Research Article

Tensile Properties and Impact Analysis of the Composite Waste Tire Sandwich Structure as a Crash Barrier

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Abstract: *Road accidents and disasters were increasing, killing many. Global governments were boosting transportation infrastructure. Crash barrier systems were strong protection barriers placed between road or track lanes to reduce collisions. Over 2020–2030, crash barrier systems were expected to grow rapidly. First, a low-cost composite waste tire sandwich structure was created. Polypropylene, waste tire, coconut fiber, and aluminum powder formed the composite. Each composition had five dumbbell shapes with filler percentages of 0, 5, 10, 15, and 20. Second, characterize and analyze the composite's composition and mechanical properties. For data, the sample was tensile tested. Tensile strength, Young's modulus, and elongation at break were measured. Third, finite element analysis compared the impact properties of the new and old W-beam structures. Current and new sandwich structure crash barrier impact properties were examined. The new crash barrier is steel-rubber composite steel. SolidWorks was used to design the crash barrier CAD model and Abaqus Explicit Software simulated the dynamic analysis of the most common crash barriers on Malaysian highways and the new design. Simulated data followed. This research product can replace the standard crash barriers. According to simulations, the sandwich structure could absorb more energy than the standard W-beam crash barrier. It was more rigid and impact resistant.*

Keywords: Roadside safety; Crash barrier; sandwich structure; Abaqus; Simulation; Impact Energy Absorption.

1. INTRODUCTION

Traffic accidents have increased over the past decade, according to Malaysia's Ministry of Transport's homepage. Over the past decade, fatalities have dropped from 7,152 in 2016 to 6,167 in 2019. Malaysia uses mostly w-beam crash barriers, so the research will focus on them. Malaysia's rural motorway has 91% W-beam guardrails, according to MIROS research. Another study found that guardrails reduce road crash injuries and damages rather than preventing them, especially when hitting a bridge or tunnel. Sandwich structures are subsets of multi-layered composite structures (Amir AL et al., 2021).

Sandwich structures have skins, cores, and adhesives or brazing. Sandwich structures require knowledge of face sheet and core properties. Today's industries need stiff, light components. Sandwich structure technology is being developed for lightweight, high-stiffness components (Zaid NZM et al., 2016). In recent years, several types of sandwich constructions with enhanced quasi-static and dynamic properties have been developed, including those based on various foams, honeycomb cores, origami cores, and truss cores.

The Finite Element Method has previously been used to build models of road safety systems to test their performance in various impact scenarios. Ogmaia D & Tasel SE (2015) examined whether finite element software Abaqus/Explicit could simulate crashes. Full-scale tests modeled the parapet installation and vehicle. The simulation ran under full-scale experiment conditions. Abaqus/Explicit can simulate a full-scale crash with the right car model and test the installation model. Aziz et al. (2018) used Abaqus to simulate the barrier's impact response. A rigid impactor weighing 900 kg at 20 degrees from the reference plane would impact at 100 km/h. The simulation results were satisfactory when compared to the experimental results.

Shen et al. optimized the vertical distance between the vehicle's center of gravity and the W-beam mounting height to improve guardrail crashworthiness. This study used Abaqus/Explicit v6.5 to simulate the safety barrier's collision response. The design with a vertical distance of 600millimeterss between the vehicle's center of gravity and the W-beam mounting height absorbed the most energy during the collision simulation. This study shows that ABAQUS/Explicit can simulate road barrier contact crashes (Shen X, Guo L, Yang L, et al., 2008). Lekhak et al. (2019) tested semi-rigid and flexible crash barriers for energy absorption and ASI value. Abaqus was used to model three types of barriers. Cable, w-beam, and three-beam steel crash barriers were used. A simplified vehicle model hit the barriers to complete the Abaqus simulation. This model hit at 60 km/h and 20°. The cable barrier had the best crash energy absorption and ASI value in model simulations. Cable barrier results were optimal.

2. METHOD & MATERIAL

The development of this project will involve a few stages and phases, some of which will be the preparation of composite samples, the testing of composites, and the simulation of an impact analysis.

2.1 Preparation of composite sample

New composites are made up of four materials that are polypropylene, waste tire, coconut fiber, and aluminum powder. The material is mixed in a HAAKE Rheomix PolyLab QC Lab Mixer. The mixing takes about an hour to fully mix. Table 1 shows the percentage of the composites in each sample.

