Effect of Dunaliella Salina Alga on Compressive Strength of Concrete

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Abstract - *This paper outlines experimental research on the effect of Dunaliella salina alga on the compressive strength of concrete. Two concentrations of the alga (30 and 50$_{mg/kg}$) are considered to substitute a portion of the cement. Cubes of size 100 mm were cast, cured, and tested after 3, 7, and 28 days of curing in water. The results indicated that in parallel to the conventional concrete, the addition of 50 $_{mg\ D.\ salina\ /kg\ cement}$ enhanced the 3rd, 7th, and 28th compressive strengths by 42.55%, 9.13%, and 15.43%, respectively. Abundant and numerous calcites were observed on such samples under SEM and confirmed chemically by EDX analysis. The latter predicted higher amounts of the individual elements (Ca, C, O, Al, Si, Fe, and Mg) and chemical compounds of CaCo$_3$. These observations could be explained that alga produced β-carotene, those belong to the conjugated dienes system and therefore generate high electron density within the concrete structure. Otherwise, such organisms deposit calcium carbonates through its metabolic activity. Both by-products (β-carotene and CaCO$_3$) filled the concrete pores and enhanced its compressive strength.*

Key Words: Alga, Compressive strength, SEM, EDX, $CaCO_3$, β-carotene.

1. INTRODUCTION

Recently, microorganisms (bacteria, fungi, and alga) are introduced into concrete to enhance the mechanical, permeation, and durability properties of concrete. Researchers of [1] registered that *Paecilomyces inflatus* precipitated vaterite and calcium, while *Plectosphaerella cucumerina* precipitated calcite only, and therefore the two fungi species were proposed for the construction of the self-healing concrete. Different methods (direct and indirect application) were suggested to apply *Bacillus subtilis* into concrete in [2], and the scholars found that regardless of the method used, the bacterial promoted the compressive force significantly. The authors of [3] invented that the addition of 10^5 *B. subtilis* JC3 cells/ml was the optimum concentration that increased the split tensile strength, compressive strength, and flexural strength by about 21.4%, 13.2%, and 16.04%, respectively. It is detected on [4] that mortars prepared with 10^5 cells/ml of *Shewanella* species showed an excellent decrement in the porosity. *Bacillus sphaericus* and *Proteus vulgarius* were examined on their ability to plug the concrete mortars' cracks [5]. It was discovered that there was a significant reduction in the water absorption and sorptivity of the bio concrete cubes compared to the conventional ones. R. Ramasubramani et al. [6] considered marine brown algae; an additive material to reduce the voids of the concrete. The alga was added to substitute 2%, 5%, 8%, and 10% of the cement content. Based on the out findings of the tests, it was outlined that the optimum proportion of alga was 8%, and beyond this limit, the strengths of specimens started to decrease. The maximum split tensile strength, compressive strength, and flexural strength of marine alga specimens were 4.6 N/mm^2, 29.24 N/mm^2, and 4.7 N/mm^2, respectively, while the strengths of the control specimens were 3.9 N/mm^2, 26.31 N/mm^2, and 3.6 N/mm^2, respectively. Furthermore, they conducted the impact test on cylindrical specimens and the deflection test on long reinforced beams. For the impact strength, the first crack of the marine alga cylinders was observed when the number of blows was 94, whereas the total failure was observed when the number was 96. On the other hand, the first crack of the control cylinders was recorded when the number of blows was 85, while the total failure was recorded when the number was 88. For the deflection test, the initial crack in the control specimens and marine alga specimens was detected, respectively, at 2.4 tons and 3.6 tons. However, the maximum deflection for the respective mentioned specimens was 13 mm, and 7.43 mm at 9.6 tons, and 11.2 tons, respectively. It was also observed that the cracks formed in marine alga specimens were uniform while was not uniform in control one. Niveditha C. et al. [7] studied the chemical properties of marine algae and then tested the effect of alga in the compressive force of cement mortars. However, concrete cubes were fabricated with 10% and 20% cement replacement with algal precipitate. It was invented that a 10% replacement with algal precipitate was the optimum mix and showed a 4% increase in the 28th day compressive strength. The algal precipitate consisted chemically of Quartz, calcium, magnesium, and silicate oxide based on X-Ray Diffraction (XRD).

2. EXPERIMENTAL PROGRAMME

This exploration investigates the effect of *Dunaliella salina* alga on the compressive strength of concrete. Two concentrations of alga are considered. The AS-30 and AS-50 series corresponds to the alga mixes prepared with, respectively, 30 and 50 mg/kg of cement. These concentrations are to substitute part of cement weight.

