CONCRETE QUALITIES AND THE USE OF CERAMIC POLISHING WASTE POWDER AND WATER GLASS

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Abstract

Large landfills are required to dispose of the vast volumes of solid waste that growing populations produce. The problem of landfills may be solved by recycling solid waste into other resources, which lowers the need for non-renewable resources. Moreover, the production of cement pollutes the environment, especially in Suez, Egypt, where fuel burning releases CO2 gas into the atmosphere. Hence, using waste and inexpensive resources to support the concrete industry and enhance its qualities was a major issue in most of the research. A great deal of interest in ceramic waste's sustainable use in the building industry has been spurred by its rapid growth. This study examined the effects of employing water glass (WG) as an addition with 0.5 and 1% and ceramic polishing waste powder (CPWP) created during the final polishing process of ceramic tiles as a partial replacement of cement with 5, 10, and 15% by weight. Fresh concrete was subjected to slump, initial and final setting periods, and air content tests; the hardened and durability of concrete specimens were assessed using compressive, abrasion resistance, permeability, and accelerated corrosion tests. According to experimental findings, CPWP substitution levels up to 10% had a favorable impact on the strength characteristics of concrete. Also, the results demonstrated that using WG as an additive in mixes containing CPWP led to better durability attributes when compared to control mix. Thus, depending on their doses, CPWP and WG might be utilized in the manufacturing of concrete without having an adverse influence on its qualities.

Keywords: Water glass, replacement cement, strength, waste, ceramic polishing waste powder

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1. Initialization

The most common building material is concrete. Using supplementary cemented materials (SCMs) can enhance concrete's qualities while minimising its negative environmental consequences. By cutting back on material usage, the long-term objective of avoiding undesirable industrial by-products can be accomplished. Around one tonne of Portland cement, which is accountable for 5% of global CO2 emissions, emits CO2 into the atmosphere.(Jin, 2013) The safe recycling of wastes is highly valued in the concrete making industry.(Hardjito et al., 2004) To fulfil consumer wants, massive volumes of trash will continue to be disposed of in solid waste landfills. Numerous different forms of solid wastes, including fly ash, silica fume, glass powder, and rice straw ash, are recycled and used in a variety of industries. Thus, the majority of research aim to minimise environmental pollution brought on by inappropriate solid waste disposal, as well as the negative effects on public health, and also develop new materials for improving concrete qualities at cheap costs in comparison to other options. The study of ceramic waste (CW) is a popular subject. CW is settled via sedimentation and eventually released, contaminating the environment and posing health risks. Because of rising demand, the ceramics sector is increasing. Concrete manufacture may make use of CW powder's pozzolanic action. (Dieb & Kanaan, 2018) shown that up to 30% of the cement in concrete grades M20 and M25 may be replaced with ceramic waste to boost compressive strength. (Raval et al., 2013) found that CW replacement might enhance the mechanical properties of concrete grades 20 and 40 by up to 30% and 20%, respectively. (Li et al., 2019) found that increasing durability needed a 40% replacement rate. According to (Atkuri & Rao, 2021), it is also more resilient than regular concrete. According to (Li et al., 2019), using CW as an alternative to paste increased mortar strength while using 33% less cement.(Rashad & Essa, 2020) A sodium silicate substance called water glass is easily dissolved in water. It is a chemical that is often utilized. Products made of cement that have been impregnated with water glass are more enduring and water resistant. Shevchenko Viktor and Kotsay Galyna discovered that water glass can speed up the hardening process in cement paste(Zhang et al., 2021). Moreover, it may be used to seal porosity natural and artificial construction materials and enhance the surface qualities of concrete. To repair concrete, (Yang et al., 2008) used sodium silicate microcapsules. (Viktor & Galyna, 2017) discovered that WG enhances concrete using recycled aggregate. Most investigations found no cause for worry regarding how sodium silicate and ceramic waste affect reinforced concrete's ability to remain fresh and durable. Hence, research on the local CPWP and WG was necessary to determine its true environmental and financial advantages.(Shaikh, 2014)

2. Proposed methods and materials

Cement version

For standard concrete with a specific surface area of 3195 cm2/kg and a compressive strength of 22.4 MPA, 40.6 MPA after 3, and 28 days, respectively, the study employed EL-Suez cement CEM I grade 42.5 N. The chemical components of utilised cement are displayed in Table 1

Chemical characteristics of unused cement (1)

Chemical components	Loss of ignition	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO3
CEM I (42.5) percentage by weight (%)	1.4	19.5	7.5	2.65	61.53	3.65	2.4

Fine-tuned aggregate

Natural sand was the fine material that was utilised. According to ECP 203/2018, the grading of the sand is shown in Figure 1. Tables 2 and 3 respectively list the sand's physical and chemical characteristics.

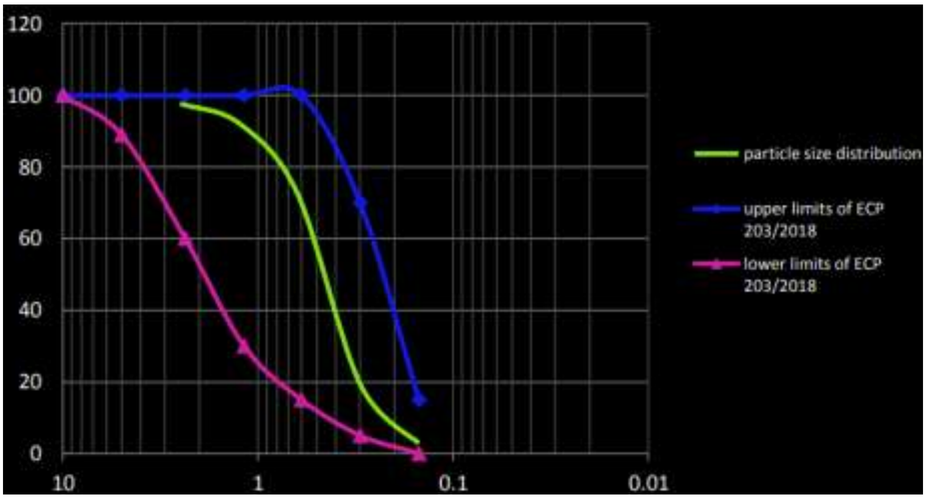

Figure 1: Curve for grading utilized fine aggregate

Table 2: Characteristics of fine aggregate

Property	Results	Limits of ES (1109/2008) and ECP 203/2018
Specific weight	2.63	2.5 – 2.75
Unit weight (t/m^3)	1.62	-
Clay and Fine Dust Content %	2.68 %	Not more than 3 %

