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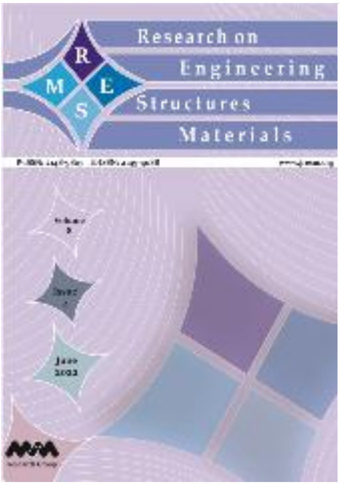

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Research Article

Effect of nano-sized clay and waste glass powder on rheological and hardened properties of self-compacting concrete

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Abstract

Two types of pozzolanic materials nano-clay (NC) and waste glass powder (WGP) have been utilized in this work, which has been carried out in three stages. The first stage is to partially replace the cement with nano-clay (2.5, 5, 7.5, and 10%). The second stage is replacing cement with 15% of the waste glass powder, and the third and final stage is partially replacing the waste glass powder partially with nano-clay (2.5%NC+12.5%WGP, 5%NC+10%WGP, 7.5%NC+7.5%WGP, and 10%NC+2.5%WGP). The results were evaluated by studying the rheological and mechanical properties of self-compacting concrete (SCC) for each stage to find out the best replacement ratio for the best properties. The results of the tests on the fresh concrete showed that the nano-clay reduces the fluidity and flowability of the mixtures, while the addition of glass has almost no effect. While the addition of glass and NC leads to an additional decrease in the flowability of the mixture. From the results of mechanical properties, it was found that the mix with 2.5% NC and 12.5% WGP gave the highest strength.

1. Introduction

In 1988 in Japan the Self-compacting concrete (SCC) was first been applied by Okamura to avoid the problems related to the concrete structures' durability caused by the lack of skilled builders to provide sufficient compaction [1]. This concrete can be considered the most sustainable type of concrete for complex shapes and elements and use under difficult conditions [2]. SCC can spread and fill all corners and all parts into complex forms of formwork under its weight and can be fully compacted without external vibration even with congested steel reinforcement. SCC is known as an innovative production of flowing concrete due to its excellent properties which provide many benefits. Concrete can be classified as SCC when the desired features of rheological behavior are achieved as stipulated in EFNARC Guidelines [3]. In addition, SCC provides significant benefits in improved construction productivity, reduced placing cost, good surface finish, short mandatory casting time, reduced labor cost as well as no noise pollution, excellent build quality, and ease of casting even with reinforced steel's encapsulation areas, which are allowing more of options in the design of building systems [4, 5].

The total annual output of domestic and industrial waste is increasing more and more due to the increase in population and development in the industrial sector. This waste represents a significant pollution source that requires increased attention to find efficient ways to get rid of it [6]. Sustainable building means creating and managing an integrated system for the environment and health as a result of efficient resource management and environmental protection [7].

Nowadays, the environmental trend aims to exploit waste as a total or partial substitute for raw materials in the construction industry. This provides many advantages in

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developing sustainable systems and not only ensures waste consumption but also provides a cleaner and greener environment at an economical cost [8, 9]. One of the main problems facing the production of SCC is the high production cost because of the need for a high cement content and chemical additives and the environmental problems caused by significant emissions, especially carbon dioxide (CO_2) resulting from cement manufacturing [10].

This issue can be solved by partially replacing cement with alternative materials such as waste glass powder, and thus it is possible to reduce the use of cement and at the same time reduce waste glass and achieve double environmental benefits. Recently there have been some investigations on the use of ground glass powder in the construction industry as a partial substitute for cement [6]. To some extent, recent work has indicated that discarded glass when grounded into small-size particles (≤ 75 μm) had a high response to pozzolanic activity and provided a higher level of hydration products and a more uniform distribution [7]. When the calcium hydroxide $Ca(OH)_2$ from cement hydration combines chemically with the pozzolanic materials that have a large amount of SiO_2 like waste glass powder, cementitious compounds known as C-S-H (calcium-silicate-hydrate) gel are formed, which can enhance the strength of concrete [8]. According to a different experiment, the ultimate load of beams with 10% and 15% waste glass powder increased by +4 to 39% in situations where reinforcement beams were present. This led to more brittle behavior because WGP concrete had a higher compressive strength [9]. Researchers found that at age of 28 days after water curing, the compressive strength of specimens with 10%, 15%, and 20% of WGP increased by 27.62%, 41.46%, and 20.18%. While, these specimens showed an increase of 22.11%, 41.75%, and 21.36% at 56 days, and 27.05%, 30.81%, and 17.2% at 90 days. But the 25% of WGP reduced compressive strength by 14.34%, 20.5%, and 19.41% at 28, 56, and 90 days, respectively, compared with referenced mixes [10,11]. In another research, the pozzolanic behavior of glass powder was investigated at concentrations of 0, 5, 10, 15, 20, and 25% by cement weight. The results showed an average of 16% increase in compressive strength [12]. Vanjare and Mature [13] produced an SCC by incorporating ground glass powder, to encourage its application in on-site construction. They pointed out that replacing cement with glass powder contributed to reducing raw materials in the SCC and creating a healthy green environment. Rahman et al. [14] studied the combined effect of using two types of industrial wastes in concrete which include glass powder and granular steel slag also as substitute materials for cement and fine aggregate on the fresh and hardened characteristics of SCC. The cement has been replaced partially with glass powder by 20%, 30%, and 40% of the weight of cement. Fine aggregate substitutes for fine slag aggregate were 40%, 60%, and 80%. The results indicated that the workability of the mixtures improved with the presence of glass powder, while the increased amount of steel slag led to a decrease in their workability. The results also showed that compressive strength, modulus of elasticity, and flexural strength were increased with a 20% cement replacement with glass powder. However, there is a downward trend in these properties with increasing glass powder ratio at a constant ratio of steel slag. Liu [15] utilized two types of ground glass of different colors were used: white glass and green glass. The cement replacement rates were 5%, 10%, 5%, and 10% while the sand replacement rates were 5%, 10%, 4%, and 9%. Liu concluded that an SCC with new desirable properties could be produced by incorporating approximately 104 kg/m^3 of glass waste, replacing 10% of the cement and sand.

