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EFFECTS OF SODIUM CARBONATE ADMIXTURE AND MIX DESIGN RATIOS ON THE COMPRESSIVE STRENGTH OF CONCRETE

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Abstract
This study aimed to investigate the impact of sodium carbonate (Na_2CO_3) admixture on the acceleration and long-term compressive strength of ordinary Portland cement (OPC) concrete at different mix ratios. Concrete cube specimens (150 × 150 × 150mm^3 size) were cast at three different mix ratios (1:1.5:3, 1:2:4, and 1:3:6) with sodium carbonate admixture added in increasing dosage of 0.5% from 0 to 2.0% by weight of OPC. Compressive strength tests were conducted on the cast specimens after curing under water for 7, 28, 56 and 90days. Additionally, tests were done to see how sodium carbonate would accelerate setting times of OPC paste. The results of the tests showed that Na_2CO_3 decreased the initial and final setting times of cement paste from 96 to 67mins and 543 to 387mins respectively. Compressive strength test results for 1:2:4 and 1:3:6 mix ratios showed an increasing trend up to 1.0% Na_2CO_3 admixture, after which there was a decrease. Meanwhile, 1:1.5:3 mix ratio showed a decrease in strength from 21.87 N/mm^2 at 0% to 14.90 N/mm^2 at 1.0% Na_2CO_3 addition, after which the strength increased with Na_2CO_3 percent addition. These results suggest that sodium carbonate has an accelerating effect on concrete setting time, and may aid its early strength development, but has negative long-term effects on concrete strength with increasing dosage. An optimal percentage of 1% Na_2CO_3 by weight of OPC is advised for accelerating effects in concrete, based on the results of this study.

Keywords: Sodium carbonate, Accelerator, Compressive strength, Mix ratio, Setting time.

1.0 INTRODUCTION

Compressive strength of concrete is an important characteristic of concrete that has a significant impact on construction. Concrete is made up of cement, fine aggregates, coarse aggregates, and water, sometimes with or without chemical admixtures. These admixtures are usually added in concrete for various reasons, depending on the interest and end-use of the concrete. Admixtures can affect the wet and dry state properties of concrete by chemically interacting with the concrete constituents. The addition of an admixture to a concrete mix could be aimed at improving the concrete's workability, strength or durability. It could also be aimed at reduction or acceleration of the setting time, inhibition of alkali-aggregate reaction, reduction of shrinkage etc. [1].

Generally, admixtures may be classified as chemical or mineral admixtures. Chemical admixtures are water-soluble compounds that are added to cement to improve the properties of concrete. Examples of these admixtures include water-reducing admixtures, retarding admixtures, accelerating admixtures, and admixtures combining two or more qualities [2]. Mineral admixtures, on the other hand, are inorganic supplementary cementitious materials that have pozzolanic properties and can help improve important properties of concrete, such strengths, permeability, durability etc. Examples of these admixtures include fly ash, ground granulated blast furnace slag, silica fume, rice husk ash etc. [3].

Particularly, accelerating admixtures have been found very useful in reducing the setting times of concrete, especially in situations where early strength development is an advantage. Such situations could arise when there is need for early removal of formwork, compensation for strength development in low temperature areas, reduction in curing time [4]. Over time, a variety of accelerators have been employed, including alkali silicates, alkali carbonates, alkali aluminates, and alkali hydroxides [5]. It has long been known and shown that calcium chloride ($CaCl_2$) works well as an accelerator.

However, because of the serious corrosion risks that come along with it, its employment in steel reinforced concretes has had a huge disadvantage [4]. Hence, preference has been given to the use of chloride-free accelerators such as nitrates, nitrites, alkali carbonates, carboxylic acids and their salts. Several researches have been conducted on the use of chloride-free accelerators. Umoh & Ujene [6] discovered that sodium nitrate when used at a dosage of up to 2% brings about great improvement in strength of periwinkle shell ash blended cement concrete. The impact of calcium nitrate on the density, consistency, early strength, and 28-day concrete strength at various temperatures was examined by Kičaitė et al. [7]. Zhang et al. [8] examined the impact of sodium carbonate and sodium phosphate on cement paste hydration. They observed that sodium carbonate brought about an acceleration in the process of cement hydration, but sodium phosphate retarded it.

