Influence of Cashew Nut Shell Liquid on Concrete Exposed to Magnesium Sulphate Environment

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ABSTRACT

Concrete is negatively impacted by magnesium sulphate attack because it expands and cracks. The purpose of this research is to investigate how concrete's resistance to magnesium sulphate is affected by cashew nut shell liquid. The functional groups of the material were identified using FTIR, and the liquid's suitability as an admixture was also determined by analysing its physicochemical characteristics. A design mix of 1:2.11:3.58, was adopted for this study. The concrete samples were made with CNSL doses of 0%, 0.6%, 1.2%, and 1.8% relative to the weight of cement. Concrete cubes with a 50 mm by 50 mm mould were cast, and they were left to cure in water for 28 and 90, days. Following 28 and 90 days of maturation in water, they were taken out, weighed, and then allowed to cure for 7, 21, 35, and 56 days in a 20% magnesium sulphate medium. The results of weight loss showed that for 28 days curing before exposure, CNSL concrete samples loss less weights than the control sample, with an optimum value of +0.51% at 1.2% dose of CNSL, at 35 days of curing age. The results of 90 days curing before exposure showed a gain in weights of all the sample, with an optimum value of -1.55%, at 1.8% dose of CNSL, at 7 days of exposure. The results of residual compressive strength showed that, at 28 days of curing before exposure in magnesium sulphate medium, control samples recorded a loss in compressive strength, likewise CNSL samples at 7- and 21-days curing; while CNSL samples at 35 and 56 days of curing age, obtained a gain in compressive strength. An optimum value of gain in compressive strength of -44.61% at 1.2% dose of CNSL at 35 days of exposure; and loss in compressive strength of +6.78% at 1.2% dose of CNSL at 35 days of exposure, for 28 and 90 days curing respectively. It can be inferred that, the CNSL influenced the mass loss/gain and residual compressive strength of concrete samples, hence better performance in the magnesium sulphate medium, when compared to the reference samples. This is attributed to the influence of anarchardic acid, cadol and cadanol interaction with Ca $(OH)_2$ in cement in the course of hydration, which leads to the formation of insoluble calcium stearate, thereby improving the performance of the CNSL concrete samples in magnesium sulphate medium.

Keywords: CNSL admixture, magnesium sulphate, physicochemical characteristics, anarchardic acid, cadol, cadanol.

1. INTRODUCTION

Due to its vulnerability to internal and external chemical attacks, especially sulphate attacks, over a protracted period of exposure, cement concrete performs differently in different climates (Hafiz & Ash 2022). Cement-based construction materials are the most widely used in the world, and the service life of concrete structures is significantly impacted by the durability of these materials. The primary factors affecting the longevity of concrete are sulphate attacks, especially those brought on by $MgSO_4$ (Liu, Zhang, Deng, Xie, Long & Tang, 2017). Sulphate ions can react with monosulfate or C_3A to make ettringite, or they can react with CH and C-S-H gel, the cement's hydration products, to form gypsum. Expansion and even micro- and macrocracks can result from these processes (Geng, Easterbrook, Li, & Mo 2015). Sulphates are considered to be one of the main problems affecting concrete buildings because of their high solubility. Sulphate attack is usually the cause of concrete deterioration, along with volume changes and cracking. Additionally, a variety of environmental settings, such as soil, saltwater, subterranean water, and industrial waste water, contain sulphates (Siad, Lachemi, Bernard, Sahmaran, & Hossain 2015). Moreover, magnesium sulphate ($MgSO_4$) has the fastest and worst effects on concrete (Yildirim & Sumer, 2013). The evidence presented by Hekal et al. (Hekal, Kishar, and Mostafa (2002) indicates that magnesium sulphate is more harmful to the properties of concrete than sodium sulphate.

