Evaluation of recycled water recovered from a ready-mix concrete plant for re-use in concrete

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A study was conducted into the recycled water quality at a ready-mix concrete plant to determine its suitability as mixing water for concrete. Concrete mixtures prepared at a water/cementitious ratio (w/cm) of 0.5, with or without 50% ground granulated blast-furnace slag, and mortars of 0.47 w/cm were prepared using municipal and recycled water. Recycled water was used to replace municipal water at various proportions of 0%, 30%, 50%, 100% then used as mix water. Tests were done on fresh and hardened concretes and mortars.

Chemical impurities present in recycled water satisfied limits given in SANS 51008 /EN 1008 and ASTM C 94 for mixing water. Use of recycled water as mix water lead to a slight reduction in slump of concrete or flow of mortar. Hydration heat output and air permeability were not affected while mortar compressive strengths increased with rise in proportional amount of recycled water used in the mix. In mortars, use of 100% recycled water gave a substantial increase in strengths of up to 8%. Within the limitations of this study, it was found that recycled water from ready-mix concrete plants can be suitable for use as mix water in concrete-making.

INTRODUCTION

Significance of recycling waste wash water from ready-mix concrete operations

Waste water from a ready-mix plant consists of wash water from rinsing out truck mixers, storm-water runoff, sprayed water from the exterior drum rinsing and sprayed water from dust suspensions. It is estimated that a truck uses approximately 500 litres of water per washout. Typically, a truck mixer washout takes place twice daily and if there are 15 trucks per day, it amounts to use of 15,000 litres of wash water per day. Combined with storm water runoff, sprayed water, conveyor water washdowns, it can be seen that significantly large quantities of waste water are generated at a typical ready mix plant in any given working day. Also, a typical ready mix plant may produce 500 m^3 of concrete per day. On the basis of 200 litres/m^3 of concrete, the plant consumes 10,000 litres of municipal water per day. This water quantity is sufficient to provide a daily supply to over 200 African households. Certainly, the industrial consumption of municipal water may exert remarkable strain on the water supply network, especially in Africa where the shortages in water are apparent with some communities lacking adequate water supplies.

Environmental pressures have also mounted on the disposal of waste water as regulations have been crafted to control water quality and provide environmental health protection. Past practices have been to dispose waste water either at construction sites, landfills, vacant plots, plant yards or almost any location provided it raised no public concern. But wash water discharge from truck wash contains cementitious materials and other impurities. According to the South Africa National Water Act (NWA, 1998), such water cannot be discharged into urban sewers due to its high content of dissolved solids and high pH. The National Water Authority does allow for the discharge of effluent provided that the water quality of effluent meets requirements of the Act. The practice of recycling has become essential, both as a means of water conservation as well as a necessary process for safe environment. When re-used in concrete, wash waste water can also contribute to an economic process as its re-use does not necessitate chemical treatment.

Wash waste water from ready mix concrete as mix water for concrete

Studies have been done on the potential use of waste water in concrete but while important conclusions have been reached some mixed results have also been reported. Abrams, 1924 conducted extensive series of tests consisting of about 6000 concrete and mortar specimens representing 68 water samples. He found that any naturally occurring or municipal water supply suitable for drinking purposes can be used as mixing water for concrete. Although no wash waste water was used in this early study, a significant finding was reached that different types of water containing impurities such as marsh water, alkaline sulphate water, and industrial waste water were satisfactory when tested in mortars or concretes since in many instances, the strength would be greater than 90% of the strength of control specimens made using pure water. But algae in mixing water was found to entrain air and reduce strength significantly.

Borger et al., 1994 examined strength, setting time, workability and sulphate resistance of mortars incorporating recycled wash water. Mortars with a water/cement ratio (w/c) of 0.485 and 1 : 2.75 aggregate-cement ratio were used. It was reported that the age of wash water had the greatest effect on strength with an increase of up to 20%. Increase in strength was generally realized when water of ages up to 8 hours were used in mortars, while workability and permeability were reduced. Sulphate resistance was also reported to have increased. These effects were attributed to increased cement content of mortars from suspended cement particles present in wash water. A study (Selih et al., 2003) of recycled water produced in three Slovenian batching plants using 30 MPa concrete, 0.4 w/c with CEM I 42.5R cement also attributed the slump and air content reduction observed, to increased level of fine particles. Unlike the findings of Borger et al., 1994, they reported a 10% loss in strength as a result of using recycled water but also indicated improved water tightness. Sandrolini and Franzoni, 2001 also investigated the use of waste wash water from a medium sized ready-mix concrete plant for use as mix water, and showed that the 28-day compressive strengths of mixtures containing wash water were at least 96% of the strength of control mix. The concrete mix used had a w/c of 0.57 with CEM II/A-L 42.5R cement. Reduction in water absorption and porosity was also reported, indicating potential improvement of durability due to use of the wash water.

