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EFFECT OF SODIUM NITRITE AS A CORROSION INHIBITOR ON WORKABILITY AND STRENGTH DEVELOPMENT OF CONCRETE

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ABSTRACT

The use of corrosion inhibitors as admixtures in the Nigerian construction industry is gradually becoming a common practice. However, studies relating to how these admixtures affect the properties of concrete are very few. This study investigated the effect of sodium nitrite - a type of corrosion inhibitor - on some properties of fresh and hardened concrete. Two different concrete mixes (C20 and C25) were prepared. Sodium nitrite was added in dosages of 0.3, 0.6 and 1.0% of the mixing water. The fresh concrete mix was tested for workability by performing a slump test, while compressive strength was determined on the hardened concrete at 7, 14 and 28 days. The results obtained showed an increase in workability when sodium nitrite was added at dosages below 0.6%, and a decrease at dosages of 1.0%. The compressive strength of concrete dosed with 0.6% sodium nitrite recorded after 7 days was similar to that of concrete without sodium nitrite. However, after 28 days, concrete mixes dosed with sodium nitrite had lower strengths compared to those without sodium nitrite. This was attributed to increased alkali-aggregate reaction and was seen to be more pronounced on the C20 concrete, which contained a higher proportion of aggregates.

1. INTRODUCTION

Most reinforced concrete structures are exposed during their service life to adverse environmental conditions such as corrosion and expansive aggregate reactions, which attack the concrete or steel reinforcement (Ormellese et al., 2009). Reinforcing steel embedded in concrete shows a high amount of resistance to corrosion because the cement paste in good quality concrete provides an alkaline environment with pH in the range of 12.5 to 13.5 (Vaysburd and Emmons, 2004). This alkaline environment protects the steel from corrosion by the formation of a protective ferric oxide film on the surface of the steel bar when it is embedded in concrete. This passive film is only a few nanometers thick and can remain stable even in highly alkaline concrete with pH of 11 - 13.5 (Broomfield, 1997). The protective action of the passive film is immune to mechanical damage of the steel surface. However, it can be destroyed by carbonation of the concrete or by the presence of chloride ions (Vaysburd and Emmons, 2004). The penetration of carbonates or chloride ions through the concrete pores to the oxide layer on the steel reinforcement results in the breaking down of the passive layer. When this occurs, the steel bar becomes vulnerable to attack, and in the presence of moisture and oxygen, corrosion will occur (California Department of Transportation, 2003).

Proper design and preparation of reinforced concrete in accordance with standard codes and timely maintenance of the structures are requirements that would guarantee them a long and efficient life in aggressive media (Abdulrahman et al., 2011). However, lack of proper adherences to these requirements leads to the need for preventive measures to sustain the service life of reinforced concrete structures. Saraswathy and Song (2007) gave a list of preventive measures applied in the construction industry which include cathodic protection, corrosion inhibitors, coatings, penetrating sealers and chloride removal.

Corrosion inhibitors are chemical admixtures that are often added in small proportions to concrete mixes to either prevent or delay the corrosion of the embedded steel reinforcement bars. They can also be utilized in the repair of reinforced concrete structures that have been exposed to corrosion attack, by painting or spraying the inhibitor on the concrete's surface and allowing it to penetrate into the concrete through the cracks on the concrete's surface (Roberge, 2000). For the case of repair, as the inhibitor penetrates into the concrete, its molecules reacts with the cement paste and steel reinforcement to restore the passivating layer surrounding the steel, thereby extending the service life of the concrete structure (Broomfield, 1997).

Corrosion inhibitors are either organic or inorganic in nature, and can be classified according to their mechanism of protection. For example, they can protect by influencing the anodic reaction or cathodic reaction or both reactions (Broomfield, 1997; Hansson et al., 1998). According to Kepler et al. (2000), they can also increase the anodic or cathodic polarization behaviour, decrease the rate of diffusion of ions to the steel's surface and increase the electrical resistance of the steel's surface.

