Waste Biomass Valor (2018) 9:1645–1654
DOI 10.1007/s12649-017-9937-6

ORIGINAL PAPER

Valorization of Wastes from Power Plant, Steel-Making and Palm Oil Industries as Partial Sand Substitute in Concrete

Seng Kuan Ong[1] · **Kim Hung Mo**[1] · **U. Johnson Alengaram**[1] ·
Mohd Zamin Jumaat[1] · **Tung-Chai Ling**[2]

Received: 18 November 2016 / Accepted: 8 April 2017 / Published online: 13 April 2017

Abstract For long, the growing amount of solid wastes from various industries has created disposal issues and caused serious environmental concerns. Increased efforts have been carried out to recycle and valorize the industrial wastes into use as concrete-making materials. Due to the current growth of construction industries around the world, natural sand is depleting rapidly and as such raises environmental issues such as erosion, flooding and disruption of eco-system. Sourcing alternative materials to replace sand in concrete would be ideal in promoting sustainability for the environment as well as the construction industry. Therefore, this research explores the potential of utilizing local industrial wastes such as palm oil clinker from the palm oil industry, coal bottom ash from power plant as well as steel slag from the steel-making industry as partial sand substitute in concrete. Based on the tested concrete properties such as compressive strength, splitting tensile strength, sorptivity and shrinkage, it was found that incorporation of these industrial wastes at 50% replacement level generally did not cause substantial negative impact to the resulting concrete. In terms of the optimum concrete performance, it is suggested to incorporate these industrial wastes at 30% replacement level.

Keywords Industrial wastes · Sustainable concrete · Waste recycling · Palm oil clinker · Bottom ash · Steel slag

Introduction

Concrete industry today is the largest consumer of natural resources [1]. In the production of concrete, conventional mining and river sand are considered as one of the main raw materials used as fine aggregate. In fact, sand has been classified as one of the most extensively consumed natural resources on earth. However, excavation of sand, either inland or coastal, causes many environmental concerns, such as flooding, lowering of water table and disruption of the natural ecosystem. In addition, due to the rapid development of cities around the world, the sources and amount of conventional sand are depleting rapidly. The diminishing supply of sand has led to utilization of by-products such as quarry dust and manufactured sand as alternatives in the construction industry. Utilization of these materials not only alleviates the issue of shortage of conventional sand, reduction of the quarry wastes could be realized as well. Hence, these by-products can be considered as environmental-friendly and sustainable material for the construction industry.

In view of the benefits of re-using by-products as substitute for conventional concrete-making materials, there have been researches carried out to utilize recycled building materials such as construction and demolition waste [2, 3], tiles [4] as well as ceramic wastes [5] in concrete. These research works have demonstrated that the wastes could be used satisfactorily as partial aggregate replacements in concrete. There are also growing interests around the world in re-using the waste materials from different industries, such as those from agriculture [6, 7], rubber [8]

✉ Kim Hung Mo
khmo@um.edu.my

✉ U. Johnson Alengaram
johnson@um.edu.my

[1] Department of Civil Engineering, Faculty of Engineering, Centre for Innovative Construction Technology (CICT), University of Malaya, 50603 Kuala Lumpur, Malaysia

[2] College of Civil Engineering, Hunan University, Changsha 410082, Hunan, China

and plastic industry [9]. In Malaysia, one of the major agriculture industries is the palm oil industry. Due to the rapid growth of the palm oil plantation industry, Malaysia has become one of the largest palm oil producing countries in the world. However, huge production of palm oil also generates significant amount of waste which require suitable disposal. About 2.6 million tons of solid wastes from the palm oil industry are produced annually in Malaysia. One of the wastes from the palm oil industry is palm oil clinker (POC), which is obtained in large sizes of boulders from the boiler as a result of burning of oil palm shell and oil palm fibre to produce steam for electricity generation. POC is currently used as either landfill or cover for roads around palm oil plantations [10]. However, these usages are fairly limited and other potential applications should be explored in an effort to further reduce the POC wastes. Considering the lightweight nature of POC due to its porous structure, researchers have recently explored using crushed POC as aggregate to produce lightweight concrete [11].

