Tikrit Journal of Engineering Sciences (2024); 31(2): 72-81
DOI: http://doi.org/10.25130/tjes.31.2.7

IRAQI Academic Scientific Journals

ISSN: 1813-162X (Print); 2312-7589 (Online)

Tikrit Journal of Engineering Sciences

available online at: http://www.tj-es.com

TJES Tikrit Journal of Engineering Sciences

The Effects of Waste Ceramic Powders and Waste Glass Powders on the Rheological and Mechanical Properties of Self-Compacting Concrete

Ammar Hisham Khairi [a*], *Saeed K. Rejeb* [b]

a Building & Construction Department, Technical Engineering College, Northern Technical University, Mosul, Iraq.
b Civil Technologies Department, Technical Institute, Northern Technical University, Mosul, Iraq.

Keywords:
Green Cement; Self-compacting Concrete; Supplementary Cementitious Materials; Waste Ceramic Powder; Waste Glass Powder.

Highlights:

- *Developing SCC from ceramic waste powder (CWP) and glass waste powder (GWP).*
- *Self-compacting concrete's rheological and mechanical performance.*
- *Developing an eco-friendly concrete mix by reducing the content of OPC and non-renewable natural resources.*

ARTICLE INFO

Article history:

Received	29 Mar.	2023
Received in revised form	01 June	2023
Accepted	27 Nov.	2023
Final Proofreading	22 Feb.	2024
Available online	05 May	2024

Citation: Khairi AH, Rejeb SK. **The Effects of Waste Ceramic Powders and Waste Glass Powders on the Rheological and Mechanical Properties of Self-Compacting Concrete**. *Tikrit Journal of Engineering Sciences* 2024; **31**(2): 72-81.
http://doi.org/10.25130/tjes.31.2.7

***Corresponding author:**

Ammar Hisham Khairi

Building & Construction Department, Technical Engineering College, Northern Technical University, Mosul, Iraq.

Abstract: Two key axes dominated this experimental research. The first was developing self-compacting concrete from ceramic waste powder (CWP) and glass waste powder (GWP), which met and followed the recommended European specification and guidelines for self-compacting concrete (EFNARC) standards. The second axis indicated the self-compacting concrete's rheological and mechanical performance. Sixteen different mixtures were produced using supplementary cementitious materials (SCMs) to replace cement partially. The replacement levels of SCMs were 5%, 10%, and 15% (by weight of cement), divided into three series: Series A (containing ceramic waste powder), Series B (containing glass waste powder), and Series C (containing combinations of ceramic waste powder and glass waste powder). The SCC rheological properties for all mixtures with different levels of SCMs replacement in the mixture gradually decreased as the substitution ratios increased. The reduction in flowability for substitution, ranging from 5% to 35%, was approximately 0% to 12%, respectively. However, the reduction was insignificant; the fresh properties remained within the limits specified by EFNARC. Regarding the mechanical properties, at an early age, the strength of mixtures decreased with increasing alternative ratios. However, after 90 days, the strength increased by about 11% and 9% of the compressive and flexural strengths, respectively, over the control mix, indicating that SCMs improve the concrete strength over time and are suitable to contribute to an eco-friendly concrete industry without compromising strength.

تأثير مخلفات مساحيق السيراميك ومساحيق مخلفات الزجاج على الخواص الريولوجية والميكانيكية للخرسانة ذاتية الضغط

عمار هشام خيري ١، سعيد خلف رجب ٢
١ قسم البناء والانشاءات/ الكلية التقنية الهندسية/ الجامعة التقنية الشمالية/ الموصل - العراق.
٢ قسم التقنيات المدنية/ المعهد التقني/ الجامعة التقنية الشمالية/ الموصل - العراق.

الخلاصة

سيطر محوران رئيسيان على هذا البحث التجريبي. الأول كان تطوير الخرسانة ذاتية الضغط من مسحوق مخلفات السيراميك (CWP) مسحوق مخلفات الزجاج (GWP)، والتي استوفت واتبعت المواصفات والمبادئ التوجيهية الأوروبية الموصى بها لمعايير الخرسانة ذاتية الضغط (EFNARC). أما المحور الثاني فقد أشار إلى الأداء الريولوجي والميكانيكي للخرسانة ذاتية الضغط. تم إنتاج ستة عشر خليطًا مختلفًا باستخدام المواد الأسمنتية التكميلية (SCMs) لتحل محل الأسمنت جزئيًا. كانت مستويات استبدال SCMs هي ٥٪، و١٠٪، و١٥٪ (حسب وزن الأسمنت)، مقسمة إلى ثلاث سلاسل: السلسلة A (تحتوي على مسحوق مخلفات السيراميك)، والسلسلة B (تحتوي على مسحوق مخلفات الزجاج)، والسلسلة C (تحتوي على مسحوق مخلفات الزجاج). مزيج من مسحوق مخلفات السيراميك ومسحوق مخلفات الزجاج). انخفضت الخواص الريولوجية SCC لجميع المخاليط ذات المستويات المختلفة من استبدال SCMs في الخليط تدريجيًا مع زيادة نسب الاستبدال. كان الانخفاض في قابلية التدفق للاستبدال، والذي يتراوح من ٥٪ إلى ٣٥٪، حوالي ٠٪ إلى ١٢٪، على التوالي. ومع ذلك، كان التخفيض ضئيلا. ظلت الخصائص الجديدة ضمن الحدود التي حددها EFNARC. وفيما يتعلق بالخواص الميكانيكية، ففي سن مبكرة انخفضت قوة المخاليط مع زيادة نسب البديل. ومع ذلك، بعد ٩٠ يومًا، زادت القوة بحوالي ١١٪ و٩٪ من قوة الضغط والانحناء، على التوالي، مقارنة بمزيج التحكم، مما يشير إلى أن SCMs تعمل على تحسين قوة الخرسانة بمرور الوقت وهي مناسبة للمساهمة في خرسانة صديقة للبيئة. الصناعة دون المساس بالقوة.