In a study on developing sustainable alkali-activated cement, Abdalqader et al. [9] observed that sodium carbonate dosage enhanced concrete compressive strength development. Choi et al. [10] studied the relationship between formation of hydrates and early-age and later-age strength development of concrete with varying amounts of nitrite-nitrate based accelerator. Gao et al. [11] noted that sodium carbonate can be an effective activator for preparation of alkali-activated ground granulated blast furnace slag (GGBFS) cement, but may slow down the development of early age strength. However, with addition of calcium carbide residue having a high concentration of $Ca(OH)_2$ the reaction of the sodium carbonate-activated slag cement can be accelerated. Camiletti et al. [12] examined how fast setting and hardening times for ultra-high performance concrete might be achieved using nano-calcium carbonate. It was also observed by Li et al. [13], that addition of sodium carbonate as an activator for production of slag/fly ash activated blends resulted in faster induction period for hydration of the slag and improved strength development.

In a study by Wang et al. [5], an investigation was conducted on how sodium carbonate and sodium bicarbonate affected the hydration and strength of Portland cement paste. The setting time of ordinary Portland cement (OPC) paste was seen to be hastened by both compounds, but as their concentration increased, the 28-day compressive strength decreased. From findings in the literature, it was observed that the effects of sodium carbonate admixture on concrete properties at different mix ratios have scarcely been examined. Hence, this research sought to find out the effect of sodium carbonate on the acceleration and long-term strength properties of concrete at different mix ratios.

2.0 MATERIALS AND METHODOLOGY

2.1 Materials

Materials used in this research include ordinary Portland cement (OPC), fine aggregate (river sand), coarse aggregate (12.7mm), water, and sodium carbonate (Na_2CO_3) with dosage ranging from 0.5% to 2.0%. Concrete cube specimens were cast using 150 × 150 × 150 mm^3 standard moulds, with variation of the design mix ratios (1:1.5:3, 1:2:4, and 1:3:6).

2.2 Experimental Program

The experimental program carried out include tests on materials, ordinary Portland cement, fresh and hardened concrete with and without the admixture.

2.2.1 Tests on materials

Physical characteristics of the coarse aggregate used for this research such as aggregate impact value (AIV), aggregate crushing value (ACV) were determined in accordance with [14] and [15] respectively. Physical properties of fine aggregate such as particle size distribution, moisture content, and specific gravity were determined in accordance with [16], [17], and [18] respectively. Fineness test, setting time and soundness tests on the cement was carried out in accordance with [19], and [20]. Vicat apparatus was used in the determination of the setting times. The admixture used was sodium carbonate (accelerator).

2.2.2 Mix design

Concrete mixes were prepared in ratios 1:1.5:3, 1:2:4, and 1:3:6 with the water-cement ratio at 0.5. First, control specimens were cast in which the mixes were prepared without the admixture. Thereafter, test specimens were prepared by adding Sodium carbonate (accelerator) to the various mixes ranging from 0.5% to 2% with increasing dosage of 0.5%. The admixture was first dissolved in water and then the dissolved liquids were added to the concrete matrix. Concrete cube specimens were then prepared from the various mixes, and cured in water for 7, 28, 56 and 90 days.

Table 1 presents a summary of the mixture proportions for the experiment.