3. MATERIALS AND METHODES

3.1 Alga

In this study, capsules preserving the *Dunaliella salina* cells and the β-carotene are purchased, weighed, and solved in acetone to free up the interiors, as depicted in Fig (1). The final volume of the alga solution is 200 ml, and its concentration is measured and is found equal to 7 mg/ml.

Fig – 1: The solution of *Dunaliella Salina* alga.

3.2 Crushed dolomite & Natural sand

The properties of the crushed dolomite and sand used in this study are listed in Table (1).

Table -1: Mechanical properties of dolomite and sand

Test	Crushed dolomite	Natural sand
Fineness modulus	2.25	2.4
Volume weight	$1.48 t/m^3$	$1.68 t/m^3$
Specific gravity	$2.5 t/m^3$	$2.5 t/m^3$
Absorption rate	2%	1.9%

3.3 Cement

Ordinary Portland cement of grade 42.5 is used. The tests revealed that the cement fineness, initial setting time, final setting time, compression strength after 3 days, compression strength after 7 days, and expansion are, respectively, equal to 4212 cm2/gm, 70 min, 200min, 263 kg/cm2, 360 kg/cm2, and 1 mm.

3.4 Water

Either casting or curing of the specimens, tap water is used. It should be clean and impurities-free.

3.5 Super-plasticizer

In this work, the super-plasticizer Sikament® -NN is added to enhance the workability of the fresh concrete. The super-plasticizer is added to the mixing water and mixed thoroughly before its addition to the aggregates and cement.

4. PREPARATION OF SAMPLES

4.1 Preparation of molds

A cubical mold of 100 mm x 100 mm x 100 mm (Fig (2)) is used to evaluate the compressive strength of control and algal concrete.

Fig – 2: The mold

4.2 Preparation of concrete mix

The dolomite is first weighed, followed by sand, cement, and finally, water containing the super-plasticizer and additives, if used. The dry ingredients are first mixed in the pan for a minute before adding water. However, the alga is first added to the water and mixed gently for minutes before adding to the mixed ingredients. The proportions of the concrete (Grade 30) are listed in Table (2). The mixing time should not, after adding the dolomite, sand, and cement be less than 2 minutes, and 1 minute after adding the water. It is to ensure that the total mixing time should not increase by 5 minutes, and the mixing velocity is not increased than its specified. That both are so that the mix becomes homogenous in both color and consistency without segregation. It is to perform a slump test to check the workability of mixes to be within the range of 3-5 cm. The results of the slump test are shown in Fig (3).

Table -2: Proportions of control concrete mix

Material	Volume (kg/m3)
Crushed dolomite	1292.78
Natural sand	695.92
Cement	350
Water	157.5
Super-plasticizer	3.5

(a) (b) (c)

Fig – 3: The slump value of the (a) CS mix = 3cm, (b) AS-30 mix = 3cm, and (c) AS-50 mix = 4cm.

4.3 Curing of samples

First, the specified mold is placed on a horizontally rigid surface or vibrating table and then filled with the concrete mix, where the confined air is eliminated. The mix should be cast directly after immediate mixing taking into account avoiding segregation of its components. The mix is fully-compacted without segregation, by the vibrating table (Fig (4)) or the compacting rod. The compacting rod is fabricated from iron, is 1.8 kg in weight, and 380 mm in the length of a square cross-section of 25 mm side length. Each layer, when compacted, the blows are distributed equally on the mold's cross-section. After compacting the top layer, a finishing trowel is utilized to adjust that one with the top level of the mold (cubes and cylinders). After casting, the prepared samples are preserved, anywhere no vibrations and no humidity loss, are and kept for 24 hours.

Fig – 4: The vibrating table

4.4 Curing of samples

The samples are removed from molds after 16-28 hours from the time water is added to the mix's ingredients. The curing is to prepare specimens for testing at the age of one day or more. This is done under specific circumstances to ensure the total hydration reaction of cement and the mixing water. The curing tank should contain clean water, changed regularly. The specimens' curing continues as much time as possible until testing. Fig (5) illustrates the curing of AS-30 and AS-50 specimens in the concrete laboratory.

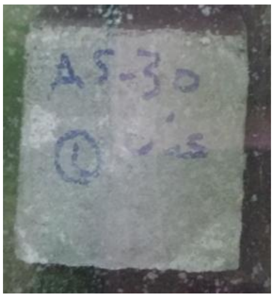

Fig – 5: Curing of AS-30 cube in tap water.

