The Effect of Dry Wastewater Sludge as Sand Replacement on Concrete strengths

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Abstract

The ever-increasing population continues to have the ripple effect on the increase in sludge production. Dry sludge generally is heaped up on a landfill, which causes environmental pollution. Therefore, the study on the alternative use of dry sludge is of paramount importance. The dry wastewater sludge obtained from the Northwest treatment plant (NWTP) in Johannesburg, South Africa was used in this study as partial replacement of sand in concrete. Concrete were produced with 0%, 1%, 3% and 5% sand replacement with dry wastewater sludge. Compressive strength and splitting tensile strength tests were performed to study the effect of the dry sludge on concrete strengths. Samples for compressive strength test were prepared with fixed Water-cement (W/C) ratios of 0.67, 0.69 and 0.8 and cured for 3, 7, 28 and 90 days. However, samples for splitting tensile strength test were prepared with fixed Water-cement (W/C) ratios of 0.67 and 0.69 and cured for 28 and 90 days. The results showed a notable reduction of concrete strengths with an increase in sludge replacement. The compressive strength of 1% replacement at a W/C of 0.67 after 90 days curing recorded 16% reduction compared to the control sample, while 13% reduction was recorded for splitting tensile strength. The 90 days strength results showed that the sludge could be utilized (for non-structural purposes) as a partial sand replacement of concrete mixtures at a W/C of 0.67 with optimum percentage lower than 3%.

Keywords:

Dry wastewater sludge, Concrete, Compressive Strength, Splitting Tensile Strength,

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1. Introduction

To address a growing concern about the increasing deterioration and degradation of the human environment and natural resources, the World Commission on Environment and Development [1] released “Our Common Future”. The investigation underpinned sustainable development as the development that meets the needs of the present without compromising the ability of the future generations to meet their own needs [1].

Sustainability is generally focused on environment, economics and social needs [1]. More focus on the environment is needed to ensure that prudent measures that are effective and comprehensively engineered to preserve our biodiversity and natural resources are implemented. In our increasingly resource-constrained world, environmental sustainability with reference to waste rotates around the three R’s in the waste hierarchy: Reduce, Re-use and Recycle.

In South Africa, the environmental management practices surrounding sustainability revolve around the establishment of best practices to deal with waste generation, particularly wastewater sludge. The development of “Guidelines for the Utilisation and Disposal of Wastewater Sludge, Volume 1” by Snyman and Herselman [2] was aimed at adopting proper procedures for compliance, handling and disposal of wastewater sludge. Though these guidelines are principles of adoption and compliance; mishandling problems associated with sludge remain a major problem for wastewater treatment managers. Innovative methods to find alternative ways of disposal of this by-product cannot be ignored in this sustainable driven environment.

The use of concrete is in a rise globally due to its demand in the engineering and the built environment. It plays a vital role in all infrastructure construction and earthworks. Concrete’s versatility allows it to bind with many types of materials and engineers are focusing on finding new, cheaper, and environmentally friendly aggregates that can increase the durability of concrete while decreasing the production cost at the same time. According to Swierczek et al. [3], there is a promising utilisation of sewage sludge in concrete when used as lightweight aggregates. Rabie [4] explored the use of wastewater dry and wet sludge as cement replacement. He reported that replacement of sludge with cement in concrete resulted to reduced compressive strength to a tone of 61.6% for dry sludge and 68.5% for wet sludge at 28 days curing. The observation of Rabie [4] was confirmed by Ramirez et al. [5], who reported that sludge in its wet state reduced the compressive strength of concrete significantly. It is evident that replacement of cement with sludge, especially wet sludge, will not yield a desired strong concrete [4-6]. Alternatively, Sludge usage in its dried state as sand replacement in concrete may be promising. This study aimed at incorporating dry wastewater sludge as partial replacement of fine aggregate in concrete mixes. The effect of the dry wastewater sludge on the chemical composition, workability, compressive strength and splitting tensile strength of concrete is investigated and discussed.

2. Experimental Details

2.1 Materials

Portland Cement (CEM II/A-M (V-L), 42.5R of the same batch, supplied by Afrisam South Africa (Roodepoort), was used throughout the investigation. The expected target strength of the concrete samples was 42.5 MPa at 28 days. The target strength was guided by the measure of strength on the cement as per the common concrete demand and supply within the Johannesburg region under AfriSam. Tap water, free from salt or any other soluble components was used. Water was kept at a cool/room temperature before use. The water supply was direct and reticulated by the Johannesburg Water, which is the custodian of all the reticulated water under the City of Johannesburg Municipality.