Table 1: Mix proportions of the concrete mix

Sample	Mix Ratio	Admixture (%)	Water-binder ratio	Mean Cement content (kg/m^3)	Mean Coarse aggregate content (kg/m^3)	Mean Fine Aggregate content(kg/m^3)	Slump
CA0	1:1.5:3	0.0	0.5	474.56	1423.69	711.85	60
CA1		0.5		475.42	1426.26	713.13	65
CA2		1.0		473.63	1420.88	710.44	62
CA3		1.5		472.28	1416.84	708.42	71
CA4		2.0		474.07	1422.22	711.11	71
CB0	1:2:4	0.0	0.5	373.54	1494.18	747.09	70
CB1		0.5		373.19	1492.77	746.38	90
CB2		1.0		371.43	1485.71	742.86	60
CB3		1.5		372.84	1491.36	745.68	60
CB4		2.0		373.19	1492.77	746.38	60
CC0	1:3:6	0.0	0.5	259.51	1557.04	778.52	70
CC1		0.5		259.01	1554.07	777.04	65
CC2		1.0		259.01	1554.07	777.04	60
CC3		1.5		260.49	1562.96	781.48	71
CC4		2.0		258.32	1549.90	774.95	65

2.2.3 Tests on concrete

The workability of the fresh concrete was measured by means of slump test and compacting factor test performed in accordance with [21] and [22] respectively. The hardened and cured concrete cube specimens were subjected to compressive strength tests using a compressive strength testing machine at the referenced curing ages in accordance with [23].

3.0 RESULTS AND DISCUSSION

3.1 Physical Properties of Materials

The physical properties of the aggregates and the cement are summarized in Table 2.

Table 2: Physical Properties of Materials

Material	Property	Value
Cement (OPC)	Fineness	8.4 %
	Specific gravity	3.08
	Initial Setting Time (mins)	96
	Final Setting Time (mins)	543
Coarse Aggregate	Specific gravity	2.74
	Aggregate Impact Value (AIV)	14.4 %
	Aggregate Crushing Value (ACV)	29.8 %
Na_2CO_3	Fineness	8.78 %

3.2 Results of Setting Time Test

Figure 1 displays the outcomes of the setting time test.

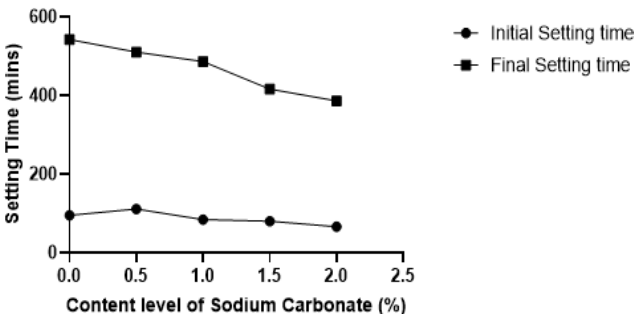

Figure 1: Variation of Setting Time with content level of Sodium Carbonate (%)

3.3 Results of Workability Test

Workability test results for the concrete mixtures with and without sodium carbonate admixture are shown in Table 3.

Table 3: Workability test results for the fresh concrete mix upon addition of Na_2CO_3 admixture

Sample	Mix Ratio	Admixture (%)	Water-binder ratio	Slump	Compacting factor
CA0	1:1.5:3	0.0	0.5	60	0.93
CA1		0.5		65	0.89
CA2		1.0		62	0.96
CA3		1.5		71	0.95
CA4		2.0		71	0.95
CB0	1:2:4	0.0	0.5	70	0.96
CB1		0.5		90	1.03
CB2		1.0		60	0.82
CB3		1.5		60	0.89
CB4		2.0		60	0.89
CC0	1:3:6	0.0	0.5	70	0.94
CC1		0.5		65	0.91
CC2		1.0		60	0.93
CC3		1.5		71	0.97
CC4		2.0		65	0.95

3.4 Results of Compressive Strength Test

Results of the compressive strength tests are presented in Figures 2 to 7.

