Improvement of eco-efficient self-compacting concrete manufacture by recycling high quantity of waste materials

NAHLA Naji HILAL (nahla.naji@uofallujah.edu.iq)
University Of Fallujah https://orcid.org/0000-0001-9403-9982
Marijana Hadzima Nyarko
University of Osijek

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Abstract

Recycling plastic waste to obtain new materials such as concrete or mortar seems to be one of the best solutions for disposing of plastic waste. Second, in the construction industry, due to the increasing costs of landfills and the lack of a natural large aggregate, the increased interest in crushed ceramics is significant. The third type of waste that is dealt with in this article is tea ash because tea is the second most consumed beverage in the world and large amounts of waste are generated. This article attempts to develop the appropriate characteristics of self-compacting concrete by adding the following waste materials: plastic waste, tea waste and collapsed ceramics. In this paper, Fresh and hardened properties of self-compacting concrete with waste materials were investigated. The diameter and time of sediment flow, segregation, L-box ratio, and density of freshly compacted concrete mixtures were measured. Moreover, both 7, 14, and 28-day bending strength and 7 and 28-day bending strength of hardened self-compacting concrete samples were measured. The results proved the possibility of using plastic waste, tea waste and collapsed ceramics in self-compacted concrete, because they do not significantly reduce the hardened and fresh properties of self-compacted concrete.

Introduction

One of the most momentous factors to consider in construction is the issue of the economy and the environment (Shi et al. 2019; Harilal et al. 2021). On the one hand, the goal of every designer is to reduce costs. On the other hand, the utilization of waste materials in concrete is an outstanding contribution to the preservation of ecology. Therefore, the use of waste materials in concrete combines these two goals, and achieves a strong correlation among the economy and environmental problems. The third goal that is set is to maintain or improve the properties of concrete such as durability, ductility and strength.

The cost of one cubic meter of concrete can be reduced by partially or completely, substituting the natural aggregate with waste aggregate such as plastic, building wrecks, etc., some of which can be used as fibers (e.g. steel fibers extracted from waste tires, plastic fibers, fibers from natural sources, etc.) and by partially substituting cement with cheaper materials (such as fly ash, egg shell or glass powder, or ground blast furnace slag) (Yildirim and Duygun 2017; Hadzima-Nyarko et al. 2019; Balraj et al. 2020; Tayeh et al. 2021; Adekomaya and Majozi 2021). Some of these waste materials as a replacement / addition to concrete, in addition to achieving both, environmental and economic goals, can also improve the above mentioned concrete properties (i.e. strength, durability and ductility).

Increasing amounts of waste in the world pose an extremely huge environmental problem. One way is the possibility of applying the waste in cement based materials. A brief review of the literature so far has shown that certain types of waste, such as plastics and crushed ceramics, have been used and researched more than others, such as waste tea ash.

Although previous research indicates that there is a possibility of using these waste materials as a replacement of cement in concrete, it is still necessary to conduct additional experiments and research to minimize any negative impact or to obtain better properties of such concrete. That is why the research conducted in this paper was performed with the aim of obtaining results that would help to understand the impact of waste materials (plastics, crushed ceramic and waste tea ash) as a substitute/additive to concrete on its properties.

Three types of waste materials will be used in the paper: plastic, crushed ceramic and tea waste. The rest of the paper is organized as follows: a brief state of the art for every waste material used in this research is given in section 2. In section 3, the experimental method is described; details about materials and design mixes, as well as the testing procedures are given. Results and discussion of obtained results are presented in section 4.

Literature Survey

2.1 Properties of concrete with recycled plastic

Today, plastic is a ubiquitous material and recently there has been a significant increase in plastic consumption worldwide. This means that the production of plastic waste is also directly increased. Plastic waste now poses a serious threat to the environment because it is a material that increasingly pollutes the soil, air and water as it consists of several toxic chemicals. Since it is a non-degradable material, filling the ground with plastic means preserving this harmful material forever. As a result, many countries have already restricted the use of plastic bags, while many are in the process.

The reuse of plastics in concrete production is the most cost-effective application in dealing with the disposal of large quantities of recycled plastic material. Recycled plastic can be utilized as a replacement for aggregate in concrete.

Siddique et al. (2008) and Saika and de Brito (2012) presented the review of the provided research regarding the utilization of waste plastic (WP) in concrete and mortar. While Siddique et al. [8] discussed about the effect of waste plastic on workability, air content, bulk density, compressive and splitting tensile strength, permeability, impact and abrasion resistance as well as modulus of elasticity, Saika and de Brito (2012) discussed toughness, thermo-physical properties, failure characteristics and durability performance.

The first and positive conclusion in both reviews was that waste plastic could be successfully and effectively applied as a partial substitution of natural aggregate in concrete. However, the addition of plastic may improve certain characteristics of concrete, while other characteristics may be deteriorated. In the following short overview, the main effects of plastics on the following properties that will be tested in this paper will be presented: workability, compressive and flexural strength.

There are two conclusions, derived from the shape and size of the recycled plastic aggregate, on the performance of workability of concrete with recycled plastic aggregate. A spherical-shaped plastic aggregate increases the slump of fresh concrete mixtures, while a porous and flaky plastic aggregate decreases it.

The waste recycled plastic in concrete reduces the density of concrete mixtures. The average reduction was by 2.5–13% when recycled plastic is added in the range from 10% to 50% (Siddique et al. 2008).

Hama (2020) investigated the properties of fresh concrete with different percentages of waste plastic. The overall conclusion was that significant loss in workability was obtained when plastic replacements were more than 10%. When plastic replacements were 35% and 40%, the mixtures showed a loss in bonding and cohesion and they showed unworkable conditions and approximately zero slump at 40% waste plastic.

Regarding the properties of hardened concrete, the reduction in various strength properties is observed when natural aggregates is substituted with recycled waste plastic partially or fully, with a relatively less prominent reduction in flexural and tensile splitting strength than the decrease in concrete's compressive strength.

