

Effects of Strong Alkaline Substances in Mixing Water on Strength and Setting Properties of Concrete

Venkateswara Reddy. and Vangala

Abstract— The quality of mixing and curing water plays a vital role in production and application of concrete. In the present study, the effect of strong alkaline substances like sodium carbonate (Na_2CO_3) and sodium bicarbonate (NaHCO_3) on setting time and strength development of concrete is assessed under the laboratory conditions. The results indicate that Na_2CO_3 in deionised water accelerates the initial as well as final setting times whereas the other compound NaHCO_3 retards the initial and final setting times in all concentrations. Na_2CO_3 and NaHCO_3 in deionised water decrease the compressive and tensile strength of concrete specimens significantly at 28 days and 90 days. Comparison of the results of strong alkaline compounds with those of the control mix reveals that both Na_2CO_3 and NaHCO_3 decrease the compressive and tensile strength significantly. The rate of decrease is increasing with the increase in concentration. The present work analyses the hydration characteristics of concrete using the technique of X-ray diffraction (XRD) and useful conclusions are obtained regarding the influence of strong alkaline substances.

Keywords— cement concrete, setting time, compressive strength, tensile strength, strong alkaline substances

I. INTRODUCTION

CONCRETE is one of the most widely used construction materials, because of its good durability to cost ratio. However, when subjected to severe environments its durability can significantly decline due to degradation. Cement used in concrete is a mixture of complex compounds. The initial setting is attributed to hydration reactions. The C_2S (Dicalcium Silicate) phase the reactions of C_3A , C_3S and C_4AF ¹. The aqueous phase is essentially a solution of the hydroxide and sulphates of Ca, Na & K and it is likely that equilibrium sets in among them².

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The quality of the water plays an important role in the preparation of concrete. Impurities in water may interface with the setting of the cement and may adversely affect the strength of the concrete³.

The IS: 456 (2000) code stipulates the water quality standards for mixing and curing of concrete⁴. In some arid areas, local drinking water is impure and may contain an excessive amount of salts due to contamination by industrial wastes. Brackish water contains chlorides and sulphates. When chloride does not exceed 500 ppm, or SO_3 does not exceed 1000 ppm, the water is harmless, but water with even higher salt contents has been used satisfactorily⁵. The appendix to BS 3148-1980 recommends limits on chloride and on SO_3 as above, and also recommends that alkali carbonates and bicarbonates should not exceed 1000 ppm. Some what less severe limitations are recommended in American literature⁶. Sea water has a total salinity of about 3.5 percent (78% of the dissolved solids being NaCl and 15% MgCl_2 and MgSO_4), and produces a slightly higher early strength but a lower long-term strength; the loss of strength is usually not more than 15% and can therefore often be tolerated⁷. Generally the effects on setting are unimportant if water is acceptable from strength consideration. Water containing large quantities of chlorides (eg, sea water) tends to cause persistent dampness and surface efflorescence. Such water should, therefore, not be used where appearance of the concrete is important, or where a plaster-finish is to be applied^{1,8}.

II. MATERIALS AND METHODS

The details of various materials used in the experimental investigation are presented below.

A. Cement

The cement used in the present investigation is of 53 grade ordinary Portland cement.

B. Fine Aggregate:

The fine aggregate used in this investigation is the river sand obtained from Pandameru River near Anantapur in Andhra Pradesh.

C. Coarse aggregate:

Crushed Granite stone aggregate of maximum size 20 mm conforming to IS 383-1970 was used⁹. The specific gravity and fineness modulus were found to be 2.622 and 6.65 respectively.

D. Water

Deionised water spiked with strong alkaline substances (Na_2CO_3 and NaHCO_3) with different concentration is used as mixing water.

III. EXPERIMENTAL SYSTEM

The following equipment is used for casting and testing of the specimens.

- i. Cube and cylinder moulds.
- ii. 200T U.T.M (Universal Testing Machine) for cube compressive strength determination.
- iii. Vicat's apparatus including moulds conforming to IS 4031 (part 5)-1988¹⁰ for testing setting times.
- iv. Cement concrete cubes and cylinders of M20 and M50 grade are casted with water containing, Na_2CO_3 in the concentration of 1, 2, 4, 6, 10, and 15 g/l, and NaHCO_3 in the concentration of 1, 2, 4, 6, 10, and 15 g/l, in mixing water.