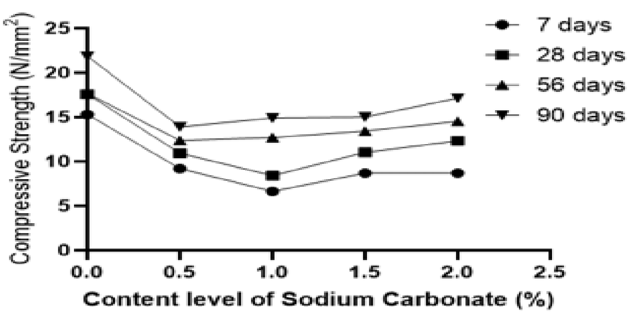

Figure 2: Variation of Compressive strength with Na_2CO_3 percentage addition for 1:1.5:3 mix ratio

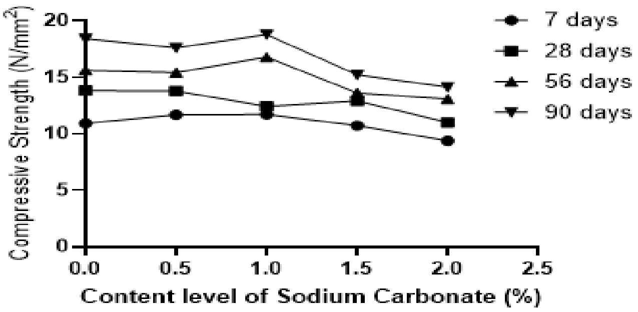

Figure 3: Variation of Compressive strength with Na_2CO_3 percentage addition for 1:2:4 mix ratio

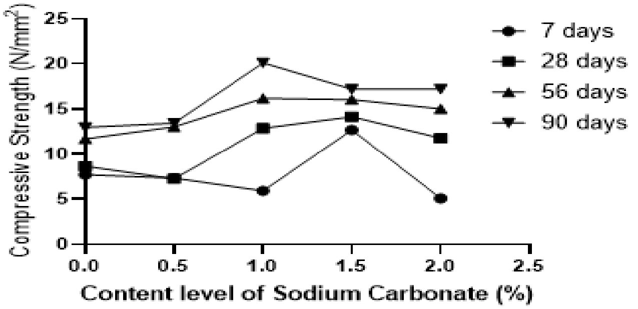

Figure 4: Variation of Compressive strength with Na_2CO_3 percentage addition for 1:3:6 mix ratio

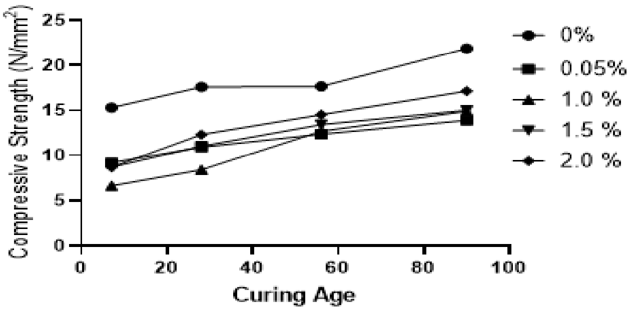

Figure 5: Variation of compressive strength with curing age for 1:1.5:3 mix ratio

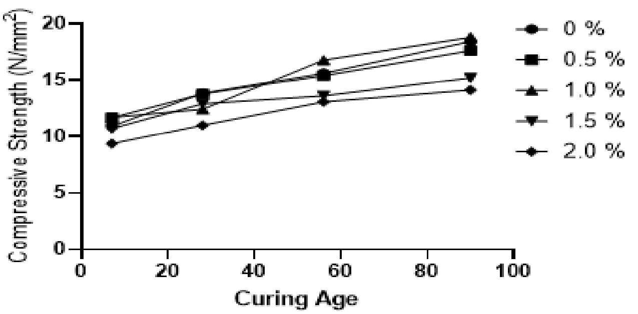

Figure 6: Variation of compressive strength with curing age for 1:2:4 mix ratio

3.5 Discussion

The results of the setting time tests show that there was an acceleration of the setting time with the addition of sodium carbonate (Na_2CO_3) admixture. Initial and final setting times for the control mix were 96 and 543 mins but gradually decreased to 67 and 387 mins respectively, with addition of Na_2CO_3 up to 2.0% by weight of cement. This trend was also observed by other researchers [5], [24]. Results of the slump tests (presented in Table 3) for the 1:1.5:3 concrete mix showed the slump value varying between 60–71 and compacting factor varying between 0.89–0.95.

