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PHYSICAL AND MECHANICAL PROPERTIES OF SPENT COFFEE GROUNDS (SCG) IN CONCRETE

(Sifat Fizikal dan Mekanikal Sisa Buangan Kopi dalam Konkrit)

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Abstract

Incorporating waste materials into concrete enhances concrete properties and aligns with sustainable construction concepts. In this study, Spent Coffee Grounds (SCG) were investigated for their potential as an additive material in the cement mortar, to be used as a preliminary investigation for the formation of SCG concrete. SCG were collected from a local traditional Malaysian coffee shop and then undergone oven-drying, grinding and sieving process under controlled laboratory environments to obtain finely grounded SCG powder to be use as additive materials. The study begins with an investigation of the physical and chemical properties of SCG before being applied into cement mortar, through SEM and XRF analysis. Previous literatures have studied the use of SCG as sand substitutes, however, limited studies were conducted in the formation of cement mortar containing SCG additives. Thus, SCG was applied as additives into cement mortar at 6 different percentages of 0%, 1%, 3%, 5%, 7%, and 10%, undergoing 6 different periods of water curing of 7-day, 14-day, 28-day, 35-day, 42-day, and 70-day, tested under compressive strength and flexural strength test. The result of the study shows that under SEM, the SCG tends to form clusters and absorb water, whereas SCG collected for this study contains high carbon content under XRF analysis. The 1 % SCG additive performed the best for both compressive strength and flexural strength outperforming the control mixes. As a conclusion, SCG can be utilized as cement mortar additives when applied at 1%.

Keywords: concrete, spent coffee grounds, cement mortar, additives, sustainability

Abstrak

Menggabungkan bahan buangan ke dalam konkrit meningkatkan sifat konkrit dan sejajar dengan konsep pembinaan mampan. Dalam kajian ini, sisa buangan kopi (SCG) telah dikaji potensinya sebagai bahan tambahan dalam simen mortar, untuk digunakan sebagai penyiasatan awal bagi pembentukan konkrit yang mengandungi SCG. SCG dalam kajian ini dikumpul dari kedai kopi tradisional Malaysia dan proses pengeringan, pengisaran dan penyaringan dijalankan dalam persekitaran makmal untuk mendapatkan serbuk SCG yang dikisar halus untuk digunakan sebagai bahan tambahan konkrit. Kajian dimulakan dengan penyiasatan sifat fizikal dan kimia SCG sebelum digunakan pada mortar simen, melalui analisis SEM dan XRF. Kajian penerbitan SCG dahulu menunjukkan bahawa SCG pernah dikaji sebagai pengganti pasir, namun, kajian SCG sebagai bahan tambahan mortar simen amat terhad. Oleh itu, kajian ini fokuskan kepada SCG digunakan sebagai bahan tambahan ke dalam mortar simen pada 6 peratusan berbeza iaitu 0%, 1%, 3%, 5%, 7%, dan 10%, menjalani 6 tempoh pengawetan air yang berbeza selama 7, 14, 28, 35, 42, dan 70 hari, akan diuji bawah ujian kekuatan mampatan dan kekuatan lenturan. Hasil kajian menunjukkan bahawa di bawah SEM, SCG cenderung untuk membentuk kelompok dan menyerap air, manakala SCG mengandungi kandungan karbon yang tinggi di bawah pemeriksaan XRF. Bahan tambahan SCG 1% menunjukkan prestasi terbaik untuk kedua-dua kekuatan mampatan dan kekuatan lenturan dimana prestasi lebih tinggi berbanding dengan campuran kawalan. Sebagai kesimpulan, SCG boleh digunakan sebagai bahan tambahan simen mortar apabila digunakan pada 1%.

Kata kunci: konkrit, sisa buangan kopi, simen mortar, bahan tambahan, kelestarian

Introduction

Concretes are made from 4 different important materials; cement, fine aggregates, coarse aggregates, and water [1]. These materials are non-renewable natural resources [2]. Every day, more buildings are being constructed to shelter the increasing global human population, leading to the increasing use of these materials that are hard to replenish [3]. According to Watts [4], the use of concrete has risen so much that concrete is now considered the world's second most consumed substance, after water. According to Nie et al. [5], it was reported that concrete production utilizes cement and to produce cement, huge amounts of carbon dioxide pollutants are released. Throughout every lifecycle of the cement, from production until the end of service life, the carbon footprint left behind by the cement cannot be underestimated [6]. Fine aggregates and coarse aggregates present in the concrete are also made up of natural resources that are hard to replenish, to obtain these aggregates, mining, and quarrying of natural resources are needed to obtain the fragments and rock materials for further processing into coarse aggregates, fine aggregates, and cement [7].

Recently, the United Nations (UN) has outlined 17 Sustainable Development Goals (SDG), and among these 17, SDG 11: Sustainable Cities and Communities, SDG 12: Responsible Consumption and Production, and SDG 13: Climate Action Indicators conveyed the need for action on promoting sustainable concepts into the construction industry [8]. Aligned with that vision, waste materials were also being studied for their application as additives in the concrete to improve the mechanical and durability properties of the concrete [9]. The addition of additives could improve the service life of the concrete and reduce the consumption of concrete materials [10].

