Effect of Palm Oil Fiber (POF) to Strength Properties and Fracture Energy of Green Concrete

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ABSTRACT

The lack of research on concrete which utilizes Palm Oil Fuel Ash (POFA), Rice Husk Ash (RHA), Recycled Concrete Aggregate (RCA) and Palm Oil Fiber (POF) simultaneously in concrete was globally observed. To meet this gap, a study on green concrete consisting of POFA, RHA and RCA with added untreated POF as binders was conducted. The study focusses on the effect of varying percentages of untreated POF, ranging from 0%, 0.25%, 0.50% and 0.75%, to the strength properties and fracture energy of green concrete. The strength properties of green concrete were investigated by conducting the compression strength test and tensile strength test on forty-eight (48) cubes and cylinders at the curing age of 7 and 28 days. The tests show that the strength of green concrete decreases, as the percentage of POF increases. This was preceded by the establishment of an optimum percentage of POF at 0.25%. The fracture energy of the green concrete was determined by testing twelve numbers of notched beams with dimensions of 100mm x 100mm x 500mm under the three-point bending test. From the three-point bending test, the load-deflection profile for each specimen with different percentages of untreated POF was obtained. Three existing theoretical models, namely Hillerborg, Bazant and CEB models were used to measure the fracture energy of the green concrete with varying percentage of fiber. Results range from 37.94 N/m to 153.81 N/m was observed. The study also successfully established the reliability of Hillerborg's model to fracture energy when models by Bazant and CEB surprisingly shows a decrease in fracture energy measurements with increase in fiber content.

Keywords: Fracture Energy, Green Concrete, Palm Oil Fuel Ash, Palm Oil Fiber, Recycled Concrete Aggregate, Rice Hush Ask, Strength Properties

1.0 INTRODUCTION

The government of Malaysia encourages the construction industry (by offering incentives) to promote the growth of sustainable development by environmentally friendly and sustainable resources [1]. Adopting the concept of using green materials is important to make sure that the irreversible environmental impact due to construction can be mitigated. Therefore, the selection of material used in the production of green concrete may act as the strategy in constructing the eco-friendly building. Malaysia is a tropical country with generous rainfall which favours the growth of an agriculture sector. Hence, the palm oil industry of Malaysia is one of the largest producers and exporters in the world. However, this also means that Malaysia is also producing many amounts of agriculture waste from the palm oil industry. The wastes from palm oil have good potential for producing green concrete by further processing the empty fruit bunches, fibers and shells of the palm oil. Through burning of palm oil agriculture waste including fibers, shells and empty fruit bunches as fuel in palm oil mill boilers a by-product called Palm Oil Fuel Ash or POFA is obtained. POFA, with its pozzolanic properties, can be used as a supplementary cementitious material for the production of concrete with good workability rate and high strength concrete. Another agriculture waste which contributes to the development of green concrete is Rice Husk Ash or RHA. Rice husk is generated from the rice milling industry during the milling of paddy. In the combustion process, a carbon neutral green material called RHA is produced with super-pozzolan characteristics. The growing demand on fine amorphous silica encourages this super-pozzolan RHA to be used for producing green concrete with high strength but low permeability. Industrial experts have also recognized the value in breathing new life from old concrete known as recycled concrete aggregate or RCA. Countless concrete structures are being demolished each year for several purposes such as refurbishment, renovation and repairing work. Hence, recycling the concrete is an effort to reduce the amount of raw materials needed to produce stone aggregate at the same time saving the waste concrete ended up in a landfill which pollute the environment. RCA materials are thoroughly screened to remove any metal, scrap or other impurities. It is then crushed down to a smaller aggregate size so that it can be repurposed for other construction and landscaping purposes. Therefore, production of green concrete is innovative as it makes good use of waste materials as part of its components.

2.0 LITERATURE REVIEW

To address the sustainability of the environment, three specific issues have been identified by the Construction Industry Development Board (CIDB). These issues are lack of sustainability-rated construction; buildings and infrastructure are not always resilient to natural calamities, high carbon emissions and energy usage of buildings and high volume of construction and demolition waste dumping. To safeguard the environment, many efforts are being made by recycling agricultural wastes and construction wastes, hence green concrete is introduced into the construction industry.

Today, pozzolanic materials are widely used as supplementary cement materials in the making of high strength concrete. There are many common types of pozzolans which are globally used as a replacement for Portland cement and an additive in concrete. It is well-known that the filler effect and the pozzolanic reaction contributes to the strength of pozzolanic concrete. Besides that, the pozzolan contains siliceous materials. The "high early strength" concrete are produced by highly reactive silica in pozzolans when combined with calcium hydroxide to give the cementitious properties [1].

Based on the research, the review of the strength properties of hardened concrete which uses POFA as an additive including compressive strength and splitting tensile strength is explained. Replacement of Portland cement with 10-50% of POFA while maintaining the water to cement of 0.6 was studied by most researchers as reported by [2]. From the study, it was found that as the amount of POFA increases, the compressive strength of the concrete decreases. The researchers concluded that 10% was the best level of POFA replacement to avoid interruption of the strength formation in concrete during the curing process. This was proven when the compressive strength testing of lightweight foamed concrete containing 10% and 20% of POFA was measured at 7.17 MPa and 7.06 MPa respectively at 90 days curing. Yet, the control concrete specimen only gives the strength of 6.50MPa. For the split tensile testing containing the same percentage of 10% and 20% of POFA, the specimens were observed to meet a higher strength by 19% and 9% when compared to the control specimen at 90 days. The observation was due to the formation of extra calcium silicate hydrate (C-S-H) gel due to the pozzolanic reaction by POFA enhanced the bonding of the specimen.

