AFRICAN JOURNAL OF SCIENCE, TECHNOLOGY AND SOCIAL SCIENCES

Journal website: https://journals.must.ac.ke

MERU UNIVERSITY OF SCIENCE AND TECHNOLOGY

A Publication of Meru University of Science and Technology

Evaluation of sulfuric acid effect on bending strength of steel used in concrete reinforcement in sanitation structures

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ARTICLE INFO

KEYWORDS

Bending Strength,

Microbiologically Induced deterioration

Sanitation Structures

Strength Reduction

ABSTRACT

Most sanitation structures in the world are constructed using concrete which is reinforced by the steel, this type of concrete is called Reinforced Cement Concrete (RCC). The RCC structure is believed to be relatively resistant to corrosion which the sanitation structures are prone to due to the aggressive environment in which they are subjected to. This belief has been compromised since the reinforced concrete used in the sanitation structures such as the concrete sewer pipes has become susceptible to Microbiologically Induced Deterioration (MID). This MID leads to degradation and compromised strength and service life of the RCC. In the reinforced concrete structure, the backbone of this structure is the reinforcing steel which when its strength is compromised by the MID, the whole structure is compromised. The present research therefore aimed at evaluating the effects of sulfuric acid, resulting from the MID process, on the bending strength of steel metal used for reinforcing concrete in sanitation structures. Reinforced concrete specimens were developed using different types of cement and different concrete cover. The three different types of cement were, Ordinary Portland Cement (OPC), Portland Pozzolana Cement (PPC) and Limestone Calcined Clay Cement (LC3), while concrete covers of 15mm and 25mm were applied. They were then subjected to a harsh environment (a sample of sewage) suitable for corrosion just like in their actual operational environment. To determine the effects of sulfuric acid resulting from MID on the steel metal, the steel metal was tested using a Universal Testing Machine (UTM). The bending strengths before and after being subjected to an aggressive environment were determined. The testing of the specimens was done at an interval of 14 days for a period of three (3) months. According to the results, for a concrete cover of 25mm, LC3 showed a minimum percentage reduction in strength compared to PPC and OPC. It had the lowest percentage reduction in strength after 84 days which was 5.25%, OPC 7.20%, and PPC 7.24%. In conclusion, there was a strength reduction for all specimens tested. LC3 showed good resistance to the effects of MID compared to PPC and OPC. In terms of concrete cover, 25mm showed good resistance to MID compared to 15mm concrete cover.

Introduction

In the Kenyan 2010 constitution Article 43 (1) (b), every person has a right to accessible and adequate housing, and to reasonable standards of sanitation. Anchoring sanitation in the constitution therefore means that the required sanitation structures such as the pit latrines, septic tanks, anaerobic baffled reactor (ABR), biogas reactor and sewer lines must be designed in such a way that they are safe and suitable for use. According

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https://doi.org/10.58506/ajstss.v2i2.207

AFRICAN JOURNAL OF SCIENCE, TECHNOLOGY AND SOCIAL SCIENCES ISSN :2958-0560

https://journals.must.ac.ke

to information from the Kenya National Bureau of Statistics, 80.75% the Kenya's population have access to sanitation facilities [1]. These sanitation facilities include pit latrines and toilets, for toilets, they are either connected to pit latrine, septic tank or sewer system [1]. In these sanitation structures, the main materials used to develop the structures are concretes reinforced with mild steel metal [2]. Reinforced concrete is made by first developing the steel metallic structure after which the mortar is poured on it and then given at least seven days to cure up [3].

Apart from being used in concrete reinforcement, the steel metal can be independently used in developing some sanitation structures [4]. Some of these structures include the vacuum trucks for transporting human waste from the septic tanks to the treatment plants and the trickling filters where the sprinklers are used to spray wastewater over the filters in treatment plant [5].The mild steel metal being used in the sanitation structure is subjected to aggressive environment which is suitable for Microbiologically Induced Deterioration (MID), which occurs in the form of corrosion [6]. Corrosion has led to tremendous reduction of strength of the mild steel metal hence weakening the structures made of it [7]. Currently, no sanitation structures can serve up to its designed service life [8]. For example, the average service life for a sewer system should be between 50-100 years, but no sewer system can last that long minus very expensive repair and maintenance [9].

