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Investigation on Potential of Recycle Plastic Bottles as a Crash Cushion for Road Barrier

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Abstract: Road accident is a major problem in the country and should be dealt with an effective ways. Road furniture is one of the factors that contributing an accidents than other factors. Therefore, this study focuses on waste material such as recycle plastic bottle that potential to be used as a road barrier and crash cushion. The objective of this study are to investigate the potential of plastic bottles filled with sand as crash cushion, examine the impact strength of plastic bottles and designing crash cushion by using recycled materials. Some plastic bottles of soft drinks containing ordinary sand was prepared and undergone experimental and simulation works. Free fall Impact test that imposed on the plastic bottles has been carried out to identify the strength and its energy absorption. The numerical simulation of impact test was conducted using Finite Element Method to obtain impact failure and to observe its details response under low velocity impact loads. The numerical results by employing FEM well agreed with practical works. Where, the absorption of energy from the impact test shows that the difference does not exceed 50%. In addition, the deformation of both test are almost similar. Therefore, the use of recycled materials such as plastic bottles filled with sand as crash cushions that can be considered as alternative and environmentally friendly materials.

1. Introduction

Road accident occurs when two more vehicles collided by themselves or the vehicle collide with some object on the road. The accident cause injuries even death of vehicle's occupants. In Europe countries, the road accidents has been brought to the attention that incidence is one of the major problems and influence in various aspects of socio-economic development [1]. One of the cause accidents is the use of inadequate attribute of road furniture. The road or highway should be completed by road furniture which to facilitate the road safety and gave protection to road users [2]. In addition, its also to increased road safety and as a warning about the dangers ahead [3]. The road furniture such as curb, guardrails and concrete barriers~~,~~ are used as a safety barrier.

The safety barrier often comes with the crush cushion to optimize the barrier from impact and hazardous errant vehicle. Usually, crash cushion is made from metal, rubber, or plastic arranged to reduce an accident from any diversion or crossing a road vehicle without endangering other vehicle. Various types of crash cushion depend on types of vary in terms of installation cost, size, ease of repair and maintenance. These aspects should be assessed carefully to select the appropriate cushion violations. However, the crash cushion least preferred due to expensive and less expertise to design it. This process is costly and time consuming [4, 5].

The plastic waste is a quite problematic for its non biodegradability and therefore can stay in the environment for a considerable length of time carrying all sorts o f problems . Meanwhile in the world, total plastic bottles disposal increase every year, more than 121 million tons, the plastic bottle give contribution of waste per year, which more than 75% of plastic water bottles cannot be re-cycled and to be disposal [6]. Usually, the type of waste bottle is Polyethylene Terephthalate (PET or PETE or Polyester). The properties of this bottle are toxic and it has materials component may contaminate water by a diffusion process or called migration [7]. However, the physical properties of this bottle type are a high degree of impact resistance and tensile strength, besides good chemical resistance [8-9]. Therefore, this investigation re-used plastic bottle which modified as a crash cushion is a potential material to reduce the cost of crash cushion production and its maintenance, also to reduce the timing installation. Additionally, utilizing the waste bottles reduce the pollution problem.

Therefore, the bottle plastic had been modified as crash cushion or Modified Bottle Crash Cushion (MBCC)

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and was tested by the drop weight impact method. This method produced the high impact energy to hit the MBCC, furthermore the characteristic and behavior impact failure of MBCC would be obtained. The high impact generated from the kinetic energy was produced by the height and velocity of impactor. The test determined energy absorption of modified bottle crash cushion. According to conservation energy law, the energy absorption can be calculated correspond to the deformation of MBCC.

Furthermore, the Finite element method conducted to validate the result test. ELFEN [10] software simulated the modified plastic bottle crash cushion subjected to impact loading. The results show that the modified plastic bottle can absorb energy impact. This test result agrees with the simulation model that the energy impact of modified plastic bottle no exceed to 35%. The investigation presented that the modified plastic bottle can be considered as road crash cushion.

