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Experimental Study on Palm Fibers Effectiveness for Sustainable Geotechnical Works

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ABSTRACT

The construction sector in the middle eastern region has been poised towards a rapid growth period in recent years. Owing to an abundance of date palm trees in the area, replacing ordinary concrete with a geopolymer and natural palm fiber-based material can be potentially considered as an eco-friendly construction alternative. This study focused on utilizing fly ash and slag blended GeoCement to produce geopolymer concrete without fibers, palm GeoCrete with palm fibers, and master GeoCrete with synthetic master fibers. The mix design preparations were in accordance with locally produced concrete in Dubai. Additionally, to explore the effectiveness of palm fibers on the resultant blends, their key properties were compared to traditional Portland Cement concrete mixes. The tests were inclusive of fresh and hard concrete tests to assess their performance. The GeoCrete blends achieved acceptable density and air content values. The addition of palm fibers to GeoCrete caused a reduction in porosity and void percentage. The resultant data clearly indicated that GeoCrete, Palm GeoCrete, and Master GeoCrete are feasible for usage in various ground conditions and geotechnical applications.

1. Introduction

Due to innumerable adverse effects that urban development can bring to the environment, preserving the environment by resource conservation has become critical. For many years, the construction sector has been one of the biggest contributors to environmental degradation due to carbon emissions and air pollution. Hence, it is important to focus towards production of green construction materials that help reduce carbon footprints and associated environmental issues. Additionally, sustainable approaches should be considered to improve the performance of geotechnical structures and reduce the carbon footprint of the utilized concrete. GeoCrete production (geopolymer concrete) is a sustainable option that comprises of GeoCement and aggregates. GeoCement is made up of zero or a slight amount of Portland cement along with waste material like fly ash, metakaolin, and slag with supplementary material [1]. Palm fibers are natural fibers that are widely present in the Gulf region. Palm fibers' notable properties include tensile strength, roughness, and water absorption [2].

Geopolymers are obtained using materials rich in alumina and silica minerals. Geopolymers are prepared from raw materials such as fly ash, slag, metakaolin, and others based on their chemical composition [3]. Through a series of chemical reactions, alum inosilicates are broken down by the addition of alkaline solutions to alum inosilicate geopolymer networks [4]. A more sustainable solution than filling landfills with waste material is geopolymer concrete [5]. A key study regarding GeoCrete and ordinary concrete found that geopolymer concrete reduces global warming by more than 50% [5]. The emissions of carbon dioxide from GeoCement production are 70-80% lower than those of ordinary cement [6]. Additionally, research has also shown that geopolymer consisting of fly ash and slag is an efficient alternative to ordinary Portland cement [3]. A comparison-based study found that GeoCrete performed better than normal concrete after exposure to chemical attacks [7]. In the study, the comparison of geopolymer concrete with ordinary Portland concrete showed that geopolymer concrete had greater strength and less mass loss after an acid attack, although its carbonation resistance was inferior. The different chemistry of geopolymer enhances durability and workability properties, especially when applied to sewer applications and geotechnical works that are exposed to various attacks [8].

	Specific Gravity
Portland Cement	3.15
Fly Ash	2.4
GGBS	2.9
20 mm CA	2.8
10 mm CA	2.84
5 mm FA	2.74
Dune sand	2.7

1.1 Fiber reinforcement in Geotechnics

Slab on grades are known to face issues like chemical attacks, cracks and water penetration [9]. Studies prove that fiber reinforced slab on grades show better resistance for weight drop loads in addition to less cracks and an increase in flexural strength [9]. Thus, using fibers with geopolymer concrete can enhance the performance of the slab on grade by combining the advantages of both fibers and geopolymer.

The same method can be followed for soil reinforcement, as it is an effective application to improve the soil's tensile and shear strength and therefore increasing its bearing capacity and improving its stability and limiting deformations and settlements [10]. Natural and synthetic fibers have been reviewed in numerous studies for geotechnical applications like soil improvement and subbase layers strengthening and applications in airfields and the enhancement of soil strength. However, not all fibers are known to affect the compressive strength [10]. Numerous studies have also highlighted that adding fibers to retaining walls enhance their stability and improve earth stability [11]. The use of natural fibers like palm fibers to silty sand soil improve the ductile behavior of the soil and the cohesion with the increase of the fiber content and aspect ratio [12]. Furthermore, the increase of the California Bearing Ratio has been documented with the addition of fibers to clayey soil Fibers improved the texture of the clay. Even though synthetic fibers obtained higher CBR, the angle of friction and thus cohesion increased with the use of natural fibers [13].

