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A Comparative Study Between Conventional Concrete and Concrete Made from Plastic Waste by Using SolidWorks Software

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Abstract

Production of conventional concrete leads to several negative impacts on the environment while the plastic waste concrete can effectively overcome the environmental issues and having better performance than conventional concrete. Therefore, this research presents the works in producing new concrete by replacing the fine aggregates in concrete by using a mixture of soft and hard plastic waste with different ratios density. In addition, this research also aims to evaluate the mechanical and physical properties of different ratios of fine aggregate plastic waste in producing a concrete. At the end of this research, a comparison is made between the optimum composition of plastic waste concrete and conventional concrete. This study is conducted by using SolidWorks software version 2021. The tests conducted include compressive strength test, drop test, and failure analysis. The results from the compressive strength test revealed that a force at 100kN with 20% plastic waste (Sample B) showed the highest stress (18.91 MPa). Meanwhile, from the drop height of 2.0m, the impact strength of Sample B showed the highest result with a value of 7.830 x106 N/m2. However, failure analysis results revealed that Sample B has more cracking than Sample A. From the study carried out, it can be summarised that an optimum replacement of 20% plastic waste as fine aggregates in a concrete gives the best performance is the most suitable option to be used as a replacement concrete in construction.

1. Introduction

Concrete is made up of cement, fine aggregate, coarse aggregate, and water [1]. Concrete is a composite material that is mostly used as one of the construction materials. Generally, concrete plays a vital role in construction works because of its strength, long-lasting, low cost, and can withstand extreme weather environment [2]. In addition, concrete is simple to work with and can be moulded into various shapes and sizes. It is also considered as a safe construction material during natural disasters such as earthquakes [3]. Nevertheless, the production of concrete also leads to several negative impacts on the environment. The English international affairs state that concrete production contributes approximately eight percent of the world's carbon dioxide emissions [1]. As a result, the emissions of carbon dioxide become a potent greenhouse gas, which can cause climate change across the world. According to Matt McGrath [4], due to the rapid development and a large amount of concrete production, the global temperature has risen significantly and the world is warmer than before. Hence, sea levels are increasing rapidly [4]. In recent years, many studies have been conducted to produce alternative concrete made from waste materials. Among the waste materials that are used by the previous researchers to replace the composition of fine aggregate in concrete are cigarette butts [5]; bottom ash [6]; plastic waste [7], and crushed glasses [8]. From the studies conducted, it can be summarized that the utilization of waste material in producing concrete maintains the mechanical properties of concrete effectively from compressive strength, tensile strength, or shrinkage and creep [6]. Other than that, the productive use of waste materials in producing concrete can effectively overcome environmental issues such as pollution, global warming, or natural disasters because the production of conventional concrete may release a lot of greenhouse gases into the atmosphere.

Therefore, the gap of this study is interested to determine the suitability of mixture of hard and soft plastic waste as a replacement of fine aggregate in producing a concrete simultaneously. In order to achieve the aim of this study, three objectives were formulated. The first objective is to determine the optimum composition of different ratios of fine aggregate plastic waste in producing a concrete by using SolidWorks software. Next, an evaluation of the physical and mechanical properties of different ratios of fine aggregate plastic waste in producing a concrete is carried out by using SolidWorks software. Finally, the properties of the optimum composition of plastic waste concrete are compared with the conventional concrete. The tests are conducted by using SolidWorks software namely, compressive strength test, drop test, and failure analysis.

1.1 Compressive Strength Test

A compressive strength test is about the capacity of concrete to withstand pushing forces from an axial direction without any crack or deflection [9]. The compressive strength test of a concrete is conducted by using a concrete cube on a compressive testing machine by applying loads onto the top surface of the concrete until it cracks. The compressive strength can be calculated by using the following equation [10]:

$$\text{Compressive strength} = \frac{Maximum\ load\ carried\ by\ specimen\ (N)}{\text{Area top surface of specimen (mm2)}} \quad (1)$$

Table 1 summarizes the summary of compressive strength test results of selected past researches on concrete replacement from waste materials.