In Malaysia, there is a total of seven coal-fired power plants which supply about 9000 MW of electricity. At the same time, coal-fired power plants generate huge amount of by-products in the form of coal bottom ash (CBA) and coal fly ash. CBA is part of coal ash which is the non-combustible material left in furnace of thermal power plants after burning of coal to generate power. In fact, about 1.7 million tons of CBA are produced in Malaysia [12]. CBA have been used as both structural fill and land filling materials on the empty lot adjoining thermal power plant sites over the years and has become an environmental menace to the surrounding. While coal fly ash has found usage and has been commercialized as a cement replacement material due to its pozzolanic properties [13, 14], CBA is not used widely in the construction industry, presumably due to its weaker pozzolanic properties and porous nature. Nevertheless, researchers from other countries have indicated that due to its similar particle size distribution as normal sand, use of CBA as sand substitute could be an interesting alternative [15]. This is because no further grinding and therefore no additional processing cost of the CBA are required [16]. The potential utilization of CBA as sand substitute should create economic value for CBA as construction material and help preserve the environment through reduction of the CBA wastes.

Steel slag (SS) is a waste from the steel-making industry, originating from electric arc furnace during the steel production process, has stone-like appearance and exhibits grey-black color. About 15% SS is obtained from the steel-making process and it is estimated that over 1 million tons of SS are produced annually in Malaysia. Research into applications of SS is vital in order to reduce dumping in landfills and production of excessive wastes [17]. SS is commonly used in road base construction and recent focus has shifted towards usage in concrete production. Due to its high density, it is advantageous to incorporate SS in concrete applications where weight is a key factor, such as breakwater blocks, foundations, shoring walls, noise barriers and radiation insulators [18]. While there are indications of prospective use of SS as coarse aggregate in concrete [19–21], research on the usage as fine aggregate in concrete is fairly limited.

In light of the background outlined above, this investigation aims to valorize industrial wastes such as POC, CBA and SS as partial sand substitute in concrete. Given that recycling these industrial wastes into concrete can bring upon economic and environmental benefits, it is also important to ascertain the effects of these materials on the performance of the resulting concrete. Therefore, the feasibility of incorporating these industrial wastes in concrete is studied in terms of the hardened concrete properties, such as density, ultrasonic pulse velocity (UPV), compressive strength, splitting tensile strength, sorptivity and the short-term drying shrinkage.

Experimental Program

Materials

For all mixes, Type I ordinary Portland cement was used as binding material. The cement had specific gravity of 3.15. Crushed granites of sizes between 5 and 20 mm were selected as the coarse aggregate in all of the concrete mixes. Particle size distribution of the crushed granite is shown in Fig. 1. Laboratory pipe water was used as mixing water.

For the reference concrete, normal sand was used as fine aggregate. The variable in this investigation is the type of fine aggregate replacement, namely POC, CBA and SS. The sand as well as the sand substitute materials

