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Development of a Bacterial Resistant Concrete for Use in Low Cost Kitchen Floors

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Abstract**—**The degrading effect due to bacterial growth on the structural integrity of concrete floor surfaces is predictable; this consequently cause development of surface micro cracks in which organisms penetrate through resulting in surface spalling. Hence, the need to develop mix design meeting the requirement of floor surfaces exposed to aggressive agent to improve certain material properties with good workability, extended lifespan and low cost is essential. In this work, tests were performed to examine the microbial activity on kitchen floor surfaces and the effect of adding admixtures. The biochemical test shows the existence of microorganisms (*E. coli, Streptococcus*) on newly casted structure. Of up to 6% porosity was reduced and improvement on structural integrity was observed upon adding mineral admixtures from the concrete mortar. The SEM result after 84 days of curing specimens, shows that chemical admixtures have significant role to enable retard bacterial penetration and good quality structure is achieved.

Keywords**—**Admixture, organisms, porosity and strength.

I. Introduction

THE premature degradation of concrete structures by organic acids, microbial impact and exposure to other aggressive environments has led to the development of a new mix proportion consisting of admixtures. It has been demonstrated that, even after typical and specific hygienic procedure, pathogenic microorganisms can survive in kitchens often for hours [1], [2]. Bacterial adhesion is also affected by the nutrient availability in the surrounding medium and the growth stage of the bacterial cells themselves [3] and by the pH, temperature of the medium and ionic concentration [4]. The most detailed studies addressing the mechanisms of interaction between microorganisms and cementitious matrices concern sewage systems [5], which differs considerably from the situation occurring in food processing environments (possible carbonation, consumption of some elements of the cement paste) [6]. This type of concrete deterioration occurs often in food processing, storage works and in the abattoirs and buildings of holding, bacteria, microscopic fungi, and algae is usually present at increased concentration [7]. Thus, the development of successful conservation treatment capable of preventing and inhibiting biodeterioration, rather than the improvement of already existing biocides is a very important issue [8]. The chosen admixtures for structural modification are Meta-kaOlin (MK) and Fly Ash (FA) is contained within the cement, for porosity reduction on the concrete matrix, and the chemical admixtures (FUGE and Borax) for water reducer, as studied mineral admixtures can improve particle packing and decrease permeability of concrete [9]. Therefore, the use of these types of mineral additives in concrete will make, not only to decrease the cost of concrete material but also to increase its long-term performance [10], [11]. Sufficient curing is essential for a concrete to provide its potential performance [12]. Neville and Aitcin [13] highlighted the essential need of wet curing from the earliest possible moment, therefore all concrete mixes were cured at 23°C and 60% relative humidity and analysis made was on strength, bacterial growth and porosity. In this study, it is aimed to develop hardened concrete structure to improve certain surface property such as porosity, strength, microbial activity to become less prone to bacterial colonization and to achieve less porous media.

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II. Material Selection

A. Materials

The study was conducted on hardened cement paste made of ordinary Portland cement, 15% quality siliceous fly ash (FA) from ash resources and a strength enhancer which complies with the chemical and physical requirements of SANS 50197 (EN197) for Class II 42,5N cement, and selected mineral admixture, MK and chemical admixture (FUGE and Borax) for water reduction. Table I show both physical and chemical properties of Ordinary Portland Cement (OPC) which is the Powercrete. A good quality of gravel and sand commonly used in concrete production obtained locally was adopted (max. grain size of aggregates = 19mm dolomite).

Table I below presents the Powercrete Plus complies with the chemical and physical requirements of SANS 50197 (EN197) for a Class II 42,5N cement.

TABLE I
Chemical Properties

Property	Powercrete Plus	EN Spec. requirement
SO_3	2.10%	≤ 3.5% m/m
Cl^-	0.051%	≤ 0.10% m/m
Physical properties		
2 day Strength	22.5 MPa	≥ 10.0 MPa
28 day Strength	56.5 MPa	≥ 42.5 ≤62.5 MPa
Initial set	200 minutes	≥ 60 minutes
Soundness	1.0 mm	≤ 10 mm
Relative Density		3.04

B. Preparation of Concrete Mixes

The mixture of cement, sand, aggregates and water was peformed separately for a specific biochemical test research, and another batch of concrete mortars was combined with different admixtures for strength and porosity as highlighted previously. The casting of specimens was done on cubes 100x100x100mm and vibrated for thirty seconds using vibrational shaker, the selectivity of mineral additives were, 5%, 10%, 15% and 0.5, 1 and 2% for chemical admixtures. The composition of cement, sand and aggregates ratio was 1:2:3 with a fixed cement content of 307 kg/m^3.