2. Material and Method

2.1 Sample of Materials

A plastic bottle that used in this investigation, which widely available in the market, usually this bottle type is PET. These investigations, 12 samples of bottle were filled by sand for impact test to identify the potential of plastic bottle as a crash cushion. Which were 6 samples possess at vertical position and the other at horizontal position. For purposes the tensile test, a bottle was cut into 200 mm x 20 mm, furthermore, it was tested under Universal Testing Machine. The plastic bottles were posed as two positions, which were vertical and horizontal for each impact test as shown in Fig. 1.

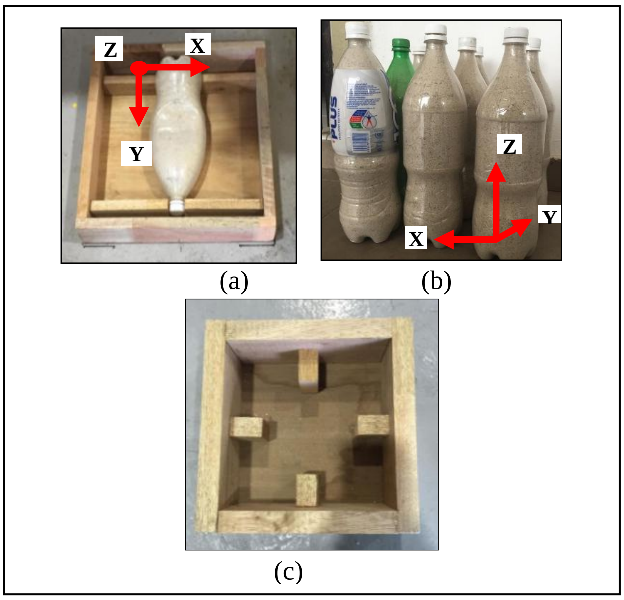

Fig. 1 Bottle Position: (a) Horizontal position, which the bottle lay on the holder. (b) MBCC. (c) Vertical position holder.

Both of positions the bottle need stable and still stand during impact test. Thus, the bottle was placed horizontally in 180mm x 180mm x 70mm of holder. While, 350mm x 390mm x 70mm was dimension of holder for vertical position. Figure 1a shows that the bottle laid on the holder represents to horizontal position, which the dimension of bottle is Width-X, Depth-Z, and Height-Y. While the vertical position as Figure 1b, the bottle dimension is Width-X, Width-Y, and Height-Z. At the vertical position, the bottle held by holder in Figure 1c.

2.2 Tensile Testing

The ability to resist breaking under tensile stress is one of the characteristics of the most important and widely measured to materials used in structural applications. So that, the tensile test was carried out to obtains the mechanical properties of current plastic bottles. This mechanical properties data also was used for computer simulation purpose. Mechanical properties of tensile stress include elastic stress, strain, yield stress, the maximum tensile stress, elongation percentage, and the percentage shortfall in the cross-sectional area. This test was applied an axial force to the specimen with its original length. The specimen would be extended and reduced in cross-sectional area until the sample fractured. This tensile test is referred to the American Society of Testing and Materials [11]. The plastic bottle was cut and shape into 220mm x 20mm. Both ends of the specimen must have sufficient length to be gripped during the test.

2.3 Impact Load Test

MBCC in set as crash cushion to be qualified able to absorb impact energy, therefore this test was conducted to determine the energy absorption of MBCC subjected to impact loading. The 105 kg flat nose shape impactor was applied to hit the MBCC with various heights i.e. 1m, 1.5m, and 2m to acquire velocities of impactor at 4.4 m/s, 5.4.m/s and 6.3 m/s respectively. Based on conservation energy law, then the impact velocity calculated as following equation as:

$$v = \sqrt{2gh} \tag{1}$$

Where, $\boldsymbol{v}$ is velocity of impactor, $\boldsymbol{g}$ is constant gravity 9.81 m/s^2 and $\boldsymbol{h}$ is height impactor when it dropped.