Coffee is a common beverage, and the level of coffee consumption is estimated to be around 2.25 billion cups consumed every day [11]. Coffee drinking offers a variety of health benefits, but the environmental effects of the coffee wastes are easily taken for granted [12]. Coffee wastes are by-products formed from coffee brewing. When coffee grounds lose their aroma, taste, and colour after being extracted to brew coffee drinks, spent coffee grounds (SCG) are formed. The common disposal method of SCG is by treating it as general waste and simply landfilling [13]. Decomposition of SCG at high volumes produces high content of nitrogen making it less preferable to be used in large quantities as plant fertilizers [14]. Hence, throwing large quantities of SCG directly into landfills may lead to soil infertility. Together with the increasing human population, the demand for coffee may increase as well, increasing coffee waste generation [15]. Thus, an alternative method is required to better manage the SCG waste and minimize the negative environmental impacts of the SCG waste.

Previous studies have utilized SCG as a material in cement mortar. A study by Saeli et al. [16], identified that SCG could be deployed as fine aggregate replacement in cement mortar. Another study by Roychand et al. [17], identified that SCG could similarly be used as fine aggregate replacement in concretes. While both researchers have investigated the use of SCG as fine aggregate materials, limited research has been conducted on the use of SCG as additive materials in cement mortar and concrete. A study by Chua [18], identified that while SCG is used as additive material in cement mortar, a retarding effect has been observed. Nevertheless, the incorporation could only be effective up to 0.6%. Therefore, from the literature reviewed, no studies have been conducted yet on the SCG incorporation in concrete. Hence, this study proceeds with identifying the potential use of SCG in concrete as additive materials by conducting a pilot study investigating the properties of the cement mortar containing SCG additives.

The coffee culture of a locality and treatment methods could affect the properties of the SCG produced, mainly due to the wide variations of roasting methods of coffee beans before being extracted to make a drink [19]. Previous literatures studying the utilization of SCG in cement mortar are mainly sourced from western coffee shops. This is deviating from the coffee beans deployed for this study. In this study, coffee beans were collected from traditional Malaysian coffee shops. The Malaysian coffee adopted a method similar to the Torrefacto method of roasting coffee beans, where sugar is added to the coffee beans [20]. Hence, the difference in roasting methods and brewing methods leads to variations in temperature, humidity, and purity of the SCG produced [21]. The differences in genotypes of the coffee bean could also cause variations in the SCG properties [22]. Therefore, while many studies were conducted on SCG obtained from Western coffee beans, there are lack of studies being conducted on Southeast Asia coffee, specifically the Malaysian coffee beans that could be obtained through local Malaysian coffee shops but not Western coffee shops in Malaysia.

With that, the objective of the study is formed, which is to investigate the applicability of Malaysian SCG as an additive material in concrete, enhancing the concrete as well as reducing the volume of SCG waste materials. SCG is selected as an additive material as opposed to sand or cement replacement due to its composition. According to a study conducted by Tapangnoi et al. [23], after conducting Carbon (C), Hydrogen (H), Nitrogen (N), and Sulphur (S) analyzer on the SCG samples, it is reported that SCG contains at least 50 % of carbon. These high carbon properties indicated that SCG is more suited as an additive as SCG lacks the composition of cement.

It is important to study SCG as an alternative for its application into cement mortar due to the high accessibility of SCG wastes. When compared to other industrial wastes that have been previously studied as concrete additive materials, wastes such as palm oil fuel ash (POFA) and rice husk ash (RHA), are wastes generated from plantation derivatives [24, 25]. Countries with cold climate temperatures tend to have increased challenges developing palm oil and rice husk plantations [26, 27]. This eventually resulted in decreased availability and accessibility of these wastes which are not commonly exported. On the other hand, coffee beans are exported and marketed globally. In the year 2019, Brazil recorded a trade export of roughly 8.06 billion kilograms while Vietnam recorded a trade export of 1.38 billion kilograms of unprocessed coffee beans [28]. The European Union recorded roughly 3.05 billion kilograms of unprocessed coffee beans imported in 2019 alone [29]. This indicated that unlike rice or palm oil where only derived products are exported, unprocessed coffee beans, not roasted nor decaffeinated, are a global trade commodity [30], therefore, indicating the significance of SCG as a suitable alternative to be explored as a concrete additive.

In this pilot study, cement mortar mixes will be used as a replication of concrete. This study investigated the physical and chemical properties of the SCG. Noting the basic properties of the SCG, the SCG will then be studied for its effect on the mechanical strength of the cement mortar samples when added through 6 different percentages, 0%, 1%, 3%, 5%, 7%, and 10%. The mechanical strength involved in this study includes compressive strength test and flexural strength test, both complying with the standards set by ASTM [31, 32]. The mechanical strength testing will be conducted at 6 different periods of water curing, that is 7 days, 14 days, 28 days, 35 days, 42 days, and 70 days.

Materials and Methods

Study area

The main focus of the study is to evaluate the efficacy of spent coffee grounds (SCG) as a filler material in cement mortar for concrete applications. Hence, this chapter looks to discuss and present the methodology involved in this study implemented to achieve the objectives of the study. This section covers from the material used, material preparations, test procedures, and test equipment involved in the study.

