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Sustainable Concrete Partially Comprised of Supplementary Cementitious Material and Alternative Fine Aggregate- A Review

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Abstract: The waste generation from agricultural and industrial activities contribute to the lack of the landfill disposal area and other environmental imbalance issue. Furthermore, the high consumption of raw materials like sand in the construction sector led to a massive depletion in natural sources to meet the pressure demand in the future. The problem of excessive carbon dioxide (CO_2) emissions from cement production activity that led to global warming has initiated this study to find the potential of reducing it. This study reviews the performance of the supplementary cementitious materials (SCM) and the alternative fine aggregates (AFA) from waste products to identify the optimum percentage of waste materials that suitable for the manufacture of sustainable concretes. The reviews enlighten the mechanical properties of the concretes like workability, compressive strength, water absorption, and fire resistance compared to the reference concrete. Quantitative research of the review involves quantifying and analyzing variables obtained from previous studies on the SCM and AFA performances. Despite some concrete properties have significantly reduced after implemented the waste products, the replacement proportions may be controlled at a certain proportion to achieve optimum concrete performance based on the summarized findings in this review. Proper selection of the materials as well as an appropriate treatment like the burning process and pre-treatment procedure could be carried out because it affected the mechanical performances of concrete. Moreover, further study on other durability properties could be the focus for more firm in understanding before implementing the waste products.

Keywords: Supplementary Cementitious Materials, Alternative Fine Aggregates

1. Introduction

Substantial population growth and economic improvement are expected to increase the demand for goods and services in the coming years and the quantity of waste materials produced by products across different sectors and other industries like agriculture, construction, and manufacturing is expected to

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rise in the future [1]. The increase in population growth has risen the issue of waste disposal due to the type and the amount of decomposed waste produced has increased over the years. These waste materials may be hazardous and cause major problems in the amount of waste generated if they remain in the environment for a longer period as they are unused and 85.00 % of these are dumped as landfill [2]. The abundant waste generations contribute to the landfill problem, which leads to associated non-availability of landfills and other environmental imbalance issues such as pollution [3]. The re-use and recycling programme had seen as a useful solution to this crisis by inventing innovative uses of waste materials such as ground granulated bottom blast slag, fly ash, silica fumes, and glass fibers that have been successfully applied in concrete for decades and have continued to move forwards [4]. Fine aggregate is utilized as a significant material for the concrete composition which contributes to the strength factor, weight, workability, and shrinkage [5].

It fills up the voids beside provides the particles mass which are suitable to resist the action applied. The existence of superior properties in sand makes them the most widely used in construction, the main sources of which included quarry dust, river sand and marine sand [6]. The extensive consumption in construction, caused by the rapid development of infrastructure and the increasing demand, leads to a massive depletion or scarcity of natural resources [7]. The exhaustion of resources as an increase in demand for sand leads to a lack of availability in the future. In addition, the depletion of these natural mineral resources has created many environmental threats, such as changes the water course of river and beach, contamination of the ground water, distraction of the ecosystem, and loss of strength to hold the strata of the soil [8]. Thus, many efforts are being made to mitigate this situation from worsen and crucial by finding the alternative material and the waste materials got to be imperative. Cement is the main composition in the concrete mixture which define by the International Energy Agency as the “glue” that holds the concrete together. Cement is produced by the combustion process of petroleum coke, fossil fuels, fuel oils, and coal in the oven at consistent temperature of 1450 ℃ [9].

In order to produce one ton of cement, the discharge of carbon dioxide, CO_2 gases to the atmosphere recorded at approximately 900 kg which contribute around 7.00 % of CO_2 emission that rise greenhouse gases and causes environmental depletion [10]. The emission of CO_2 that are released into the atmosphere from the cement production cause the global warming [11]. The reduction of CO_2 emission can be achieved through the improvement in production process by the cement manufacturers besides reducing the cement content in concrete with the utilization of supplementary cementitious materials such as fly ash, blast-furnace slag, natural pozzolans, and biomass ash. The advance development in Malaysia depends on the production that run by the energy produced by a finite resource like coal and petroleum derivative which can cause an extension in CO_2 discharge and lead to the global warming [11]. This review is to identify the optimum percentage of waste materials that were utilized as supplementary cementitious materials and alternative fine aggregates for the manufacture of sustainable concretes. In addition, to compare the mechanical properties of such sustainable concretes with the conventional concrete that comprised of compressive strength values, water absorption values, and fire resistance values.

2. Supplementary Cementitious Material (SCM)

Concrete is the commonly used construction materials worldwide by volume in form of a mixture contained Portland cement, sand, coarse aggregate, and water. Portland cement production through the calcination process contributed to the increment of energy consumption and high amounts of CO_2 emission that led to global warming. Intensive efforts are needed to design and develop sustainable concrete with the enhancement in concrete strength and durability performance. Nowadays, supplementary cementitious materials (SCM) are widely introduced to concrete mixtures as a replacement of cement in concrete. These materials are generally by-product sourced from agricultural activity that contained pozzolanic characters. A pozzolan is a finely ground siliceous or aluminous material that reacts with calcium hydroxide released by the hydration of Portland cement in the presence of moisture to form calcium-silicate and other cement compounds. Candidate SCM materials include palm oil fuel ash (POFA), rice husk ash (RHA), corn cob ash (CCA), sugar cane bagasse ash (SCBA), and wood waste ash (WWA). This approach leads to a reduction in costs, a drop in environmental impact, and better durability.

2.1 Palm oil fuel ash (POFA)

Palm oil fuel ash (POFA) is known as an agricultural waste products produced by palm oil mill during combustion process of empty fruit bunches, palm oil fibers, and shell for self- generating energy in steam formed which in turn produces electricity for palm oil mill [10]. The temperature, treatment processes and other conditions of POFA play a role in determining the physical properties of the POFA. The appearance of unground POFA is usually in grey colour and becomes darker with rising of un-carbon proportions. The carbon compositions can be eliminated by heating the ground POFA for one hour at 500 °C [13]. The particles of ground POFA are usually found to be spherical in shape, vast range of sizes and it have a smaller specific gravity than OPC [14]. Based on the observation of the morphology on OPC and POFA, POFA is observed to have more porous structure than OPC and both material have a collection of particle shape that laid on top of each other [13]. Ground POFA going through grinding process to reduce particle sizes and minimize structure porosity, it can survive in high thermal degradation and seemly used as a micro filler in concrete that can enhance particle packing and offer additional properties to the fresh concrete. The specific gravity of the POFA is expected to be increase when going through grinding process due to the minimization of structure porosity [15].

On top of that, the risen in compressive strength of concrete as well as the hydration rate are influenced by the finer particles distributions [16]. The workability of the fresh concrete that represents how much ease it can be mixed, handled, and compacted is measured by the slump value. The moderate slump value range for the concrete containing 100 % OPC is 190 mm. The concrete containing ultrafine POFA at dose of 10.00 % improves the workability of the high strength concrete that attributed to lower specific gravity of POFA compared to OPC [14]. This property provides better coating characters since it can fill the pores between the particles of the concrete components and provides lubricant that helps the fresh concrete moves. Normal POFA (median particle size 17.10 μm) caused the fresh concrete to agglomerate or the particles formed a mass due to lower repulsion force [18]. This situation is caused by the higher loss on ignition (LOI) that increased POFA ability to absorb water as well as due to the irregular shape and more porous particles of POFA. Superplasticizer were used to generate the plasticizing effects on wet concrete that known as the improved chemical admixtures to increase the repulsion force within the concrete components. The essential mechanical property of hardened concrete is the compressive strength which were divided into the early-age and later- age to determine their durability.

