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Influence of nanobubble treated wastewater on concrete

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Abstract

The large consumption of potable water in the construction industry is a rising issue, and along with the ever-increasing demand for fresh water, an alternative solution needs to be investigated, more specifically in concrete production. This study investigates the feasibility of using nanobubble-treated wastewater or contaminated water to produce concrete. The use of untreated, contaminated water in concrete can have positive or negative effects on its properties. Nanobubbles were incorporated with contaminants in the form of table salt (chlorides), sugar, detergents, and algae, respectively, to determine the ability of nanobubbles to mitigate the effects of these contaminants on concrete properties.

Concrete tests were conducted on samples that made use of untreated and treated concrete mixing water. The results were compared based on the chemical analysis of the water, the flowability of the concrete, the compressive strengths, and finally the absorption of the concrete. The chemical results show that the nanobubbles neutralise the water, while the compression strength results indicate that the nanobubbles reduce the negative or positive effects of the contaminants. From the results, it can be concluded that there is great potential for treating wastewater with nanobubbles for use in concrete.

Keywords: wastewater, nanobubbles, contaminants, treated, untreated, concrete

1. INTRODUCTION

In the last decade, research into nanobubbles has reached new heights. The potential of this recent technology is already so vast, with the promise of even greater problem-solving potential after further research [1, 2].

These nanobubbles present unique characteristics that prove to be beneficial for several applications within technological areas – these properties include the high surface area versus the volume of the bubbles, along with the significant stability and longevity of the bubbles. Nanobubble research related to pollutants or contaminants has shown enhanced removal of contaminants such as oils, colloidal soils, and organic or inorganic precipitates [3]. The research also revealed that nanobubbles behaved in a stable manner within the water and organic solutions; this stable behaviour was recorded for months without any significant changes in the nanobubble's size or concentration [4].

Furthermore, nanobubbles have the potential to remove toxins from various types of wastewater and the contaminants that are present in them, as recently demonstrated by their use in water treatment procedures [5]. This treatment is done by initiating chemical reactions that would not have occurred without the addition of nanobubbles, thus catalysing the wastewater treatment process and increasing its efficiency.

The general wastewater treatment process involving nanobubbles includes flotation, aeration, and disinfection. These processes are usually done to increase the efficiency of existing treatment methods, rather than acting as individual treatment methods [5].

Research on the influence of nanobubble waters on concrete has been conducted but remains limited. Research suggests that the nanobubble water used within the concrete mixture penetrates the microstructures of the cement paste, forming part of the cement hydration process due to increased zeta potential and surface tension of the mixing water. These increased characteristics catalyse the hydration reaction process and accelerate the pozzolanic reaction, increasing the concrete's water tightness and compressive capability [6].

Research using both microbubbles and nanobubbles within concrete yielded an improvement in the concrete’s strength and a decrease in the concrete’s workability. The compressive strength and tensile strength increased by 16% and 19%, respectively, and the setting temperature of the concrete was reduced. Other changes measured within the concrete made using microbubbles and nanobubbles relative to the mixture made using standard potable water were that the early-stage and later-stage setting times decreased, requiring the concrete to be cast within a shorter period [7].

Nanobubble technology in concrete is still in the initial stages of research, and more is needed to apply it to the wastewater treatment required for concrete use. This study used untreated and nanobubble-treated contaminated water in concrete to determine the effect of four common contaminants on the concrete’s properties before and after treatment.

2. EXPERIMENTAL FRAMEWORK

2.1. Contaminants for Chemical and Concrete Tests

Chemical and concrete tests were conducted using untreated and nanobubble-treated contaminated water with four contaminants: chlorides, sugar, detergents, and algae. The concentration limits prescribed for use in concrete are discussed below.

Chlorides are often found in sea or brackish water, highly mineralised surfaces, or groundwater. One of the concentration limits for chlorides within concrete mixtures is 10 000 mg/l [8]. Chlorides were added to potable water in the form of sodium chloride or table salt, which has a 61.24 % composition of chlorides. This results in a concentration limit of 16 329 mg/l of sodium chloride to achieve the 10 000 mg/l of chlorides within each sample contaminated with chlorides.