Tap water was used for preparing the mixture with a water-cementitious material ratio of 0.6 which was kept constant for all the mixes. The amount of admixtures added were substracted from sand and allowed a moisture content of 1.5%, while choosing a slump 75 – 100mm in order to achieve good workability. The specimens were de-molded 24 hours later and cured in a controlled environment and corresponding relative humidity.

C. Testing Methods

In order to achieve expected results, tests were performed to determine the physical properties of materials and the effect of microbial impact on concrete surfaces, after incorporating both mineral additives and chemical admixtures, the first test was density which was done using the stereopycnometer to check the quality of structure in terms of weight. The obtained results were then used to determine the material porosity, using the equation below:

$$P = \frac{V_p}{V_T} \quad (1)$$

where ***P*** is a dimensionless value of porosity, V_p is the volume of pores (m^3) and V_T is the total volume of the cylinder (m^3). The porosity test was measured accordingly at an interval of, 0, 7, 14, 56, and 84 days respectively, according to Van der Molen [14], it was found that chosing a water-cement ratio of 0.6, complete curing can be achieved in a duration approximately three months. And the depth carbonation of 15mm can be reached in 15 years on the floor casting [15]. The material Compressive strength was also performed accordingly to an interval of 3, 7, 14 and 28 days respectively, other test which were performed were biochemical test, pH, to evaluate the concrete specimens before impregnation with microorganisms, and also to test for their reactivity when impregnated together on a single concrete specimen with or without admixtures. The pH was used as indicator of bacterial activity towards concrete surface. The SEM results were done on a control mixture and on chemical admixtures of concrete specimens.

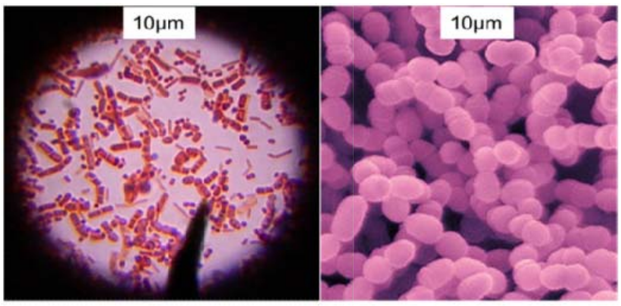
D. Microorganisms

Four different organisms species where selected for the study (*Salmonella, E. coli, Staphylococcus,* and *Bacillus*) which were prepared on a TSB (Tryptic soya bath) and were used 7 days later of incubating at 37°C. *Salmonella* and *E. coli* are rod-shaped gram negative organisms which can be found in eggs and on the intestine of healthy cattle, goats and sheep [16], [17], *Salmonella* isolates to plastic, cement, stainless steel and it is observed that the biofilm formation of both isolates was very similar with the highest density being on plastic followed by cement and stainless steel [18], *Bacillus* is a gram positive aerobic, spore forming rod [19], that is commonly isolated from food and *Staphylococcus* is a gram positive unaerobic, non-sporeforming rod and is able to grow in a wide range of temperature [20], pH [21] and sodium chloride concentration up to 15%.

Therefore concrete specimens were each inoculated with four selected organism 500µl quantity per organism using micropipette, and these was performed on a laminar cabinet flow cleaned with 70% ethanol, and connected to the UV light. The organism were given sufficient time to penetrate through concrete specimens.

III. Results and Discussion

Biochemical test refers to the chemical identification of unknown substances or bacterium within a living thing. In order to identify bacteria from this method; a gram staining technique is employed, in which both slant and broth cultures are prepared. Fig. 1 illustrates the results obtained from the culture, rod-shaped gram negative bacterium species (a) was identified as *E. coli* on an Optical microscope after gram staining at 10µm, and the second bacterium species identified was *Streptococcus* (polymeric chain structure). The test was done seven days later of curing immediately before the impregnation of microorganisms; this indicates the existence of microorganisms even on the newly casted structure of kitchen floor surfaces. When these organisms are supplied with nutrients they can cause serious damage, which will result in structural failure. Hassan et al., [22] reported that for each 10% replacement of OPC by FA in a concrete mix, the water content reduces by 3-4%. This in turn, improves the packing capacity of the concrete ingredients and reduces its porosity.