An important part of the widespread acceptance of nanotechnology provides improved system reliability, extends functionality beyond traditional applications, and reduces cost, size, and energy consumption.

The incorporation of nanotechnology into the field of materials facilitates an increase in the durability of materials and provides materials with superior performance. It also allows for more efficient use of natural resources and achieving the properties of the necessary materials with minimal effort [16]. Pozzolanic materials such as nano-silica, nano-alumina, and nano-clay (NC) are characterized by Pozzolanic reacting with CaOH producing additional C-S-H gel that increases the strength of the mortar or concrete. [17, 18]. Niewiadomski et al. studied the effect of nanoparticles with different amounts of SiO2, TiO2, and Al2O3 nanoparticles on the microstructure of SCC. They found an improvement in the microstructure, toughness properties, and a higher density microstructure [15]. Al-Ani [19] utilized nano-clay (NC) from the local Iraqi natural kaolin clay in SCC production. The study was conducted using three different proportions of NC as a partial cement substitution (2%, 4%, 6%) with the use of quicklime powder (QLP) with (50, 75, and 100) kg. The results showed that the addition of NC alone has a greater effect on SCC samples than reference SCC without any addition of NC and QLP. The best value was obtained for SCC with 6% NC. The addition of NC and QLP has a noticeable effect on strength and durability properties. It found that using 4% NC with 100 kg QLP could improve the workability, strength, and durability of SCC. Hosseini et al. [20] showed through their experimental work that the addition of NC up to 1% resulted in a decrease in the flow diameter spread in the slump test. Also, an increase in flow time (for the V -funnel flow and slump flow tests) was noticed indicating an increase in the viscosity of the fresh SCC. According to test results, 0.5% NC gave the highest strength at both 7 and 28 days of water-curing treatment. But 0.25% of NC content gave the highest compressive strength at 56 days of water-curing treatment. By adding 0.25, 0.50, 0.75, and 1.00% NC to the reference SCC mixture, the water penetration depth was decreased by 17, 27, 39, and 43%, respectively. This means improving the durability of SCC mixtures and acting as dense barriers against the penetration of chemical solutions. Researches show a scientific debate about the global warming phenomenon. One of the main reasons for this phenomenon is carbon dioxide emissions.

As mentioned earlier, the cement industry accounts for about 5-8 of the total global CO2 value. One of the main disadvantages of SCC is the need for a large amount of cement according to EFNRAC, the recommended amount is 400-600 kg/m3 to achieve the required rheological properties, which in turn increases the risks of environmental pollution because of increases the amount of carbon dioxide emitted [21]. It has been found that incorporating alternative materials into concrete is a successful way to reduce cement and thus reduce carbon dioxide emissions. In this current work, the focus was on three-point:

- Using nano-clay as a partial replacement for cement
- The use of 15% waste glass powder as a partial substitute for cement in concrete mixtures.
- Used a combination of waste glass powder and nano-clay by replacing 15% glass powder partially with nano-clay.

2. Materials and Methods

2.1. Materials

Ordinary Portland cement (OPC) with fineness and specific gravity of 325 m2/kg and 3.15 respectively, was utilized for casting all the concrete mixtures. The chemical properties from the XRF test for cement are illustrated in Table 1, which satisfied the Iraqi specification No.5/1984 [22].

The raw material for Iraqi natural kaolin clay is abundantly available in the quarries of Wadi Houran in the western desert of Anbar Governorate. When this clay is been burned at 700 ° C for two hours, it turns into metakaolin. Its effectiveness can be increased by the ground of the metakaolin to particle size up to the nanoscale and obtained nano-clay (NC). Al-Ani [19] showed in her study the possibility of producing NC from Iraqi metakaolin and using it effectively in SCC. The NC used in this work was verified by a particle size distributions test (PSD) and scanning electron microscopy (SEM) test, as shown in Figures 1 and 2, respectively. one can see that the particle size of NC is not homogeneous as illustrated by the PSD test results and a wide range of shapes from irregular, spherical particles and agglomerates to rounded nanoparticles were noticed as illustrated in the SEM test result. The XRF test results to illustrate the chemical composition of NC is listed in Table 1. The pozzolanic activity of NC was found to be 106.46 at 28 days. So, NC used in this work meets the ASTM C618-12 [23] requirements for pozzolanic materials.

Table 1. The main chemical composed from XRF test results for cement, NC, and WGP

Oxide composition	Cement	Nano-clay powder	Waste glass powder
CaO	65.26	< 15	1.460
SiO2	20.11	50	79.400
Al2O3	6.42	42	0.822
Fe2O3	3.37	<0.5	0.204

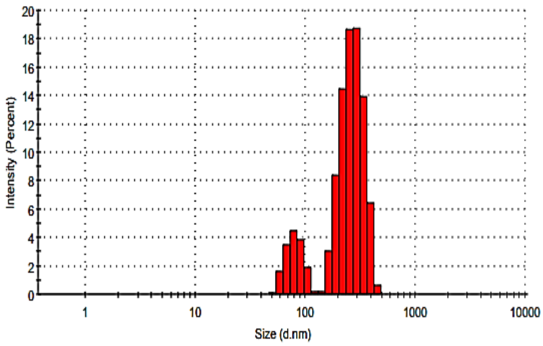

Fig. 1 Particle size distribution for NC

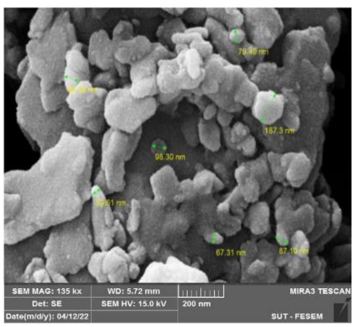

Fig. 2 SEM test for NC

To prepare glass powder, the waste of broken window glass was collected from glass sell shops, and after the collection was completed, the steps for preparing glass powder began as follows: First, wash the collected glass to clean it from dust or any other substance, and then crush it into fine aggregate. Finally, it was ground into a fine powder and passed through the No. 200 sieve, as illustrated in Figure 3. The waste glass powder (WGP) was verified by XRF (see Table 1), PSD, and SEM tests, as shown in Figures 4 and 5, respectively. The pozzolanic activity of WGP was found to be 92.07 at 28 days. So, WGP used in this work meets the ASTM C1240-05 [24] requirements for pozzolanic materials.