Depending on the water source or impurities present, certain recycled water may not be suitable for use in some concretes. Such findings were reported by Kuosa, 2005 in a study of five types of water containing detergents. The recycled water, used in proportions of 26 to 100% of mix water, had no effect on setting time and strength of concretes. But its use adversely affected the air-void structure and spacing factor, rendering its effect in air-entrained concrete a potential issue of durability concern regarding freeze-thaw resistance. Potential use of sludge water as mix water in concrete has also been investigated with mixed results. Concretes with w/c's of 0.5, 0.6 and 0.7 were studied (Chaatveera et al., 2006) for unit weight, slump, temperature rise, and mechanical properties of compressive strength, modulus of elasticity as well as drying shrinkage and acid attack. While the unit weight and temperature of fresh concrete were not affected by use of sludge water, slump and strength decreased. Increasing the proportion of sludge water in mix the water also increased drying shrinkage and weight loss due to acid attack.

Assessing suitability of recycled water for use in concrete

The traditional criterion widely employed to define suitability of mix water has been to compare its quality to fitness for drinking. However, specifications have been developed with limits of acceptable chemical impurities and their effects on certain concrete properties. These major criteria are given in SANS 51008 and ASTM C 94 in which the 7-day or 28-day compressive strength of concretes or mortars incorporating recycled water must achieve at least 90% of strength of control samples made with municipal or distilled water. For mixes containing recycled water, C 94 allows deviations of 1 hour and 1.5 hours for initial and final sets respectively, while SANS 51008 specifies deviations not exceeding 25% of setting time of a control mix made with distilled water.

While use of recycled water in the ready-mix concrete industry in South Africa is practiced, and encouraged in the interest of water conservation and environmental protection, there has been little or no investigation into its effects on properties of concrete. This study examined the recycled water quality at a ready-mix concrete plant in Gauteng, to determine its suitability as mixing water for concrete. Tests done on fresh and hardened properties of mortars and concretes include slump or flow, unit weight, setting time, total hydration heat output, compressive strength, and air permeability.

EXPERIMENTAL

Materials and mixes

A 200 litre water sample was collected from the water pit at the ready-mix concrete plant and kept in a drum for laboratory use. Water stored in the drum was manually agitated before being drawn for concrete mixing. In the water pit, an agitator is used to stir water to prevent solids from settling at the bottom. A 200 litre sample of municipal water was also collected to be used in the mixes at different replacement proportions. CEM I Portland cement compliant with SAN 50197-1 and ground granulated blast furnace slag (ggbs) complying with SANS 1491-1 were the cementitious materials used. In all the mixtures, 19 mm granite coarse aggregate, crushed granite sand, natural filler sand, and a water reducing admixture of type *Omega 101* were used.

Recycled water was used to replace tap water at the various levels of 0, 30, 50 and 100% then used for making mortars and concrete mixes. As given in TABLE 1, a total of eight concrete mixes with w/cm's of 0.5 were made. Four of the mixes contained 100% CEM I 42.5N while the other four mixes consisted of a 50:50 CEM I /ggbs blend. 100 mm cubes made were used to test 7 or 28 day compressive strengths, and 150 mm cubes were used for air permeability measurement done using the Torrent permeameter (Andrade et al., 2000). Four mortar mixes with a w/c' of 0.47 and aggregate/cement ratio of 2.5 were prepared then tested for flow using a flow table and for compressive strength using 50 mm cubes. No ggbs was used in the mortar mixes. Concrete mix designations C0%, C30%, C50% and C100% consisted of only CEM I cement while designations starting with 'CS' contained 50:50 CEM I/ggbs blend. Designations with 'M' indicate mortar mixes. The percentage value in the designation represents the proportion of recycled water in the mix water used.