Table 3: Content of sulphate and chloride in fine aggregate

Property	Results	Limits of ECP 203/2018
Total chlorides	0.035	0.06
Total sulfate	0.020	0.40
PH	7.8	-

Rough Aggregate

Crushed dolomite was employed as the coarse aggregate in this investigation. The findings of evaluating physical and chemical characteristics are displayed in Tables 4 and 5. The coarse aggregate grading curve in accordance with ECP 203/2018 is shown in Figure 2.

Table 4: Coarse aggregate's physical characteristics

Property	Results	Limits ECP 203/2018
Specific weight	2.62	2.6 -2.7
Unit weight (t/m^3)	1.33	-
Abrasion index (loss Anglos apparatus)	25.5 %	Not more than 30 %
Clay and fine material content %	1.78 %	Not more than 3 %
Water absorption %	2.42 %	Not more than 2.5 %

Table 5: Content of sulphate and chloride in coarse aggregate

Property	Results	Limits ECP 203/2018
Total chlorides	0.037	0.04
Total sulfate	0.011	0.4
PH	7.9	-

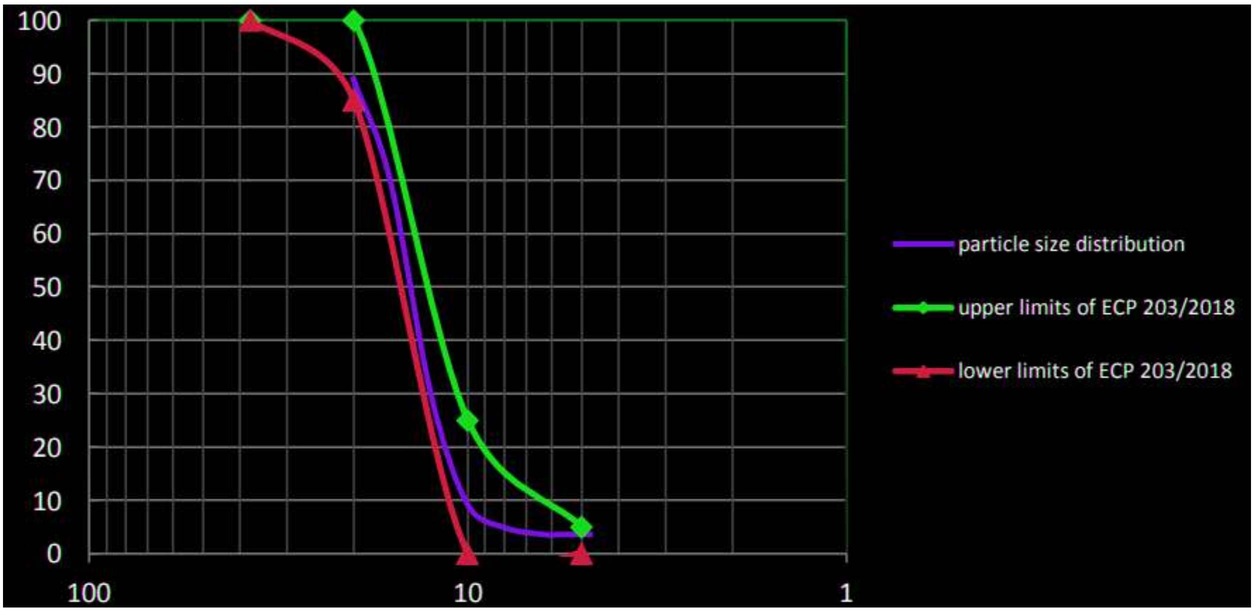

Figure 3: Using coarse aggregate grading curve

Powder from ceramic polishing waste

The Ceramica Venezia factory in 6 Octoper, Egypt provided the ceramic polishing waste powder (CPWP) used in this investigation. It is challenging to get rid of the CPWP from the environment. The CPWP that was gathered was entirely dry, with an average particle diameter of 1410 nm, and had a specific surface area of 1131 m2/kg. Table 6 displays the CPWP's chemical makeup. Figures 4 and 5 depict an example of an energy dispersive X-ray analysis of CPWP and its mass atom density, respectively.

Table 6 for the utilized ceramic waste powder's XRF analysis (CPWP)