(a) (b)

Fig. 1 (a) *E. coli* and (b) *Streptococcus* represents biochemical test results on of gram-staining microbial evaluation of pure concrete mixture cured for 7 days

A. Porosity

The addition of nutrient agar on concrete mortar matrix helps reducing water content; however it terrible affects the structural integrity of material and significantly increases porosity, the presence of microorganisms on newly casted specimens observed in Fig. 1 are able to rapidly multiply by means of binary fission. Fig. 2 of the study shows the behavior of concrete structure with different composition of nutrient agar versus concrete (the concrete trend in all graphs represents the control non-admixture material). The trends in Fig. 2 show higher porosity at 2% composition of NA, this elaborates on the capability of microbial activity to degrade structures in kitchen floor surfaces. When there is sufficient NA onto concrete mortar, microorganism survives to a greater extent within the pores. This indicates the dissolution and structural failure of the cementitious matrix.

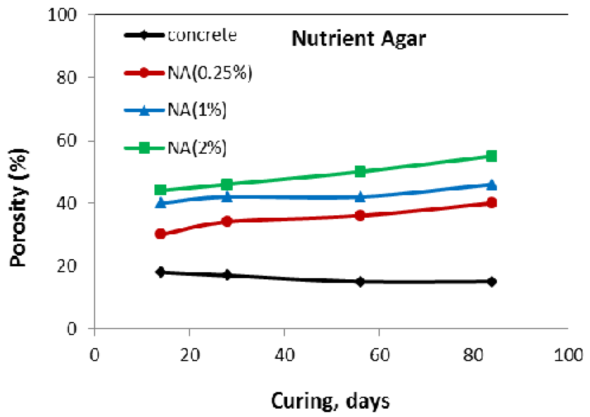


Fig. 2 Porosity increase of specimens during concrete curing

The results in Fig. 3, illustrates the enhancement of structure when MK admix is added on concrete mortar, the fineness of the particles improves packing of the mortar matrix and reduction in pores is achieved. The experiment has been carried up to 84 days respectively and the observation of pore reduction improved by up to 6%, these has been attributed from the control mixture on a seventh day of curing.

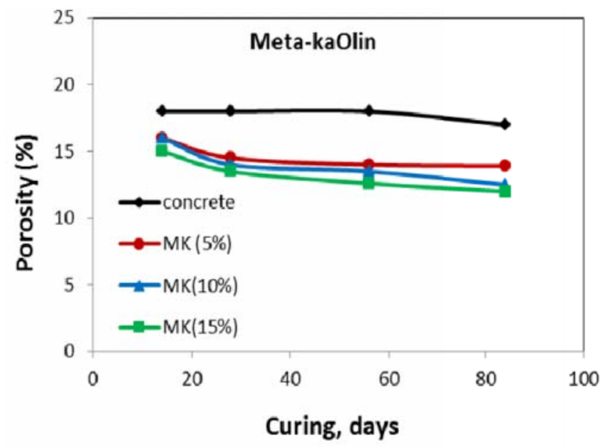


Fig. 3 Porosity decrease of specimens during concrete curing

The graphical presentation of pH range values of microorganisms prepared media culture is observed in Fig. 4, according to the selection. The illustration shows the pH range values of 7.2-8.2, with *E. coli* obtaining the highest pH value and TSB to be the lowest. The *E. coli* which was identified during biochemical test as one of the organisms already present on concrete mortar has once again been added, due to its highly microbial reactivity when in contact with organic acids. The alkalinity of cement with higher pH value is affected by microorganism’s interaction, and when in contact with organic acids the structure becomes acidic, and the cement paste slowly gets leached off.

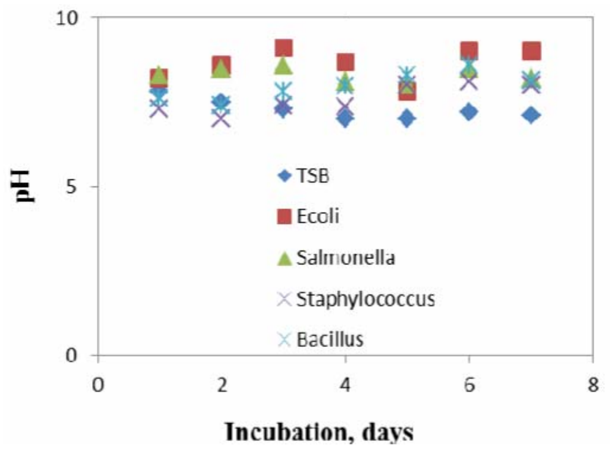


Fig. 4 pH of microorganisms incubated at 37^{O}C for 7 days

The ingress of bacteria through pores penetrates even further allowing the structure to degrade; and furthermore the crack development continues and ultimately results in spalling of surfaces. The selection of organisms was made based on their availability on food processing industries. Visual optical microscope helps identifying bacteria relatively with their behavior in terms of molecular structures on gram staining technique after streaking, and incubating.

