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ORIGINAL PAPER

Properties of environmental concrete that contains crushed walnut shell as partial replacement for aggregates

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Abstract

Concrete production consumes a large amount of fine and coarse aggregates. Therefore, eliminating or reducing the consumption of aggregates in concrete can produce environment-friendly building materials. Considerable research has confirmed that the use of waste materials in concrete addresses the high utilisation of raw materials. Walnut is a common farming product in the north of Iraq. A substantial amount of walnut shells is disposed of in landfills. In the present work, crushed walnut shells (CWS) were selected as partial substitute for coarse and fine aggregates at ratios of 5 to 25% with an increment of 5%. The experimental work was divided into three parts. Firstly, fine aggregates were replaced with CWS at the preceding ratios. Secondly, coarse aggregates were substituted with CWS at the aforementioned ratios. Thirdly, fine and coarse aggregates were replaced by CWS at the same proportions. Absorption ratio, compressive strength, flexural strength, splitting strength and dry density were determined at 28 days for all the mixtures and the control sample. Results showed that all tested properties, except absorption ratio, decreased when CWS was used. Optimal results were achieved when fine and coarse aggregates were replaced together with CWS. Advantageous values were obtained with a 15% CWS replacement for both types of aggregates.

Keywords Absorption ratio · Compressive strength · Density · Flexural strength · Splitting strength · Walnut shells

Introduction

Recycling waste materials is beneficial for maintaining natural raw materials, reducing environmental contamination and conserving energy. These waste materials have several types, including industrial by-products, plastic wastes and agriculture wastes (Almeshal et al. 2020; Agwa et al. 2020). Agricultural wastes may be eliminated by burning or disposing in landfills. However, these methods adversely affect the environment. Thus, using agriculture wastes to produce new materials for manufacturing other products can be the best method for discarding these wastes. Construction materials, such as concrete, can benefit from these agricultural waste materials (Zeyad et al. 2018).. Many studies have reported the successful utilisation of these agricultural wastes in the production of concrete non-structural and structural elements. Numerous researchers have studied the effects of using these wastes as partial substitute for cement or aggregates to provide concrete properties, such as density, porosity, workability and durability characteristics, apart from strength (Zeyad et al. 2016, 2017).

Patel and Raijiwala (2015) and Mangi et al. (2017) found that sugarcane bagasse is an appropriate partial substitute for cement. Modani and Vyawahare (2013) indicated the appropriate use of sugarcane bagasse as a partial substitute for fine aggregates.

Kumar and Lemessa (2017) found that compressive strength of concrete samples, which consist of 50% quarry dust and 10% groundnut shell as cement substitute, improved compared with that of ordinary Portland cement concrete. Ismail and Jaeel (2014) investigated the use of giant reed fibres and ash in concrete. They found that density is reduced when giant reed–ash ratio is increased. The best flexural and compressive strengths are achieved at an optimal ratio of 7.5% giant reed ash. Zareei et al. (2017) found that using 15% rice

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husk ash as a substitute for cement increases water absorption, compressive strength and chloride ion infiltration by approximately 20%. Prusty et al. (2016) determined that concrete produced by utilising cork exhibits better cyclical strength and thermal insulation compared with ordinary concrete.

Potter et al. (2002) studied the effect of using ash of sunflower seed shells (SSAs) on concrete properties and microstructure. SSAs were utilised as partial replacement for cement in three dosages (5%, 7.5% and 10%) during concrete production. The authors determined the pozzolanic activity index, chemical components and SEM of the used SSAs. The results showed that SSAs can attain the identified and expected properties of heterogeneous nucleation influence, dilution influence, filler influence, positive degree of chemical influence and inorganic admixture influence. Moreover, the SSA dosage of > 5% exerts a severe effect on concrete properties.

Kang et al. (2019) used rice husk ash instead of inactive quartz filler as a reactive filler in producing ultrahigh-performance concrete to enhance its properties at normal curing. The results demonstrated the possibility of obtaining a compressive strength of 200 MPa at 91 days under normal conditions (60% relative humidity and 20 °C).

Walnut, one of the oldest agricultural products, was discovered in 2000 B.C. in Iraq. Walnut-producing trees were planted in the middle region of the world because of the nut's pleasant taste. Malhotra (2008) stated that the walnut shell (WS), which consists of the fruit's husk, contains lignocellulose materials. The fundamental elements of WS are N, O, H, S, K, Mg, Na, Fe, Ca and C. Several of these elements were found by using the plasma component emission technique. Based on thin shell theory, Chomiak et al. (2017) showed that a crack appears on a WS when a range of force (74–154 N) is applied. Thus, a WS takes a long time to break down or decompose.