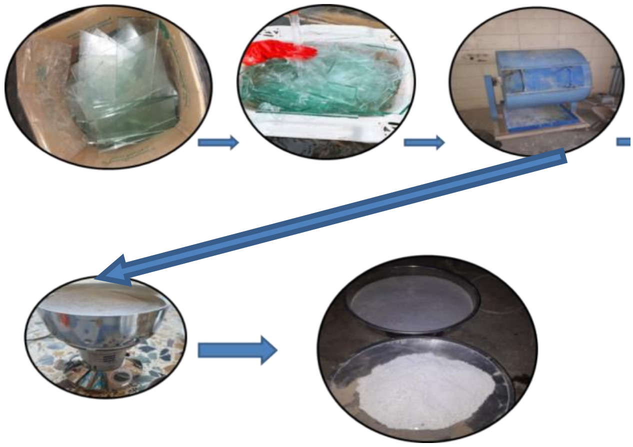

Fig. 3 Glass powder preparation stages

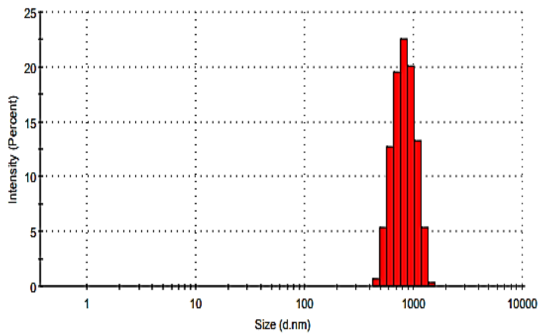

Fig. 4 Particle size distribution for WGP

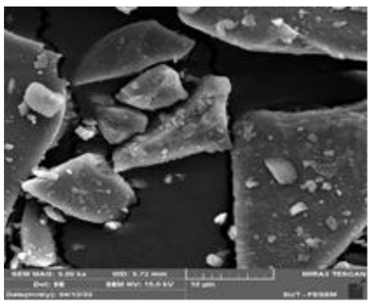

Fig. 5 SEM test for WGP

An aqueous solution of polycarboxylic (sika discrete – 5930) type F was used as a superplasticizer, which meets the ASTM C 494 limitation [25]. Tap water was used for the mixing and curing process.

Natural local sand of 2.5 fineness was used as a fine aggregate. The specific gravity of used sand was 2.62 , while percentage of sulfur trioxide (SO_3%), and the absorption ratio were, 0.1%, and 0.13%, respectively, and these properties were all within the limits of Iraqi Standard No. 45/1984 [26].

Crushed gravel was used in this work with a maximum size of 10 mm as coarse aggregate and has a specific gravity of 2.67. while SO3%, and the absorption ratio for used coarse aggregate were 0.05%, and 0.3%, respectively, and these values were all within the limits of the Iraqi specification No. 45/1984 [26]. The sieve analysis of fine and coarse aggregates is listed in Table 3.

Table 3. Sieve Analysis of All Used Aggregate

Sieve size (mm)	Cumulative passing %	
	Coarse aggregate	Fine aggregate
12.5	100	100
10	86.76	100
4.75	14.12	95.3
2.36	0.6	85.9
1.18	-	77.3
0.6	-	62.4
0.3	-	16.8
0.15	-	2.0
0.075	-	0.005

2.2. Mix Proportion, Procedure and Tests

The EFNARC Guidelines [3] were utilized as a reference for designing the reference mixture (without NC or WGP). Experimental mixes were made in the laboratory to design the reference mix, which was achieved by trial-and-error method to obtain the best concrete mix design and the best rheological properties of SCC without separating and bleeding, the quantity of mixes constituted are listed in Table 4.

Ten mixes with the same water/binder ratio of 0.365 and a superplasticizer dose of 0.86% by weight of the binder were prepared for the current investigation. The mixes included one reference mix, four sets were completed by partially substituting the cement with various amounts of NC ranging from (2.5 to 10 percent) by weight, one mix with 15% waste glass powder, and four sets were completed by partially substituting the cement with various amounts of NC and waste glass powder, as shown in Table 4. Cement is added to the mixer after the coarse and fine aggregates have been combined for 30 seconds. How to include nanoparticles into concrete mixtures without affecting their original composition and physical qualities is one of the most essential aspects to take into account. In this work, a wet mixing approach was used, in which NC was gradually added to the concrete mixture after being completely mixed for two minutes with some mixing water. The remaining water was used to dissolve the superplasticizer. After the superplasticizer was gradually added, the mixture was mixed for an additional three minutes to achieve complete dissolution, Figure 6 illustrated the mixing process.

The flow capacity of the SCC was evaluated by measuring slump flow diameter (mm), T500 (the time at flow diameter be 500 mm) (sec), V-funnel (sec), and L-box test. For evaluating the ability to pass with the appropriate viscosity that is needed for the fresh mix to remain homogeneous in its composition, a segregation test was adopted, see Figure 7. The results of fresh tests were compared with the limitations of EFNARC standards [3].

For each mix, three 100×100×100 mm cubes for compressive strength based on BS EN 12,390–3 [30], three prisms of 100×100×500 mm sizes for the modulus of rupture test based on ASTM C78-15a [31], three cylinders of diameter 100 mm and height 200 mm for splitting strength based on, ASTM C496-C [32], and three cylinders of diameter150 mm and height 300 mm for modulus of elasticity ASTM C469-14 [33], were made. The mechanical properties tests are illustrated in Figure 8.