الكلمات الدالة: الاسمنت الاخضر، الخرسانة ذاتية الضغط، المواد الأسمنتية التكميلية، مسحوق مخلفات السيراميك، مسحوق مخلفات الزجاج.

1.INTRODUCTION

Concrete is widely used as one of the most essential building materials in the world [1]. The great workability of concrete is necessary when the section is complex and narrow, or when there are inaccessible areas or several corners, as well as when steel reinforcing is dense, making it difficult to place or compact concrete. So, full consolidation may be performed with minimum effort [2, 3]. Self-compacting concrete (SCC) in its fresh state has several significant advantages, the most notable of which are that it does not require vibration to completely fill the formwork and adequately surround the reinforcement (even in densely reinforced areas), leave voids, and segregate either while it is being cast or after it has been cast. To achieve this, the SCC must, in addition to possessing high fluidity, display a good ability to flow and pass between the reinforcing bars, as well as an exceptional capacity to flow in the manner of a "viscous fluid" [4, 5]. One of the most advanced concrete technologies is self-compacting concrete (SCC) [6]. However, SCC is being reconsidered due to its high cement content, which results in an increased carbon footprint in response to the rising demand for sustainable development. With increased awareness of environmental preservation and sustainable construction, using waste powder as a cement substitute is gaining popularity [7]. Research should focus on locating new materials and raising the replacement levels. The qualities of SCC are the consequence of altering the composition of traditional vibrated concrete by inserting a high powder content, mostly cement, vibrating the concrete at a higher frequency. The widespread substitution of fine waste materials for cement can reduce the carbon footprint caused by manufacturing concrete [8]. Therefore, partially replacing cement in concrete with ceramic and glass waste provides significant energy savings and environmental advantages. Furthermore, cement accounts for more than 45 percent of the total cost, significantly impacting the concrete cost [9]. The building sector has made substantial progress in recycling industrial byproducts and waste, such as waste glass and ceramic powder. Recycling this waste by transforming it into supplemental cementitious materials (SCMs) not only saves landfill space but also lessens the demand for extracting natural raw materials for construction activities, according to Rakshvir and Barai [10]. Since these alternatives necessitate substantial research into their impact on concrete characteristics, several studies have been conducted. Rahhal et al. [11] used two distinct forms of ceramic waste as a substitute for cement. The research findings indicated that using glass waste powder (GWP) enhanced the concrete properties of other natural pozzolans. As defined by Thomas [12], pozzolanic activity refers to a material's ability to react with calcium hydroxide when in contact with water. Zeng et al. [13] studied the activity of residues from tile polishing. Their research concluded that these residues possessed pozzolanic properties. Several studies have examined the impact and utilization of GWP as cementitious materials. These studies concluded that using more than 20% CWP reduced elements for CSH formation, delaying both early and late strengths. Furthermore, a decrease was observed in strength [15-18]. Researchers investigated the characteristics of concrete incorporating GWP as an addition to cement mixture [16]. The results demonstrated that adding GWP improved strength, abrasion resistance, and resistance to sodium sulfate in concrete. Additionally, it was found that incorporating GWP into mixes could enhance their mechanical properties, workability, and chemical resistance [19-21]. Other studies [22-25] that investigated using CWP and GWP concluded that it had no pozzolanic action at young ages but did at older ages. All investigations came to the same conclusion: CWP and GWP impacted early strength and required a longer time to acquire strength. The present research aims to establish the viability of partially included waste ceramic and glass combinations by conducting engineering tests and sustainability analysis.

2.RESEARCH SIGNIFICANCE

The significance of this research lies in its attempts to provide performance data on SCC produced in the northern region of Iraq to bring attention to the possibility of its efficient use in building and construction. On the other hand, in this work, local cement, local aggregates, admixtures produced by local suppliers, and local cementitious materials (GWP and CWP) were used to enhance the sustainability of SCC mixes by reducing the demand for cement, thus reducing CO2 emissions from the cement factories and also reducing the demand for non-renewable natural resources.

3.MATERIALS AND EXPERIMENTAL PROGRAM

3.1.Cement

The chemical and physical parameters of Type I Portland cement from Badush Cement Factory in Mosul, Iraq, following ASTM C150, are listed in Table 1.