Compound	Al_2O_3	SiO_2	K_2O	CaO	FeO	Total
Mass %	16.38	70.42	2.64	2.12	8.39	100

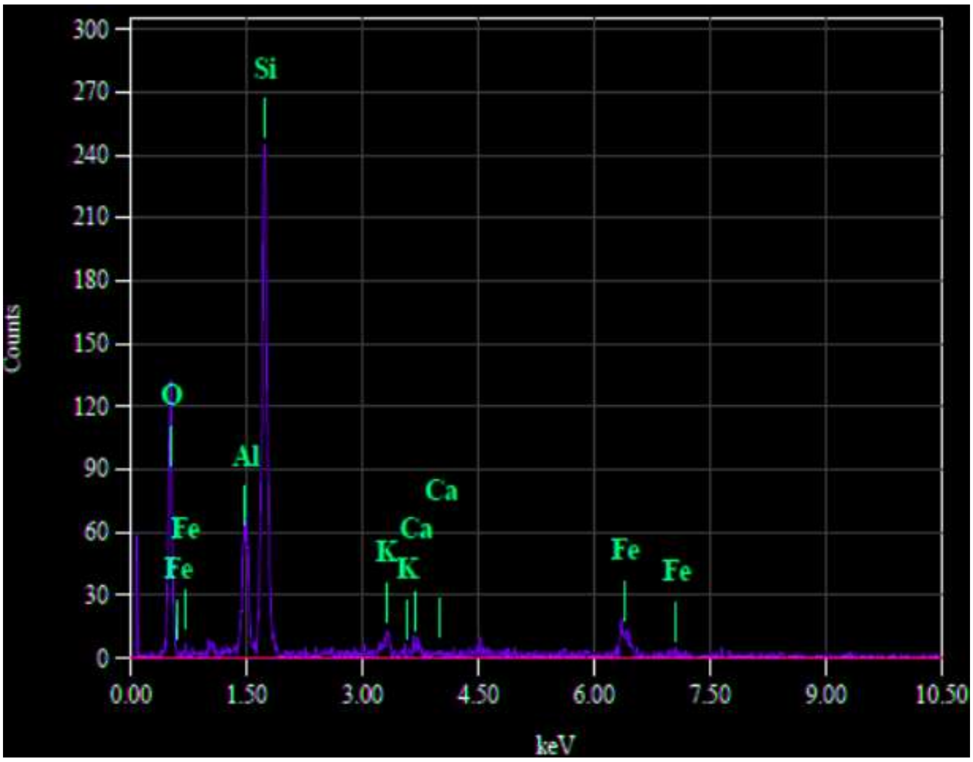

Figure 4: Typical EDX micrograph of CPWP

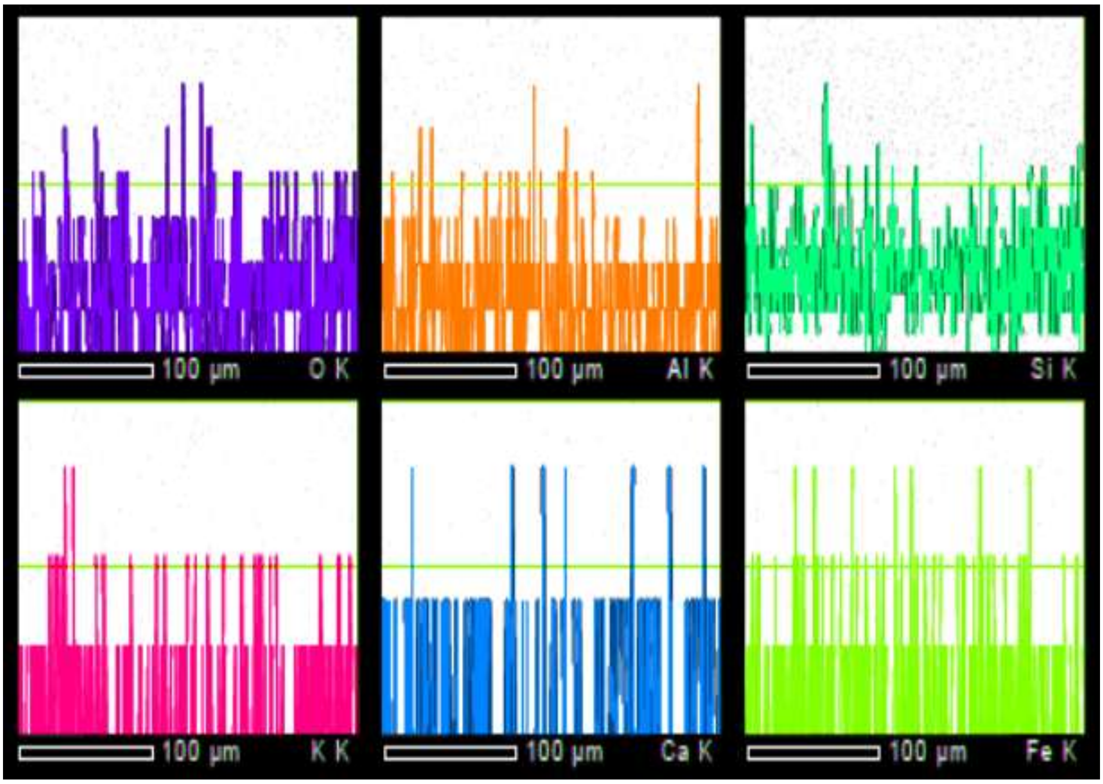

Figure 5: Mass atom density of CPWP

Water Cup

Egypt Global Silicates Company in Suez city provided the water glass utilised in the investigation. The ratio of SiO2 to Na2O in the solution gave it a modulus of 3.3. The liquid utilised was a clear, white solution of sodium silicate.

Water

Concrete was mixed and dried using portable water. It complies with ECP criteria.

Design for concrete mix

Two sets of concrete mixes with various CPWP and WG doses were created. Group 1 consists of four concrete mixtures with CPWP replacement levels of 0, 5, 10, and 15%. Group 2 consists of the following four concrete mixtures: (5% CPWP+0.5 WG), (5% CPWP+1% WG), and (10% CPWP+0.5%WG). All cement percentages by weight were added by the WG. The water to cement ratios for all concrete mixtures was 0.5. The specifics of the mix proportions are shown in Table 7.

Table 7: proportions of the concrete mix per cubic meter of concrete

Mixture	Cement (kg/m3)	Natural Sand (kg/m3)	Coarse aggregate (kg/m3)	CPWP (kg/m3)	Water glass (L/ m3)	Water (L/m3)
CM0	400	580	1159	0	0	200
CM1- 5%CPWP	380	580	1159	20	0	200
CM2- 10% CPWP	360	580	1159	40	0	200
CM3-15% CPWP	340	580	1159	60	0	200
CM4- (5% CPWP+0.5 WG)	380	580	1159	20	2	200
CM5- (5% CPWP+1% WG)	380	580	1159	20	4	200
CM6-(10% CPWP+0.5%WG)	360	580	1159	40	2	200
CM7- (10% CPWP+1%WG)	360	580	1159	40	4	200

Approach to Experiments

Testing concrete mixtures serves as the first step in examining the impact of CPWP and WG. All intended mix outcomes are compared to control concrete CM0 mix results. All of the specimens were poured into moulds using a water-to-cement ratio of 0.5; after around 24 hours, the specimens were removed from the moulds and allowed to cure for 28 days in water.

