Cement saturation and the effect on stability and compressive strength of concrete

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Abstract. This research work is aimed at determining the effect of saturation of cement on the stability and compressive strength of concrete. Three different mix ratios were considered: 1:1½:3, 1:2:4 and 1:3:6; alongside three different water - cement ratios: 0.55, 0.60 and 0.65. The key concrete characteristics checked for were stability, workability and compressive strength. Results indicate that mix ratio 1:1½:3 produced a high workability for the three cement ratios considered, mix ratio 1:2:4 produced a low workability for water cement ratio 0.55 and 0.60 and a high workability for 0.65; while for mix ratio 1:3:6, a dry mix was produced for the three water cement ratios considered, thereby requiring additional water which eventually gave a low workability. The compressive strength results indicate that the mix with the highest values of strength were 1:1½:3 at water – cement ratio of 0.55 with a strength of 29.3N/mm² after 28 days and 1:2:4 at water – cement ratio of 0.55 and strength of 26.4N/mm² after 28 days. The mixes with the least strength are 1:3:6 at water - cement ratio of 0.65 having a strength of 13.6N/mm² after 28 days, and 1:3:6 at water – cement ratio of 0.60 with strength of 13.3N/mm² after 28 days. The deduction is also made that for the three mix ratios considered, the most suitable water – cement ratio is 0.55 based on stability and compressive strength.

Keywords: Cement, Compressive Strength, Concrete, Mix – ratio, Stability, Water – Cement ratio.

1. INTRODUCTION

Concrete is composed of the mixture of water, cement, fine and coarse aggregates and these can be mixed in different proportions and for specified purposes; each concrete mixture has different characteristics in both freshly mixed state and hardened state. On a human timescale, concrete has played a major role in the construction of building, bridges, dams, roads etc. going back to 6500BC. It is a composite material made essentially of Portland cement, water, fine and coarse aggregates (1). The active constituent of concrete is cement paste and the performance of concrete is largely determined by the quality of the cement paste which is a product of the quality of the ingredients, their proportions, placement, and exposure conditions. Concrete continues to gain strength as it cures. The Industry has adopted the 28-day strength which is about 90% of its actual strength as a reference point (2). It is believed that concrete attains sufficient strength necessary for service and load application after 28 days.

Concrete has different properties at both freshly mixed state and hardened state. Some of the properties in fresh state include setting, workability, hydration and stability; while properties at hardened state include strength, deformation under load, creep, shrinkage and permeability, durability
and thermal conductivity. The aim of this research is to determine the effect of cement saturation on the stability and compressive strength of concrete. Specifically, the objectives include the following:

1. To check the effect of varying water – cement content on the stability and compressive strength of concrete.
2. To measure workability of concrete at varying water - cement ratios.
3. To analyze result and determine the relationship with stability and compressive strength.
4. To establish the most workable and most suitable water - cement ratio for the mix ratios considered based on stability and compressive strength.

The performance of concrete depends on the constituent members; cement, fine and coarse aggregates and water. When water is added to the mix, the cement undergoes a series of chemical reactions to form “gel” (a colloidal system). The fine cement particles are broken down into even smaller particles (thus increasing the reactive surface) by crystallizing out from the supersaturated solution formed. A series of immensely strong Si-O-Si bonds form between the particles, making a network in which the aggregates are trapped. In addition, bonds are formed to the aggregates, but these are much weaker, especially for smooth, inert, hard aggregates; because they have a smaller surface area than rough aggregates. These reactions continue to take place for some time (depending on the exact composition of the cement), and after the initial brief expansion of the cement, the material shrinks as unreacted water is lost. It is rare for all the cement to react; usually after five months, the grains are only hydrated to a depth of 6-9µm, while cement grains range up to 100µm in diameter (3).

