



Spent ground coffee – awaking the sustainability prospects

Ahmad Beng Hong Kueh^{1,*}

¹*Department of Civil Engineering, Faculty of Engineering, Universiti Malaysia Sarawak, 94300, Kota Samarahan, Sarawak, Malaysia*

Abstract

This paper outlines the threat of spent coffee ground (SCG) towards environmental health and some promising remedial efforts carried out by the scientific community working against it. To maintain human and earth wellbeing, massive biowastes left behind by the rising popularity of coffee drinking and its processing must be properly addressed. The recent waste to wealth value engineering efforts carried out to repurpose these biowastes are first presented. Some promising applications of SCGs in various prospective civil engineering areas alongside their favorable findings are then summarized. Attributed to beneficial properties as reported in existing studies, silica fume is recommended as the potential constituent to mix with SCG for future construction materials exploration in overcoming both the biowaste and industrial waste issues.

Keywords :

Spent ground coffee; value engineering; waste; construction industry; silica fume

1 Introduction

Coffee, a drink brewed using the roasted and ground coffee beans of African origin, remains one of the three most consumed beverages worldwide along with tea and water. It ranks second only to fossil fuel in terms of the product traded around the globe (Murthy and Naidu, 2012a). Coffee is classified under the genus *Coffea* in the Rubiaceae family. As much as bringing huge economic impact to the coffee-producing countries, coffee drinking has deeply embedded in modern society and culture due to its long historical heritage. Accredited to health benefits of coffee consumption such as reduced risks of heart disease and some cancers, including favorable properties like anti-oxidant (Gómez-Ruiz et al., 2007), anti-bacterial (Meckelburg et al., 2014), remedial functions on type 2 diabetes (Akash et al., 2014), as well as anti-obesity and anti-inflammation (Jia et al., 2014) advantages as reported in scientific studies, the demand of the beverage is expectedly on the rise. Each ton of fresh coffee yields half as much mass of coffee pulp along with 0.18 ton of coffee husk from an estimated daily consumption of about 2.3 billion cups of coffee worldwide (Roussos et al., 1995), resulting in an annual amount of 6 million tons spent coffee grounds (SCG) (Mussatto et al., 2011). SCG comprises high quantities of organic compounds, including amino acids, polyphenols, fatty acids, minerals, and polysaccharides that enhance its recycling merit. Some recent innovations explored its uses as domestic agricultural fertilizer or landfill leachate absorbent (Ching et al., 2011; Gomes et al., 2014).

It is also potentially considered a secondary ingredient for the food and drink industry. Nonetheless, a huge SCG harvesting scheme for recycling or marketable purposes has yet to be reported. Although the drink is arguably harmless unless a large amount is consumed, it has been found that coffee production is not a completely green process. Mismanagement of its by-products could cause an extensive water quality deterioration, thereby posing detrimental effects on the water resources of major coffee producers around the globe while negatively impacting the revenue for manufacturers. The Specialty Coffee Association of America found that the wastewater resulted from the coffee processing pollutes 40 times more water vs. those from the typical municipal sewerage. Since coffee pulp in particular has not been well exploited practically or economically, this rate of biowaste production poses a challenge to the health of our environment, as rivers and lakes near the production areas can be potentially polluted. The disposal of coffee waste, which contain tannins, caffeine, and chlorogenic acid, into the environment can exert serious toxicity impacts on the surrounding ecology (Fernandes et al., 2017). The landfill may be one of the currently practiced removal techniques, intelligently repurposing these by-products in various applications can improve their worthiness by turning waste into wealth from the value engineering perspective. Moreover, there is a crucial necessity to adopt the economic SCG and explore its prospects in developing new construction materials to amplify the overall sustainability of the coffee agro-industry and to prevent it from ending in landfills and causing water pollution.

It is worth noting that in preparing this brief perspective note, references have been made from several good reviews (Murthy and Naidu, 2012a; Janissen and Huynh, 2018). Readers are welcomed to seek these reviews for insights into numerous discussions on coffee in its various forms. Hence, this article is not so much a review paper. Rather, it is a summarization of some major directions of SCG applications for progress advancement purposes. Naturally, no attempt is made to involve the expansive coverage of all studies

* Corresponding Author.