Table 1 *Summary of compressive strength results of selected past researches on concrete replacement from waste materials*

Waste material	Results	Source
Cigarette butts	The compressive strength of cigarette butts in concrete decreases gradually with the increase of adding cigarette butts.	[11]
Bottom ash	Bottom ash increases the compressive strength of concrete, but cannot be used in a large amount.	[6]
Plastic waste	The compressive strength of plastic waste in concrete has been found to decrease gradually with the increase of adding plastics.	[12]
Crushed glass	With an increasing crushed glass in concrete, the strength of concrete increases.	[11]

1.2 Drop Test

Drop test is used to determine an object's ability to withstand a defined amount of physical impact by dropping it from a specified height onto a hard surface or floor [13]. During the drop test, the concrete block should maintain its shape after dropping on the ground surface without any damage. Table 2 shows the summary of selected past researches on the drop test results conducted to the concrete made from waste materials.

Table 2 *Summary of drop test results of selected past researches on concrete replacement from waste materials*

Waste material	Results	Source
Micro-steel fiber	The strength of concrete with micro-steel fiber decrease with increasing drop heights and weights.	[14]
Cigarette butts	The use of cigarette butts in concrete can improve the impact value of concrete.	[11]
Crushed glass	The use of crushed glass in concrete can improve the impact value of concrete.	[11]

1.3 Failure Analysis

Failure analysis is a method of identifying and investigating the reason for a failure. During the process, various corrective actions are taken to recover and address the problems from getting worst [15]. The most common failure analysis technique that is used by previous research works is the Root Cause Failure Analysis (RCFA) [16], [17]. RCFA is one of the effective techniques in solving manufacturing production issues accurately and effectively. RCFA is used to identify the root cause behind a problem and provide an accurate solution to solve the problem [18].

2. Materials and Methods

In this study, a mixture of hard and soft plastics will be used and prepared in different ratios to replace fine aggregate in producing concrete. Hard plastic in this context refers to High-Density Polyethylene (HDPE) while the soft plastic refers to Low-Density Polyethylene (LDPE). At the same time, a control sample with 100 % fine aggregate of concrete is also prepared to compare the properties between conventional concrete and concrete made from plastic waste. Five samples of fine aggregate plastic waste are prepared. The ratios of the samples prepared by plastic waste are 20 %, 40 %, 60 %, 80 %, and 100 % respectively [19]. In this study, the samples are designed in a cube with a size of 100 mm x 100 mm x 100 mm. The drafting standard and unit system under the document properties are set up before the designing process. After the sample cube is produced, right-click the Material in Feature Manager Design Tree. Edit material for the cube. The physical and mechanical properties of plastic waste concrete and conventional concrete were tested by using SolidWorks software version 2021. SolidWorks software is a mechanical design automated software that allows designers to swiftly sketch out concepts, play around with features and measurements, and create models and detailed drawings [20]. The tests involved are compressive strength test, drop test, and failure analysis. The mechanical properties of concrete made from plastic waste are tested by using the compressive strength test and drop test. Meanwhile, the physical properties of concrete made from plastic waste are determined by failure analysis. In compressive strength test, a study is created. The save completed cube file is opened and the simulation tool in the Office is chosen. On the simulation tool, Study Advisor is selected and Static is chosen. Next, the material to be used is selected and applied. In this case, the materials chosen are fine aggregate, soft and hard plastics. Secondly, in the Simulation study tree, right-clicked the Fixture folder and clicked Fixed Geometry. Thirdly, in the SolidWorks Simulation Manager tree, right-clicked the External Loads folder and Force is selected. Fourthly, in the Simulation study tree, right-clicked the Mesh icon and selected Create Mesh. Fifthly, in the Simulation study tree, right-clicked the First Study icon and clicked Run to start the analysis. When the analysis is completed, SolidWorks Simulation automatically generates default result plots stored in the Results folder. The plus sign beside the Results folder is clicked and all the default plots icons appear. Then, double-clicked Stress1 (-vonMises-) to display the stress plot. All the 5 samples, which are Sample A, Sample B, Sample C, Sample D, and Sample E are tested with three different forces, which are 1 kN, 10 kN, and 100 kN in the compressive strength test.