State-of-the-art properties

The study includes measurements of several parameters that are tested for all concrete mixes, including slump, beginning and final setting times, and air content.

Rigorous state exams

- The characteristics of concrete mixes including CPWP and WG were tested. An average of three concrete samples were obtained for each test of concrete, according to individual test results.
- Using 100x100x100 mm cubes, all concrete mixes were subjected to a compressive strength test at 7 and 28 days in accordance with Egyptian Code for Design and Construction of Building 203/2009.
- Using (150x150x150) mm cubes, a 56-day water permeability test was conducted in accordance with Egyptian Code for Design and Construction of Building 203/2009.
- Concrete (70 x 70 x 70 mm) cubes were subjected to an abrasion resistance test
-
- after 28 days in accordance with Egyptian standard requirements No. 2005 / 1-269.
- Using 100 x 100 x 500 mm prisms, an accelerated corrosion test was conducted after 28 days to determine the optimum concrete mixtures in each group.

2. Results and Discussion

Brand-new properties Slump

With CPWP blends, the initial slump was reduced when the CPWP replacement quantity was increased. Slump was 85 mm for CM0 and 79 mm for CM3. There are 84 and 80 mms in CM1 and CM2, respectively. The fact that CPWP has a smaller mean particle size (1.4 m) than regular Portland cement and a higher specific surface area (1131 m2/kg) may be to blame for this little decrease. It could possibly be connected to fine ceramic particles' enhanced water absorption. Nevertheless, does not reveal a sizable decrease due to low replacement levels of CPWP. The initial slump of concrete mixes for (CPWP+WG) mixes increased with WG as an added level. An ideal value for CM5 (5% Plus 1%) was 110 mm, whereas the initial slump for CM0 was 85 mm. The results were 100, 95, and 105 mm for CM4 (5% + 0.5%), CM6 (10% + 0.5%), and CM7 (10% + 1). This little increase in workability may be attributable to WG being in a liquid condition with constant water to cement ratios throughout all combinations. Figure 6 displays the millimetre findings of the slump test.

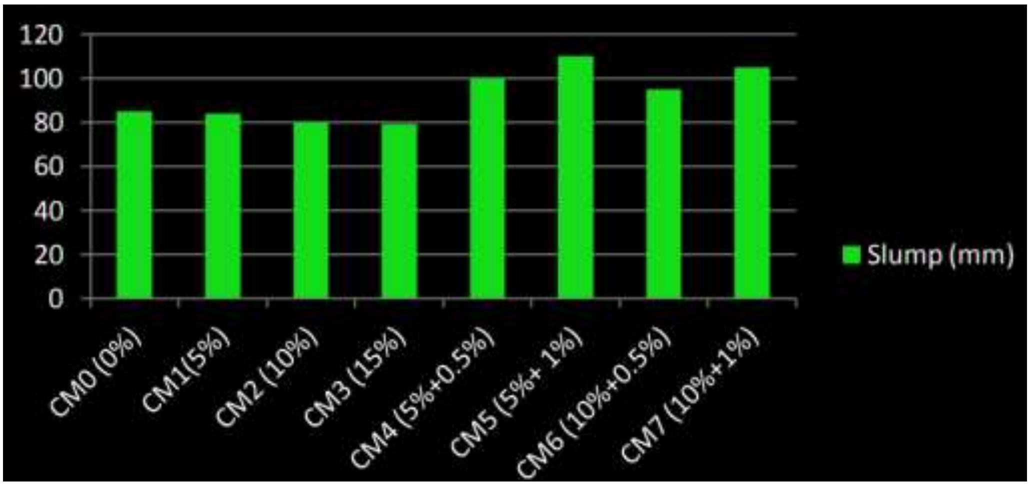

Figure 6: slump test results in mm

Both the initial and final settings

Starting and final setup durations for CPWP mixes slightly lowered when CPWP levels rose in comparison to CM0. As comparison to CM0, CM3 (15%) needed 260 minutes to achieve its ultimate setting with a 16-minute acceleration (276 min.). CM1 (5%) and CM2 (10%) also took 267 and 262 minutes, respectively. That could be because of the capacity of CPWP's small particles to absorb some free water, shortening the setting time. Using CPWP and WG in concrete mixtures clearly decreased initial setting time and final setting time for (CWP + WG) mixes. Final setup times with an acceleration of 26 and 36 minutes compared to CM0 were 250 and 240 minutes for CM6 (10% + 0.5%) and CM7 (10% + 1). (276 minutes). Moreover, the ultimate setup time for CM4 (5% + 0.5%) was 256 minutes, compared to 255 minutes for CM5% (5% + 1). The start and ultimate setting durations for concrete mixtures are shown in Figure

7. This acceleration effect, which is evidently brought on by the addition of WG to concrete mixtures, may be caused by the interaction of sodium silicate from water glass with calcium hydroxide from the cement hydration process, which results in the production of more calcium silicate hydrates (CSH) gel and an acceleration effect when compared to CM0.