The influence of recycled plastic aggregates on the concrete's compressive strength was investigated in the work of Al-Manaseer and Dalal (1997). For concrete samples with 10%, 30%, and 50% of waste plastic, the compressive strength was reduced 34%, 51%, and 67%, respectively.

Ismail and Hashmi (2008) partially replaced sand (0 to 20% of the weight) with waste recycled plastic. Research has shown that the addition of waste plastic as a substitute for aggregates in concrete is a good approach to reduce material costs, and on the other hand solves the problem of disposing of solid non-degradable waste such as plastic. Compared to the reference mixtures, the slump values of concrete with WP decreased, as well as the compressive and flexural strengths. The lowest values, i.e. 30.5 % and 40 % reduction compared to the reference mixture were achieved for 28-days flexural and compressive strength for concrete with substitute of 20% of waste plastic.

Batayneh et al. (2007) investigated the compressive strength of concrete mixes with waste plastics of up to 20%. For a 20% replacement of the fine aggregates with recycled waste plastic, the compressive strength decreased by 72% compared with the reference mix, while for a 5% substitution, the compressive strength was reduced by 23%.

Al-Hadithi and Hilal (2016) investigated fresh and hardened properties self-compacting (SCC) concrete with added waste plastic fibers in percentages from 0.25% to 2% by volume. With the increase in plastic fibers, obtained by cutting beverage bottles, V-funnel flow times and the slump flow increased. However, an increase in flexural and compressive strength was observed when the addition of waste plastic fibers was lower than 1.75 %. The addition of small amount of waste plastic fibers resulted positively for hardened properties of SCC.

Hama and Hilal (2017) also investigated fresh and hardened properties of SCC with fly ash as partial substitution of cement (30% by weight of cement) and three different sizes of waste plastic as partial substitution of sand in percentages from 2.5% to 12.5%. The results of this research showed successful use of waste materials as fine aggregate in SCC.

A general conclusion that can be drawn regarding the compressive strength of concrete with waste plastics is that concrete produced with 10% recycled waste plastic performs relatively well compared to the reference concrete (Olofinnade et al. 2020). This implies that an optimum of 10% of recycled waste plastic can be used in producing lightweight non-structural concrete elements.

The cause of the reduced compressive strength of concrete with waste plastic can be explained by:

- the poor bond between the plastic aggregates and the cement paste and or
- the low strength characteristic for plastic aggregates.

The type of observed failure of concrete with waste plastic was not brittle, which was normally obtained for conventional concrete, but more of a gradual failure, and this depended on the content of plastic aggregates. The failure type became more ductile with an increasing of the content of waste plastic (Al-Manaseer and Dalal 1997).

2.2 Properties of concrete with crushed ceramic

Recycling of crushed ceramics is an environmentally friendly way of disposal to prevent the accumulation of large amounts of waste and preserve natural sources of materials. One of the ways of reuse is the use through recycled aggregate, obtained by crushed ceramics obtained during production. Research have shown that about 30% of materials go to waste (Medina et al. 2012; Zimbili et al. 2014)), and currently they are not beneficially used. Floor and wall tiles, crushed bricks and roof tiles, sanitary ware, flowerpot, household and technical ceramics represent some of the most commonly produced ceramics, mainly made of natural materials containing a high proportion of clay minerals.

Regarding the source of raw materials, ceramic waste can be divided into two categories (Pacheco-Torgal and Jalali 2010). One category refers to ceramic waste generated in structural ceramic factories that use red pastes to produce products (bricks, blocks and tiles). The second category includes waste ceramic produced in stoneware ceramics (wall and/or floor tiles and sanitary ware). Waste ceramic materials can become a cheaper but almost equivalent alternative to fly ash, metakaolin or ground granular blast furnace, and other supplementary binder materials used in concrete (Muralidharan et al. 2016).

The problem with using some of the ceramic waste e.g. crushed brick or tiles as a concrete aggregate is the high porosity and absorption of the aggregate which can influence the workability of the concrete in its fresh state. Therefore, it must be fully saturated before implementing in concrete (Hansen 1992). A reduction in the workability of the fresh concrete mix can also be caused by the proportion of dust particles, which must be considered. In case of a large proportion of dust particles, additional amount of water is needed to improve workability, and this at the same time causes a lower final strength of the concrete. If the allowable reduction in strength is constrained to about 5%, the proportion of dust particles should also be limited: 5% to the total amount of aggregate for low workability of concrete mix with coarse aggregate (> 4 mm), 10% for low workability of concrete mix with fine aggregate (0-4 mm) and at 20% for high workability if only fine aggregate grains were used (Khalaf and DeVenny 2004).

Hansen (1992) made experimental tests of the strength of brick grain that were of different strengths before crushing. After providing the results of the test, he concluded that there was a relationship between the grain strength of the brick aggregate and the final concrete's compressive strength in which the crushed brick was used as aggregate. This is confirmed by various tests, which give opposite results - in some waste crushed ceramic increased the compressive strength of such a concrete, while in others the compressive strength of concrete with waste crushed ceramics decreased.

For example, at the age of 28 days, the compressive strength reduction of concrete with coarse recycled brick is 10% to 35% compared to concrete with natural aggregate, and for concrete with fine recycled brick about 30% to 40% (Debieb and Kenai 2008).

Ikponmwosa and Ehikhuenmen (2017) investigated the effects of partial replacement (25%, 50% and 75%) of coarse aggregate with crushed ceramic on concrete strength properties. They measured considerable reduction in the workability and the compressive strength as replacement level increased. At 90-days, compressive strength for 25%, 50% and 75% replacement levels decreased by 11.7%, 19.5% and 27.6% respectively. They explained that the cause of the decrease in density and strength was crushed ceramic waste, which is lighter and more porous than natural coarse aggregate. Accordingly, their conclusion was that if the main goal is to increase the compressive strength, crushed ceramic waste is not a suitable material for concrete production.

By using crushed ceramic tiles as a coarse aggregate with different volumetric ratios, Mashitah et al. (2008) achieved increased compressive strength ranging from 41.4 MPa to 48.8 MPa.