Reports by [3] have shown that the raw rice husk consists of about 40% cellulose, 30% lignin group and 20% silica. Commonly, the RHA is produced when cellulose lignin matrix of raw rice husk was burned away and left the porous silica skeleton upon combustion. After grinding the porous silica skeleton of rice husk, rice husk ash (RHA) is produced in the form of a fine powder with the high surface area and its highly reactive pozzolanic material due to its high silica content. Sandhu and Siddique [4] concluded the strength properties of self-compacting concrete (SCC) with the addition of RHA. The researchers [4] concluded that 10%-15% of RHA contribute to the significant influence on the concrete strength properties. At 28 days, a range of compressive strength between 36.7 MPa and 41.2 MPa was achieved. Similarly, the strength of 39.6 - 46.4 MPa was observed on 56 days with 10-20% RHA of water to binder ratio of 0.41 contained in the SCC mix. From the study, 15% of RHA mix attained the largest value of compressive strength, whereas SCC control mix gives a strength of less than 20% of RHA mixed with 56 days curing. This phenomenon was due to the presence of calcium silicate hydrates through the reaction with water and calcium hydroxide by highly reactive RHA particles. Another observation includes 15% replacement of RHA increases the strength properties of split tensile.

It was found that the substitution of RCA up to 30% of virgin aggregate shows similar compressive strength as normal concrete. As for tensile strength, the substitution of RCA on concrete reduces the value by 10%. The tensile strength of concrete was said to be more dependent on the binder quality rather than the aggregate used [5].

The 3rd ACF International Conference [6], established that POF, as a natural fiber, was a suitable binder due to its ability to improve the tensile strength of concrete materials. These concrete material with added POF was also found to be a good fire resistant material with high durability. The main intention to incorporate POF into concrete was to yield reinforcement and delay the growth of cracks by improving the tensile strength. Besides that, it helps to transmit stress across the cracked section in order to achieve larger deformation possible beyond its peak stress. The lengths of POF used ranges from 1-5 cm of the fiber to avoid the fiber balling effect resulting in an uneven distribution throughout the concrete [7]. To avoid the balling effect, research has shown that the percentage of fiber was normally added in the range of 0.25%, 0.50% and 0.75% [8].

The impact of adding untreated POF towards the performance of green concrete against cracking resistance could be measured by fracture energy [9]. Fracture energy is the amount of energy required to create one unit area of crack and it is one of the important parameters that characterize concrete fracture. Fracture energy is the area under the load-deflection curve per unit fracture area. To enhance the crack resistance of green concrete, untreated palm oil fiber is added. The main aim of this research was to determine the fracture energy of green concrete with varying percentage of palm oil fiber. Therefore, the effect of adding palm oil fiber to the fracture energy was investigated by carrying out a series of experimental works using the three-point bending test.

3.0 FRACTURE ENERGY

Fracture energy is the most important parameter that governs the cracking and failure of a certain structure. The value of fracture energy can be determined by using Hillerborg's model [10], Bazant model [11] and Comite Euro-International du Beton (CEB) model [12].

Hillerborg model [10] is the fundamental model that had been used in analyzing the fracture energy for mortar and concrete. The fracture energy for concrete is based on area under the load-deflection curve as follow:

$$G_F = \frac{W_o + m_g \delta_f}{B(D - a_o)} \quad [1]$$

where, W_o is area under load versus deflection curve, m_g is mass of beam, δ_f is maximum deflection, B is width of the specimen, D is depth of the specimen and a_o is notch depth.

Bazant [11] proposed a simple formula to determine the fracture energy of concrete. The formula includes compressive strength and water-cement ratio as follow:

$$G_F = 2.5\alpha_o \times \left(\frac{f_c}{0.058}\right)^{0.4} \left(1 + \frac{D_{max}}{1.94}\right)^{0.43} \left(\frac{w}{c}\right)^{-0.18} N/m \quad [2]$$

where, α_o is aggregate size factor which is 1 for rounded aggregate and 1.44 for angular aggregate, D_{max} is maximum aggregate size, f_c is compressive strength of concrete, $\left(\frac{w}{c}\right)$ is water-cement ratio.

Fracture energy of concrete can also be determined using Comite Euro-International du Beton (CEB) model [12]. CEB model consider the maximum aggregate size and compressive strength of concrete in calculating fracture energy. Formula proposed by CEB is as follow:

$$G_F = [0.0469(D_{max})^2 - 0.5D_{max} + 26] \times (\frac{f_c}{10})^{0.7}\ N/m \quad [3]$$

where, D_{max} is maximum aggregate size and f_c is compressive strength of concrete.

4.0 MATERIALS

4.1 Raw Materials

For this study, the green concrete comprises of four waste materials made from POFA, RHA, RCA and POF, see Figure 1. All the agricultural wastes and construction wastes was collected from different sources. Both POFA and POF were obtained from Bell Oil Palm Plantation located at Parit Sulong, Johor. Whilst RHA was collected from the rice milling factory at Jelapang Selatan, Muar, Johor. Lastly, RCA were obtained from crushed concrete cubes and cylinders available at the Heavy Structures Laboratory, Universiti Tun Hussein Onn Malaysia. To complete the green concrete mix, Portland cement Type 1, sand of saturated surface dry (SSD) condition and natural coarse aggregate with sieve size of 5-9 mm were used.