Table 1: Specific gravities of used materials

Besides, metakaolin based specimens were tested under elevated temperatures where fibers improved crack control and rupture under elevated temperatures [14]. These materials can be used in applications like tunneling and numerous other areas where fire resistance is an essential property.

2 Methodology

In this study, waste products and natural substitutes were used to replace the main ingredients in ordinary concrete. The optimum mix of constituents for GeoCement was chosen to proceed with the GeoCrete, followed by production of GeoCrete, Palm Geocrete, and Master GeoCrete blends. The blends were then tested for their fresh and hardened properties to compare the performance of the mixes to a conventional Portland cement mix. The GeoCrete mixes were carefully designed to meet geotechnical needs and local restrictions. The mix design was developed using the specific gravity method and the commonly used ratios with fixed a w/s of 0.37.

3 Material characterization

The blends that were compiled together in this study consisted of three key components; cementitious material, aggregates, and fibers.

3.1 Cementitious material

- **Portland cement**

The cement was supplied from National Cement, complying with BS 197-1.

Table 2: Cement Chemical Composition %

SiO_2	**20.27**
Al_2O_3	**4.91**
Fe_2O_3	**3.2**
CaO	**63.4**
MgO	**1.62**
C_3S	**52.93**
Cl	**0.05**
Na_2O	**0.58**
C_2S	**18.2**
C_3A	**7.6**
SO_3	**2.75**
LOI	**2.76**

Table 2: Mix Designs

Material quantity kg/m^3				
Mix type				
Material	**Concrete**	**GC**	**Palm GC**	**Master GC**
PC	271	0	0	0
Fly Ash	0	247	247	247
GGBS	152	165	165	165
CA (20mm)	719	700	700	700
CA (10mm)	338	330	330	330
FA(0-5mm)	626	610	610	610
Dune sand	220	214	214	214
Modified Water	151	138	138	138
Water	4.5	6	6	6
Activator 5%	0	20.6	20.6	20.6
Fibers	0	0	2.5	2.5

3.2 Ground Granulated Blast Furnace Slag

GGBS was supplied by Cemex from Falcon Slag. The specific gravity of the material was found to be 2.90.

Table 4. GGBS physical properties

Description	Specification	Result
% moisture	<1.0	0.18
Fineness, m^2/kg	>275	423
Soundness, mm	No limit	0.1
% Slag activity index		
7 days	>45	71
28 days	>70	106

Table 5. GGBS chemical composition %

SiO_2	31.57
Al_2O_3	15.3
Fe_2O_3	0.6
Mn_2O_3	0.16
CaO	34.31
MgO	8.02
S^{2-}	0.48
Cl	0.01
Na_2O	0.8
TiO_2	0.65
SO_3	0.09
LOI	0.81

3.2 Fly Ash

The fly ash that was used is a high-quality Dura-Pozz ash, sourced from Ash resources South Africa, with a specific gravity of 2.50.

Table 6. Fly Ash chemical composition %

Description	Specification	Result
LOI	<5.0	0.46
LOI	<5.0	0.88
Sulphur content	<2.5	0.03
FCaO	<1	0.08
Total alkalis	<5	0.11
Fineness	<40	11.47
Fineness	<12.5	10.8

Table 7. Fine aggregate properties

The RAP aggregates were further evaluated for key properties such as gradation, binder content, and aggregate specific gravity.

3.2 Aggregates

The blends used a variety of both fine and coarse aggregates.

Table 8. Coarse aggregate properties

Description	Dune Sand	Washed Sand
Bulk Specific Gravity (Oven Dry)	2.66	2.7
Bulk Specific Gravity (SSD)	2.69	2.73
Apparent Specific Gravity	2.75	2.78
Water Absorption %	1.30	0.90
Moisture Content %	1.25	0.947

3.3 Fibers

Description	10 mm Crushed Aggregates	20 mm Crushed Aggregates
Bulk Specific Gravity (Oven Dry)	2.79	2.81
Bulk Specific Gravity (SSD)	2.8	2.83
Apparent Specific Gravity	2.82	2.87
Water Absorption %	0.7	0.4
Moisture Content %	0.7	0.417