Materials and preparation methods

The fine aggregates used are river sand. Fine aggregates were first sieved with ASTM E11 Test Sieve No. 8 with a pore opening of 2.36 mm [33]. Only the fine aggregates that pass the 2.36 mm sieve opening will be selected for this study. After the fine aggregates are sieved, the fine aggregates will then be left to dry under the sun before being used for casting the cement mortar. The cement used in this study is ordinary Portland cement (OPC). The OPC used belongs to a Type 1 cement supplied by YTL Corporation Berhad. The OPC used were kept in a plastic container away from heat with silica gel desiccant to avoid the OPC exposure to moisture conditions.

The spent coffee grounds (SCG) used in this study were first collected from traditional Malaysian coffee shops and then brought to the concrete lab at Universiti Malaysia Pahang Al-Sultan Abdullah for processing. Unlike typical Western coffees, the coffee grounds used to make Malaysian coffee are a type of pour-over coffee, requiring a coarse grind to medium coarse ground, resulting in irregularity in shapes, fineness, and sizes. The collected SCG was washed with tap water and any impurities were removed. The washed SCG was then sent to dry in a 100 ˚C oven for a minimum period of 24 hours. SCG wastes are considered dry when consecutive weight readings indicate no changes. The dried SCG were then grounded with a grinding machine and then sent for further crushing with a Los Angeles Abrasion (LAA) Machine. According to BS EN 13139, for a material to be able to be used as a filler, the material will have to pass a sieve size of 63 microns [34]. After the SCG is grounded in the LAA machine, the SCG is sieved and the SCG that has passed the 45-micron sieve size is used for the study. The processed SCG were then stored in a container with silica gel desiccant to keep in a cool and dry condition.

Test equipment and procedures

To grind the SCG into fine powder to be used as an additive in cement mortar, the Los Angeles Abrasion (LAA) machine is used. The LAA machine was used with 21 metal balls crushing at 1500 cycles on the SCG samples [35]. The grounded SCG was then sieved to pass 45 microns. To understand the morphology characteristics of materials before being used into concrete, a Scanning Electron Microscopy (SEM) test was conducted. SEM test is a method of analysis involving the use of a microscopic tool that could allow for high magnifications into a material while producing high resolution images [36]. From the material analysis through SEM, the surface morphology and characteristics of the particles could be determined [37]. In this study, the SCG wastes before application into cement mortar were analysed for the physical characteristics through SEM test. From this test, the shape and size of the finely grounded SCG material are observed and recorded. To obtain the chemical composition of concrete materials, previous literatures have identified the use of SEM coupled with Energy Dispersive X-Ray (EDX) analysis to perform chemical composition determination [38]. However, the EDX analysis coupled with SEM is only possible at specific area of interest in the materials after specific magnifications [39]. When compared to the X-Ray Fluorescence (XRF) test, the elemental and oxide composition of the material could be obtained through an averaged analysis over a bulk specific area [40]. Previous literatures have also reported that the XRF analysis is generally able to provide higher precision and sensitivity when compared to the EDX techniques when analysing bulk samples [41]. Therefore, for this study, to obtain a general chemical composition of the SCG wastes, the SCG is tested through the use of X-Ray Fluorescence (XRF) spectroscopy. The XRF spectroscopy was run for both elemental and oxides analysis.

To obtain a quantifiable analysis of the performance of SCG in concrete, the mechanical performance test is conducted on the cement mortar samples containing SCG. Concretes are renowned for their use as building construction materials. Among all types of forces involved in a concrete structure, compressive forces and flexural forces are crucial to identify the potential of the concrete in supporting load [42]. With limited studies conducted on the use of SCG as additive materials in concrete, as a pilot study, cement mortar samples were adopted as a replication of concrete samples. This is carried out to determine the optimum proportion of SCG to be added into concrete for improved strength performance. In a study conducted by Al-Jabri et al. [43], it is found that when studying the use of copper slag as fine aggregates, the best performance cement mortar and concrete were observed to have the same proportion of substitute materials. Another study by Son et al. [44] discovered that when studying the cement mortar samples containing substitute materials and the concrete containing similar proportions of substitute materials, the differences in the best compressive strength performance differ by only 6.60%. Hence, previous works of literature have identified that the difference in proportions of additive materials present in the concrete could affect the properties of the concrete and that a pilot study could be conducted on cement mortar samples before their application into concrete. Thus, in this study, the proportions of SCG to be involved in the cement mortar samples are investigated. From here, through the mechanical strength performance investigation, the most optimum content of SCG to be added into the cement mortar can then be determined.

Cement mortar cube samples (50 mm x 50 mm x 50 mm) and cement mortar prism samples (40 mm x 40 mm x 160 mm) were casted and then water-cured in a curing tank for a total of 70 days. Compressive strength tests, per ASTM C109/C109M – 20 were conducted on the cube test samples while flexural strength test, per ASTM C348 – 08 were conducted on the prism test samples. All the cube and prism samples will be tested for its mechanical performance at 6 different periods of water curing, 7 days, 14 days, 28 days, 35 days, 42 days, and 70 days. For each proportion of additive used in the cement mortar, three samples are cast during each of the six different water curing periods, resulting in a total of 108 cube and 108 prism samples. This comprehensive approach ensures accurate results with high repeatability. The compressive strength and flexural strength data are obtained by averaging the strength values of the three cement mortar samples for each percentage and each water curing period.