Table 1. Formulation of the materials composite in the specimens

Specimens	**Materials (%)**			
	Polypropylene	Tire Waste	Coconut Fibre	Aluminum powder
Control	70	30	-	-
1	70	30	5	3
2	70	30	10	3
3	70	30	15	3
4	70	30	20	3

HAAKE Rheomix PolyLab QC Lab Mixer is used for 1 hour per sample at 180°C and 60 rotations per minute. After mixing, the composite rests. The composites are labeled. Hydraulic vulcanizing press machines will shape composites into rectangles after mixing. Pressing and resting the composite will take four minutes. After cooling, composites will be cut into 2mm-thick following the ASTM D412 standard.

2.2 Tensile Testing of Composites

The tensile test will be run using the Galdabini model Quasar 100. The crosshead speed is set to 10mm/min with a gauge length of 50mm and a load of 10 kN. From the tensile testing, three data will be obtained that is tensile strength, Young's modulus, and elongation at break.

2.3 Simulation of an Impact Analysis

ABAQUS 2020 analyses the impact crash test between standard W-beam and sandwich structure W-beam. Post bottoms had fixed boundary conditions. The simulation assumed bolt connections between beams, posts, and spacers through tie interactions. Drawing the W-beam uses AASHTO M 180 - 89 dimensions (Class A Type 2). The two-meter W-beam. S355JR, the W-beam metal. The composite's material properties are in result and discussion.

Table 2. Material properties of steel

Young's Modulus, E (MPa)	**210000**
Poisson's Ratio, υ	0.3
Yield Stress, σy (MPa)	355
Density (ton/mm3)	7.8e-9

After developing all simulation components, a model could be assembled. After assigning material attributes to model parts, they were imported into the assembly module like in Figure 1 to form the model. Translate and rotate joined the pieces. At the bottom of each barrier post, fixed conditions for the boundary were put in place.

The velocity chosen is 90 km/h. For Abaqus software, the velocity must be converted to millimeters per second (mm/s) as a universal unit that is 25000mm/s. The nominal mass used in research standard crash tests was 1500 kg, which was used to represent light vehicles. To represent impact conditions of speed, speeds of 25000mm/s were used as per the design speeds for mountainous terrain. The simulation period is two milliseconds.

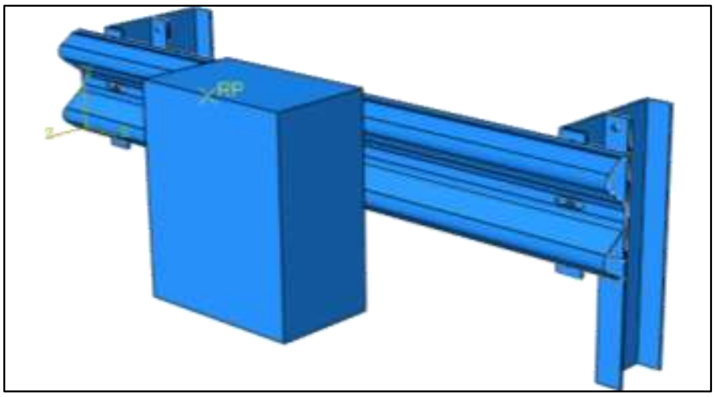

Figure 1. Assembled modelling.

3. RESULT AND DISCUSSION

3.1 Experimental Result

There were all five samples for each filler, but only the best three are chosen for this research. The data will be averaged out for the findings of the tensile strength, young`s modulus, and elongation at break.

Table 3. Experiment data for tensile test.

Filler loading	Tensile strength (MPa)	SD	Young's modulus (MPa)	SD	Elongation at break (%)	SD
PP/WT	3.80	0.27	58	10.26	22	1.4
PP/WT/CF/A1	4.20	0.27	62	11.53	18	1.1
PP/WT/CF/A2	4.35	0.52	70	4.51	14	0.5
PP/WT/CF/A3	5.13	0.22	96	12.66	13	0.1
PP/WT/CF/A4	4.07	0.39	97	9.45	12	2.7