WSs can be ground to numerous pieces ranging from very small to very coarse. Ground WSs were used in a mixture as an upper floor layer to increase the wear reluctance of the floor when exposed to large compressive loads (Tan et al. 2013; Brannon et al. 2003). Shahbazpanahi and Faraj (2020) proved that SPA and SSA can be used as replacement of cement. Fleming and Temyer (2009) reported a cementitious product that consists of two materials. One of these materials comprised of a minimal amount of treated wood or crushed fruit pieces.

Gürü et al. (2008) used a mixture of WS and fly ash to improve water resistance and bending strength (the maximum value was 3.8 N/mm^2). WSs were utilised to prepare the surfaces of concrete cast in situ owing to their high hardness; the cast was used for masonry walls and floors and as an abrasive material (Husain et al. 2017).

Cheng et al. (2017) presented an eco-friendly lightweight wet-mixture shotcrete by substituting ordinary coarse aggregates with WS in different dosages (i.e., 25%, 50% and 75%). Polyethylene terephthalate and polypropylene fibres were utilised in this shotcrete mixture to enhance its properties. The results indicated that splitting tensile and compressive strengths of concrete decrease with an increase in the volume

Table 1 Chemical properties of cement

	Weight (%)	Limits of Iraqi SpecificationNo. 5/1984
Oxide		
CaO	62.3	-
SiO_2	20.28	-
Al_2O_3	5.55	-
Fe_2O_3	4.20	-
MgO	2.60	< 5.0
K_2O	0.75	-
Na_2O	0.4	-
SO_3	2.5	< 2.8
Lime saturation factor	0.81	0.66–1.02
Insoluble remains	0.5	< 1.5%
F.L	0.65	-
Total	99.63	-
Compound		
C3S	50.05	-
C2S	20.45	-
C3A	4.05	-
C4AF	13.20	-

Table 2 Physical properties of cement

Physical properties	Limits of Iraqi SpecificationNo. 5/1984	Test result
Setting time(min)		
Initial setting	120	≥ 45 min
Final setting	360	≤ 600 min
Fineness by Blaine method (m^2/kg)	300	≥ 230
%Auto clave	0.31	≤ 0.8

ratio of WS compared with that of plain concrete. Such reduction reached 68.8% and 63.6% in splitting tensile and compressive strengths, respectively, at a volume ratio of 75% WS. Pressure drop and slump values decrease with an increase in gravel substitution with WS within the range of 0 to 75%. The addition of fibres can improve splitting tensile strength and shooting ability in terms of decreasing the increase in buildup thickness and rebound rate. The use of fibres reduces compressive strength, flowability and slump values of fresh concrete.

Grubeša et al. (2019) investigated the use of WS slag in certain dosages (i.e., 10%, 20% and 30%) as a partial substitute for fine aggregates. The results showed that concrete's strength properties were reduced compared with those of ordinary concrete. The authors concluded that the use of WSs as aggregates in concrete produces a compressive strength of 29.3 N/mm^2, which can satisfy the requirements for structural lightweight concrete.

Kamal et al. (2017) studied the partial replacement of fine aggregates by WS in concrete production. Water/cement (w/c) ratio varied from 0.38 to 0.52, and WS dosage varied from 1.72 to 58.28% of concrete weight. The authors tested compressive strength, density and water absorption of all the mixtures. In addition, they utilised the response surface methodology (RSM) to model and optimise their results. The RSM results demonstrated that WS dosage exerts an important influence on density and compressive strength. By contrast, w/c ratio has an important quadratic influence on the entire water absorption compared with the reference specimens. Nevertheless, the authors concluded the possibility of substituting fine aggregates with WS by up to 30% at a w/c ratio of 0.38 without severely affecting the required compressive strength for ordinary structural concrete.

Hilal et al. (2020) indicated that all established properties decrease by increasing WS volume fraction. However, lightweight self-compacting concrete can be gained at a fraction volume of WS equivalent and or more than 35%. Compressive strength, bond strength and slump flow diameter were 35 MPa, 6.55 MPa and 560 mm, respectively, at a 35% ratio of WS.