MBCC were posed as two position, which were vertical and horizontal for each impact test. Horizontal and vertical position of MBCC was tested separately with each varying heights. This impact test engendered the kinetic energy ($\boldsymbol{E_k}$), which is proposed from velocity and mass ($\boldsymbol{m}$) of impactor by the equation below:

$$E_K = \frac{1}{2} mv \tag{2}$$

2.4 Simulation of ELFEN Software

This investigation ELFEN software was used for the impact simulation. This software is provided to design and develop a model to forecast accuracy in elastic, plastic and failure mode under dynamic loading. This simulation investigation was required an actual data from experimental work, such as tensile strength, modulus elasticity of target, velocity, mass, impactor material, boundary condition both target and impactor. The simulation results were compared to experimental work result.

3. Results and Discussion

3.1 Deformation of MBCC Testing

Tables 1 and 2 present the MBCC deformation due to impact test for horizontal and vertical position. At horizontal position, the biggest displacement of MBCC suffered by 6.3 m/s impact loading due to highest impact energy. However, the result shows all deformations were not significantly different. It indicates that the plastic bottle of MBCC was good tensile in horizontal position. Besides, sand is unique materials when it subjected to impact loading, the cavity formation of heterogeneous granular systems of sand able to absorb energy impact or reduce the kinetic energy [12]. From the result of all impact loading on specimens in horizontal position show that at Width-X direction was weakest. It is clearly, this direction the MBCC has lowest elastic strain. It is correspond to consideration of the bottle design [13]. At vertical position as presented in Table 2, shows the biggest displacement was Height-Z less than 5.4 m/s impact velocity and factually, the bottle suffered by 6.3 m/s had been crushed.

Table 1 Displacement of MBCC at horizontal position

Bottle Description	Velocity					
	4.4 m/s		5.4 m/s		6.3 m/s	
	Before (mm)	After (mm)	Before (mm)	After (mm)	Before (mm)	After (mm)
Height-Y	312	316	312	316.5	312	316.6
Width-X	94	110	94	114	94	117
Depth-Z	94	66.5	94	63	94	60

Table 2 Displacement of MBCC at vertical position

Bottle Description	Velocity					
	4.4 m/s		5.4 m/s		6.3 m/s	
	Before (mm)	After (mm)	Before (mm)	After (mm)	Before (mm)	After (mm)
Height-Y	94	94	94	112.5	94	149
Width-X	94	94	94	915	94	745
Depth-Z	312	259.5	312	230	312	214

The deformation of the bottle is related to the inertia sensitive of energy absorbing structure [14] and similar to with 'crooked plates' [15]. The bottle should be constrained laterally to maximize the energy absorption than unconstrained. This condition would be produce a large volume of material to reach the plasticity and generated more plastic hinges during collapse in collapse mechanism [16]. The bottle did not expand in direction of Width-X and Width-Y, when it was subjected to 4.4 m/s impact loading in vertical position. The axial crushing was occurred in bottle [17], however the elastic and plastic stress of bottle could withstand the compressive stress that generated by impact loading.

3.2 Kinetic Energy

Kinetic energy of the experimental could be calculated by using Equation 2, which the load impactor was 105 Kg and impact velocities were 4.4m/s, 5.4m/s and 6.3 m/s, hence, the kinetic energy present in Table 3. [1], in their simulation stated that the small car produces 4169.5 Nm of impact energy to deform the cushion as 538 mm. This indicates that the MBCC carry 24.6% factual impact energy for 4.4 m/s impact velocity, similarly to 5.4 m/s and 6.3 m/s impact velocities which were carry 36.9% and 49.3% factual impact energy respectively.

Fig. 2 shows tensile strength of PET plastic bottle that it has high plastic range and high Young's modulus. This condition, the plastic bottle can carry load of dynamic impact load, which generated the tensile stress [16]. However, the impact firstly produced the higher compressive stress and the result show that the plastic bottles quite enough withstand the compressive stress of dynamic load. This indicate that the sand in bottle contribute to increasing elastic and plastic stress against dynamic impact loading.