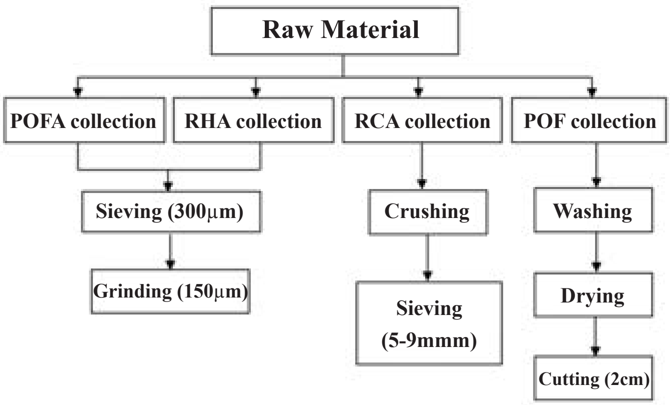


Figure 1: Preparation of Raw Materials

4.2 Concrete Mix Design

The targeted design strength of 30 MPa was employed. The green concrete mix design, as shown in Table 1, was adopted from the American Concrete Institute ACI 211.1 Standard [13]. A total of 48 specimens were cast which consists of 24 cubes of size 100mm x 100mm x 100mm and 24 cylinders of size 100mm x 200mm. There were in total four types of mixtures proposed, namely MC, M1, M2 and M3 with POF at 0%, 0.25%, 0.50% and 0.75% respectively. The specimens were subjected to water curing upon 24 hours of casting and tested at 7 days and 28 days strength. The concrete mixtures for MC, M1, M2 and M3 are as illustrated in Table 2 for cubes and Table 3 for cylinders.

Table 1: Green Concrete Mix Design

Mix Design				
Quantity	Cement (kg/m³)	Fine Aggregate (kg/m³)	Coarse Aggregate (kg/m³)	Water (kg/m³)
1m³	400	872	688	228

Table 2: Compressive Strength

Mixture	Cement (kg)	RHA (kg)	POFA (kg)	RCA (kg)	Coarse Aggregate (kg)	Sand (kg)	Water (kg)	POF (kg)
MC	0.300	0.060	0.040	0.138	0.550	0.872	0.256	-
M1	0.300	0.060	0.040	0.138	0.550	0.872	0.256	0.001
M2	0.300	0.060	0.040	0.138	0.550	0.872	0.256	0.002
M3	0.300	0.060	0.040	0.138	0.550	0.872	0.256	0.003

Note: MC – Control specimen

Table 3: Split Tensile Strength

Mixture	Cement (kg)	RHA (kg)	POFA (kg)	RCA (kg)	Coarse Aggregate (kg)	Sand (kg)	Water (kg)	POF (kg)
MC	0.471	0.094	0.063	0.216	0.864	1.369	0.401	-
M1	0.471	0.094	0.063	0.216	0.864	1.369	0.401	0.002
M2	0.471	0.094	0.063	0.216	0.864	1.369	0.401	0.003
M3	0.471	0.094	0.063	0.216	0.864	1.369	0.401	0.005

Note: MC – Control specimen

5.0 TESTING METHOD

5.1 Material Tests

The slump test was conducted to examine the fresh properties of green concrete. The testing for hardened concrete comprises of it's harden density, compressive strength and split tensile strength. Table 4 list the codes of practises on which the respective test procedures on fresh and hardened concrete was conducted.

Table 4: Code of Practise for the Hardened Concrete Testing

No.	Properties of Concrete	Type of Testing	Codes of Practise
1.	Fresh Concrete	Slump Test	ASTM C143/C143M-15 [14]
2.	Hardened Concrete	Hardened Density	BS EN 12390-7:2009 [15]
3.		Compressive Strength Test	BS EN 12390-3:2009 [16]
4.		Split Tensile Strength Test	ASTM C496/C496M – 04 [17]

5.2 Three Point Bending Tests

Three point bending test on V-notched prisms was adopted to determine the fracture energy of green concrete. The prism specimen size of 100mm x 10mm x 500mm (Figure 2) and the testing method for three point bending test was proposed in reference to ASTM E1820 [18]. Three point bending test was prepared by resting the beam on roller supports and applied point load in the middle span of the beam where the notch was located, see Figure 3. The point load was applied at a rate of 0.5mm/min and a linear variable displacement transducer (LVDT) was used to measure the deflection of the specimen up to failure. The value of the load and deflection at midspan (δ) were recorded continuously

Table 5: Total Number of Prism Specimens with V-Notch

Fiber Content (%)	Specimen ID	Number of Beam Specimen
0.00	0F/S1P	3
	0F/S2P	
	0F/S3P	
0.25	25F/S1P	3
	25F/S2P	
	25F/S3P	
0.50	50F/S1P	3
	50F/S2P	
	50F/S3P	
0.75	75F/S1P	3
	75F/S2P	
	75F/S3P	
TOTAL SPECIMEN		**12**

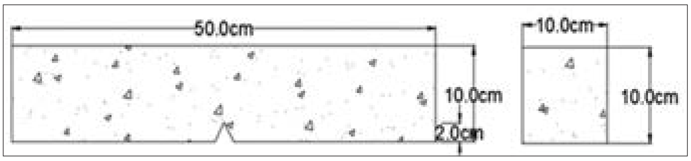


Figure 2: Dimension of Prism Specimen with V-Notch

Figure 3: Three Point Bending Test

by a dedicated computer. The total number of prism specimen and its identification are shown in Table 5.

6.0 RESULTS AND DISCUSSIONS

6.1 Workability

Based on the results illustrated in Table 6, the control specimen (MC) and green concrete mix (M1, M2, M3) with several percentage of POF gave slump values ranging from 50mm (0% POF) to 35mm (0.75% POF), which is about a 30% reduction in slump value. Therefore, it was observed that as the percentage of POF increases, the binding behaviour of POF in the concrete mix effectively reinforcing the fresh matrix, reducing its workability behaviour. However, the lower slump value observed at higher percentage of POF indicate the potential reduction of the moisture content in the green concrete mix. The trend of the slump result was the same as other green concrete with the incorporation of POF which decreases with increased POF [19].