Email Address : kbahmad@unimas.my

<https://doi.org/10.33086/etm.v1i1.2016>

Received from 17 March 2021;

Received in revised from 29 April 2021;

Accepted 29 April 2021;

Available online 30 April 2021;

regarding coffee from the scientific literature. Attributed to this, the content of the paper is inevitably incomplete. After the introductory section, various valuable aspects of coffee as repurposed products as reported in many major works are highlighted. Advancements made to exhibit some prospects of SCG in construction and building industries also from existing technological findings are next summarized. A recommendation to marry organic and industrial wastes in the form of SCG and silica fume, respectively, in the cementitious matrix is then made for future exploration as construction materials innovation by first noting some beneficial characteristics of silica fume. The paper closes with a brief note on the outlook of SCG from the perspectives gathered thus far from the existing publications.

2 Value engineering

Table 1 summarizes some important waste to wealth value-engineered applications of SCG alongside their major findings

Table 1 Coffee waste to wealth value engineering

Application	Major finding	Study
Biofuel	Ethanol production – 50% yield	Machado (2009)
	Ethanol production – 8.5% yield	Gouvea et al. (2009)
	Ethanol production – 78% yield	Woldesenbet et al. (2016)
	Biodiesel production – 10–15% yield	Kondamudi et al. (2008)
	Biodiesel production – 16% yield	Park et al. (2016)
Enzyme	Solid-state fermentation	Torres-Mancera et al. (2011)
	Substrate for cellulose production with <i>Paenibacillus chitinolyticus</i> – 71% yield	Buntić et al. (2016)
	8.6 fold <i>Tannase</i> using coffee husk	Battestin and Macedo (2007)
Mushroom	β -fructofuranosidase & fructooligosaccharides production with <i>Aspergillus japonicus</i>	Mussatto and Teixeira (2010)
	Biological efficacies between 125 & 138%	Velázquez-Cedeño et al. (2002)
	88.6, 85.8, & 78.4% efficacies, respectively, by the treated SCG, coffee husk, & mixed substrates <i>Flammulina velutipes</i> cultivation	Pushpa and Manonmani (2008)
Vermicomposting	~73% of coffee husk for mushroom cultivation	Song et al. (1993)
	Boost soil fertility and plant growth	Martínez-Carrera et al. (2000)
Organic acid	Microorganism inoculation enhances the composting quality and rate of SCG with low phenolic compounds (e.g., 120% barley germination index within 20 weeks)	Sathianarayanan and Khan (2008)
	10 g dry coffee husk yields 82% 1.5 g citric acid	Hachicha et al. (2012)
	Optimal Cassava bagasse with 492.5 mg/kg coffee husk	Shankaranand and Lonsane (1994)
Bioactive compound	Polyphenols extraction by coffee pulp	Machado et al. (2002)
	65–70% anti-oxidant activity from bioactive conserves of coffee by-products	Sera et al. (2013)
Biogas	Phenolics – 3.6% yield	Murthy and Naidu (2012b)
	Biomethanation with coffee husk cultivated with thermophilic <i>Mycotypha</i>	Al-Dhabi et al. (2017)
Dietary fiber (DF)	Fiber complex combined with anti-oxidant properties offer greater benefit	Jayachandra et al. (2011)
	5-fold insoluble DF vs soluble DF	Murthy and Naidu (2012b)
Activated carbon and biosorbent	Phosphoric acid with coffee pulp inflicts great adsorbing capacity	Ballesteros et al. (2014)
	Heavy metals elimination from solutions	Irawaty et al. (2004)
Toxin removal	Landfill leachate absorbent	Oliveira et al. (2008)
Water treatment	Synthesis of silver nanoparticles	Ching et al. (2011)
		Mangindaan et al. (2020)