Among common corrosion inhibitors are chromates, nitrates, benzoates, phosphates, borates (Konno et al., 1982; Isaacs et al., 2002) with nitrites being used as inhibition admixture in reinforced concrete (Montes et al., 2004; Sideris and Savva, 2005; Anna et al., 2006). The suitability of any one selected depends on many factors ranging from the material of the system they have to act in, to the nature of the substances they are added into and their operating temperature. There are three major concerns regarding the use of corrosion inhibitors. The first one is the long-term stability and performance of the inhibitor. The second is the inhibitor's effect on corrosion propagation after corrosion initiation, while the third is the effect of the inhibitor on the physical properties of the concrete over the service life of the structure (Persson, 2000).

In a recent survey conducted alongside this study, it was observed that the use of corrosion inhibitors as admixtures in Nigeria is gradually becoming a common practice, with most of these inhibitors produced locally. A major problem that was highlighted by most contractors was the lack of research data showing the impact such admixtures had on the properties of the concrete. One of such inhibition admixture that was commonly used is nitrite (calcium or sodium nitrite). Nitrites have been reported to have good corrosion inhibition properties (O'Reilly et al., 2013; Gaidis, 2004; Anna et al., 2006). They block the corrosion reaction of the chloride-ions by chemically reinforcing and stabilizing the passive protective film on the steel. However, very few studies have looked at how its use affects the properties of concrete, especially in tropical environments like Nigeria. This paper reports the effects of sodium nitrite on some properties of locally made concrete.

2. MATERIALS AND METHODS

2.1. Materials

Portland cement (CEM I 42.5R) and aggregates used for this study were provided by the Department of Civil Engineering, University of Benin. The sodium nitrite ($NaNO_2$) used as the corrosion inhibitor, was procured from a local vendor.

2.2. Concrete Mix Design

Two grades of concrete of 28-day target strength – 20 N/mm^2 and 25 N/mm^2, designated as C20 and C25 were used for the study. Theses grades were selected for the study because they are widely used in the construction of most reinforced concrete structures. The mix ratios of the various constituents are as shown in Table 1. Sodium nitrite was added in specific dosages of 0.3, 0.6 and 1.0% of the mixing water. The sodium nitrite was dissolved in the mixing water before it was added to the concrete mix.

Table 1: Mix ratios of starting materials

Mix	Water/cement ratio (w/c)	Cement (kg/m^3)	Fines (kg/m^3)	Coarse (kg/m^3)
C20	0.47	3.645	5.805	10.737
C25	0.43	4.005	5.670	10.530

2.3. Sample Preparation and Curing

The various constituents (cement, water, aggregates and sodium nitrite) were weighed separately and placed in the concrete mixer. Mixing was done in accordance with BS EN 1992-1-1:2004, but at a temperature of 23 ± 2°C. After mixing, the concrete was placed into 100 mm cube moulds. The moulds were covered with thin polythene sheets and left to cure in the laboratory for at least 24 hours, after which the cubes were demoulded and placed in water bath for curing. The cubes were cured at a temperature of 22 ± 2°C, for periods up to 28 days.

2.4. Test Methods

The following tests were carried out to evaluate the effect of sodium nitrite on concrete properties:

- Slump test
- Compressive strength test

2.4.1. Slump test

After mixing, a portion of the concrete was poured into the slump cone to determine the slump value in accordance with EN 12350-2:2002. This was used to assess the impact of the corrosion inhibitor on the workability of the concrete.

2.4.2. Compressive strength test

Compressive strength was determined on triplicate samples at specific ages of 7, 14 and 28 days. At the test age, the concrete cubes were brought out and surface dried at room temperature. The cubes were weighed before testing. The compressive strength (in MPa) was taken as the failure load (in kN) divided by the cross sectional area of the concrete cube (in m^2), as specified in BS EN 1992-1-1:2004.

3. RESULTS AND DISCUSSION

3.1. Workability

Figures 1 and 2 shows the effect of sodium nitrite dosage on the workability of the C20 and C25 concretes respectively.