Table 4. Mixes proportions for one cubic meter

Mixes	Cement kg	Nano-clay kg	Waste glass powder kg	FA kg	CA kg	Water kg	Sp kg
0NC0WGP	465	0	0	870	800	175	4
2.5NC0WGP	453.375	11.62 5	0	870	800	175	4
5NC0WGP	441.75	23.5	0	870	800	175	4
7.5NC0WGP	430.125	34.87 5	0	870	800	175	4
10NC0WGP	418.5	46.5	0	870	800	175	4
0NC15WGP	395.25	0	69.75	870	800	175	4
2.5NC12.5WGP	395.25	11.62 5	58.125	870	800	175	4
5NC10WGP	395.25	23.5	46.5	870	800	175	4
7.5NC7.5WGP	395.25	34.87 5	34.875	870	800	175	4
10NC5WGP	395.25	46.5	23.5	870	800	175	4

NC: Nano-Clay, WGP: Waste Glass Powder, 0NC0WGP: refer to 0% NC and 0% WGP
SP: Superplasticizer, FA: Fine Aggregate, CA: Coarse Aggregate

All specimens were cast for each mix and poured into moulds without using any vibration. Before this, all casting moulds are cleaned, and the internal surfaces are lubricated with a suitable liquid. All specimens were prepared at the laboratory conditions with a temperature of 20±2°C and a relative humidity of 60±5%. After casting, the concrete samples were covered with nylon plates in the laboratory for 24 hours before being demoulded and transferred to a water-curing tank for 28 days. All specimens are tested after 28 days of curing.

Fig. 6 Mixing processes

" (d) Slump flow tests (c) V-funnel tests (b) L-box tests (a) Segregations tests

Fig. 7 Fresh Properties' Tests

3. Results and Discussion

3.1. Rheological tests results

3.1.1. Flow diameter, T500, and V-funnel fresh tests

Figure 9 shows the slump flow diameters (SFDs) for each SCC mix. According to EFNARC guidelines [3], the SFD results for all SCC mixes were divided into the SF2 and SF3 groups. Additionally, the SFDs results showed that the reference mix (0NC0WGP), 2.5NC0WGP, 0NC15WGP, and 2.5NC12.5WGP belonged to the SF3 classification and the highest recorded value was 780 mm for 0NC0WGP.

In SCC mixes with NC alone, the SFD values decrease from 780 mm for 0NC0WGP to 708 mm for the 10NC0WGP mix. Figure 10 shows the recorded time required to reach a flow diameter of 500 mm i.e. T500 in a second. The higher recorded value was 3.45 sec. for the 10NC5WGP mix and the lower value was 1.95 for 0NC0WGP. According to these results, all mixes lie in VS2 classification except the 0NC0WGP mix, which lies in VS2 classification. Where the VS1 and VS2 presented viscosity classes expressed by T500.

Figure 11 shows the recorded time required to pass through V shape funnel in a second. The higher recorded value was 23.6 sec. for 10NC5WGP mix and the lower value was 8 sec. for 0NC0WGP. According to these results, all mixes lie in the VF2 classification The reason why the SFDs for NC mixes are smaller than the SFD for the control mix while T500 is higher compared to the control mix is primarily due to the high surface area of nanoparticles that led to an increase in the surface area of cementitious paste. In addition, the finer nanoparticles are causing an increase in water demand and absorbing more water, leaving less free water and contributing to the flow ability. Also, the stiffening influence of NC, which likewise decreased the SFDs is another factor [34, 35].

While the increase in V-funnel time can be attributed to the flocculation mechanism, which results in a thickened fresh mix because NC particles increase the flocculation ability of fresh concrete mixture. In reality, flocculation draws particles into the water, increasing the volume of solids and stiffening the fresh mixture as a result [36, 37]. and similar results were found by Al-Ani [19].