Awoyera et al. (2018) researched the compressive strength of concrete with crushed ceramic with partially and fully replaced fine and coarse aggregates (0%, 25%, 50%, 75% and 100%). The obtained results indicated that the compressive strength increased with increasing crushed ceramic coarse aggregate substitution. After 28 days, about 36.1% increase in concrete's strength was achieved with 100% crushed ceramic coarse aggregate compared to the control mixture.

Hilal et al. (2020) showed that the utilization of crushed ceramic waste led to an increase in compressive and splitting tensile strength at room temperature. The maximum increase in strength was achieved by replacement of 60% crushed ceramic waste, and it was 164% and 128%, respectively, compared to control mixture without crushed ceramic waste and limepowder. Another conclusion of this research was that the use of crushed ceramic waste improves the behavior of mixtures exposed to high temperatures.

2.3 Properties of concrete with tea waste

Approximately 7% of total carbon dioxide (CO_2) is emitted by the cement industry sector (Lo et al. 2020; Bayraktar 2021). Associated with concrete production, consisting of cement manufacturing, the emission of CO_2 is between 0.1 and 0.2 tons per ton of produced concrete (Datta et al. 2019).

The reduction of CO_2 emissions from cement production can be achieved using agricultural waste that can be utilized as a substitution for cement in cement-based material (He et al. 2020).

Tea production increases by 4.4% annually, reaching 5.77 million metric tons in 2016 (Jakhrani et al. 2019). The leading tea producer is China, producing 42% of tea worldwide. Considering these numbers, an enormous amount of waste is generated thus representing a burden to the environment.

Various researchers have utilized tea waste in various studies and based on the obtained test results, provided appropriate outcomes and proposed recommendations. However, very limited studies have been found in the literature regarding the use of tea waste as a replacement for cement. Demirbas and Aslan (1998) studied the influence of spruce and beech woods, ground hazelnut shell, and black tea waste as a substitute for cement in percentages of 2%, 5%, 7.5% and 10% on flexural and compressive strength of mortar. For tea waste substitution in cement using percentages of 2%, 5%, 7.5% and 10%, they obtained compressive strength reduction of 41.1%, 49, 52.2% and 56 %, respectively.

Jakhrani et al. (2019) made mortar samples by adding two different amounts of tea waste and perlite particles of 1% and 3% by volume of cement. The results showed that any adverse effect on compressive and tensile strength using tea waste and perlite particles was small.

On the other hand, Nasr et al. (2019) investigated the impact of black tea waste ash as a partial substitution of cement (0%, 2.5%, 5%, 7.5% and 10% by weight) on the mechanical characteristics of mortar. Their results indicated that waste tea can improve the compressive strength of the hardened mortar, with the best improvement obtained by replacing the cement with 7.5% of waste tea, which was about 10% higher when compared to the control (conventional) mortar.

In order to research the effect of tea waste and fly ash on the compressive and tensile strength of concrete, Datta et al. (2019) replaced cement with tea waste and fly ash in two percentages (5% and 10%). The conclusion of their research was that the optimum results were achieved by 5% tea waste and fly ash.

Although previous research suggests that there is a possibility of using waste tea ash as a substitution of cement in the mortar, it is necessary to conduct additional experiments to confirm or refute this claim. The possibility of utilization of tea waste as a replacement for cement in concrete has been explored very little.

Experimental Method

In order to determine the possibility of applying plastics, crushed ceramic and waste tea ash in concrete and to compare the properties in the fresh and hardened state with the results obtained in a small number of existing studies, mixtures with the addition of plastics, crushed ceramic and waste tea ash in certain percentages were made.

3.1 Materials

The main components used in this research work, whose physical and chemical characteristics are presented in Tables 1 to 3, were as follows:

- Ordinary Portland cement (OPC) which manufactured by Al mass factory (Table 1)
- Natural coarse aggregate (sedimentary rock source) (Table 2)
- Normal fine aggregate (sand) (Table 2)
- Tap water
- Superplasticiser (Table 3)
- Waste plastics
- Crushed ceramics
- Tea waste ash (TWA) (Table 1).

In this study, Ordinary Portland Cement (OPC) with specific gravity of 3.15g/cm^3 was used. The chemical composition for OPC is given in Table 1.

Table 1. Physical features and chemical compositions of OPC and TWA

Chemical analysis (%)	OPC	TWA
SiO2	20.9	44
CaO	63.22	48
MgO	3.85	0.2
Al2O3	4.89	0.5
Fe2O3	2.82	1.4
SO3	2.73	0.34
K2O	0.92	4.0
LOI	11.8	
Specific gravity (g/cm^3)	3.15	2.06
Specific surface area(m^2/kg)	2500	

River sand and crushed sand with maximum size of 4.0 mm were used as natural fine aggregate. Crushed ceramic and gravel with maximum size of 14.0 mm were used as coarse aggregate.

Sieve analysis of fine and coarse aggregate are within limits of IQS No.45, 1984 (Iraqi specification No. 45, 1984). The granulometry of the aggregates used in the concrete is shown in Figure 1.

Preparation of waste materials which were used in this study were as follows:

Two type of plastic waste: recycled plastic (RP) and polypropylene plastic (PP) (Figure 2 a) were collected and cut into small sizes by using grinding machine to get fine particles, which were used as fine aggregate.

Ceramic waste was gathered from damaged buildings in Al-Falluja city and cut into small sizes, which were used as coarse aggregate (Figure 2 b).

Tea waste (TWA), obtained from many restaurants, was dried in oven at 105 °C for one day, then ground and burnt at 700 °C for 2.0 h. After that, TWA was sieved by passing through a sieve of 75 μm so that it could be used as cement replacement (Figure 2 c). Specific gravities and water absorption of used aggregates is presented in table 2.

Superplasticizer (SP) of type Polycarboxylic ether was used for SCC mixes. Its specific gravity was 1.07 g/, while other characteristics of SP obtained by local suppliers are given in Table 3.