Sanitation structures are subjected to five main forces which they must be able to withstand. The forces are shear, torsional, bending, compressional and tensional forces [8]. This makes mild steel metal to be a very integral part of these structures even though it is vulnerable to corrosion [4]. A sanitation structure may not be subjected to all these forces at the same time but a sanitation structure must be subjected to at least one of them at any time [8]. Mild steel metal has a desirable characteristic which makes it to be preferred for construction purposes like in constructing the sanitation structures. It has the ability to withstand, shear, bending, torsional and tensional loads which are among the common loads which the sanitation structures are subjected to [8,10, 11]. Concrete alone has a perfect compression strength [12], therefore reinforcing it with mild steel makes it all round fit to be used in any sanitation structures. What happens therefore if this backbone of sanitation structure is overwhelmed by corrosion is that that the reliability and the service life of these structures are compromised.

Worldwide, there are sewer infrastructures which have existed for more than 100 years of investment [9]. According to [9], the designed service life for sanitation structures should be more than 100 years so that value of the initial costly investment can be realized. For example, in the United State of America, the sewer system is valued at approximately $1 trillion [6]. In Kenya, according to the African Ministers' Council on Water (AMCOW), there is an annual investment of US$386 million for sanitation structures [13]. This costly investment is under serious deterioration which is microbiologically induced in the form of corrosion [14]. The main cause of corrosion in sanitation structures is hydrogen sulfide (H2S) which leads to the formation of sulfuric acid, hydrogen sulfide exists in human waste, wastewater and industrial waste [15-17]. According to [9], there is an annual investment of more than $1 billion used in maintenance, repair and replacement of worn-out parts of the sewer system. He then concluded that developing a technique which can improve the service life of the sewer system by one year would save the world more than $ 1 billion per year.

Among the Sustainable Development Goals (SDGs), the SDG number 6 advocates for available and sustainable sanitation for all [18]. The advocacy is also found in the Kenyan 2010 constitution Article 43(1) (b). This therefore means that sanitation structures should be taken seriously and their constructions should be up to the required standards with the required material to

S/No	Cement	Description
1	LC^3	Prepared by blending 50% clinker, 30% ground fired clay bricks, 15% limestone and 5% gypsum inter-ground in a laboratory ball mill.
2	PPC	PPC (32.5 N/mm^2) is manufactured using volcanic ash as pozzolana
3	OPC	OPC (42.5N/mm) is Prepared by blending then inter-grinding clinker and 5% gypsum in the laboratory ball mill.

Table 1 : *Description for PPC, OPC and LC3 [21]*

avoid their failure. Their frequent failure may make the users revert to Open Defecation which is being campaigned against [19, 20]. Quick and amicable solutions should be put in place to counter anything which may compromise their service lives or condition of use. The aim of this research was to evaluate the effects of sulfuric acid on the performance of available mild steel in the Kenyan market when used in sanitation structures. Steel metals from reinforced concretes made from different types of cements, Ordinary Portland Cement (OPC), Portland Pozzolana Cement (PPC) and Limestone Calcined Clay Cement (LC^3) were tested. Different concrete cover sizes, 15mm and 25mm were also applied. This was to determine the best type of cement and perfect concrete cover size which can be resistant to corrosion resulting from the sulfuric acid.

Materials and Methods

Materials

OPC and PPC were commercially acquired from the local market in Kenya. OPC was in accordance with the standards set by the European Standard-EN-197-1 for class-42.5R cement while PPC was in accordance with the standards set by the American Society for Testing and Materials for 52.5R cement as per ASTM C15O. The LC^3 was obtained from Meru University of Science and Technology (MUST). The type of LC^3 cement used was composed of the following, 50% clinker, 30% calcined clay, 15% limestone and 5% gypsum according to [21]. The sand was commercially acquired from local suppliers who harvest it from the nearby River Sio located in Nambale sub-county, Busia County. It was in line with the set standards by the American Society for Testing and Material as per ASTM C778-17. The sand was well graded as it contained particles of varying sizes between 150 microns and 4.75millimeters [22, 23]. Coarse aggregates were obtained commercially from the stone crushers located at Nambale in Busia County. The aggregates were as per the ASTM D692M-20. They had varying sizes between 6mm and 20mm, therefore they were also well graded [24, 25]. The steel of diameter 8mm (D8) was in accordance with the set standards for American Society for Testing and Material for materials with designation number 3(10) as per ASTM A615/615M-20, it was obtained commercially from the local market. The descriptions for PPC, OPC and LC^3 are shown in Table 1.