In the drop test, the SolidWorks simulation is changed into SolidWorks Simulation Professional. Then, a study is created. The save completed cube file is opened and the simulation tool in the Office is selected. On the simulation tool, Study Advisor is selected and Drop test is chosen. Next, the material to be used is selected and applied. Secondly, Setup is selected and inserted the drop height, acceleration of gravity, and the orientation of the impact plane. The program automatically calculates the velocity before impact (2Gh) 1/2 (G stands for gravity, h is for drop height and velocity is square root of 2 x gravity x height). The top surface of the cube is chosen as the face for direction, while the gravity reference is pointed downward. The default angle of the floor or other surface onto which the cube drops are normal to gravity. Thirdly, in the Simulation study tree, right-clicked the Mesh icon and Create Mesh is selected. Fourthly, in the Simulation study tree, right-clicked the Second Study icon and Run is clicked to start the analysis. When the analysis is completed, SolidWorks software automatically creates default result plots stored in the Results folder. The plus sign beside the Results folder is clicked and all the default plots icons emerged. Then, Stress1 (-vonMises-) is double-clicked to display the stress plot of sample. All the 5 samples in this study, which are Sample A, Sample B, Sample C, Sample D, and Sample E are tested with four different heights, which are 0.5m, 1.0m, 1.5m, and 2.0m in the drop test. All of the data obtained are recorded and analysed by using Microsoft Excel. The flowchart of the research methodology is presented in Fig. 1.

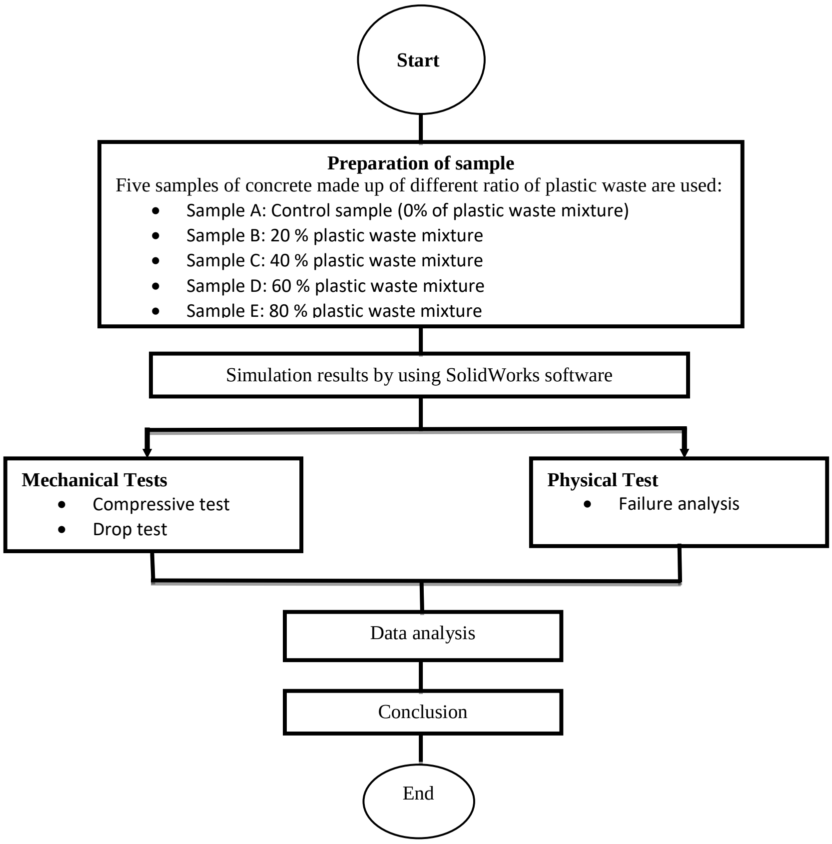


Fig. 1 *Flowchart of research methodology*

3. Results and Discussion

Table 3 shows the results of compressive strength test from the SolidWorks software simulation analysis. The data indicated that at a percentage of 20% plastic ratio with a force at 10 kN gives the best performance in producing a concrete.