Spent coffee grounds (SCG) cement mortar mix design

In this study, SCG was added into the cement mortar as filler additives through 6 different percentages, that is 0 %, 1 %, 3 %, 5 %, 7 %, and 10 %. The rationale behind the 6 percentages is mainly due to concrete additives that are usually added into concrete at a range of 0.5 % to 8 % [45, 46]. Chemical agents such as water reducing admixtures and superplasticizer are available in liquid form [47]. Nevertheless, previous studies have identified the use of mineral admixtures, which are available in powder form, studied for its addition into concrete up to 10% [48]. Hence, the percentage of SCG additives to be added into the cement mortar becomes the focus of the study, in order to achieve the objective of finding the most optimum SCG additive proportion for the formulation of an improved performance cement mortar when compared to controlled cement mortar. The controlled cement mortar mix is casted according to the IS 2250 guidelines, utilizing a standard design of 1 part binder to 3 parts of fine aggregates, with a water-cement ratio of 0.5 [49]. Adhering to the standards, the mix design of the cement mortar utilized for this study is listed in Table 1.

All the cement mortar specimens were produced in the laboratory environment under normal room temperature using plastic molds of cubes (50 mm x 50 mm x 50 mm) and prisms (40 mm x 40 mm x 160 mm). The casting process begins with dry mixing the fine aggregates and the cement for about 2 minutes. SCG was then added to the mixing process without the addition of water. Until the materials were dry mixed homogenously, water was slowly added in 3 batches. The wet cement mortar mix will then be poured into the plastic cube and prism molds, which will then undergo a 24-hour setting time under air curing before being removed from the plastic molds to be soaked into water for water curing.

Table 1. Cement mortar mix design applied for this study

Mixes	Cement (kg/m^3)	Fine Aggregates (kg/m^3)	Water (kg/m^3)	SCG (kg/m^3)
SCG-0	50	150	25	0
SCG-1	50	150	25	0.5
SCG-3	50	150	25	1.5
SCG-5	50	150	25	2.5
SCG-7	50	150	25	3.5
SCG-10	50	150	25	5

Results and Discussion

Physical properties of the spent coffee grounds (SCG)

The physical characteristics of the SCG were determined through the use of scanning electron microscopy (SEM) spectroscopy. From the analysis, as shown in Figure 1, the SCG compounds used for this study have been grounded down to sizes finer than 45 microns through the use of the LAA Machine. The SCG material other than having irregularly shaped compounds, tends to form a cluster (as shown in the red rectangle box highlighted in Figure 2), combining with other SCG particles despite being kept away from moist conditions. These results obtained are like the results obtained by Nagaratnam et al. [50] on the microstructure of palm oil fuel ash (POFA) which reported that the material tends to form small clusters and contain irregular shapes. Due to the tendency of the SCG material to form clusters, the SCG materials could be hypothesized to contain a fair amount of carbon composition. This is illustrated by Qing et al. [51], where materials containing high amounts of carbon are reported to form clusters as they have a high-water absorbency with high water retention capacity. Materials with a high tendency to absorb water without utilizing the excess water for other chemical reactions in the concrete results in adverse effects on the inner structure and mechanical strength of the concrete [52]. Noting the hypothesized characteristics of the SCG materials, the content of SCG in the cement mortar will have to be adjusted carefully.

The negative effects of high water retention capacity of concrete materials is reported in a research by Beaudoin and Odler [53], whereby when large amount of water is being absorbed by concrete materials at the initial stage, the cement in the concrete will face water deficit required for hydration process to take place, and when water absorbed by the concrete materials evaporates, this eventually causes void formation in the concrete, causing the cement matrix to loses compaction and ultimately decreasing the mechanical strength of the concrete. Thus, from the physical characteristic investigation using SEM, careful measures of the SCG content should be considered in the cement mortar mix.

Chemical composition of the spent coffee grounds (SCG)

According to ASTM C618-19, a material can be classified as pozzolan if it has a minimum content of 70% by mass of silicon dioxide (SiO_2), aluminum oxide (Al_2O_3), and ferrous oxide (Fe_2O_3) [54]. Pozzolans are materials for the formation of secondary C-S-H gel in the concrete by consuming the calcium hydroxides formed from the cement hydration process, increasing the durability and mechanical strength of the concrete. The chemical composition of the SCG materials were investigated using the X-Ray fluorescence (XRF) test.

From the XRF elemental and oxide analysis, the chemical composition of the SCG is presented as shown in Table 2. Carbon and oxygen are highest in SCG with 51.2% by mass and 46.1% by mass. This indicates that the SCG material does have a high carbon content, confirming the hypothesis formed from the inspection of the physical characteristics of the SCG clumping together. These findings could be supported by the biochar particles, where the high carbon and high porous particles resulted in the biochar having a high tendency to absorb water [55].

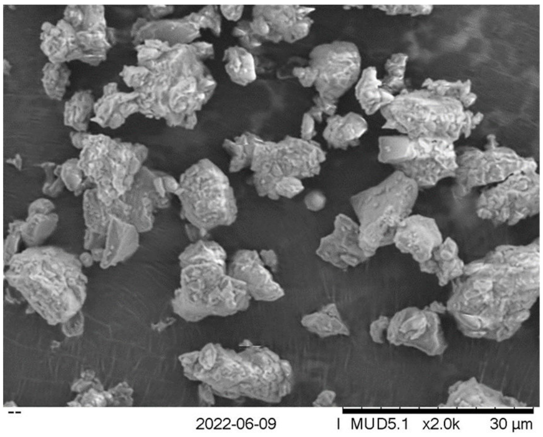

Figure 1. Results obtained from SEM spectroscope at 2000 times magnification.