Methods

Particle Size Distribution for River sand and Coarse Aggregate

The river sand and the coarse aggregates were tested for particle size distribution to ensure their conformity to the international set standards. The river sand was tested to confirm its conformity to the American Society for Testing and Materials, ASTM C778-17 while for the coarse aggregate, it was to conform to ASTM D692M -20. To conduct the test, the river sand and the coarse aggregate were passed through different sets of sieves. For the river sand, the set of sieves used had varying sizes between 4.75millimeters at the top and 150 microns at the bottom. The set of sieves for grading the coarse aggregates had sizes varying between 20mm at the top and 6mm at the bottom. For each test, the percentage weight retained and percentage passing weight were recorded.

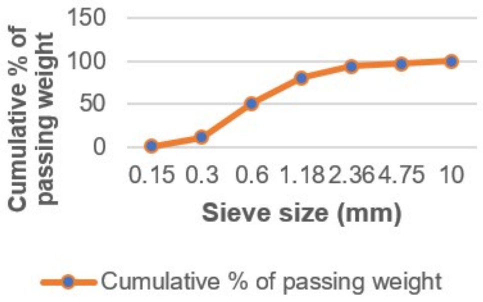

Figure 1: *Sand Particles size distribution*

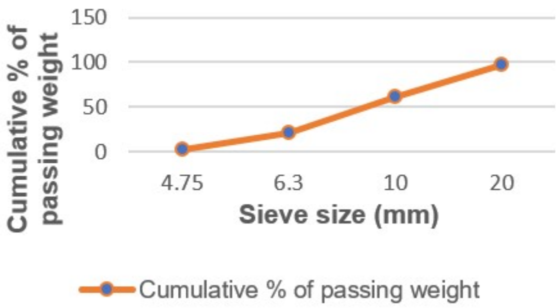

Figure 2 : *Coarse aggregates particles size distribution.*

Preparation of the Reinforced Concrete

Wooden structures with the shape and size of the reinforced concrete specimen were made. The structures were in two sizes with a rectangular shape. The first one had internal dimensions of 40mm × 40mm × 150mm to produce reinforced concrete with a cover of 15mm. The second one had internal dimensions of 60mm × 60mm × 150mm to produce reinforced concrete with a cover of 25mm. After making the wooden structures, mortar was poured into them then they were given a period of seven (7) days to cure up. The reinforced concretes were removed from the wooden structures after 7 days then they were submerged into the sewage sample contained in a concrete tray. The mortar had mixing ratio of 1: 2: 3:0.5 for cement, sand, coarse aggregate and water.

Determination of Bending Strength of the Steel Specimens

Data for bending strength of the steel specimens was collected at an interval of 14 days for a period of 3 months. This was done by taking the specimen out of the concrete tray and then removing the concrete cover after which, the steel metal was tested using UTM. The concrete tray contained sewage sample which provided an environment similar to the actual environment which the reinforced concrete is subjected to in the sanitation structures.

The specimen (which is the steel metal) was placed centrally on the jig mounted on the UTM table. A vertical load was then applied at its center using a steel bar of thickness 24mm. The vertical load was supplied from the automatic hydraulic system of the UTM. The load was applied until the specimen failed by bending inwards. The load at the yielding point was recorded in newton (N). This same procedure was repeated for all the 42 specimens which were subjected to this test.

Results and Discussion

Results

Particle Size Distribution for River sand and Coarse Aggregate

From the data collected, the figures 1 and 2 show the plotted graphs for distribution of particles per sizes in river sand and coarse aggregate respectively.

From figure 1, the sand was well graded as it contained particles of varying sizes from 0.15mm to 4.75mm. It had a fineness modulus of 2.6473 according to [26].

Fineness modulus = Σ (cumulative % of retained weight)/100= 264.73/100 = 2.6473

The coarse aggregated was also well graded as it contained particles of varying sizes from 4.75mm to 20mm as shown in figure 2. It had a fineness modulus of 2.1736 also according to [26].