Sugar is predominantly found in rivers and groundwater along the east coast of South Africa, near sugar cane plantations. The concentration limit for sugar within concrete mixtures is 1 500 mg/l [9], and normal food-grade white sugar was used.

Detergents are a significant contaminant present in residential greywater. While the concentration limit for detergents is not well defined in literature, it was determined for this study using the general mass of detergent (90 grams) for the average amount of water used in a single load of laundry (70 litres of water), resulting in a concentration limit of 1 286 mg/l.

Algae are found in several water sources and are especially present in dams and rivers. Algae water from a pond in the Botanical Gardens of Stellenbosch University was used as the source of algae water for this study. The concentration of this water was not tested, but it had a green-to-yellow appearance, indicating the presence of significant amounts of algae.

For the chemical tests, the concentration limits mentioned above were used. The chemical analysis for the contaminated water was tested at a nanobubble replacement level of 0% and 90%. For the concrete tests, five times the concentration limit was used: 10% of the water was contaminated with the respective contaminants, followed by the addition of 90% potable water for the untreated water and 90% nanobubble water for the treated water.

2.2. Concrete Mixtures

Conventional concrete was used as the basis for all mixtures. The cement used was a CEM II 52.5 Suretech Portland cement manufactured by PPC (Pretoria Portland Cement). Locally available natural quarry sand, known as Malmesbury sand, with a fineness modulus of 2.6 and a relative density of 2.6 was used as fine aggregate. The coarse aggregate used was a 13-mm Greywacke stone with a relative density of 2.8. The cement and aggregate remained constant throughout the experimental process, while the water used for mixing varied.

The reference mixture used municipal or potable water, as appropriate for conventional concrete. The other concrete mixtures contained untreated contaminated water and nanobubble-treated contaminated water, respectively. The concrete mixtures and their proportions are given in Table 1.

Table 1: Concrete mix proportions

	Reference Mixture (kg/m^3)	Chloride Mixtures (kg/m^3)	Sugar Mixtures (kg/m^3)	Detergent Mixtures (kg/m^3)	Algae Mixtures (kg/m^3)
Cement	348	348	348	348	348
Sand	901	901	901	901	901
Stone	900	900	900	900	900
Water	209	209	209	209	209
Pollutant	0	17.1	1.6	1.3	*

*The concentration of the pollutant is unknown due to the fact that the water is not dosed but collected.

2.3. Chemical and Concrete Tests

A chemical analysis was performed on both the untreated and treated water samples using a HACH Pocket Pro+ tester. The water samples were tested to get an indication of the pH and conductivity values before and after the samples were treated with the nanobubbles.

A slump test was performed on one concrete sample in accordance with the guidelines given by SANS 5862-1:2006. The compressive capability of a concrete mixture was determined on 100-mm concrete cubes according to the guidelines set out by SANS 5863:2006. Three cubes were tested for each concrete mixture at 3, or 5, 7, 14, 21, and 28 days (the algae mixtures were tested on 5 days while the other mixtures were tested on 3 days).

The ASTM C1585-13:2013 provided a procedure in which the water absorption of the various concrete mixtures was determined. For each concrete mixture, three samples were tested. This procedure involves measuring the weight of the specimen according to a specific time scale and period while the cast concrete cube has one face exposed to water. This increase in mass is attributed to the capillary suction due to the capillary pores in the concrete.

3. EXPERIMENTAL RESULTS AND DISCUSSION

3.1. Influence of Chlorides

The pH readings of the water increased from 6.67 to 7.61 with the addition of sodium chloride at the concentration limit, caused by the sodium (Na^+) ions. This pH increase is, however, stabilised to that of municipal water once treated with nanobubbles. The conductivity results for the sodium chloride water were inconclusive due to tester limitations.

The slump test produced information on the flowability of the concrete mixes and showed that the slump increased from 36 mm to 105 mm with the addition of sodium chloride to the municipal water. The nanobubble-treated concrete mixture decreased the slump measurement slightly to 98 mm.