According to Kwang-Myong, Su-Ho, Jae-Im, and Soon-Oh (2014) concrete structures exposed to soil, groundwater, and marine conditions may perform less effectively due to sulphate assault. Expandable hydration results in the production of gypsum and ettringite, which are caused by hazardous ions like sulphate ions seeping into concrete and combining with calcium hydroxide and calcium aluminatehydrate. Concrete structures may eventually become less sturdy as a result of cracking and softening. Sulphates are commonly present in soils, groundwater, river water, and seawater in salty, saline, and offshore environments (Ouyang, Nanni, & Chang 1988). According to observations made by Aziez and Bezzar (2019) sulphates are believed to be among the most hostile ions in the environment that can badly damage concrete structures. Concrete exposed to sulphate assault always experiences considerable expansion and is more likely to collapse (Zhao, Shi, Fan, Cui & Xie 2020).

The enlargement, according to reports, is caused by the corrosion products or hydrates produced by the sulphate assault (Liu, You, Diab, Liu, Zhang & Guo 2020). The volume of products, especially ettringite, during chemical corrosion is said to substantially exceed the volume of reactants (Li, Xie, Zhao & Li 2020). Additionally, the strength of corrosion products is quite low, which significantly reduces the strength of concrete (Zhang, Ji & Liu 2020). The volume of hydrates, $Na_2SO_4.10H_2O$, is noticeably several times bigger than the amount of Na_2SO_4. As a result, concrete's performance is greatly reduced by sulphate attack, whether it is chemical or physical (Tan, Yu, Ma Zhang & Wu 2017).

Corral-Higuera et al. (2011) did a study on sulphate attack and reinforcement corrosion in concrete with recycled concrete aggregates and supplementary cementing materials. Their results indicate that the reason the concretes first lost weight was because the specimens' initial weights increased after they were exposed to the sodium test solution. After four months, the weight loss of the 100% compound Portland cement concrete recycles coarse increased significantly. For the specimens with SCM, there is a slight increase in weight loss that becomes apparent after four months. Following a half-year of exposure, the specimens made of 100% compound cement, recycled course, and 10% silica fume concrete had the biggest weight losses (2.8%), followed by specimens made of 30% fly ash, recycled coarse, and 10% silica fume concrete (0.37% and 0.14%, respectively. A partial replacement of cement with 10% silica fume decreases weight loss by approximately 20 times compared to concrete without extra cementing ingredients. A partial replacement of cement with 30% fly ash lowers weight loss by approximately 8 times because of sulphate attack.

Gaowen, Mei, Mengzhen, and Henghui (2020) published a study. According to their research, sulphate attack puts concrete structures-especially cast-in-situ concrete structures-at substantial risk by causing significant weight loss and expansion during the later phases of corrosion. The results also showed that sulphate diffusion happens more quickly in cast-in-situ concrete due to its accelerated crack development compared to precast concrete. The chemical reactions between magnesium sulphate and concrete are summarised as follows: the sulphate ion ($SO4^{2-}$) reacts with the aluminate and portlandite to form gypsum and ettringite, respectively; the magnesium ion (Mg^{2+}) may combine with the hydroxyl ion (OH^-) to generate brucite [Mg $(OH)_2$] or the magnesium may partially replace the calcium silicate hydrate (C-S-H). Consequently, when the magnesium silicate hydrate (M-S-H), which lacks binding properties, may form in the second step, the hydrated paste becomes mushy and incoherent (Higgins, 2003).

According to Ahmed and Kamau (2017) most research have concentrated on developing composites with cement, lime, and other cementitious elements such as pozzolanic materials like ground pulverised fly ash (PFA) (Divya, Rafat and Kamal 2015); ground granulated blast furnace slag (GGBS); rice husk ash (RHA) and palm ash (PA) (Kamau, Ahmed, Hirst & Kangwa 2016); corn cob ash (CCA) (Kavitha, Aruraj, & Prince 2016); metakaolin (MK), zeolite and silica fume (SF) (Najimi, Sobhani, Ahmadi and Shekachi 2012) etc. Because of the composition's high silicate content, these materials absorb portlandite during the sulphate reaction, resulting in more C-S-H gel and less gypsum. Sulphate still affects concrete, even with the use of these pozzolanic materials to lessen its attack, and less researches has been done on the use of adjuvants to lessen sulphate attack in concrete. This dilemma led to the investigation of using cashew nut shell liquid (CNSL) as an additive in concrete exposed to an environment containing 20% magnesium sulphate. This study explores the use of green admixture to ameliorate the magnesium sulphate attack of concrete.