Early- age (7 days) of concrete containing POFA reduce as the increases of the amount of POFA. The reduction caused by the less of hydration product named calcium hydrate silicate (C- H- S) that helps to the strength of concrete [10]. The compressive strengths of OPC concrete at 28 days were 30 MPa. The strength of concrete reduced at the high replacement ratio (40.00 % of POFA) due to highly reduction in the amount of Portland cement. The strength of concrete at the low replacement ratio (10.00 %) was relatively high attributed to the pozzolanic reaction of POFA and the dispersion POFA particles in concrete due to the reduction water to binder, W/B ratio. The increasing amount of POFA was found decreasing the with compressive strength of concrete [17]. The optimum level of 10.00 % replacement with POFA was suggested because it found may not affect the long- term strength formation of concrete. Concrete permeability plays a key role that caused the ingress and movement of ions from the environment and through the building materials which can cause the degradation of structures if not control. Water absorption determines the water- tightness of concrete which measures the amount of water that penetrates in concrete when submersed. The amount of water absorption of concrete containing POFA increase due to greater porosity which increased the possibility of pores connectivity effects [18].

The presence of voids in the concrete as well as the un- reacted POFA particles induced pores in the concrete which allowed greater absorption of external water. The greater rate of hydration due to the continuous curing process leaded to reduce of the connectivity of pores which as well initiated the lower pozzolanic reaction that produces C-S-H which contributed to the strength of the concrete. The concrete containing POFA with water to binder ratio of 0.3 helps for the pozzolanic reaction by refining the pores of the microstructures [13]. Fire resistance measures the concrete susceptible to fire when the concrete was exposed to an elevated temperature from room temperature. Concrete properties like compressive strength, concrete density, durability, and concrete appearance such as colour and surface structure affected by the elevated temperature that introduced on the concrete. The concrete containing 20% by weight of POFA for cement replacement was noticed to gradually decreased in compressive strength as the temperature increase from the room temperature to 500 °C [17]. When the temperature is increased gradually shows that the mass loss recorded which could be due to the POFA particles contained greater water content that held by porous microstructure. The strength of the POFA concrete indicated sharply decrease beyond 600 °C which then lead to crack development which were observed on the surface of the concrete. The concrete containing POFA shows a reduction of cracking when subjected to elevated temperature when compared to the control concrete may due to diminution of $Ca(OH)_2$ from further hydration [14].

2.2 Rice husk ash (RHA)

Paddy industry is highly protected under the arguments for food security and it not contributed significantly to foreign exchange earnings like oil palm, pepper, natural rubber, and cocoa beans crops. The shortage in supply from domestic production of paddy urged the government to import rice from various countries, such as Thailand, Myanmar, and Vietnam [19]. Rice husk is the outer layer of paddy grain that is removed during dehulling process for rice production due to its less nutritional value and high calories value thus finally used as fuel in the boiler of the rice processing industry [20]. The burning process of rice husk to generate energy for the boiler produced approximately 20.00 % of rice husk ash (RHA) [21]. Each ton of paddy rice produced approximately 200 kg rice husk and the combustion process in boiler produced about 40 kg of rice husk ash from it [22]. This situation caused a severe problem in disposal of rice husk and become more challenging if there are dumped in landfill that increase the area cover as well as the cost to manage them [23]. The application of rice husk ash has widened to mitigate the problems that arise which it has been introduced as a feasible pozzolanic material used in construction industry. The ashes that are integrated from the husk have the colour range from white grey to black which effected by the duration, method incineration, time, raw material as well as the temperature for the burning process [24].

RHA have cellular structures and there are micropores on the surface which consists of reactive silica that suitable to be used ad pozzolanic material [23]. The burning condition and cooling processes affected the development of microstructure in RHA which determine the specific surface area and the pore volume [25]. The median particle size of the ashes is between 5.0 μm to 7.41μm and the specific gravity are between 2.06 to 2.16 [26]. The fresh concrete containing rice hush ash (RHA) was observed to become physically stiffer at proportion replacement of 15.00 % and 20.00 % and less workable. The concrete containing 10.00 –20.00 % RHA at a low water to cement ratio of 0.30–0.34 to see the gap graded aggregate properties has lower workability as the percentage of replacement increase [58]. The lower workable of the concrete are caused by the lower specific gravity of RHA that are necessary in attractive force among the particles. The use of high volume RHA as a partial substitute for fine aggregate decreased the workability and segregation, where the concrete containing RHA up to 5.00 % maintained satisfactory workability [27].

In order to produce higher workability which indicated through the slump value, the use of high binder contents along with RHA and super plasticizer has enabled to obtain a cohesive mix without the problem of segregation. The optimum workability in RHA concrete can be obtained by the application of an appropriate amount of super plasticizer [27]. Concrete containing rice husk ash (RHA) of 10.00 % dose showed a compressive strength at 28 days in range of 20.1- 22.8 MPa. The reduction in compressive strength increased when the replacement dose of RHA is increased up to 20.00 % by weight when compared to control concrete with a water to cement ratio of 0.35 [28]. The use of 5.00 – 10.00 % RHA significantly increased the strength of the concrete and comparable with the concrete containing same amount of silica fume. The decreasing strength of concrete containing 20.00 % RHA compared to 10.00 % RHA is possibly related to the decreases of micro-filler effect between RHA and aggregates in the Interfacial Transition Zone (ITZ) or the zone develops around the aggregate from a different microstructure of the surrounding hydrated cement paste [21]. The silica content present in 10.00 % RHA replacement founds to densify and strengthen the ITZ. Some other reason is due to the pozzolanic reaction of the available silica in RHA and the amount of C-H available from the hydration process for dose 10.00 % RHA.

Concrete densification tends to be reduced with a further increase in the RHA amount, which is observed to increase the demand for water in fresh concrete [21]. Concrete containing rice husk ash had lower water absorption compared to control concrete due to the reduction in porosity for up to 30.00 % substitution of OPC. The control concrete has the effective porosity of 18.06 % [24]. The concrete containing 10.00 % of RHA at 7, 28 and 56days of examined have water absorption value of 2.51 %, 1.66 % and 1.47 % respectively [57]. The reduction of water absorption concrete containing RHA is noticed upon increase in the replacement amount. The absorption of water for RHA concrete by the method of immersion was sharply increased when the volume of ash by weight of cement exceeded 25.00 % [22]. The water absorption of the concrete the concrete containing treated RHA was much lower than the concrete containing normal RHA [71]. The increasing amount of RHA content up to 15.00 % in self- compacting concrete has a decrease in the sorptivity [58]. The sorptivity increased as the RHA dose increased to and beyond 20% due to the formation of micropores, which is attributed to the higher surface area of the RHA and the resulting water demand for concrete [28].

2.3 Corn cob ash (CCA)

Corn cob is a waste product derived from maize or corn, a common globally grown crop that is often produced along with the needs. FAO's latest forecast for world cereal production in 2020 was revised upwards by 9.3 million tonnes in July and now stands at almost 2 790 million tonnes, with global output expected to exceed a record high of 3 percent (81.3 million tonnes) in 2019 [29]. The production of corn increase the substantial waste section of the plant comprised of shelled cobs and corn stover aster harvest which ended at landfill [30]. Thus, there is a significant opportunity from that situation by using the ash as a potential replacement of fly ash in concrete. The ashes were produced from the early stage of assemble the corn cob from the field and then dried down to approximately 11.00 % relative humidity in a drying container. The kernels were removed as soon as it dried using a sheller machine and then chopped then into smaller pieces using a 12.7 mm screen size of grinder. Additives such chemical substances used during those process before it burned further in a furnace by using an open burning method (without fuel). The temperature ranged 600 to 700 and the ash will produced around 1.60 % from 205 kg of the corn cob [31]. The produced ash from these stages then placed in a muffle at 550 ℃ for 30 minutes to burn further that can remove the unburnt carbon and convert it into carbon dioxide (CO_2) gas [32].