Fineness modulus = Σ (cumulative % of retained weight)/100= 217.36/100 = 2.1736

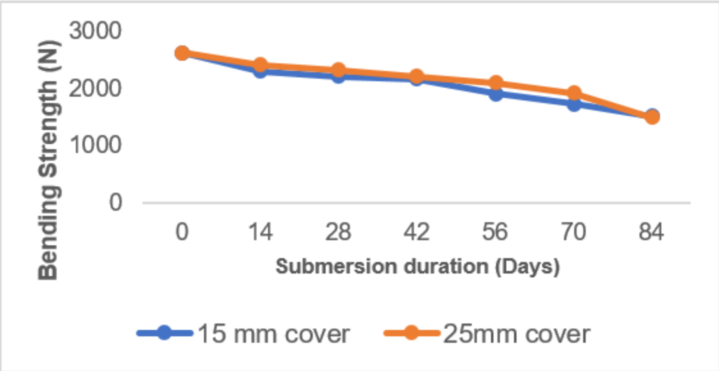

Figure 3 : *Bending strength against submersion duration for OPC.*

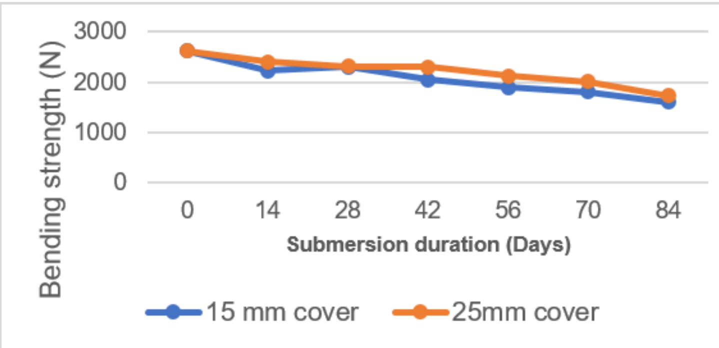

Figure 4: *Bending strength against submersion duration for PPC.*

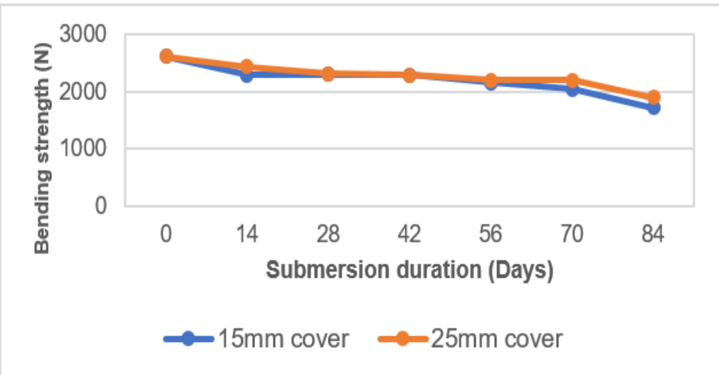

Figure 5: *Bending strength against submersion duration for LC³.*

Bending Strength

Graphs shown in Figures 3,4, and 5 graphs were plotted from data collected after performing bending strength tests.

From the graphs, it can be observed that the steel metal from the reinforced concrete made with the LC³ cement had the highest bending strength at the end of 84 days of submission into the sewage, followed by PPC then OPC. It had a bending strength of 1899.97N for concrete cover of 25mm and 1711.23N for a concrete cover of 15mm as indicated in figure 3.5. PPC had a strength of 1722.31N for concrete cover of 25mm and 1600.09N for a concrete cover of 15mm. For OPC, it had a strength of 1499.35N for concrete cover of 25mm and 1521.20N for a concrete cover of 15mm. The initial bending strength of the steel metal before being submerged into the sewage was 2619.08N.

Discussion

Analysis of the graphs plotted

As per the analysis of the plotted graphs, as the number of submersion days increased, the bending strength of the steel metal in all the three types of cement, OPC, PPC and LC³ decreased. This is attributed to microbiologically generated sulfuric acid (biogenic sulfuric acid) during the MID process [27, 28]. This reduction of strength recorded was similar to the findings of [4] who also recorded reduction in strength of the metallic reinforcement. Comparing strengths generally in terms of concrete cover size, a bigger concrete cover size, 25mm in size, showed good resistance to sulfuric acid effects hence compared to a cover size of 15mm, its reduction in strength was relatively low. The same results were recorded by [21]. The reason behind the difference in strength reduction between 15mm concrete cover size and 25mm concrete cover size was the ingression time. The time taken for the microbiological organisms and the acids (chloride and sulfuric acid) to reach the steel metal imbedded inside the concrete varied depending on the concrete cover size [29]. The lesser the concrete cover size the lesser the ingression time [29, 30].

The cement which portrayed good resistance to the corrosive environment was the LC^3 followed by PPC and then OPC, these findings were related to what [21] found. The resistivity was attributed to low porosity and low chloride and sulfuric acid ingress of LC^3, PPC and OPC accordingly [21]. The steel metal from reinforced concrete made of LC^3 generally had low reduction in strengths compared to both PPC and OPC, though there are some rare cases in which PPC and OPC showed low strength reduction compared to LC^3. This is from visual analysis of the plotted graphs.