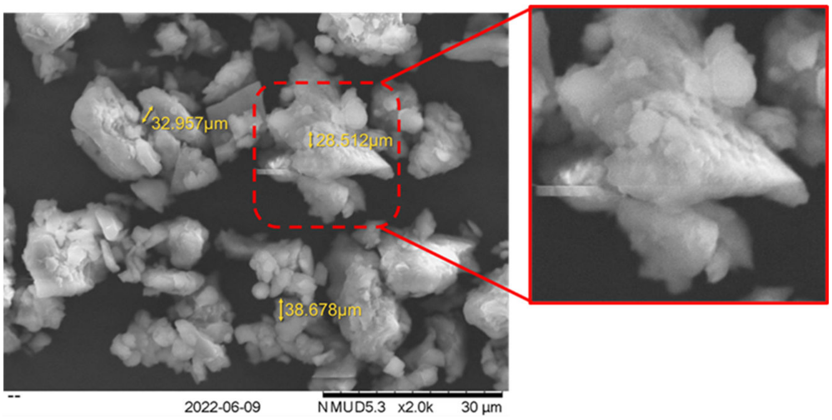

Figure 2. Sizes of the SCG materials from 2000 times magnification (in Red: Clustering of SCG materials).

In the oxide analysis, the highest oxides reported are also carbon and dioxygen with 53.3% by mass and 42.2% by mass, indicating a parallel result with elemental analysis. The SiO_2, Al_2O_3, and Fe_2O_3 compounds in the SCG reported 1.01%, 0.15%, and 0.45%, respectively. The total amount of SiO_2, Al_2O_3, and Fe_2O_3 compounds in the SCG is 1.61%, indicating its pozzolanic properties. However, these properties are expected to make only a marginal difference to the cement mortar mix. When comparing the chemical composition of the SCG to cement, as shown in Table 2, SCG does not possess any similarities with cement's chemical composition [56]. In cement, the highest oxide composition is calcium oxide (CaO) while SCG only contains 0.6% of CaO. This makes SCG unsuitable to be used as a cement substitution.

Hence, from all the findings presented, SCG containing high carbon content can only be used as a filler additive into the cement mortar mix to fill in the pores present in the internal structure of the cement mortar. The SCG in the study reported to not possess any pozzolanic properties and no resemblance to the composition of the cement. The percentages of its use in cement mortar should be low to avoid SCG from absorbing water in the wet mix and releasing it through evaporation, resulting in inefficient use of water in the cement mortar mix.

Table 2. Data excerpt of Elemental and Oxide analysis of SCG compared with cement

Spent Coffee Grounds (SCG)				Cement [56]	
Elemental	**Mass %**	**Oxides**	**Mass %**	**Oxides**	**Mass %**
C	51.20	C	53.30	LOI	5.94
O	46.10	O_2	42.20	O_2	-
K	0.57	SiO_2	1.01	SiO_2	18.68
Si	0.46	K_2O	0.71	K_2O	0.36
Ca	0.42	CaO	0.60	CaO	62.88
Fe	0.31	P_2O_5	0.55	P_2O_5	0.11
P	0.23	Fe_2O_3	0.45	Fe_2O_3	3.31
S	0.17	SO_3	0.44	SO_3	3.78
Cl	0.13	MgO	0.30	MgO	1.04
Mg	0.18	Al_2O_3	0.15	Al_2O_3	5.00
Al	0.07	Na_2O	0.14	Na_2O	0.35
Na	0.11	Cl	0.13	Cl	-

Compressive strength of the spent coffee grounds (SCG) cement mortar

From the compressive strength test result shown in Figure 3, the 1% SCG additive had outperform the 0% controlled cement mortar throughout all 70 days of water curing. At higher percentages 3%, 5%, 7%, and 10%, the SCG additives experienced a huge strength reduction and resulted in a lower strength when compared to the controlled cement mortar. At 7% and 10% additive, the strength was too low for the compressive strength test machine to record a reading, thus the data was not included in Figure 3. Suarez-Riera et al. [57] reported that with the use of biochar, a material high in carbon, the strength of the concrete increased only at small percentages, whereas at higher percentages of additives, the concrete experienced a significant drop in mechanical strength. At 28 days of water curing, where concretes are known to have achieved almost 90% of the concrete strength, the 0% controlled cement mortar has a strength of 24.23 MPa whereas the 1% SCG cement mortar has a strength of 28.23 MPa. Upon reaching 42 days of water curing, the compressive strength of the 0% controlled cement mortar has reached its peak and plateau until the 70-day curing. The 1% SCG cement mortar illustrated an increase in strength throughout the 70 days of curing. The difference in strength between 1% SCG mixes and 0% SCG mixes are illustrated in Figure 4, at 7 days of curing, the 1% SCG has a strength value of 20.95 MPa, which is higher than conventional cement mortar mixes by 9.86%. From the 7th day of curing, the gap of strength difference between 1% SCG mixes and 0% SCG mixes continues to increase. The strength of the 1% SCG cement mortar is 28.23 MPa, higher than the control mixes by 16.51% with a peak at 70 days of curing where the strength difference between 1% SCG and 0% SCG grows to 29.86%. The increase in the gap towards 42-day and 70-day water curing is mainly due to the compressive strength of the 0% SCG mixes plateau after 42 days of curing while the 1% SCG mixes continue to gain strength.