2. MATERIALS AND METHODS

2.1. The materials used and mix proportions

To produce concrete specimens for sulphate resistance test, OPC, complying to BS 12 1999. The cashew nuts were obtained from Petegi town of Petegi Local Government Area, of Kwara State. The cashew nuts were processed to obtain CNSL in Nigeria cereal research institute in Bida, Niger State. The characteristics of the CNSL is presented in the form of functional groups confirming the polyometric chains which possess the carboxylic and hydroxyl groups, as given in Figure 1. Table 2 shows the physicochemical properties of CNSL. Fine aggregates were obtained from river Gumu, Bauchi state- Nigeria, while crushed granite of 10mm size was obtained from Moulds quarry site Lamingo, Jos, Plateau State -Nigeria. The physical properties of the aggregates are presented in Table 3 and 4, respectively.

2.2. Specimen preparations

The concrete samples were prepared with a design mix of 1:2.11:3.58, and with 0%, 0.6%, 1.2% and 1.8% CNSL dose in relation to the weight of cement. Concretes cubes of 50mm-by-50mm mould were cast and cured in water for 28 and 90 days. 60 samples were cast for 28 days curing and another 60 number of samples were cast for 90 days curing. After curing to maturity for 28 and 90 days in water, they were removed and weighed then subjected to curing in 20% magnesium sulphate medium at 7, 21, 35 and 56 days of exposure respectively which is in consonance with ASTM C 1012 (2004). The concrete mix proportion is presented in Table 5.

2.3 Methods for Testing sulphate Resistance and Residual Compressive Strength

After that, the weight loss of the samples was determined, then the samples were crushed to determine the amount of residual compressive strength in the cured sulphate medium. The two tests were performed in accordance with the standard procedure prescribed in ASTM C 1012 (2015). Equation 1 was used to compute the weight loss, while Equation 2 was used to determine the residual compressive strength. The Department of Building's concrete laboratory served as the test site.

$$\text{The weight loss \%} = \frac{w_0 - w_i}{w_0} \times 100 \quad (1)$$

Where ω_o = weight (in grammes) of the specimen before immersion.

ω_i = weight (in grammes) of cleaned specimens after immersion.

(i = 7, 21, 35, and 56 days).

The residual compressive strength % = $\frac{f_0' - f_t'}{f_0'} \times 100$ (2)

Where f_0'= compressive strength of sample before immersion.

f_t'= compressive strength after t, days of immersion in sulphate solution.

(t = 7, 21, 35, and 56 days).