[Insert TABLE 1]

Test procedures

Tests for slump, density and strength of concrete were done in accordance with SANS 5861 and SANS 51250 respectively, while setting time evaluation was conducted on all mixes according to BS 5075-1. The compressive strengths of mortars were tested in accordance with SANS 51255 while mortar flow tests were done to ASTM C 230. Water analysis was performed to ISO 9002 using analytical instruments consisting of Varian A10 Atomic Absorption Spectrophotometer, Liberty 150 ICP and PW 1400 X-ray spectrometers, Gas Chromatograph. The setting time, mortar strength tests and water analysis were done as required by SANS 51008 criteria for water evaluation. Measurement of the rate of heat evolution from hydrating cement in concrete was done by adiabatic calorimetry (Ballim and Graham, 2003). It involved placement of a one-litre sample of fresh concrete in a water bath such that a stationary air pocket separated the concrete sample from water. The signal from the thermal probe placed in the sample was computer monitored while the water bath was automatically maintained at constant temperature. The Torrent permeameter (Andrade et al., 2000) used to assess air permeability was an apparatus which created a controlled, uni-directional flow of air from the pores into the inner chamber, while the outer chamber acted as a guard ring, thus ensuring stable conditions of measurement. The non-destructive test gave a coefficient of permeability of concrete to air.

RESULTS AND DISCUSSION

Chemical analyses of recycled water

The analyses of recycled water and municipal water are reported in TABLE 2 giving amounts of chemical impurities. Values obtained for recycled water satisfy the maximum limits set out in SANS 51008. The pH of recycled water was 12.1 as compared to 7.9 for municipal water. The recycled water presumably contained highly alkaline suspended cement particles gathered from rinsing of truck mixers, which resulted in the high pH measured. The amount of chlorides and sulphates present in both the recycled water and municipal water were within required limits but the total dissolved solids (TDS) of 1991 mg/L in recycled water was significantly higher than in municipal water that had 107 mg/L TDS. While the alkali content due to sodium and potassium content is higher in recycled water, its sodium equivalent Na_2O_e of 58 ppm is much lower than the 600 ppm required to cause concerns for alkali silica reaction. Recycled water also contained high quantities of calcium, carbonate and bicarbonate, compared to municipal water. Comparing the analyses of recycled water with limits set out by the National Water Act of South Africa in terms of discharge into municipal storm water drains, the values for pH, conductivity, carbonates, calcium and TDS are all above the required maximum limits.

[Insert TABLE 2]

Effect of recycled water on properties of fresh concrete

The results for the properties of slump, density, setting times, strength, permeability, and heat of hydration tests conducted on concretes are given in TABLES 3 to 4, and FIGURES 1 to 5.

Slump and density

A trend is noticeable in FIGURE 1 showing that as the proportion of recycled water replacing municipal water in the mixes is increased, there is some steady corresponding decrease in slump. Recycled water contained high levels of fine particles possibly reducing the effective w/c ratio compared to corresponding mixes of municipal water. As shown in TABLE 3, results also gave a small but steady general increase in density of concrete as the proportion of recycled water used to replace municipal water was increased.

[Insert FIGURE 1]

Setting times

The setting time results of concrete mixes are reported in TABLE 3. The control mix C0% achieved an initial set of 2 hrs 10 mins and final set of 4 hrs 08 mins while mixes C30%, C50%, C100% containing recycled water all gave shorter initial and final setting times. C100% had the fastest setting times giving respective initial set and final setting times 20 and 35 minutes shorter than those of control mix. For mixes containing ggbs, CS0% achieved an initial set of 2hr 44 mins and a final set of 4 hr 35 mins, which are longer setting times than those of the control mix C0%. These longer setting times of CEM I /ggbs mixes are attributed to presence of slag, being known to increase setting time of concretes for the same w/c ratio. But for all mixes of the same binder, the CS - mixes also showed a relative reduction in setting times with increase in proportion of recycled water incorporated in the concrete mixtures. Mix CS100% showed fastest setting by 10 mins for initial set and by 13 mins for final set relative to CS0%. But the reduction in setting times for mixes containing ggbs were not as pronounced as for mixes without ggbs in the binder. Analysis of these results satisfy requirements of SANS 51008 as the setting times of the mixes made with recycled water are above 1 hour for initial set and below 12 hours for final set, and do not deviate by more than 25% from the setting times of their respective control mixes.