Table 2. Main properties of used aggregates

Maximum size (mm)	**Water absorption**	**Specific gravities**	**Properties Type of aggregate**
4.0	0.57	2.67	**River sand**
4.0	0.90	2.44	**Crushed sand**
4.0	0	0.53	**Polypolpren**
4.0	0	0.69	**Waste plastic**
14.0	0.43	2.72	**Normal gravel**
14.0	0.13	2.52	**Crushed ceramic**

Table 3. Properties of Superplasticizer

Properties	Superplasticizer
Name	Sika, “ViscoCrete ® - 5930, High performance superplastizier concrete
State	Liquid
Color tone	White emulsion
Chemical description	Polycarboxylic type polymer
pH	8.0 ±1.0
Density	1.08 kg/liter
Recommended dosage (% binder content)	1–3 %
Chloride Content	Nil (EN934-2)

3.2 Design of self-compacting concrete (SCC) mixes

The SCC mixtures with waste materials prepared for this work were designed in order to obtain a constant w/c ratio of 0.39 and to have a total binder content of 500 kg/m^3. In all, sixteen SCC mixtures and one control SCC mixture were designed (Table 4). The first mix, which was taking into account as the control mix (control SCC mix) contained 0% of polpropylen plastic (PP) and recycled plastic (RP). The mixtures from Group A were designed with the inclusion of PP in percentages from 5% to 25%. The mixtures from Group B were designed with the inclusion of RP in percentages from 5% to 25%. The mixtures from Group C were designed with the inclusion of PP+RP in percentages from 5% to 25%. Details of other components, such as superplastizicer (SP), coarse aggregates (crushed ceramic (CC-C) and natural aggregates (NA-C)), fine aggregates (crushed ceramic (CC-F) and natural aggregates (NA-F)) are given in Table 4.

Table 4. Proportions of SCC mixes for 1 m^3

Notation	Mix ID	Cement	TWA	Coarse aggregate		Fine aggregate		Water	SP	PP	RP
				CC-C	NA-C	CC-F	NA-F				
	Control	400	100	409.7	409.7	246	574	156	10	0	0
Group A	PP5	400	100	409.7	409.7	234	545	156	10	8	0
	PP10	400	100	409.7	409.7	222	517	156	10	16	0
	PP15	400	100	409.7	409.7	209	488	156	10	24	0
	PP20	400	100	409.7	409.7	197	459	156	10	32	0
	PP25	400	100	409.7	409.7	185	430	156	10	40	0
Group B	RP5	400	100	409.7	409.7	246	574	156	10	0	11
	RP10	400	100	409.7	409.7	234	545	156	10	0	22
	RP15	400	100	409.7	409.7	222	517	156	10	0	32
	RP20	400	100	409.7	409.7	209	488	156	10	0	43
	RP25	400	100	409.7	409.7	197	459	156	10	0	54
Group C	PP+RP5	400	100	409.7	409.7	234	545	156	10	4	7
	PP+RP10	400	100	409.7	409.7	222	517	156	10	8	12
	PP+RP15	400	100	409.7	409.7	209	488	156	10	12	17
	PP+RP20	400	100	409.7	409.7	197	459	156	10	15	23
	PP+RP25	400	100	409.7	409.7	185	430	156	10	19	29

3.3 SCC Casting

When considering self-compacting concrete, the dosing and mixing procedure is extremely important, as well as the mixing sequence and duration of mixing in order to accomplish homogeneity and uniformity. The procedure of batching and mixing suggested by Khayat et al. (2000) was followed. According to this procedure, the coarse and fine aggregates, the PP and/or RP, were mixed homogeneously for one minute (60 s) in a power-driven revolving pan mixer. After 60 s, half of the mixing water was poured into the mixer and mixing was continued for another 60 s. With the aim to absorb the water, the aggregates and PP were left in the mixer for 60 s. Cement and waste tea ash (TWA) were then added to the mixture and mixed for another 60 s. The SP was then poured into the mixer with the rest of the water and the mixture was mixed for 240 s and then left to rest for 120 s. Finally, to complete the production, the concrete was mixed for an additional 120 s.

The abilities of passing and workability of SCCs were examined using different tests. In order to measure the compressive strength of SCC, three cubes of 100 mm were taken. After casting the concrete, the specimens were wrapped with plastic sheet and left for 24 hours in the laboratory at 20 ± 2 ° C. After 24 hours, the specimens were demolded and tested after a 7, 14 and 28-day water curing period.

3.4 Testing procedure

3.4.1 Fresh properties of SCC with waste materials

The slump flow and slump flow time tests are the tests used to determine the flow and viscosity of the SCC with waste materials in the absence of an obstacle. The T_{500} test measures the flow rate and an indication of the relative viscosity of the SCC. The test also serves to visually check the consistency of the concrete and the possibility of segregation.

The slump flow time (T_{500}), the slump flow diameter (SFD), V-funnel flow time, L-box ratio, and segregation resistance tests were determined on the fresh SCC mixtures in accordance to the recommendations in EFNARC [36] (Table 5). The primary check for the fresh concrete consistency in order to meet the specifications is the slump flow value. This sensitive test, used to describe the fluidity of fresh concrete in unconfined conditions, can normally be determined for all SCC mixtures.

Individually the slump flow and V-funnel flow time are used for the viscosity measurement. The V funnel is filled with fresh self-compacting concrete and then released from the funnel, and the elapsed time of fully flow is recorded as the flow time of the V funnel. The flow of fresh concrete through narrow and confined spaces like congested reinforcement areas without segregation is defined by the L-Box test, which is taken for the passing ability of fresh concrete measurement. The blockings to flow of fresh concrete is also defined by the L-box test. The L-box test can also measure the loss of uniformity of fresh concrete mixtures. the wet density test was performed According to ASTM C 642 standards (2006).

