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REVIEW

Partial Replacement of Cement by Solid Wastes as New Materials for Green Sustainable Construction Applications

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ABSTRACT

The manufacturing of ordinary Portland cement is an energy-intensive process that results in pollution and CO_2 emissions, among other issues. There is a need for an environmentally friendly green concrete substitute. Waste products from a variety of sectors can be recycled and used as a green concrete substitute. This decreases the environmental effects of concrete manufacturing as well as energy consumption. The use of solid waste materials for green building is extremely important now and in the future. Green concrete is also in its infancy in terms of manufacturing and application. Academics must intervene by encouraging business implementation. The aim of this review paper is to raise awareness about the importance of repurposing recycled materials and to highlight new technologies for producing green, sustainable concrete.

1. Introduction

Nine separate mixtures with a water-to-binder ratio (W/B) of 0.8 with differing Stabilized polystyrene (SPS) content ratios of 0, 60 and 100 % were prepared and tested as a partial substitution of the natural fine aggregate with an approximate amount of 0, 20 and 40 % fly ash substitution with Portland cement. The properties of the concrete tested were compressive strength and ultrasonic pulse velocity (UPV) at 28-day age. The findings suggest a drop in compressive strength and UPV with increasing concentrations of SPS and fly ash in concrete [1].

Polymer mortar and polymeric composites have been prepared using recycled polystyrene waste and cement dust waste as a filler due to cost and environmental concerns. For comparison, virgin polystyrene and Portland cement are used. To strengthen the adhesion between the filler and the polymer matrix, cement dust was treated with a stearic acid reaction. Composites are made by mixing different quantities of refined and raw cement dust (30, 50, 70, and 90 wt%) with virgin or recycled polystyrene. Mechanical properties, water absorption, and chemical resistance were used to demonstrate the suitability of formulated cement materials as building materials.

Chemical resistance and mechanical properties have improved after a week of immersion in water, 10% sodium chloride (NaCl), and 10% sodium sulphate (Na_2So_4) solutions, and water absorption has been delayed. The

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recycled polystyrene composites filled with treated cement dust had the strongest abrasion resistance, weight loss, compressive and bending strength. Chemical resistance and mechanical properties have been improved, and water absorption has been delayed, after regular immersion in water, 10% sodium chloride (NaCl), and 10% sodium sulphate (Na_2SO_4) solutions. The highest abrasion resistance and lowest weight loss, as well as the greatest compressive and bending strength, were achieved with recycled polystyrene waste packed with treated cement dust. [2].

It is traditional practice to make concrete masonry units, such as concrete blocks or tiles, using portal cement in conjunction with aggregates. The previous technique has combined one section of cement with ten aggregate pieces, conventionally fine and rough aggregates, typically in the shape of sand and gravel or crushed stone. Limited quantities of other materials can be applied to facilitate or postpone reactions or to provide the desired properties to the cement. Portland cement is a mixture of calcium-aluminum-magnesia-silicate. The addition of water to a dry mixture of Portland cement results in a series of crystallization reactions that give concrete the strength required for use in construction industry. Due to the complexities of different chemical reactions, a great deal of study has been carried out to assess their effect on cured products, both in reaction conditions and in reactants. Such an investigation has an impact on the development of standardized quality standards for cement, as laid out by the American Association for Measuring Materials (ASTM). Materials such as sulfates, retardants, chlorides as accelerators, and pozzolans are among the various chemicals used in the processing of concrete and concrete block items. Although these pozzolans are not of cement quality or binding, they do interact with lime in the presence of water to form cementitious substances. Additives include products such as fly ash, silica dust, and silica-containing materials such as ground concrete, burnt shale, and some slag. Suitable fly ash formulations for the preparation of cement blocks include all of those fly ash compositions set out in ASTM C 618, ‘Standard Specification for Fly Ash and Pure or Calcined Natural Pozzolan for use as a natural additive in Portland Cement Concrete [3].

In a global environment where the demand for quality housing is growing with an increased quality of life and a rising population, over-exploitation of natural resources as construction materials is becoming a significant issue. In this case, the incorporation of non-biodegradable waste materials into better construction materials would be highly useful. This report experimentally tested the use of expanded polystyrene mechanically recycled as 50 percent of total EPS for the composite foam concrete panel. The findings of the experimental program have been investigated concerning different useful structural behaviors in compression and flexicurity. The use of this foam concrete in combination with cement fiber boards results in a lightweight wall panel that can be used for both load-bearing and non-load-bearing walls in multi-story buildings. These light-weight panels allow for fast construction while also reducing the total weight of the building [4].