3.2.Fine Aggregate (Sand)

Natural river sand from the Kanhash region of Mosul, Iraq, was utilized for this study. Its specific gravity was 2.67, according to ASTM C128 [33].

3.3.Coarse Aggregate (Gravel)

The coarse aggregate used in this paper was natural river-rounded gravel from the Khazer area of Mosul, Iraq. Its nominal maximum size was 12.5 mm, and its specific gravity was 2.7, according to ASTM C127 [34].

3.4.Water

For mixing and curing concrete mixtures, regular tap water was used.

3.5.Super Plasticizer

In most SCC combinations, a high-range water-reducing and retarding super plasticizing admixture (Sika® ViscoCrete®-1316 Hi-Tech, type G) was added.

3.6.Ceramic Waste Powder (CWP)

The chemical and physical attributes are shown in Table 1. They were collected from broken ceramic materials in Mosul's ceramic storages, cleaned, crushed, ground, and sieved through No. 325 mesh (ASTM E11).

3.7.Glass Waste Powder (GWP)

After being cleaned, crushed, and ground, Mosul, Iraq's leftover broken glass (Drink bottles and waste of windows glass) was sieved through No. 325 (ASTM E11) to obtain a powder with a fineness similar to the fineness of the cement. Table 1 shows the chemical and physical characteristics of this glass.

3.8.Concrete Mix Proportion and Preparation

Mixtures for SCCs were designed using the guidelines established in EFNARC [26]. Sixteen different mixtures were produced using supplementary cementitious materials (SCMs) to replace cement partially. The replacement levels of SCMs were 5%, 10%, and 15% (by weight of cement), divided into three series: Series A (containing ceramic waste powder), Series B (containing glass waste powder), and Series C (containing combinations of ceramic waste powder and glass waste powder). All the mixtures had the same sand, gravel, water, and superplasticizer amounts. Table 2 summarizes all mixes' mix ratios and design factors. First, the gravel and sand were combined in a dry mixer for one minute. After the appropriate amount of CWP and GWP were mixed with cement in a separate container, it was added to the aggregate matrix (mixed earlier). Following adding a predetermined quantity of water and superplasticizer to the mixture, it was vigorously combined for an additional five minutes to obtain a homogeneous mixture. After the concrete was mixed, its workability was evaluated using many different tests according to EFNARC [26], including the slump, the V-funnel, the L-box, the J-ring, and the V-funnel tests at T5min. It was established that the values of the tests conducted on concrete using various levels of SCM substitution continued to fulfill the requirements of the EFNARC specification. A smooth steel trowel was used to finish the surface of the concrete after it was laid without being compacted. Before the material was removed from the mold, it was allowed to remain damp inside the mold for twenty-four hours. Following removing the molds, the concrete was subjected to a period of curing in a water tank before being tested.

Table 1 The Chemical and Physical Characteristics of OPC, CWP, and GWP.

Property	OPC %	GWP	CWP
CaO	73.14	10.655	11.35
MgO	3.83	1.184	1.21
SiO_2	23..88	74.745	72.6
Al_2O_3	6.75	3.65	10.25
Fe_2O_3	2.83	0.86	0.74
SO_3	1.97	2.28	1.03
LOI	1.22	2.456	0.97
Free lime	1.57	--------	--------
Physical properties			
Specific surface (cm^2/gm)	3194	2078	2260
Setting Time (min)	Initial- 145 Final- 185	---------	--------
Specific gravity	3.08	2.87	2.63

The testing of the materials was done at the laboratories of Soran University.

Table 2 Designed for Self-Compacting Concrete, Mix Proportions: 1:1.67:1.62 /0.33.

Mix. Series	* Mix. ID	Cement (kg/m³)	CWP (kg/m³)	GWP (kg/m³)	Water (kg/m³)	Sand (kg/m³)	Gravel (kg/m³)	Super. (%)
Control	MC0G0	516	0	0	170	862	836	1.7
A	MC5G0	490	26	0	170	862	836	1.7
	MC10G0	464	52	0	170	862	836	1.7
	MC15G0	439	77	0	170	862	836	1.7
B	MC0G5	490	0	26	170	862	836	1.7
	MC0G10	464	0	52	170	862	836	1.7
	MC0G15	439	0	77	170	862	836	1.7
C	MC5G5	464	26	26	170	862	836	1.7
	MC5G10	439	26	52	170	862	836	1.7
	MC5G15	413	26	77	170	862	836	1.7
	MC10G5	439	52	26	170	862	836	1.7
	MC10G10	413	52	52	170	862	836	1.7
	MC10G15	387	52	77	170	862	836	1.7
	MC15G5	413	77	26	170	862	836	1.7
	MC15G10	387	77	52	170	862	836	1.7
	MC15G15	361	77	77	170	862	836	1.7

* E.g., MC0G0 denotes a mixture with 0% CWP and 0% GWP.

4.EXPERIMENTAL TESTING

4.1.Strength Activity Index (SAI)

The activity index of the SCMs was determined by comparing the compressive strength of mixes based on pure cement (control mix) to mixes in which the SCMs replace 20% of the cement. The SAI after three days must be greater than 75%, as required by ASTM C311[32] to classify the SCMs under research as pozzolan.