Heat output due to hydration

As shown in FIGURE 2, the concretes with or without recycled water showed similar characteristics in terms of total heat output, giving peaks of 313.2, 312.1, 296.8, 314.8 kJ/kg for mixes C0%, C30%, C50% and C100% respectively, although mix C50% indicated a slightly reduced total heat output. Similarly, the maturity heat rates obtained were not found to be significantly different.

[Insert FIGURE 2]

Effect of recycled water on hardened concrete properties

Compressive strength

FIGURES 3 and 4 show results of compressive strengths of hardened concrete for mixtures of CEM 1 and 50:50 CEM I/ggbs binders respectively. It can be seen that for concrete mixes, the difference in strengths was 2 to 3 MPa with no particular trend associated with the proportion of recycled water in the mixture. As with most other properties, small changes can normally be masked in concretes due to large volumes of aggregates. In this study, compressive strengths measured with mortars were used as required by specifications, to determine a clearer effect of using recycled water.

[Insert FIGURE 3, 4]

Air permeability

Permeability results are given in FIGURE 5 for mixes of CEM I and CEM I/ggbs binders. It can be seen that variation is relatively less for mixes of CEM I binder compared to mixes of CEM I/ggbs binder. The results indicate that blending of recycled water with tap water at varied levels has insignificant effect on permeability.

[Insert FIGURE 5]

Workability and strength effects of recycled water in mortars

Results of flow tests and 28 day compressive strengths measured for mortars are given in TABLE 4. It is clear that flow reduces in proportion to increase in recycled water used, confirming findings showing slump reduction already discussed earlier for concretes. The 28 day strength of mortar made with 100% municipal water was 62 MPa while mixes containing partial combinations of municipal and recycled water gave higher strengths than the control sample. The mix with 100% recycled water gave 66.5 MPa, an increase of 8% over the strength of control. Interestingly, compressive strength monitoring of ready-mixed concretes made using recycled water and used for a major project in Gauteng, South Africa has also found that use of recycled water consistently increases the strength of concrete (Attwell, 2010).

[Insert TABLE 4]

CONCLUSIONS

Based on results of this investigation, the following conclusions on use of recycled water from ready-mix concrete plants can be made:

1. Recycled water was highly alkaline with a pH of 12.1, had relatively high amounts of total dissolved solids, carbonates, and calcium compared to municipal water whose pH was determined as 7.9. Treatment of the waste wash water would be required prior to its discharge into municipal storm water system.

2. A trend showing some loss in workability of up to 10 mm, and an increase in unit weight were observed when recycled water was used to partially or fully replace municipal water

as mix water for use in concrete or mortars. Although these effects are small and may be considered negligible, they are notable and may be attributed to presence of fines and cement particles in recycled water.

3. Setting times of concretes made with CEM I binder were more prominently reduced by use of recycled water compared to concrete mixes incorporating slag. In plain concretes, initial and final setting times were reduced by as much as 20 and 35 minutes respectively, on use of 100% recycled water.

4. Compressive strength increase was realized as the amount of recycled water in the mixing water increased, when tested using mortars. Concrete did not show strength increase as found for mortars but all the concrete mixes satisfied achievement of at least 90% of strength of control with some results equaling or exceeding the control mix strengths. In mortars, an increase in strength of up to 8% was observed due to use of recycled water.

5. Observations indicate that recycled water may be used as mix water without causing significant adverse effects to concrete properties.

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TABLE 1 Concrete mixtures

Materials	Concrete mixtures and designations							
	C0%	C30%	C50%	C100%	CS0%	CS30%	CS50%	CS100%
Cement (CEM I), (kg)	384	384	384	384	192	192	192	192
GGBS (kg)	0	0	0	0	192	192	192	192
19 mm stone (kg)	1140	1140	1140	1140	1140	1140	1140	1140
Crusher sand (kg)	640	640	640	640	630	630	630	630
Filler sand (kg)	65	65	65	65	63	63	63	63
Recycled water (kg)	0	58	96	192	0	58	96	192
Fresh water (kg)	192	134	96	0	192	134	96	0
Total water (kg)	192	192	192	192	192	192	192	192
Water reducer (g)	1920	1920	1920	1920	1920	1920	1920	1920