Table 6: Slump Results

Mixture	Slump (mm)	Remark
MC	50	0% POF
M1	42	0.25% POF
M2	38	0.50% POF
M3	35	0.75% POF

Note: MC – Control Specimen

6.2 Hardened Density

The density of hardened green concrete was measured at 7 and 28 days strength and results were tabulated in Table 7. From the results obtained, the density of green concrete shows a slight reduction from 7 days to 28 days. The highest density green concrete was measured with 0% POF while the lowest density was observed at 0.75% POF. This trend was similarly observed by the experimental work from other researchers [20] [21]. At 7 days, the addition of 0.75% of POF (M3) causes a reduction of density by 5% when compared to 0% POF (MC). Meanwhile, a reduction of nearly 4% of density was recorded at 28 days. It is also known that a normal weight concrete density lies within the specified range of 2200 kg/m3 to 2600 kg/m3 [21]. This also highlights the density of green concrete lies within the density of normal concrete.

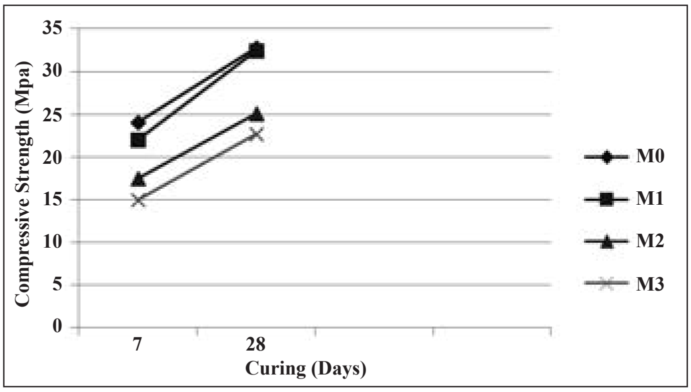
Table 7: Density Development of Green Concrete at 7 Days and 28 Days

Mixture	Dry Density (kg/m3)		Remark
	7 days	28 days	
MC	2244	2267	0% POF
M1	2186	2240	0.25% POF
M2	2160	2196	0.50% POF
M3	2130	2180	0.75% POF

Note: MC – Control specimen

6.3 Compressive Strength Test

Figure 4 shows the development of green concrete with different mix percentage of POF at 7 days and 28 days. From the results obtained, the compressive strength of green concrete at 28 days was higher than that of 7 days. This proved that the strength of green concrete increases during the curing period. At 7 days, concrete mix MC (0% POF) achieved the highest compressive strength of 24.1 MPa with concrete mix M1 (0.25% POF) showing a slightly lower compressive strength properties at 22.0MPa. M3 (0.50% POF) and M4 (0.75% POF) showed lower compressive strength as illustrated in Figure 4. At 28 days strength, all concrete mix (MC, M1, M2 and M3) shows



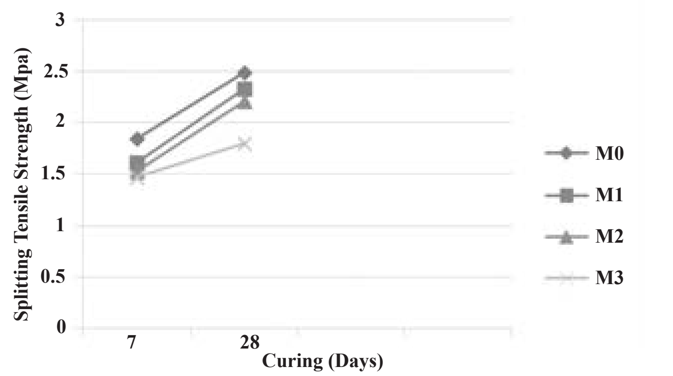
Note : M0 = MC = 0% POF, M1 = 0.25% POF, M2 = 0.50% POF, M3 = 0.75% POF

Figure 4: Compressive strength of green concrete at 7 days and 28 days

an increased in its compressive strength. However, concrete mix M1 (0.25% POF) shows the best increment in terms of its strength as it recorded a value of 32.4 MPa, which was similar to control specimen MC (0% POF).

6.4 Split Tensile Strength Test

From observation, split tensile strength for green concrete increases steadily as the curing period increases. Generally, the highest value of split tensile strength was from control mix MC (0% POF) as clearly illustrated in Figure 5. At 7 days, concrete mix M1 (0.25% POF) shows the highest split tensile strength at 1.61 MPa, however, a lower tensile strength was recorded at 1.47 MPa for concrete mix M3 (0.75% POF). As Figure 5 shows, the split tensile strength for all concrete mix (MC, M1, M2 and M3) increases upon reaching its 28 days strength. Nevertheless, the presence of POF in the concrete mix shows a definite influence to the split tensile strength similar to the reduction of its compressive strength as presented in Section 6.3 above. At 28 days, the concrete mix MC (0% POF), M1 (0.25% POF), M2 (0.50% POF) and M3 (0.75% POF) shows an increasing trend from its 7 days strength but reduces with increased percentage of POF from 2.50 MPa, 2.30 MPa, 2.20MPa and 1.80 MPa respectively.