Evaluation of the Bending Strength of the Concrete Reinforcing Steel

To evaluate the strength of the steel metal in terms of percentage reduction in strength, qualitative

B_i = Initial bending strength of the steel metal = 2619.08N

B_f = Final bending strength of the steel metal:

a. For OPC, cover 15 mm = 1521.20N and cover 25mm = 1499.35N
b. For PPC, cover 15mm = 1600.09N and cover 25mm = 1722.31N
c. For LC^3, cover 15mm = 1711.23N and cover 25mm = 1899.97N
d. η_{SMiB} = Initial strengthof the steel metal considering bending strength, assuming = 100% before being submerged into the sewage sample.
e. η_{SMfB} = Final strength of the steel metal considering bending strength after being submerged into the sewage sample.
f. η_{reB} = Reduction of strength of steel metal considering bending strength

Strength of steel metal after being submerged considering bending strength was:

a. For OPC, cover 15mm: $\eta_{\mathrm{reB}} = \frac{Bi-Bf}{Bi} \times 100 = \frac{2619.08-1521.20}{2619.08} \times 100 = 41.92\%$
$\eta_{\mathrm{SMfB}} = 100\text{-}41.92 = 58.08\%$
b. For OPC, cover 25mm : $\eta_{\mathrm{reB}} = \frac{Bi-Bf}{Bi} \times 100 = \frac{2619.08-1499.35}{2619.08} \times 100 = 42.75\%$
$\eta_{\mathrm{SMfB}} = 100 - 42.75 = 57.25\%$
c. For PPC, cover 15mm : $\eta_{\mathrm{reB}} = \frac{Bi-Bf}{Bi} \times 100 = \frac{2619.08-1600.09}{2619.08} \times 100 = 38.91\%$
$\eta_{\mathrm{SMfB}} = 100 - 38.91 = 61.09\%$
d. For PPC, cover 25mm : $\eta_{\mathrm{reB}} = \frac{Bi-Bf}{Bi} \times 100 = \frac{2619.08-1722.31}{2619.08} \times 100 = 34.24\%$
$\eta_{\mathrm{SMfB}} = 100 - 34.24 = 65.76\%$
e. For LC^3, cover 15mm : $\eta_{\mathrm{reB}} = \frac{Bi-Bf}{Bi} \times 100 = \frac{2619.08-1711.23}{2619.08} \times 100 = 34.66\%$
$\eta_{\mathrm{SMfB}} = 100 - 34.66 = 65.34\%$
f. For LC^3, cover 25mm: $\eta_{\mathrm{reB}} = \frac{Bi-Bf}{Bi} \times 100 = \frac{2619.08-1899.97}{2619.08} \times 100 = 27.46\%$
$\eta_{\mathrm{SMfB}} = 100 - 27.46 = 72.54\%$.

analysis was done as follows.

Considering that:

E*valuation of Final Strength of steel metal in Terms of Percentages.*

From the calculations done on evaluation of effects of sulfuric acid on bending strength of steel metal, subjecting the steel metal to the aggressive environment similar to the one in which the reinforced concrete is normally subjected to in sanitation structure led to its reduction in strength. This reduction in strength of the reinforcing steel when concrete is subjected to aggressive environment was also recorded by [4]. LC^3 cement showed less reduction in strength followed by PPC then LC^3.This was in order of their porosity and rate of chloride and sulfuric acid ingress as per the findings of [21]. According to [21], LC^3 had low porosity and chloride and sulfuric ingress [21]. A concrete cover of 25mm also showed low reduction in strength compared to a concrete cover of 15mm due to its low ingress time. These results were similar to the one obtained by [21] in his research.

Conclusions

In light of the results obtained and the analysis done, the following conclusions were made:

i) Sulfuric acid had a negative effect on the reinforcing steel. This was justified by strength reduction which became more rapid as the days of submersion increased.

ii) The reduction in strength was dependent on the type of cement used and the concrete cover size.

iii) For the types of cement, LC^3 showed less reduction of strength compared to other types hence should be used in construction reinforced concrete in sanitation structures.

iv) For concrete cover size, 25mm showed less strength reduction compared to 15mm hence a cover of same size or greater than that should be applied in construction of sanitation structures.

Recommendation

Within the limits of this research, LC^3 cement has shown good performance. Given that it is relatively new in Kenya and globally in general and in the efforts for realization of better service life of the sanitation structures, more research and encouragement in using it in the markets should be encouraged. The results have also shown that concrete cover size of not less than 25mm is encouraging.

Declaration of competing interests

The authors declare that no competing interests exist.

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