The corn cob ashes are well coated in lignin and the lignin covers the corn cob residue with a thick rough film that covers multiple areas of fracture [33]. The roughness probably corresponds to mineral salts containing silicates [33]. The slump for the concrete decreases as the corn cob ash content increases due to the CCA particles formed some agglomeration as it more angular and larger than OPC. The slump decreases from 35 mm to 12 mm as the percentage CCA substitution increases from 0.00 % to 25.00 % which resulted the compacting factor decreases from 0.89 to 0.67 [34]. The concrete becomes stiffer as the CCA percentage increases exceed 25.00 % which portrayed that the mix proportion needs more water to make the fresh concrete more workable [30]. Less specific gravity of ash as compared to cement results in more volume of ash for the same weight thus increasing the water demand of mix [34]. The increase amount of silica in the mixture requires high demand for water as the CCA content increases in the concrete mixture. The silica-lime reaction causes more water demand which necessary during hydration of cement. This is common for pozzolan cement concrete. Both initial and final setting times revealed to be increase along with the addition of CCA proportion caused by the extension workability period of the concrete [32].

This is particular importance in ready mixed concrete as there is extra time to affect delivery to site. The partial replacement of OPC in concrete with CCA reduces the compressive strength significantly with an increase in the age of the specimens. The strength of the concrete containing 3.00 % and 20.00 % CCA were 2.00 % and 42.00 % less than the control group. CCA replacement up to a maximum of 10.00 – 20.00 % when compared with the compressive strength of the control (0.00 % CCA replacement) [31]. Similar trend was observed at 28 days as indicated that CCA concrete gain strength slowly at early curing age which caused by the pozzolanic reaction at room temperature. The compressive strength at 28 days for mix proportion ranges 17.97 MPa for 25.00 % CCA replacement while improves at 10.00 % CCA replacement which was 23.3 MPa [34]. The increase may be attributed to the improved characteristic of the reactive silica content in CCA concrete which affects the pozzolanic reaction [31]. The higher compressive strength caused by the available silica in CCA react with the lime that produced during hydration of cement to produce more cementitious characteristics. Sharp reduction in strength was noticed beyond 15.00 % CCA replacement which suggest that the presence of CCA above the range of 10.00 –15.00 % is not advantageous in improving the compressive strength of concrete.

Concrete containing corn cob ash that replaced the cementitious materials was found to reduce the water absorption as the amount of replacement reduced which attributed to crystallization of ash during hydration. The smooth and shiny texture of the CCA particle, blocks the pores and results in a refined pore structure and a reduced number of pores which reduces the water absorption capacity. However, the replacement of CCA specimens at the 30.00 % has 126.00 % higher coefficient of water absorption than at 7.50 % replacement [35]. Replacement of CCA concrete at 7.50 % was lower than the control specimens by 8.00 %. The concrete permeability reduction between 1.50 % and 34.40 % at CCA replacements of between 2.00 % and 15.00 % [23]. The increasing of water absorption in CCA concrete related to porosity factor and the effective diffusion coefficient which can be considered through the material property. Concrete incorporating CCA can exhibit less water absorption if the replacement be less than 15.00 % and the proportions more resistance to sulfate attack compared to the concrete made with ordinary Portland cement (OPC) [83].

The compressive strength of all mixes containing CCA at dosage range 5.00 – 20.00 % was noticed increases up to elevated temperature of 300 ℃ [36]. The compressive strength of normal concrete at 28 days that subjected to a temperature of 300 °C was noted to be 13.00 ,72.00 % higher than concrete at normal temperature. Across all mixes compressive strength significantly decreases beyond this temperature. The reduction in strength of CCA concrete at 300 ℃ for replacement of 5.00, 10.00, 15.00 and 20.00 % are 13.18 %, 16.20 %, 11.09 % and 14.29 % respectively after 28 days curing age compared to referral concrete at 13.72 % reduction [36]. At the elevated temperature of 450 ℃ and 600 ℃, the same trend of concrete strength reduction has been observed that attributed to the chemically-bound water starts to disintegrate and evaporate at this temperature [33]. High reduction in compressive strength was noted at this elevated temperature levels. The result shows that any reaction that allows concrete strength is completed at about 300 °C. The maximum CCA content is recommended as 10.00 % that equivalent to elevated temperature of 300 °C.

2.4 Sugar cane bagasse ash (SCBA)

Sugar cane bagasse ash (SCBA) is an agricultural commodity produced in sugar mills during the extraction of sugar from the sugar cane, which is produced by a large fibrous waste product called bagasse [37]. The burning of bagasse at a particular temperature leaves a bulk quantity of ash known as sugar cane bagasse ash or SCBA [38]. The percentage of ash only covers less than 3.00 % of the original mass of the bagasse but the large amount of the combustion of it can produce massive amount of SCBA that gave impact to the economic and ecology [39]. As fibrous bagasse is burned at a temperature of around 600–800 °C, it creates ash with a significant volume of amorphous silica, which has excellent pozzolanic properties [37]. The colour of SCBA is dark, reddish-grey, and white, and the variations of the burning process, indicating both a higher carbon content and the structural transition of silica in the ash depends on its completeness. [38]. Sugarcane bagasse ash comprised of moisture that can be eliminated by 24 hours heating at 105–110 °C, and some other experiment for 4–6 hour, burning at 600–800 °C [40]. The presence of unburnt carbon particles has led to low specific gravity [40]. The fibrous particles can be broken off and fine particles are reduced further in shape and size, thereby increasing the pozzolan composition by grinding them into the ball mill. [41].

Particles of a variety of prismatic, circular, irregular and fibrous forms were observed in raw bagasse ash [42]. Particles were observed of irregular shape. The reactivity of the particles towards the concrete components will be more effective when the size in particle reduces due to the increasing specific surface area [12]. The workability of the concrete containing SCBA increase as the amount proportions for cement replacement increase due to the absorption of water by the SCBA particles [41]. The reduction in workability generally indicated the mixing, compacting, moulding, and transporting abilities of the fresh concrete. The effect of SCBA as cement replacement at the dosage of 5.00, 10.00, 15.00, 20.00, 25.00 and 30.00 % by weight and observed increase in the slump values as the SCBA concentration increase [43]. In addition, examined on all SCBA replacement levels (5.00, 10.00, 15.00, 20.00 and 25.00 %) by [91] found that the slump values are higher than the control concrete mix. It shown that the concrete with SCBA had high compaction factor values and adequate workability as compared to the control concrete as the dosage increase up to 25.00 %. Other study revealed that workability value of the SCBA concrete are suitable for self- compacting concrete as the pozzolanic properties presence in the particles increases the workability and the dosage was recommended not more than 20.00 % [44].