The 3% SCG cement mortar initially has a significantly low compressive strength but witnessed a huge increase from 2.74 MPa at 14 days to 15.28 MPa at 28 days, depicting a strength increase of 45.8%, achieving satisfactory strength at 70 days of curing with a compressive strength of 20.75 MPa. From Figure 3, the compressive strength of the 3% SCG cement mortar continuously gains strength throughout the 70 days of curing. Initially, the strength of the 3% SCG cement mortar is 98.79% lower than that of conventional mixes. Towards the 70-day curing, the difference slowly decreased to 27.91% at the end of the curing period. Though the strength is still lower when compared to the 0 % SCG mixes, the SCG cement mortar continues to gain strength at a quicker rate with the period of curing.

For the 5% SCG cement mortar, the cement mortar increases strength gain with curing time, initially the strength of the 5% SCG cement mortar was 0.17 MPa, and after 70 days of curing, the strength increased to

2.11 MPa. When comparing the differences between the 5% SCG cement mortar and the 0% SCG mixes, the strength differential remains substantial, with a reduction of 92.67% compared to conventional mixes even after 70 days of water curing. Consequently, although the 5% SCG exhibits strength improvement over the curing period, its compressive strength remains unsatisfactory for use in the construction industry. Thus, from this compressive strength test findings, when cement mortar mixes were added with 1 % SCG, the strength generally increased, however, for SCG cement mortar at other percentages of mixes, there is a need for longer curing time.

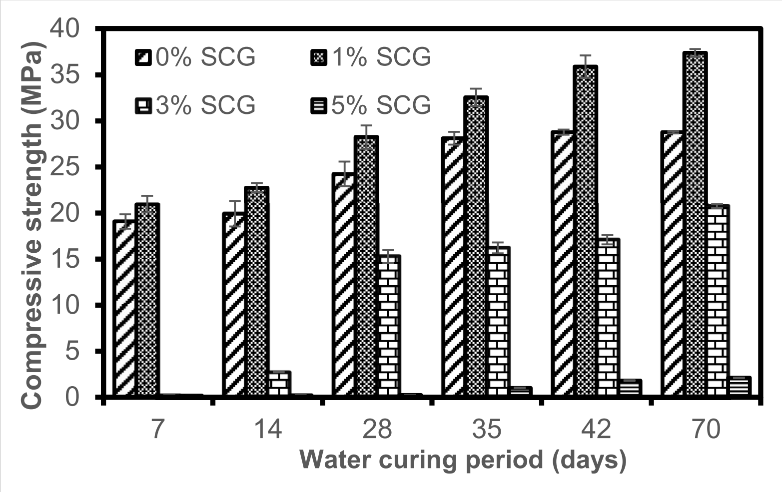

Figure 3. Compressive strength performance of SCG cement mortar

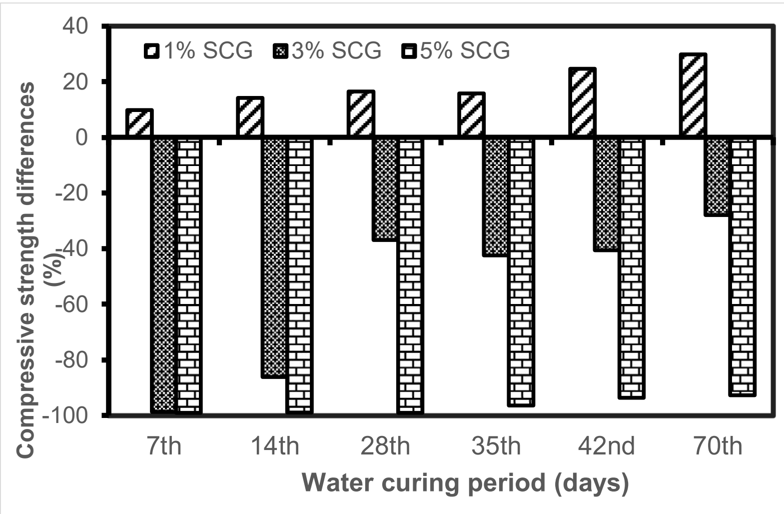

Figure 4. Gap of differences in compressive strength to 0% SCG cement mortar.

Flexural strength of the spent coffee grounds (SCG) cement mortar

From the flexural strength test shown in Figure 5, over the curing period of 70 days, the 1% SCG cement mortar has the highest flexural strength. At 28 days of water curing, the flexural strength of the 1% SCG cement mortar was recorded at 4.75 MPa, which is higher when compared to the 0 % controlled cement mortar specimen at 4.39 MPa. At percentages higher than 1% SCG additives, a decreasing trend was observed for the 3%

and 5% SCG cement mortar samples, like the trend observed in the compressive strength test. At 7% and 10% SCG additives, the cement mortar exhibited low flexural strength, rendering it unable to withstand hand abrasion. As a result, there is no numerical value to report. The difference in strength between 0% SCG cement mortar is shown in Figure 6, 1% SCG cement mortar overall shows higher strength compared to the 0% cement mortar. Unlike the increasing gap from compressive strength test results, the flexural strength indicated a decrease in the gap at 70 days of curing. Hence, cement hardening is still occurring in the beam samples as compared to the cube samples, where pores continue to harden due to the larger volume, filling up the pores internally.