The effects of cement content and water-cement ratio on workable fresh concrete properties were investigated with slump changing between 90 to 110mm, and determined the relationship among fresh concrete properties such as slump values, compacting factor values, unit weight and setting times of mortar with temperature history. The experiments were conducted under laboratory conditions on eight different concrete mixtures prepared from ordinary Portland cement (300, 350, 400, 450, 500, 550, 600 and 650kg/m³) and crushed limestone coarse and fine aggregates. It was observed that increasing the cement content causes increase in the slump, compacting factor, and fresh concrete unit weight, and reduces Veebee time (4). They also established that consistency and workability of fresh concrete were significant criteria for the concrete mix design proportioning and important properties affecting the placing of fresh concrete on site and the later performance of the hardened state of concrete. A research found that workability represents diverse characteristics of freshly mixed concrete that are difficult to measure quantitatively (5).

A number of other studies have also been carried out, considering other materials as aggregates. For instance, in a study carried out to check the compressive strength of concrete using lateritic sand and quarry dust as fine aggregates; various combinations of lateritic sand and quarry dust were considered as complete replacement for conventional river sand fine aggregate. The quantity of laterite was varied from 0% to 100% against quarry dust at intervals of 25%, and mix ratios 1:1:2, 1:1.5:3 and 1:2:4 were considered; it was discovered that 0.5 water – cement ratio produced higher compressive strength for mix ratio of 1:1:2, while 0.6 water – cement ratio exhibit better workability for mix ratio of 1:1.5:3 (6). Another investigation was carried out to determine the effects of water – cement ratio on compressive strength of natural and recycled aggregate, the results indicate that compressive strength of concrete is related to water – cement ratio; it was observed that when water – cement ratio is above 0.57, compressive strength of recycled aggregate concrete decreases as water – cement ratio increases which is similar to that of natural concrete (7). The adjustment of the water – cement ratio and super-plasticizer dosage was found to be one of the main properties in proportioning of self-compacting concrete (SCC) mixtures (8). (9) hold that among the various methods of evaluating workability of fresh concrete, there is a lack of methodology for evaluating stability of fresh concrete during transportation, placing till initial setting phase. The study investigated the stability of fresh self – compacting concrete by developing a method to test whether or not concrete
has suitable viscosity between matrix and coarse aggregate; the method was discovered to be in agreement with other methods such as U – box test and L – box test, while also making it possible to assess whether or not the ingredients of fresh concrete distribute uniformly during transportation, placing and construction. In another study (1), the use of manufactured sand as a replacement for natural sand and Ground Granulated Blast-furnace Slag (GGBS) as partial replacement of cement was considered within the range of 0 - 55% of cement, the study found that the manufactured sand (quarry dust) can be used as an alternative to natural sand, as it improves the mechanical property of concrete if used along super plasticizer, while the optimum quantity of GGBS was found to be 53% of cement which produced a comparable compressive strength after 28 days curing while also observing increased workability at 0.45% chemical admixtures, thereby reducing the cost of concrete.

2. METHODOLOGY
Ordinary Portland cement (CEM 1) was considered for this research work which was carried out at the University of Lagos, Structural Engineering workshop. Three different mix ratios were considered: 1:1½:3, 1:2:4 and 1:3:6; and also three different water - cement ratios which are 0.55, 0.60 and 0.65. Laboratory tests carried out include slump test and compacting factor test to determine workability; and compressive strength tests on cast concrete cube of size 150mm x 150mm x 150mm, to determine the strength values at 7days, 14days, 21days and 28days respectively.

All experiments were carried out based on American society for testing and materials ASTM standards (10) (11) (12) (13). Grain size analysis was carried out to quantify the size classes by percentages based on weight, the weight percentages are calculated for the particles passing (or finer than) designated sieve sizes. Consistency test was also carried out on the cement to determine the standard consistencies; initial setting time and final setting time. The initial setting time is the period elapsing between the time when the water was added to the cement and the time at which the needle ceases to pierce the test block.