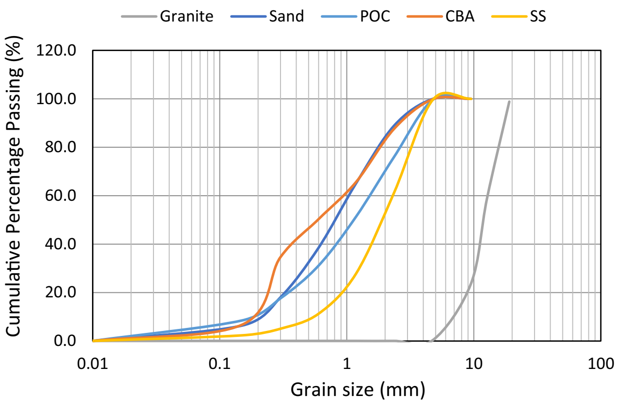

Fig. 1 Particle size distributions of coarse and fine aggregates

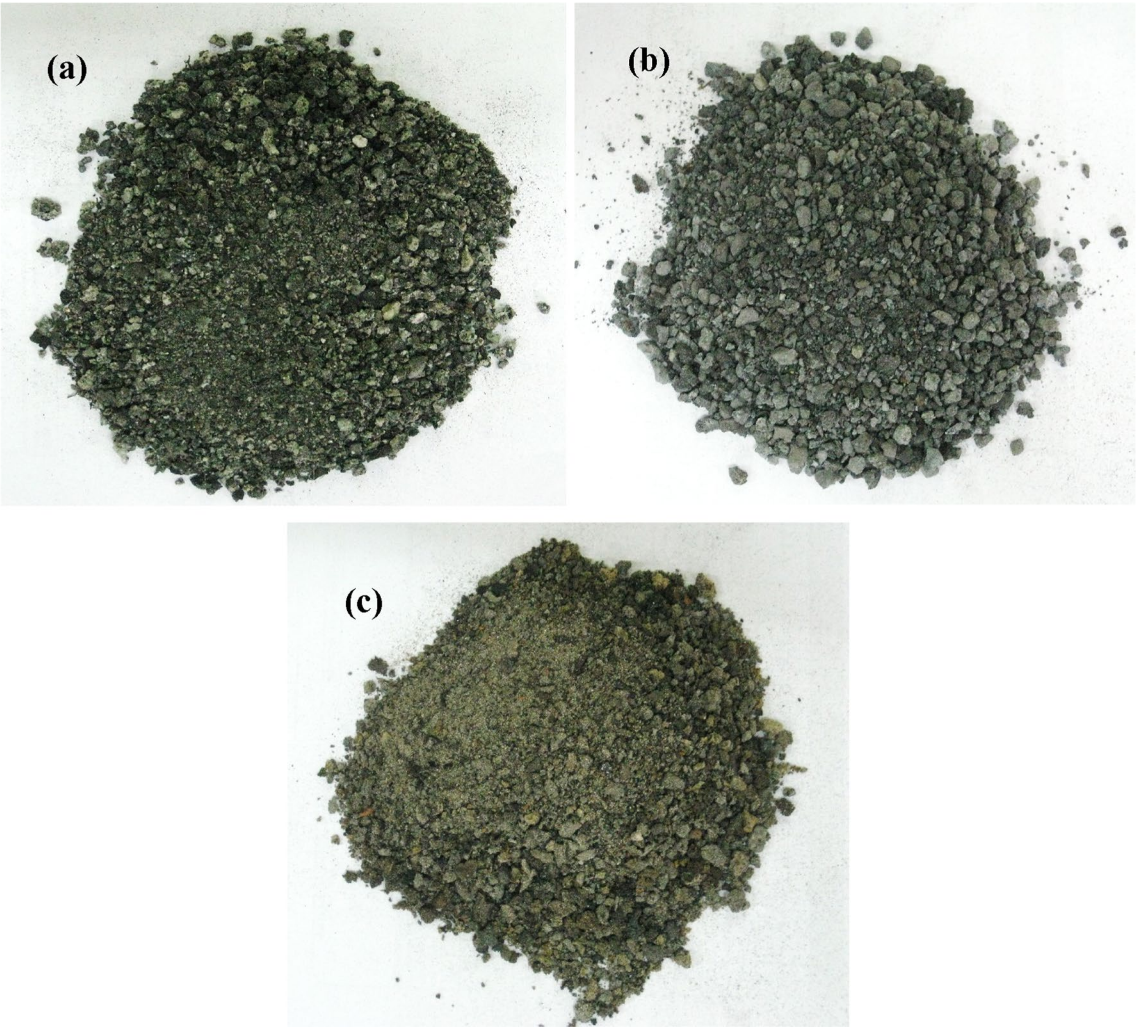

Fig. 2 Appearance of **a** POC, **b** SS and **c** CBA

Table 1 Physical properties of fine aggregates

Physical properties	Sand	POC	CBA	SS
Specific gravity	2.6	1.7	2.2	3.4
Water absorption (24 h) (%)	2.3	19.9	25.2	2.4
Fineness modulus	2.83	3.16	2.55	3.93
Moisture content (%)	0.09	0.38	0.17	0.11

Table 2 Selected chemical composition of industrial wastes

Material	Chemical composition (%)				
	SiO_2	CaO	Al_2O_3	Fe_2O_3	MgO
POC	50.61	3.98	2.39	3.93	4.04
CBA	49.37	2.45	15.16	7.00	0.92
SS	7.62	29.80	15.80	15.30	9.85

of sizes below 5 mm were used. The appearance of the industrial wastes are shown in Fig. 2. The POC was collected from a local palm oil mill in large chunks of boulders before being crushed and sieved in the laboratory to obtain the desired sizes. Both CBA and SS were collected from a local power plant and steel factory, respectively and sieved accordingly before used in concrete casting. Tables 1 and 2 shows the physical and chemical properties of these different types of industrial wastes, respectively. The particle size distributions of the POC, CBA and SS are given in Fig. 1. The percentage of particles passing through the 0.075 mm sieve size for POC, CBA and SS was 4.1, 8.0 and 1.7%, respectively.

Mix Proportions and Procedure

The concrete mix was designed to achieve cube compressive strength of 40 MPa at 28 days. The variables are the type of fine aggregate (POC, CBA and SS) and the fine aggregate replacement level, namely 30 and 50% by mass. The mix proportions are given in Table 3.