5. INSTRIMENTATION

5.1 Scanning Electron Microscope (SEM)

SEM is an equipment utilized to clarify and characterize the morphology, composition, and crystallographic of the specimen microstructure.

5.2 Energy Dispersive X-ray spectroscopy (EDX)

EDX is analytical equipment used to analyze and characterize the chemical elements of the sample.

6. RESULTS

Chart (1) shows the overall relationship between the compressive behaviors of the water cured groups, AS-30 and AS-50, versus the CS group. The CS mix showed strengths equal to13.82, 21.9, and 31.1 N/mm^2 after 3, 7, and 28 days of curing. Yet, this group is selected as a reference to obtain the desirable algal concentration for the optimum improvement of the compressive strength. The AS-30 specimen increased the respective strengths by 30.25%, 4.11%, and 6.91%. On the other hand, the AS-50 specimen increased them by 42.55%, 9.13%, and 15.43%. That reveals that the alga showed more enhancement of the strength in the AS-50 mix rather than the AS-30. This incident is due to the numerous crystals of calcite are detected on the SEM micrographs of the mix treated with 50$_{\text{mg } D. salina \text{ /kg cement}}$ after 28 days of curing in water, as shown in Fig (6). This observation is confirmed, as mentioned below. Based on the EDX analysis, the AS-50 mix cured for 28 days in water showed higher weights of the elements; Calcium (31.77%), carbon (9.52%), oxygen (47.56%), aluminum (1.54%), silicon (6.71%), iron (1.51%), and magnesium (0.46%). Moreover, the AS-50 mix displayed higher precipitates of $CaCO_3$ (79.35%), SiO_2 (14.35%), Al_2O_3 (3.31%), and MgO (0.77%). The EDX spectra of the AS-50 is depicted in Chart (2).

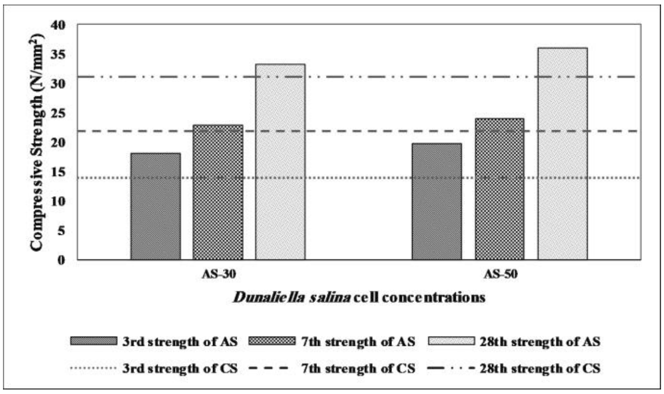

Chart -1: Comparison between the compressive strengths of the *D. salina* mixes and the control mix cured in tap water