B. Compressive Strength

The compressive strength results of up to 28 days of different composition of chemical and mineral additives has been studied and presented in Figs. 5-8. On the plot of NA versus Strength in Fig 5, the performance is significantly poor at 0.25% NA, this is due to enough nutrients on mortar mixes which caused elevation in porous media and less dense material is achieved. However the results are extremely poor at 2% composition achieving the strength of 5MPa, availability of nutrients surpassed the uniformity of structure and bacteria’s were able to survive for extended period

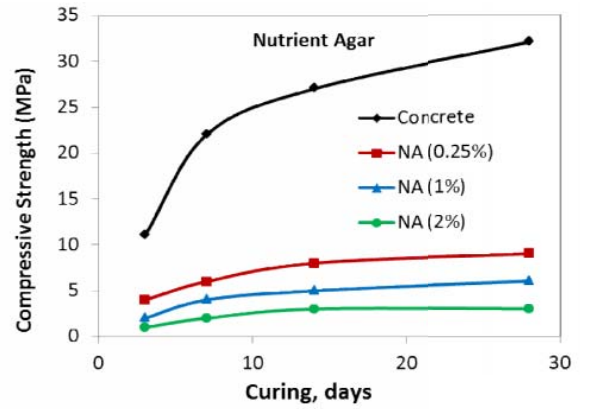


Fig. 5 Strength Measurement of NA on a 28 days period

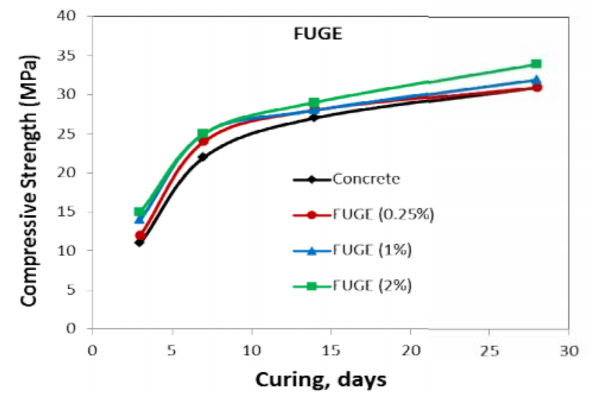


Fig. 6 Strength Measurement on FUGE chemical on a 28 days period

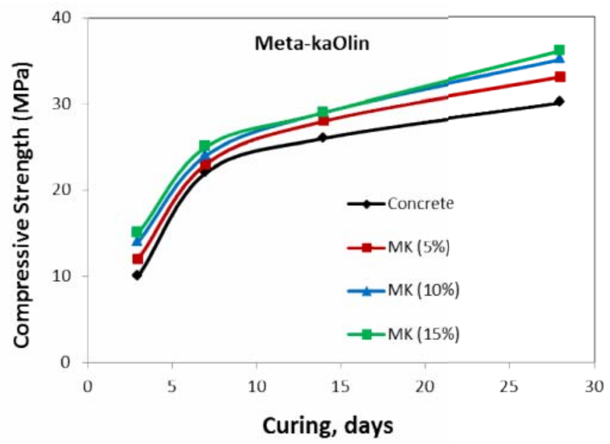


Fig. 7 Strength Measurement of MK on a 28 days period

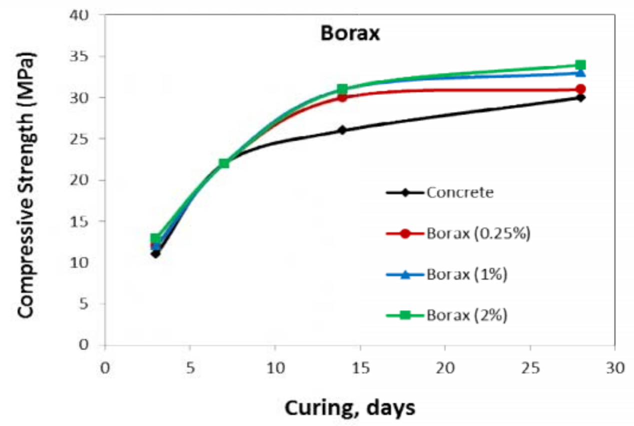


Fig. 8 Strength Measurement of Borax on a 28 days period.