The results, shown in Figure 1, of the compression tests performed on the sodium chloride-contaminated concrete cubes indicated that the strength of the treated concrete yielded similar results to the reference mixture, while the untreated concrete strength was considerably higher than both the reference and the treated concrete mixtures. This increased strength can be attributed to the accelerated setting and hardening effect caused by the higher sodium chloride content [10]. It was observed that the strength of the nanobubble-treated concrete mixture followed a similar strength curve to that of the reference mixture, which is an indication that the treatment method cancelled out the influence of the sodium chloride on the compression strength.

Following the absorptivity test, it was found that the sodium chloride-contaminated samples had lower absorption than the reference mixture, which can be seen in Figure 2. The treated sample shows higher absorption compared to the untreated concrete samples but is still slightly lower than the reference mixture. This shows that the nanobubble treatment is effective in reducing the influence of sodium chloride contaminants on the concrete's compressive strength and absorptivity.

3.2. Influence of Sugar

The pH of the water samples increased slightly from 6.67 to 6.91 with the addition of sugar compared to the reference water. The pH decreased to 6.76, which is similar to that of the municipal water, after the addition of the nanobubbles. The conductivity of the treated water samples decreased from 45 mS to 39.6 mS.

The flowability of the concrete increased significantly to 186 mm with the addition of sugar to the mixing water, as expected due to sugar greatly influencing the setting and flowability of concrete [11]. Treating the water with nanobubbles slightly decreased the slump, resulting in a slump value of 175 mm.

The strength curve of the untreated sugar concrete in Figure 1 illustrates the expected effect of sugar on concrete, a delayed setting time, which can be seen by the low initial compressive strength. This compressive strength is much lower compared to the reference concrete mixture. The untreated mixture's overall strength also remained below that of the reference mixture throughout the 28-day testing period, indicating a negative influence on the compressive capabilities of the concrete.

The treated mixture shows a significant increase in gradient at the early age strength compared to the untreated mixture; this shows that the treatment method has the potential to reduce the retardation effect that sugar has on concrete setting and strength gain.

Additionally, the compressive strength of the treated concrete is above the untreated sugar curve, which indicates an overall increase in compressive strength. The treated mixture had a higher compressive strength than the reference mixture between 12 and 21 days, after which it normalised to the reference mixture's strength. Treating sugary water with nanobubbles has the potential to eliminate the retardation effect on the concrete's setting time, which improves early-age strength development.

From Figure 2, the absorptivity tests showed that the sugar-contaminated water absorbed significantly less water (1.75 mm) compared to the reference (3.28 mm), indicating that the sugar makes concrete less susceptible to water ingress via capillary suction, which could potentially improve the concrete's durability. This can potentially be attributed to the influence sugar has on the setting and hardening time of concrete, which results in the formation of denser hydration products. With the addition of nanobubbles, the absorptivity depth decreased slightly to 1.60 mm compared to the untreated mixture.