In general, aggregates comprise between 60 and 75 % of the overall volume of a concrete mix. The concrete properties are highly dependent on the aggregates selected. Afrisam South Africa, uses a crushed granite sand and the maximum sized coarse/crushed stone of 22.4 mm from the Eikenhof Quarries. These aggregates are commonly used by Johannesburg concrete manufacturers. SANS 5844 [7] and SANS 5845 [8] were used to determine the density of the coarse aggregates, before testing was conducted. The crushed sand was treated in the same manner as the coarse aggregates and it was ensured that as per AfriSam standards, the model was in accordance with SANS 5838 [9] and SANS 201 [10]. In accordance with SANS 5844 [7] and SANS 5845 [8], the recorded densities for the tests were: Relative Density (RD) of 2.91, Loose Bulk Density (LBD) of 1780 kg/m^3 and Consolidated Bulk Density (CBD) of 2051 kg/m^3. The grading analysis of the crushed sand was done according to SANS 201 [10]. The grading curve is shown in Fig. 1. The top left of the graph shows that the bulk of the quantity was fine sand, compared to no records of retained coarse sand on the bottom right of the graph. The wastewater sludge was obtained from the Northwest treatment plant (NWTP) in Johannesburg, South Africa.

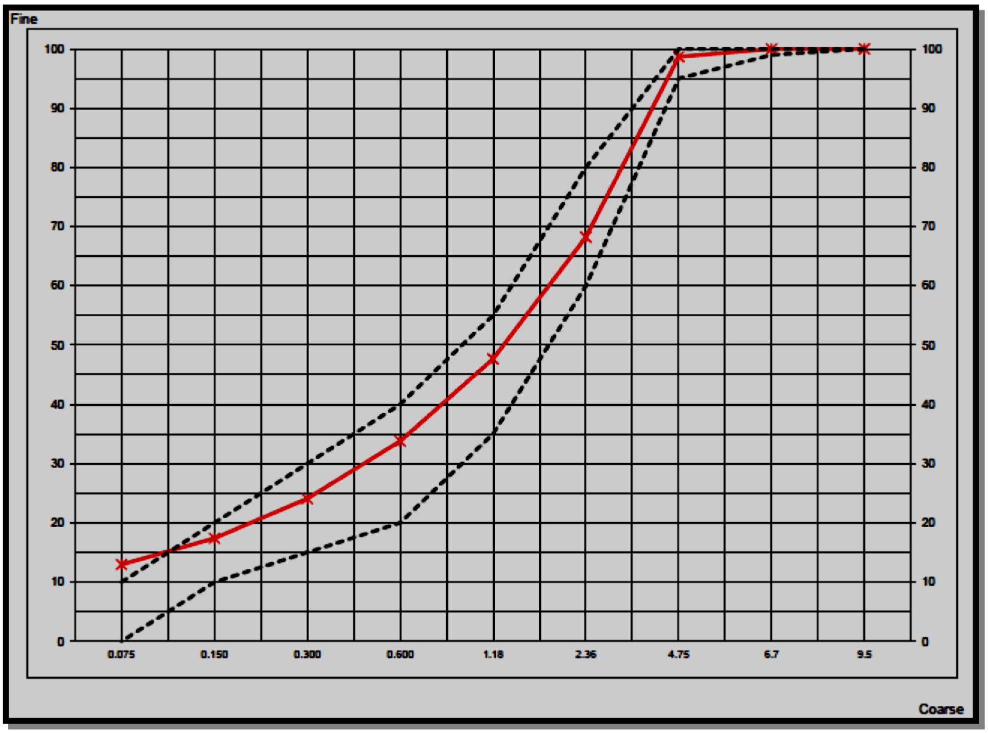


Fig. 1: Grading Curve of the crusher sand

2.2 Sample preparation

Samples were mixed in accordance with ASTM C192, in line with the SANS 5863 [11] for hardened concrete. Concrete with 0 % sludge replacement was used as the control. Four comparative mixes containing 0 %, 1 %, 3 % and 5 % of sand-sludge replacement were used to examine the effect of the included sludge on the strength of the concrete. Mineral or chemical admixtures were not added to any of the mixes. Three water cement ratios (0.67, 0.69 and 0.80) were selected. The mix proportion of the samples are recorded in Table 1. Based on the target strength of 42.5 MPa at 28 days, the mix design resulted in different quantities of cement, crushed sand and stone required for the three W/C ratios.

Table 1: Mixture Proportions for 1 m^3 of Concrete Samples.

Mix	Samples	Cement	Crushed sand (kg)	22.4 mm Stone content (kg)	Municipal water (kg)	Sludge replacement (kg)	W/C	Slump (mm)
MIX A	Control (0.67)	312	1013	1050	208	0.00	0.67	100
MIX B	Control (0.69)	300	990	1050	208	0.00	0.69	100
MIX C	Control (0.80)	250	1050	1050	200	0.00	0.80	100
MIX A	1 % Sludge/0.67	312	1003	1050	208	10	0.67	105
	3 % Sludge/0.67	312	983	1050	208	30	0.67	115
	5 % Sludge/0.67	312	962	1050	208	51	0.67	15
MIX B	1 % Sludge/0.69	300	980	1050	208	10	0.69	125
	3 % Sludge/0.69	300	960	1050	208	30	0.69	125
	5 % Sludge/0.69	300	940	1050	208	50	0.69	60
MIX C	1 % Sludge/0.80	250	1040	1050	200	11	0.80	110
	3 % Sludge/0.80	250	1019	1050	200	32	0.80	115
	5 % Sludge/0.80	250	998	1050	200	53	0.80	75

All concrete mixes prepared for all the tests were subjected to a mechanical mixing process prior to the casting of 100 mm cubes. After mechanical vibration, the cubes were kept in the mould, covered with polythene plastic for 24 hours at a controlled room temperature of approximately 22 °C before submerging in a water curing bath. This process was in accordance with SANS 5862-1 [12] and SANS 5861-3 [13].