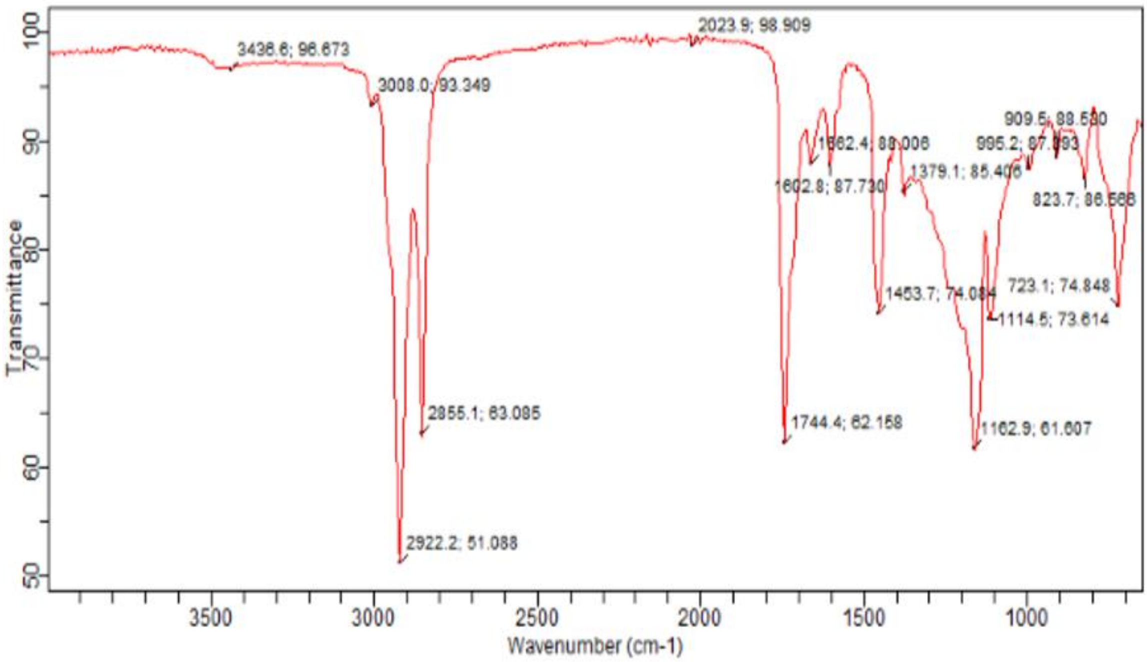


Figure 1: Fourier Transform Infrared Spectroscopy of Cashew Nut Shell Liquid Showing the Functional Groups

Table 1: Preliminary Results on the Physicochemical Properties of Cashew Nut Shell Liquid (CNSL)

Property Determined	Properties of CNSL
Free Fatty Acid (MgKOH/g)	36.00
Flash Point (°C)	110.00
Cloud point (°C)	-11.00
Acid Value (MgKOH/g)	42.00
Density 15°C (Kg/m^3)	886.00
Kinematic Viscosity at 40^{0}C Mm 2/5	63.50
Low heat Value (LHV) MJ/kg	21.28
Power of Hydrogen ion concentration (pH)	5.50
Oil yield (%)	38.00
Saponification Value (kg/g)	290.67
Iodine Value (Mg/g)	63.12
Perioxide Value (Emq/kg)	9.00

Table 2: Physical properties of Fine aggregates

Specimen	Amount Retained on No 2.00 sieve size	Density (g/cm^3)	Silt Content%	Absorption%	Fine Modulus%	Free Moisture Content %
River Sand	19.31	2.60	2.93	0.78	2.81	0.15

Table 3: Physical Properties of Coarse Aggregates

Specimen	Bulk Density	Specific Gravity	Aggregate Impact Value%	Aggregate Crushing Value
Crushed Granite	1.29	2.86	11.09	16.58

Table 4: Quantity of Ingredient Concrete Required per meter Cube

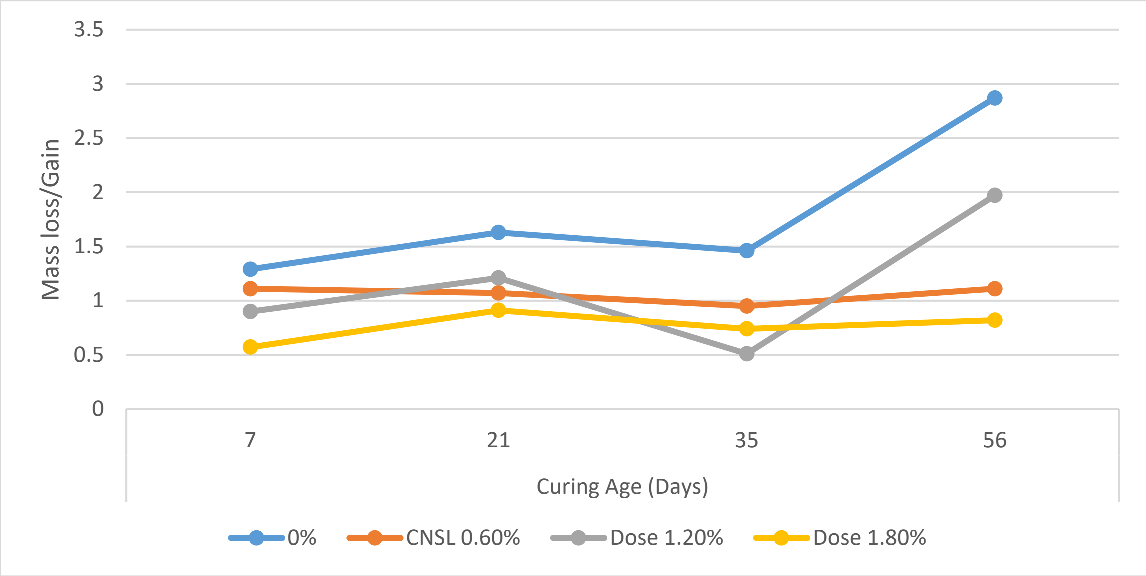
Ingredient	Normal Concrete
Cement	335
Fine Aggregate	720
Coarse Aggregate	1220
Water	190
CNSL 0.0%	0.00
CNSL0.6%	2.01
CNSL1.2%	4.02
CNSL 1.8%	6.03