The preceding paragraphs indicate that the use of WSs in concrete production is seldom studied in the literature. In the present work, compressive strength, splitting tensile strength, flexural strength, dry density and absorption ratio were investigated by using crushed walnut shell (CWS) as sand, gravel and sand and gravel with different dosages in normal Portland cement concrete. This work also established a relationship amongst the studied properties to determine the optimum dosage of WS.

The north of Iraq has three governorates that produce walnut, which is considered a basic food for the population of this northern region. Walnut is also used in sweets in other Iraqi governorates. Consequently, a large amount of WS waste is produced. Such waste can be utilised in concrete production as a substitute for gravel or sand to preserve natural raw materials and dispose this waste.

Materials and methods

Materials

In the present work, materials used were ordinary Portland cement, ordinary fine aggregates, ordinary coarse aggregates, clean water and CWS waste particles. Ordinary Portland cement type I manufactured at a cement factory (Al-Mass) was utilised for all the mixtures. Cement used conformed to Iraqi

Table 3 Properties of sand

Physical properties	Test result	Limit of Iraqi Specification No. 45/1984
Fineness modulus	3.18	-
Specific gravity	2.7	-
Sulphate content	0.19%	(0.5–1)%
Absorption	1.50%	-
Density (kg/m^3)	2650	-

Specification No. 5/1984 (Tables 1 and 2). Ordinary fine aggregate was saturated surface dry clean river sand, and Table 3 provides its properties. Figure 1 presents the sieve analysis of the used sand. The grading curve of the used sand was within the bounds of Iraqi Specification No. 5-1984. Clean river gravel with a maximum size of 12.5 mm and a specific gravity of 2.66 was utilised as ordinary coarse aggregate for the mixtures. Figure 2 presents the results of the sieve analysis test. The grading of the coarse aggregate was in accordance with the limitations of Iraqi Specification No. 5/1984. Clean potable water was utilised for mixing and curing all the specimens. CWS waste granules were collected from households and small-scale food industries, cleaned, dried and crushed into polygonal, flaky or semi-rounded particles. WS had a specific gravity of 0.96, a hardness of 3.6 MOH and 85 Rockwell. Figure 3 shows the grading of the different CWS samples used in this work. The CWS used as a coarse aggregate had a maximum size of 9.4 mm. Figure 4 presents the CWS used.

Testing

Testing included the investigation of dry density, absorption ratio and compressive, flexural and splitting strengths of concrete produced using CWS particles as partial replacement for sand, gravel or sand and gravel. The same previously considered properties of the reference concrete with 0% CWS particles were also measured. Accordingly, three groups of mixing were created. The first group was obtained by replacing natural sand with CWS particles in ratios of 5%, 10%, 15%, 20% and 25% of sand volume. In the second group, natural gravel was replaced with CWS particles in the same ratios used in the first group. The third group was cast by substituting natural gravel and sand with the same ratios adopted in the first group. A total of 48 cubic samples with dimensions of 100 mm × 100 mm × 100 mm, 48 cylindrical samples with dimensions of φ100 mm × 200 mm and 48 prism samples with dimensions of 100 mm × 100 mm × 500 mm were cast to test compression strength, dry density, splitting tensile strength and flexural strength, respectively. Compressive, flexural and splitting strength tests were conducted in accordance with BS 1881: parts 116–118 (1983) and ASTM C 496. A dry density test was conducted in accordance with ASTM C 138-86. Symbols used for describing the tested specimens consisted of letters and numbers. The letters FW, CW and FCW were used for the first, second and third groups, respectively. The number after the letters referred to the CWS ratio. For example, FW5 was a specimen made of concrete with a replacement of 5% volume of natural sand by CWS.