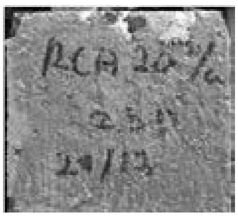
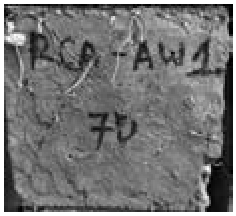
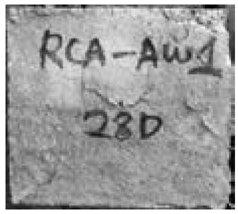
Note: M0 = MC = 0% POF, M1 = 0.25% POF, M2 = 0.50% POF, M3 = 0.75% POF

Figure 5: Splitting Tensile Strength of Green Concrete at 7 Days and 28 Days

6.6 Failure Mode

After the compression and split tensile strength test, all the cubes and cylinders shows a consistent failure mode with little damage. Equally distributed cracks on the surface of the cube specimens were also observed. Typical failure modes for the cubes and cylinders are shown clearly in Table 8 and Table 9 for concrete mix MC (0% POF) and M1 (0.25% POF). Overall, the green concrete cubes and cylinders have shown good failure criteria whilst achieving the targeted design strength of 30 MPa.

Table 8: Failure Modes of Green Concrete After Compressive Test

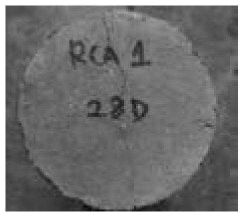
Concrete Mix	Failure Mode Under Compression Strength Test	
	7 Days	28 Days
MC		
M1		

Note: MC = Control specimen (0% POF) ; M1 = 0.25% POF

Table 8: Failure Modes of Green Concrete After Compressive Test

Note: MC = Control specimen (0% POF) ; M1 = 0.25% POF

Table 9: Failure Modes of Green Concrete After Splitting Tensile Test

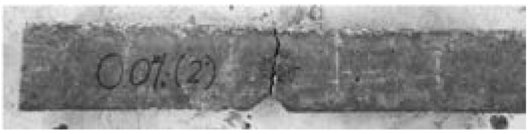
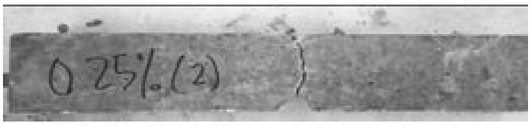
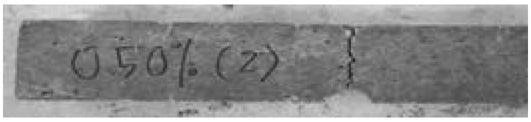
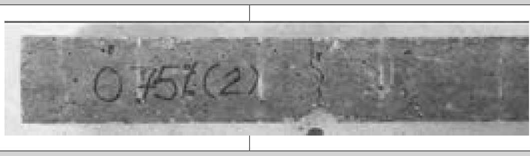
Concrete Mix	Failure Mode Under Splitting Tensile Strength Test	
	7 Days	28 Days
MC	 	 
M1	 	 

Note: MC = Control Specimen (0% POF) ; M1 = 0.25% POF

6.7 Failure Mode

From close observation, the crack pattern for all specimens are similar, where cracks occurred at the mid-span of specimen, see Table 10. The formation of cracks were observed at the notched region where high stresses are expected at the narrow end of the v-notch. The cracks propagated from the tip of the notch to the upper surface of the beam. It can be seen that the cracks in all specimens are approximately vertical in direction with very slight changes in its angle.

Table 10: Failure Mode of Specimen

Specimen ID	Crack Pattern and Deflection at Failure
0F/S2P	 **Deflection at failure: 0.29mm**
25F/S2P	 **Deflection at failure: 0.32mm**
50F/S2P	 **Deflection at failure: 0.34mm**
75F/S2P	 **Deflection at failure: 0.47mm**

6.8 Load-deflection Profile

All notched prism specimens in various fiber percentage of 0.00%, 0.25%, 0.50% and 0.75% are tested with three point bending test. All specimens are cast with constant size of 100mm x 100mm x 500mm and a notch with depth of 20mm at mid-span. The specimens are loaded at centre until it experiences crack and fracture.

The data obtained from three point bending test are recorded and analysed to produce load-deflection profile. The load-deflection profile at peak load, displacement at peak load and load and displacement at failure is summarized in Table 11. The load-deflection profile for each specimen was plotted to compute the area under the profile. The area under load-deflection profile were then used to calculate the fracture energy of green concrete in accordance to Hillerborg's model [10].

Table 11: Load and Deflection of Peak Load and Failure Load

Fiber content (%)	Specimen ID	Experimental Results			
		Peak load (kN)	Deflection at peak load (mm)	Load at failure (kN)	Deflection at failure (mm)
0.00	0F/S1P	-	-	-	-
	0F/S2P	7.62	0.27	0.08	0.29
	0F/S3P	7.30	0.25	0.10	0.30
0.25	25F/S1P	7.16	0.21	0.16	0.27
	25F/S2P	7.37	0.20	0.20	0.32
	25F/S3P	6.96	0.25	0.19	0.35
0.50	50F/S1P	7.00	0.17	0.30	0.36
	50F/S2P	6.52	0.18	0.29	0.34
	50F/S3P	7.68	0.18	0.24	0.38
0.75	75F/S1P	6.67	0.23	0.24	0.46
	75F/S2P	6.14	0.22	0.28	0.47
	75F/S3P	6.22	0.18	0.30	0.42

The load-deflection profile for 0F/S2P (see Figure 6) shows that the deflection increase simultaneously with the increasing applied load until it reaches peak load of 7.62kN. The maximum deflection at peak load is recorded at 0.27mm. After reaching the peak load, it is observed that the load decrease sharply with slight increase in deflection. The overall load-deflection profile for 0F/S3P shows similar trend with 0F/S2P. However, it was found smaller peak load and lower deflection at peak load with value of 7.30kN and 0.25mm are recorded for 0F/S3P.