A. Setting Time

Vicat's apparatus confirming I.S. 4031 (part 5) 1988 consists of a frame to which a movable rod having an indicator is attached which gives the penetration, weighing 100gms and having diameter and length of 10 mm and 50 mm respectively.

B. Compressive Strength

The test specimens for the determination of compressive strength of concrete are prepared using the standard metallic cube moulds adopting I.S procedure for the rodding and hard compactions.

C. Split Tensile Strength

The test specimens for the determination of split tensile strength of concrete are prepared using the standards metallic cylinder moulds adopting I.S procedure for the rodding and hard compaction.

IV. RESULTS AND DISCUSSION

The interpretation of results obtained in this investigation is based on the guidelines specified by IS 456 (2000) as mentioned below.

A. Setting Time

Test results of setting times of the test block made from different water samples and deionised water are reported in fig. 1.

From the figure 1 (a), it is observed that both the initial and final setting times of cement got accelerated with the increase of the sodium carbonate (Na_2CO_3) concentration in deionised water. The decrease in the initial and final setting times is significant only when the sodium carbonate concentration is 6 g/l and 4 g/l respectively. The decrease in the initial setting time is about 63 minutes and final setting time is about 60 minutes at the maximum concentration of 15 g/l, when compared with that of the test blocks made with deionised water.

The effect of NaHCO_3 on initial and final setting times is shown Fig. 1 (b). From the figure, it is observed that both initial and final setting times got retarded with an increase in sodium bicarbonate concentration in the deionised water. The retardation of initial and final setting times is significant (i.e. more than 30 minutes) when the sodium bicarbonate content is 4 g/l and 6 g/l, respectively. When the sodium bicarbonate content is 15 g/l (Maximum), the initial setting time is 218 minutes which is 89 minutes more than that of the control mix; the difference observed in the case of final setting time is 53 minutes with respect to the control mix.

B. Compressive Strength & Tensile Strength

Test results of the cubes prepared from water containing different neutral salts are presented in fig. 2 and 3.

The results indicate that, there is significant decrease in the compressive strength of all concrete cubes at 28 days and 90 days and the rate of decrease in compressive strength also gradually increases with the increase in the concentration of the Na_2CO_3 . The significant decrease in strength starts when the concentration of Na_2CO_3 is equal to 6 g/l. When Na_2CO_3 concentration is maximum, i.e., 15 g/l, the decrease in compressive strength is 20.10% for M 20 (90 day) grade concrete and 21.40% for M 50 (90 day) grade concrete respectively, when compared with that of cubes prepared with the deionised water (control test sample). Similar trend is observed for tensile strength of OPC. When Na_2CO_3 concentration is maximum, i.e., 15 g/l, the decrease in tensile strength is 20.07% for M 20 (90 day) grade concrete and 21.38% for M 50 (90 day) grade concrete respectively, when compared with that of cylinders prepared with the deionised water (control test sample).

The effect of NaHCO_3 concentration on the compressive strength of ordinary Portland cement concrete is presented in Fig.3. The results indicate that, there is decrease in compressive strength of the OPC cubes prepared with NaHCO_3 solution is observed as the sodium bicarbonate concentration increases, the maximum concentration considered being 15 g/l. There is significant decrease in the compressive strength of cubes with the increase in the concentration of the NaHCO_3 . For M 20-90 day and M 50-28

day, 90 day samples, significant decrease in strength starts when concentration is equal to 10 g/l, where as this significant decrease in compressive strength for M 20-28 day samples observed at concentration of 15 g/l. When NaHCO_3 concentration is maximum, i.e., 15 g/l, the decrease in compressive strength is 16.40% for M 20 (90 day) grade concrete and 19.23% for M 50 (90 day) grade concrete respectively, when compared with that of cubes prepared with the deionised water (control test sample). Similar trend is observed for tensile strength of OPC. When NaHCO_3 concentration is maximum, i.e., 15 g/l, the decrease in tensile strength is 16.39% for M 20 (90 day) grade concrete and 19.22% for M 50 (90 day) grade concrete respectively, when compared with that of cylinders prepared with the deionised water (control test sample).