Slump test was carried out to determine the workability of the fresh concrete by filling the slump mould in three layers, each approximately one – third of the height of the mould; and giving 25 strokes of the tamping rod per layer, after which the top was struck off and leveled so that the mould was exactly filled, then, the mould was removed immediately from the concrete in a slow and careful manner, in a vertical direction. Outcome of slump tests were varied yielding true slump, shear slump or collapse slump, which was measured visually or using steel rule to determine the level of slump. The compacting factor test was also carried out to assess the workability using the compacting factor apparatus; the mixed concrete paste to be tested was placed in the upper hopper to the brim, and the bottom gate valve was opened after two minutes to allow concrete fall into the lower hopper, after which the bottom gate valve of the lower hopper was opened to allow the concrete fall into the cylinder; the cylinder full of concrete was measured as the partially compacted concrete, after which the cylinder was emptied and filled in five layers, with each layer well rammed to obtain full compaction. Where the compacting factor (CF) result was observed to be less than 0.75, the apparent workability was recorded as very low; it was classed as low workability if CF result fell between 0.75 and 0.85; medium workability was recorded where the CF result fell between 0.85 and 0.92; while high workability was recorded where CF result lies between 0.92 and 0.95; but when CF result was greater than 0.95, very high workability was recorded (14).

The compressive strength i.e. the value of the uniaxial compressive stress reached when the material fails completely was measured by casting a concrete cube according to the mix ratios and water cement ratios previously reported, compacted and left for 24 hours before de-moulding, then cured for 7, 14, 21 and 28 days respectively and thereafter tested in the compressive testing machine. A total of 108 concrete cubes were cast with three samples of each specimen in order to determine the average value.
3. RESULTS AND DISCUSSION

The result of the grain size analysis is shown in Figure 1, and the slump test results are shown in Table 1, with the additional weight of water added shown in Table 2. The compacting factor test results are shown in Table 3. The slump test results were also compared with the compacting factor results and the comparison is shown in Table 4, with the results of compressive strength tests shown in Figure 2. From the consistency test, the standard water – cement ratio for standard consistency was obtained as 0.27 for the cement considered, while the initial setting time was observed to be 02hr 07min 45sec, and the final setting time is 03hr 22min 30sec.

![Figure 1: Grain size analysis plot](image)

Table 1: Slump test results

| S/N | Water-Cement ratio | Mix-ratio | Slump type      | Slump value (mm) | Workability type |
|-----|--------------------|-----------|-----------------|------------------|------------------|
| 1   | 0.55               | 1:1½:3    | Collapse slump  | 145              | High             |
| 2   | 0.55               | 1:2:4     | True slump      | 0                | Low (Dry mix)    |
| 3   | 0.55               | 1:3:6     | True slump      | 0                | Low (Dry mix)    |
| 4   | 0.6                | 1:1½:3    | Collapse slump  | 200              | High             |
| 5   | 0.6                | 1:2:4     | True slump      | 33               | Low              |
| 6   | 0.6                | 1:3:6     | True slump      | 5                | Low (Dry mix)    |
| 7   | 0.65               | 1:1½:3    | Collapse slump  | Total collapse   | High             |
| 8   | 0.65               | 1:2:4     | Collapse slump  | 188              | High             |
| 9   | 0.65               | 1:3:6     | True slump      | 7                | Low (Dry mix)    |
Table 2: Additional water distribution for the three mix ratios

| Mix-ratio | Water - cement ratio | Wt of additional water added (kg) | % of water added |
|-----------|----------------------|-----------------------------------|------------------|
| 1:3:6     | 0.55                 | 1                                 | 16.45            |
| 1:3:6     | 0.6                  | 1.5                               | 23.7             |
| 1:3:6     | 0.65                 | 1.5                               | 22               |

Table 3: Compacting factor test results

| S/No. | Water-Cement ratio | Mix-ratio | C.F value | Workability type |
|-------|--------------------|-----------|-----------|------------------|
| 1     | 0.55               | 1:1½:3    | 0.99      | Very high        |
| 2     | 0.55               | 1:2:4     | 0.84      | Low              |
| 3     | 0.55               | 1:3:6     | 0.83      | Low              |
| 4     | 0.6                | 1:1½:3    | 0.98      | Very high        |
| 5     | 0.6                | 1:2:4     | 0.93      | Medium           |
| 6     | 0.6                | 1:3:6     | 0.91      | Medium           |
| 7     | 0.65               | 1:1½:3    | 0.89      | Medium           |
| 8     | 0.65               | 1:2:4     | 0.98      | Very high        |
| 9     | 0.65               | 1:3:6     | 0.9       | Medium           |