3.4.2 Hardened properties of SCRC

ASTM C78-84 (1989) and ASTM C39/C39M-12 (2012) standard methods were followed for conducting flexural tests and compression test respectively for SCRC mixtures. Compression and flexural tests were performed for three different ages of SCRC specimens (7, 14, and 28-days). According to the standards, the specimens are cubes with dimensions 100x100x100 mm. For every test, three specimens were taken and the results are based on the average values of three test results.

Results And Discussion

The results of tests on fresh SCC mixes, i.e. slump flow diameter (SFD), slump flow time (T_{500}), L-box ratio, segregation and density, are shown in Table 5.

Table 5. Testing the properties of freshly SCC mixtures

Property	Testing method	Class designation			
Flowability	Slump flow test	550 – 650 mm		SF1	
		660 – 750 mm		SF2	
		760 – 850 mm		SF3	
Viscosity	T_{500} value	≤ 2 s	> 2 s	VS1/VF1	VS2/VF2
The passing ability	L-box test	≥ 0.8 2 bars	≥ 0.8 3 bars	PA1	PA2
	V-funnel time test	≤ 8 s	9-15 s	VS1/VF1	VS2/VF2
Segregation	Sieve segregation test	≤ 20		SR1	
		≤ 15		SR2	

The performed slump flow test can be used to describe the viscosity and flow of the barrier-free concrete, measuring two parameters: slump flow time (T_{500}) and slump flow diameter (SFD). The test also serves to visually check the consistency of the concrete and the possibility of segregation. Undoubtedly, the simplest and most commonly used test is the slump flow test. The higher the value of the slump flow, the greater its ability to fill the formwork with its own weight. This direct correlation facilitates the use and interpretation of the results. Figures 5 and 6 present the test results of the flow rate and T_{50} flow time. The cone is filled with fresh concrete to the top, which is previously laid on a flat slab. When the cone is pulled upwards, as the concrete mix flows out, its time is measured until it reaches a line on the circle with a diameter of 500 mm. The time from the lifting of the cone to the spreading of the concrete to a diameter of 500 mm (T_{500}) is measured. The concrete mixture is allowed to stop completely on the slab and the diameter is measured in two vertical directions. The diameter is expressed as the mean of these two readings and is denoted by SFD. The control mixture was tried to be proportioned at the upper level of self-compatibility in order to remain within the set limits even after the addition of waste material. In Figure 5 it can be seen that the SDF results range between 720–762 mm, while in Figure 6 it can be seen that the T_{500} results range between 2.25 to 3.44 s. The values of slump flow generally become lower with the addition of waste plastic, i.e. it was found that the percentages of decrease in the value of the slump flow increase with the increase of the plastic waste content. It is convenient to note that the reduction in slump flow is greater for recycled plastic (RP) than for polypropylene plastic (PP) (Figure 5). Generally, the flow time T_{500} was longer for mixtures containing a higher content of waste plastics than mixtures with a low content. This happened because an increase in the content of polymer fibers leads to an increase in the viscosity of the mixture. Only the mixture PP10 did not behave in accordance with this statement. It is possible that in this part of the mixture there were clusters of polypropylene plastic fibers that compromised the ability to pour concrete.

The L-box, which consists of a vertical and a horizontal part between which there is a movable cover, is used to test the ability of fresh SCC mixes to bypass obstacles, i.e. bars. Reinforcement bars are placed next to the cover and therefore represent an obstacle that concrete needs to overcome. L-box ratio is calculated as the ratio of the height difference between the concrete surface and the top of the vertical part of the L-box [mm] (H_1) and the height difference between the concrete surface and the top of the horizontal part of the L-box [mm] (H_2). The obtained results, which determine the class of ability to bypass obstacles for the tested SCC mix, are presented in Figure 7. It can be seen from Figure 7 that all mixtures met this condition (in accordance to the Table 5). Otherwise, the L-box ratio is reduced by the addition of waste plastics.

Segregation resistance, i.e. the ability of concrete to remain homogeneous in composition in its fresh state is presented in Figure 8. After a sample of fresh concrete (10 ± 0.5 l) is taken, it is left to stand for 15 (± 0.5) minutes. Each separation of the bleed water is recorded. After 15 minutes, the fresh SCC mix is poured into a sieve. After 2 minutes, the weight of the material passed through the sieve is measured. Then, the segregation ratio is calculated as the proportion of sample passing through the sieve. It can be seen from Figure 8. that, for all mixtures, the segregation is reduced by the addition of waste plastics. Segregation is greater for addition of polypropylene plastic (PP) than recycled plastic (RP) or their combination (PP+RP).

Fresh density results for SCCs mixtures are shown in Figure 9. It can be seen from Figure 9. that, for all mixtures, the fresh density is reduced by the addition of waste plastics.

The overall results of fresh properties of SCC mixes can be seen in Table 6.

Table 6. Properties of SCC mixes in fresh state

Notation	Mix ID	SFD mm	T_{50} sec	T_V sec	L-box	Segregation %	Fresh density kg/m^3
Control	770	1.45	7	0.95	20	2400	
Group A	**PP5**	765	2.25	8	0.94	18	2380
	PP10	760	2.55	9	0.93	16	2360
	PP15	755	2.3	10	0.92	14	2340
	PP20	750	2.36	11	0.91	12	2320
	PP25	745	2.39	12	0.90	10	2300
Group B	**RP5**	760	2.4	11	0.93	19	2382
	RP10	750	2.85	12	0.92	18	2364
	RP15	740	3.01	13	0.91	17	2346
	RP20	730	3.21	14	0.90	16	2328
	RP25	720	3.44	15	0.89	15	2310
Group C	**PP+RP5**	762	2.32	9	0.93	17	2381
	PP+RP10	754	2.53	11	0.91	16	2362
	PP+RP15	746	2.57	13	0.90	15	2343
	PP+RP20	738	2.97	15	0.89	14	2324
	PP+RP25	730	3.39	16	0.88	13	2305

The addition of waste plastics leads to decrease in 7, 14 and 28-days compressive strength of all mixtures compared with a control mixture (Figure 12). The SCC mixtures developed compressive strengths ranging from 49 MPa to 55 MPa, from 42 MPa to 47 MPa, and from 43 MPa to 52 MPa, at 28 days for group A, B and C, respectively. Only mixtures RP15 and RP25 do not follow this pattern in decreasing strength.