2.3 Test procedures

2.3.1 X-Ray Fluorescence (XRF) Analysis

The XRF analysis was utilized for determining the chemical composition of the dry wastewater sludge. A representative sample was used for this test. The analysis was done through a Katanax fluxer Panalytical + XRF spectrometer (AfriSam- South Africa).

The loss on ignition (LOI) was determined by firing the sampled sludge at 1000°C for at least 3 to 4 hours until a stable weight was recorded. A glass disk was prepared by fusing a mixture of 1 g of the dry wastewater sludge sample with 6 g of $Li_2B_4O_7$ at 1000 °C.

2.3.2 Workability

The slump test was used as a measure of the workability for all the concrete mixes. Mixing and testing procedures were done according to SANS 5861-2 [14]. "Workability is defined as the easement at which the freshly mixed concrete can be placed, compacted and finished".

2.3.3 Compressive strength test

The compressive strength test was conducted following the mixing procedure according to SANS 5863 [11]. The concrete samples cured in a water curing bath were tested for compressive strength at the end of 3, 7, 28 and 90 days. Compressive strength was calculated using Eq. (1).

$$F_c = \frac{P}{A} \quad (1)$$

where:

F_c = Compressive strength, N/mm^2

P = Load at failure, N

A = Cross-sectional area, mm^2

2.3.4 Concrete splitting tensile strength test

The splitting tensile strength was determined at the end of the 28 and 90 days curing periods. The standard 100 mm cubes were prepared for the splitting tensile strength, in accordance with SANS 5863 [11] and ASTM C 496 [15]. The mixing procedures and curing methods were identical to those applied to the compressive strength samples. The splitting tensile strength of concrete was determined according to SANS 6253 [16]. The samples were batched and prepared as per SANS 5861-3 [13] and SANS 5861-2 [14]. Split tensile strength was calculated using Eq. (2).

$$F = \frac{2P}{\pi . a^2} \quad (2)$$

Where:

F = Tensile strength (N/mm^2)

P = Compressive load at fracture (N)

a = Size of cube (mm)

3. Results and Discussion

3.1 Workability

The workability results presented in Table 1 indicate that 1 % and 3 % replacement of sand with dry wastewater sludge resulted in increased workability on the sludge concrete, compared to the control mix. However, a further increase of sludge to 5 % affected the workability and setting time process. The decline in the slump for the 5 % replacement was a result of the high-water absorption of the sludge due to the high surface area of the solids. This outcome is similar to the findings by Snyman et al. [2], Mun 2007 [17] and Jamshidi et al., 2011 [18], on the impact of organic matter content on workability.

This observation may have adverse effect on compressive strength as high sludge content with low W/C will result in a loss in compressive strength [19]. The findings by Monzo et al. [20] concluded that the non-spherical shape and particle sizes of the dry wastewater sludge had an adverse effect on workability. This is the same outcome and shape that the sludge sampled for this research provided. An increased W/C ratio of 0.69 showed increase in slump values. The 5 % sludge replacement for 0.69 W/C had a higher slump than for 0.67 W/C at 5 % replacement. This is attributed to the fact that increasing the water content improved the workability of the concrete, which may result to lower strength.

A W/C of 0.8 produced a reduced slump pattern compared to Mixes with 0.67 and 0.69 W/C at 1 % and 3 % replacements. This result can be linked with the higher content of sand required for this W/C to maintain the target strength of 42.5N. The higher the sand in the mix, the higher the content of the sludge that is added for all the percentage replacement. The reduction in slump as compared to 0.67 and 0.69 W/C can be as a result of the excessive water absorption by dry wastewater sludge, resulting in a lower slump value of fresh concrete [19]. The 5 % dry wastewater sludge replacement for 0.8 W/C yielded a better workability than that of 0.67 and 0.69 W/C. This is accredited to the fact that the high organic content in the sludge balanced the water absorption, resulting in relatively good workability of concrete. These findings agree with Mun [17].

3.2 XRF Results

The representative samples of the dry wastewater sludge were subjected to the XRF analysis, to determine the chemical compositions. The XRF results of the dry wastewater sludge as indicated in Table 2 were obtained after ignition at 1000°C. As was the case in the findings of Jamshidi et al. [21], the results of the XRF indicate a high loss on ignition (LOI).