C. Powder X-ray Diffraction Analysis

Fig. 4(a) depicts the Powder X-ray Diffraction pattern for OPC prepared with deionised water and the Powder X-ray Diffraction pattern for OPC with mixing water containing Na_2CO_3 concentration of 6 g/l is presented in Fig. 4(b). The comparison of this present pattern with that of deionised water indicates the formation of $\text{Ca}_4\text{Si}_6\text{O}_{15}(\text{OH})_2\cdot 3\text{H}_2\text{O}$ (Gyrolite) compound, which is evident by the presence of d-spacings 3.74391 Å, 2.58332 Å, 1.50479 Å, which are absent in that of the control mix. Further analysis of compounds formed in the X-ray diffraction pattern revealed the formation of $\text{Ca}_5(\text{Si}_6\text{O}_{18}\text{H}_2)4\text{H}_2\text{O}$ (11- Å Tobermorite) compound, which is evident by the presence of d-spacings 1.89036 Å, 1.65818 Å and 1.53106 Å. The probable reasons for above behaviour of concrete with Na_2CO_3 in mixing water are discussed below through corresponding chemical reactions.

The probable chemical reaction upon the hydration of cement with mixing water containing Na_2CO_3 is $\text{Na}_2\text{CO}_3 + 5\text{CaO} + 7\text{SiO}_2 + 4\text{H}_2\text{O} \rightarrow \text{Ca}_4\text{Si}_6\text{O}_{15}(\text{OH})_2\cdot 3\text{H}_2\text{O} + \text{Na}_2\text{SiO}_3 + \text{CaCO}_3$. The end compound formed i.e., CaCO_3 may again participate in the chemical reaction as follows.

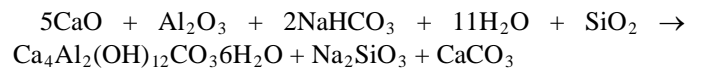
$4\text{CaO} + 6\text{SiO}_2 + 6\text{H}_2\text{O} + \text{CaCO}_3 \rightarrow \text{Ca}_5(\text{Si}_6\text{O}_{18}\text{H}_2)4\text{H}_2\text{O} + \text{H}_2\text{CO}_3$. The acceleration of setting of cement could be possibly attributed to the formation of Gyrolite. Continuous and significant decrease in the compressive strength for all samples at 28 day and 90 day could be due to the formation of Gyrolite and Sodium Silicate. Alkali-silicate gel (Gyrolite) of variable chemical composition is formed in the presence of hydroxyl and alkali-metal ions. The mode of attack in the concrete involves depolymerization or breakdown of silica structure of the sand by hydroxyl ions followed by adsorption of the alkali-metal ions (Na_2SiO_3) on the newly created surface of the reaction product. Gyrolite gel when comes in contact with water; it swells by imbibing a large amount of water through osmotic process. The hydraulic pressure so developed leads to expansion and cracking of the cement paste matrix surrounding the aggregate, thus leading to the significant decrease in the compressive strength.

The byproduct CaCO_3 may again involves itself in the reaction with cement constituents in accordance with the

second equation given to form tobermorite and carbonic acid (H_2CO_3). These two byproducts may cause further decrease in the strength of the concrete.

Powder X-ray Diffraction pattern shown in Fig. 4(c) depicts the concrete cubes prepared with NaHCO_3 (10 g/l) in deionised water. The comparison of this pattern with that of deionised water indicates the formation of $\text{Ca}_4\text{Al}_2(\text{OH})_{12}\text{CO}_3\cdot 6\text{H}_2\text{O}$ (Tetra calcium aluminate carbonate 12-hydrate) compound which is evident from the presence of d-spacings 3.27506 Å, 2.91895 Å and 2.09811 Å, which are absent in the pattern for the control mix. The probable reasons for above behaviour of concrete with Na_2CO_3 in mixing water are discussed below through corresponding chemical reactions.