Construction has far-reaching social, economic, and environmental consequences. Given the materials used, such effects are dependent on the development of concrete, since it is the most widely used commodity, and its products are linked to the use of Portland cement, which accounts for a large portion of the industry’s CO_2 emissions. The aim of this study was to investigate the use of recycled rubber in lightweight concrete with metakaolin, with the dual goal of reducing cement consumption while maintaining adequate strength. Metakaolin was created in the lab, and the minimum temperature for kaolin production was determined. Compressive strength, calorimetry, and mortar thermal conductivity measurements were used to evaluate lightweight concrete (in which sand was replaced by rubber). The researchers discovered that metakaolin produced at 800°C is more effective at replacing silica smoke. The 40% rubber mortar has a compressive strength of 20 MPa. This strength in light concrete allows for the production of materials with low cement consumption, such as mortar (22.9 kg of cement/m^3/MPa) and concrete (13 kg of cement/m^3/MPa). The concrete-rubber results revealed the best thermal conductivity indices, allowing building projects to be constructed more energy-efficiently, lowering their operating costs [5].

The mechanical properties of a wide variety of structural fine aggregates concrete mixtures are measured by a non-destructive ultrasonic testing process. This research includes about 84 different formulations checked between 3 and 180 days with compressive strengths ranging from 30-80 MPa. The effect of multiple influences on the relationship between ultrasonic pulse velocity and compressive intensity is investigated. These considerations include the form and quantity of cement, the quantity of water, the form of mixture, the initial wetting conditions, the type and volume of aggregate, and the partial substitution of the normal gross weight and fine aggregates with lightweight aggregates. Changing design parameters has a different effect on lightweight and standard weight concretes. The non-destructive ultrasonic pulse velocity test is also used to test the calculation of the mortar's strength properties. A generalized definition is proposed to estimate the compressive force based on the dependence of the ultrasonic pulse velocity on the stiffness and flexibility of concrete, regardless of the shape of concrete and its structure. More than 200 results were analyzed for different types of aggregates and concrete compositions, yielding a high correlation analysis [6].

Aggregates have low-cost volumes, containing between 66% and 78% of concrete. With growing concern about the unsustainable processing of natural and quality aggregates, the aggregate generated from industrial waste and agricultural waste is a viable new source of building materials. This review was undertaken to assess the feasibility of the use of coconut shells as aggregates in concrete. It is not only solves the issue of disposing of this solid waste but also helps preserve natural resources.

The crushed coconut shell aggregate's mechanical strength has been demonstrated. Rough aggregate is often used to represent fresh concrete properties such as density, slump, and 28-day compressive strength of lightweight concrete made from coconut shells. The results showed that the coconut shell aggregate had a high water absorption rate of about 24%, but the crushing value and impact value were comparable to other lightweight aggregates. The coconut shell concrete aggregates had an average fresh concrete density of 1975 kg/m^3 and a 28-day cubic compressive strength of 19.1 N/mm^2, respectively. It is concluded that crushed coconut shells are ideal for use as a replacement for traditional aggregates in the manufacture of light concrete [7].

In the presence and absence of enhanced additives, two difficult waste materials, cement kiln dust (CKD) and poly(styrene) (PS), were unutilized for the production of lightweight cementitious bricks suitable for subsequent building applications. To maximize the mechanical properties of the substance, various doses of Portland cement, iron slag, and crushed waste glass were mixed with the two main components (CKD and PS). The compressive strength, density, porosity, and water absorption of the various samples were evaluated under various conditions to determine their mechanical stability and physical properties. The microstructure of different sample compositions dependent on different variables has been studied using scanning electron microscopy (SEM), energy-dispersive X-ray (EDX), and spectroscopic analysis (FTIR and XRF). The mechanical strength results show that PS is unable to increase CKD reliability in the absence of other improved additives. In addition to CKD, 5% iron slag, 10% Portland cement, 10% ground waste glass, and 3% PS shredded waste were the required ratios for achieving an appropriate composite of feasible integrity. The nominated product has met the recommended value for building construction on outer shielding and internal non-loading walls, ensuring maximum mechanical and physical specifications in compliance with international standards. One of the benefits of this study is that it served two important roles for the environment: it consumed a by-product of environmental waste recycling, it was not financially costly, and it did not waste energy during its processing, and it primarily assisted us in getting rid of this waste [8].

2. Green Cement and Sustainability

Much research has been done to make adjustments to the cement manufacturing process to reduce greenhouse gas emissions from its manufacture. Approximately 50% of industrial pozzolana (cold ash or iron slag) has been suggested in the cement, thereby decreasing the emissions of carbon dioxide resulting from the burning of fuels into concrete clinker and also reducing pozzolan concrete mixing water [9]. The research competed in providing alternatives to traditional cement, and it used a type of industrial pozzolana, which is fly ash that is collected by special filters from combustion gases in electric power plants by burning coal. Where this ash is fine and the US produces about 70 million tonnes per year. Also, to the value of minimizing CO_2 emissions in natural or industrial pozzolana use [10].