The control mix in Figs. 5–8; shows similar trend reaching strength of 30MPa. In Figs. 6 and 8, the chemical admixtures greatly retard the microbial impact, the trends shows correlation of results from 0.25-2%, with 30MPa achieved on a lower composition and 35MPa on higher composition. These shows good workability results, structural integrity and uniformity, and it also prove the extent of bacterial inhibits on the structure.

The results obtained on this study clearly indicates that the life span of concrete floor structure in food processing industries will be extended, observed from the results increased in strength, attributed to mineral admixture (MK), which provides additional improvement on porosity and hence contribute to material durability, consequently as concrete cures the strength increases to 38MPa in Fig. 7. Attempts to correlate permeability with strength for different concrete types have indicated the difficulty of obtaining a unique relationship [23], [24].

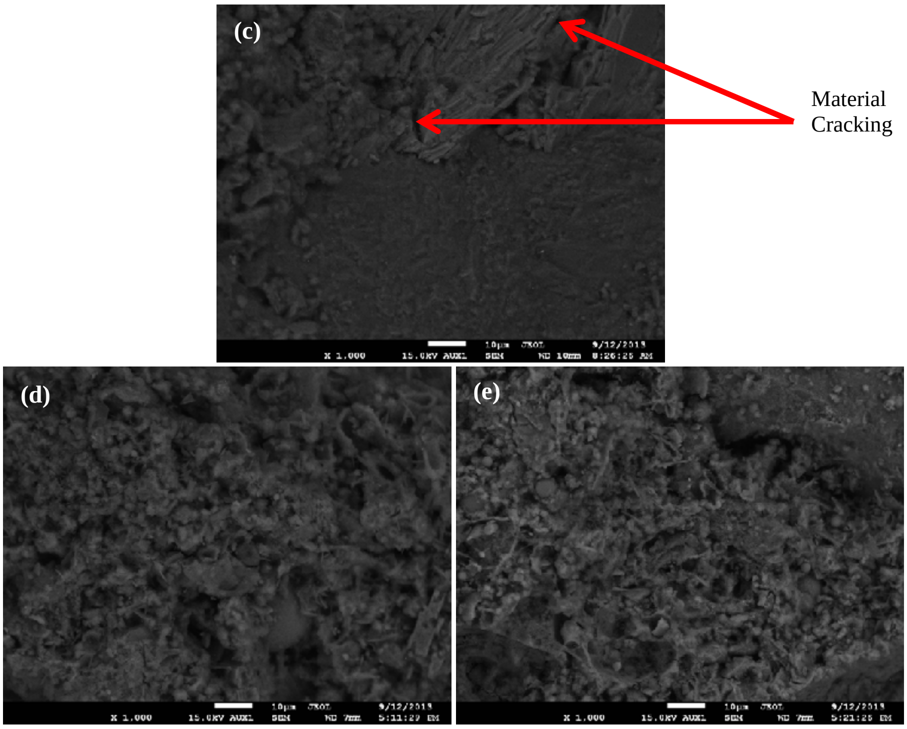


Fig. 9 Scanning Electronic Microscope (SEM) results control mortar and chemical admixtures (c) control mix, (d) FUGE and (e) Borax solution (1000x) after 84 days of curing

IV. Conclusion

The conclusion made from this study is drawn according as follows:

- In Food processing plants, the bacterial action on floor surface it is highly encountered by means of moisture, food, organic acids and the cost of rehabilitation exceed that of newly casted structures, thus the investigation has been performed and the mix design meeting the requirements has been developed.
- The mineral admixture (MK) lowers the porosity by up to 6%, maintains uniformity due to its particles fineness and compressive strength is increased; cement material due to its pozzolanic effects when mixed with chemical admixture strongly prevents microbial activity. This is a good indication of material durability.
- The Scanning Electronic Microscope demonstrates the behavior of mortar matrix during curing. The control mortar (c) is seen developing micro cracks due to permeability of microorganisms as results of exposure to aggressive agents. The image on (d) and (e) the situation shows good performance no cracks observed at an early age of curing.

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