The 3% SCG cement mortar at the early stages of water curing had values lower than the 5% SCG cement mortar, reporting 1.08 MPa and 1.12 MPa, respectively. However, the 3% SCG cement mortar eventually increased in strength gain at a rate quicker than 5% SCG cement mortar, achieving 1.16 MPa for both percentages at 14 days of curing. In Figure 6, the gap of difference between the 0% cement mortar in 3% SCG cement mortar is initially higher compared to the 5% SCG mixes. Starting from the 14th day, the gap of difference is similar. After 28 days of curing, the 3% SCG cement mortar had higher strength values than the 5% SCG cement mortar, and the same trend was observed until the 70-day water curing period, resulting in the gap of 3% SCG cement mortar being slightly higher as compared to 5% SCG mixes. A significant gap was observed at 42 days of water curing, where the 3% SCG cement mortar reported 26.47% lower than 0% cement mortar, while the 5% SCG cement mortar reported a 53.92 % lower than 0 % cement mortar. By 70 days of water curing, the 3 % SCG cement mortar had a flexural strength of 4.35 MPa, while the 5% SCG cement mortar reported only 2.42 MPa, with the biggest difference of roughly 44.37% between the two mixes.

Saeli et al. [16], reported that when deploying SCG as fine aggregate substitute, the flexural strength dropped when compared to that of the controlled cement mortar not containing SCG. Comparing the data obtained from the flexural strength to previous literature by Saeli et al. [16], the flexural strength of the cement mortar containing SCG in this study presented higher values with an improvement of 116%. This indicated that the study is a success in improving the flexural strength of cement mortar while incorporating SCG as part of its mix design. Overall, for all samples, the SCG cement mortar gains strength with the increasing water curing periods, and this trend is similar to the compressive strength test results. Thus, when 1% of SCG was added to the cement mortar mix, the strength generally increased. However, for higher percentages than 1%, there is a need for longer curing time.

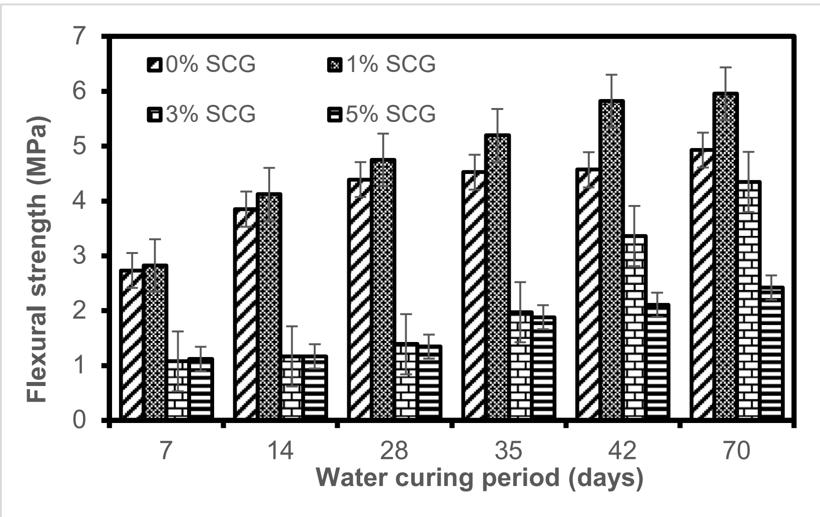

Figure 5. Flexural strength performance of SCG cement mortar

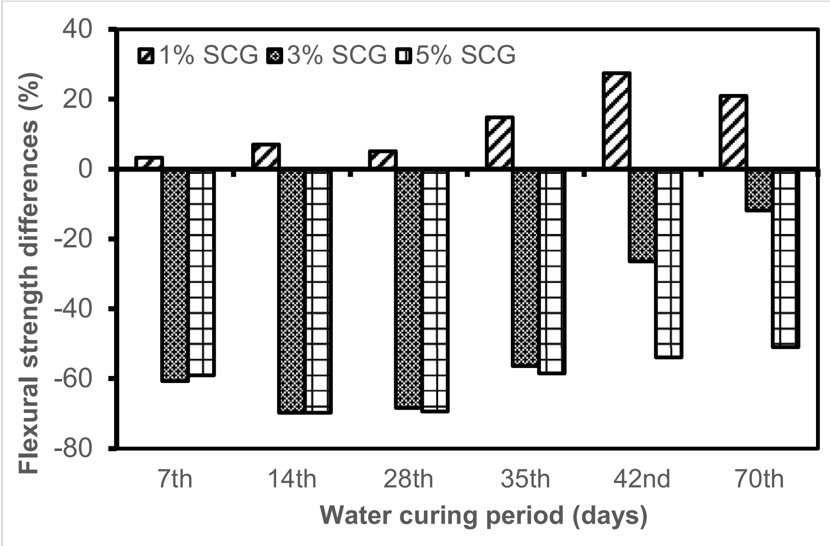

Figure 6. Gap of differences in flexural strength to 0% SCG cement mortar

Mechanical properties of the spent coffee grounds (SCG) cement mortar

From both the compressive strength test and the flexural strength test, a similar trend could be observed for both mixes. Generally, at 1% SCG additive, the strength of the cement mortar would increase. The appearance of the 1% SCG cement mortar is shown in Figure 7. It can also be concluded that at mixes with 3% SCG additive, at longer curing times, the strength of the cement mortar may be significantly increased up to satisfactory mechanical strength. For 5% additives, the strength of the cement mortar up to the 70-day water curing mark has shown non-satisfactory values. At 7% and 10%, the cement mortar does not have sufficient strength to withstand hand abrasion and no data could be recorded from the machine. A study by Gallegos-Villela et al. [58] utilized a curing period of up to 90 days before the concrete containing waste materials indicated an increase in mechanical strength. Hence, a similar methodology may be suggested for future studies on SCG additives into concrete at higher percentages than 1%. Nevertheless, this study concluded that the most optimum percentage of SCG additive would be 1%.