Natural date palm fibers were obtained from date palm trees in a local farm located in Northern UAE, Kalba Region. The stem of the palm tree consists of several parts, where the lower parts are hard and stiff, hence were excluded. The fibers of the leaves are weak, thus also excluded. The fibers were extracted from the remaining parts of the stem. The extraction process of natural fibers started by collecting long stems from palm trees and then washing them to remove the dust, followed by drying them under normal weather conditions for a week. The hard lower parts of the stem were then cut out using a saw, the leaves removed, and the stem cut into smaller pieces and immersed in 4% of NaOH solution for 24 hours. Next, the stem pieces were washed and the fibers were separated manually. Fibers were then cut in lengths of 50 mm to 70 mm and an approximate diameter of 0.6 mm. The fibers were stored in polyethylene bags until needed.

The synthetic fibers were supplied by Master Builders Solutions. Master Fiber MAC 2200 CB are macro-synthetic fibers made from polyolefin with 54mm in length and 0.8mm diameter.

3.4 Chemical additions

Admixtures are added to the mix to enhance its properties [15]. This is why water reducers are used both in conventional concrete and in GeoCrete. The Master Glenium is used for conventional concrete which is Poly carboxylic ether based while MasterCrete AC 1000 is used for GeoCrete (geopolymer concrete). Both these high range water reducing agents which are produced by Master Builders Solutions comply with BS EN 934-2:2009+A1:2012 specifications for concrete admixtures, mortar and grout, definitions, requirements, conformity, marking and labelling. The water reducers consist of 70% of water.

The geopolymer chemical activator used was MasterCrete AC 500. This solution is sodium hydroxide with a molarity value of approximately 16, and water content of 50%.

4. Preparation of test specimens

Material storage and preparation - The aggregates, cementitious material, and synthetic fibers were stored in warehouses, while the activator and admixtures were stored in the laboratories at room temperature. The Palm fibers were sealed in plastic bags and stored in vacuum. The materials were then weighed one day prior to mixing and the weighed quantities were segregated in buckets for each batch. The activator and admixtures were weighed using cylinders just before the mixing procedure.

Mixing procedure - Each mix design was prepared in 3 batches of 20-liters, with a final quantity of 60 liters for each blend, followed by production of separate mixtures of conventional concrete, GeoCrete, palm GeoCrete and master GeoCrete.

Placement - The produced specimens were then casted into 150 by 100 mm plastic cube molds. Before pouring the concrete into the molds, the internal sides of the molds were wiped with oil to avoid sticking of concrete. The concrete was then poured into the molds with an active vibration after which the top of the mold was paved and the sides wiped. After 18 hours the samples were demolded.

Curing – Conventional concrete samples were demolded after 18 hours and placed in water tanks. A thermometer is used to measure the temperature of the water in the tank. The curing process lasts for 28 days. However, for geopolymer concrete, water is not needed since the geopolymerization reaction does not depend on water as the crystallization reaction of conventional concrete. Also, High curing temperatures increase the compressive strength of the obtained fly ash based GeoCrete, hence for this study dry curing was done in normal weather conditions which is around 38 degrees Celsius in Dubai.