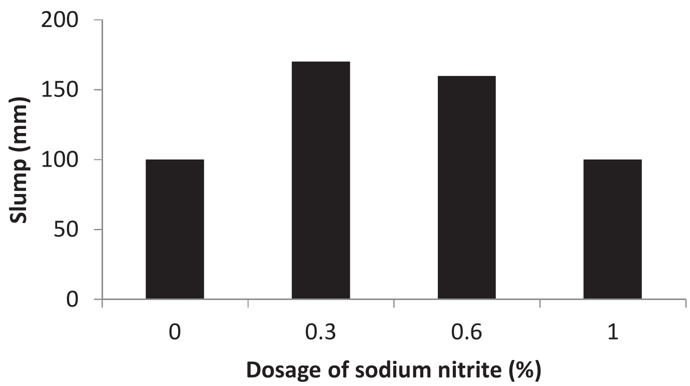

Figure 1: Effect of dosage of sodium nitrite on the workability of C20 concrete

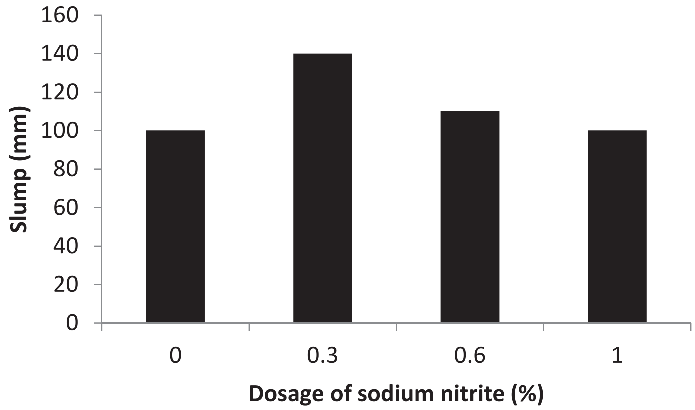

Figure 2: Effect of dosage of sodium nitrite on the workability of C25 concrete

From both figures, it can be seen that the addition of sodium nitrite to the concrete mixes initially resulted in an increase in the workability of both concretes. However, as the dosage was increased from 0.3% to 0.6% and from 0.6% to 1.0%, there was a slight decrease in the workability of the concrete mixes, with the effect appearing to be more significant for the lower C20 concrete grade. This implies that the effect of sodium nitrite as a corrosion inhibitor on the workability of the concrete is dependent on the grade of the concrete and on the amount added (dosage).

In terms of the impact of dosage of the corrosion inhibitor on workability, for the C20 concrete as shown in Figure 2, it can be seen that the control mix (having a dosage of 0%) had the lowest workability with a slump value of about 100 mm. The addition of 0.3% sodium nitrite resulted in an increase of about 70% in the slump value, but as the dosage was increased to 1.0%, the reverse occurred with the slump value decreasing by about 60% to a value of 100 mm. Similar trends were also observed for the C25 concrete, as seen in Table 3. As the dosage was increased from 0 to 0.3% and from 0.6 to 1.0%, there was an increase of about 40% and a decrease of about 10% respectively, in the slump value of the fresh concrete. The trend observed is somewhat different from that reported by Rosenberg et al. (1977), who observed that the initial set of concrete was accelerated by more than 2 hrs when corrosion inhibitors was used. However, in their study, they used calcium nitrite whereas in this study, sodium nitrite was used. According to Gaidis (2004), sodium nitrite has the potential of increasing the alkali – aggregate reaction, when used as a corrosion inhibitor. This may be the reason for the initial increase in workability observed at lower dosages, and the decrease in workability observed at higher dosages.

3.2. Compressive Strength

The effect of the dosage of sodium nitrite on the compressive strength of concrete is presented in Figures 3 and 4. Figure 3 shows the effect of sodium nitrite on grade C20, while Figure 4 shows the effect sodium nitrite on grade C25.