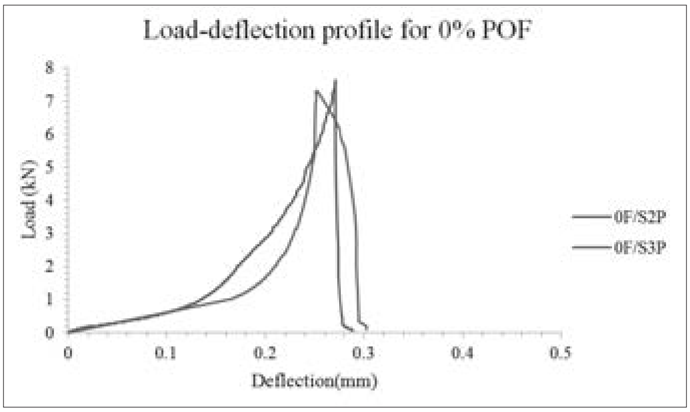


Figure 6: Load-deflection Profile for 0% POF

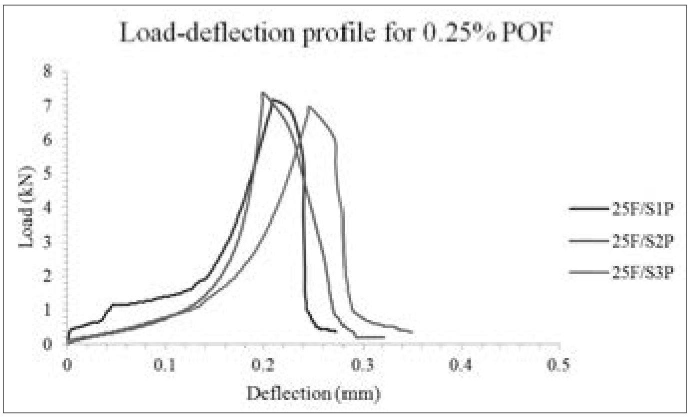


Figure 7: Load-deflection Profile for 0.25% POF

Figure 7 clearly shows the load-deflection profile for green concrete with 0.25% POF. From Figure 7, it is observed that the profile for 25F/S1P is similar with load-deflection profile for 0F/S3. This profile trend is similarly observed for 25F/S2P and 25F/S3P. A peak load value of 7.16kN, 7.37kN and 6.96kN with deflection of 0.21mm, 0.20mm and 0.25mm are recorded for 25F/S1P, 25F/S2P and 25F/S3P respectively. As illustrated in Figure 7, the load capacity for all specimen decreased sharply after peak load is achieved. This decrease in load capacity coincides with a slight increase in deflection value.

The load-deflection profile for specimen 50F/S1P shows gradual increase in deflection with an increase in load. At peak load, specimen 50F/S1P recorded a load value of 7.00kN with a deflection at 0.17mm. The same trend is observed for 50F/S2P and 50F/S3P in Figure 8. A peak load of 6.52kN and 7.68kN with deflection of 0.18mm and 0.18mm are recorded for 50F/S2P and 50F/S3P respectively. All specimen show a gradual decrease in load after peak load is reached. This gradual decrease in load coincides with an increase in deflection. When maximum deflection of 50F/S1P reaches 0.36mm, the final load was recorded at 0.30kN. The post-peak behavior for 50F/S2P and 50F/S3P show a similar trend with a gradual reduction in its load capacity recorded at 0.29kN and 0.24kN and a maximum deflection at 0.34mm and 0.38mm respectively.

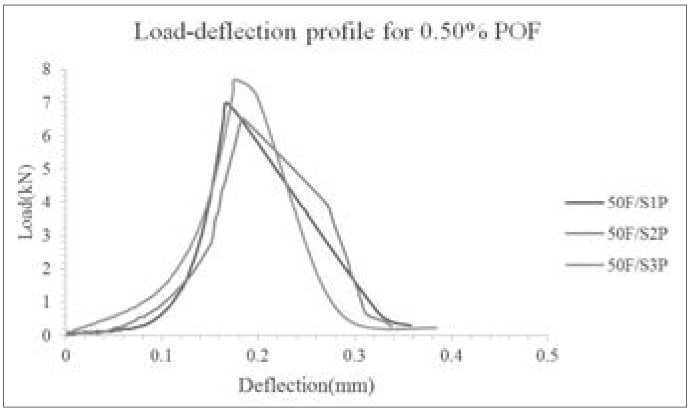


Figure 8: Load-deflection Profile for 0.50% POF

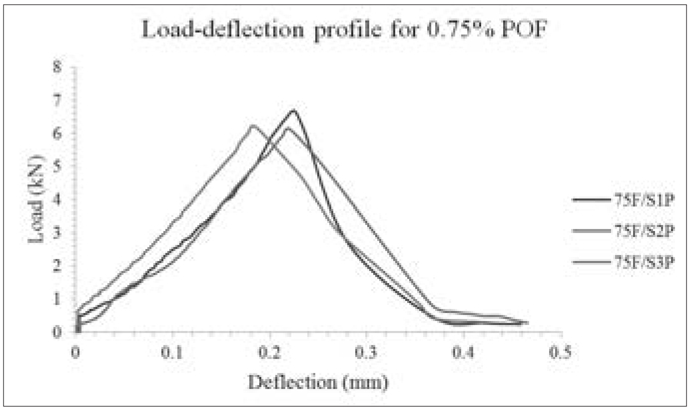


Figure 9: Load-deflection Profile for 0.75% POF

Figure 9 shows the load-deflection profile for green concrete with 0.75% POF until failure. It is observed that the initial behavior of specimens under load show no significant increase in deflection. The load is then increase linearly with deflection until reaching peak load. The post peak behavior of all specimen show gradual decrease until failure. A peak load value of 6.67kN, 6.14kN and 6.22kN with deflection of 0.23mm, 0.22mm and 0.18mm are recorded for 75F/S1P, 75F/S2P and 75F/S3P respectively.