The replacement of cement in M20 concrete at dosage 5.00 % found to be an optimum substitution with water to cement ratio range 0.425- 0.5 while the concrete with 10% SCBA has a compressive strength greater to the control mix at 7 and 28 days. 5.00 % substitution of cement by the bagasse ash gave the maximum compressive strength [88]. In addition, the substitution of 10.00 % by weight of cement by SCBA resulted demonstrated that the compressive strength increase at 7 and 28 days than the referral concrete [42]. Despite, the concrete increased up to 15.00 % SCBA replacement and then decreased. However, it can be improves through treated SCBA by further burning of the ash through open burning process at temperature range of 600–700 ℃ for 3 days to increase the compressive strength and reported that the M20 grade concrete has increase the optimum replacement up to 20.00 % dosage [45]. The optimum percentage of the SCBA replacement by cement weight is at dosage of 15.00 % since the compressive strength at the maximum (29.94 MPa) and comparable to the referral concrete [38]. The water absorption of concrete containing SCBA had significantly reduced after 28 and 56 days of curing as the water penetration has significantly reduced [42]. The water absorption percentage increased in the presence of SCBA during 28 days of curing, which is possibly due to the hygroscopic in nature of SCBA and the particles are finer than OPC [42].

The investigation on the pore structures of SCBA concretes found that it is possible the water absorption decrease as the dosage of replacement increased [46]. The water absorption percentage decreased obviously at 50.00 % dose of SCBA replacement by weight after 90 days of curing [47]. This result is attributed to the addition of SCBA, which reduced the permeable voids and the gradual closing the pores by fill in with SCBA particles. Obviously, the use of SCBA significantly enhances the resistance of concrete to water penetration. Concrete containing 15.00 % cement replacement of sugar cane bagasse ash maintains its strength from room temperature to certain elevated temperatures after 24 days of curing [45]. It is also said that the strength increases up to a cement replacement of 10.00 %, which can be attributed to the function of pore size and grain size refinement associated with the SCBA pozzolanic action [48]. At 15.00 % cement replacement, the strength remains at a level with the reference mixture comprising Portland cement alone. The gradual increase in the content of SCBA results in a further reduction in the compressive strength [45]. Similar findings are often achieved by increasing the sustained temperature, with a gradual decrease in the compressive strength of all mixtures, regardless of the percentage of cement substitution by SCBA. In all variants, residual strength decreased only marginally to 300 °C which the rate of drop in strength is affected by an increase of the ash-to-binder ratio [48].

2.5 Wood waste ash (WWA)

Wood waste ash primarily consists of annihilation wood, beds, fiber sheets, wood deposits, railroad sleeper, arches, and so on which it is biomass- free and can also be called an inexhaustible fuel and in this manner, it is extremely appealing for extensive scale biomass ignition plants [49]. WWA is produced from the ignition in wood- terminated power plants, paper factories, sawmills, pastry kitchen, and other wood- consuming production lines [49]. WWA is discarded from the environment in a different structure approximately over 70.00 % for years [50]. The wood items such as chips and barks are ignited and produced waste generation known as WWA. The over production of WWA as one of the commodities to fulfil the demands increased potential for ash due to production from the combustion of wood residues [51]. Thus, several research and development to utilize WWA as a partial replacement of cement are conducted due to WWA exhibits pozzolanic characteristics that nearly similar with those of cementitious materials in concrete. WWA is observed in several different particle shapes and sizes, the small crystalline particles are intermixed with bigger, and most of it are in irregularly shaped that form in fibrous particles [49]. Microstructure testing of the WWA concrete shows that the overall porosity along with the associated pore diameter was reduced in contrast to the control [53].

The specific gravity and compacted bulk density for WWA, which were found to be 2.13 kg/m^3 and 760 kg/m^3, respectively [54]. The colour of the WWA is grey due to the combustion process of the wood residue that reduced carbon content as well as the present of heavy metal in it [49]. One of the important features for the pozzolanic properties would be the ability to seal the untight pores which specifically indicate through the calcium oxide, CaO content. WWA is observed to have 2.07 % of CaO and is determined as lower than OPC [55]. The utilization of WWA in concrete at 20.00 % and 30.00 % replacement by cement weight, it was found that the slump flow yielded the highest output at 40 mm and its compound structure fell below the pozzolana standard when the dosage was exceeded [54]. The demand for water was decreased as WWA was introduced to the mixture resulting in reduced workability. This effect was attributed to the low explicit surface area of the WWA and the application of superplasticizer could reduce the agglomeration affects from low repulsion force among particles [53]. The minimization of cement reduced the workability of WWA concrete to 30 mm with no addition of WWA. The increase in the content of WWA increased the demand for water and the timing of the paste. The result showed 10.00 % and 20.00 % WWA paste fulfilled the recommended setting time standard and workable compared to control specimen, whereas 30.00 % and 40.00 % showed higher values [56].

The expansion on workability of WWA content decreased the compressive strength of different ages. The strength of WWA concrete gradually decreases with an increase in the replacement of the cement by this waste materials. The decrease in strength was for the most part identified with the silica given by 10.00 % of the WWA; this silica content was deficient for responding with the calcium hydroxide created by the hydration of cement [49]. The increasing in WWA content exceed 20.00 % resulted a decrease in strength at 28 and 60 days. In this case, the silica present in the mixture was an excess of the amount needed for the mixture with the calcium hydroxide of the hydrating cement [56]. The excessive amount of silica seemed to have no pozzolanic value and was merely filled as a filler. The 25.00 % by weight replacement of WWA results in a reduction of approximately 75.00 % in the strength of the control mixture. The low specific gravity of the WWA causes the particles to settle on top of the slurry and produces a lack of homogenous mixture in the composite such that the top surface of the composite is filled with accumulated particles [51]. Concrete with 20.00 % WWA content produced a substantial compressive strength at 7 and 28 days, so that percentages was considered for the optimum replacement amount.

The water absorption of the specimens containing WWA increases gradually as the amount of WWA increases (5.00 %, 10.00 %, 15.00 %, 20.00 % and 25.00 %) which indicated the lower bonding strength between the WWA particles and cement caused the ingress and molecule movement of water that immerse [53]. The high hydrophilic nature woody materials like WWA was possibly the reason of resulting in higher water absorption rate other. In addition, the low bulk density of WWA which caused more void space in the concrete compound results in expansion or water absorption rate [51]. The concrete properties without addition of WWA has maximum water absorption of 11.80 % for control [55]. However, it was observed that there is a moderate decrease in water absorption after addition of other waste materials mentioned in this review. It is verified that the primary source of observed open pores in the paste matrix contained free water in it. The decrease of its bulk density is also correlated with this [56].

Table 2: Summary of usage waste product in concrete as the supplementary cementitious materials

Waste Product	Dosage (%)	Effect of usage of waste materials in concrete	Reference
POFA	10- 20	• Concrete workability reduced • Better coating characters • High pozzolanic activity • Water demand increased • Setting time increased • Compressive strength reduced at 7- days but comparable to control concrete after 28- days • Compressive strength gradually decreased as the temperature increase from the room temperature to 500˚C, sharply decrease beyond 600 ˚C	[14] [17] [13] [18]
	40 and above	• Compressive strength sharply reduced • Porosity increased • Bulk density increased • Water absorption increased	[10]
RHA	5- 10	• Satisfied workability • Compressive strength increased after 28 days • Comparable water absorption • Setting time increased	[27]
	10, 15 and 20	• Concrete workability reduced • Low specific gravity • Water absorption reduced • Compressive strength reduced 28 days • Micro-filler effect between RHA and aggregates decreased • Porosity increased	[21] [57] [58] [22]