Table 2: XRF Analysis of dry wastewater sludge

Elements	LOI	SiO_2	Al_2O_3	CaO	Fe_2O_3	MgO	TiO_2	Mn_2O_3	Na_2O	K_2O	P_2O_5
(%)	74.6	30.12	7.25	25.76	3.83	3.92	1.48	0.47	0.05	2.05	23.7

The XRF results in this research showed no chloride content. These results are in agreement with the research findings of Mun [17], Valls et al. [22] and Rodriguez et al. [23]. The clear visual assessment of change on ignition was evidenced by colour patterns from white-creamy to grey, as also observed by Yague et al. [24]. The outcome also showed a high percentage of P_2O_5, SiO_2, and CaO due to excessive organic content and clay content in the wastewater sludge [21]. However, the high content of P_2O_5 may result in retarding hydration process. Previous researchers have shown that the present of P_2O_5 slows down the hydration reaction [25, 26]. According to Naus et al [25], P_2O_5 will develop strength more slowly due to the reduction of C_3S:C_2S ratio it will cause.

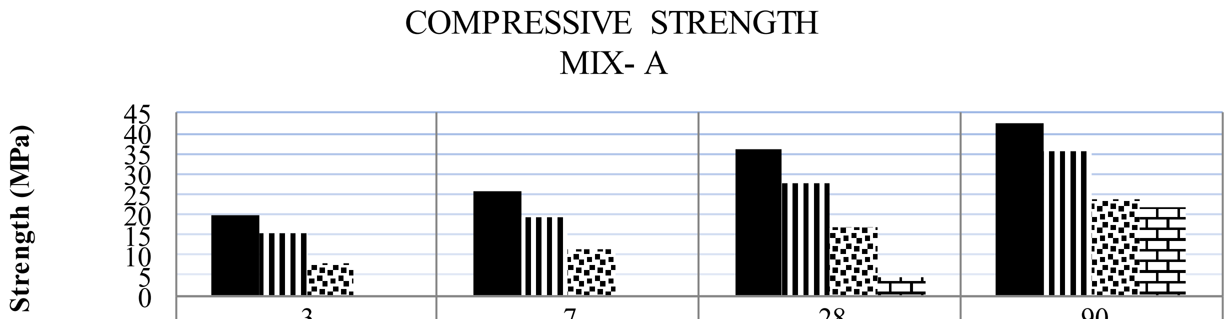
The high organic content is attributed to the pre-sampling of the wastewater sludge, before it was disposed away on a dedicated land disposal [23]. Jamshidi et al. [18] in their research, concluded that 54.5 % of SiO_2 made the sludge more compatible in concrete mixing. The dry sample used in this study has SiO_2 content of 30.12%, which resulted in 45% percentage difference from the result of Jamshidi et al. [18]. Therefore, before a similar conclusion can be drawn that the sludge used in this study is compatible in concrete making, its effects on strengths need to be analysed as discussed in the successive sections.

3.3 Compressive Strength

3.3.1 Compressive Strength of Mix A (0.67 W/C)

Fig. 2 indicates that the control mix (0 % sludge) achieved the target strength of 42.5 MPa at 90 days, as per the specifications of CEM II/A-M (V-L) 42.5R (Afrisam). The samples with 5 % wastewater sludge replacement did not exhibit any measurable strength within the first 7 days, this could be attributed to the reduced cohesiveness of the concrete at this replacement level.

At 3 days, the control mix showed a higher early strength development than the 1 % and 3 % sludge replacements. This is similar to the findings by Valls et al. [22], where wastewater sludge had an effect on early strength development. The 1 % sludge replacement achieved 35.6 MPa at 90 days, which can be attributed to the low effect of the small dosage of the sludge on the strength of concrete. The 3 % and 5 % sludge replacements had respectively recorded 23.8 MPa and 21.8 MPa at 90 days, which is approximately 50 % less, relative to the control mix. This may be directly attributable to the high-water absorption in wastewater sludge concrete, which resulted in retardation [17]. In addition, the slow strength development may also be linked to the retardation of cement hydration caused by the presence of organic substances especially P_2O_5.



	3	7	28	90
Control - 0	19.7	25.9	36.2	42.6
Mix - 1%	15.2	19.5	27.7	35.6
Mix - 3%	7.9	11.6	17	23.8
Mix - 5%	0	0	4.6	21.8

Period (Days)

Fig. 2: Compressive Strength – Mix A (0.67 W/C)