5. Results and discussions

5.1 Fresh concrete slump test

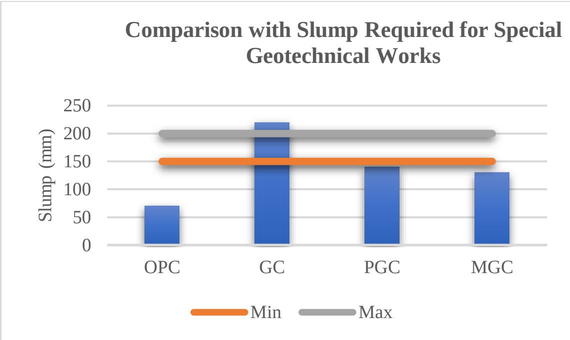

Fig 1. Slump test results

No bleeding was observed for all the mixes. The unique rheology of GeoCrete prevents bleeding. GeoCrete had the highest slump measured for the same water/solids ratio of the four mixes at 220 mm. Due to the high viscosity of the activating solutions, the use of geopolymer increases slump. Conversely, the addition of fibers decreases the slump because the yield stress in fresh concrete increases. In line with these results, a research study in 2017 also highlighted a reduction in slump from 100 mm to 75 mm was reported with the addition of short steel fibers [16]. Also, as a result of the addition of activator, the GeoCrete mixture tends to become sticky [4], which gives it a quite different rheology than that of ordinary concrete. A 2013 study reported that when the concentration of the NaOH based activator was 45% the slump of geopolymer concrete was the maximum [17]. On the other hand, longer mixing periods reduce the slump of the geopolymer concrete where the slump can no longer be measured after 30 minutes [3]. Another factor that impacts the workability is the percentage of GGBS, where an increased contribution of slag to GeoCement attains a lower slump value due to the increase in the setting time caused by GGBS [18]. Another study showed that GeoCrete had a collapsing slump reported at 230 mm and below with 150 mm for ordinary concrete [17]. This confirms the obtained results that geopolymer concrete always reaches a higher slump than ordinary concrete. Generally, geotechnical structures require high slump and sometimes self-consolidating concrete for proper concrete placement to overcome construction obstacles [19].

5.2 Fresh concrete density

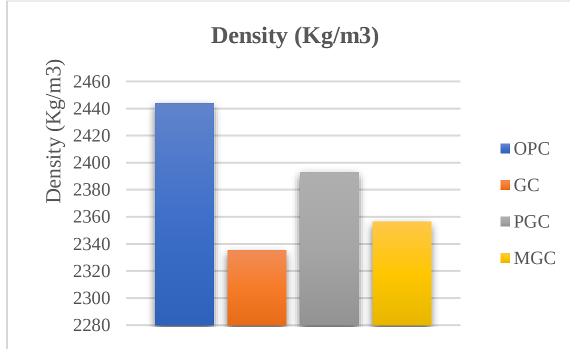

Fig 2. Density test results

Fresh concrete was poured into a watertight container for the density to be measured. GeoCrete was measured at the lowest density at 2335 Kg/m3. The specification for execution of special geotechnical works (Bored Piles BS EN 1536:2010+A1:2015) states that fresh concrete must comply with the requirements of BS EN 206, where the accepted concrete density should fall within the range of 2000 Kg/m3 and 2600 Kg/m3.

Several studies have shown that the addition of fibers increases the density of GeoCrete [16]. This implicates that GeoCrete has the tendency to be developed as a lightweight concrete using the properties it already possesses along with the addition of lightweight aggregates. A 2018 study also demonstrated equivalent results for fresh and hardened density [20].

5.3 Fresh concrete air content

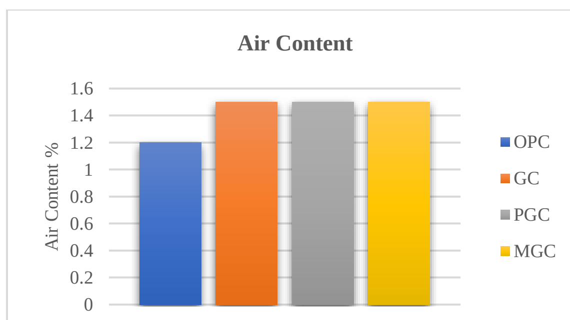

Fig 3. Air content test results

The air content of fresh concrete was measured using the pressure gauge method. The results presented in Figure 3 show that the air content of GeoCrete mixes was higher than that of conventional concrete mix. The air content for GC, PGC & MGC was 1.5 bar higher than that of OPC which is 1.2 bar. The viscosity of GeoCrete requires longer vibration durations after which the air content can be reduced. Meanwhile, conventional concrete requires less vibration time for the same value of air content. So, the same air content can be achieved for GeoCrete with more vibration during placement. The difference is referred to the different texture of GeoCrete. This test concluded that increasing the percentage of palm fibers or increasing the mixing time can reduce the air content of Palm GeoCrete and therefore it will be equal or less than that of conventional concrete. A 2021 study that utilized fly ash based geopolymer revealed that the air content of geopolymer concrete was less than that of conventional concrete where the increase in fly ash content is expected to decrease air content [21].

5.4 Hardened concrete compressive strength

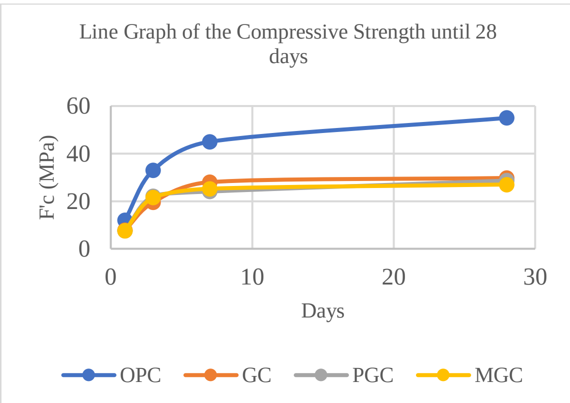

Fig 4. Compressive strength test results

As seen in the graph, the compressive strength obtained by conventional concrete is higher than that of GeoCrete. The development of strength follows almost the same behavior between the four mixes but the GeoCrete mixes are characterized by slow development when compared to ordinary concrete.