	30 and above	Superplasticizer needed Water absorption reduced Porosity increased Drastically reduced in compressive strength	[24]
CCA	0- 25	Superplasticizer needed Workability reduced Water demand increased Porosity increased as dosage increased 10% replacement had better compressive strength than 25% replacement since the sharp reduction stated at 15% Setting time increased Compressive strength for dosage range 5- 20% increased up to elevated temperature of 300 ℃	[32] [34] [31] [36] [33]
	30 and above	Physically deteriorated at 450 ℃ and 600 ℃, Water absorption increased sharply Workability reduced Compressive strength reduced significantly Lower slump value	[35]
SCBA	5- 10	High porosity value Adequate workability value Compaction improved Setting time increased Water absorption increased 5% substitution gave the maximum compressive strength and comparable concrete strength at 10% dose at 28 days 10% dosage maintained compressive strength when imposed to an elevated temperature up to 300 °C	[42] [38]
	15- 25	Workability reduced Water absorption increased 15% dose had remains in the compressive strength and decreased only marginally to 300 °C and above	[45] [44] [41]
	50	Compressive strength reduced significantly Water absorption increase drastically	[47]
WWA	10- 20	Fulfilled setting time standard Water absorption increased Compressive strength adequate value at 10% Bulk density reduced	[49] [56] [49]
	20, 30, 40	Water demand decreased Workability reduced Superplasticizer needed Setting time increased Compressive strength reduced significantly when increase the replacement dosage	[53] [51] [52]

3. Alternative Fine Aggregate

The construction sector is largely responsible for the decline of natural resources and environmental deficiencies due to its unplanned mining activities. Because of its superior properties, natural sand is commonly used in construction. The extensive use of concrete as a result of the surge in the massive development of infrastructure has led to the over-extraction of natural sand from the riverbed. This has contributed to many negative effects for the environment and the lack of supply of high qualities raw materials. As a result, the extensive consumption led to massive scarcity, river course changes, shallow rivers and beaches, groundwater pollution, and devastation of flora and fauna. This has led researchers to use alternative materials as fine aggregates without ignoring the quality of performance in construction. Candidate AFA materials include expanded perlite (EP), crumb rubber waste (CRW), marble waste (MW), electric arc furnace slag (EAFS), and waste foundry sand (WFS). This approach leads to a reduction in costs, a drop in environmental impact, and better durability.

3.1 Expanded perlite (EP)

Perlite are known as an aluminous-siliceous material that integrate naturally from an amorphous volcanic rock just like other volcanic glasses which is obsidian and pitchstone. The crude perlites rock contained approximate 2.00 -5.00 % of water and when heated to a suitable temperature at range 900 ℃ - 1200 ℃, it will expand and transform into a cellular material [59]. The texture of perlite ore is smooth, fractured and splitting while after it going through burning process it turns into cellular and frothy sphere. The colour of the EP is bright white while the crude perlite ore similar like quarry stones which dark grey. The crude perlite rock will expand up to 5- 20 times from its original volume and turn into a low bulk density of expanded perlite (EP) due to the vaporised of water within the structure and produces bubbles on the surfaces. The raw perlites turned to forty- like microstructure or hollow with high porosity properties and became lighter after burned [60]. The specific gravity of EP much lesser than fine aggregates and fine aggregates much denser than EP due to the restructured of perlite ore under heating process [61]. The lightweight of expanded perlite are suitable to be an insulation material in the construction as an alternative to the conventional materials and it is comparable [66]. Apart of that, the low density of perlite are beneficial in producing lightweight concrete by replacing fine aggregates in the concrete mix [62]. However, reported that the substituting a part of fine aggregates with EP caused a reduction in 35 days of compressive strength as well as the modulus elasticity of the concrete [63].

This could be due to the high porosity of the EP structure and caused the EP less dense which in turn reduce the concrete compressive strength [65]. In the meantime, there are a significant improvement reported in the workability of high strength concrete (HSC) mixture with partial replacement of sand by 2 mm of EP size [64]. Workability of the concrete is the first step in evaluating the properties which portrays the ability to mix, handle, mould, and transport the fresh concrete. The introduction of perlite for sizes within 0- 4mm as an alternative fine aggregate in concrete revealed a reduction in the workability. The substitution of 5.00 %, 10.00 %, and 15.00 % of perlite by volume recorded the reduction in the slump height of 4.92 %, 3.28 % and 3.28 %, respectively [65]. The reduction in workability is correlative with the low water content in the concrete mix design resulted from the low specific gravity of particles which can be improves by the introduction of superplasticizer in the concrete mix [60]. The influence of partially substituting cement with 20.00 % and 30.00 % by weight to the fresh concrete setting time found that the setting time of pastes increased as increasing perlite content [66]. The improvement in the workability resulted from the addiction of superplasticizer could be related to the increase in the repulsion force within the molecules in the mixture without affecting the amount of water content [60]. The compressive strength of concrete with 5.00 % and 10.00 % perlite is comparable to the reference sample, although the bulk density decreases by 12.00 % and 16.00 % compared to the reference sample [60].

Decrease in compressive strength was observed with a higher waste perlite content, but this changes significantly when the waste perlite content reaches 40.00 % [59]. Numerous studies have shown that perlite reduces the specific weight and compressive strength of lightweight concrete. A significant decrease in compressive strength was observed with an increase in the replacement of sand by perlite.

The compressive strength of perlite concrete depends not only on the strength of the aggregate, but also on the porosity of the material. This decrease could be due to the porous structure that perlite created in the matrix. The increase in porosity resulted in a decrease in density, which resulted in a decrease in strength [65]. The decrease in strength can also be due to the higher ratio of water to cement in the interface transition zone. It can be concluded that the inclusion of perlite in the aggregate decreased strength as reported in most of the previous studies. The water absorption of concrete containing perlite as an alternative fine aggregate at levels of 5.00 %, 10.00 %, 15.00 %, 20.00 %, 30.00 % and 40.00 % reported an increment after curing for 28- days as the substitution dosage increases by weight [66]. The sorptivity rate or the capillary sorption capacity rate also reported an increase for perlite size range 4 mm that indicated the increase in the water permeability. The increases could be due to the porous microstructure characteristic of the perlite as well as the perlite less dense than fine aggregates. The raw perlites turned to forty- like microstructure or hollow with high porosity properties and became lighter after burned due to the vaporisation of water within the structure [67].

The increased water absorption and sorption capacity of perlite-containing concrete, whereby most corrosive substances can ingress into the concrete matrix can affect its durability. Therefore, the higher water absorption of the perlite matrix is the main disadvantage of using this material as the composition of concrete. The application of coating on perlite concrete surface with commercially available waterproof materials can help solve this problem [61]. Fire resistance of the concrete containing perlite as partial sand replacement is investigated by exposure to an elevated temperature to analyse the compressive strengths. At 400 °C, compressive strengths recorded were for sand replacement of 0.00, 10.00, 20.00, 30.00 and 40.00 % have 2047.31 MPa, 44.37 MPa, 44.81 MPa, 43.52 MPa, and 43.34 MPa respectively [61]. The concrete without the application of perlite recorded as the highest compressive strength and the reduction in compressive strength of the perlite concrete seems significantly decreases with the increase of perlite content. At replacement of 20.00 %, the higher compressive strength of concrete among the dosages, and the strength continue to drop until 40.00 % EP. Similarly, this pattern occurred in other elevated temperatures of 700 °C and 1000 °C at 20.00 % of EP replacement that recorded the maximum compressive strength of 16.95 MPa and 11.61 MPa respectively. The effects may be due to the dehydration effect of $Ca(OH)_2$ that turned into calcium oxide (CaO) when concrete passes a temperature of 400 °C [59]. Eventually, after 700 °C, the concrete begins to fail where the compressive strength of the concrete has been reported below 30 MPa which is consistent with literature where the perlite concrete failed after 600 °C. This trend shows that, at elevated temperatures, the expanded perlite begins to produce thermal resistance effects on concrete and 20% replacement can be concluded as the best percentage of EP replacement in concrete.