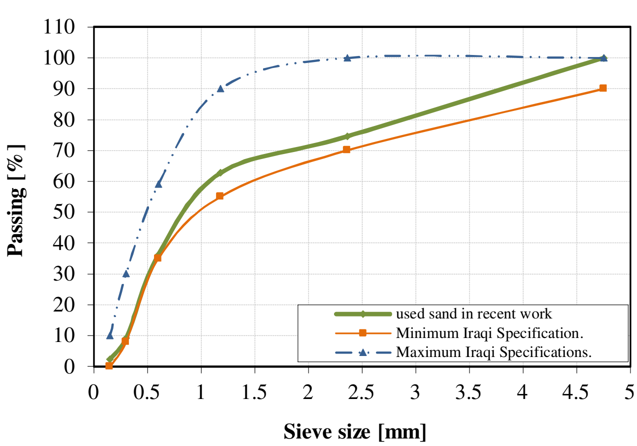

Fig. 1 Sieve analysis of used sand in the recent work

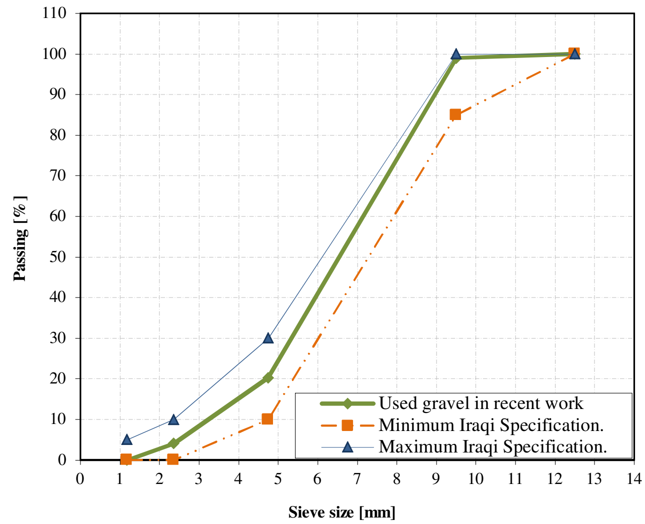

Fig. 2 Sieve analysis of used gravel in the recent work

Concrete mixes and mixing

In all the series and reference one, the concrete mix proportion was kept approximately constant at 1-1.48-2.95 with a constant w/c ratio of 0.55. The same amount of cement (400 kg/m^3) was used for all the mixtures. The ordinary fine and coarse aggregates were changed for all the series to obtain the same previous proportion (Table 4). An electrical tilting drum with a capacity of 0.16 m^3 was used for mixing all the samples in the laboratory at an ambient temperature of 24 °C ± 1 °C. Prior to casting, lubricant oil was carefully applied to each inner surface of the moulds.

Firstly, a small amount of cement was mixed with gravel and sand or CWS particles for approximately 3 min until they were covered with cement. Half of the amount of used water and the remaining cement were added to the mixer. The materials were then mixed for another 3 min. The remaining water was added to the materials, and then they were mixed for an additional 2 min.

The specimens were packed with concrete in three layers. Every layer was exposed to exterior vibration.

Fig. 3 The different used CWS: **a** FW, **b** CW, and **c** FCW

The upper surface of the cast concrete was satisfactorily levelled using a trowel. The specimens were demoulded after 1 day of casting. The specimens were cured in a laboratory at 24 °C ± 1 °C in a water tank for 28 days. Then, the cured specimens were left in the laboratory for 1 day to be dried before the test.

Results and Discussions

Size, shape, surface texture, absorption and strength of the aggregates evidently affect density, fresh concrete workability, durability and microcracking (strength) of hardened concrete. Therefore, properties of concrete produced using CWS will change in variable amounts obtained through this recent experimental work.

Table 5 presents the results for all the tested groups. Figure 5a shows that density was reduced when CWS was used as an alternative to aggregates. Such decrease was attributed to the lower specific gravity of CWS than that of ordinary aggregates. A low density was observed when 25% CWS was utilised in the three groups. The decrease in density was variable in all the groups. A substantial reduction occurred in GP2, followed by GP3 and GP1. This difference in density reduction could be attributed to the size and irregular figure of the CWS particles. When CWS was as large as that in GP2, the concrete samples were more difficult to pack compared with the samples from other groups. This situation led to the production of numerous voids and a subsequent decrease in density.

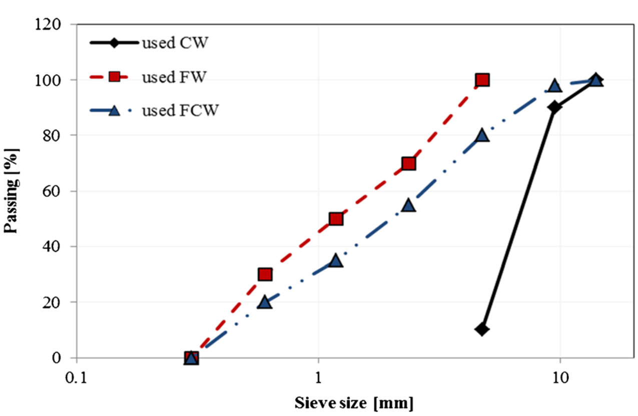

Fig. 4 Sieve analysis of fine CWS

Relative absorption ratio increased when CWS was used as aggregate in all the groups (Fig. 5b). The lowest increase occurred in GP3, whereas the highest augmentation was observed in GP2 at 25% CWS volume, which reached 208% of absorption ratio for the reference mix. The increase resulted from the ability of the WS to absorb more water than ordinary aggregates. The water absorption of WS was 31.4%.