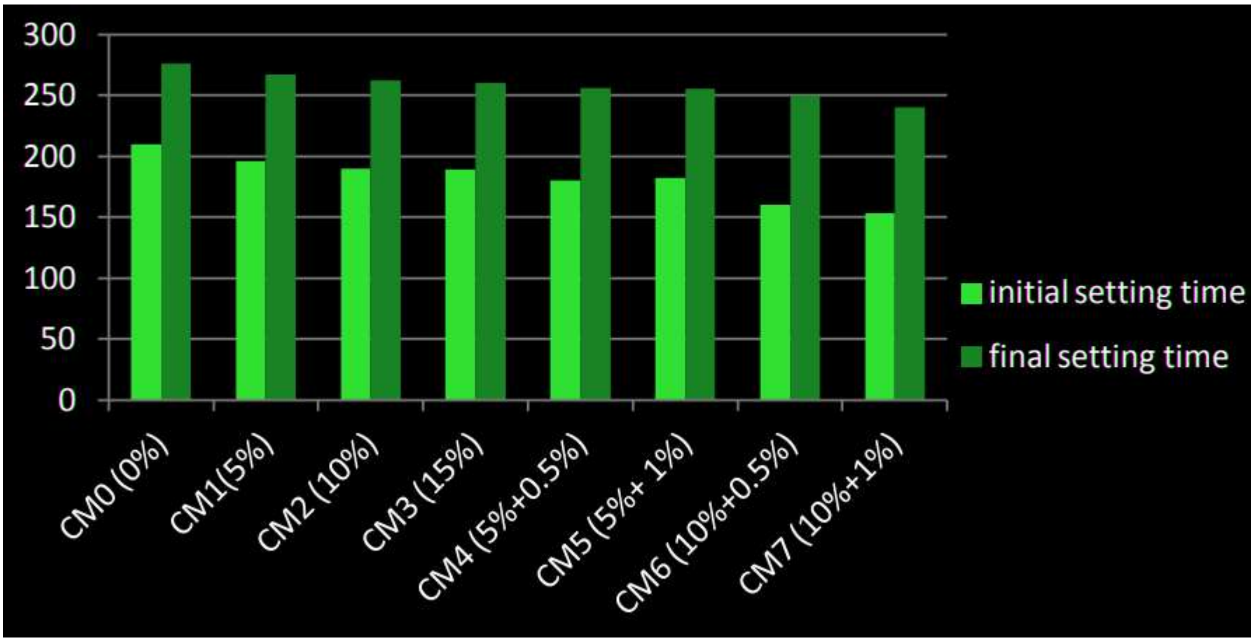

Figure 7: minutes for both the initial and final settings

By applying the pressure technique, air content
Three groups showed a little increase in the proportion of air in the fresh mixtures. It was more obvious in group two (CPWP + WG mixes), possibly as a result of the water's propensity to produce more air bubbles in early fresh mix than control mix in WG solution. Air content values varied from 1.9% to 2.4%. Table 8 lists the percentages of air in fresh concrete mixtures.

Table 8: Air content percentages

Mixture	CM0	CM1 (5%)	CM2 (10%)	CM3 (15%)	CM4 (5% + 0.5%)	CM5 (5% + 1%)	CM6 (10%+ 0.5%)	CM7 (10% + 1%)
Air content %	1.9	2.1	2.35	2.4	2.5	2	2.3	2.2

Hardened characteristics
Compression power
Results for CPWP mixtures demonstrated that up to 10% cement substitution with CPWP increased compressive strength compared to CM0 without. The specimens exhibited little strength change after 7 days of curing compared to 28 days of variation, while CM2 (10%) had a maximum strength of 21 MPA. After 28, CM2's strength (10%) grew to 35.3 MPA while CM0's strength remained at 27.3 MPA. CWP replacement levels of 5, 10, and 15% may attain 33, 35.3, and 32.5 MPA with enough improvements in compressive strength of 20.8, 29.3, and 19% after 28 days. Due to the high silicon oxide (SiO_2) concentration in CPWP interacting with the calcium hydroxide ($Ca(OH)_2$) from cement hydration products in the late ages, this may be connected to pozzolanic reactions. Al_2O_3 in CWP may also result in early strength characteristics. Moreover, the tiny ceramic waste powder fragments can fill gaps and improve the densification and durability of CPWP mixtures. The findings for the (CPWP + WG) mixes revealed that the addition of WG to CPWP-concrete mixes did not increase compressive strength compared to mixes with CPWP alone, but the results were still greater than CM0 and equivalent to CPWP mixes. After 28 days, the best mixture was CM4 (5% + 0.5%), which achieved 33.5 MPA. The results for CM0, CM5 (5% + 1%), CM6 (10% + 0.5%), and CM7 (10% + 1%) were 27.3, 30.5, 30.7, and 29, respectively, with strength improvements of 22.7, 11.7, 12.4, and 6.2% when compared to CM0. This enhancement may be attributable to the WG's ability to plug tiny fractures in concrete mixtures, resulting in a denser microstructure and greater strength. Nevertheless, tests on strength revealed that the addition of CPWP and WG to the same

mix had no good impact on the hydration process. Results for compressive strength for all concrete mixes are shown in Figure 8 after 7 and 28 days of curing.