3.2 Crumb rubber waste (CRW)

Rubber waste is one of the most critical pollutants in the world. Annually 1000 million tyres are projected to be end their useful lives. By 2030, up to 1200 million tyres, representing almost 5000 million tyres including stock piled will be discarded on a regular basis [68]. The rubber waste reduction and recycling are very important components in a waste management system for the protection of natural resources and to reduce the need for landfill areas uses [69]. In concrete production, rubber waste is found to have bright potential in partly substituted the mineral aggregates. Waste tyre includes rubber and steel fibres can be distinguished by applying various techniques from the shredding stage, chips and granules become a final product with a purity of 99.00 % [68]. The waste will be put in the grinding machine and ground to mesh size 24 after collection of the rubber waste and the resulting material is known as the rubber crumb [70]. Crumb rubber that replaces sand, is produced by special mills where large rubbers are converted into smaller particles that are torn. Depending on the type of mill used and the temperature produced, different sizes of rubber particles can be formed with high irregularities of 0.425–4.75 mm are produced using a simple method [71]. Density of crumb rubber waste may vary as 0.95 g/cm^3 and rubber waste can be used as lightweight aggregate due to its low density [72].

Rubber particles have a relatively smooth and elastic surface which is expected to weaken the interface bonding between the rubber particles and the cement paste [73]. Crumb rubber are black in colour and there are micro- porosity structure that indicated on top of the particle surface under a microstructural study [74]. The flow of the fresh concrete containing partial substitution of crumb rubber as fine aggregates is reduced which reflected the low repulsion force of the compound. The workability of the prepared concrete is dropped with the replacement of the river sand by crumb rubber waste as fine aggregates reduce the workability of concrete with the increasing level of the replacement. The influence of partial replacement crumb rubber waste in concrete and the workability found that 5.00 %, 10.00b%, and 15.00 % of crumb rubber reduced the flow by 14.00 %, 29.00 %, and 50.00 %, respectively, compared to the reference mix [72]. The roughness of the crumb rubber surface could be the reason for the rubberized concrete mixes to flow more resistantly when compared to the mixes without rubber [75]. Another explanation for decreased workability may also be the impurities in the surface of the crumb rubber aggregate [74]. In conclusion, the substitution of fine aggregate with crumb rubber at range 5.00 – 30.00 % results in reduces gradually the fresh concrete flow by 30.00 –80.00 %.

It has been observed that concrete strength decreases with increase in the percentage of crumb rubber at 7 and 28-day of compressive strength test. The effects of the dosage of crumb rubber waste and the compressive strength found that the utilization of 4.00 % and 5.50 % of CRW partially as the alternative fine aggregate results in concrete strength reduction by 3.79 % and 17.80 % respectively as compared to control concrete [76]. The reason is because the insufficient of adhesion between the smooth rubber particles and cement paste. Decreases in concrete strength will initiated cracks around the rubberised concrete when certain loads are pointed which results in rapid rupture of concrete. The reduction of concrete strength also caused by the larger percentage of voids which developed naturally in crumb rubber microstructure [76]. Besides that, the rubber has limited specific gravity and weaker bonds with other concrete components which the CRW particles tend to shift upwards during vibration and a greater concentration of rubber found at the top layer than other areas of the concrete specimens [68]. Consequently, the concrete strength reduces as this lack of uniformity of the concrete. The presents of crumb rubber waste in concrete has been observed to increase the water absorption after 28-day of curing which substantially increase with the percentage of crumb rubber replacement.

Higher capacity of the water absorption reduced the concrete workability which results from the generation of voids and cracks that known to be the nature of CRW particles. The water absorption of crumb rubber concrete after for 5.50 % replacement is 3.21 %, however for control concrete substitution, water absorption is 1.91 % [76]. This reduction in the workability is due to the higher capacity of the water absorption by the rubbers than sand. The increase in water absorption was due to fine nature of crumb rubber which result into generation of cracks and voids [72]. The percentage of voids ratio in the concrete increases as the addition of crumb rubber in concrete mix which allows the water to penetrate inside the concrete easily. The concrete became more porous due to the increment in of voids when the replacement of fine aggregates by waste rubber aggregates exceed 25.00 % [71]. The strength properties of rubberized concrete when exposed to various elevated temperatures, and found that the rise in compressive strengths at a temperature of 150 °C compared to the strength of the specimens stored at laboratory temperatures [69]. The decrease in the calcium hydroxide fraction, which was beneficial to the formation of the dense concrete microstructure, could be attributed to that rise in rubberized concrete strength at this temperature [74].

The damage factors for control and rubberized concrete with different rubber volume were mostly converging to 300 ° C [76]. The fire resistance then dropped strongly when following exposure up to 400 °C as the rubber content is gradually increases (5.00 %, 10.00 %, and 15.00 %). The higher level of rubber in the mixture was observed to have the drastic type of damage factor feature. The damage mechanisms for reference concrete can be mainly due to the temperature gradient imposed on the specimens which is responsible for water evaporations and the decomposition of the calcium-silicate-hydrate (C-S-H) the main product of cement hydration and the main cause of strength in cement-based materials [74]. For rubberized concrete, the combustion of the rubber-based aggregate, which left the voids in concrete structure, and thus increased its porosity affected the reduction of resistance towards heat.

3.3 Marble waste (MW)

Dumping of marble waste into the soil, groundwater and atmosphere often creates contamination, which can be minimised by recycling it [77]. The marble aggregate is found to have potential for replacing fine aggregate in concrete and encouraged the effort to develop an economical and green concrete. The use of marble waste as a resource would not only reduce the environmental impact of marble waste disposal, but also contribute to the conservation of natural resources, thereby paving the way for sustainable growth [78]. Marble was generated using diamond wires by cutting the marble plates into required shapes and sizes. The huge amount of slurry consisting of water- mixed marble particles are produced during this process. This slurry is passed into multiple sedimentary tanks and separated into coarser and finer particles. Marble waste that obtained from the bottom of the first sedimentation tank are used since it fulfilled the suitable size requirement of fine aggregates. The waste was dried openly and then oven drying to remove the excess water [79]. Marble waste has white colour that the particle is physically in angular shape when demonstrated in scanning electron microscope (SEM) image [80]. Waste marble aggregates are finer as compared to the natural river sand. These fines will help in providing filler effect in concrete.

The marble waste less than 4.75 mm is sieved and used as an alternative fine aggregate [81]. The fineness modulus value for the marble waste is indicated as 2.80 which in the range of the fineness modulus for medium type sand that portrayed the particle grain size while the specific gravity of the marble waste is found as 2.88 [72]. Bulk density which reflects the weight required to fill a at specified unit volume of concrete for marble waste is 1753 kg/m^3 [80]. The water absorption of the waste is recorded as 0.84 % and the lower water absorption was attributed to CaO content of marble. Concrete containing marble waste as partial fine aggregates replacements was observed to loss in workability with an increment dosage of 10.00, 20.00, 30.00, 40.00, 50.00, and 60.00 % [82]. The workability of concrete affected by the material characteristics, grade level, and fine aggregates shape. The marble waste indicated large in specific surface area and the particles are angular in shape that caused increase in water demand to achieve required workability [83]. Large in specific surface area increase in the surface area to be wetted, hence decreasing the workability. The effect of marble waste aggregates addition in a concrete mix, found that it makes the mix highly cohesive and less workable, thereby increasing the water demand [79].