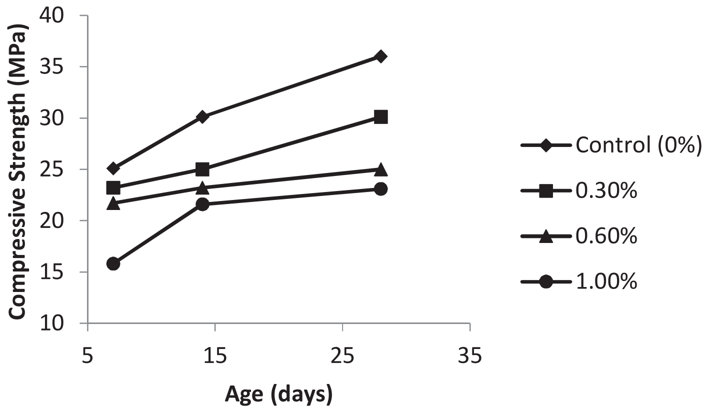

Figure 3: Effect of dosage of sodium nitrite on strength development of C20 concrete

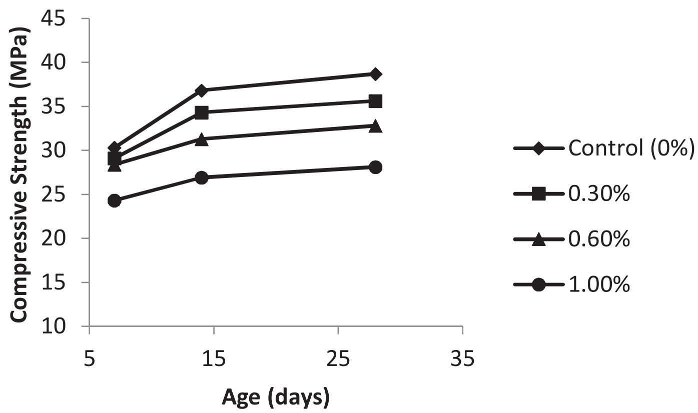

Figure 4: Effect of dosage of sodium nitrite on strength development of C25 concrete

The figures show that the addition of sodium nitrite generally resulted in a decrease in compressive strength. For the C20 concrete, after 7 days, dosages of 0.3 and 0.6% did not have any significant effect on the compressive strength, whereas a dosage of 1.0% resulted in about 40% decrease in the compressive strength when compared with the control mix. Similar trends were also observed for the C25 concrete, as seen in Figure 4. This agrees with the results obtained by Craig and Wood (1970) but appears to be in contrast with those obtained by O'Reilly et al. (2013), where a 12% increase in compressive strength was observed for mixes containing corrosion inhibitors. However, it is important to note that in the study by O'Reilly et al. (2013), calcium nitrite was used; whereas in this study, sodium nitrite was used. The reason for the decrease in strength observed here is not clear, as no microstructural observations were carried out. However, it is generally known that alkali – aggregate reactions results in a reduction in strength (Gaidis, 2004), and this could be the reason for the reduced strength observed for the mixes containing sodium nitrite.

Also, as was observed in the results of the slump test, the reduction in strength as a result of the addition of the sodium nitrite appeared to be more significant on the lower C20 grade concrete. The reason for this can be seen from Table 1, which showed that the C20 concrete contained more aggregates than the C25 concrete. As mentioned before, the addition of sodium nitrite increases the potential for alkali – aggregate reaction, which can lead to a decrease in strength. This decrease in strength is bound to be more pronounced on the C20 concrete, since it contained more aggregates, and could be the reason why the reduction in strength observed as a result of the addition of sodium nitrite was more significant in the C20 concrete.

4. CONCLUSION

This study investigated the effect of sodium nitrite as a corrosion inhibitor on the workability and strength development of concrete. While sodium nitrite may be a good corrosion inhibitor as reported in previous studies, the results obtained from this study have shown that the addition of sodium nitrite to concrete mix as a corrosion inhibitor can have adverse effect on the workability and strength development of the concrete. This effect was seen to be dependent on the grade of the concrete, and the dosage or amount of sodium nitrite added to the concrete mix.

In conclusion, the following points are highlighted:

- Sodium nitrite when added to concrete at lower dosages below 0.6% of the mix water tends to improve workability; but at higher dosages of 1.0% and above, the reverse occurs.
- The addition of sodium nitrite to concrete leads to a reduction in strength.
- It is important to point out that there are several other factors that could have influenced the findings of this study, such as the use of higher strength grades of concrete like C35 and C40, or the use of higher dosages of sodium nitrite, or the use of concretes prepared from contaminated aggregates. However, these were not investigated in this study.

5. ACKNOWLEDGEMENT

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6. CONFLICT OF INTEREST

There is no conflict of interest associated with this work.

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