Influence of strong alkaline substances (sodium carbonate and sodium bicarbonate) in mixing water on strength and setting properties of concrete

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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$_2$CO$_3$) and sodium bicarbonate (NaHCO$_3$) on setting time and strength development of concrete is assessed under the laboratory conditions. The results indicate that Na$_2$CO$_3$ 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$_2$CO$_3$ 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$_2$CO$_3$ 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.

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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 reaction of these with water leads to setting and hardening of cement when it is gauged with water. The C$_3$A (tricalcium aluminate), C$_3$S (tricalcium silicate) and C$_4$AF (tetracalcium alumina ferrite) phases react very rapidly and the gauging water become saturated with Ca(OH)$_2$ formed in the hydrates rather slowly. The initial setting is attributed to hydration reactions. The C$_2$S (dicalcium silicate) phase the reactions of C$_3$A, C$_3$S and C$_4$AF$^3$. The aqueous phase is essentially a solution of the hydroxide and sulphates of Ca, Na and K and it is likely that equilibrium sets in among them$^2$.

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 concrete$^4$. The chemical constituents present in water may participate in the chemical reactions and thus affect the setting, hardening and strength development of concrete. A popular yard stick to the suitability of water for making concrete is that if it is fit for drinking, it is fit for making concrete. The IS: 456(2000) code stipulates the water quality standards for mixing and curing of concrete$^4$. 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 satisfactorily$^5$. 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. Somewhat less severe limitations are recommended in American literature$^6$. Seawater has a total salinity of about 3.5% (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 tolerated$^7$. 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$^1,8$. 

The minimum grade of concrete required for RCC work is M20 and for special concretes like prestressed concrete M50 grade is required. Hence, in the present investigation to find the effects of quality of water on setting and strength properties of concretes, both M20 and M50 grades of ordinary Portland cement concrete are considered. The chemical substances present in water are generally classified into (i) neutral salts, (ii) strong alkaline substances, (iii) slightly acidic substances and (iv) strong acids. The effects of strong alkaline substances on setting, hardening and strength development of cement concrete are not known much. Hence, an investigation is carried out in order to evaluate the effect of strong alkaline substances on setting time and strength of concrete under laboratory conditions.

Materials and Methods

Materials

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

Cement

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

Fine aggregate

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

Coarse aggregate

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

Water

Deionised water spiked with strong alkaline substances (Na₂CO₃ and NaHCO₃) with different concentration is used as mixing water.

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 confirming to IS 4031 (part 5)-1988 for testing setting times, and (iv) Cement concrete cubes and cylinders of M20 and M50 grade are prepared with water containing, Na₂CO₃ in the concentration of 1, 2, 4, 6, 10, and 15 g/L, and NaHCO₃ in the concentration of 1, 2, 4, 6, 10, and 15 g/L, in mixing water.

Setting time

Vicat’s apparatus confirming IS 4031 (part 5) 1988 consists of a frame to which a movable rod having an indicator is attached which gives the penetration, weighing 100 g and having diameter and length of 10 mm and 50 mm respectively. Vicat’s apparatus included three attachments-square needle for initial setting time, plunger for determining normal consistency and needle with annular collar for final setting time.

Compressive strength

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

The cubes are demoulded after 24 h of casting and cured in water having similar quality as used in the preparation of mix. The cubes are tested for compressive strength after 28 days and 90 days. The compressive strength is computed as the average value of the three samples.

Split tensile strength

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

The cylinders are demoulded after 24 h of casting and cured in water having similar quality as used in the preparation of mix. The cylinders are tested for split tensile strength after 28 days and 90 days. The split tensile strength is computed as the average value of the three samples.

Results and Discussion

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

The average of both the setting times of three cement samples prepared from water under consideration are compared with those of the cement specimens prepared from deionised water. If the difference is less than 30 min, the change is considered to be negligible and if the difference is more than 30 min, the change is considered to be significant.

Average compressive strength and average split tensile strength of at least three specimens prepared
with water under consideration is compared with that of three similar cases prepared with deionised water (control). If the difference in the strength is less than 10% it is considered to be insignificant, else it becomes significant.

**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 Fig 1a, it is observed that both the initial and final setting times of cement got accelerated with the increase of the sodium carbonate (Na$_2$CO$_3$) 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 min and final setting time is about 60 min 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 this 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 min) 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 min which is 89 min more than that of the control mix; the difference observed in the case of final setting time is 53 min with respect to the control mix.