3. RESULTS AND DISCUSSION

This subsection, presents the results of evaluation of cashew nut shell liquid concrete samples exposed to an aggressive environment of magnesium sulphate in-terms of mass loss/gain and residual compressive strength. The samples were cast and cured in water for 28 and 90 days of maturity. The two sets of samples were then subjected to 20% magnesium sulphate curing, at 7, 21, 35 and 56 days of curing. The samples were then tested for mass loss/gain and residual compressive strength and the results were discussed as follows:

3.1. Mass Loss in Magnesium Sulphate Medium after 28 Days Curing in Water

mass variation of the samples in contact with $MgSO_4$ at ambient temperature is shown in Figure 2. At 7 days of curing age in 20% $MgSO_4$ under ambient temperature environment, the control sample decreased in weights by +1.29%, while 0.6%, 1.2% and 1.8% CNSL doses, recorded a decrease in weights value of +1.11%, +0.90% and +0.57% respectively. At 21 days of curing in $MgSO_4$ medium, the highest decrease in weight by the control sample was 1.63%, while 0.6%, 1.2% and 1.8% CNSL dose obtained in weight values loss of +1.07%, +1.21% and +0.91% respectively. At 35 days curing, in chemical environment, the control sample consistently recorded a decrease in weight of +1.46%, compared to 0.6%, 1.2% and 1.8% CNSL that obtained a decrease in weight values of +0.95%, +0.51% and +0.74% respectively. At 56 days of curing the reference sample, got 2.87% weight loss, while 0.6%, 1.2% and 1.8% CNSL dose, recorded weight loss values of +1.11% +1.97% and +0.82%respectively. The investigation showed that the control sample decrease more in weights than the CNSL concrete samples. This is attributed to the shrinkage of control sample as a result of gypsum in the environment, while the CNSL samples experienced the same interaction of gypsum and anarchadic acid which led to the reduction in weight loss than the control sample. This is in consonance with research carried out by Aziez and Bezzar (2017).



Legend: - = Percentage weight gain + = Percentage weight loss

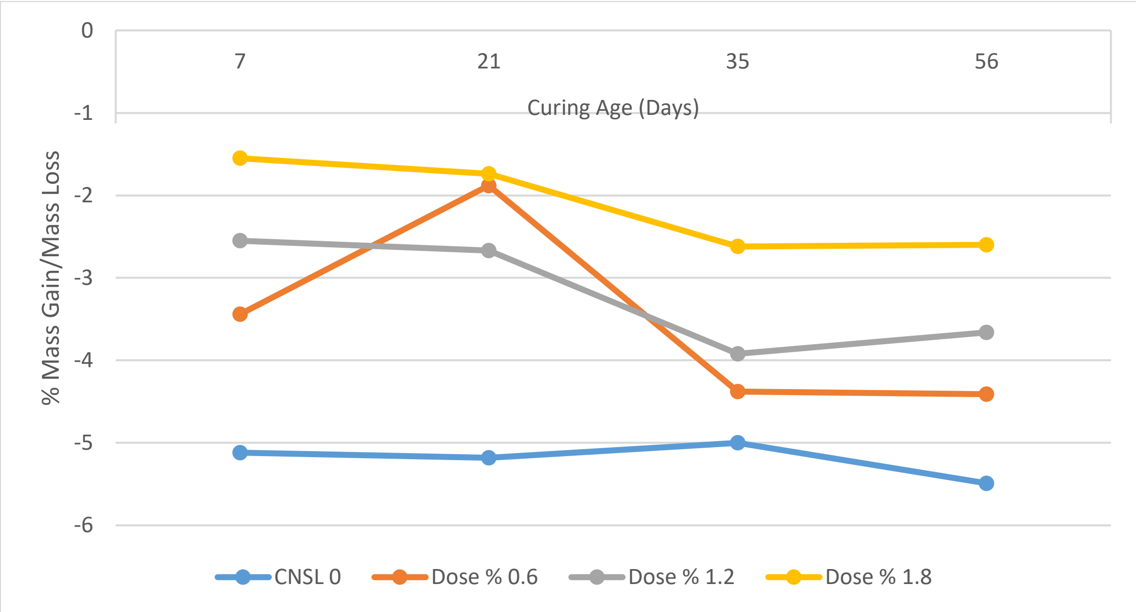
Figure 2: Percentage Mass Gain/ Loss of CNSL Concrete Samples in Magnesium Sulphate Medium after curing for 28 Days in Water