Similar situation is when observing flexural strength (Figure 13). The flexural strength decreases with addition of waste plastics. Only mixture PP+RP25 does not follow this pattern in decreasing strength.

The overall results of hardened properties of SCC mixtures are given in Table 7.

Table 7. Properties of SCC samples in hardened state

Notation	Mix ID	Dry densitykg/m^3	Absorption (%)	Compressive strength MPa			Flexural strength MPa	
				7day	14day	28day	7day	28day
Control	2390	0.59	50	55	62	5.2	7	
Group A	**PP5**	2370	0.70	45	48	55	4.0	5
	PP10	2350	0.74	44	47	53	3.8	4.2
	PP15	2330	0.79	43	46	52	3.5	4
	PP20	2310	0.84	42	45	51	3	3.5
	PP25	2290	0.89	40	44	49	2.5	3
Group B	**RP5**	2380	0.74	43	47	47	3.8	4.3
	RP10	2370	0.79	41	46	45	3.6	4
	RP15	2360	0.82	40	45	46	3	3.7
	RP20	2350	0.88	38	43	42	2.8	3.5
	RP25	2340	0.99	35	40	45	2.5	3.3
Group C	**PP+RP5**	2360	0.74	47	50	52	4.5	6.5
	PP+RP10	2340	0.79	43	46	50	4	5.9
	PP+RP15	2325	0.82	41	45	48	3.7	4.6
	PP+RP20	2310	0.88	39	43	45	3.2	4.2
	PP+RP25	2295	0.99	37	41	43	3	4.7

Dry density results for SCCs mixtures are given in Figure 10. It can be seen from Figure 10. that, for all mixtures, the fresh density is reduced by the addition of waste plastics.

Conclusion

The use of recycled material as a substitution for aggregate or additive for cement in the production of concrete and/or mortar, in addition to environmental, can have a positive effect from an economic point of view. This way of building implies the use of cheap materials that can be used without negative impact on the environment. The paper tried to use three different wastes: crushed ceramics, waste plastics and waste tea ash.

For SCC mixtures with the addition of waste materials, SDFs in the range of 720 to 762 mm were obtained. The control mixture as well as mixtures with waste materials were in class SF2 according to

EFNARC. Although the increase in the content of waste materials led to a decrease in the diameter of slump flow, the obtained results are acceptable for many normal applications of SCC.

Compared with a control mixture, compressive strength of all mixtures decreased with the addition of waste plastics in 7, 14 and 28-days. Only two mixtures, RP15 and RP25, did not follow this pattern in decreasing strength.

When observing flexural strength, similar situation occurred: the addition of waste plastics leads to the flexural strength decreases. Only mixture PP+RP25 did not follow this pattern in decreasing strength.

The effect of such use of waste materials affects the reduction and utilization of waste, and does not significantly reduce the properties of SCC.

Declarations

Ethical Approval: Not applicable.
Consent to Participate: Not applicable.
Consent to Publish: Not applicable.

Author contributions:

Nahla Hilal: Development and implementation of ideas and methodology; investigation; data acquisition; formal analysis and processing results of research; writing - original draft.

Marijana Hadzima-Nyarko: Conceptualization; Methodology; Processing results of research; writing - original draft; writing—review and editing.

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Competing Interests: The authors declare no competing interests.

Availability of data and materials: The datasets used or analyzed during the current study are available from the corresponding author on reasonable request.

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Figures

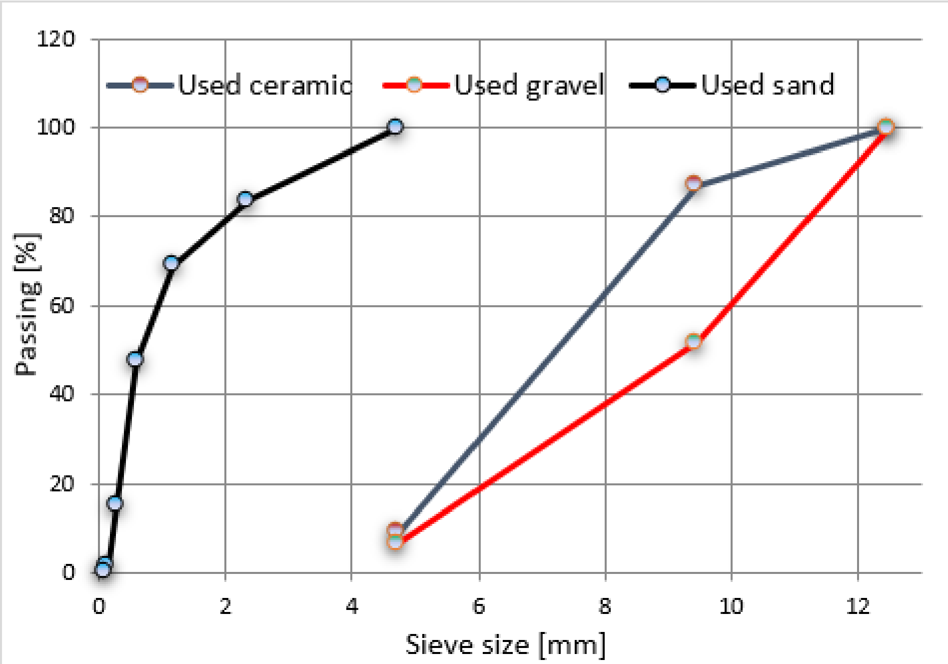
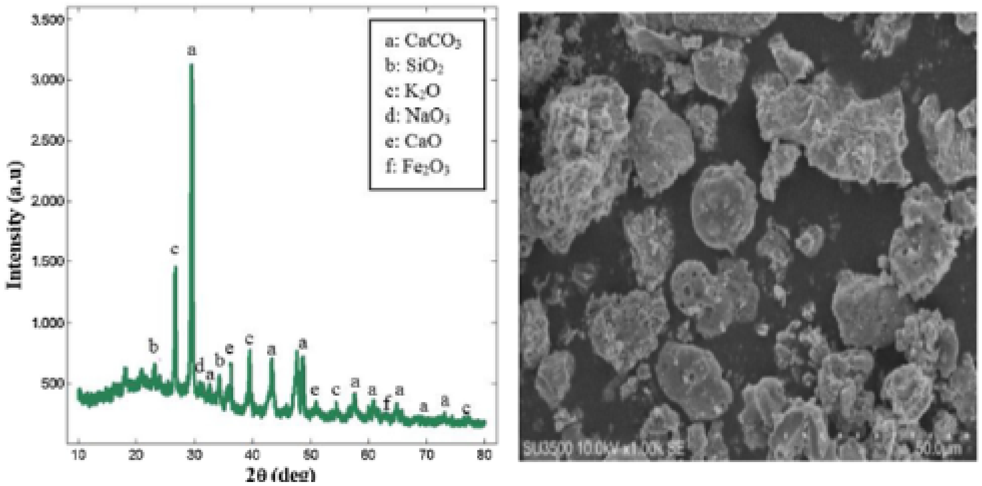