In the mixing process, firstly the coarse and fine aggregates were dry mixed, followed by the addition of cement. After mixing of cement, water was added for wet mixing. In the case of CBA50 mix, it was observed that the mix was still dry after all of the mixing water was added and hence a minimum dosage of 0.12% PCE-based superplasticizer (SP) was added. After thorough mixing, the fresh concrete was poured into oiled steel moulds and compaction was done on a vibration table. All of the concrete specimens were de-moulded the following day and the specimens were water-cured until the age of testing.

Test Method

Non-destructive Evaluation

The rebound hammer and UPV tests were done to determine the quality of the concrete through non-destructive means. The rebound number measures the surface hardness of the concrete as an indication to the compressive strength of concrete. The higher the rebound number, the higher its indication of compressive strength for the concrete. The UPV indicates the uniformity and homogeneity of concrete, as well as detecting internal flaws and correlating with compressive strength of concrete. The rebound hammer and UPV tests were carried out on 100 × 100 × 100 mm cube specimens prior to compressive strength test using the guidelines provided in ASTM C805-02 and ASTM C597-09, respectively.

Mechanical Properties

Hundred millimetre cube specimens and cylindrical specimens measuring 100 mm in diameter and 200 mm in height were used for testing of compressive and splitting tensile strengths, respectively. The compressive and splitting tensile strengths were tested in accordance with BS EN 12390-3: 2002 and BS EN 12390-6: 2000. For the compressive strength, specimens were tested at ages of 1-, 3-, 7-, 28-, and 90-days whereas the splitting tensile strength test was carried out at the age of 28 days. Three specimens were tested for each case and the average value was taken.

Sorptivity Index

Sorptivity is an index of liquid being absorbed and transported into concrete due to the capillary suction in the pore spaces of concrete versus the time taken. It is crucial to carry out sorptivity test to determine durability of concrete as it can predict its service life, efficiency and performance [22]. The sorptivity test was carried out on concrete disc specimens of 100 mm diameter and 50 mm thick. The test was conducted based on the procedure set out in previous research [23, 24]. A total of three specimens were tested for each mix to obtain the average value. The concrete specimens were pre-conditioned by oven drying for 48 h at temperature of 105 °C. After cooling the specimen to room temperature, the sides of the specimens were sealed with silicone and then the specimens were placed on steel rods in a tray whereby water was filled up to the level of about 5 mm from the base of the concrete specimen. The quantity of water absorbed by the concrete specimens at intervals of 1, 4, 9, 16, 25, 36, 49 and 64 min were determined for calculation of the sorptivity index (Eq. 1).

$$i = A + s \times t^{0.5} \tag{1}$$

where i is the cumulative water absorbed (mm^3), A is the constant which takes into account effect of initial water

Table 3 Mix proportions of concrete

Mix	Content (kg/m^3)						
	Cement	Granite	Sand	POC	CBA	SS	Water
C0	365	1100	735	–	–	–	200
POC30	365	1100	514.5	220.5	–	–	200
POC50	365	1100	367.5	367.5	–	–	200
CBA30	365	1100	514.5	–	220.5	–	200
CBA50[a]	365	1100	367.5	–	367.5	–	200
SS30	365	1100	514.5	–	–	220.5	200
SS50	365	1100	367.5	–	–	367.5	200

[a] Superplasticizer (SP) was added at dosage of 0.12% by mass of cement to facilitate workability of the mix CBA50

filling at concrete surface, s is the sorptivity index (mm/min$^{0.5}$) and t is the time taken (min).

Drying Shrinkage

Prismatic specimens having cross-section of 75 × 75 mm^2 and length of 300 mm were used for the drying shrinkage test. After curing of 7 days, DEMEC studs were attached to the concrete specimens and stored in a room with temperature of 20 ± 2 °C. The movement of the DEMEC studs were monitored constantly through the use of a length comparator for the determination of the drying shrinkage up to 180 days.

Results and Discussion

Saturated Surface Dry (SSD) Density

The saturated surface dry (SSD) density for mixes C0, POC30, POC50, CBA30, CBA50, SS30 and SS50 was 2485, 2453, 2430, 2396, 2340, 2552 and 2603 kg/m^3, respectively. In general, the density of the reference concrete was higher than concretes with POC and CBA as partial fine aggregate replacement and lower than the concrete containing SS fine aggregate. Replacement of up to 50% of the fine aggregate resulted in reduction of density by up to 3 and 6% for the case of POC and CBA aggregates while the density was increased by up to 5% with the use of SS aggregate. For the concretes with CBA and POC as fine aggregate replacements, the lower density was due to the porosity of these materials and lower specific gravities. Conversely, SS concrete exhibited increment in density as the SS aggregates were denser and had higher specific gravity compared to normal sand. The percentage of density reduction in concrete made with POC and CBA was similarly reported by Abutaha et al. [25] and Singh and Siddique [15], respectively. Similar amount of density increment in the concrete with steel slag was also found by Monosi et al. [26].