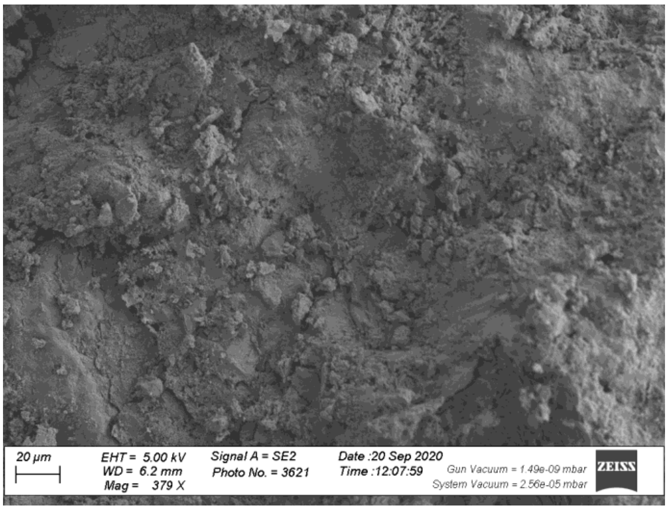

Fig -6: Precipitates in the AS-50 mix

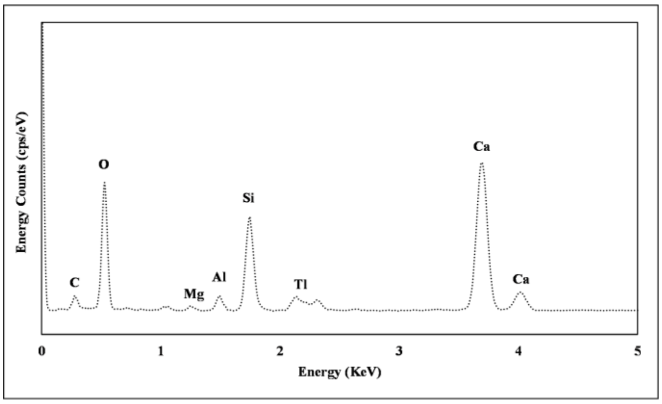

Chart -2: EDX spectra of the AS-50 mix

7. DISCUSSION

Alga in nature appears with different colors; that is because it contains basic photosynthesis pigments and auxiliary pigments besides. The basic pigments are Chlorophylls (Chlorophyll a and b) and Carotenoids (β- and α-carotene). Alga is, however, considered one of the most abundant sources of β-carotene over the world. The carotenoids are the droplets that give alga the orange color, though the alga's original color is green. It is found in the chloroplast, and necessary to prohibit damage of chlorophyll because of the higher temperature, salinity, and light intensities as well as the nutrient deficiency that could be during the culture conditions. Neither the Chlorophylls nor the Carotenoids pigments dissolve in water but can in alcohol, acetone, or ether. Regardless of the surrounding environment where *D. salina* exists, such an organism can survive and produce numerous amounts of lycopene, cryptoxanthin, lutein, alpha-carotene, zeaxanthin, and β-carotene. However, high light intensity and water salinity are recommended for the best photosynthetic behavior of the microalga.

Coming close to the beta-carotene, it is, chemically, hydrocarbons free of oxygen, and obey the conjugated dienes system. This system involves two double-bonded molecules separated from each other by a single bond. The double bonds in the system facilitate the delocalization, over three or more atoms, of the electron density and enhancement of the molecule stability. This property is achieved as the pi orbitals are positioned and can overlap, which, as a result, gives the strength to the single bond. β-carotene has 11 conjugated π bonds, as shown in Fig (7). The mentioned properties confirm that such carotenes can generate high electron density within the concrete structure. That, in turn, fill the pores, decrease permeability, and increase the compressive strength of concrete.

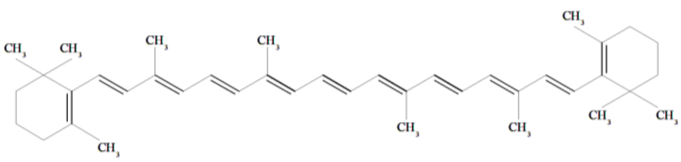

Fig – 7: Chemical structure of β-carotene

Besides, the alga is a photosynthetic organism, derives the energy from the sun and CO_2 from the atmosphere. The metabolic activity quiet shifts the equilibrium of carbonate and bicarbonate ions, Eq (2), and typically increases the pH of the surrounding, Eq (3). This reaction, however, in the presence of calcium ions, alga can produce calcium carbonate, Eq (4).

$$CO_2 + H_2O \rightarrow (CH_2O) + O_2 \quad (1)$$

$$2HCO_3^- \leftrightarrow CO_2 + CO_3^{-2} + H_2O \quad (2)$$

$$CO_3^{-2} + H_2O \leftrightarrow HCO_3^- + OH^- \quad (3)$$

$$Ca^{+2} + HCO_3^- + OH^- \leftrightarrow CaCO_3 \downarrow + 2H_2O \quad (4)$$

Due to the insolubility, the deposited calcite minerals refined the pores and improved the compressive characteristics of concrete.

8. CONCLUSIONS

Based on this exploration work, the following is revealed:

- Addition of $50_{mg\ D.\ salina\ /kg\ cement}$ (AS-50 mix) increased, respectively, the compressive strength by 42.55%, 9.13%, and 15.43% pass by 3, 7, and 28 days of curing compared to the conventional one (CS mix).
- Numerous calcite minerals are observed clearly under SEM on the AS-50 specimen.
- Based on EDX analysis, more weights of the individual elements (Ca, C, O, Al, Si, Fe, and Mg) were detected on the AS-50 mix. Higher amounts of the predicted chemical compound $CaCO_3$ were also found based on EDX analysis.
- This incident is because that alga can produce β-carotene wherever it exists. These pigments belong to the conjugated dienes system and therefore generate high electron density within the concrete structure. That, in turn, fills the pores and increase the compressive strength of concrete.
- Furthermore, alga depends on the metabolic activity to shift the equilibrium of carbonate and bicarbonate ions and increases the pH of the concrete matrix. Wherever calcium ions exist, alga can produce or precipitate calcium carbonates.

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