3.1.1 Tensile strength

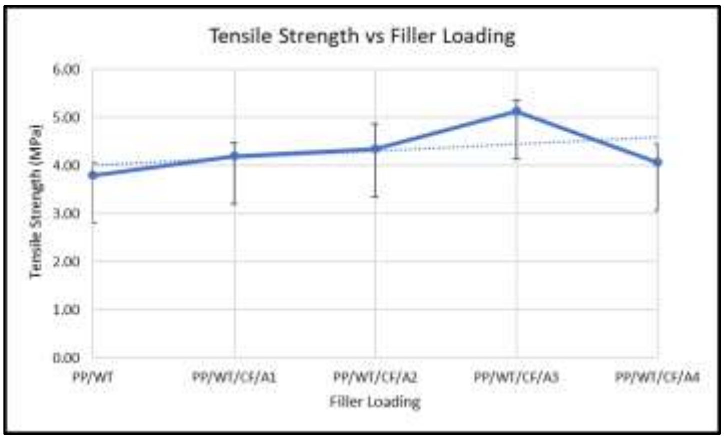

Figure 2. Tensile strength vs filler loading

The tensile slightly increased but when reach 20% filler loading, the tensile decreased. Density matters in tensile properties for lightweight materials (Sathishkumar TP et al., 2012). In another case, Song et al. (2005) explained that stress transfers improve tensile strain capacity, increasing tensile strength for reinforced concretes over unreinforced controls. The trend of the graph is increasing.

3.1.2 Young's modulus

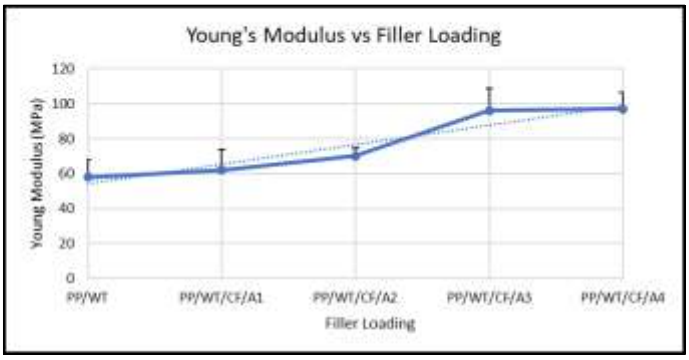

Figure 3. Young's modulus vs filler loading.

The graph indicates that the pattern of Young's modulus is slightly increased proportionally to the filler loading. Salmah et al. (2014) proved that Young's modulus increase due to additional reinforcement content is due to the increase of stiffness. The trend of the graph is increasing.

3.1.3 Elongation at break

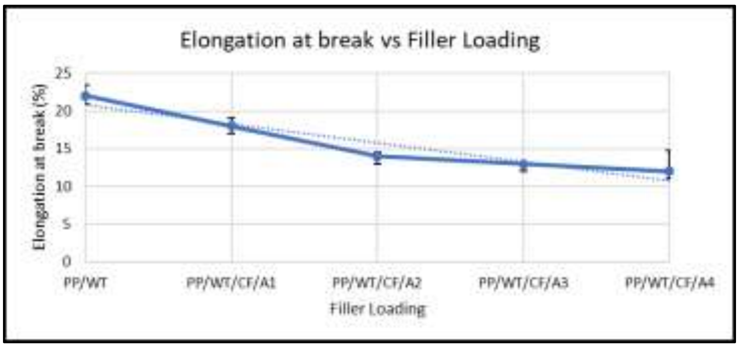

Figure 4. Elongation at break vs filler loading.

The graph indicates that the pattern of elongation at break continuously decreased as the filler loading increased. Salmah et al. (2014) proved that the elongation at break decrease due to the weak interfacial bonding between reinforcement and matrix surface. The trend of the graph is decreasing.

3.2 Analysis result for dynamic simulation

After the tensile test, Abaqus will simulate the composite material's tensile strength and Young's modulus. After that, data will be collected to compare to the simulation result, and the results are listed as follows.

3.2.1 Result Simulation of Stress and Deformation

Table 4. von Mises stress and deformation.

Sample	von Mises (MPa)	Deformation (mm)
Standard w-beam	1371	51.12
PP/WT	1197	47.16
PP/WT/CF/A1	1255	47.2
PP/WT/CF/A2	1183	47.23
PP/WT/CF/A3	1181	47.24
PP/WT/CF/A4	1241	47.25

The standard W-beam has the highest stress, which is 1371 MPa, as shown in Table 4, The material with the lowest von Mises stress is PP/WT/CF/A3 with a value of 1181 MPa. All the sandwich structure W-beam gets results lower than the standard W-beam in terms of von Mises stress. This demonstrates that the sandwich structure has reduced the von Mises stress in the W-beam. In any structural design, stress should be as low as possible.