Experiments also show that several significant qualities are the characteristics of this form of cement, such as its strength in soil and groundwater and resistance to natural factors, its low porosity, permeability, and thermal cracks, which influence conventional cement [11]. A team of Australian researchers sought to produce a new mixture of cement, using magnesium oxide with "Portland cement" to replace part of the limestone [12]. Consequently, the heating furnace temperature drops to about seven hundred degrees Celsius, which can be obtained by burning biofuels and some other fuels with lower carbon emissions. Despite the importance of this proposal, it soon turned out to be ineffective in reducing emissions, as the process of producing magnesium oxide is done by heating magnesium carbonate, and this process causes the emission of large quantities of carbonate gas [13].

Cement manufacturing is considered one of the developmental and strategic industries because it is directly related to the construction and reconstruction works, where cement is used as a hydraulic binder from building materials [14]. The cement industry may result in severe diseases as it contains compounds such as carbon, hydrogen, suspended particles, phosphorous, dust, smoke, fog, fumes, and others [15]. When cement

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kilns are used to destroy components of hazardous waste, careful assessment of alternative disposal pathways is required, adherence to strict environmental, health, and safety standards, and no harm to the final product [15]. All these reasons have prompted most countries of the world to adopt the idea of sustainability and green buildings. Green buildings are buildings that provide a better life for people and take into account environmental standards at every stage of construction, design, implementation, operation, and maintenance, thus reducing the harmful environmental impact of the building on societies [16]. Sustainability is based on three main concepts, and the matter can only be correct by taking into account its variables; the economy, society, and the environment [16]. Green buildings are an integrated system that contributes through its ability to provide the consumption of types of cement that contribute to increasing the life span of the building, improving human health, and preserving the ecosystem in a way that reflects positively on the economy and productivity [17]. Various studies have been proposed to replace harmful types of cement with a by-product of rice husk as a partial substitute for ordinary Portland cement. Several studies have suggested optimal values for replacing rice husk ash, from 10% to 20%, which showed a significant improvement in the strength of the resulting mixed concrete [18]. However, these optimum values depend heavily on the burning preparation of rice husk ash that adversely affects the amorphous silica components and, consequently, the pozzolanic activities of the rice husk ash in the concrete [18]. A potential approach has been conducted to convert rice husk to be improved, highly reactive rice husk ash is provided by controlled combustion and milling. The results showed that mortar or concrete containing rice husk ash showed a notable reduction in mass loss when exposed to the hydrochloric acid solution and a significant decrease in the expansion of alkali, silica, and sulfate [19]. It is worth noting that around the world, 100 million tons of by-products are obtained from rice fields. Rice husk ash also has a good reaction when used as a partial substitute for cement. In another study, the results revealed that ash of coconut husk and rice husk used as alternatives to concrete, and it is one of the best sustainable and environmentally friendly products [20]. The mixed formulation had 20% coconut husk ash and 20% rice husk ash had 15.3% greater compressive strength than the reference formulation after aging 180 days. The mixtures of coconut husk ash and rice husk ash showed the highest compressive and pulling efficiency for all aging periods tested. Rice husk ash has a similar chemical composition to many organic fibersand composed of cellulose($C_5H_{10}O_5$), lignin ($C_7H_{10}O_3$), hemicellulose, silicon dioxide (SiO_2), and holocellulose [21]. Rice husk ash can differ according to the source and the processing type. The heating technique can also alter the overall chemical composition of the ash [22].

Silicate is one of rice husk ash's most essential components. During the firing process, the ingredients evaporate, and the only constituent left is silicates. Silicates are the component that gives the ability to react pozzolanic to rice husk ash [23].

3. Conclusions

Replacing cement with large quantities of fly ash and silica dust to develop new green cement and cohesive materials is a promising trend. It improves the use of renewable raw materials and alternative fuels by producing or improving cement with less energy consumption during manufacturing. The use of appropriate alternatives to Portland cement, particularly in construction industry such as fly ash, iron slag, and silica dust is very vital to minimize pollution. Also, attempts to use efficient recycling materials as an alternative to concrete aggregates, such as recycled aggregates, are becoming very significant.

References

[1] B. A. Herki, J. M. Khatib, and E. M. Negim, "Lightweight concrete made from waste polystyrene and fly ash," *World Appl. Sci. J.*, vol. 21, no. 9, pp. 1356-1360, 2013.

[2] J. N. Asaad and S. Y. Tawfik, "Polymeric composites based on polystyrene and cement dust wastes," *Mater. Des.*, vol. 32, no. 10, pp. 5113-5119, 2011.

[3] M. H. Wills Jr, "Concrete masonry units incorporating cement kiln dust." Google Patents, Oct. 04, 1983.