Compressive, flexural and splitting strengths decreased when CWS was used as a partial replacement for aggregates. Compressive strength decreased at an approximately lowest rate compared with flexural and splitting strengths in all the groups. The least reduction of all the strengths occurred in GP3, followed by GP1 and GP2. At a volume fraction of 15% CWS, splitting, compressive and flexural strengths for GP3 decreased by 27%, 30% and 35%, respectively. Splitting, compressive and flexural strengths for GP3 decreased by 62%, 42% and 62%, respectively, at 25% CWS volume. The reduction in all the strengths could be attributed to the low strength of CWS particles compared with those of ordinary aggregates and irregularly shaped (flaky or many-sided) CWS particles. This condition negatively affected the mixing and compaction of concrete specimens. The considerable reduction in flexural and splitting strengths could be due to the shape and texture of walnut, which is fairly rough and convex on one side and smooth and concave on the other side. Accordingly, additional cement paste was necessary to cover the walnut. This condition led to reduced connection with the other components of the concrete matrix, additional voids and weakness at the interfacial transition zone. Consequently, flexural and splitting strengths sharply decreased. The optimal results of GP3 resulted from the use of different sizes (fine and coarse) of CWS

Table 4 Quantity of used materials for 1 m^3

No.	Mix ID	Cement (kg)	Sand (kg)	Gravel (kg)	Water (kg)	Walnut shell (kg)
Ref.	Reference	400	590	1179	220	0
GP 1	FW5	400	560.5	1179	220	29.796
	FW10	400	531	1179	220	59
	FW15	400	501.5	1179	220	88.5
	FW20	400	472	1179	220	118
	FW25	400	442.5	1179	220	147.5
GP 2	CW5	400	590	1120.05	220	58.95
	CW10	400	590	1061.1	220	117.9
	CW15	400	590	1002.15	220	176.85
	CW20	400	590	943.2	220	235.8
	CW25	400	590	884.25	220	294.75
P 3	FCW5	400	560.5	1120.05	220	58.95
	FCW10	400	531	1061.1	220	117.9
	FCW15	400	501.5	1002.15	220	176.85
	FCW20	400	472	943.2	220	235.8
	FCW25	400	560.5	884.25	220	294.75

particles. This approach led to smaller size and number of voids in the internal composition and good interface with other concrete components.

Compressive strength is one of the major substantial considerable variables in the design of concrete structures and is contingent on density. Figure 6a shows the relationship between dry density and compressive strength for each group in this study, which was comparable with the relation found by Cheng et al. (2017). Compressive strength was proportional to splitting strength (Fig. 6b) and analogous with the relationship obtained by Cheng et al. (2017). Moreover, the relationship between compressive and splitting strengths was approximately the same for the three groups.

Figure 6c shows the relationship between compressive and flexural strengths, which were nearly the same in all the groups. A linear empirical equation was found for each group. Splitting strength was proportional to the flexural strength (Fig. 6d). A linear experimental

Table 5 Attained results

Mix ID	Dry density (kg/m^3)	Compressive strength (MPa)	Splitting strength (MPa)	Flexure strength (MPa)	Absorption (%)
Reference	2400	41.65	3.919	3.39	1.3
FW5	2370	32	3	2.5	1.5
FW10	2300	27	2.5	2.11	1.75
FW15	2230	25	2	1.9	1.95
FW20	2130	23	1.8	1.7	2.25
FW25	2030	21	1	1.5	2.5
CW5	2250	28	2.7	2.13	1.72
CW10	2200	25	1.9	1.9	1.93
CW15	2150	21	1.2	1.46	2.1
CW20	2050	19	1	1.3	2.6
CW25	2000	17	0.9	1.1	2.7
FCW5	2320	34	3.1	2.6	1.6
FCW10	2280	31	2.98	2.4	1.75
FCW15	2200	29	2.88	2.2	1.85
FCW20	2100	25	2	1.85	1.9