The deformation of the W-beam measured in millimeters is presented in Table 4, The standard W-beam exhibits the greatest amount of deformation, measuring 51.12 millimeters. With a value of 47.25 mm, the PP/WT/CF/A4 paper has the least amount of deformation output. The w-beam with the sandwich structure experiences a steadily decreasing amount of deformation. The findings indicate that the degree of rigidity of the parts contributes significantly to the amount of deformation that occurs. When the part's stiffness is increased, the amount of deformation that the W-beam interactions drop.

3.2.2 Internal energy and absorbed energy

The results of the simulation are presented in Table 5, under the heading "Internal Energy Obtained." The value of the standard w-internal beam's energy, which comes in at 2250.57J, is the lowest. The PP/WT/CF/A4 had a value of 6550.81J, which was the highest possible internal energy that could be obtained from the simulation. The sandwich structure has been contributing to an increase in internal energy. The pattern that emerges from this table is that the amount of internal energy obtained from the W-beam increases proportionally with the filler loading.

The lowest absorbed energy percentage is the standard W-beam which is 0.48%. while the highest absorbed energy percentage is the PP/WT/CF/A4 composite structure which is 1.4%. the trend of the absorbed energy is increasing. When the sandwich structure is added to the W-beam, the absorbed energy will increase even though the percentage is small because the simulation is run with a time step of 2ms. The sandwich structure performs much better than the standard W-beam.

Table 5. Internal Energy Obtained

Sample	Internal energy (J)	Absorbed energy (%)
Standard W-beam	2250.57	0.48
PP/WT	6355.99	1.36
PP/WT/CF/A1	6429.91	1.37
PP/WT/CF/A2	6474.91	1.38
PP/WT/CF/A3	6505.81	1.39
PP/WT/CF/A4	6550.41	1.4

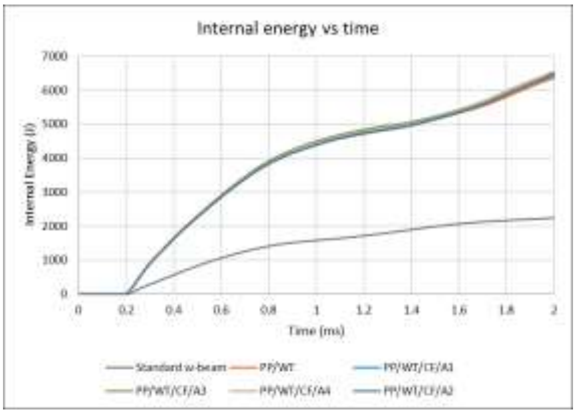

Figure 5. Internal energy vs time.

4. COMMERCIALIZATION POTENTIAL

A composite based on waste materials has significant commercialization potential. Waste materials such as tire waste can be cost-effective, as the waste material is often available at huge amounts and low prices or even free. The composites that are used in tire waste can be lightweight but still strong and durable making them suitable for a variety of applications such as use in a crash barrier sandwich structure. According to the u.s. epa, using tire waste as the raw material for making composite structure also have environmental benefits, as it can reduce the amount of waste in landfills, and it can reduce greenhouse gas emission.

Continuation research and development of the full potential of making composite using tire waste are an innovative application for tire waste composites in the future.

5. CONCLUSION

First, varying reinforcement compositions of polypropylene, waste tire, coconut fiber, and aluminum powder (PP/WT/CF/A) were successfully developed. The composite's mechanical properties were characterized and analyzed for the second objective. Tensile strength increased until 15% filler loading, then decreased. 29.8% separates maximum and minimum tensile strength. The matrix cannot cover all the material at higher filler loading percentages, decreasing strength. Filler loading increases Young's modulus. stiffening. 50.3% separates the maximum and minimum Young’s modulus. The composite matrix filler toughened the elongation of break. 58.8% separates maximum and minimum break elongation. Thirdly, impact properties were compared between the new and existing w-beam structure. W-beam stress drops by 14.9%. 8.1% less W-beam deformation. W-beams gain 97% internal energy. Overall, PP/WT/CF/A4 has greater absorption compared to the new W-beam sandwich structure and it also has a significant commercialization potential.

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