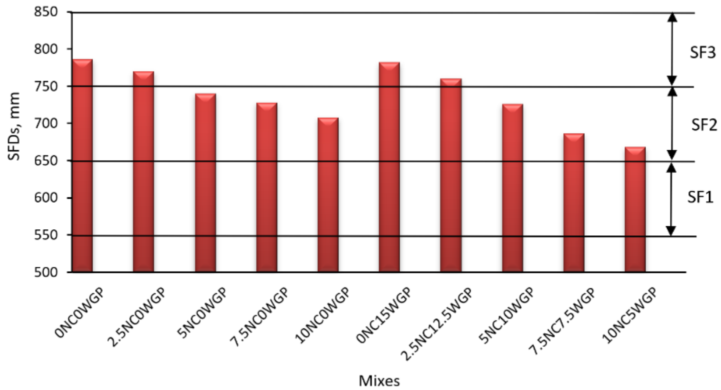

Fig. 9 SFDs for all SCC mixes

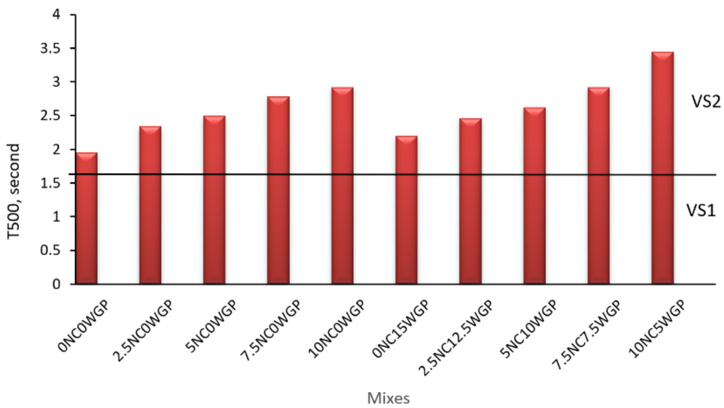

Fig. 10 T500 for all SCC mixes

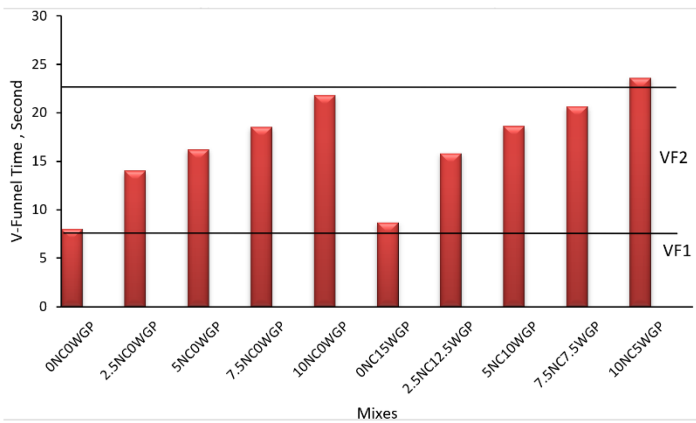

Fig. 11 V-funnel time for all SCC mixes

The SCC mixes with 15% WGP alone and has an SFD of 782 mm. This means that adding waste glass powder did not affect the flow diameter of the mixture. The recorded T500 value was 2.2 sec. for the 0NC15WGP mix vs. 1.95 sec. for 0NC0WGP. While the recorded V-funnel time value was 8.86 sec. for 0NC15WGP mix vs. 8 sec. for 0NC0WGP. This outcome may be attributable to the fact that the particle size distribution of cement and WGP is somewhat close [38]. Similar results were found by Khudair et al. [38]. By using recycled glass powder as a partial cement replacement, they looked at the characteristics of self-compacting concrete both while it was fresh and when it had hardened. Five mixtures were prepared for their study, each with a different percentage of ground glass powder used as a cement replacement: 0%, 10%, 20%, 30%, and 40% by weight. The rheological characteristics of the produced self-compacting concrete were examined using the following metrics: slump flow diameter, the time required to reach a flow diameter of 500 mm, sieve segregation resistance, and L-box height ratio. The test findings show that increasing the partial substitution of cement with glass powder resulted in a minor reduction in T500 mm time and maintenance of flow ability. The SCC mixes with the combination of WGP and NC show a decrease in SFDs and an increase in flow time. This may be due to the combined effect of these two pozzolanic materials that led to an increase in the volume of solids and stiffening of the fresh mixture as a result [11], [20].

Figure 12 illustrates the relationship between V-funnel flow and T500 flow time and these results are within the EFNARC 2005-recommended viscosity scale. A linear relation was found between Tv-funnel and T500 with R2 equal to 0.8909 as follows:

$$T_{v-funnel} = 11.526(T_{500}) - 13.546 \quad (1)$$

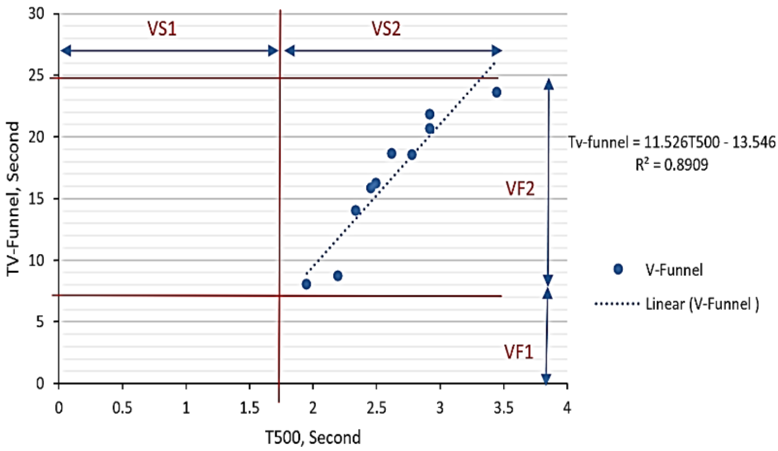

Fig. 12 V-funnel time vs. T500 for all SCC mixes

3.1.2 L-box and Sieve Segregation tests

The blocking ratio can be defined as the ratio between the concrete height at the end of the horizontal section (H2) of the L-box, and the height of the remaining concrete in the vertical section (H1) of the L-box.

The highest blocking ratio from L-Box's test was obtained for the 0NC0WGP mix (0.94) and 0NC15WGP (0.93) and the lowest ratio was obtained for the 10NC5WGP mix (0.82), as shown in Figure 13. Replacing cement with NC or NC with WGP gradually reduced the L-box ratio results, whereas WGP did not affect the L-box ratio results of the SCC mix. The same behavior was noticed in the segregation test, the segregation ratio was decreased with replacing cement with NC and WGP, as shown in Figure 14. The reason for this is that NC has a large specific surface area, it easy to form a flocculent network microstructure, and can absorb more free water during hydration [39] and along with the fact that both NC and WGP have active pozzolanic reactions, which raise the need for water demand and decrease workability.