The combination effect of increased mix cohesiveness and large surface area to be wetted caused the workability reduction of the mix containing marble waste as replacement of fine aggregates. The application of superplasticizer to enhance the workability of the concrete mix containing marble waste was recommended since it does not reduce the concrete strength. The compressive strength of the concrete increases with the inclusion of the marble waste aggregates in the mixture up to 40.00 % of the replacement dosage. The 28-day compressive strength of the mixes increased by 9.70, 15.80, 21.10, 22.40, 21.30 and 20.20 respectively for 10.00, 20.00, 30.00, 40.00, 50 .00 and 60.00 % replacement respectively that comparable to the standard mix [79]. The compressive strength results clearly indicate that marble waste can be partially substitute the natural sand as better compressive strength of the mix are achievable. In addition, marble waste has better filler effect in concrete matrix due the presence of finer aggregates in the particle size range of 1.18 mm–300 μ helps to increase the concrete strength [84]. This situation refined the pore structure which in turn improved the microstructure of concrete matrix. Other than that, indicated that lesser pores on the concrete and stronger bond between the aggregates and cement paste which attributed from lower water absorption of fine marble waste aggregates, found to increase the concrete strength.

Water absorption of fine marble waste aggregate concrete decreased as expected at gradual increment of replacement dosage (10.00, 20.00, 30.00, 40.00, 50.00, and 60.00 %) with increase in curing age [79]. This indicated that the concrete matrix is denser caused by the continuous hydration of concrete. Water absorption decreased with the addition of waste marble aggregates when compared to the reference mix is at 28-days and 365- days is 5.10 % and 2.68 % respectively. The decrease in water absorption by marble waste addition indicates refinement of aggregate-interface zone because it generally related to the structural pores [84]. The reduction in water absorption resulting in improvement of overall durability of the mix. At 28 days, the marble waste containing concrete with 40.00 % of fine aggregates replacement recorded the lowest value of water absorption which is 3.79 % compared to the natural fine aggregates. The lower water absorption was attributed to CaO content of marble which affected the strength and sorptivity results of the concrete [85].

3.4 Electric arc furnace slag (EAFS)

Steel making industry is one of the essential industries that contribute to the movement of world economy. This commodity records an expansion demand in 2019 which was 1 868.8 million tonnes of crude steel production when compared to the previous year at 1 813.6 million tonnes (IISI, 2020). According to World Steel Association, Malaysia records 4.5 million tonnes of crude steel demand [86]. Approximately 90.00 % (by weight) of the solid by-products formed by iron and crude steel are slag while some of the by-products are gases, dust, and sludge [87]. The accumulation of steel slag not only takes up a substantial portion of land, but also contaminates the surrounding environment. Exploring the implementation of steel slag is therefore vital to the conservation of the environment amidst of the natural resources scarcity crisis that construction industry facing today. Steel slag is obtained either from conversion of iron ore from iron to steel in a basic oxygen furnace (BOF), or by the melting of scrap to make steel in the electric arc furnace (EAF) [88]. Steel slag (SS) are usually categorised by the type of furnace they are processed in. The slag's properties depend on the type of process used for producing the crude steel, the slag cooling conditions and the process of valorisation [89]. Steel slag present a dark in colour, cavernous, and irregular surface shape which has a major impact on mixing proportions measurement, demands more water for concrete mix fluidity and makes it more consistent [90].

Low- cooled slag from the electric arc-furnace (EAF) is the suitable slag that could be implement as fine aggregate to produce concrete because the treatment has achieved excellent mechanical properties, even before being crushed it was comparable with natural ones [71]. The density of the aggregate decreases in size due to the presence of iron and the EAFS aggregate has an average density of 3.15 g/cm^3, which is a very dense and very cavernous material. The fineness modulus is found to be 5.00 % of that obtained experimentally [91]. The results of the slump test for reference concrete mix showed a true slump value of 35 mm at 0.00 % of the replacement level. The slump decreases, as the percentage of level replacement increases, from 0.00 to 50.00 % at a 10.00 % interval [89]. This is due to the increase in water absorbing property and the lack of fines in the EAF slag aggregate compared to natural sand. As a result, more water is absorbed by steel slag and less cement for hydration with the constant water-cement ratio of 0.55. The addition of fine EAF slag decreases the air content of the concrete mixture and could result in a decrease of fluidity [92]. The higher the percentage of replacement by steel slag of aggregates, the less the workability of the concrete as the slump value reveals.

Decreasing trend in workability as well as a declining compressive strength with a rising amount of EAF slag added and concluded that the ratio of EAF slag can be up to 40.00 % during curing process [87]. The addition of steel slag as fine aggregate at dosage 10.00 %, 20.00 %, 30.00 % and 40.00 % steel slag increased the concrete strength by 24.90 %, 27.90%, 24.40 % and 11.50 %, respectively at 28- days [87]. The steel slag concrete increased in concrete strength at the beginning and then decreased with an increase in steel slag content. The rougher surface of the steel slag causes the stronger bonding strength of the components and cement paste as the mechanical interlock force and cohesive force in concrete improves compared to natural sand [93]. Nevertheless, the surface roughness of steel slag can increase the water absorption which reduced the concrete strength may due to the hydration process of the cementitious material become insufficient. Thus, steel slag requires more cement as it has high angularity to be effectively coated. The high replacement of natural sand with steel slag resulted in a decrease in mechanical properties. 20.00 % steel slag replacement ratio, indicating the optimum content of steel slag sand for the optimum compressive strength [104]. Water absorption is a key feature of the EAF slag since it reflects the ability of fluids to enter the structure of the concrete and causes degradation [87].

Water absorption for EAF slag concrete varies from 0.50–4.00 % with a density of 2.8–3.9 g/cm^3 [93]. Higher percentage of EAF slag content in concrete results in higher water absorption values due to the porous structure of EAF slag [91]. The surface roughness of the steel slag also resulted in increased water absorption of the steel slag which more cement is needed to coated sufficiently the high angularity concrete. The high angularity from the addition of steel slag reduces the hydration of the cementitious materials, which results in a weak cohesiveness between the cement paste and the steel slag. Although it had a slightly higher water absorption, the application of EAF slag aggregate fulfilled the requirements regulated by the Malaysian Public Works Department for road pavement [89].

3.5 Waste foundry sand (WFS)

The most common approach for making moulds for the manufacture of metal parts is to use green or resin-bonded sand in the foundry industry [94]. Foundry sands are typically recycled and reused until their properties degenerate into a stage where they cannot be used further and where their quality for mould production is decreased because of the accumulation of metal residues which will be discarded from the foundry [95]. This discarded material consists of high-quality silica sands with binders as a waste foundry sand (WFS), a waste product of the ferrous and nonferrous metal casting industries [96]. These binders hold the sand together to maintain its shape as the molten metal is poured into the mould and the type of binder either clay or chemical bonded sand classify the type of foundry sands [97]. The discarded sand is the main industrial waste in the foundry sector that is responsible for environmental contamination and industrial sites. WFS was washed using water to eliminate impurities such as fine and clay particles as soon as they were obtained from the iron-based foundry plant. These separated particles were then dried in the oven at 105 °C for 24 hours or under the sun to eliminate moisture before being used in the concrete [98]. The microstructure of WFS has a uniform and smooth surface morphology, the shape of it is sub-angular to rounded and present in a light brown colour [96].