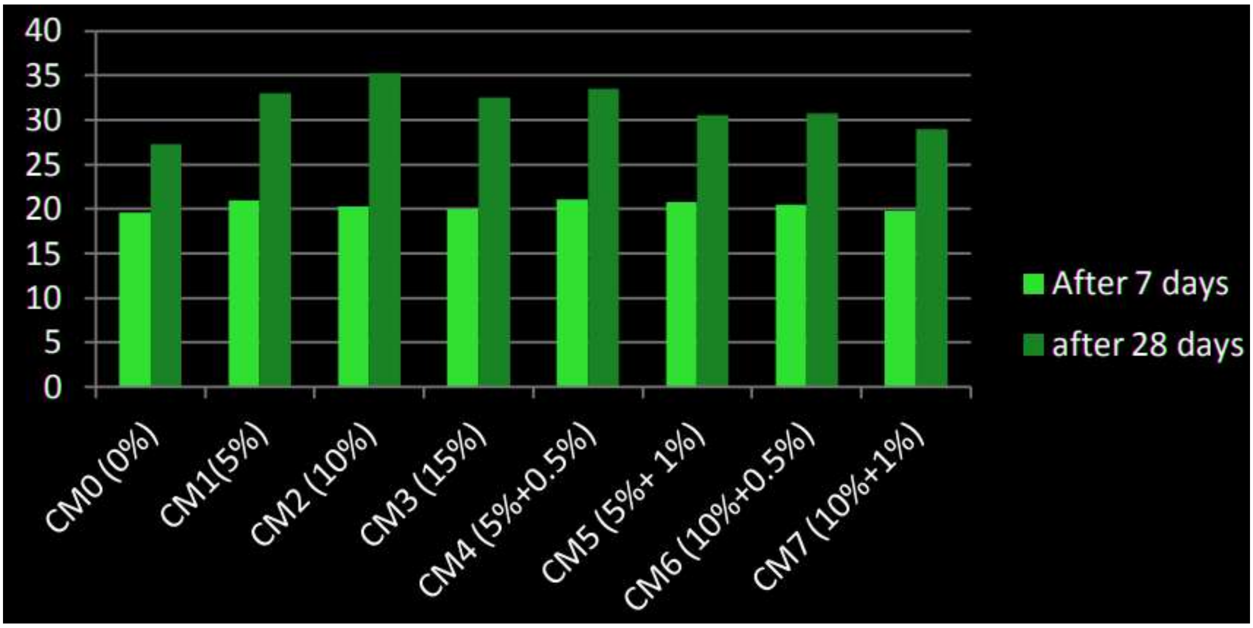

Figure 8: MPA's compressive strength

Test for permeability

For CPWP mixtures, the water column depth was measured after each specimen was tested under 5 bar of pressure for 72 hours. The findings demonstrated that boosting the dose of CPWP in concrete decreased the depth of water penetration. Whereas CM3 (15%) had 1.9 cm, CM0 had 2.8 cm. CM1 (5%) and CM2 (10%) were 2.2 and 2 cm, respectively. Pores can be filled with CPWP to increase water resistance while also enhancing mix uniformity and compactness. By adding more C-S-H (calcium silicate hydrates) and C-A-H (calcium aluminate hydrates) during the secondary hydration process using Ca(OH)2, it also increased the concrete's resistance to permeability. The findings of combining CPWP and WG in one mix for (CPWP + WG) mixes indicated a greater increase in permeability resistance of mixes. With the addition of WG, the penetration depth reduced, allowing WG products from chemical interactions with Ca(OH)2 to penetrate small cracks in concrete mixes and create a denser microstructure and greater permeability resistance. CM4 (5% + 0.5%) and CM5 (5% + 1%) showed penetration depths of 1.6 and 1.3 cm, respectively. The ideal outcome was for CM7 (10% + 1%) to be equal to 1 cm deep, while CM6 (10% + 0.5%) was 1.2 cm. The results of a permeability resistance test are displayed in Figure 9 as penetration depth in cm.

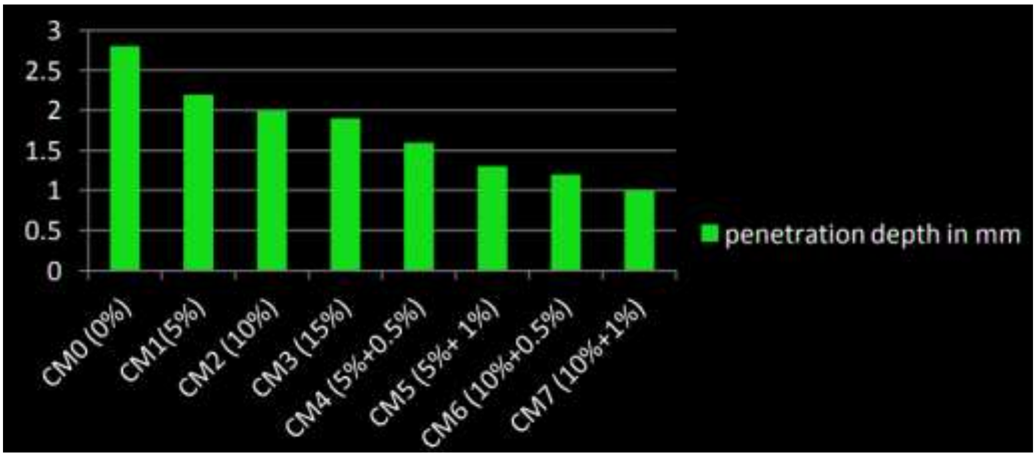

Figure 9: penetration depth (in cm)

Test for abrasion resistance

For each combination, an abrasion test was conducted on (70 70 70) mm standard cubes at the age of 28 days. From equation 1, the actual loss in thickness S in mm for each specimen was calculated. The findings for CPWP mixtures showed a marginal improvement in abrasion resistance with higher CPWP dosages. In contrast to CM0, CM2 (10%) exhibited a 1.9 mm drop in thickness and a -2% difference (1.86 MM). CM1 (5%) and CM3 (15%), however, lost 1.8 and 1.76 mm of thickness, respectively. The strong adherence between the ceramic particle and cement paste may be responsible for this little improvement. More hydration reaction products might also strengthen the cohesive forces between mixture components and fill in any gaps, which would increase abrasion resistance. Due to the use of both CWP and WG in the mixes, the findings for (CWP + WG) mixes exhibited higher abrasion resistance compared to CM0 but did not differ significantly from utilising CPWP exclusively in mixes. The best result was 1.72 mm for CM4 (5% + 0.5%), which is a 7.5% increase over CM0 (1.86 mm). Additionally, with CM5 (5% Plus 1%), it was just 1.8 mm. Furthermore, 1.82 and 1.75 mm of thickness were lost in CM6 (10% + 0.5%) and CM10 (10% + 1). The loss in thicknesses (in mm) as a result of the abrasion resistance test is shown in Figure 10.

$$S = \frac{10W}{D \times A}$$

Where S is the thickness reduction, W is the weight loss, and D is the density the loading zone