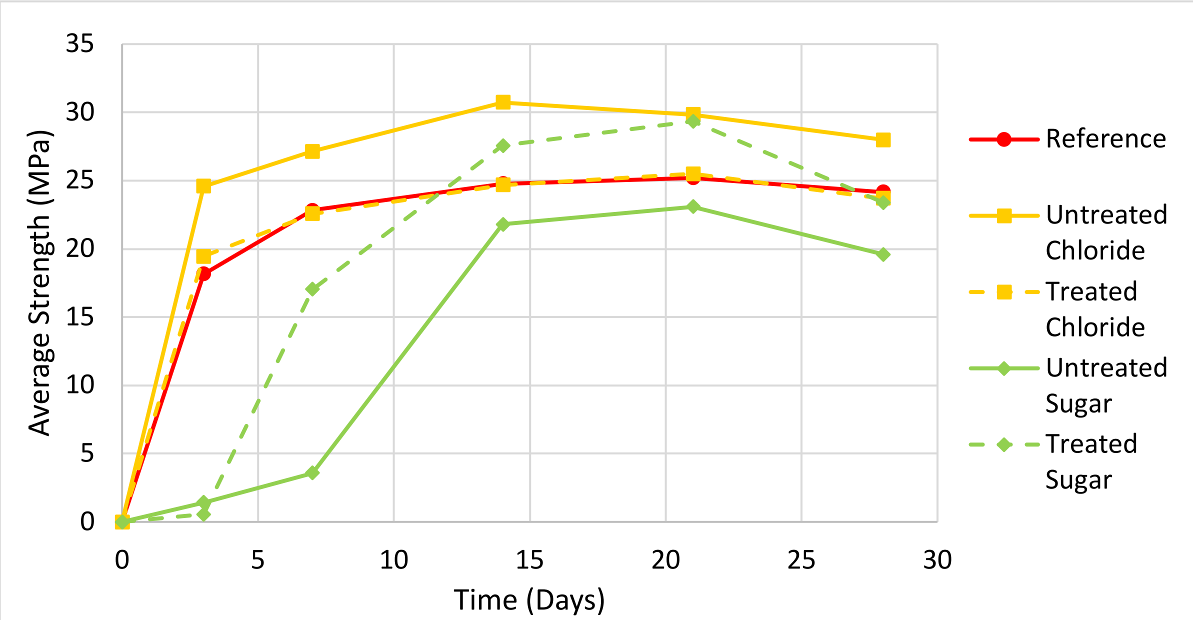

Figure 1 Chloride and sugar compression strength results

3.3. Influence of Detergent

The addition of detergents to water caused a significant increase from 6.67 to 10.13 in the pH compared to the reference water, changing the water into a basic solution. This indicates a greater possibility of alkali-aggregate reactions, which can negatively impact concrete durability. It was found that the addition of nanobubbles did not change the pH significantly.

The conductivity of the samples treated with nanobubbles decreased from 3105 mS to 1614 mS relative to the untreated sample.

The addition of detergents significantly increased the slump measurement to 134 mm compared to the 36 mm of the reference mixture. There was a negligible decrease of 4 mm in the slump measurements by treating water with nanobubbles.

The influence of the detergent decreased the compression strength significantly relative to the reference mixture, which can be seen in Figure 3. This is likely due to the significant increase in entrapped micro air bubbles caused by the detergent's visible foaming effect. The treatment using the nanobubbles showed a slight increase in the compressive strength of the concrete mixture compared to the untreated mixture, and the nanobubbles have the potential to decrease the negative influence of detergents on the concrete's compressive strength.

Analysing the results of the concrete cubes contaminated with the detergent mixing water, as shown in Figure 2, an absorption depth of 2.99 mm was recorded, which slightly decreased compared to the reference mixture. The treated detergent concrete showed similar absorption to the untreated concrete.