Table 3 *Results of compressive strength test*

No.	Sample	Plastic waste ratio (%)	Stress (N/mm2) (MPa)		
			1 kN	10 kN	100 kN
1	A	0	0.1532	1.532	15.32
2	B	20	0.1238	1.238	18.91
3	C	40	0.1280	1.279	12.79
4	D	60	0.1320	1.320	13.20
5	E	80	0.1359	1.359	13.59

Penerbit UTHM

As shown in Fig. 2 below, when the force increases, the effect of plastic ratio decreases. Thus, it can be said that increasing plastic ratio will not increase the strength of concrete made from plastic waste under high force (100kN). Therefore, it can be said that at a percentage of 20% plastic ratio with a force at 10 kN gives the best performance in producing a concrete. In addition, the 20% plastic waste concrete is also suitable for construction as it follows JKR standard, in which the compressive strength of plastic waste concrete (18.91 N/mm2) exceeds the minimum permissible average compressive strength for concrete (5.2 N/mm2) [21]. This finding is in line with previous research works conducted by Ali et al. [22]. In their study, Ali et al. [22] have proven that using 3% HDPE plastics in producing concrete illustrates the best performance (15.9 N/mm2) for compressive strength of concrete. It can be concluded that less plastic waste gives better performance in producing concrete [22, 23].

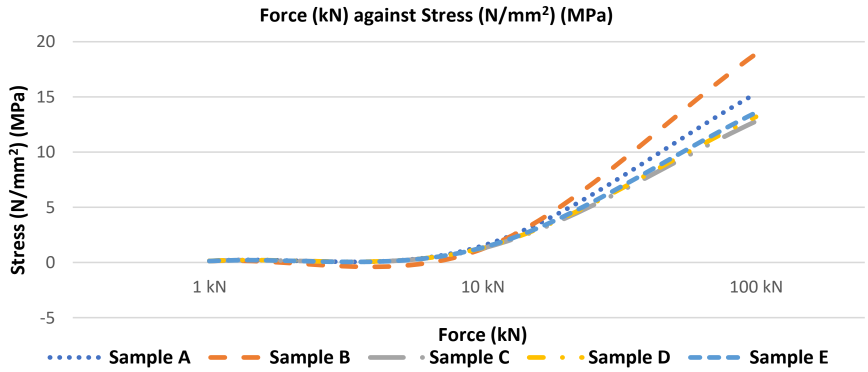
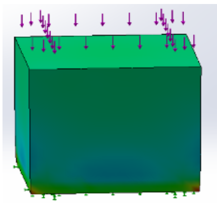
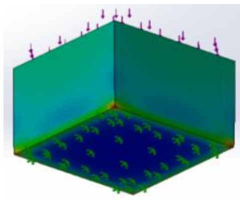
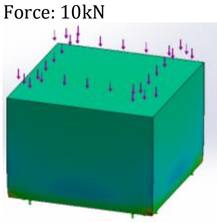
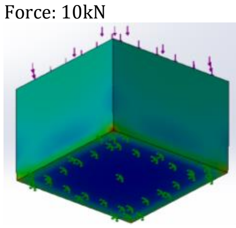


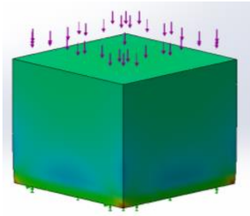
Fig. 2 *Force (kN) against stress (N/mm2) (MPa)*

From the compressive strength test results, Sample B gives better compressive strength than Sample C, Sample D, and Sample E. Therefore, the failure analysis is conducted based on the comparison between the control sample (Sample A) and the optimum sample (Sample B) after the simulation of compressive strength test. Table 4 shows the failure analysis results between compressive strength of Sample A and Sample B.

Table 4 *Results of compressive strength test between Sample A and Sample B*

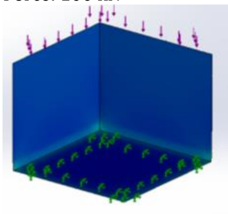
Sample A	Sample B
Force: 1kN	Force: 1kN
	
Load at failure: 0.1532 MPa	Load at failure: 0.1238 MPa
Force: 10kN	Force: 10kN
	
Load at failure: 1.532 MPa	Load at failure: 1.238 MPa

Force: 100 kN



Load at failure: 15.32 MPa

Force: 100 kN



Load at failure: 18.91 MPa

In terms of failure analysis, the analysis is conducted based on the comparison between the control sample (sample A) and the optimum sample (sample B) at different compressive force, namely 1kN, 10kN and 100kN. At 1kN force, the load of failure of sample A (0.1532 MPa) is higher than sample B (0.1238 MPa). In addition, the load of failure of sample A (1.532 MPa) is also higher than sample B (1.238 MPa) at 10kN force. However, at 100kN force, the load of failure of sample B (18.91 MPa) is higher than sample A (15.32 MPa). It can be said that under low force (1kN) and medium force (10kN), the effect of plastic ratio does not affect much the compressive strength in the plastic waste concrete compared to the high force (100kN). As the force gets higher, the increasing plastic ratio in a concrete will not improve its strength. Therefore, it can be said that plastic concrete can be used as a concrete for development such as panel, boundary, or filling for floor and roof slabs. This is because the presence of plastic waste in concrete performed crystalline structures with more cross-linking in the concrete, which block pores within concrete, making the concrete denser and stronger than conventional concrete [24]. Therefore, the use of plastic waste in producing concrete is more stable than conventional concrete [22, 23, 24].