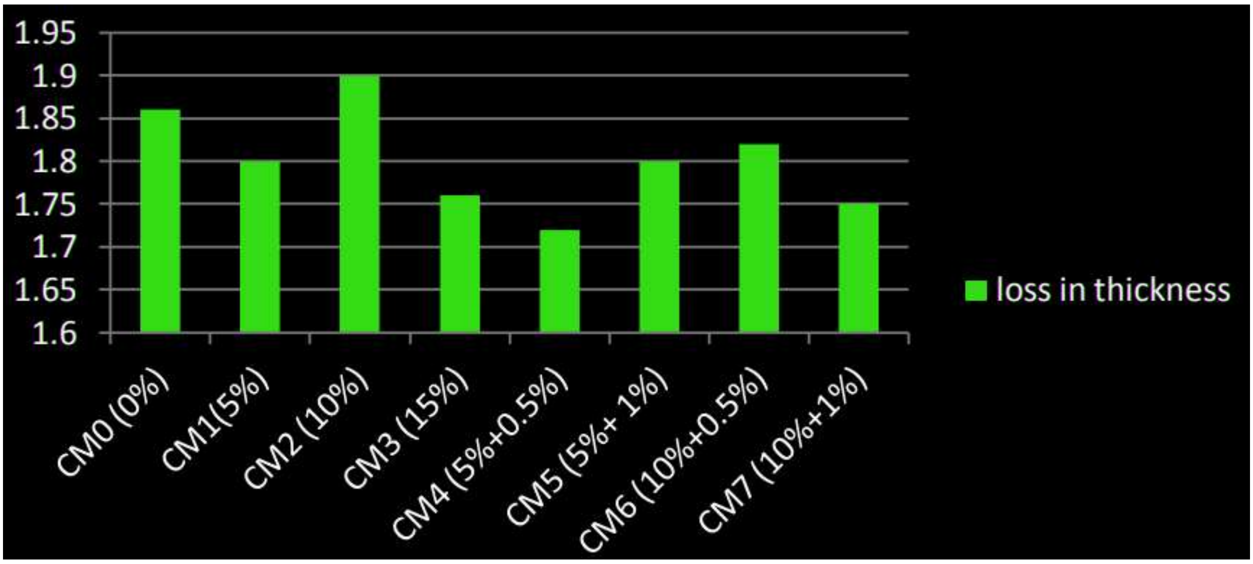

Figure 10: loss in mm thicknesses

Test for accelerated corrosion

After 28 days of curing, concrete samples from the CM0, CM2 (10%), and CM4 (5% + 0.5%) classes were subjected to an accelerated corrosion test (Figure 11). Steel rods of 16 mm in diameter and 30 cm in length were used as anodes, while copper rods of the same size were used as cathodes, to create an electrical circle. A 3.5 percent NaCL solution was used to immerse all of the concrete specimens. For each specimen, a 3 volt, 2 amp adapter was used in the test. As illustrated in figure 12, each specimen's time was determined until the fracture thickness attained at least 0.01 mm. The specimens were crushed to remove the steel rods after the test. Once each steel rod had been cleaned of corrosion using a 12% HCL solution, the weight loss for each rod was determined. Compared to a control mix, results from concrete mixes including CPWP and WG were better. With CM0, it took 918 hours to attain the requisite 0.01 mm fracture thickness, while for CM2 (10%) and CM4 (5% + 0.5%) specimens, it took longer (946 and 972 hours). Moreover, corrosion-related weight loss of steel rods coincided with a cracking tendency in terms of timing. While CM2 (10%) and CM4 (5% + 0.5%) shed 2.99% and 2.81% of their weight, respectively, CM0 has 4.4%. In NaCl, chloride ions are hostile anions. Cl- eliminates the passive hydroxide coating that an alkaline atmosphere produces on steel surfaces. Chloride ions must enter the reinforced concrete structure as part of the corrosion process and transfer to steel rod. More Cl- ions can reach the steel rod surface thanks to porous concrete. Because fewer Cl- ions are reaching steel rod surfaces thanks to the use of CPWP and WG in concrete mixtures, the rate of corrosion is reduced. Moreover, it has been noted that sodium silicate acts as a corrosion inhibitor (Giannaros et al., 2016). It can create a thin layer of silicate on the surfaces of steel bars, protecting them from anodic dissolution and reducing corrosion on steel surfaces. In contrast to the control mix, anodic sites on steel surfaces are shielded from cathodic action, resulting in reduced current density and increased corrosion resistance. Table 9 displayed rates of difference relative to CM0, weight losses on examined specimens, and time to achieve 0.01 fracture width. Concrete specimens for (A) CM0, (B) CM2 (10%), and (C) CM4 (5% + 0.5%) exhibit cracks, as shown in Figure 12.