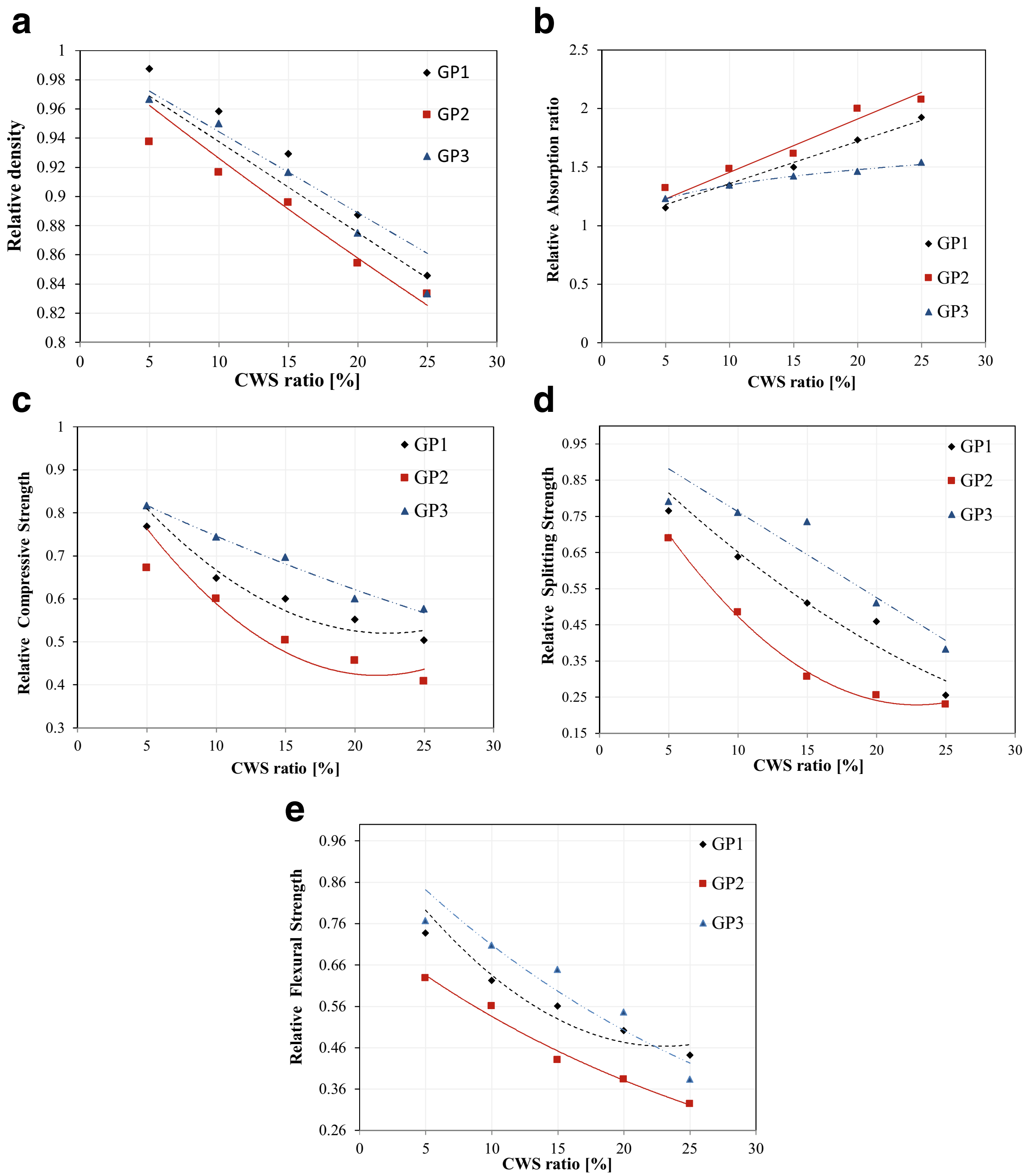

Fig. 5 The relationship between the tested properties and CWS ratio: **a** relative density and CWS ratio, **b** relative absorption ratio and CWS ratio, **c** relative compressive strength and CWS ratio, **d** relative splitting strength and CWS ratio, and e relative flexural strength and CWS ratio

equation was found for every group. Splitting strength was approximately 1.08–1.19 times flexural strength for all the groups.