3.1 Drop Test Results

Table 5 shows the results of plastic waste concrete with the lowest plastic ratio (sample B – 20%) to the highest plastic ratio (sample E – 80%). The samples were dropped from four different heights, which are 0.5m, 1.0m, 1.5m, and 2.0m. The results revealed that the stress of impact for all samples increases when the drop height increases. Sample A is used as a control sample in this study. Sample B with the lowest plastic ratio had the highest impact strength while sample E with the highest plastic ratio had the lowest impact strength. This is because higher dosage of plastic fibres reduces the cohesive strength between plastic and cement in the concrete. Therefore, the higher the drop height, the more damage it caused to the sample with higher plastic ratio.

Table 5 *Results of drop test*

Sample	Drop height (m)	Result (x106 N/m2)
A	0.5	19.457
	1.0	29.386
	1.5	36.009
	2.0	41.601
B	0.5	3.903
	1.0	5.528
	1.5	6.775
	2.0	7.83
C	0.5	3.386
	1.0	4.797
	1.5	5.883
	2.0	6.799
D	0.5	2.835
	1.0	4.018
	1.5	4.932
	2.0	5.708
E	0.5	2.69
	1.0	3.801
	1.5	4.653
	2.0	5.367

As shown in Fig. 3 below, when the plastic ratio decreases, the impact strength of samples increases. Thus, it can be said that increasing plastic ratio will not increase the impact strength of plastic waste concrete with increasing drop heights. Therefore, it can be said that at a percentage of 20% plastic ratio gives the best performance in drop test. This is because a higher dosage of plastic fibres reduces the cohesive strength between plastic and cement in the concrete. The higher the dosage of plastic fibres, the more it will occupy the surface area and thus, result in insufficient bonding or adherence of fibres in the concrete. As a result, the mechanical property of plastic waste concrete has to be improved with an optimum plastic ratio. This finding is in line with previous research works conducted by Bhogayata and Arora [25] in which their results indicated that the addition of plastic fibres in producing concrete can improve the impact resistance of conventional concrete. The impact resistance of the samples improved at the initial cracking and final cracking.

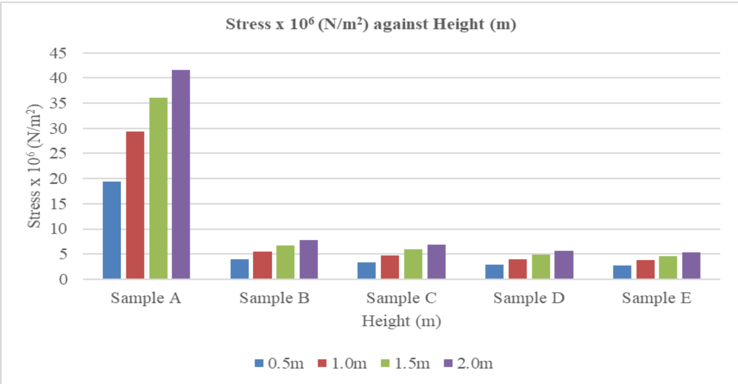
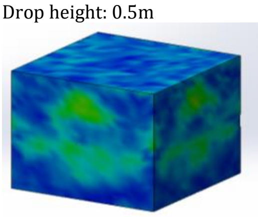
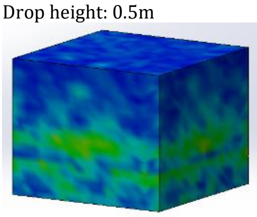
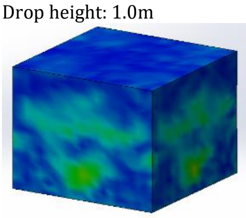
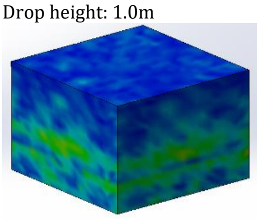
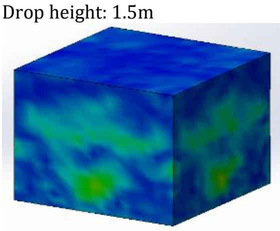
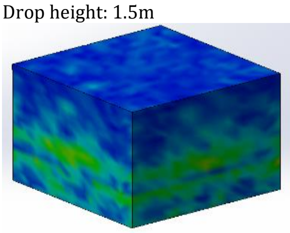
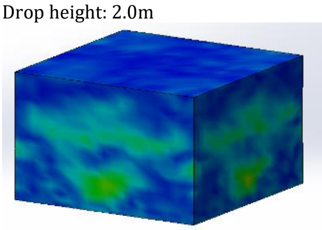
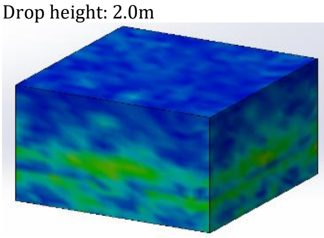