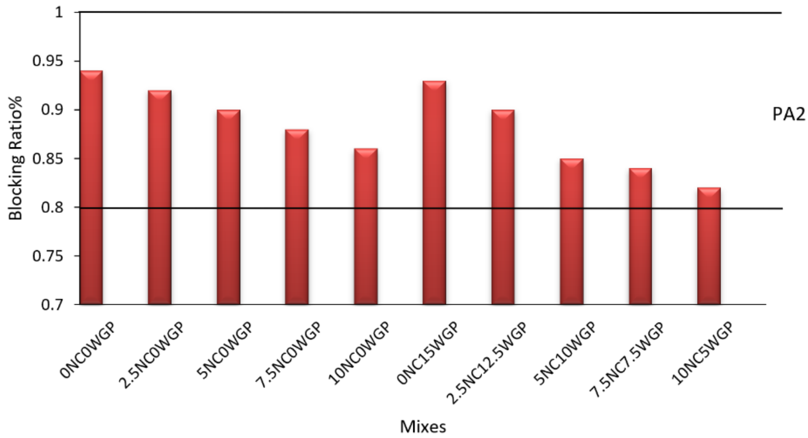

Fig. 13 Blocking ratio for all SCC mixes

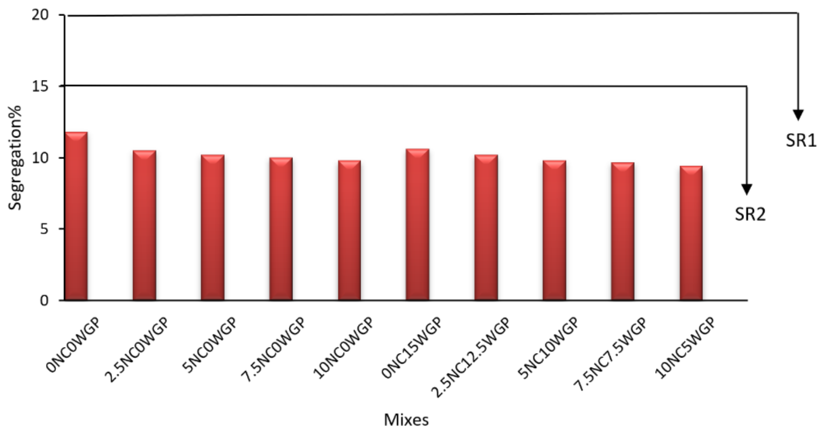

Fig. 14 Segregation ratio for all SCC mixes

3.2. Mechanical Properties

3.2.1. Compressive strength and modulus of elasticity

Figure 15 shows the compressive strength of reference and SCC mixes incorporating various weight percentages of NC and WGP. The highest compressive strength was found for 2.5NC12.5WGP (80.6 MPa). for all mixes, the compressive strength was higher than the one for the reference mix (62 MPa) except for the 10NC0WGP mix (58.8 MPa), which has the lowest compressive strength and 10NC5WGP (60.28).

The modulus of elasticity of concrete is mostly correlated with compressive strength [40]. The modulus of elasticity is calculated through the compression test of the cylinder, where the resulting stress and strain are recorded so that the modulus of elasticity is calculated from the following equation:

$$E_c = \frac{S_2 - S_1}{\mathcal{E}_2 - 0.00005} \tag{2}$$

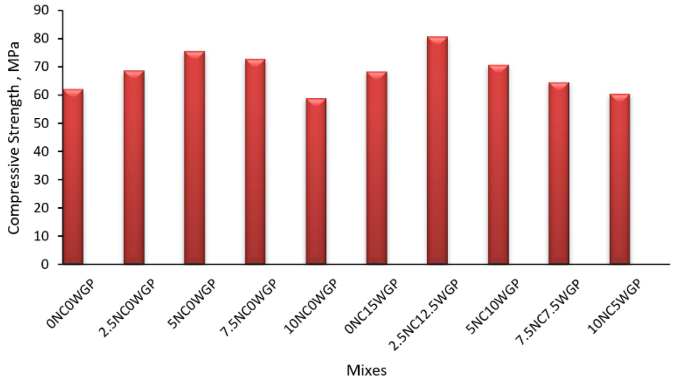

Fig. 15 Compressive strength for all SCC mixes

Where Ec is the static modulus of elasticity (MPa), S2 is stress corresponding to (40%) of ultimate strength (MPa), S1 is stress corresponding to a longitudinal strain (Ɛ1=0.00005) (Mpa), and Ɛ2 is Longitudinal strain formed by stress S2. The results of the modulus of elasticity are illustrated in Figure 16. The highest modulus of elasticity was found for 2.5NC12.5WGP and the lowest modulus of elasticity was for 10NC0WGP.

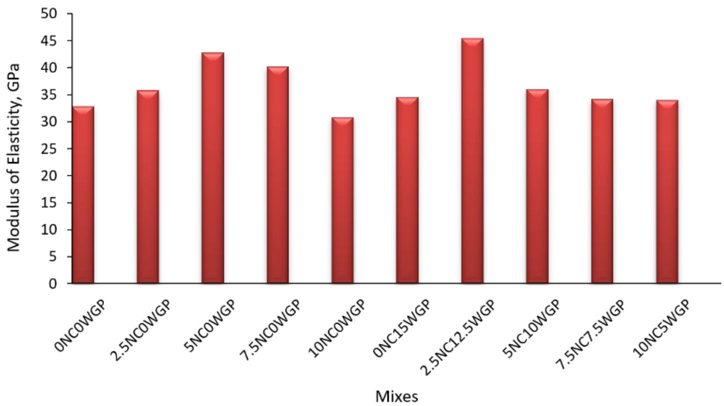

Fig. 16 Modulus of elasticity for all SCC mixes

As a result of NC and WGP particles' pozzolanic behavior in the cementitious matrix and their reaction with $Ca(OH)_2$, which results from cement hydration, form a dense Calcium Silicate-Hydrate (C-S-H) gel, so the compressive strength of SCC mixed with NC has increased. Additionally, NC particles can fill the micropores and strongly bond with the bulk volume of the matrix to create a more compact and integrated microstructure [41].

But increased NC content of more than 7.5% led to a decrease in compressive strength. This is because of a weakening of the interfacial transition areas in the mortar or concrete matrix [42] The scattering defect results in fewer matrix contact points and has a negative influence on bonding with cement particles [43, 44]. According to experimental results, a linear relationship between compressive strength and modulus of elasticity is suggested as shown in Figure 17 and illustrated in the following equation:

$$E_c = Ec = 0.6341fc - 6.5585 \quad (3)$$

Where: Ec = is static modulus of elasticity (GPa) and fc = compressive strength (MPa)