3.2 Mass Loss in Magnesium Sulphate Medium After 90 Days Curing in Water

Figure 3 shows mass change percentage values of mass loss/ gain of samples cured in $MgSO_4$, after 90 days curing in water. At 7 days of exposure in sulphate medium, the reference sample has an excessive weight gain of -5.15%, while CNSL shows a reduction in weight increase, while 0.6%, 1.2% and 1.8% CNSL recorded an increase in weight value of -3.44%, -2.55% and -1.55% respectively. At 21 days of curing in the sulphate medium, the control sample still maintained the highest value of -5.18% mass increase, while 0.6%, 1.2% and 1.8% dose of CNSL showed reduction in weight gain of -1.88%, -2.67% and -1.74% respectively. The 35 days of exposure in $MgSO_4$ environment the reference sample recorded -5.00% weight gain, and 0.6%, 1.2% and 1.8% CNSL dose gain weight values of -4.38%, -3.92% and -2.62% respectively. At 56 days of exposure in the chemical medium, the control sample obtained weight gain of -5.49%, while 0.6%, 1.2% and 1.8% CNSL dose obtained weight gain of values of 4.41%, 3.66% and 2.60% respectively. The results showed an increase in weight for all the samples during the curing periods in $MgSO_4$. The results are in tandem with a study carried out by Corral-Higuera et al. (2011). The results also showed that the control sample increased in weight more than the samples containing CNSL at the variation of the curing ages.

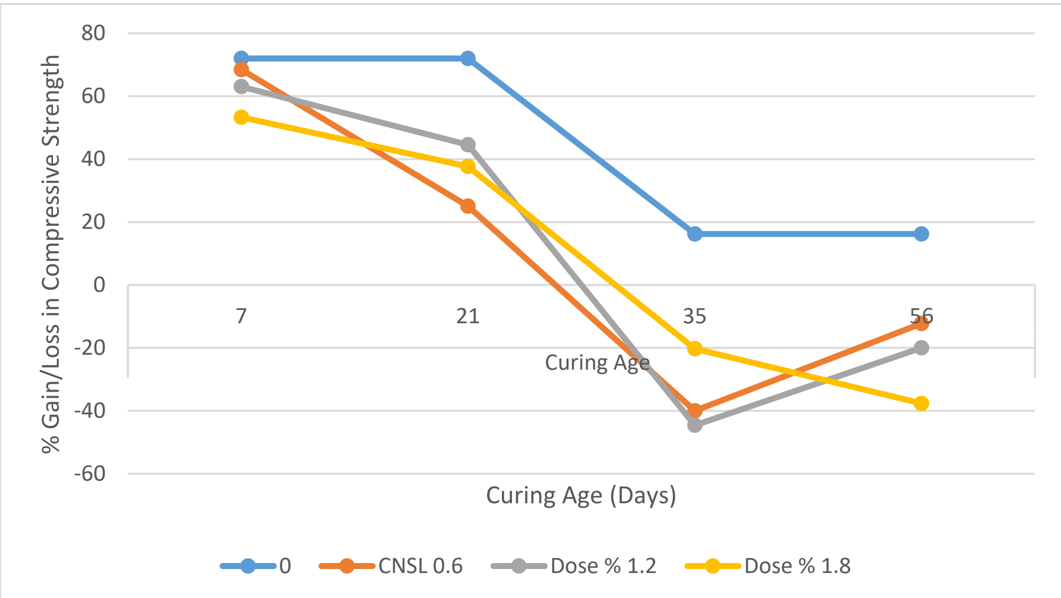
3.3 Loss/Gain in Compressive Strength of CNSL Concrete Samples in Magnesium Sulphate Medium after 28 Days Curing in Water