Fig. 3 *Stress x 106 (N/mm2) against Height (m)*

From the drop test results, Sample B gives better impact strength than Sample C, Sample D, and Sample E. Therefore, the failure analysis is conducted based on the comparison between the control sample (Sample A) and the optimum sample (Sample B) after the drop test simulation result. Table 6 shows the failure analysis results after drop test between Sample A and Sample B.

Table 6 *Results of drop test between Sample A and Sample B*

Sample A	Sample B
Drop height: 0.5m  Result: 19.457 x 106 N/m2	Drop height: 0.5m  Result: 3.903 x 106 N/m2
Drop height: 1.0m  Result: 29.386 x 106 N/m2	Drop height: 1.0m  Result: 5.528 x 106 N/m2
Drop height: 1.5m  Result: 29.386 x 106 N/m2	Drop height: 1.5m  Result: 5.528 x 106 N/m2
Drop height: 2.0m  Result: 36.009 x 106 N/m2	Drop height: 2.0m  Result: 6.775 x 106 N/m2

In terms of failure analysis, the analysis is conducted based on comparison between the control sample (sample A) and the optimum sample (sample B). During impact, the stress was concentrated at the bottom of the concrete cube. The more colour change at bottom of samples indicates the sample has experienced more cracking in the drop test simulation. At the 0.5m drop height, sample A (19.457 x 106 N/m2) has higher impact strength than sample B (3.903 x 106 N/m2), which means that sample A is more stable than sample B. At the 1.0m drop height, sample A (29.386 x 106 N/m2) has higher impact strength than sample B (5.528 x 106 N/m2) with more colour change at bottom sample B than sample A. At the 1.5m drop height, sample A (36.009 x 106 N/m2) also has higher impact strength than sample B (6.775 x 106 N/m2) with more colour change at bottom sample B than sample A. At the 2.0m, sample A (41.601 x 106 N/m2) has higher impact strength than sample B (7.83 x 106 N/m2) with more colour change at bottom sample B than sample A. From the results, it can be summarised that even though sample B has more cracking than sample A, sample B is still stable and can be used for construction. This is because the existence of the plastic waste material is able to improve the impact strength of the concrete [26].

4. Conclusion

From the study that was carried out, in can be concluded that an optimum replacement of 20% plastic waste as fine aggregates is the most suitable option to be used as a replacement concrete in construction. This is because in terms of the compressive strength, at a force 100kN, Sample B showed the highest stress (18.91 MPa) compared to the other sample. Meanwhile, from the drop height of 2.0m, the impact strength of Sample B showed the highest result with a value of 7.830 x10^6 N/m^2. However, one of the biggest limitations that occurs when conducting this study is that the simulation test only shows the results simulatively but unable to determine the accuracy of the result. Therefore, lack of accuracy in simulation tests make it difficult to verify the precision of the result. To overcome the limitations of the research, it is recommended that experimental testing must be conducted to determine the results obtained from the simulation study. Among the experimental tests that can be conducted include:

i) Tensile strength test;
ii) Thermogravimetric Analysis (TGA);
iii) X-ray diffraction (XRD); and
iv) Scanning Electron Microscope (SEM).

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Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

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