**Compressive strength and tensile strength**

Test results of the cubes prepared from water containing different neutral salts are presented in Figs 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$_2$CO$_3$. The significant decrease in strength starts when the 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 min) 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 min which is 89 min more than that of the control mix; the difference observed in the case of final setting time is 53 min with respect to the control mix.
concentration of Na$_2$CO$_3$ is equal to 6 g/L. When Na$_2$CO$_3$ concentration is maximum, i.e., 15 g/L, the decrease in compressive strength is 20.10% for M20 (90 day) grade concrete and 21.40% for M50 (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$_2$CO$_3$ concentration is maximum, i.e., 15 g/L, the decrease in tensile strength is 20.07% for M20 (90 day) grade concrete and 21.38% for M50 (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 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 M20-90 day and M50-28 day, 90 day samples, significant decrease in strength starts when concentration is equal to 10 g/L, whereas this significant decrease in compressive strength for M20-28 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 M20 (90 day) grade concrete and 19.23% for M50 (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 M20 (90 day) grade concrete and 19.22% for M50 (90 day) grade concrete respectively, when compared with that of cylinders prepared with the deionised water (control test sample).

**Powder X-ray diffraction analysis**

Fig. 4a 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$_2$CO$_3$ concentration of 6 g/L is presented in Fig. 4b. The comparison of this present

![Fig. 3a](image1.png)

Fig. 3a—Variation of compressive strength of OPC corresponding to various concentrations of NaHCO$_3$ in deionised water

![Fig. 3b](image2.png)

Fig. 3b—Variation of tensile strength of OPC corresponding to various concentrations of NaHCO$_3$ in deionised water

![Fig. 4a](image3.png)

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

![Fig. 4b](image4.png)

Fig. 4b—X-Ray diffraction pattern of powdered concrete sample prepared Na$_2$CO$_3$ (6 g/L) in deionised water
pattern with that of deionised water indicates the formation of Ca₄Si₆O₁₅(OH)₂₃H₂O (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 Ca₃(Si₆O₁₈H₂)₄H₂O (11-Å Tobermorite) compound, which is evident by the presence of d-spacings 1.89036 Å, 1.65818 Å and 1.53106 Å. The reasons for above behaviour of concrete with Na₂CO₃ in mixing water are discussed below through corresponding chemical reactions.

The chemical reaction upon the hydration of cement with mixing water containing Na₂CO₃ is

\[ Na₂CO₃ + 5CaO + 7SiO₂ + 4H₂O \rightarrow Ca₄Si₆O₁₅(OH)₂₃H₂O + Na₂SiO₃ + CaCO₃ \]

The end compound formed, i.e., CaCO₃ again participate in the chemical reaction as follows.

\[ 4CaO + 6SiO₂ + 6H₂O + CaCO₃ \rightarrow Ca₅(Si₆O₁₈H₂)₄H₂O + H₂CO₃ \]

The acceleration of setting of cement 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 concrete involves depolymerization or breakdown of silica structure of the sand by hydroxyl ions followed by adsorption of the alkali-metal ions (Na₂SiO₃) on 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 by-product CaCO₃ again involves itself in the reaction with cement constituents in accordance with the second equation given to form Tobermorite and carbonic acid (H₂CO₃). These two by-products cause further decrease in the strength of the concrete.

Powder X-ray diffraction pattern shown in Fig. 4c depicts the concrete cubes prepared with NaHCO₃ (10 g/L) in deionised water. The comparison of this pattern with that of deionised water indicates the formation of Ca₄Al₂(OH)₁₂CO₃₆H₂O (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 reasons for above behaviour of concrete with Na₂CO₃ in mixing water are discussed below through corresponding chemical reactions.

The chemical reaction by the hydration of cement with mixing water containing NaHCO₃ is

\[ 5CaO + Al₂O₃ + 2NaHCO₃ + 11H₂O + SiO₂ \rightarrow Ca₄Al₂(OH)₁₂CO₃₆H₂O + Na₂SiO₃ + CaCO₃ \]

One of the reasons for the retardation of setting times of cement could be the formation of tetra calcium aluminate carbonate 12-hydrate. Continuous and significant decrease in the compressive strength could be due to the formation of same tetra calcium aluminate carbonate 12-hydrate and sodium silicate. Alkali-silicate gel (tetra calcium 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 (Na₂SiO₃) on newly created surface of the reaction product. Tetra calcium 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.

Conclusions

Based on the present investigation, the following conclusions can be drawn: (i) Presence of Na₂CO₃ 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. (ii) 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. (iii) Strong alkaline substances under consideration (Na$_2$CO$_3$ and NaHCO$_3$) in water reduce the compressive strength and tensile strength significantly, thus requiring caution in the use of water containing these substances.

References