TABLE 2 Specifications and chemical analyses results of water

	SANS 51008	NWA*	Recycled water	Municipal water
pH		4.5-9.0	12.11	7.9
Conductivity, mg/L		150	510	25
Fluoride, mg/L		1	0	0.19
Nitrite, mg/L		4	0	0.73
Nitrate, mg/L	500	44	6.51	1.2
Chloride, mg/L	1000	200	45.36	9.97
Sulphate (SO_4), mg/L	2000	400	27.27	10.9
Phosphate, mg/L	100	N/S	0	0
Carbonate, mg/L		20	660.3	0
Bicarbonate, mg/L		N/S	1389.58	93.94
Alkalinity ($CaCO_3$), mg/L		N/S	2239.5	77
Sodium, mg/L	1500	200	28.96	7.64
Potassium, mg/L		50	43.48	2.63
Calcium, mg/L		150	484.51	21.23
Magnesium, mg/L		70	0.54	5.88
Boron, mg/L		1.5	0	0.01
Total dissolved solids, mg/L	50000	1000	1991.2	107.03

*National Water Act

TABLE 3 Fresh concrete properties measured for various mixes

	C0%	C30%	C50%	C100%	CS0%	CS30%	CS50%	CS100%
Slump (mm)	70	70	65	60	80	75	70	70
Unit weight (kg/m^3)	2424	2434	2428	2439	2415	2409	2418	2440
Initial setting time (hr:mins)	02:10	02:12	02:09	01:49	02:44	02:46	02:55	02:32
Final setting time (hr:mins)	04:08	03:55	03:52	03:33	04:35	04:34	04:32	04:22
Compressive strength (MPa)	52.5	51.8	54.4	53.8	47.2	46.8	45.9	47.1
Air permeability (x10^{-16} m^2)	0.122	0.118	0.121	0.152	0.222	0.125	0.249	0.136

TABLE 4 Flow and 28-day compressive strengths of mortars

	M0%	M30%	M50%	M100%
Flow (mm)	600	600	565	535
Strength at 28 days (MPa)	61.8	62.0	64.2	66.5