Table 3 Energy kinetic of impactor and displacement of MBCC in impactor direction

Impact Velocity (m/s)	Displacement		Energy Kinetic (Nm)
	Horizontal position Depth-Z (mm)	Vertical position Height-Z (mm)	
4.4	27.5	52.5	1025.7
5.4	31.0	8.2	1542.3
6.3	34.6	98	2057.4

Critical conditions for autoignition of non-premixed ethanol flames are shown in Figs. 2 and 3. Fig. 2 shows the temperature of air at autoignition as a function of mass fraction of fuel at the fuel duct exit. The data is obtained at a fixed value of strain rate $a_2 = 300\ s^{-1}$. Measured values of Seiser et al. [8] agree well with the numerical calculations as shown in Fig. 2.

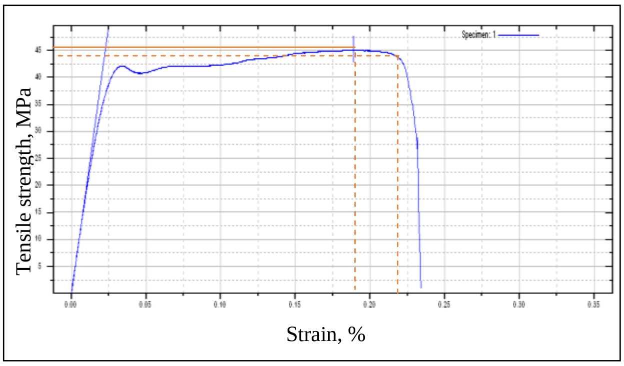

Fig. 2 Tensile strength behavior of PET plastic bottle

Fig. 3 shows the kinetic energy obtained from simulation software and testing ELFEN impact on velocity data. This graph is upward due to an increase in velocity. Therefore, the higher the speed, the higher the kinetic energy acquired. Velocity imposed load of 105kg is 4.43 m / s, 5:42 m / s and 6.26 m / s or 15.92 km / hr., 19:52 km / h and 22:54 km / hr. Where, small cars weighing 820kg could have an impact on offense with speed cushions 72km / h [10-11]. Thus the ratio of this exam on small cars is 1: 8.

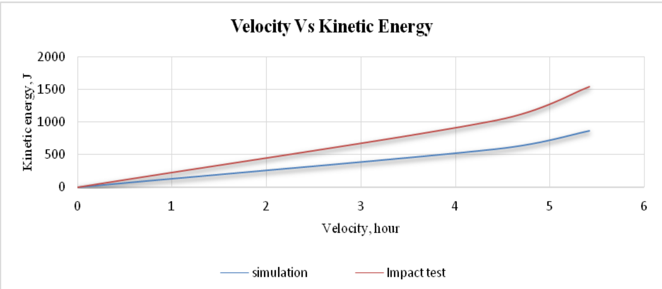

Fig. 3 Graph of the kinetic energy and simulation software through the velocity

3.3 Comparison of Displacement between Simulation and Experimental Works

Correspond to the displacement, the impactor produced the kinetic energy was absorbed by MBCC. When the high impact stroke a bottle target, it was related to compressive plastic waves and the impact energy that produced by kinetic energy converted to strain energy. This is associated to deformability of the bottle target. This deformation relates to local plastic collapse of the bottle and the absorption energy is taking place. Intended displacement was recorded in simulation is a deformation of the target (bottle) in line with the impactor direction.

Fig. 4 shows the process simulation history of MBCC displacement when 4.4 m/s impact energy stroke the MBCC target. The graph shows maximum displacement occurred at 4.607x10^{-3} seconds of impact history. It indicates that this period, the simulation showed the elastic stress occurred in BMCC. Further, the graph gradually going up indicated the simulation impress the elastic material and it cannot be shown due to materials collapse.