However, a 2016 study's resultant data showed that at 28 days, for fly ash and GGBS geopolymer (GeoCrete), the reported strength was lower than that of ordinary concrete but after 28 days the strength developed significantly and it reached higher values than ordinary concrete [22]. Therefore, observing the strength development beyond 28 days is recommended for further comparison as the strength of geopolymer is expected to develop higher than ordinary concrete. It should be mentioned that sodium hydroxide increases the temperature and causes efflorescence, which results in a lower strength at an early stage [4]. Another study reported that the strength of geopolymer concrete continues to increase till after 180 days slowly [17]. Additionally, it was reported that increasing the molarity of the alkali activating solution increases the obtained compressive strength [23]. The execution of special geotechnical works (BS EN) sets the accepted range of compressive strength to be between C20/25 and C45/55.

5.5 Water Absorption

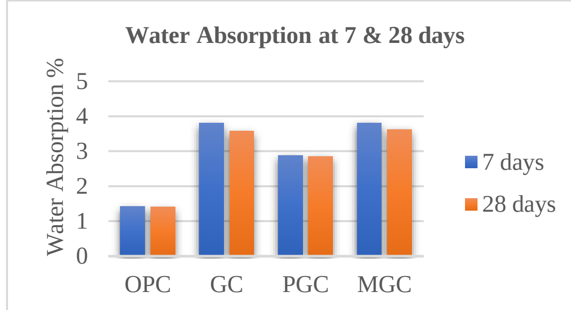

Fig.5 Water absorption results

In accordance with the standard water absorption test, specimens were cored from 150 mm cylinders with a diameter of 75 mm and 75 mm long. The water absorption of conventional concrete was measured at 1.4%. At 28 days the water absorption of GeoCrete reaches 3.58% compared to 2.85% for Palm GeoCrete and 3.62% for Master GeoCrete. This test indicates that palm fibers filled in the pores of GeoCrete. The difference between the palm fibers and the master fibers is the flexibility of palm fibers and the ability to bend and deform which eases the way to fill the pores. Additionally, the volume occupied by palm fibers was higher than that occupied by master fibers because the weight of one palm fiber is much less than that of master fiber CB 2200. Therefore, it can be concluded that increasing the amount of added palm fibers can reduce water absorption significantly to be even lower than that of OPC.

In line with the graphical results of this study, another study conducted on conventional concrete with added date palm fibers showed that the absorption of fiber concrete was higher than that of normal concrete, however it was noticed that the absorption levels started to decrease until it became less than that of conventional concrete [24]. In this study, the increase in the percentage of palm fibers led to a decrease in the absorption that was monitored for 91 days. Therefore, observation for longer than 28 days is necessary, as it is noticeable that the absorption of fiber concrete and geopolymer concrete can decline gradually during curing.

5.6. Porosity and voids percentage

After measurement of the sample's weight, the tests

Results showed that OPC had the highest hardened

Table 9. Densities of all mix types

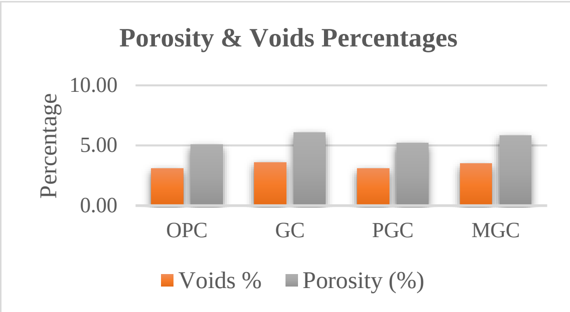

Fig. 6 Porosity and void percentage results

density. The density of GC is 2.45 Kg/m3, it increases to 2.46 Kg/m3 for PGC and 2.5 Kg/m3 for MGC. As for the voids, OPC is 3.1 %, while GC is at 3.6 %. The addition of palm fibers reduced the voids content of GC to 3.09% and 3.5% of voids content was obtained in MGC. Finally, the porosity of OPC is 5.09%, which increases to 6.09% for GeoCrete, 5.21% for PGC and 5.84% for MGC.