4.2.Rheological Properties of SCC

According to EFNARC [26], a concrete mixture may only be classified as SCC if all three requirements are met. The functional requirements of SCC are:

1- Filling ability: the SCC's capacity to flow under gravity into and completely fill any spaces within complex formwork containing obstacles, such as dense reinforcement.

2- Passing ability: the SCC's capacity to flow through spaces approaching the size of the coarse gravel, such as the spaces between reinforcing rebar, without any segregation.

3- Resistance to segregation: the SCC's capacity to maintain homogeneity throughout transporting, casting, and finishing.

In this study, slump flow, V-funnel, V-funnel at T5 min, L-box, and J-ring tests were done on three series of mixes (A, B, and C) to ensure the rheological properties of SCC. The slump flow and V-funnel tests were used to evaluate SCC's filling ability, the L-box and J-ring tests were used to evaluate SCC's passing ability, and the V-funnel at T5 min test was used to evaluate SCC's resistance to segregation, as shown in the Fig. 1. Testing was done in compliance with European SCC standards [26].

(a) (b) (c) (d)

Fig. 1 (a) Slump Flow Test, (b) V-Funnel and V-Funnel at T5 min Tests, (c) L-Box Test, and (d) J-Ring Test.

4.3. Hardened Concrete Tests

After mixing mixtures that met the three requirements of passing ability, resistance to segregation, and filling ability, specimens were cast in molds using their weights for compaction. After one day of casting, all specimens were de-molded in a controlled room at 22 ± 2 °C and cured in water at 22 ± 2 °C and 65% RH until testing. Three 100×100×100 mm cubes and three 100×100×400 mm prisms were tested for each mix to measure its compressive and flexural strengths, respectively, as shown in Fig. 2. The compressive strength test was done according to BS 1881, Part 116 [30], and the flexural strength test was done according to ASTM C78 [31].

(a)

(b)

Fig. 2 (a) Compressive Strength Test and (b) Flexural Strength Test.

5. TEST RESULTS AND DISCUSSION

5.1. Strength Activity Index (SAI)

At the age of 7 days, the Strength Activity Index (SAI) of the SCMs provided a good SAI, fulfilling the ASTM C311 standard for natural pozzolan [32]. The SAI at seven days for mortar cubes (50×50×50 mm) was 90% and 87% for GWP and CWP, respectively. as shown in Table 3.

Table 3 Strength Activity Index Test According to ASTM C311.

Mix.	Binder %	Compressive Strength (MPa)	SAI %
Control	OPC 100%	25	-------
GWP	OPC 80% and GWP 20%	22.5	90
CWP	OPC 80% and CWP 20%	21.75	87

According to ASTM C311, the SAI should be ≥ 75%.

5.2. Rheological Properties of SCC

The rheological test results are highlighted because they demonstrate the effects of waste glass (GWP) and ceramic waste (CWP) powder substitution as supplementary cementitious materials (SCMs) on the fresh behavior of SCC mixes. Table 4 summarizes the fresh test findings for all SCC mixes: covering filling ability, i.e., slump flow and V-funnel test; passing ability, i.e., L-box and J-ring test; and segregation resistance (V-funnel at T5 min. test). All testing was done in compliance with EFNARC [26]. The results for rheological properties (fresh concrete tests) of self-compacting concrete are shown in Table 4. Table 4 shows that the workability of all mixtures with different levels of SCMs replacement in the mixture gradually decreased as the substitution ratios increased [24, 20]. However, the reduction was insignificant; the rheological properties remained within the limits specified by EFNARC. It is worth noting that the effect of ceramic waste was very similar to that of glass waste, as both work to reduce workability slightly; however, the effect of ceramics was due to an increase in water demand (water absorption capacity), whereas the effect of glass waste was due to the surface roughness (angular shape) of the glass particles [27, 24]. According to slump flow and V-funnel test results (Table 4), SCMs negatively impacted filling ability, consistent with [28, 29]. SCC mixes with SCMs substitution ratios had slump flow values ranging from 665 to 775 mm and a V-funnel time ranging from 7 to 11.8 sec. All SCC mixes met the EFNARC target values except for the mixture MC15G15, whose value was slightly outside the limits of the specification. In terms of passing ability (L-box and J-ring tests), all SCC mixtures demonstrated good values in the range of 0.96 to 0.8 and 5.8 to 8.4 mm, respectively, which corresponded to the EFNARC target and was attained by all SCC mixes. The same principle applies to segregation resistance (V-funnel at T5 min. test). According to the EFNARC Acceptance Criteria of the SCC, all values obtained showed satisfactory outcomes.

Table 4 Rheological Test of SCC.