3 Prospects in construction and building industries

The pursuit of sustainability in building materials usage has found the route of utilizing biowastes or manufacturing by-

products in the construction industry a necessity. The popularization of the worldwide coffee consumption phenomenon leaves a tremendous amount of SCG biowastes, pending for innovative repurposing in various potential applications. SCG is insoluble waste material rich in organic content, hence, useful as the con-

from existing studies. The list is by no means complete or even comprehensive. Nevertheless, it shall offer a preliminary overview of some of the current efforts of the scientific community to furnish various coffee by-products with valuable traits. Biofuels, enzymes, mushrooms, composting, organic acids, bioactive compounds, biogases, dietary fibers, activated carbon and biosorbents, toxin removal, and water treatment are only some of the highlighted major arenas that are benefitted from the waste to wealth efforts. Other applications too many to elaborate within the constraint of the scope include employing coffee by-products as the colorant, animal feed, food products, aroma compounds, and bioactive ingredients, to name but a few. It is worth noting that despite giving a negative impact on the water quality, the reverse can be achieved through the synthesis of silver nanoparticles (AgNPs) as developed by Mangindaan et al. (2020). AgNPs have recently been well-recognized and recommended for the water treatment event (Syafiuddin et al., 2017, 2018, 2020).

stituent material for instance in cementitious composites such as concrete. The potential of SCG in the construction industry can be traced from its high similarity to sands (Arulrajah et al., 2014). Table 2 highlights existing technological initiatives aiming to adopt SCGs as constituents in various construction materials for prospects in

numerous civil engineering applications. It can be noticed that the utilization stretchability of SCGs is highly versatile, ranging from lightweight aggregates, road pavement, structural ceramics, bricks, subgrade fillers to thermal and sound absorbents.

Table 2 SCG in civil engineering applications

Civil Engineering Application	Characteristic/Purpose	Study
Lightweight clay ceramic aggregate Pavement Panel	For draining and green roofing purposes	Andreola et al. (2019)
	Damaged or aged asphalt repair	Jalkh et al. (2018)
Structural ceramic	Structural and non-structural panels with coffee husk – superior bending and bonding characteristics	Bekalo and Reinhardt (2010)
	Improve water absorption and apparent porosity. Can be used as secondary material for bricks with good thermal insulation	Sena da Fonseca et al. (2014)
Brick	Improve mechanical strength by 15% coffee husk ash addition	Acchar and Dultra (2013); Acchar et al. (2016)
	Increase water absorption but decrease compression strength and thermal conductivity	Eliche-Quesada et al. (2011a)
Subgrade filler	Lower mass but higher porosity, which provides greater insulation and good mechanical behavior. 3% SCG optimum content enhances the compression strength	Eliche-Quesada et al.
	17% SCG provides a compression strength of > 10 N/mm ² ; SCG combustion reduces bulk density, hence, enhances porosity but decreases thermal conductivity	Velasco et al. (2016)
	Great water and organic contents, great compressibility but reduced shear strength and density; need stabilization for high traffic loads; SCG as non-structural filler for embankment	Arulrajah et al. (2014)
	30% fly ash replacement & 1.8 alkali liquid activator-to-fly ash ratio in SCG-fly ash geopolymers for road subgrade or structural embankment Slag is superior to fly ash in geopolymerization of SCG	Arulrajah et al. (2016)
Thermal insulator	Glass-SCG-fly ash-slag	
	Geopolymers are sufficiently strong for road subgrade > 20% addition of fly ash and slag in SCG can be used as the structural subgrade	Kua et al. (2016) Arulrajah et al. (2017)
Sound absorbent		Kua et al. (2017a); Kua et al. (2017b)
	Greater SCG content reduces thermal conductivity and thermal diffusivity	Lachheb et al. (2019)
Sound absorbent	Sound absorption coefficient increases with frequency due to SCG porosity	Yun et al. (2020) Gama et al. (2017)
	Rigid foams containing SCG offer good sound absorption	Ricciardi et al. (2017)
	Cold-pressed panels for soundproofing	

4 Marrying organic and industrial wastes

It is well-known that the inclusion of biowaste especially into construction materials like concrete carries one common problem; poor interfacial bonding that could lead to premature failure before the designed strength. Therefore, the incorporation of the industrial by-products, for example, tin slag and silica fume, offers an innovative solution in ensuring the synergetic and beneficial interaction between biowaste and the construction material matrix. This has been proven by some early findings on the production of high-performance composites, which have gained attention from the scientific community (Kua et al., 2016; Kua et al., 2017a; Kua et al., 2017b; Arulrajah et al., 2017).