Rebound Hammer Number

From Table 4, it can be seen that the rebound number increased with the age of concrete. Generally, by comparing the rebound number index, SS concrete showed better performance than the POC and CBA concretes. The higher rebound hammer value for SS concrete could be associated with the robustness and higher density of the SS aggregate. The rebound hammer values of both POC and SS concretes were decreased with higher replacement level of fine aggregate while for the CBA concrete, 50% replacement level gave higher rebound hammer value than the 30% replacement level. The latter could be attributed to the addition of SP in the mix which could have increased the strength of the concrete.

Ultrasonic Pulse Velocity (UPV)

Table 5 showed the results of UPV test carried out in this study. According to the concrete quality classification based on UPV values, the concrete quality at 1-day could be determined as having ‘good quality’ since the UPV values were 4.0 km/s. The UPV values increased along with the concrete age and at the later age of 28-days, generally, all of the concrete specimens had UPV values between 4.60 and 4.81 km/s, which fell within the range of ‘excellent quality’ concrete. Furthermore, the UPV values of all concretes were beyond 4.60 km/s after 90-days of water curing.

With the exception of POC50 mix, generally the CBA and POC concrete mixes had similar UPV values as the reference concrete after 28-days. Minor difference in the UPV values between normal concrete and CBA concrete was also reported by Singh and Siddique [27]. Abutaha et al. [25] opined that due to the small void-to-aggregate ratio of the POC aggregate, partial fine aggregate replacement had negligible effect on the strength properties, thus the concrete exhibited similar UPV values as the reference concrete. On the other hand, as shown in Table 5, concrete with SS as partial fine aggregate replacement had higher UPV compared to the reference concrete.

Table 4 Rebound hammer number of concrete

Mix	Rebound hammer number				
	1-day	3-days	7-days	28-days	90-days
C0	11.1	15.0	16.3	21.4	23.6
POC30	12.0	14.2	16.0	21.2	24.3
POC50	12.3	13.1	15.3	19.1	22.3
CBA30	11.7	14.3	15.0	20.1	23.0
CBA50	12.8	14.8	15.6	20.9	23.4
SS30	10.2	13.8	17.4	22.8	24.7
SS50	11.8	13.6	18.0	21.9	23.4

Table 5 Development of UPV values

Mix	UPV (km/s)				
	1-day	3-days	7-days	28-days	90-days
C0	4.21	4.48	4.55	4.70	4.76
POC30	4.13	4.43	4.62	4.68	4.75
POC50	4.01	4.35	4.40	4.60	4.67
CBA30	4.01	4.51	4.65	4.78	4.79
CBA50	4.10	4.39	4.67	4.78	4.79
SS30	4.04	4.70	4.74	4.81	4.85
SS50	4.05	4.44	4.55	4.78	4.83

Table 6 Compressive strength development and splitting tensile strength of concrete

Mix	Compressive strength (MPa)					28-days splitting tensile strength (MPa)
	1-day	3-days	7-days	28-days	90-days	
C0	17.99 (39)	29.75 (65)	36.60 (80)	46.06	47.23 (103)	3.66
POC30	18.80 (40)	25.79 (54)	37.10 (78)	47.65	53.41 (112)	3.53
POC50	16.04 (41)	26.69 (68)	32.00 (81)	39.44	44.08 (113)	3.23
CBA30	14.69 (34)	27.56 (63)	37.04 (85)	43.51	50.45 (116)	3.35
CBA50	19.42 (39)	32.04 (65)	38.46 (77)	49.69	53.64 (108)	3.73
SS30	17.71 (36)	27.14 (56)	35.94 (74)	48.84	49.16 (101)	3.63
SS50	18.21 (42)	25.05 (58)	32.10 (74)	43.21	44.43 (103)	3.75

Values in bracket denote percentage of corresponding compressive strength to the 28-days compressive strength