Conclusions

The following conclusions were drawn based on the results:

- A low change (decrease or increase) of each tested concrete property was observed in mixtures produced by replacing fine and coarse aggregates with CWS, such as in GP3. By contrast, a considerable change was observed in mixtures produced by substituting coarse aggregates with CWS, such as in GP2.
- Dry density decreased when CWS was used as fine, coarse or fine and coarse aggregates in the three tested groups.
- Absorption ratio increased by utilising CWS in all the tested groups.
- All the strengths decreased by using CWS in all the tested samples. A low reduction was found in compressive

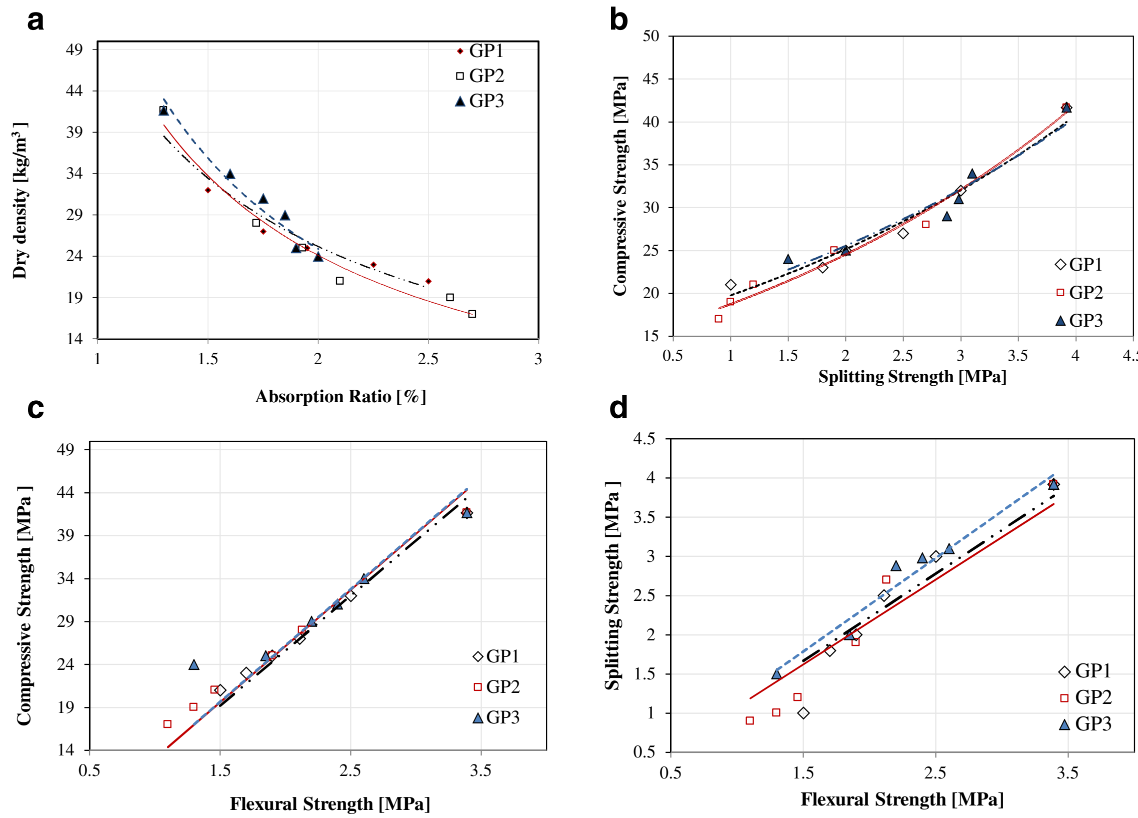

Fig. 6 the relationship between different tested properties: **a** dry density and absorption ratio, **b** compressive and splitting strengths, **c** compressive and flexural strengths, and **d** splitting and flexural strengths

strength, followed by splitting strength and flexural strength for all the groups.

– When the concrete structures were not exposed to extreme moisture conditions, 25% of the fine and coarse aggregates could be replaced with crushed WS in concrete production to achieve appropriate strengths and low dry density, conserve natural materials and protect landfills.
– Durability of concrete that contains CWS should be examined in future studies to understand CWS reaction under severe attack condition and the effect of prolonged CWS use on concrete properties.

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