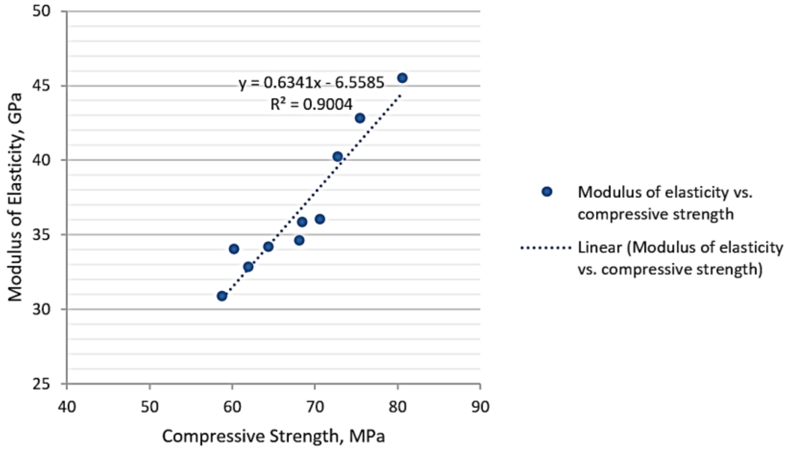

Fig. 17 Modulus of elasticity vs. compressive strength for all SCC mixes

3.2.2. Flexural and splitting strengths

Figure 18 and Figure 19 show the flexural and splitting strengths, respectively of reference and SCC mixes incorporating various weight percentages of NC and WGP. The highest flexural tensile strength was found for 2.5NC12.5WGP (5.84 MPa) and 5NC0WGP (5.5 MPa). While the lowest flexural tensile strength was for 10NC0WGP (3.88 Mpa). The highest splitting tensile strength was found for 5NC0WGP (4.64 MPa) and it was closed for 2.5NC12.5WGP (4.6 MPa). While the lowest splitting tensile strength was also for 10NC0WGP (2.8 Mpa), as shown in Figure 19. This is because the specimens' bonding and hydration were enhanced by the finer size and specific gravity of NC and the pozzolanic nature of both NC and WGP [8, 45, 46]. According to experimental results, a linear relationship between compressive strength and indirect tensile strengths are suggested as shown in Figure 20 and 21 and illustrated in the following equations:

$$f_t = 0.6341f_c - 6.5585 \quad (4)$$

$$f_{st} = 0.6341f_c - 6.5585 \quad (5)$$

Where: ft = is flexural tensile strength (MPa) and fst = splitting tensile strength (MPa).