Mix. series	Mix. ID	Filling Ability		Passing Ability		Segregation Resistance
		Slump Flow (mm)	V-funnel (sec.)	L-box (h2/h1)	J-ring height (mm)	V-funnel at T5 min. (sec.)
Control	MC0G0	760	7.0	0.95	6.2	10.1
A	MC5G0	755	7.5	0.96	6.5	10.4
	MC10G0	740	8.1	0.92	6.8	11.1
	MC15G0	730	8.3	0.93	7.3	11.2
B	MC0G5	760	7.8	0.95	5.8	10.8
	MC0G10	750	8.3	0.9	6.7	11.2
	MC0G15	720	9.4	0.89	7.6	12.5
C	MC5G5	745	7.6	0.92	7	10.7
	MC5G10	710	8.1	0.88	7.4	11.3
	MC5G15	705	10.0	0.86	7.7	13.0
	MC10G5	715	10.0	0.9	7.2	13.0
	MC10G10	700	9.0	0.89	7.6	12.3
	MC10G15	680	9.8	0.85	8	13.0
	MC15G5	690	11.3	0.87	7.9	14.8
	MC15G10	685	11.8	0.83	8.1	15.4
	MC15G15	665	12.8	0.8	8.4	16.6
SCC Acceptance Criteria According to EFNARC						
	Min.	650	6	0.8	0	0
	Max.	800	12	1.0	10	+3*

* "+3" refers to the increase in the time of the second test (V-funnel at T5 min test) over the time of the first test (V-funnel test).

5.3.Hardened Properties of SCC

As for the SCC hardened performance, the compressive strength and flexural strength of SCC specimens that were cured with water for up to 28, 56, and 90 days were tested. The mean compressive strength and the mean flexural strength, measured from three samples for each mix, are shown in Table 5. The control mixtures at different ages were chosen as the reference mixtures; the goal was to compare the strengths of several mixtures at different ages by comparing the strength values for each series to the control strength value. Table 5 shows that at 28 days, the compressive strength values decreased between 2% and 33% of the control strength value. The value for the control sample was the highest, and the value for the MC15G15 sample was the lowest. At 90 days, the MC10G0 sample had the maximum compressive strength and exceeded 11% over the control strength value, whereas the MC15G10 sample had the lowest, decreased by 17% less than the control strength value. Also, at 28 days, the flexural strength values ranged between 3% more than the control strength value and 16% less than the control strength value. The MC0G10 sample value was the highest, and the MC15G15 sample was the lowest. In 90 days, the MC0G10 sample had the maximum flexural strength, 9% more than the control strength value, whereas the MC15G15 sample had the lowest, 9% less than the control strength value. Fig. 3 shows the difference between compressive strength values at different ages, and Fig. 4 shows the difference between flexural strength values at different ages.

Table 5 Hardened Test of SCC.

Mix. Series	Mix. ID	Compressive Strength			Flexural Strength		
		28 Days	56 Days	90 Days	28 Days	56 Days	90 Days
Control	MC0G0	48	52	54	6.8	7.1	7.4
A	MC5G0	47	52	57	6.7	7.2	7.7
	MC10G0	45	53	60	6.6	7.3	8.0
	MC15G0	44	52	58	6.8	7.1	7.9
B	MC0G5	47	48	53	6.9	7.2	7.8
	MC0G10	46	49	55	7	7.3	8.1
	MC0G15	46	50	55	6.7	7.0	7.6
C	MC5G5	45	51	56	6.9	7.1	7.4
	MC5G10	44	47	52	6.7	7.2	7.7
	MC5G15	41	46	51	6.5	6.9	7.5
	MC10G5	39	47	54	6.3	6.6	7.2
	MC10G10	41	44	52	6.4	7.1	7.7
	MC10G15	34	42	47	6.1	6.5	7.4
	MC15G5	37	44	48	6.4	6.8	7.4
	MC15G10	36	41	45	6.3	6.6	7.2
	MC15G15	32	38	46	5.7	6.2	6.7