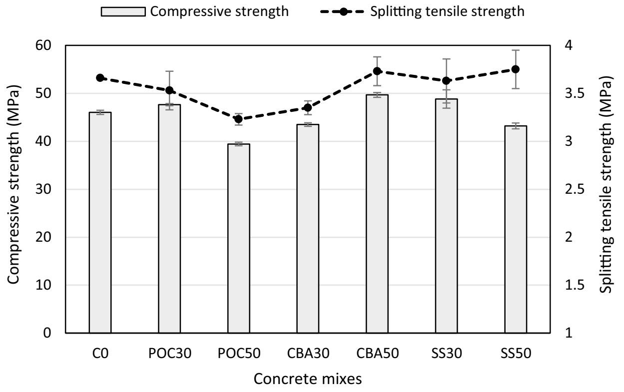

Fig. 3 28-days compressive and splitting tensile strengths of concrete

Compressive Strength

Table 6 and Fig. 3 present the results of the compressive strength of concrete containing different types of industrial wastes as partial replace fine aggregate replacement at the age of 1-, 3-, 7-, 28- and 90-days. Since all of the concretes had undergone hydration process continuously in the presence of water, the compressive strength increased with concrete age. For the compressive strength at 1-day, all of the concretes gained at least 30% of the 28-days strength while at 7-days, all of the mixes achieved more than 70% of their respective 28-days compressive strengths.

For the POC concrete, replacement at 30% gave similar compressive strength at 28 days while further increase to 50% replacement resulted in strength reduction by about 14%. Similarly, Abutaha et al. [25] found comparable compressive strength with normal concrete when POC was used as fine aggregate replacement. The comparable compressive strength could be attained due to the similar packing arrangement of POC as normal sand and hence significant formation of voids were avoided. The slight reduction of the compressive strength of the POC50 mix was due to the inherent lower strength and stiffness of the POC aggregate than normal sand [25]. Interestingly, at 90 days, the compressive strength gain for both POC30 and POC50 mixes was about 12% from the 28-days compressive strength and this was higher than the reference concrete, which recorded only 3% gain in strength. One possible reason is the pozzolanic properties of the finer particles of POC aggregate as POC aggregate contains high amount of silica [11].

In the case of CBA concrete, the 28-days compressive strength was lower for the case of CBA30 while higher compressive strength was attained for the CBA50 mix in comparison with the reference concrete. The compressive strength of CBA30 mix was 5% lower than the reference mix while increment of 17% in the compressive strength was observed for the mix CBA50. The reduction in strength for the CBA30 mix could be attributed to the porous and weaker particle of CBA compared to normal sand [15, 16]. Reduction in compressive strength when CBA was used was also reported by Rafieizonooz et al. [12]. On the other hand, due to the addition of SP in the CBA50 mix, increased compressive strength was observed. Similar to the use of POC fine aggregate, inclusion of CBA as fine aggregate replacement resulted in higher strength gain at 90 d compared to the reference concrete. The gain was 16 and 8% respectively for CBA30 and CBA50 mixes. This could also be due to the pozzolanic reaction of fine CBA particles, as reported in the past [28]. According to Kim et al. [29], pozzolanic reaction might occur due to the rough surface of CBA.

For the SS concrete, the 28-days compressive strength of SS30 was higher than the reference while the SS50 mix had lower strength compared to the reference concrete. While the mechanical interlocking due to the higher angularity of SS aggregate [30] as well as intrinsic hardness of the SS aggregate itself [31] were said to contribute to improved compressive strength of concrete with SS, the reduction in the compressive strength for SS50 in this investigation could be caused by the lower number of fine particles in the SS used compared to normal sand. The lower number of fines of SS could have reduced the particle packing in

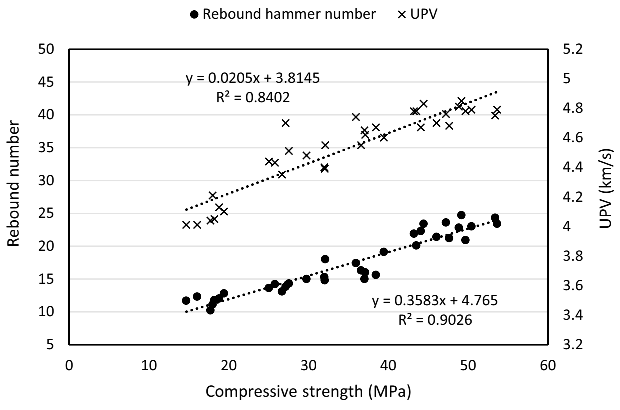

Fig. 4 Relationship between rebound hammer number and UPV with compressive strength of concrete

the SS concrete compared to the reference concrete. Devi and Gnanavel [32] found that when SS was used as partial fine aggregate replacement by up to 40%, the compressive strength increased; further increase in the replacement level, however, resulted in decrease in the compressive strength.