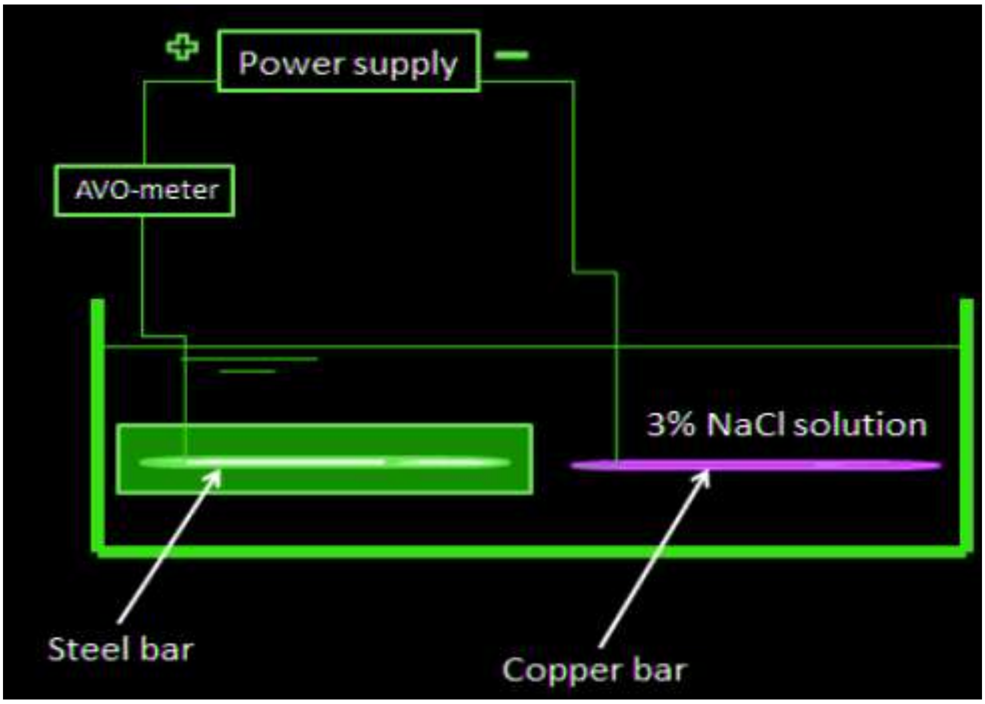

Figure 11: Accelerated corrosion testing for concrete

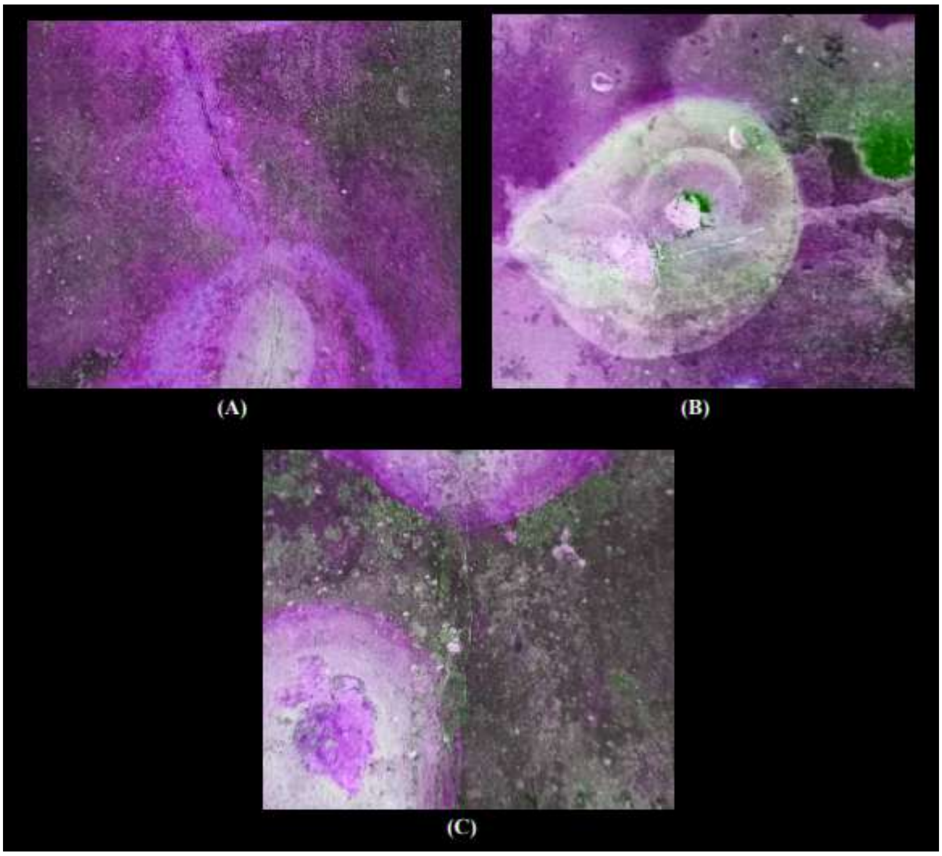

Figure 12: Concrete examples with cracks

Table 9: Weight losses in steel rods and the time it takes to achieve 0.01 fracture width

Mixture	**Weight loss (%)**	**Variations (%)**	**Time elapsed to reach 0.1 mm crack thickness (hours)**	**Variation (%)**
CM0	4.4	0	918	0
CM2 (10%)	2.99	32	946	3.05

3. Conclusion

The following conclusions may be taken from the experimental findings;

1. Due to its tiny particle size and modest acceleration of setting time when compared to control mix, using CPWP as a partial replacement for cement caused a little reduction in the workability of concrete.
2. Because of CPWPC's dual effects on pozzolanic activity and microfilling capacity, concrete's compressive strength has increased.
3. As compared to the control mix, the enhancement rate from CM2 (10% CWP) produced the highest compressive strength.
4. When CM3 (15%) was compared to CM0, abrasion resistance increased by 5.3%, and penetration depth decreased by 0.9 cm.
5. Concrete's CPWP use increased its resistance to corrosion. Compared to control mix, 10% CPWP mixture took 28 hours longer to attain 0.01 crack thickness.
6. When WG was added to CPWP mixes, the mixes became easier to work with and visibly sped up setting time compared to mixes that merely had CPWP and control mix.
7. Compressive strength enhancement over blends of CPWP alone was unaffected by the addition of WG, but it was still greater than the control mix. In group two, CM4 (5% + 0.5%) exhibited the highest compressive strength, with a rate increase of 21.5% when compared to CM0.

8. Maximum abrasion resistance was achieved by CM4 (5% + 1%) with a 7.5% improvement rate over CM0.
9. The optimal water penetration depth in concrete mixes including CWP and WG was from CM7 (10% + 1%), which had a minimum penetration depth that differed by 1.8 cm from CM0.
10. Corrosion resistance increased when CPWP and WG were combined, as opposed to when CPWP was used alone. CM4 (5% + 0.5%) took 54 hours longer than the control mix to develop a crack thickness of 0.01 mm.

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