In light of the above results, we can conclude that the density values are approximately in conformity with the fresh density results with GeoCrete having a density lower than that of OPC and fibers clearly increasing the density of GeoCrete. Moreover, the addition of palm fibers to GeoCrete reduced its porosity and voids content. Studies confirm that adding fibers to concrete decreases its density [24]. Also, a study conducted on the addition of steel fibers to geopolymer concrete proved that the more fibers are introduced to the mix the less the porosity [16].

Meanwhile, usually the volume of voids decreases for

Mix	OPC	GC	PGC	MGC
Density	2.56	2.45	2.46	2.5

fly ash and slag blended geopolymer when compared to ordinary Portland cement concrete [17], so by altering the mix design the void content can be less than that of OPC although the difference is small.

5.6 Abrasion resistance

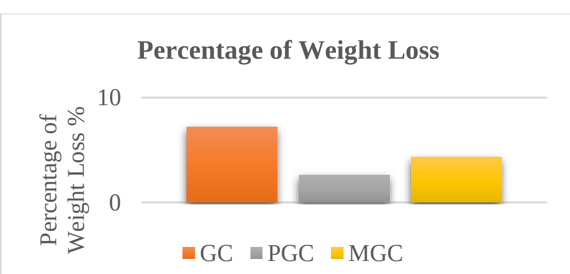

Fig 7. Abrasion resistance results

Abrasion was tested on square specimens of 50 mm thickness and 500 mm length after 28 days of normal curing conditions. The percentage of weight loss in GeoCrete was 7.2%, but decreased to 2.58% in Palm GeoCrete and 4.3% in Master GeoCrete. Based on the results of this test, palm fibers increase the surface roughness of GeoCrete, since using palm fibers increases the wear resistance of the sample and decreases the percentage of weight loss. A 2014 study's results also demonstrated a similar pattern where the addition of fibers increased the surface roughness of concrete [25].

The acquired results can have important implications in the geotechnical work, as the skin friction and surface roughness between the geotechnical systems (piles, foundations, shoring systems, etc..) and the soil will be expected to increase. Synthetic fibers also contributed to roughness, but the performance of the natural fibers was enhanced.

6. Conclusions

To adequately investigate the effectivity of palm fibers within concrete, this research analyzed key properties of produced blends of geopolymer concrete without fibers, palm GeoCrete with palm fibers, and master GeoCrete with synthetic fibers, and further compared them to the properties of traditional Portland cement. The properties that were assessed were inclusive of slump value, density, air content, compressive strength, water absorption, porosity, and abrasion resistance.

The results demonstrated that the high slump values give GeoCrete the eligibility to be used in special geotechnical works that require high slump and flow and sometimes self-consolidating concrete in which the GeoCrete mix can be developed to meet its requirements. From the test results for fresh concrete, the performance of GeoCrete in terms of density is close to that of conventional concrete. Furthermore, palm fibers increased the density of Palm GeoCrete due to the considerable volume the fibers occupy in the mix. Additionally, the air content values for geocrete blends were higher in comparison to OPC.

Moving on to the hardened properties, the compressive strength results showed a gradual increase. The efflorescence formation is a contributor in the slow development of early strength. However, the strength should be monitored for longer durations to obtain the full strength of GeoCrete. The decrease in water absorption in Palm GeoCrete is a clear proof of the contribution of palm fibers to the enhancement of durability properties of GeoCrete, which are considered critical in ground applications. The depth of penetration increased in GeoCrete with the addition of fibers due to the higher porosity caused by activators. But the results for GeoCrete and conventional concrete were the same. Also, the void content of the GeoCrete mixes was close to that of conventional concrete. Finally, the abrasion test demonstrated that the roughness of the surface of GeoCrete increased with the addition of palm fibers more than when adding synthetic fibers. Also, the increase in surface roughness improves the performance of the different geotechnical applications.

Based on the performance of the tested materials through various tests, it can be concluded that GeoCrete, Palm GeoCrete and Master GeoCrete can be a feasible and more sustainable choice for use in a variety of applications including fire-resistant coatings, soil enhancement, soil stabilization, roads, pavements, slab on grade, foundations, retaining walls, piles, and numerous others. However, it is still important to carry out further experimental work by increasing the total observation time for some properties to better evaluate the behavior of GC and PGC.

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