Figure 1

Gradation size distribution curves for aggregates

Figure 2

Steps to prepare the materials used in the research a) Plastic waste, b) Crushed ceramics, d) Waste tea ash (TWA)



a) b)

Figure 3

a) XRD pattern of PWTA, b) SEM image of PWTA (Djamaluddin et al. 2000)

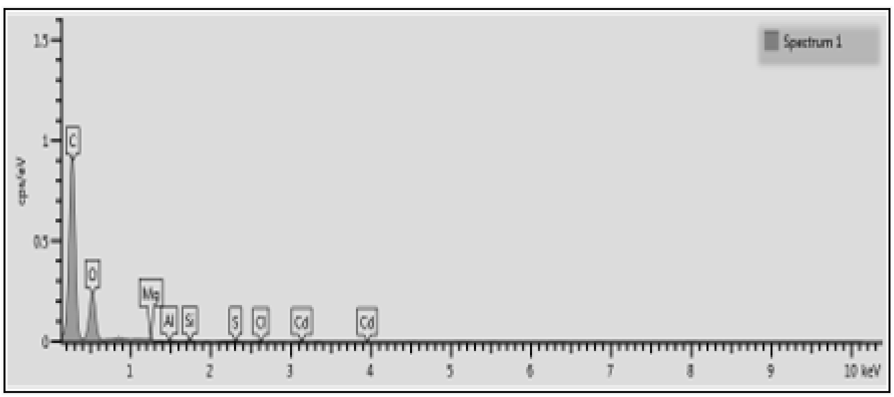


Figure 4

EDS Analysis of polypolpren (PP)