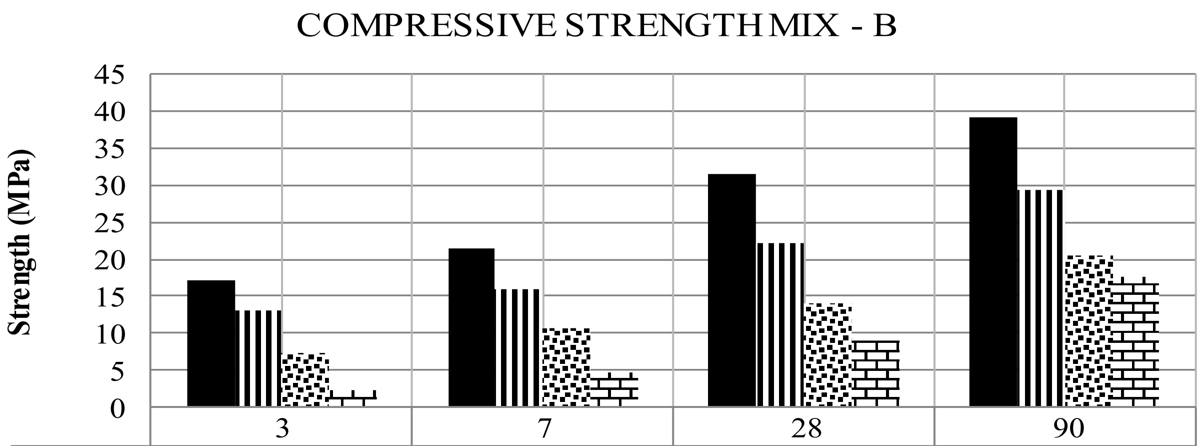
3.3.2 Compressive Strength of Mix B (0.69 W/C)

As generally expected, with an increase in W/C (from 0.67 to 0.69), the control mix (0 % sludge replacement) showed a concomitant reduction in compressive strength from 42.6 MPa to 39.2 MPa, as shown in Fig. 3.

At 90 days, the 1 % and 3 % sludge replacement respectively recorded a decline in compressive strength from 29.4 MPa and 20.4 MPa, compared to 35.6 MPa and 23.8 MPa in the case of the W/C of 0.67 mixes respectively. This reduction in strength was a further attribute that increasing W/C affects the long-term behaviour of concrete's compressive strength.

At 3 and 7 days, the 5 % sludge replacement respectively recorded an early strength development of 2.2 MPa and 4.6 MPa, compared to the 0 MPa recorded at 0.67 W/C. According to Cyr et al. [19], water content will not always have an adverse effect on the dry wastewater sludge concrete mixes.

The concrete mix containing wastewater sludge performed better in the case of the longest curing period. This was also found to be the case by Jamshidi et al. 2012. Valls et al. [22], Yague et al. [24] and Jamshidi et al. [27] in their respective researches, concluded that dry wastewater sludge with high SiO_2 could be used at higher quantities in concrete mix designs. However, due to gradual strength development, considerable reduction in water content must be considered. It was observed that the higher W/C affects the strength development negatively due to high water dosage. These findings are applicable to the 0 %, 1 %, 3 % and 5 % sludge replacement in this research.



	3	7	28	90
Mix 0%	17.1	21.5	31.5	39.2
Mix 1%	13	16	22.1	29.4
Mix 3%	7.2	10.6	14.1	20.4
Mix 5%	2.2	4.6	8.9	17.7

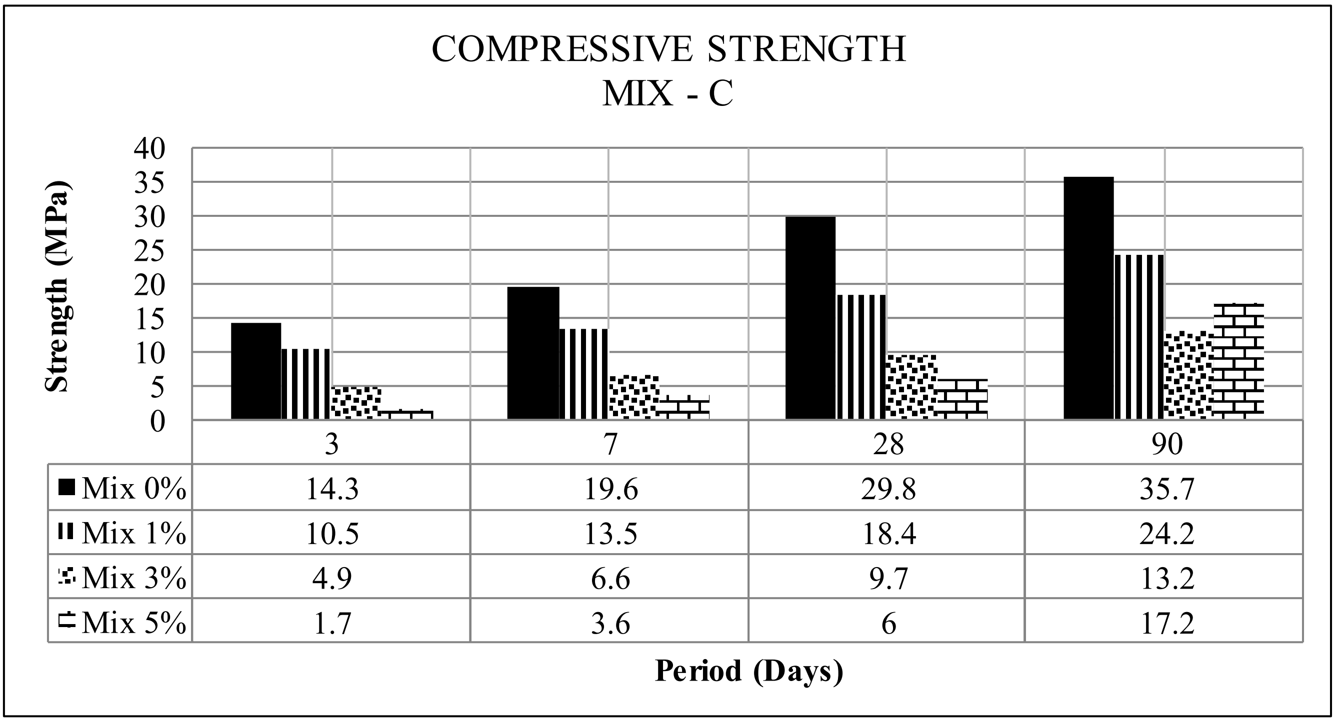
Period (Days)