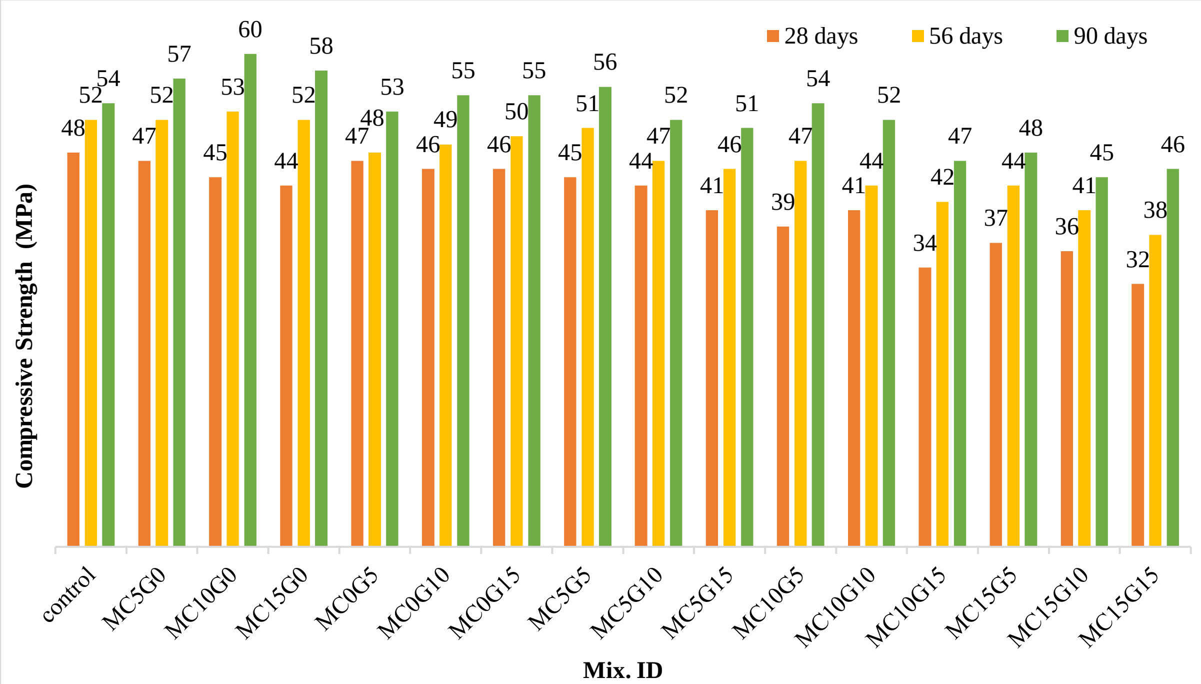

Fig. 3 Compressive Strength (MPa) at 28, 56, and 90 Days.

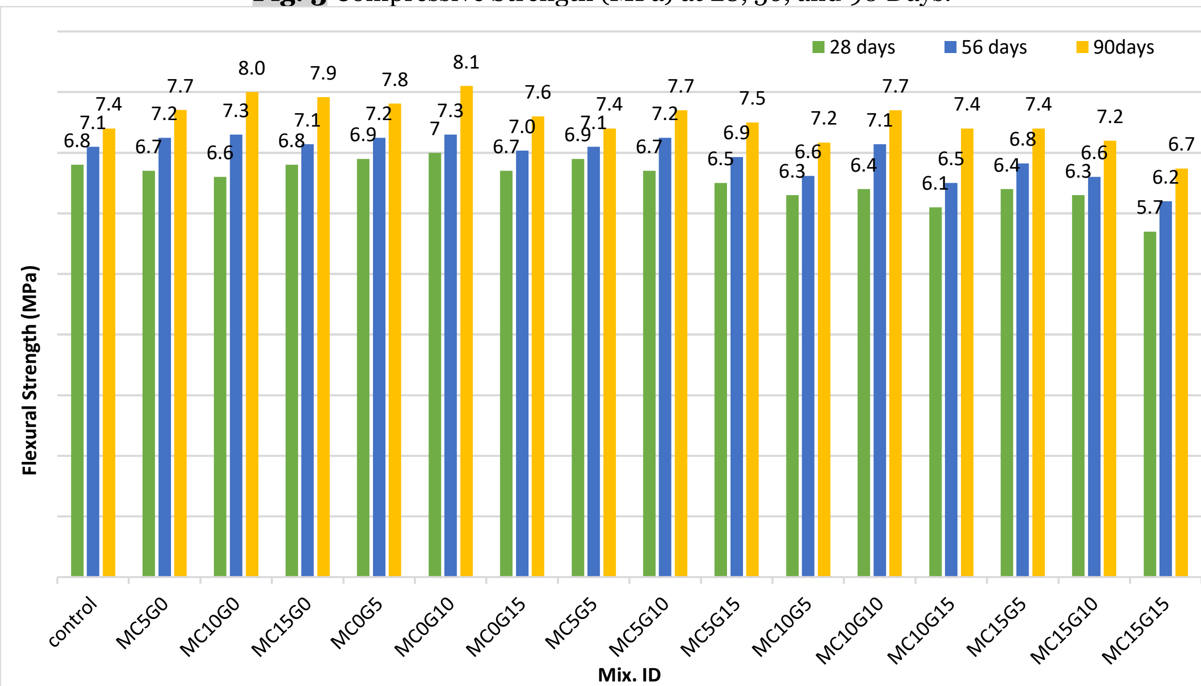

Fig. 4 Flexural Strength (MPa) at 28, 56, and 90 Days.

The value for the control sample was among the highest values at an early age, indicating that including SCMs in SCC decreased the compressive strength and flexural strength at an early age [20]. However, the results exceeded those of the SCC mix controls at a later age [23]. This process can be attributed to the fact that when glass waste and ceramic waste are powdered into microparticles, they will be subjected to pozzolanic reactions with cement hydrates at late ages, resulting in secondary calcium silicate hydrate (C-S-H) gel, which significantly contributes to the cementitious character [35]. Here, too, the function of GWP and CWP is better understood since they merely serve as an inert filler that decreases the strength of the SCMs series. Nonetheless, SCMs already performed significantly at later ages, with the slower pozzolanic reactions that contributed to the mixture of the SCMs. Some researchers' findings showed that using GWP in mixtures with CWP could drop the strength at an early age. However, the effect of SCMs was noticed at a later age, as all of the studied SCC concretes can reach compressive and flexural strengths of more than 60 MPa and 8.1 MPa, respectively, after 90 days. These results agree with [28, 29].