Load-deflection profile for specimen 0F/S2P, 25F/S2P, 50F/S2P and 75F/S2P is visualized in Figure 10 to illustrate the influence of POF to the peak load and maximum deflection of green concrete. Peak load of 7.62kN, 7.37kN, 6.52kN and 6.14kN with maximum deflection of 0.30mm, 0.32mm, 0.34mm and 0.47mm are recorded for 0F/S2P, 25F/S2P, 50F/S2P and 75F/S2P respectively. It is clearly seen that the peak load of specimen is decreasing with increasing POF percentage. However, higher percentage of POF improves the ductility behaviour as show in figure 10.

7.0 FRACTURE ENERGY

The fracture energy G_F of green concrete prims is analysed using three models, namely Hillerborg's model 10], Bazant model [11] and Comite Euro-International du Beton (CEB) model [12].

7.1 Hillerborg's Model [10]

The analysis using Hillerborg's model depends on the experimental result obtained from three point bending test. The area under load-deflection profile for each specimen will greatly influence the value of fracture energy. The fracture energy of

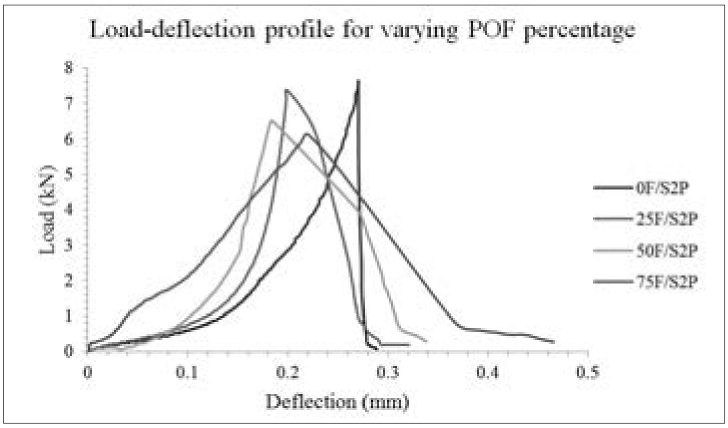


Figure 10: Load-deflection Profile for Varying POF Percentage

Table 12: Fracture Energy of Green Concrete Based on Hillerborg's Model [10]

Fiber content (%)	Specimen ID	W_o (N.m)	m_g (N)	δ_f (m)	B (m)	D (m)	a_o (m)	G_F (N/m)
0.00	0F/S1P	-	-	-	0.1	0.1	0.02	-
	0F/S2P	0.53	118.11	0.0003	0.1	0.1	0.02	70.39
	0F/S3P	0.54	118.11	0.0003	0.1	0.1	0.02	71.68
0.25	25F/S1P	0.67	112.82	0.0003	0.1	0.1	0.02	87.54
	25F/S2P	0.65	112.42	0.0003	0.1	0.1	0.02	85.52
	25F/S3P	0.69	112.23	0.0003	0.1	0.1	0.02	90.50
0.50	50F/S1P	0.86	118.31	0.0004	0.1	0.1	0.02	112.44
	50F/S2P	0.84	117.72	0.0003	0.1	0.1	0.02	110.12
	50F/S3P	0.86	117.72	0.0004	0.1	0.1	0.02	113.10
0.75	75F/S1P	1.10	118.50	0.0005	0.1	0.1	0.02	144.22
	75F/S2P	1.19	116.05	0.0005	0.1	0.1	0.02	154.88
	75F/S3P	1.18	115.07	0.0004	0.1	0.1	0.02	153.81

green concrete analysed using Hillerborg's model is obtained from figure 10 above and summarised in Table 12.

The fracture energy values G_F tabulated in Table 12 are calculated using the fracture energy equation based on Hillerborg's model as shown in Equation.1. It was observed that the inclusion of POF in green concrete shows positive effect on the fracture energy. The fracture energy from specimen with higher POF content show better results where the fracture energy increased from 70.39N/m to 153.81N/m when POF content increased from 0% to 0.75%. The increasing influence of POF to fracture energy of green concrete in Hillerborg's model are illustrated in Figure 11 below.

7.2 Bazant [11] and CEB [12] Model

Fracture energy of green concrete were also analysed using Bazant and CEB models which was shown as Equation 2 and Equation

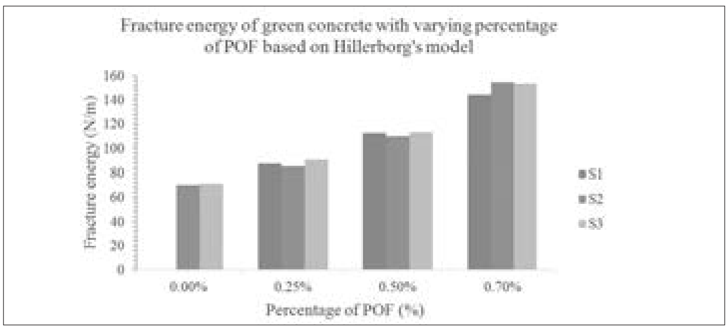


Figure 11: Fracture Energy of Green Concrete with Varying Percentage of POF Based on Hillerborg's Model [10]

3 above. Bazant and CEB models employs the cylindrical compressive strength, maximum size of aggregate, water-cement ratio in determining its fracture energy of green concrete. The value of fracture energy analysed using these models are tabulated in Table 13 and Table 14 respectively.

Based on the values shown in Table 13 and Table 14, the fracture energy obtained for green concrete without adding POF was the highest followed by specimen with 0.25%, 0.50% and 0.75% POF. The fracture energy was found to decrease with increasing fiber content. This observation was contributed mainly due to the presence of compressive strength of concrete from Bazant and CEB models whilst the parameter for the maximum size of aggregate and water-cement ratio remains constant. The cylindrical compressive strength of green concrete without fiber was the highest at 26.27 MPa compared to 0.25%, 0.50% and 0.75% POF with a compressive strength of 25.92 MPa, 20.11 MPa and 18.21 MPa respectively. This shows that the compressive strength of specimen will affect the value of fracture energy from Bazant and CEB model.