Fig. 3: Compressive Strength – Mix B (0.69 W/C)

3.3.3 Compressive Strength of Mix C (0.80 W/C)

The mix proportion of Mixture-C had a W/C ratio of 0.8. The standard W/C's that are usually used in concrete are not above 0.7. However, a W/C ratio of 0.8 was utilized to further evaluate any effect that a higher water content had on wastewater sludge with excessive phosphorus oxide. To note, this W/C was excluded in the splitting tensile strength test.

Fig. 4 indicates the compressive strength development of concrete of Mix C. Fig. 3 shows the same pattern as that pertaining to the W/C of 0.69, where early strength development for 0 %, 1 %, 3 % and 5 % was recorded. At the 90 days period, none of the replacements reached the target strength of 42.5 MPa. The 5 % sludge replacement only achieved 6 MPa at 28 days, which is attributable to slow strength development. This result can be due to high water content which affected the binding content of wastewater sludge with concrete components. Jamshidi et al. [27] determined that increasing both the water content and dry sludge content in concrete reduced its workability considerably. This reduction in workability has a direct affect in the early strength development between 3 and 7 days. These findings are evident in the W/C of 0.8 compared to W/C of 0.69. Jamshidi et al. [21] concluded in their research that the negative effect of the dry sludge on the mechanical properties of concrete is due to the presence of organic matter content. They also concluded that water absorption by sludge resulted in a low binding content. This finding by Jamshidi et al. [21] is comparable to this research as it was evident in this mix design. The organic matter in sludge increased the water absorption, resulting in a low binding effect, which in the long-term reduced the strength development on of all the mixes.



	3	7	28	90
Mix 0%	14.3	19.6	29.8	35.7
Mix 1%	10.5	13.5	18.4	24.2
Mix 3%	4.9	6.6	9.7	13.2
Mix 5%	1.7	3.6	6	17.2

Fig. 4: Compressive Strength– Mix C (0.8 W/C)

3.4 Splitting Tensile Strength

3.4.1 Splitting Tensile Strength of Mix – A (0.67 W/C)

In Mix A, a W/C of 0.67 was utilized to compare the splitting tensile strength at 0 %, 1 %, 3 % and 5 % sludge replacement for the 28 and 90 days periods. The samples underwent the same mixing and curing conditions before finally assessing their failure mode at each age. From Fig. 5, a comparison between 0 % and 1 % sludge replacement indicates that the 1 % sludge replacement concrete had 28.75% more strength development between 28 and 90 days than 0 % sludge. The outcome shows that each increase of wastewater sludge content leads to a decrease in the splitting tensile strength as detailed in Fig. 5. This is comparable to the outcome by Jamshidi et al. [24] on their research regarding performance of sludge concrete on splitting tensile testing. The effect of wastewater sludge is visible in both the 3 % and 5 % sludge replacement for the early and long-term strength development. In these samples (3 % and 5 % sludge replacement), the splitting tensile strengths are quite low compared to the control sample at both testing ages.

These failures are directly attributable to the organic matter content in sludge, which had a negative effect on the splitting tensile. It can be summarized that the higher the organic matter in sludge, the more the adverse effect it has on water absorption, setting of concrete, and the early and long-term strength development.