The probable chemical reaction by the hydration of cement with mixing water containing NaHCO_3 is



One of the possible reasons for the retardation of setting times of cement could be the formation of tetracalcium aluminate carbonate 12-hydrate. Continuous and significant decrease in the compressive strength could be due to the formation of same tetracalcium aluminate carbonate 12-hydrate and sodium silicate. Alkali-silicate gel (tetracalcium aluminate carbonate 12-hydrate) of variable chemical composition is formed in the presence of hydroxyl and alkali-metal ions. The mode of attack in concrete involves depolymerization or breakdown of silica structure of the sand by hydroxyl ions followed by adsorption of the alkali-metal ions (Na_2SiO_3) on newly created surface of the reaction product. Tetracalcium aluminate carbonate 12-hydrate gel comes in contact with water and swells by imbibing a large amount of water through osmotic process. The hydraulic pressure so developed may lead to expansion and cracking of the cement paste matrix surrounding the aggregate and thus leading to the significant decrease in the strength.

V. CONCLUSIONS

Based on the present investigation, the following conclusions can be drawn:

- Presence of Na_2CO_3 in water at concentrations of 6 g/l and 4 g/l accelerates significantly, the initial and final setting time of cement respectively. Further, a concentration equal to 6 g/l results in significant decrease in compressive strength and tensile strength of concrete.
- Presence of NaHCO_3 in concentrations equal to 4 g/l and 6 g/l retards significantly the initial and final setting time respectively. Further, a concentration equal to 10 g/l results in significant decrease in compressive strength and tensile strength.
- Strong alkaline substances under consideration (Na_2CO_3 and NaHCO_3) in water reduce the compressive strength and tensile strength significantly, thus requiring caution in the use of water containing these substances.

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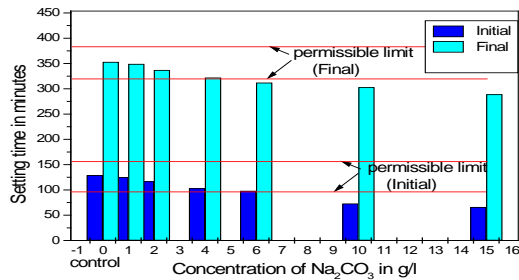


Fig.1. (a) Variation of setting times of cement corresponding to various concentrations of Na_2CO_3 in deionised water

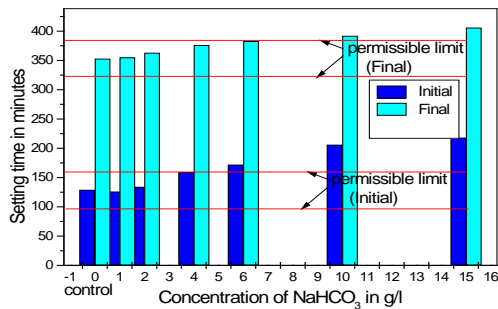


Fig.1. (b) Variation of setting times of cement corresponding to various concentrations of NaHCO_3 in deionised water

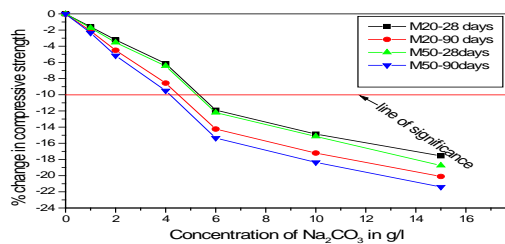


Fig.2. (a) Variation of compressive strength of OPC corresponding to various concentrations of Na_2CO_3 in deionised water

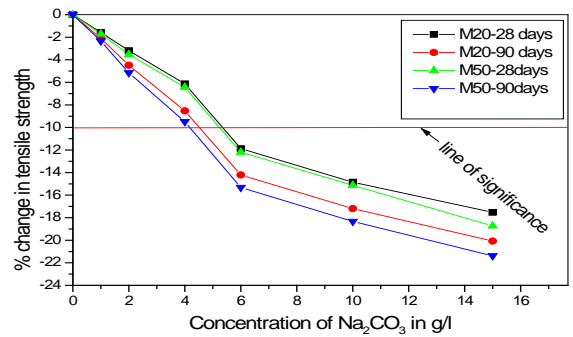


Fig.2. (b) Variation of tensile strength of OPC corresponding to various concentrations of Na_2CO_3 in deionised water