Table 4: Comparison of slump test and compacting factor test

| S/No. | Water-Cement ratio | Mix-ratio | Workability type | C.F Workability type |
|-------|--------------------|-----------|------------------|----------------------|
| 1     | 0.55               | 1:1½:3    | High             | Very high            |
| 2     | 0.55               | 1:2:4     | Low              | Low                  |
| 3     | 0.55               | 1:3:6     | Low              | Low                  |
| 4     | 0.6                | 1:1½:3    | High             | Very high            |
| 5     | 0.6                | 1:2:4     | Low              | Medium               |
| 6     | 0.6                | 1:3:6     | Low              | Medium               |
| 7     | 0.65               | 1:1½:3    | High             | Medium               |
| 8     | 0.65               | 1:2:4     | High             | Very high            |
| 9     | 0.65               | 1:3:6     | Low              | Medium               |
From the grain size analysis shown in Figure 1, the coefficient of uniformity ($C_u$) and coefficient of curvature ($C_c$) were found to be 2 and 2.39 respectively. The $C_u$ is less than 4 and the $C_c$ is greater than 1; it was also observed that more than 75% of the sand had grain size between 0.1mm and 1mm; therefore, it can be concluded that the sand used was a uniformly-graded sample.

The slump type and slump value for each mix is shown in Table 1. It was discovered that mix ratio 1:1½:3 produced a collapse slump for 0.55, 0.60 and 0.65 water cement ratios, which shows that they were wet mixes of high consistency and unstable concrete; while mix ratio 1:2:4 produced a true slump for 0.55 and 0.60 while producing a collapse slump for 0.65 water cement ratio which gives a dry mix, low workability and high consistency for 0.55, 0.60 and 0.65 water cement ratio respectively. Mix ratio 1:3:6 produced true slump for the three water cement ratio considered and the mixes were also observed to be extremely dry with additional quantity of water added in the proportion shown in Table 2.

The results of the compacting factor tests are shown in Table 3, and it can be seen that the compacting factor C.F values for mix ratio 1:1½:3 reduces as water cement ratio increases thereby yielding high workability for water cement ratios 0.55, 0.60 and medium workability for 0.65 respectively, hence decrease in stability. The C.F values for mix ratio 1:2:4 increases as the water cement ratio increased, producing mixes of low, medium and high workability respectively, hence increase in stability. Mix ratio 1:3:6 also have increment in C.F values from 0.55 to 0.60 water cement ratio, but decreased at 0.65 water cement ratio, thereby producing a low workability for 0.55 water cement ratio and medium workability for 0.60, 0.65 water cement ratios giving improvement in stability.
By comparing the slump test results with the compacting factor test results as seen in Table 4, it can be seen that the stability which is a function of the workability varies with change in water – cement ratio. Though, the workability of both tests were not exactly the same, we can arrive at a reasonable conclusion on what the approximate workability level is for each mix considered.

The compressive strength values for the three mix – ratios were observed as shown in Figure 2 for water – cement ratios 0.55, 0.60 and 0.65 respectively. 0.55 and 0.65 mix ratios were seen to increase from 7 days curing to 28 days curing except for 0.55:1:3:6 which dropped at 28 days and 0.65:1:3:6 which dropped at 21 days, while for water – cement ratio 0.60, the compressive strength was observed to drop at 28 days for 1:1½:3, and at 21 and 28 days for both 1:2:4 and 1:3:6 mix ratios.