The specific gravity of the WFS is indicate as 2.36 which lower than the natural fine aggregate but had fulfilled the standard of fine aggregate requirement [99]. Bulk density of WFS is 1811 kg/ m^3, the particles is denser due to the present of accumulated metal residues, clay and friable particles if compared to the natural one. The particles are finer which indicated through the fineness modulus values at 2.37 [100]. The concrete containing waste foundry sand as partial replacement of fine aggregate at 10.00, 20.00, 30.00, 40.00, and 50.00 % reveals decreases the workability of the concrete along with the increase in replacement [101]. The mixes with more WFS show a significant loss in the slump value, presumably because of the fineness amount contained in WFS. It was found from the sieve study that almost 11.00 % of the WFS passes through 150 mm [101]. The content of fines would be increased by an increase in WFS replacement, which raises the demand for water [102]. Inclusion of WFS in concrete can increase the demand for water and reduce the workability of the fresh concrete. Significant reduction in workability might also results from the lower value of fineness modulus of WFS than natural sand. The reduction of workability might due in increasing specific surface area that caused the water requires for lubrication of the particles increase [96].

The compressive strength concrete containing 5.00, 10.00, 15.00, 20.00, and 25.00 % WFS at 7, 14, 21 and 28 day of cured M30 concrete mix and found that results test show that the compressive strength increases with increasing WFS aggregate up to 20.00 % by weight of replacement [102]. Significant reduction in compressive strength of the WFS concrete was observed when the replacement exceeds 20.00 % replacement. The reduce in concrete strength resulted in fracture surfaces when physically observed. Substitution percentage weight of more than 20.00 % contributed to a rapid release of stored energy from both testing machine and the specimens compared to the control specimen which the micro cracks are developed from the middle in gradual effects before fracture. This is due to the low porosity and high brittleness of specimens with a high WFS content. The concrete moulded with the application of waste foundry sand tends to be more porous and less resistant to a higher replacement and to be replaced by not more than 15.00 % can be considered viable for non-structural purposes [100]. Water absorption for waste foundry sand after 28 day cured M30 grade concrete found the increases in absorption capacity by immersion in water and the volume of voids dropped with the increase of the waste compared to the reference specimen.

The addition of WFS to concrete at up to 50.00 % replacement level results in viable water absorption, however further increase in WFS percentage up to 100.00 % caused significant increase in the water absorption at 56.60 % [105]. The implementation of WFS as the alternative fine aggregate results in more porous and permeable of the moulded concrete than the natural sand one. The slower of pozzolanic activity of WFS also the main cause of the higher water absorption of WFS mix series since the volume of hydration decrease and the degeneration of microstructure. WFS become denser at the substitution of 40.00 % and determined as the lowest result obtained for water absorption. The high silica in WFS is naturally hydrophobic, but because of its excess surface area it attracts water.

Table 2: Summary of usage waste product in concrete as the alternative fine aggregate

Waste Product	Dosage (%)	Effect of usage of waste materials in concrete	Reference
EP	5- 15	• Water demand increased • Porosity and water absorption increased • Bulk density decreased • Compressive strength at 5% and 10% comparable to the reference sample at 7 and 28 days	[65] [60]
	20- 40	• Setting time increased • Workability reduced • Early strength decreased • 40% has the lowest compressive strength value and significant drop after burned at 400 °C • 20% is the maximum compressive strength after burned at 400 °C • Concrete failed after 600 °C	[66] [67] [61]
CRW	5- 15	• Workability decreased • Concrete strength reduction as increase in dosage after 7 and 28-days • Porosity and water absorption increased • Compressive strengths at a temperature of 150 °C up to 300 ° C increased. Significant drop at 400 ° C	[72] [75] [76] [69]
MW	10- 40	• Density decreased • Porosity increased • Workability reduced • Water demand increased • Compressive strength increases and comparable to reference concrete up to 40% replacement after 28 days	[83] [79] [84]

		• Better filler effect	
EAFS	10- 40	• Water demand increased • Porosity, surface roughness, and water absorption increased • Bulk density decreased • Concrete strength increased at the beginning and then decreased with an increase EAFS content • 20% replacement is the optimum ratio for an optimum compressive strength	[103] [104] [89]
WFS	5- 25	• Workability reduced • Water demand increased • No effect on setting time • Porosity increased • Pozzolanic activity reduced • Compressive strength increased up to 20% replacement and reduced significantly when exceed 20%	[100] [101] [96]
	40- 50	• Concrete becomes denser • Significant high in water absorption • Compressive strength reduced sharply	[105]

4. Conclusion

Concrete with palm oil fuel ash (POFA) shows comparable compressive strength after 28- days of curing at range 10.00 to 20.00 % by weight of cement substitution. It has better coating characteristic due to high pozzolanic activity in the mix compared to reference mix. The utilization of rice husk ash (RHA) at dosage amount of 5.00 to 10.00 % range by weight of cement produced a satisfy workability as well as a comparable water absorption to the control specimen. The compressive strength of RHA concrete at this dosage increased after 28- days of curing period. Next, corn cob ash can be utilized at dosage between 5.00- 10.00 % by weight of cement replacement since it found to increase in compressive strength when exposed to an elevated temperature up to 300 ℃. Inclusion of sugar cane bagasse ash (SCBA) in concrete at 5.00 to 10.00 % replacement by weight improved the compaction properties due to the adequate value obtained from the workability. The compressive strength for 28- days of SCBA concrete at maximum for 5.00 % substitution while 10.00 % dosage maintained in concrete strength when imposed up to 300 °C. Then, concrete contained wood waste ash (WWA) fulfilled setting time standard and comparable concrete strength after 28- days at 10.00 % replacement. It suitable for lightweight concrete production since this waste products had lower bulk density compared to other materials.

From this review, it can be suggested that the use of expanded perlite (EP) in the range of 5.00- 10.00 % as a partial replacement of fine aggregates improves concrete strength after curing for 7 and 28 days. It suitable for lightweight concrete casting since EP is more porous and lighter than natural sand. The review uncovers that incorporation crumb rubber waste (CRW) not more than 15.00 % by weight of fine aggregate increased in concrete strength when imposed to heat at 150 °C up to 300 ° C. Addition of marble waste (MW) as an alternative fine aggregate increased the 28- days compressive strength up to 40.00 % of replacement. MW found to have better filler effect due to the large amounts of finesses that improves the microstructure of the concrete matrix. Concrete with electric arc furnace slag (EAFS) shows comparable compressive strength 20.00 % of replacement for both 7 and 28- days of curing. Microstructure of EAFS is porous and high angularity which reduced the bulk density and the concrete mass. When waste foundry sand (WFS) is utilized as partial substitution of fine aggregate, compressive strength increased up to 20.00 % replacement and reduced significantly when exceed. Less workable of WFS concrete mix can be solve by adding appropriate amount of superplasticizer to increase repulsion forces among particles.

Supplementary cementitious materials and alternative fine aggregates from waste products could affect some properties of concrete decreased like water absorption, slump value, strength features. Despite that, the percentage of replacement may be controlled at a certain proportion to achieve optimum concrete performance based on the summarised findings in this review. Proper selection of the materials as well as an appropriate treatment like the burning process and pre-treatment procedure could be carried out because it affected the mechanical performances of concrete. The high mechanical performance of the concrete initiates the efforts to produce green concrete that helps in managing the waste generation and conserving the environment for future generations. Natural sources like fine aggregates could reduce their use in this industry due to the recycling waste materials approach for sand replacement. In the nutshell, this overall review concluded that waste products mentioned have bright potential that can be applied as a part of concrete components to the durability standard. Further study on other durability properties could be the focus for more firm in understanding before implementing the waste products.

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