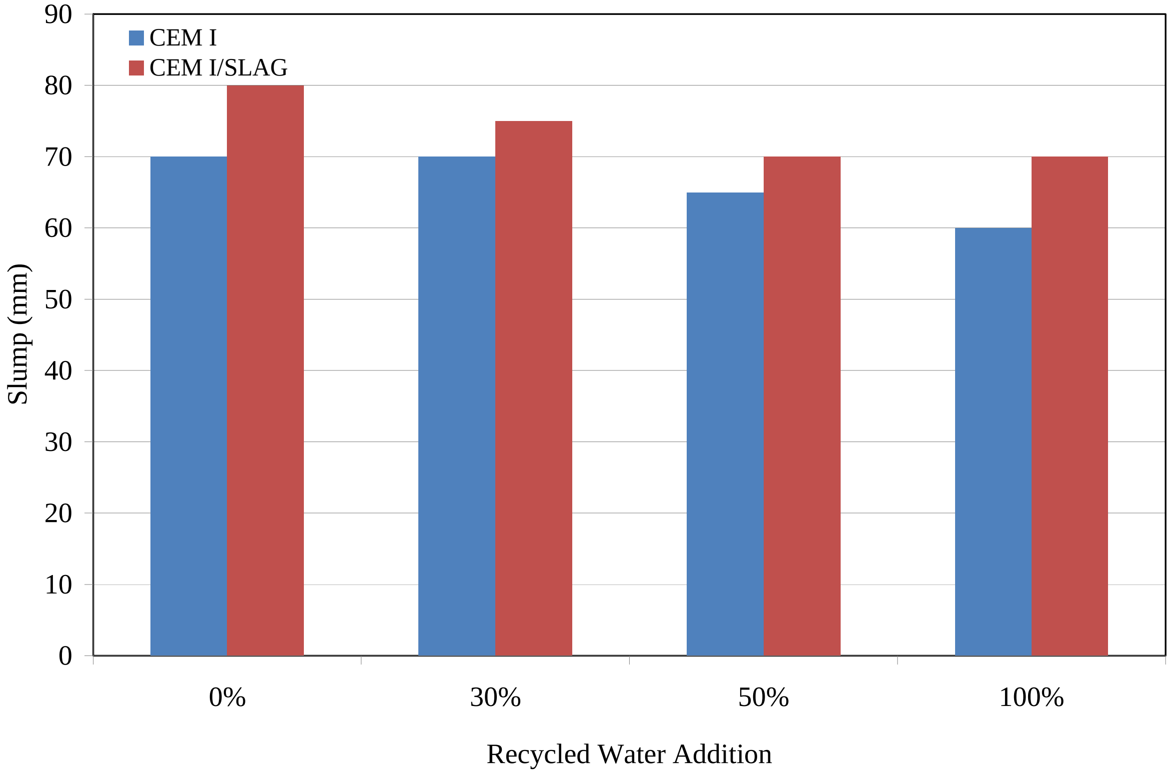

FIGURE 1 Slump of fresh concretes made with recycled water

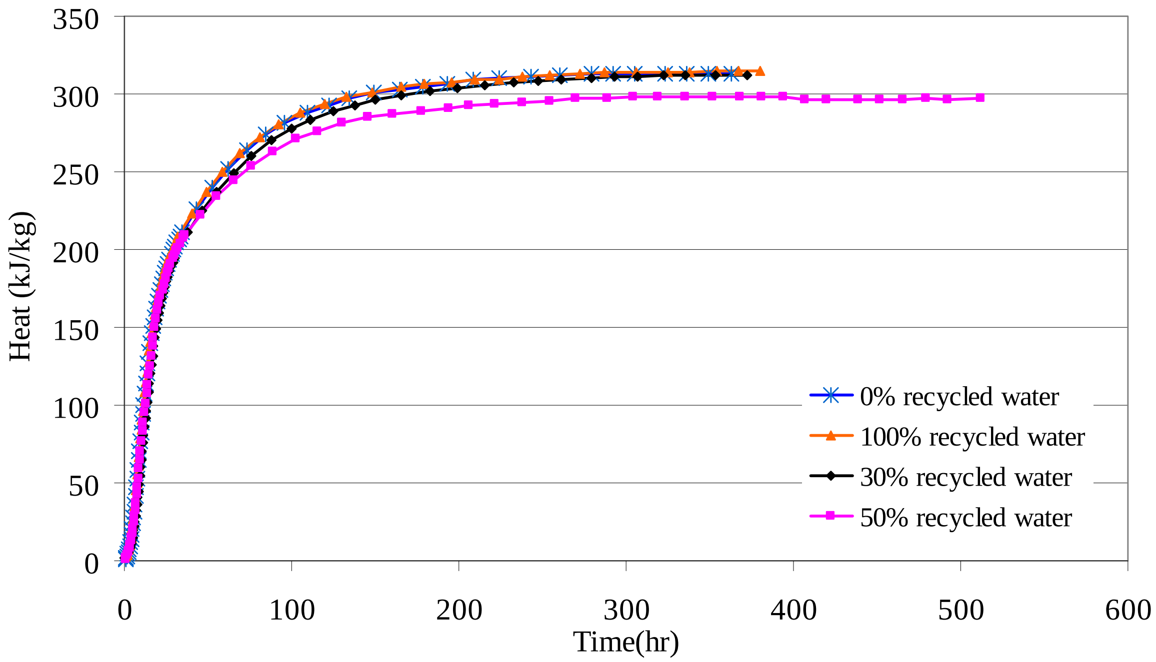

FIGURE 2 Heat output for CEM I concretes (‘C’ mix designation) of 0.5 w/c made with varied proportions of recycled water