6.CONCLUSIONS

The following conclusions were drawn from the results:

1- It is possible to create SCC mixtures with good strengths by combining CWP and GWP (Ceramic Waste Powder and Glass Waste Powder) as supplementary cementitious materials in partial replacement with cement. The study's [14, 16] conclusions have reported the same.
2- Using CWP and GWP individually or in combination with SCMs significantly improved mechanical strength. At 10%, as a partial substitution of cement, achieved the maximum compressive strength (60 MPa) and flexural strength (8 MPa) at 90 days, which were 11% and 8.1%, respectively, more than the reference mix (54 MPa and 7.4 MPa, respectively). The same was reported in [35].
3- Using GWP and CWP in SCC decreased strength at an early age. However, the strength values exceeded the control values at a later age, i.e., attributed to the long duration of pozzolanic reactions. The same conclusion was reported in [20, 23].
4- The rheological properties of SCC for all mixtures with different levels of SCMs replacement gradually decreased as the substitution ratios increased. The reduction in flowability for substitution, ranging from 5% to 35%, was approximately 0% to 12%, respectively. However, the reduction was insignificant. The fresh properties remained within the limits specified by EFNARC. The same conclusion was reported in [27, 28, 29].
5- The best ratio that included CWP and GWP used in this study, which enhanced the sustainability of SCC mixtures by reducing the amount of cement and non-renewable natural resources, was MC10G10, although it was not the strongest. However, it included the highest replacement ratio (10% CWP and 10% GWP) that met all the SCC functional requirements (filling ability, passing ability, and resistance to segregation) without compromising strength. Its compressive strength (52 MPa) equaled 96% of the reference mixture strength, and its flexural strength (7.7 MPa) was 4% higher than the reference mixture strength at 90 days.

NOMENCLATURE

SCC	Self-Compacting Concrete
CWP	Ceramic Waste Powder
GWP	Glass Waste Powder
SCMs	Supplementary Cementitious Materials
EFNARC	European Federation Dedicated to Specialist Construction Chemicals and Concrete Systems
SAI	Strength Activity Index

REFERENCES

[1] Gill AS and Siddique R. **Durability Properties of Self-Compacting Concrete Incorporating Metakaolin and Rice Husk Ash. Constr.** *Construction and Building Materials* 2018; **176**: 323–332.

[2] Al-Ameeri AS, AL-Hussain K, Essa M. **Predicting a Mathematical Models of Some Mechanical Properties of Concrete from Non-Destructive Testing.** *Civil and Environmental Research* 2013; **3**: 78–97.

[3] Abdullah QN, Abdulla AI. **Flexural Behavior of Hollow Self Compacted Mortar Ferrocement Beam Reinforced by GFRP Bars.** *Case Studies in Construction Materials* 2022; **17**: e01556, (1-27).

[4] Abdullah QN, Abdulla AI, Al-Mashaykhi M. **Shear Behavior of Hollow Ferrocement Beam Reinforced by Steel and Fiberglass Meshes.** *Tikrit Journal of Engineering Sciences* 2022; **29**(4): 27-39.

[5] Schutter GD, Audenaert K. **Durability of Self-Compacting Concrete-State-of-the-Art Report of RILEM Technical Committee.** *RILEM publications* 2007; **38**: 205-DSC.

[6] Zhao H, Sun W, Wu X, Gao B. **The Properties of the Self-Compacting

Concrete with Fly Ash and Ground Granulated Blast Furnace Slag Mineral Admixtures. *Journal of Cleaner Production* 2015; **95**: 66–74.

[7] Plank J, Winter C. **Competitive Adsorption between Superplasticizer and Retarder Molecules on Mineral Binder Surface.** *Cement and Concrete Research* 2008; **38**(5):599–605.

[8] Wang JJ, Jing YY, Zhang CF, Zhao JH. **Review on Multi-Criteria Decision Analysis Aid in Sustainable Energy Decision-Making.** *Renewable and Sustainable Energy Reviews* 2009; **13**(9): 2263–2278.

[9] Puertas F, García-Díaz I, Barba A, Gazulla MF, Palacios M, Gómez MP, Martínez-Ramírez S. **Ceramic Wastes as Alternative Raw Materials for Portland Cement Clinker Production.** *Cement and Concrete Composites* 2008; **30**(9): 798–805.

[10] Rakshvir M, Barai SV. **Studies on Recycled Aggregates-Based Concrete.** *Waste Management & Research* 2006; **24**(3): 225–233.

[11] Rahhal V, Irassar E, Castellano C, Pavlík Z, Černý R. **Utilization of Ceramic Wastes as Replacement of Portland Cements.** *Construction Materials and Structures IOS; Press*: 2014, pp. 208–213.

[12] Thomas M. **Supplementary Cementing Materials in Concrete.** CRC press, 2013.

[13] Zeng Q, Li L, Liu J, Lu T, Xu J, Al-Mansour A, Wang J, Xia J. **Microstructure and Properties of Concrete with Ceramic Wastes**. *In Handbook of Sustainable Concrete and Industrial Waste Management*. 2022; pp. 229–253.