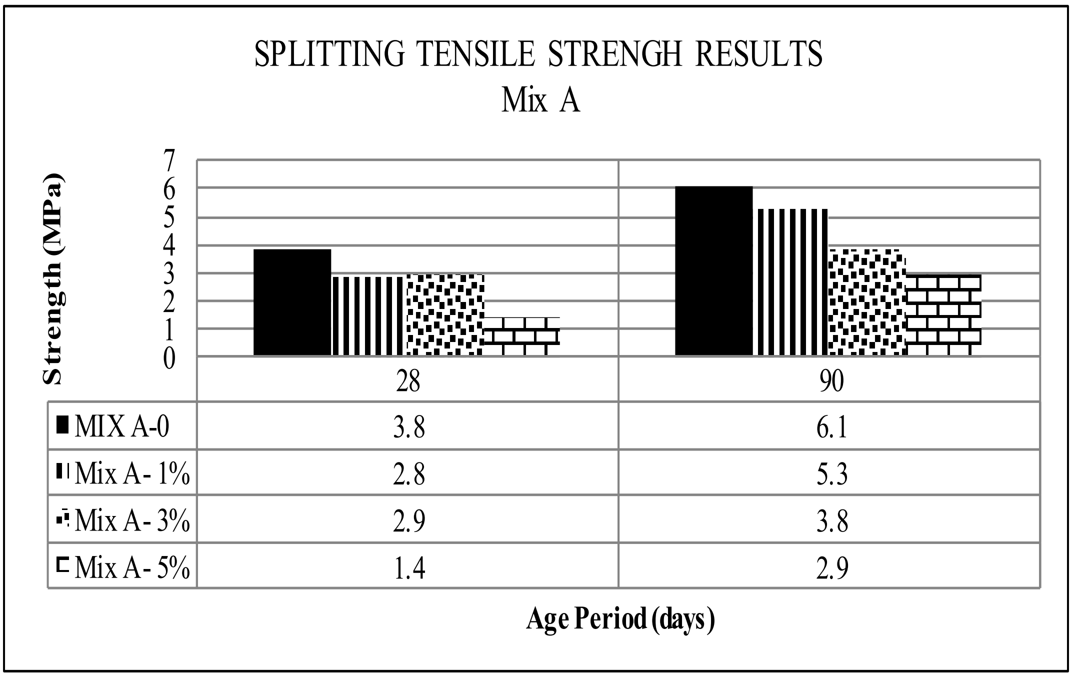


Fig. 5: Splitting Tensile Strength Chart – Mix A (0.67 W/C)

3.4.2 Splitting Tensile Strength of Mix – B (0.69 W/C)

Fig. 6 presented the splitting tensile strength results of Mix B. As shown in Fig. 6, the control (0 % sludge replacement) concrete had 27.9 % strength development between 28 days and 90 days. At 90 days, the 1 % replacement was still lower than the 0 % at 28 days, which indicated that an increase in water content reduced early strength development. It was found by Jamshidi et al. 2011b that increasing the percentages of dry sludge in concrete with higher water content increased early failure on splitting tensile strength. This conclusion was particularly evident in the case of the 5 % sludge replacement.

When comparing Fig. 5 to Fig. 6, it shows that the higher the W/C, the lower the splitting tensile strength results obtained for all the samples at 90 days. This confirmed the observation of Cyr et. al. [19] that water content has direct effect on strength of concrete, regardless of the proportion of sludge integration.

These findings are in agreement with the effect of water content when measuring splitting tensile strength for sludge concrete by Valls et al. [22]. It can therefore be concluded in this research that both wastewater sludge and water content increment had a negative impact on the strength of concrete.

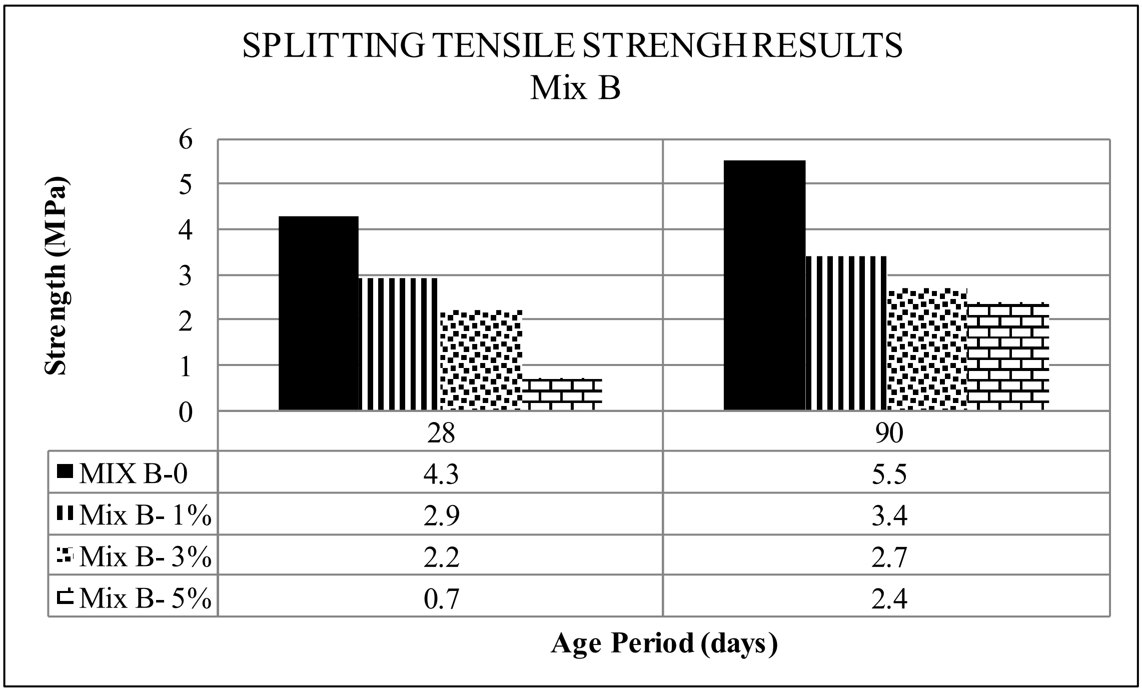


Fig. 6: Splitting Tensile Strength Chart – Mix B (0.69 W/C)