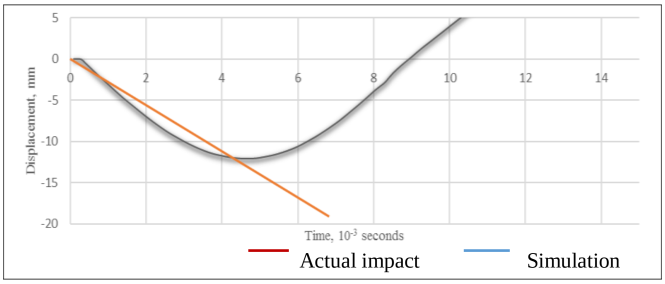

Fig. 4 Graph of displacement against time at a speed of 4.4 m/s at vertical position

There was difference in resulting displacement of experimental impact and simulation, which the displacement of experimental was 52.5 mm and simulation recorded the maximum deformation was 12.11 mm or 76.94%. Although different displacement was significant, the regression between simulation and experimental was close and similar deformation impact.

Furthermore, the values of 5.4 m/s and 6.3 m/s impact velocities (Fig. 4 and 5), which have same trend with 4.4 m/s. The experimental test recorded that impact test were 82 mm and 98 mm for 5.4 m/s and 6.3 m/s impact velocity respectively. The regression graphs displacement of both simulation impact velocities have similar and close with the experimental result. After reach maximum displacement, the simulation verified those both graphs tend to ascending to indicate the collapsing of materials.

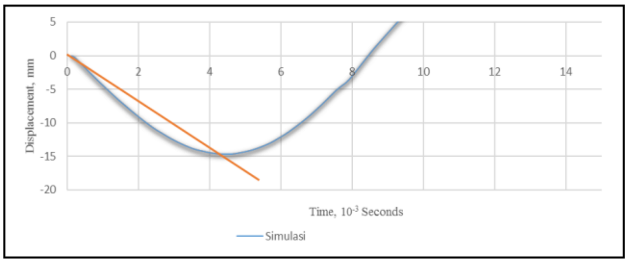

Fig. 5 Graph of displacement against time at a speed of 5.4 m/s at vertical position

Meanwhile, the horizontal position of simulation MBCC presents in Fig. 6 and 7. After reach the maximum deformation, the graphs tend to ascending then, it was logged constant at the end of simulation. This indicates the simulation was not finding collapse on the MBCC. The result regressions of all impact velocities were similar with the vertical position.

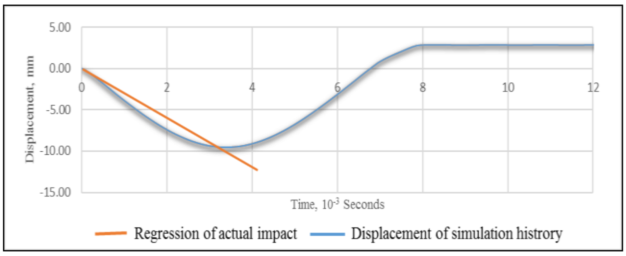

Fig. 6 Graph of displacement against time at a speed of 4.4 m/s at horizontal position

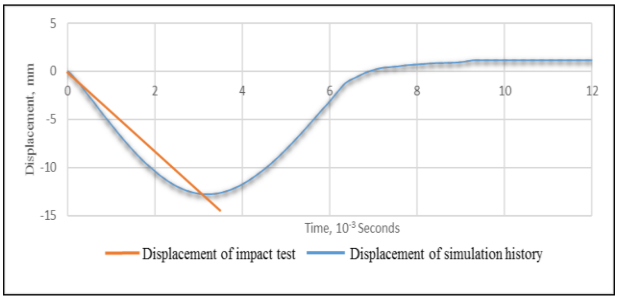

Fig 7 Graph of displacement against time at a speed of 5.4 m/s at horizontal position

4. Conclusion

Sand as filler in bottle increase the strength of PET bottle under impact loading, it potentially as crash cushions (MBBC). Re-use the bottle for crush cushion help to solve the environmental problem. Experimentally, results showed that the MBCC withstand the compressive stress of impact due to high elastic and plastic strain of bottle, beside sand as stress ‘reinforcement’. The deformation occurred in three dimensional, however the critical in impact or direction, i.e. Depth-Z for horizontal position and Height-Z for vertical position. The displacements generally represent the actual collide accident of crash cushion by errant vehicle. The simulation shows that displacement had similar trend with the experimental results.

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