The distribution of fracture energy from Bazant and CEB model with varying percentage of POF are illustrated in Figure 12 and Figure 13 respectively. The figures below shows that the fracture energy of green concrete decreases with increasing fiber content for both models.

Table 13: Fracture Energy of Green Concrete Based on Bazant Model [11]

Fiber content (%)	Specimen ID	α_o	D_{max} (mm)	f_c (MPa)	$\frac{W}{C}$	G_F (N/m)
0.00	0F/S1C	1.44	9	25.76	0.57	96.00
	0F/S2C	1.44	9	26.32	0.57	85.80
	0F/S3C	1.44	9	26.72	0.57	86.39
0.25	25F/S1C	1.44	9	25.2	0.57	84.10
	25F/S2C	1.44	9	27.6	0.57	87.69
	25F/S3C	1.44	9	24.96	0.57	83.73
0.50	50F/S1C	1.44	9	20.72	0.57	76.86
	50F/S2C	1.44	9	19.12	0.57	74.07
	50F/S3C	1.44	9	20.48	0.57	76.45
0.75	75F/S1C	1.44	9	17.84	0.57	71.74
	75F/S2C	1.44	9	18.64	0.57	73.21
	75F/S3C	1.44	9	18.16	0.57	72.33

Table 14: Fracture Energy of Green Concrete Based on CEB Model [12]

Fiber content (%)	Specimen ID	D_{max} (mm)	f_c (MPa)	G_F (N/m)
0.00	0F/S1C	9	25.76	49.06
	0F/S2C	9	26.32	49.81
	0F/S3C	9	26.72	50.34
0.25	25F/S1C	9	25.2	48.32
	25F/S2C	9	27.6	51.49
	25F/S3C	9	24.96	47.99
0.50	50F/S1C	9	20.72	42.13
	50F/S2C	9	19.12	39.82
	50F/S3C	9	20.48	41.79
0.75	75F/S1C	9	17.84	37.94
	75F/S2C	9	18.64	39.12
	75F/S3C	9	18.16	38.41

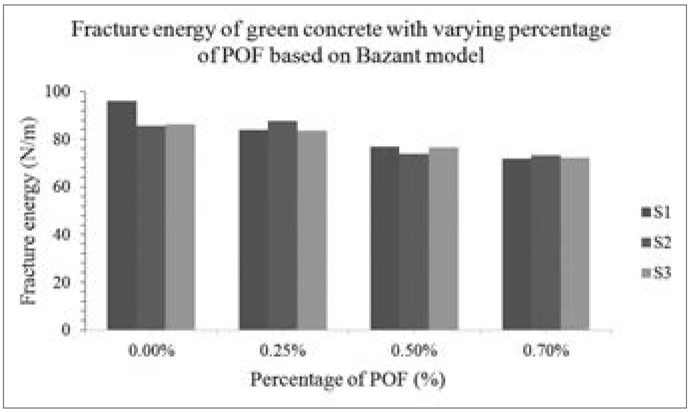


Figure 12: Fracture Energy of Green Concrete with Varying Percentage of POF Based on Bazant Model [11]

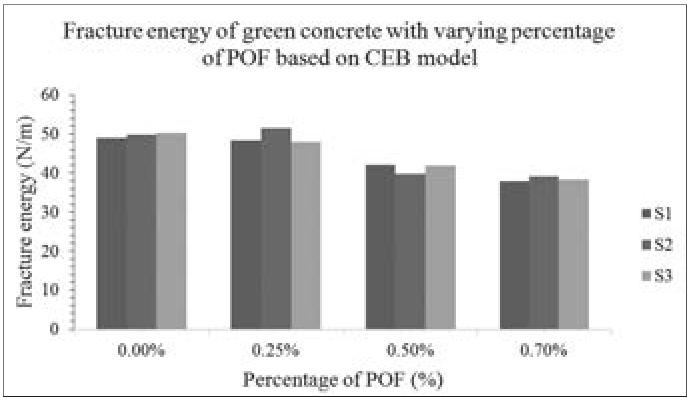


Figure 13: Fracture Energy of Green Concrete with Varying Percentage of POF Based on CEB Model [12]

8.0 CONCLUSION

Throughout the research, it was noted that the agricultural waste materials used in the mixture of green concrete possess an excellent potential to enhance the strength properties of green concrete. As proven from the results, the concrete mix MC without the addition of POF achieved the value higher than the targeted design strength of 30 MPa. However, the concrete mix M1 of 0.25% POF also presented satisfactory results as the strength development on 28 days was 32.4 MPa. Therefore, the mixture of all the material proposed can definitely be used to create green concrete to mitigate the global warming by reducing a significant amount of carbon dioxide from the use of cement.

Fracture energy for green concrete with varying percentage of POF was also determined. Fracture energy of green concrete with varying percentage of palm oil fiber was found to be in the range of 37.94N/m to 150.97N/m. The result of three-point bending test shows that 0.75% inclusion of palm oil fiber gives the highest fracture energy but lowest compressive strength. The fracture energy of green concrete calculated using Bazant and CEB models are lower than fracture energy analyzed using Hillerborg model. This is due to the fracture energy value according to Bazant and CEB modes highly depend on compressive strength compared to Hillerborg model which rely on the area under the load-deflection profile. Finally, this research has successfully achieved its aims in determining the strength properties and fracture energy of green concrete utilizing waste materials from POFA, RHA, POF and RCA.

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