Figure 4 shows percentage loss/gain in compressive strength in $MgSO_4$ medium after 28 days curing in water. At 7 days curing in $MgSO_4$ medium, the control sample recorded the higher loss in compressive strength value of 72%, while 0.6%, 1.2% and 1.8% CNSL dose samples showed residual compressive strength values of +68.50%, +63.03% and +53.33%. At 21 days of exposure, the control sample still maintained the higher loss in compressive strength of 72.00%, compared to 0.6%, 1.2% and 1.8% CNSL dose specimens recorded +25.00%, +44.61% and +37.64% respectively. At 35 days of exposure, the control sample maintained the same consistency higher loss in compressive strength values of +16.20% and 0.6%, 1.2% and 1.8% CNSL dose samples showed gain in compressive strength values of -40.00%, -44.61% and -20.32% respectively. At 56 days of exposure, the control sample still showed a loss in compressive strength of value +16.20%, while 0.6%, 1.2% and 1.8% CNSL dose samples showed gain in compressive strength values of -12.25%, -20.00% and -37.64% respectively. The investigation reveals that at 7 and 21 days of exposure in the magnesium sulphate medium, the control and CNSL concrete samples showed loss in compressive strength values but at 35 and 56 days of exposure, the CNSL samples showed gain in compressive strength. The is attributed to the interaction between Ca $(OH)_2$ and anarchardic acid, thereby slowing down the rate of $MgSO_4$ attack.



Legend: - = Percentage weight gain + = Percentage weight loss

Figure 3: Percentage Mass Gain/ Loss of CNSL Concrete Samples in Magnesium Sulphate Medium after curing for 90 Days Curing in Water