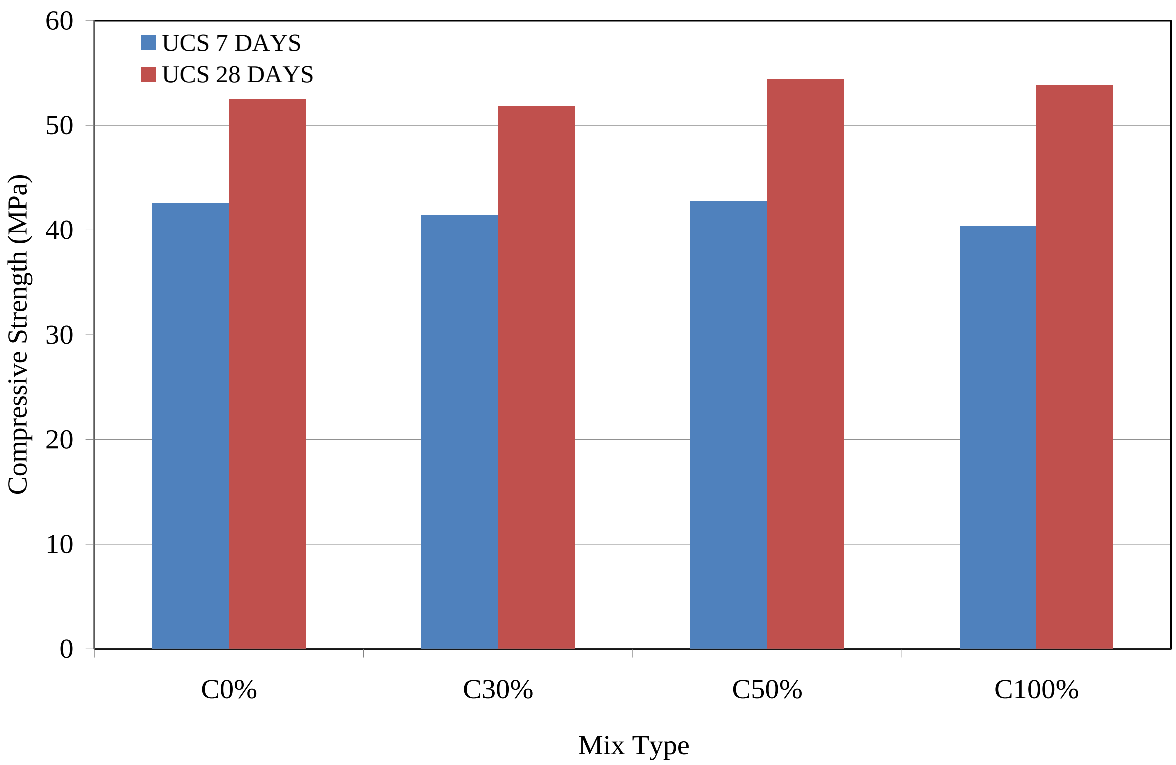

FIGURE 3 Compressive strengths of CEM I (‘C’ mix designation) concrete mixes

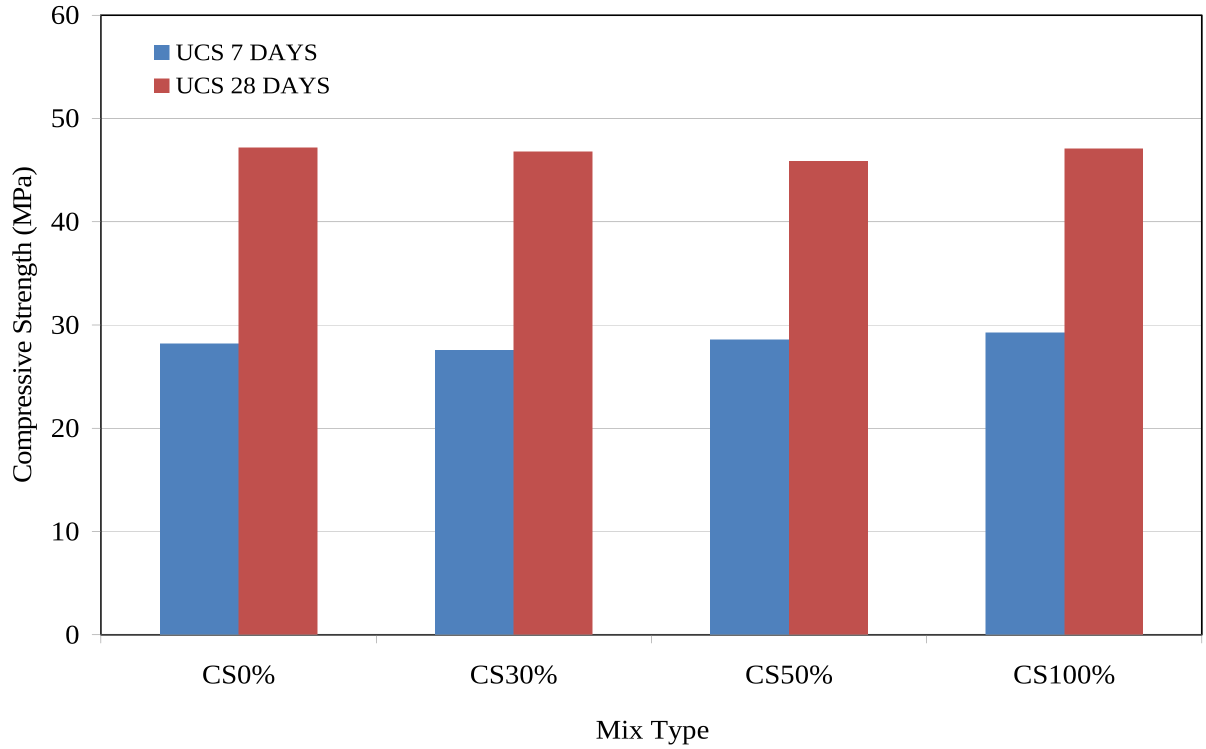