Figure 4 shows there is a linear relationship between rebound hammer values and UPV with the corresponding concrete compressive strengths. The higher the rebound hammer number or UPV value, the higher will be the concrete compressive strength. Therefore, this indicates that the rebound hammer and UPV tests could be adequately used to predict the compressive strength of concrete containing the industrial wastes.

Splitting Tensile Strength

Splitting tensile test is one of the indirect tensile tests to evaluate the tensile strength of concrete by using cylinder specimens. The splitting tensile strength results in this study are presented in Table 6 and Fig. 3. As stipulated in ACI 318, the minimum splitting tensile strength of structural concrete is 2.5 MPa. From the results obtained, all the mix design had exceeded the requirement with splitting tensile ranging from 3.23 to 3.75 MPa after 28 days.

Generally, the splitting tensile strength at 28 days was similar for most of the concrete, except for the cases of POC50 and CBA30. The splitting tensile strength was reduced by 12% when 50% POC was included as replacement for normal sand. Shafigh et al. [33] noted that replacement of POC fine aggregate by 25% did not significantly reduce the splitting tensile strength of lightweight aggregate concrete; however, due to the weaker POC aggregate, further replacement resulted in substantial decrease in the splitting tensile strength.

The reduction in splitting tensile strength was about 8% when 30% CBA was used as partial sand replacement. The reduction in tensile strength when CBA was incorporated could be attributed to the increase in porosity of CBA concrete. However, Singh and Siddique [15] reported that the use of chemical admixture could enhance the splitting tensile strength of CBA concrete. This explained the increase in the splitting tensile strength of the mix CBA50 in which SP was added.

For the case of SS aggregate, regardless of the replacement levels, the splitting tensile strengths obtained were comparable to the reference concrete. San-Jose et al. [34] also found that SS concrete achieved similar splitting tensile strength as the concrete with normal sand, and there was excellent adhesion between cement matrix and the SS fine aggregate.

Sorptivity Index

Sorptivity test results of all concretes are shown in Fig. 5. For both POC and CBA concretes, the sorptivity index was generally higher than the reference concrete and this index increased with higher fine aggregate replacement level. This could be attributed to the porous nature of POC and CBA which increased the pore area of the concrete. Yuksel et al. [35] and Kim et al. [29] reported that the presence of CBA would increase the capillarity of the concrete as water can be easily diffused through a more porous structure. Bai et al. [36] recommended 30% replacement of normal sand with CBA with consideration for compressive strength, permeability and sorptivity of concrete.

In contrast, the sorptivity index of concrete with SS as partial sand replacement was slightly lower than reference mix and the sorptivity index decreased with the increase of replacement level. The reduced sorptivity of SS concrete was also reported by Tripathi and Chaudhary [37] and this was attributed to the irregularity of the aggregates which contributed to the incoherence of particle–particle

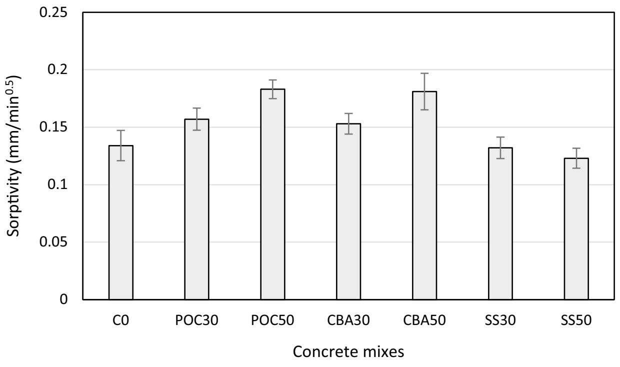

Fig. 5 Comparison of sorptivity values of concrete at 28 days

connection and restricted the continuity of water uptake through capillary action.

Drying Shrinkage

Higher drying shrinkage is commonly related to concrete made with aggregates with high porosity and water absorption [38]. Figure 6 presents the drying shrinkage strains of different types of concrete over time. In general, the drying shrinkage strain of the reference concrete was highest after 180 days, which was about 385 micro-strains. At 180 days, the drying shrinkage of the POC and CBA concretes were similar, which was about 350 micro-strains and 9% lower than the reference concrete. For the case of CBA concrete, past investigations [28, 36] have suggested that due to the porous structure of CBA, internal curing could occur which aided the reduction in drying shrinkage of concrete. The internal curing effect could have taken place whereby the moisture contained in the porous CBA aggregate was slowly released back into the concrete during the drying process, and hence reduced the free shrinkage of the concrete. Similar effect could apply for the case of the POC fine aggregate which is also porous as Aslam et al. [39] reported similar reduction in the drying shrinkage of lightweight concrete with the incorporation of POC.