[4] P. L. N. Fernando, M. T. R. Jayasinghe, and C. Jayasinghe, "Structural feasibility of Expanded Polystyrene (EPS) based lightweight concrete sandwich wall panels," *Constr. Build. Mater.*, vol. 139, pp. 45-51, 2017.

[5] F. Pelisser, A. Barcelos, D. Santos, M. Peterson, and A. M. Bernardin, "Lightweight concrete production with low Portland cement consumption," *J. Clean. Prod.*, vol. 23, no. 1, pp. 68-74, 2012.

[6] J. A. Bogas, M. G. Gomes, and A. Gomes, "Compressive strength evaluation of structural lightweight concrete by non-destructive ultrasonic pulse velocity method," *Ultrasonics*, vol. 53, no. 5, pp. 962-972, 2013.

[7] K. Gunasekaran and P. S. Kumar, "Lightweight concrete using coconut shell as aggregate," in *Proceedings of the ICACC-2008. International conference on*

advances in concrete and construction, Hyderabad, India, 2008, pp. 7-9.
[8] H. M. Saleh, A. A. Salman, A. A. Faheim, and A. M. El-Sayed, "Sustainable composite of improved lightweight concrete from cement kiln dust with grated poly (styrene)," *J. Clean. Prod.*, p. 123491, 2020.
[9] X. Shi, N. Xie, K. Fortune, and J. Gong, "Durability of steel reinforced concrete in chloride environments: An overview," *Constr. Build. Mater.*, vol. 30, pp. 125-138, 2012.
[10] Z. Giergiczny, "Fly ash and slag," *Cem. Concr. Res.*, vol. 124, p. 105826, 2019.
[11] S. Demirdag, "Effects of freezing-thawing and thermal shock cycles on physical and mechanical properties of filled and unfilled travertines," *Constr. Build. Mater.*, vol. 47, pp. 1395-1401, 2013.
[12] M. Schneider, M. Romer, M. Tschudin, and H. Bolio, "Sustainable cement production—present and future," *Cem. Concr. Res.*, vol. 41, no. 7, pp. 642-650, 2011.
[13] M. S. Imbabi, C. Carrigan, and S. McKenna, "Trends and developments in green cement and concrete technology," *Int. J. Sustain. Built Environ.*, vol. 1, no. 2, pp. 194-216, 2012.
[14] U. N. Environment, K. L. Scrivener, V. M. John, and E. M. Gartner, "Eco-efficient cements: Potential economically viable solutions for a low-CO_2 cement-based materials industry," *Cem. Concr. Res.*, vol. 114, pp. 2-26, 2018.
[15] P. K. Gupta, "Toxicologic Hazards of Solvents, Gases, Vapors, and Other Chemicals," in *Concepts and Applications in Veterinary Toxicology*, Springer, 2019, pp. 121-142.
[16] L. Zhang, J. Wu, and H. Liu, "Turning green into gold: A review on the economics of green buildings," *J. Clean. Prod.*, vol. 172, pp. 2234-2245, 2018.
[17] A. Alwisy, S. BuHamdan, and M. Gül, "Criteria-based ranking of green building design factors according to leading rating systems," *Energy Build.*, vol. 178, pp. 347-359, 2018.
[18] M. M. Hossain, M. R. Karim, M. Hasan, M. K. Hossain, and M. F. M. Zain, "Durability of mortar and concrete made up of pozzolans as a partial replacement of cement: A review," *Constr. Build. Mater.*, vol. 116, pp. 128-140, 2016.
[19] S. Donatello, A. Palomo, and A. Fernández-Jiménez, "Durability of very high volume fly ash cement pastes and mortars in aggressive solutions," *Cem. Concr. Compos.*, vol. 38, pp. 12-20, 2013.
[20] Z. A. Zeidabadi, S. Bakhtiari, H. Abbaslou, and A. R. Ghanizadeh, "Synthesis, characterization and evaluation of biochar from agricultural waste biomass for use in building materials," *Constr. Build. Mater.*, vol. 181, pp. 301-308, 2018.
[21] H. Moayedi, B. Aghel, H. Nguyen, and A. S. A. Rashid, "Applications of rice husk ash as green and sustainable biomass," *J. Clean. Prod.*, vol. 237, p. 117851, 2019.
[22] B. S. Thomas, "Green concrete partially comprised of rice husk ash as a supplementary cementitious material-A comprehensive review," *Renew. Sustain. Energy Rev.*, vol. 82, pp. 3913-3923, 2018.
[23] C. Sonat and C. Unluer, "Development of magnesium-silicate-hydrate (MSH) cement with rice husk ash," *J. Clean. Prod.*, vol. 211, pp. 787-803, 2019.

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