Silica fume (SF) is the by-product of silicon metal and ferrosil-

icon alloy factories. SiO₂ vapors, by yielding silicon from quartz at high temperatures, undergo oxidization and condensation at low temperatures to form non-crystalline silica particles. Physically, smaller than 1 μm SF particles can be obtained through this process with a production efficiency of > 95%. SF is mostly spherical while chemically rich in amorphous silicon dioxide. Low quantities of magnesium, iron, and alkali oxides can be commonly observed. Some advantages of SF include (Siddique, 2011):

1. Great modulus of elasticity, tensile, compressive, and bending strength
2. Great interfacial strength
3. Enhanced toughness and durability
4. Low permeability, hence, good resistance to water infiltration and chemical attack
5. High abrasive resistivity
6. Good electrical resistance

Furthermore, identified applications of SF include functioning as a constituent in high-performance concrete for naval constructions, bridge floor components, highway bridges, parking decks; SF shotcretes for rock strengthening, tunnel liners, as well as restoration of aging bridges and maintenance of coastal piles and columns, etc.

Environmentally conscious construction practices have expanded the types and nature of aggregate being used in the industry. SF in various forms had been studied to find their niche in the construction domain to conserve and regularize the commonly employed aggregate consumption. Due to enhanced performance in the cement-aggregate interfacial zone, SF was identified as able to boost the initial strength and robustness of concrete matrix for high-strength cementitious materials production (Lee and Lee, 2010). Employing SF had a beneficial outcome on the fiber-matrix transition region while improving up to 20 times material strength and electrical resistance attributing to the pozzolanic effects and portlandite decline such that the mixing consistency, density, and bond qualities were hugely enhanced (Sadr-momtazi et al., 2018). Therefore, SF can be used in two different ways; as an economic cement substitution and as one of the constituents for concrete properties augmentation (Nochaiya et al., 2010).

In the recent innovation, SCG has been integrated for structural purposes, e.g., as panels (ECOR, 2019), exhibiting its potential as a construction material. Hence, the scarceness of information regarding SF performance in a variety of concretes mixed with natural by-products like SCG calls for the need for study in exploring a better performing concrete material. Hence, future exploration may involve finding the optimal mix design of concrete composites mixed with SCG and SF for strength and durability. Further, the proper mode of failure should be well-characterized especially in addressing the concrete interfacial bonding issues. In addition to structural requirements, other good functionalities such as thermal and soundproofing for human tenant comfort are some new aspects worth exploring especially for applications in different climates including tropic and four-season regions (Tay et al., 2021a; Tay et al., 2021b). The outcomes from these studies could provide the feasibility scale of the proposed materials in terms of sustainability and performance as well as their acceptance level for structural-grade construction applications.

5 Concluding thoughts

As humankind progresses to making numerous achievements in various fields, technological advancements in manufacturing industries to support the demands suggest that our environmental health is in constant threat due to improper by-products or waste disposal. Driven by rising consciousness on continual exhaustion of irreplaceable natural resources, emerging creative and innovated approaches for alternately repurposing biowastes and industrial wastes for environmental health security and sustainability have been the primary pursuit of material researchers worldwide. Coffee being one of the global favorite beverages leaves a massive amount of biowastes, if improperly discarded, can potentially pose harm to human and environmental wellbeing. The paper summarized in brevity some potential areas that value engineering can be employed via the waste to wealth analogy. Some limited but promising evidence gathered from the scholarly findings were then presented to demonstrate that more studies are warranted for higher confidence in applications of spent coffee ground in civil engineering focusing particularly on the construction fields. Attributed to numerous beneficial traits, silica fume, in particular, had been highlighted as the prospective constituent from the industrial waste to wed with the spent coffee ground as the biowaste. In the future, as our awareness of the hazards of many biowastes and industrial wastes grows, we will be seeing an elevated development trend in waste to wealth operation

in paving greener industrial revolution not only with better efficiency but also with low threat towards the ecosystem. Only with a comprehensive understanding and thereby further optimization of the material added with the spent coffee ground and silica fume can the right and successful technique be put into practice to satisfy both performance and cost efficiencies. A comparative investigation against existing materials from the life cost forecast perspective is one of the recommended future investigations to measure their economic, climate, and environmental implications in human lifestyle and construction practices. That is the current hot cup for thoughts.

Declaration of competing interest

The author declares no known competing interests that could have influenced the work reported in this paper.

Acknowledgements

The author thanks the Universiti Malaysia Sarawak for facilitating the current work.

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