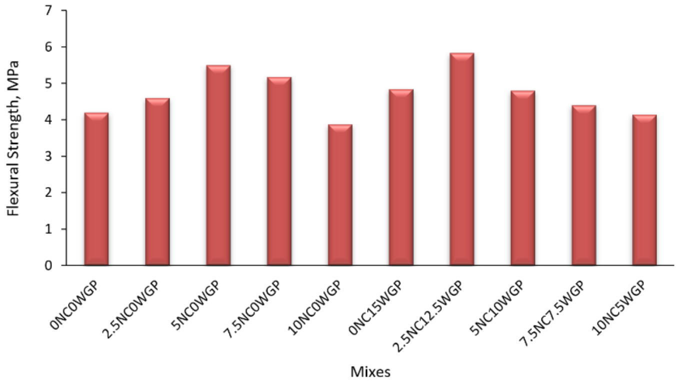

Fig. 18 Flexural strength for all SCC mixes

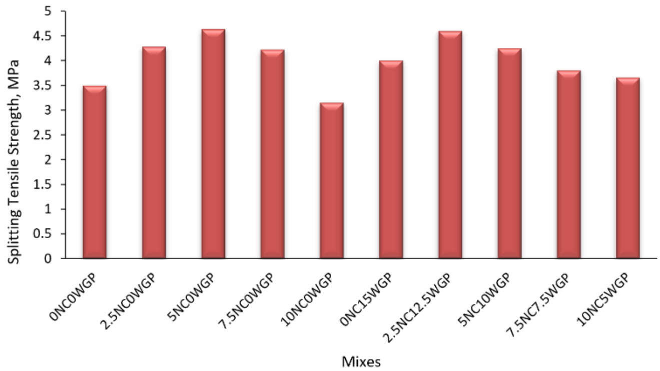

Fig. 19 Splitting strength for all SCC mixes

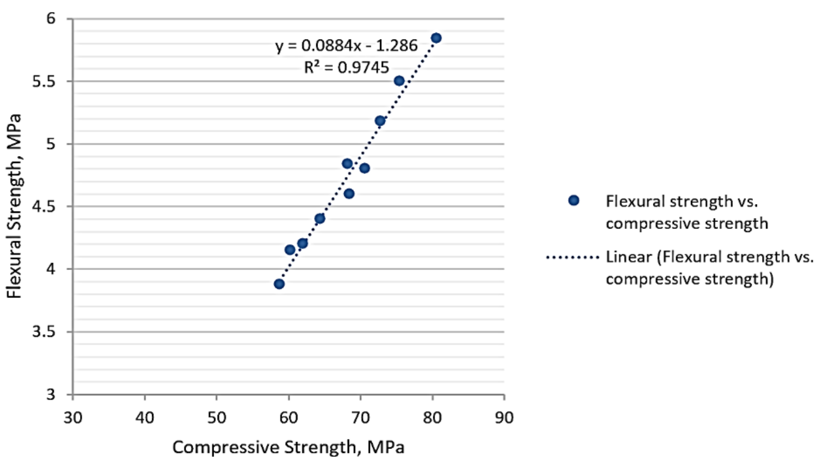

Fig. 20 Flexural strength vs. compressive strength for all SCC mixes

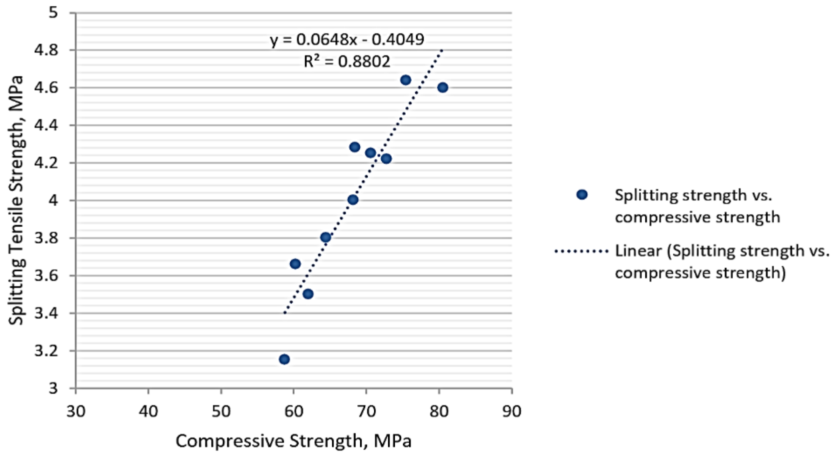

Fig. 21 Splitting strength vs. compressive strength for all SCC mixes

3.3. Permeation's Properties

The results of the experiments on absorption and permeable void ratios are shown in Figure 22 and 23, respectively. The findings showed that the SCC mixes' water absorption was reduced by the addition of NC and WGP. Additionally, compared to the reference SCC, the water absorption values for NC and WGP were lower. Additionally, the higher weight percentages of NC (> 7.5%), in contrast to all other contents of NC alone or with WGP in SCC, resulted in higher water absorption than the reference mix.

The amount of free water that can be kept in a mixture depends on the surface area of the solid particles and their fineness. Additionally, free water is not disturbed when there is no compacting procedure. As a result, the ITZ has fewer pores since there is less of a tendency for water to flow into and concentrate around aggregates [47, 48]. Lower water absorption is shown when more fillers or pozzolanic materials, such as NC and WGP, are added to the SCC mixture [47]. This effect may be attributed to improved particle distribution, less inter-particle friction, and increased packing density. A Higher NC replacement value (10%), however, may result in higher water absorption. Therefore, using NC and WGP to replace the cement has a favorable effect on SCC.

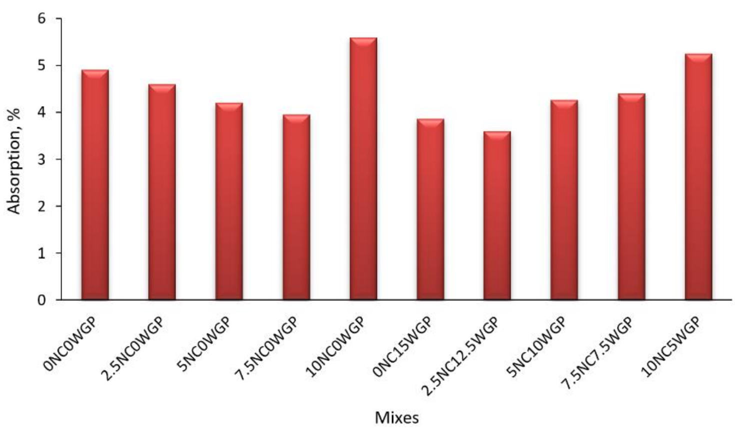

Fig. 22 Water absorption% of all mixes

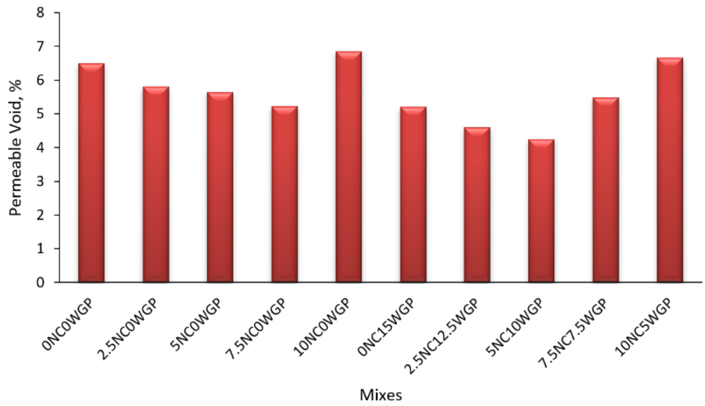

Fig. 23 Permeable voids % of all mixes

4. Conclusions

Based on experimental work the following conclusions are drawn:

- For all SCC mixes contain NC, the SFD values decrease from 780 mm for 0NC0WGP to 708 mm for the 10NC0WGP mix.
- The SCC mix with 15% WGP has an SFD of 782 mm. This means that adding waste glass powder did not affect the flow diameter of the mixture. The recorded T500 value was 2.2 sec. for the 0NC15WGP mix vs. 1.95 sec. for 0NC0WGP. While the recorded V-funnel time value was 8.86 sec. for 0NC15WGP mix vs. 8 sec. for 0NC0WGP.
- The higher recorded T500 value was 3.45 sec. for the 10NC5WGP mix and the lower value was 1.95 for 0NC0WGP. According to these results, all mixes lie in the VS2 classification except the 0NC0WGP mix, which lies in the VS2 classification.
- The results of the tests on the fresh concrete showed that the NC reduces the fluidity and flowability of the mixtures, while the addition of glass has almost no effect. While the addition of WGP with NC led to an additional decrease in the flowability of the mixture.
- The highest compressive strength was found for 2.5NC12.5WGP and 5NC0WGP. For all mixes, the compressive strength was higher than the one for the reference mix (62 MPa) except 10NC0WGP and 10NC5WGP.
- The highest modulus of elasticity of SCC is found at 45.5 GPa for 2.5NC12.5WGP, while the lowest value was found for 10NC0WGP.
- The highest flexural tensile strength was found for 2.5NC12.5WGP and 5NC0WGP. While the lowest flexural tensile strength was for 10NC0WGP.
- The highest splitting tensile strength was found for 5NC0WGP and it was closed for 2.5NC12.5WGP. While the lowest splitting tensile strength was also for 10NC0WGP
- The results showed that the SCC mixes' water absorption was reduced by the addition of NC and WGP. Additionally, compared to the reference SCC, the water absorption values for NC and WGP were lower. Additionally, the higher weight percentages of NC (> 7.5%) water absorption than the reference mix.
- Finally, it can be concluded that the replacing cement with 2.5%NC and 12.5%WGP gave the best fresh and haredend properties for SCC mix.

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