The SS concrete mixes exhibited the lowest drying shrinkage in this investigation. After a drying period of 180 days, the shrinkage strain was 310 and 290 micro-strains for the SS30 and SS50 mix, respectively and this represents a reduction in shrinkage by 19 and 25%, correspondingly. It is believed that due to the inherent stiffness and strength of the SS aggregates, the aggregates were able to restrain shrinkage movement and hence lower drying shrinkage was observed. In addition, it is possible that due to the coarser size of SS aggregate compared to normal sand, a greater restraining effect was provided by the SS aggregate on to the movement of the cement paste. It can be said that concrete containing SS exhibited greater dimensional stability as compared to the reference concrete. The reduction in drying shrinkage with the use of SS fine aggregate was also reported previously by Tripathi and Chaudhary [37], for sand replacement of up to 70%. Monosi et al. [26], on the other hand, found negligible effect of SS on the drying shrinkage of concrete.

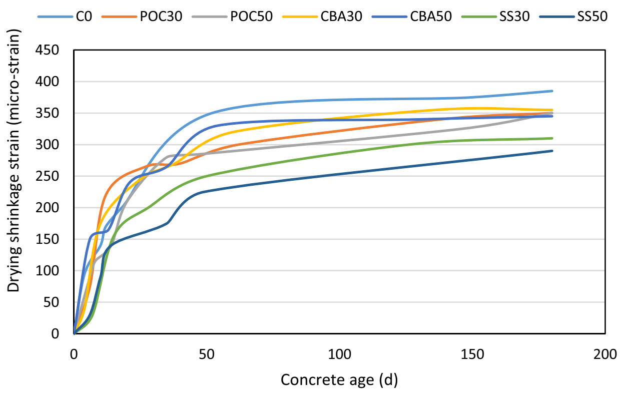

Fig. 6 Drying shrinkage over 180 days

Conclusion

In this study, an effort was made to valorize and re-use industrial wastes such as POC, CBA and SS as partial fine aggregate substitute in concrete. Therefore, in this paper, various concrete tests were carried out to investigate the feasibility and the effects of incorporation of these materials. The findings are summarized as follow:

a. Density of concrete was slightly reduced when POC and CBA were used as partial sand replacement while the density was increased when SS were used as partial sand substitute.
b. Regardless of the type and amount of industrial wastes used as fine aggregate replacement, the resulting concrete can be classified as having ‘good’ and ‘excellent’ quality after 1 and 28 days, respectively based on the UPV results.
c. Increased compressive strength was observed when 30% of sand was replaced with POC and SS while 50% replacement with POC and SS reduced the compressive strength of concrete. When CBA was used at 30% replacement level, the compressive strength was lower than the reference concrete at 28 days but exceeded that of the reference concrete at 90 days.
d. All of the concretes containing industrial wastes had similar splitting tensile strength as the reference concrete, except the concrete with 30% POC and 30% CBA, which had slightly lower tensile strength by about 10%.
e. Water sorptivity index was lower for concretes containing SS compared to the reference concrete while it was higher for the case of concretes with POC and CBA as fine aggregate substitute.
f. All of the concretes incorporating the industrial wastes had lower drying shrinkage than the reference concrete. Among the industrial wastes investigated, the SS concrete had the lowest drying shrinkage.

Based on the preliminary tests on the determined concrete properties, it can be suggested that there was no substantial negative effect with the use of these industrial wastes as partial fine aggregate replacement by up to 50% in concrete. Replacement of conventional sand with these industrial wastes in concrete can bring both economic and engineering improvements to construction industry and at the same instance benefit the environment by alleviating the problem of dwindling natural resources. For the optimum replacement level, it is recommended that the industrial wastes to be used at 30% replacement level for the best concrete performance.

Acknowledgements The financial support provided by University of Malaya under the grant GC003D-15SUS: 'Application of environmental-friendly building materials consisting of local waste materials for affordable housing' is gratefully acknowledged.

Compliance with Ethical Standards

Conflict of interest The authors declare that they have no conflict of interest.

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