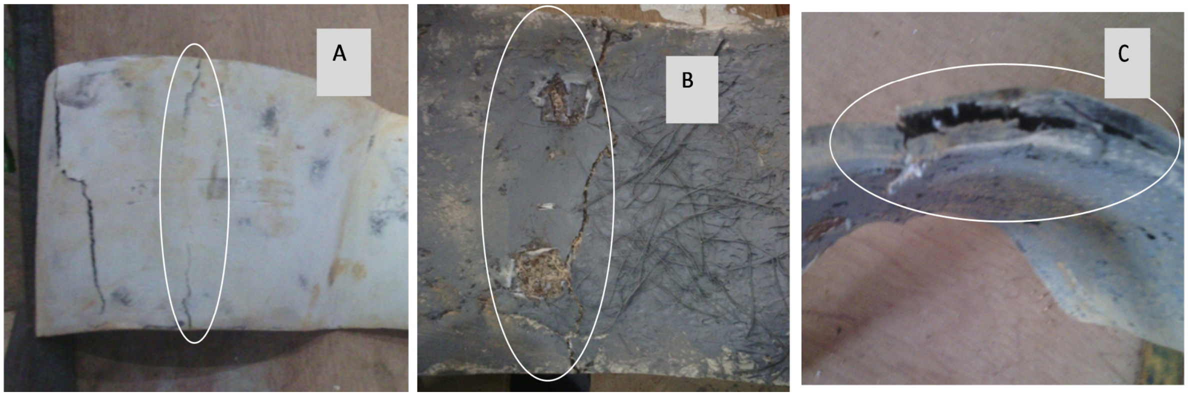

Figure 7: Bumper after impact test with two-point restraints showing Tears and Cracks on external surface (a) and internal surface Tears and Cracks (b) matrix delamination

Figure 8(a): Color lightening of bumper surface after impact test with complete restraints

Figure 8(b):Color lightening of bumper surface after test with two-point restraints

4. CONCLUSION

An automotive bumper was produced from Lallohplant (*Corchorustriden L.*)fibre reinforced epoxy composite for the urban concept of the Shell Eco Marathon car. Also, a test rig modeled after the Dynatup Model 8150 test set up was produced to test the bumper. Two variants of the test were used to ascertain the efficacy of the bumper in service. In both the test variants the bumper performed satisfactorily based on the damage assessment criteria outlined by the Insurance Institute for Highway Safety. However, in the second test variant, tears and delamination of the bumper material were observed, which can be repaired, as such will not affect the overall reliability of the bumper to the extent that it fails to perform its intended function.

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