4 Conclusions

Dry wastewater sludge was used as a partial sand replacement in concrete production and the effect on the concrete strength were analysed and discussed. The results revealed that the balance between water and sludge quantities directly influenced the workability of concrete with sludge. The various W/C's of 0.67, 0.69 and 0.8 had little effect on the workability of concrete for the 1% and 3 % sludge replacement. However, the workability of 5 % sludge replacement was negatively affected. The XRF results showed a high weight loss on ignition (LOI). The presence of organic matter in the sludge caused an adverse effect on the final compressive strength results for 1 %, 3 % and 5 % sludge replacement. An assessment of the concrete containing sludge, relative to the control mix, proved that dry wastewater sludge could be utilized as a partial sand replacement of concrete mixtures at a low W/C (of 0.67) with optimum percentage lower than 3%. This is based on the long-term strength development for all replacements for 90 days curing period. The dry wastewater sludge concrete can be utilized for brick production, where high strength is not required.

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References

[1] World Commission on Environment and Development (WCED). Our Common Future. Oxford: Oxford University Press. (1987).

[2] H.G. Snyman, J.E. Herselman. WRC Report no: TT261/06. ISBN 1-77005-422-7, South Africa. (2006).

[3] L. Swierczek., B.M. Cie_slik, P.K. Onieczka, Journal of Cleaner Production. 200 (2018) 342 - 356

[4] G.M. Rabie, Journal of Civil & Environmental Engineering, 6:1(2016) 2-7

[5] K.G. Ramirez, E. Possan, B.G. Dezen, M. Colombo, Management Of Environmental Quality: An International Journal, 28, Issue 6 (2017) 821-838

[6] A.D. Mandlik, S.A. Karale, International Journal for Research in Engineering Application & Management, 03 Issue 10 (2018) 22-27

[7] SANS 5844:2006: Particle and Relative density of aggregates.

[8] SANS 5845:2006: Bulk densities and voids content of aggregates.

[9] SANS 5838: 2006: Sand equivalent value of fine aggregates.

[10] SANS 201:2008: Sieve Analysis, fines content and dust content of aggregates.

[11] SANS 5863: 2006: Concrete testing – Compressive strength of hardened concrete.

[12] SANS 5862-1: 2006: Concrete testing – Consistence of freshly mixed concrete (slump test).

[13] SANS 5861-3: 2006: Concrete testing making and curing of test specimens.

[14] SANS 5861-2: 2006: Concrete testing – Sampling of freshly mixed concrete.

[15] ASTM C 496 Annual Book of ASTM Standards, 04 Issue 02 (2007) 293-297.

[16] SANS 6253:206 Concrete Tests- Tensile Splitting Strength of Concrete: ISBN 978-0-626-27111-4.

[17] K. Mun, Construction & Building Materials, 21(2007) 1583-1588.

[18] N. Jamshidi, M. Jamshidi, A. Mehrdadi, Journal of Environmental Studies. 37, Issue 59 (2011a) 4-6.

[19] M. Cyr, P. Coutand, P. Clastres, Cement and Concrete Research. 37 (2007) 1278–1289.

[20] J. Monzo, J. Paya, M.V. Borrachero, J.J. Morenilla, M. Bonilla, P. Calderón, Proceedings of the International RILEM Conference on the use of Recycled Materials in Building and Structures (2004) 814-823. Valencia, Spain: RILEM Publications.

[21] M. Jamshidi, N. Jamshidi, A. Mehrdadi, F.P. Shasavandi, Faculty of Environment, University of Tehran, Iran. (2011b)

[22] S. Valls, A. Yague, E. Vazquez, C. Mariscal, Cement and Concrete Research. 34 (2004) 2203-2208.

[23] N. Rodriguez, S. Ramirez, B. Varela, M. Guillem, J. Puig, E. Larrotcha, J. Flores, Cement and Concrete Research, 40 (2010) 778-786.

[24] A. Yague, S. Valls, E. Va´Zquez, F. Albareda, Cement and Concrete Research. 35 (2005) 1064-73.

[25] D.J. Naus, C.H. Mattus, L.R. Dole, Final Report –Oak Ridge National Laboratory Managed by UT-Battelle, LLC. Prepared for the U.S. Nuclear Regulatory Commission Office of Nuclear Regulatory Research Under Interagency Agreement No. 1886-N600-2N NRC FIN No. N6002(2006)

[26] L. Kalina, V. Bílek Jr., R. Novotný, M. Monˇceková, J. Másilko, J. Koplík, Materials (Basel), 04, Issue 02 (2016) 1-9.

[27] A. Jamshidi, M. Jamshidi, N. Mehrdadi, A. Shasavandi, F. Pacheco-Torgal, Materials Science Forum, (2012) 730-732:462-467.