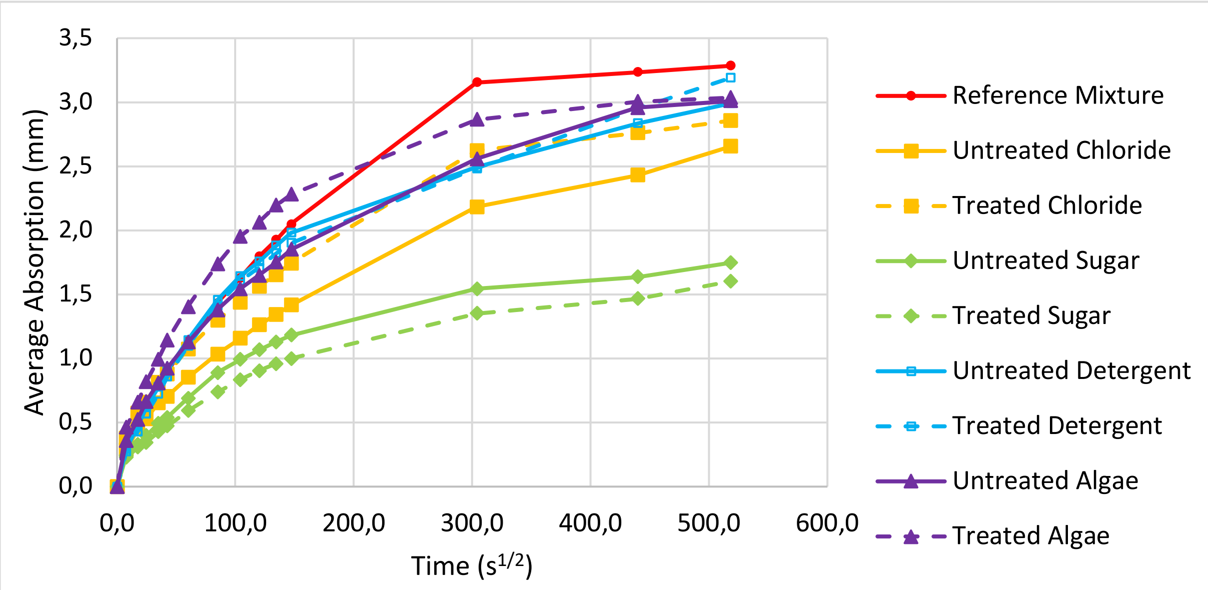

Figure 2 Absorptivity of all concrete mixtures

3.4. Influence of Algae

Treating the contaminated algae water with nanobubbles reduced the pH of the samples from 7.03 to 6.5, which is close to that of municipal water. The addition of nanobubbles caused a decrease in the water's conductivity capability from 277 mS to 250.75 mS.

The algae showed a negligible effect on the slump, both relative to the reference mixture as well as between the treated and untreated concrete mixtures.

From Figure 3, the algae-contaminated concrete mixtures resulted in slightly higher compressive strengths than the reference mixture. The reason for this increase is unclear and requires further investigation. Once the water was treated using nanobubbles, the concrete's compressive strength tended towards the reference mixture, indicating that the treatment is useful in reducing the influence of the contaminants on the concrete's hardened properties.

As seen in Figure 2, the initial absorption for the treated algae concrete increased slightly in relation to the reference mixture but decreased after 200 seconds to a value just below that of the reference concrete. The untreated concrete abruption was, however, lower than both the reference and treated algae concrete.

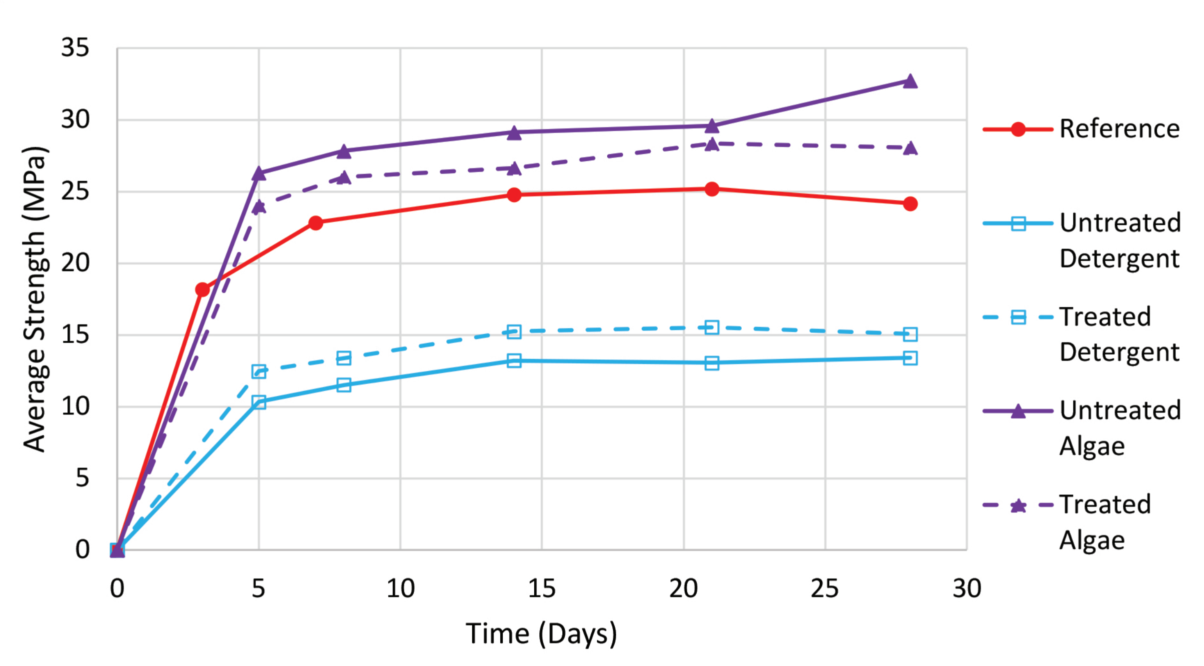

Figure 3 Detergent and algae compression results

4. SUMMARY AND CONCLUSIONS

The following significant conclusions can be drawn from this study.