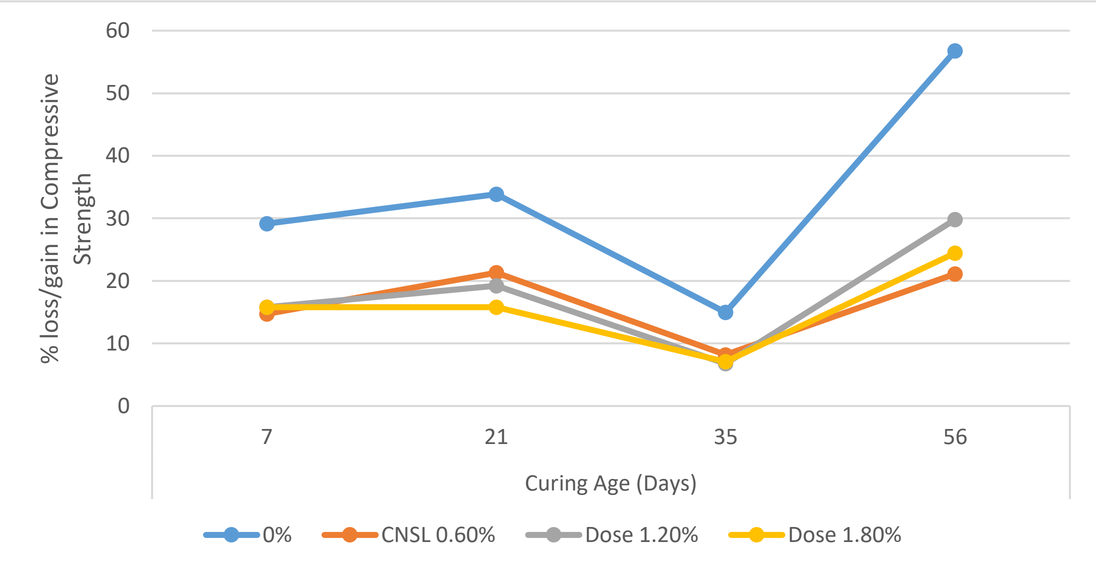


Legend: + = loss in compressive strength = gain in compressive strength

Figure 4: Percentage Loss/Gain in compressive strength of CNSL Concrete Samples in $MgSO_4$ Medium After 28 Days of Curing in Water

3.4 Percentage Loss/Gain in Compressive Strength of CNSL Concretes in magnesium Sulphate Medium after 90 Days Curing in Water

Figure 5 shows percentage loss/gain in Compressive Strength of CNSL Concrete in $MgSO_4$ medium After 90 days of curing in water. The investigation showed that at 7 days of curing in $MgSO_4$ medium, the control sample recorded the higher loss in compressive strength of +29.14%, compared to 0.6%, 1.2% and 1.8% CNSL dose samples which showed residual compressive strength of values of +14.75%, +15.79% and +15.79% respectively. At 21 days of exposure in chemical environment, the control sample recorded a loss in compressive strength value of +33.87%, compared to 0.6%, 1.2% and 1.8% CNSL dose samples that showed residual compressive values of +21.31%, +19.25% and +15.79% respectively. At 35 days of exposure in the chemical medium, the control sample recorded +14.97% compressive strength loss, while 0.6%, 1.2% and 1.8% dose of CNSL showed loss in compressive values of +8.20%, +6.78% and+ 7.08% respectively. At 56 days of curing age, the control sample showed loss in compressive strength value of +56.76%, compared to 0.6%, 1.2% and 1.8% CNSL dose, that recorded a loss in compressive strength values of +21.13%, +29.82% and +24.46% respectively. The evaluation reveals that the CNSL helps in improving the chemical resistance of the samples compared to the control samples, because the control sample loss greater compressive strength than the CNSL samples. This is attributed to interaction of the carboxylic functional group of the anarcardic acid and the hydration products.



Legend: + = loss in compressive strength   = gain in compressive strength

Figure 5: Percentage Loss/Gain in Compressive Strength of CNSL Concrete Samples in $MgSO_4$ Medium After 90 Days of Curing in Water

4. CONCLUSION

The findings of mass loss/gain after 28 days of curing before exposure in magnesium sulphate medium, indicate that the mass of the control sample increases with increasing curing age, while the mass of the samples containing CNSL dose decreases with increasing dose percentage. However, according to the results of the mass gain/loss analysis conducted 90 days curing before exposure, the control sample gained noticeably more weights than the CNSL concrete samples. The optimum dose of CNSL admixture for gain/loss is 1.2% CNSL at 35 days of exposure in chemical solution after 28 days curing; and 1.8% CNSL dose at 7 days of exposure after 90 days curing. The results of the residual compressive strength, cured 28 days prior to exposure, showed a loss in compressive strength at 7 and 21 days of curing age, at increasing CNSL dose percentage; and for 35 and 56 days of exposure, there was a gain in compressive strength of samples, at increasing CNSL dose percentage. The best dose of CNSL for residual compressive strength is 1.2% dose of CNSL at 35 days of curing in magnesium sulphate solution after 28 and 90 days of curing, before exposure. Furthermore, it can be concluded that CNSL samples outperform the reference sample in terms of $MgSO_4$ attack resistance.

5. RECOMMENDATIONS

Based on the findings, the following recommendations were made:

a. Since the study considered Brazilian cashew nut shell liquid, other varieties of cashew nut shell liquid can be investigated on magnesium sulphate resistance of concretes.
b. Grade 20 concrete was used for this investigation. It is recommended that grade 25 and grade 30 concretes resistance to magnesium sulphate should be investigated with the same percentage of doses.

Concrete can be attacked by acid in a polluted environment, like industrial areas, the influence of cashew nut shell liquid on concrete exposed to acidic media can be studied.

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