FIGURE 4 Compressive strengths of CEM I/ggbs (‘CS’ mix designation) concrete mixes

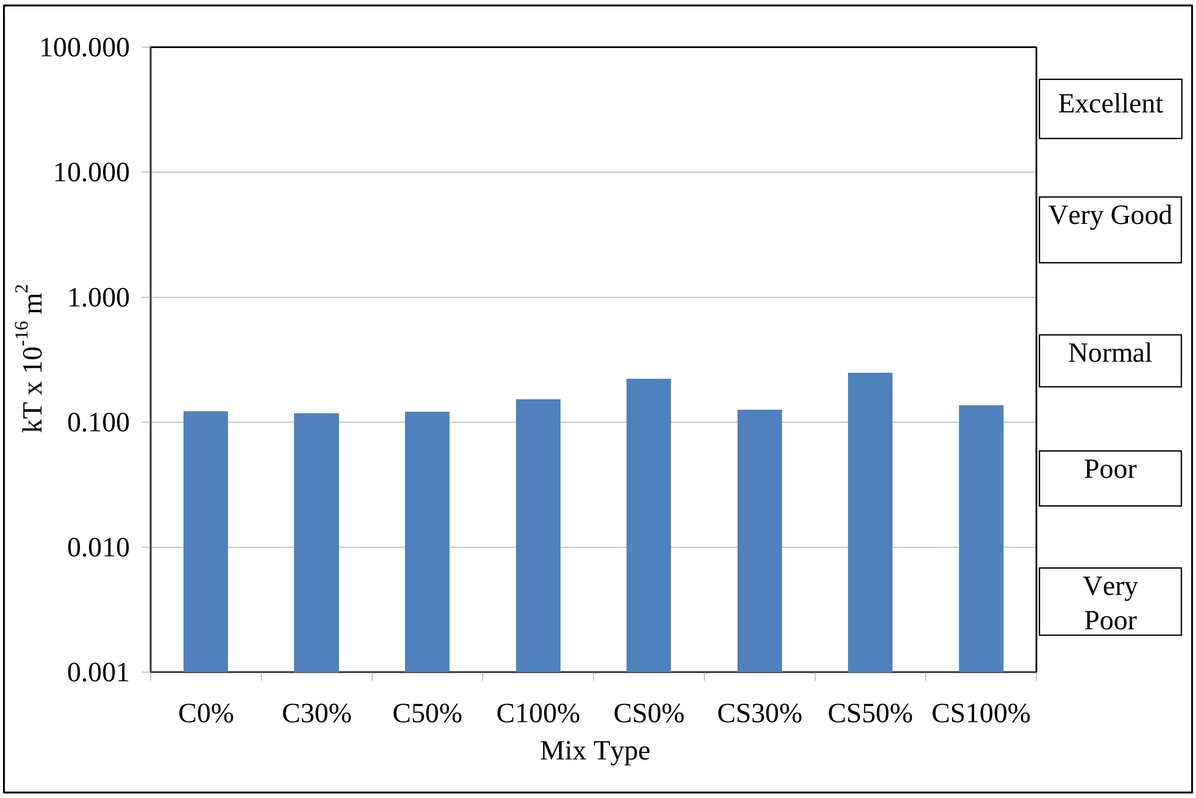

FIGURE 5 Permeability of concrete mixes made with varied proportions of recycled water