4. CONCLUSION
Based on experimental results, the following conclusions could be deduced:

- The three mix – ratios gave different results at the three water – cement ratios considered. For mix-ratio 1:1½:3, an unstable concrete was observed for the water-cement ratios due to the concrete being of a very high consistency. It can be concluded for mix-ratio 1:2:4 that improvement in stability was produced; while for 1:3:6, a dry concrete mix was produced, thereby also producing unstable concrete.
- It can also be concluded that the three water-cement ratios were too small for mix-ratio 1:3:6, while they were too high for mix-ratio 1:1½:3, but optimum for 1:2:4.
- It can be concluded from the compressive strength tests that the mix ratios 0.55:1:1½:3, 0.55:1:2:4, 0.65:1:1½:3 and 0.65:1:2:4 increased in their compressive strength as the curing age increased; while for others the increment was not consistent.
- The compressive strength results indicate that the mix with the highest values of strength are 1:1½:3 at water – cement ratio of 0.55 with a strength of 29.3N/mm² after 28 days and 1:2:4 at water – cement ratio of 0.55 having strength of 26.4N/mm² after 28 days, while the mixes with the least strength are 1:3:6 at water - cement ratio of 0.65 having a strength of 13.6N/mm² after 28 days, and 1:3:6 at water – cement ratio of 0.60 with strength of 13.3N/mm² after 28 days.
- The deduction is also made that for the three mix ratios considered, the most suitable water – cement ratio is 0.55 based on stability and compressive strength.

REFERENCES
(1) Gowda, L; Ramesh, V. and Raju, S., 2015. Experimental Investigation on Strengths and Durable Properties of Concrete on Manufactured Sand and GGBS with Chemical Admixtures. International Journal of Civil and Structural Engineering Research, Vol 3, Issue 1, pp (128 – 133).
(2) Korman, T., 2016. Construction Depth Reference Manual for the Civil PE Exam. Second edition. www.ppi2pass.com 8
(3) NZIC, N., The Manufacture of Portland Cement. New Zealand Institute of Chemistry, www.nzic.org.nz.
(4) Marar, K. and Eren, O., 2011. Effect of Cement Content and Water – Cement Ratio on Fresh Concrete Properties without Admixtures. International Journal of Physical Sciences, Vol. 6(24), pp. 5752 – 5765.
(5) Mehta, P.K., and Monteiro, P., 1993. Concrete Structure, Properties and Materials. Unpublished manuscript for revision of Mehta, PK and Monteiro, PJM Concrete: Structure, Properties, and Materials.
(6) Ukpata, J.O.; Ephraim, M.E. and Akeke, G.A., 2012. Compressive Strength of Concrete using Lateritic Sand and Quarry Dust as Fine Aggregates. ARPN Journal of engineering and applied sciences, 7(1), pp. 81-92.
(7) Xu-hua, D., 2005. Study on effect of compressive strength of recycled aggregate concrete with water cement ratio (J). Concrete, 2, pp. 46-48.
(8) Burak, F.; Selcuk, T. and Bulent, B., 2007. Effect of Water – Cement Ratio on the Fresh and Hardened Properties of Self – Compacting Concrete. *Journal of Building and Environment* 42(4):1795-1802.

(9) Youjun, X., Gaungcheng, L., and Yanguang, L., 2005. A new method for evaluating stability of fresh self – compacting concrete. *1st International Symposium on Design, Performance and Use of Self – Consolidating Concrete* (Vol. 292), Paris: RILEM Publications SARL.

(10) ASTM C39/C39M-18, 2018. Standard test method for compressive strength of cylindrical concrete specimens, ASTM International, West Conshohocken, PA, [www.astm.org](http://www.astm.org).

(11) ASTM C143/C143M-15a, 2015. Standard test method for slump of hydraulic-cement concrete, ASTM International, West Conshohocken, PA, [www.astm.org](http://www.astm.org).

(12) ASTM C150/C150M-18, 2018. Standard specification for Portland cement, ASTM International, West Conshohocken, PA, [www.astm.org](http://www.astm.org).

(13) ASTM C172/C172M-17, 2017. Standard practice for sampling freshly mixed concrete, ASTM International, West Conshohocken, PA, [www.astm.org](http://www.astm.org).

(14) Bartos, P.J.M., Sonebi, M., Tamimi, A.K., 2002. Workability and Rheology of Fresh Concrete: Compendium of Tests – Report of *RILEM Technical Committee TC 145-WSM* (Vol. 24). RILEM publications.