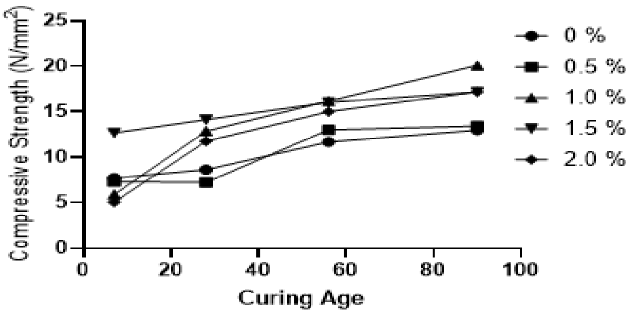

Figure 7: Variation of compressive strength with curing age for 1:3:6 mix ratio

Slump and compacting factor values for 1:2:4 mix ratio was slightly decreasing with increasing dosage of sodium carbonate admixture from 70–60 and 0.96–0.89 respectively. The results of the slump and compacting tests for mix ratio 1:3:6 were similar to that of 1:1.5:3, with its values ranging between 60–71 and 0.91–0.97 respectively. These findings seem to indicate that the sodium carbonate admixture did not have a clearly significant impact on the workability of the concrete. Further research may yet be conducted on the effect of this admixture on the workability of concrete. Compressive strength test results for the 1:2:4 and 1:3:6 mix ratios show that the compressive strength rises first to attain its peak strength at 18.77 N/mm^2 and 20.10 N/mm^2 respectively, at 1.0 % Na_2CO_3 addition, after which there was a decrease in strength.

On the other hand, the compressive strength results of the 1:1.5:3 concrete mix shows a decrease of strength first from 21.87 N/mm^2 at 0 % admixture to 14.90 N/mm^2 at 1.0 % Na_2CO_3 addition, after which there was an increase in strength. Figures 5 – 7 also show that the Na_2CO_3 admixture has an improving effect on strength for lower mix ratios (1:3:6 and 1:2:4) especially at 1.0 % admixture. Meanwhile, a negative strength effect is seen with the 1:1.5:3 mix ratio, with the 1.0 % admixture addition giving the least strength. [5] similarly observed that Na_2CO_3 addition could cause early-age compressive strength increase, but latter-age decrease in compressive strength with increasing content of the admixture. They noted that the decrease in compressive strength could be attributed to the partial replacement of Ca^{2+} in the C-S-H gel by Na^{+} ions introduced, hence causing the discontinuity of the C-S-H gel.

4.0 CONCLUSION

In summary, this research sought to explore the effects of sodium carbonate admixture on concrete compressive strength at different mix ratios. Based on the results, the following conclusions can be drawn:

a) Initial and final setting time of ordinary Portland cement (OPC) paste decreased with increase of sodium carbonate, and hence acts as an accelerating admixture for concrete.
b) Compressive strength test results at different mix ratios show sodium carbonate has a positive long-term strength effect on concrete with lower mix ratios but negative long-term strength effects for concrete with higher mix ratios.
c) An optimal percentage addition of 1 % Na_2CO_3 is advised, as an accelerator in concrete, based on the results of this study.

REFERENCES

[1] Collepardi, M. "Admixtures: Enhancing concrete performance," in *Admixtures-Enhancing Concrete Performance: Proceedings of the International Conference held at the University of Dundee, Scotland, UK on 6 July 2005*, 2005, pp. 217–230.

[2] ASTM C494, "ASTM C494: Standard specification for chemical admixtures for concrete," 2005.

[3] Khan, S. U., Nuruddin, M. F., Ayub, T., and Shafiq, N. "Effects of different mineral admixtures on the properties of fresh concrete," *The Scientific World Journal*, vol. 2014, 2014.

[4] Myrdal, R. "Accelerating admixtures for concrete. State of the art," 2007.