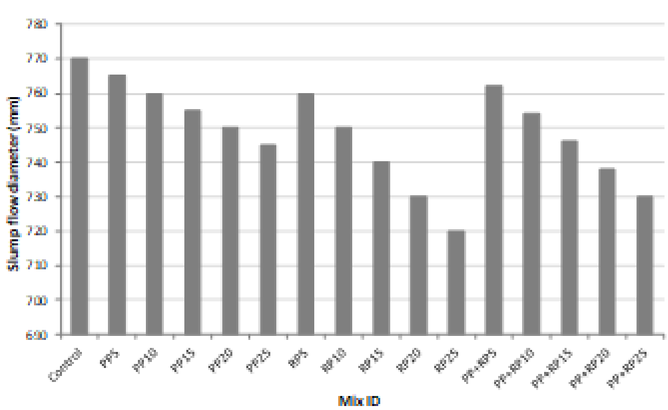


Figure 5

. SDF for SCCs mixtures

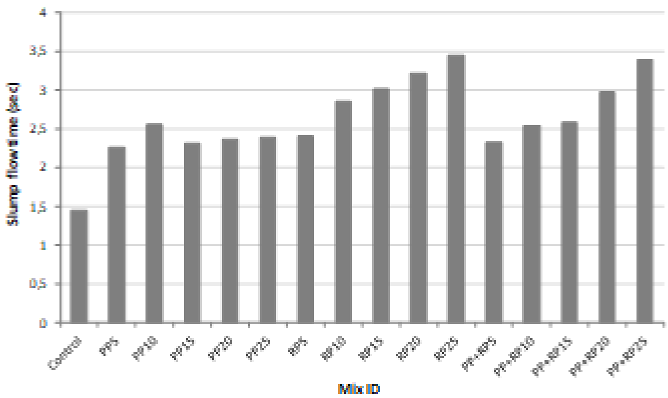


Figure 6

T500 for SCCs mixtures

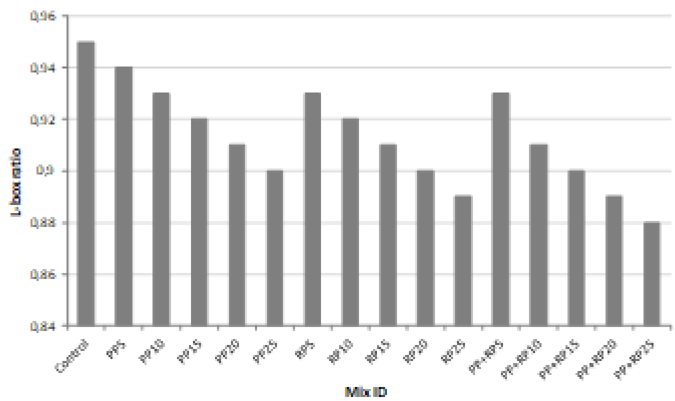


Figure 7

L-box ratio for SCCs mixtures

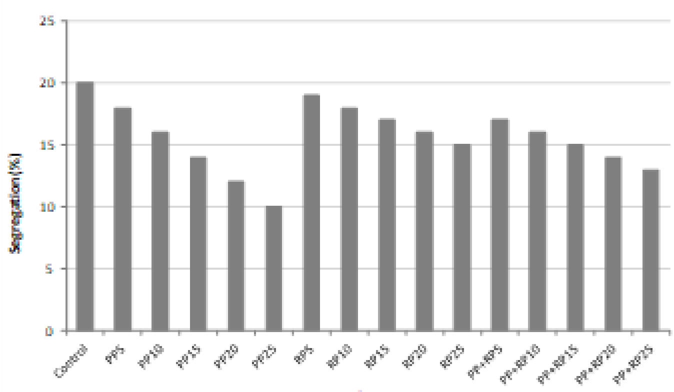


Figure 8

Segregation for SCCs mixtures

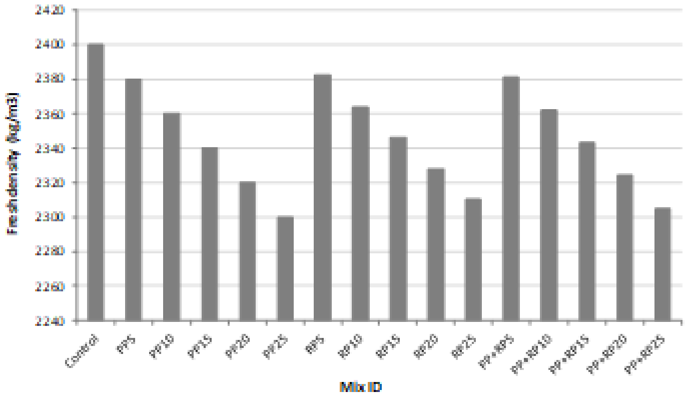


Figure 9

Fresh density for SCCs mixtures

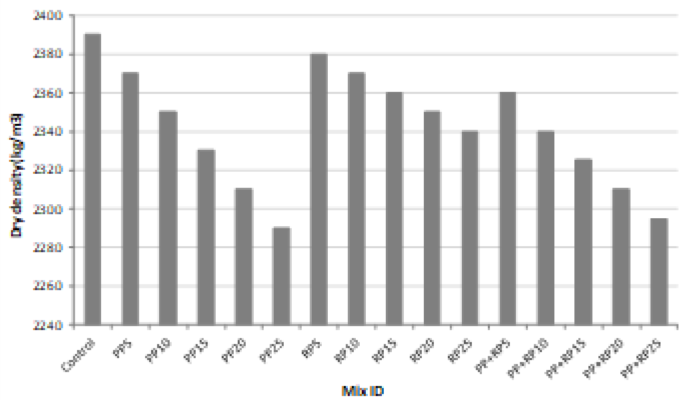


Figure 10

Dry density for SCCs mixtures

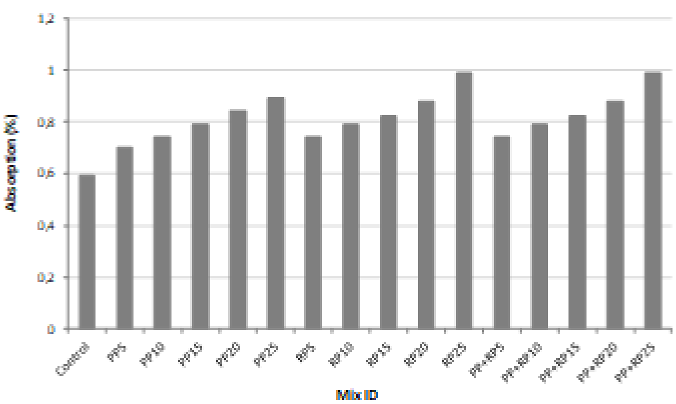


Figure 11

Results of absorption for SCCs mixtures

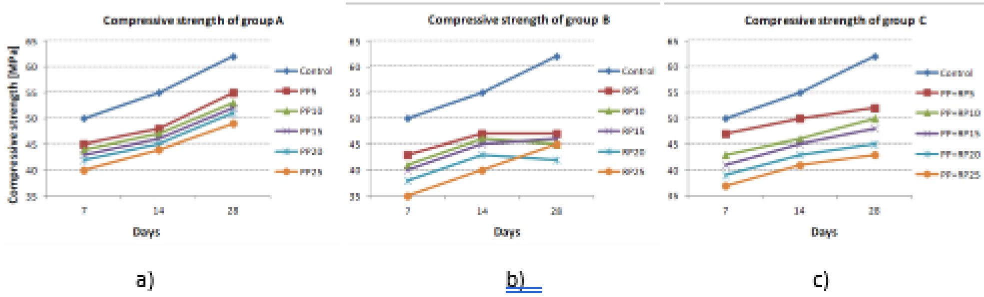


Figure 12

7, 14 and 28-days compressive strength for SCCs mixtures for: a) group A, b) group B, c) group

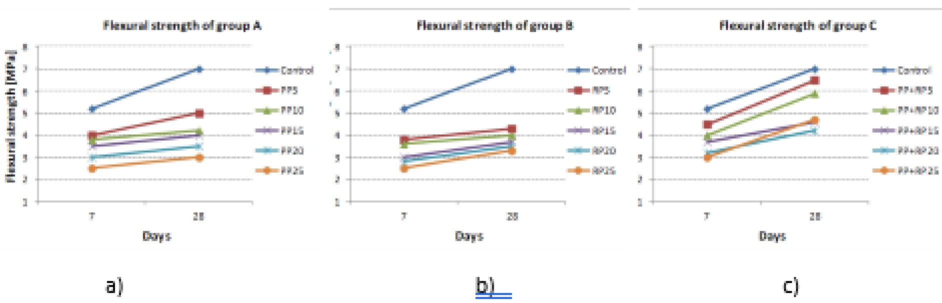


Figure 13

7 and 28-days flexural strength for SCCs mixtures for: a) group A, b) group B, c) group C

Supplementary Files

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- graphicabstract.png