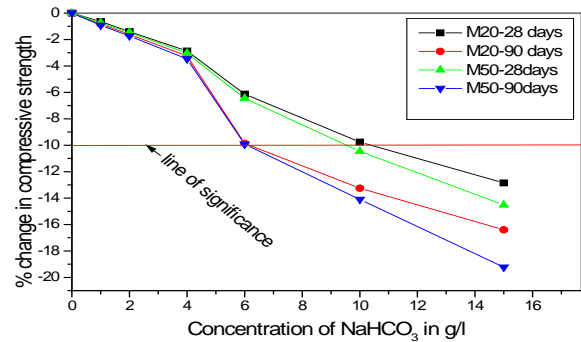


Fig.3. (a) Variation of compressive strength of OPC corresponding to various concentrations of NaHCO_3 in deionised water

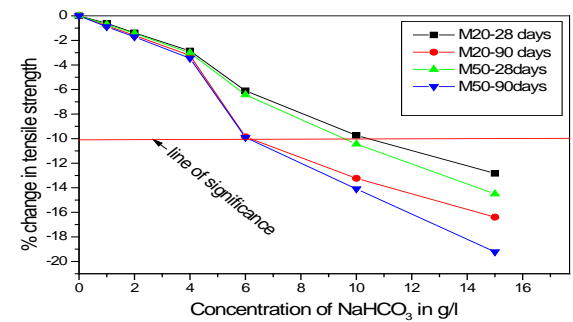


Fig.3. (b) Variation of tensile strength of OPC corresponding to various concentrations of NaHCO_3 in deionised water

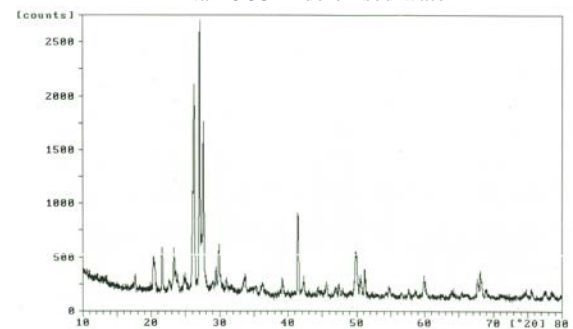


Fig.4. (a) X-Ray diffraction pattern of powdered concrete sample prepared with deionised water in deionised water

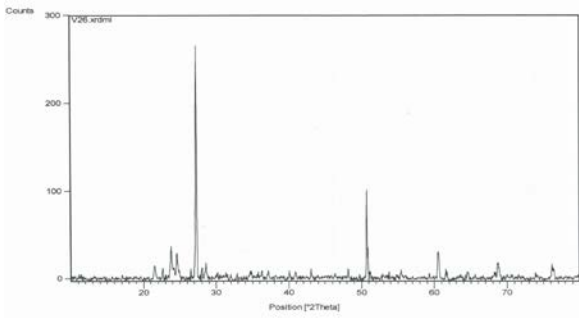


Fig.4. (b) X-Ray diffraction pattern of powdered concrete sample prepared Na₂CO₃ (6 g/l) in deionised water

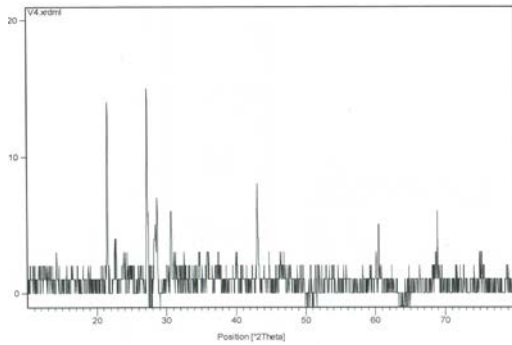


Fig.4. (c) X-Ray diffraction pattern of powdered concrete sample prepared with NaHCO₃ (10 g/l) in deionised water