[5] Wang, Y., He, F., Wang, J., and Hu, Q. "Comparison of effects of sodium bicarbonate and sodium carbonate on the hydration and properties of Portland cement paste," *Materials*, vol. 12, no. 7, p. 1033, 2019.

[6] Umoh, A. A., and Ujene, A. O. "Improving the strength performance of high volume periwinkle shell ash blended cement concrete with sodium nitrate as accelerator," *Journal of Civil Engineering, Science and Technology*, vol. 6, no. 2, pp. 18–22, 2015.

[7] Kičaitė, A., Pundienė, I., and Skripkiūnas, G. "The influence of calcium nitrate on setting and hardening rate of Portland cement concrete at different temperatures," in *IOP Conference Series: Materials Science and Engineering*, 2017, vol. 251, no. 1, p. 012017.

[8] Zhang, T., Ma, B., Tan, H., Qi, H., and Shi, T. "Effect of sodium carbonate and sodium phosphate on hydration of cement paste," *Journal of Building Engineering*, vol. 45, p. 103577, 2022.

[9] Abdalqader, A. F., Jin, F., and Al-Tabbaa, A. "Development of greener alkali-activated cement: utilisation of sodium carbonate for activating slag and fly ash mixtures," *Journal of Cleaner Production*, vol. 113, pp. 66–75, 2016.

[10] Choi, H., *et al.*, "Physicochemical study on the strength development characteristics of cold weather concrete using a nitrite–nitrate based accelerator," *Materials*, vol. 12, no. 17, p. 2706, 2019.

[11] Gao, X., Yao, X., Yang, T., Zhou, S., Wei, H., and Zhang, Z. "Calcium carbide residue as auxiliary activator for one-part sodium carbonate-activated slag cements: Compressive strength, phase assemblage and environmental benefits," *Construction and Building Materials*, vol. 308, p. 125015, 2021.

[12] Camiletti, J., Soliman, A. M., and Nehdi, M. L. "Effect of nano-calcium carbonate on early-age properties of ultra-high-performance concrete," *Magazine of Concrete Research*, vol. 65, no. 5, pp. 297–307, 2013.

[13] Li, G., Tan, H., Zhang, J., Deng, X., Liu, X., and Luo, Z. "Ground granulated blast-furnace slag/fly ash blends activated by sodium carbonate at ambient temperature," *Construction and Building Materials*, vol. 291, p. 123378, 2021.

[14] BS 812-112, "Testing aggregates — Part 112: Methods for determination of aggregate impact value (AIV)." British Standard, UK, 1990.

[15] BS 812-110, "Testing aggregates — Part 110: Methods for determination of aggregate crushing value (ACV)." British Standard, UK, 1990.

[16] BS 812-103, "Testing aggregates — Part 103: Methods for determination of particle size distribution." British Standard, UK, 1990.

[17] BS 812-109, "Testing aggregates — Part 109: Methods for determination of moisture content." British Standard, UK, 1990.

[18] BS 812-2, "Testing aggregates — Part 2: Methods of determination of density." British Standard, UK, 1995.

[19] BS EN 196-6, "Methods of testing cement - Part 6: Determination of fineness." British Standard, UK, 2018.

[20] BS EN 196-3, "Methods of testing cement - Part 3: Determination of setting time and soundness." British Standard, UK, 2016.
[21] BS EN 12350-2, "Testing fresh concrete — Part 2: Slump test." British Standard, UK, 2016.
[22] BS 1881-103, "Testing concrete — Part 103: Method for determination of compacting factor." British Standard, UK, 1993.
[23] BS EN 12390-3, "Testing hardened concrete. Compressive strength of test specimens." British Standard, UK, 2019.
[24] Coppola, L., Coffetti, D., Crotti, E., Dell'Aversano, R., Gazzaniga, G., and Pastore, T. "Influence of lithium carbonate and sodium carbonate on physical and elastic properties and on carbonation resistance of calcium sulphoaluminate-based mortars," *Applied Sciences*, vol. 10, no. 1, p. 176, 2019.