[14] Steiner LR, Bernardin AM, Pelisser F. **Effectiveness of Ceramic Tile Polishing Residues as Supplementary Cementitious Materials for Cement Mortars.** *Sustainable Materials and Technologies* 2015; **4**: 30–35.

[15] Dawood ET, Mhmood MS, and Malallah MA-K, **An Approach for Designing Different Sustainable and Economical Concrete Mixes.** *Journal of Physics: Conference Series* 2021; **1973** (1): 012156, (1-13).

[16] Dawood ET, Mizaal AM. **Proportioning of Green Mortar by Using Different Cementitious Materials.** *Journal of Physics: Conference Series* 2021; **1973**(1): 012004, (1-11).

[17] Aldabagh IS, Abed JM, Khaleel BA, Hamah Sor N. **Influence of Water Quality and Slag on the Development of Mechanical Properties of Self Compacting Mortar.** *Materials Today: Proceedings* 2022; **57**: 892-897.

[18] Keryou AB. **Effect of Using Windows Waste Glass as Fine Aggregate on Some Properties of Concrete Foundation of Technical Education.** *Tikrit Journal of Engineering Sciences* 2016; **23**(3): 47–54.

[19] Nunes S, Matos AM, Duarte Figueiras TH, Sousa-Coutinho J. **Mixture Design of Self-Compacting Glass Mortar.** *Cement and Concrete Composites* 2013; **43**: 1–11.

[20] Tariq S, Scott AN, Mackechnie JR, and Shah V. **Glass Powder Replacement in Self-Compacting Concrete and Its Effect on Rheological and Mechanical Properties.** *Journal of Sustainable Cement-Based Materials* 2022; **11**(3): 240–256.

[21] Ali AH, Ibrahim AK. **Mechanical Properties of Reactive Powder Concrete (RPC) Exposed to Acidic Solutions.** *Tikrit Journal of Engineering Sciences* 2013; **20**(7): 55–62.

[22] Irassar E, Rahhal V, Tironi A, Trezza M, Pavlík Z, Pavlíková M, Jerman M, Cerný R. **Utilization of Ceramic Wastes as Pozzolanic Materials.** *Technical Proceedings of the NSTI Nanotechnology Conference and Expo, NSTI-Nanotech* 2014; **3**(3): 230–233.

[23] Pacheco-Torgal F, Jalali S. **Compressive Strength and Durability Properties of Ceramic Wastes Based Concrete.** *Materials and Structures* 2011; **44**: 155–167.

[24] Ali AH, Al-Attar AA, Kasm ZE. **Effect of Solid Ceramic Waste Powder in Partial Replacement of Cement on Mechanical Properties and Sorptivity of Cement Mortar.** *International Journal of Civil Engineering and Technology* 2019; **10**: 3055–3066.

[25] Rejeb SK, Ayad AM. **Effect of Fibers and Filler Types on Fresh and Hardened Properties of Self-Compacting Concrete.** *Tikrit Journal of Engineering Sciences* 2014; **21**(1): 77-83.

[26] EFNARC-2005, The European guidelines for self-compacting concrete specification. production and use, 2005.

[27] Vandhiyan R, Ramkumar K, Ramya R. **Experimental Study on**

Replacement of Cement by Glass Powder. *International Journal of Engineering Research & Technology* 2013; **2**(5): 234–238.

[28] Aly ST, El-Dieb AS, Taha MR. **Effect of High-Volume Ceramic Waste Powder as Partial Cement Replacement on Fresh and Compressive Strength of Self-Compacting Concrete.** *Journal of Materials in Civil Engineering* 2019; **31**(2): 4018374.

[29] Belouadah M, Rahmouni ZEA, Tebbal N. **Influence of the Addition of Glass Powder and Marble Powder on the Physical and Mechanical Behavior of Composite Cement.** *Procedia Computer Science* 2019; **158**: 366–375.

[30] BS 1881, Part 116, "Method for Determination of Compressive Strength of Concrete Cubes", *British Standards Institution*, 1881; PP.3, 1989.

[31] ASTM C78-09: Standard Test Method for Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading). *Annual Book of ASTM Standards, ASTM International, West Conshohocken,* PA; 2009.

[32] ASTM C311 – 00," Standard test methods for sampling and testing fly ash or natural pozzolans for use as a mineral admixture in portland-cement concrete", *Annual Book of ASTM Standards, 2004*.

[33] ASTM C 128-01, Standard Test Method for Density, Relative Density (Specific Gravity), and Absorption of Fine Aggregate, ASTM International, West Conshohocken, PA, 2001.

[34] ASTM C 127-01, Standard Test Method for Density, Relative Density (Specific Gravity), and Absorption of Coarse Aggregate, *ASTM International, West Conshohocken*, PA, 2001.

[35] Islam GS, Rahman M, Kazi N. **Waste Glass Powder as Partial Replacement of Cement for Sustainable Concrete Practice**. *International Journal of Sustainable Built Environment* 2017; **6**(1): 37-44.