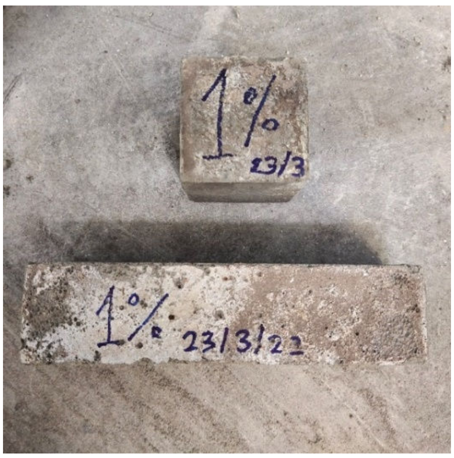

Figure 7. The 1% SCG cement mortar that exhibits the highest strength properties

Implication of the research study

From this research, spent coffee grounds (SCG) could only be utilized in cement mortar up to 1 % as additives. Through this study, the level of addition of SCG into the cement mortar is significantly lower when compared to its other counterparts such as rice husk ash (RHA) and palm oil fuel ash (POFA) [59, 60]. Nevertheless, this study is still significant due to the high availability of SCG wastes around the world. SCG wastes are widely accessible around the world. In regions with extreme climate conditions, under high or low temperatures, paddy and palm oil plantations are suppressed [61-63]. This leads to the lowered availability of these waste products unlike coffee, a common beverage consumed globally unaffected by weather and climate [64]. Though coffee plantation is not practiced worldwide, the coffee beans are exported to all parts of the world resulting in the accessibility to these wastes compared to rice husk ash or palm oil fuel ash that may not be readily available from their exported end products.

Cement mortar mixes use cement and sand in their mixture. Though sand is available in abundance, sand that can be used for construction is still a natural resource that is decreasing and limited in volume [65]. Meanwhile, cement production is a damaging industry with detrimental environmental effects [66]. One study revealed that every ton of cement produces approximately 0.79 tons of carbon emissions [67]. With SCG as additives, the cement mortar could have increased service life, reducing the consumption rate of sand and cement. Previous research on incorporating spent coffee grounds (SCG) into concrete has highlighted their potential application in concrete mixtures. However, no published studies have been identified regarding the utilization of SCG from traditional Malaysian coffee shops, where coffee is prepared using the pour-over method, as additives in concrete. This study initiates an exploration into the use of such SCG as additives in concrete and suggests potential future research directions. These directions include investigating the application of Malaysian SCG in various concrete products such as high-strength concrete, lightweight concrete, architectural concrete, among others.

Sustainable Development Goals are goals outlined to achieve the social and economic development of a nation while protecting environmental values and balancing social equity. Through the involvement of waste materials in the construction industry, reducing demand for non-renewable raw natural resources through repurposing of wastes achieves the UN SDG 12 Responsible Consumption and Production. At the same time, by reducing reliance on environmentally detrimental materials such as cement, the UN SDG 13 Climate Action is achieved, making the incorporation of SCG a sustainable alternative for the construction industry.

Conclusion

As a conclusion of the study based on the experimental results, spent coffee grounds (SCG) sourced from local Malaysian coffee shops could be utilized as an additive into cement mortar up to 1%. The mechanical performance of SCG cement mortar at 1% incorporation indicated improved performance as compared to cement mortar without SCG. The physical properties of SCG after lab processing have a particle size of finer than 45 microns with irregularly shaped particles that have a high tendency to clump together. Chemical properties of SCG, investigated through XRF analysis shows that carbon is the highest chemical composition in the SCG.

The limitations of the study include that the spent coffee grounds (SCG) used may not fully represent all SCG properties globally. Different sources of materials could result in variations in their reactions with concrete and differences in the physical and chemical properties of the SCG. The tests involved in this study utilized casting of cement mortar. To strongly correlate the use of SCG in concrete and its strength properties, concrete mixes have to be tested as there are chances in which the data may differ in this study when SCG is applied into concrete mix. Water curing period conducted in this study is only limited up to 70 days due to the COVID-19 restrictions in lab activities. While there are other studies that reported strength increase only noticeable after 90 days, further studies may be conducted to investigate the strength gain of the SCG additive concrete after 90 days of water curing.

For future studies, it is recommended that SCG additives at 1% can be tested for its application into concrete mixes to confirm if the concrete produced at 1% additives yields the highest in performance. The curing period in this study is limited to 70 days and it is recommended for future studies to carry out further testing and utilize a curing period of up to 90 days and more to observe the performance of strength of the SCG additive in concrete.

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