- The results obtained from the chemical analysis show that the addition of nanobubbles had a neutralising effect on the pH values of chloride-, sugar-, and algae-contaminated water. This neutralising effect on the pH reduces the chances for alkali-silica reactions. The nanobubbles resulted in a slight decrease in the conductivity of the sugar- and algae-contaminated water. A big reduction was seen in the conductivity values for detergent water. This lower conductivity has the potential to lower the corrosion of steel, which is an electrochemical process due to the flow of ions and electrons.
- The untreated chloride and algae concrete yielded greater compression strengths than the reference mixture. The strength was reduced to near the reference mixture when the contaminated water was treated with nanobubbles. The addition of sugar had a negative effect on the compression strength of concrete due to its retardation effect on the setting time. However, treating the sugar-contaminated water with nanobubbles significantly reduced the retardation effect and increased the early-age strength of the concrete. The use of detergent-contaminated water significantly

lowered the compression strength of the concrete compared to the reference concrete. Treating the water with nanobubbles had a slight positive change in its strength characteristics.

- The treatment with nanobubbles slightly decreased the absorption of sugar-contaminated concrete, whereas it increased the absorption of the treated chloride, detergent, and algae concrete.
- All the results indicate that, in general, treating contaminated water with nanobubbles neutralises the effect that the contaminant has on the concrete's properties. This shows that treating contaminated water using nanobubble technology has the potential to allow the use of non-potable and contaminated waters within concrete.

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REFERENCES

[1] Aggarwal, Y., and R. Siddique. 2014. "Microstructure and properties of concrete using bottom ash and waste foundry sand as partial replacement of fine aggregates." *Constr. Build. Mater.* 54: 210–223.

[2] Khoshroo, M., Javid, A. A. S., and Katebi ,A. 2018. "Effects of micro-Nano bubble water and binary mineral admixtures on the mechanical and durability properties of concrete." *Constr. Build. Mater.* 164 (Mar): 371–385.

[3] Azevedo, A., Oliveira, H. and Rubio, J. (2019) "Bulk Nanobubbles in the mineral and environmental areas: Updating research and applications," *Advances in Colloid and Interface Science*, 271.

[4] Takahashi, M., K. Chiba, and P. Li. 2007. "Free-radical generation from collapsing microbubbles in the absence of a dynamic stimulus." *J. Phys. Chem. B* 111 (6): 1343–1347.

[5] Temesgen, T., Bui, T., Han, M., Kim, T. and Park, H., 2017. Micro and Nanobubble technologies as a new horizon for water-treatment techniques: A review. Advances in Colloid and Interface Science, 246, pp.40-51.

[6] Kim, S., H. Kim, M. Han, and T. Kim. 2019. "Generation of sub-micron (Nano) bubbles and characterization of their fundamental properties." *Environ. Eng. Res.* 24 (3): 382–388.

[7] Arefi, A., Saghravani, S. F., and Mozaffari Naeeni, R. 2016. "Mechanical behavior of concrete made with micro-Nano air bubbles." *Civ. Eng. Infrastruct. J.* 49 (1): 139–147.

[8] Alexander, M. (2021). Fulton's Concrete Technology, 10th Edition, Cement and Concrete SA.

[9] Owens, G. (2009). Fulton's Concrete Technology, 9th Edition, Cement and Concrete Institute.

[10] Ojoawo, S.O., Oladejo, A.M. and Olaniyan, O.S. (2014) "Effect of chloride-contaminated water on the compressive strength of Plain Concrete," *IOSR Journal of Mechanical and Civil Engineering*, 11(3), pp. 99–108.

[11] Otunyo, A.W., Onwusiri, S.C. and Nwaiwu, N. (2015) "Effect of sugar cane juice on slump values, setting times and strength of concrete," *Nigerian Journal of Technology*, 34(2), p. 254.