BATCHING METHODS AND THEIR INFLUENCE ON PROPERTIES OF CONCRETE – A LIMITED STUDY

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Abstract - *The effect of mass and volume batching on the fresh and hardened properties of concrete was investigated using a single mix proportion and water-cement or w/c ratios of 0.5, 0.55 and 0.65. Volume batching was carried out by means of a constructed gauge box, while mass batching was effected via a well calibrated mass scale. All concrete samples were manufactured using OPC 42.5N CEM Type 1 cement and the specimens were cured in water for 7, 14 and 28 days as required. It was found that the workability increased with w/c ratios for both methods of batching, although it was somewhat higher for mass proportioning than for volume batching. In addition, higher compressive strengths were obtained for concrete specimens proportioned by mass, for all w/c ratios. In most cases the coefficients of variation of the compressive strength test results for the concrete batched by mass were markedly lower than their equivalent counterparts produced by volume proportioning. It was concluded that these findings were in broad agreement with the results of previous research in the literature.*

Key Words: Batching method, mix proportion, water-cement ratio, curing age, concrete, workability, compressive strength.

1. INTRODUCTION

Concrete is universally regarded as a composite material comprised of a mixture of coarse/fine granular materials or aggregates, cement, water and admixture all combined in certain proportions which may be varied depending on the desired nature and characteristics of the fresh and hardened concrete. The property of the fresh concrete of primary interest here is the workability, defined as the amount of mechanical work or energy needed to produce complete compaction of the concrete without segregation (Mindess et al. [1]). In a qualitative sense, the term describes the ease with which the concrete can be mixed, placed, compacted and finished (Kong and Evans [2]). With regards to the hardened concrete, the major mechanical property of concern is the compressive strength, although in several circumstances the main focus may be on the flexural and tensile strengths of the hardened concrete.

The manufacture of concrete involves several steps namely batching, mixing, transporting, placing, compaction, curing and finishing in that order (Shetty and Jain [3]). Batching of aggregates and cement, the first stage, is defined as the process of measuring and introducing into the mixer the ingredients of the batch (Mehta and Monteiro [4]). There are generally two methods available in this regard, namely proportioning by mass or volume batching. According to Kellerman [5], Mindess et al. [1] and Mehta and Monteiro [4], batching by mass is generally accepted as the preferred means of proportioning. Since water and liquid admixtures alone can be measured accurately by volume, it is not surprising that the quantification of solids like cement and aggregates on a volume basis may result in gross errors (Mindess et al. [1]). In addition, if fluctuations or changes in aggregate moisture contents take place, proportioning by mass easily facilitates convenient and rapid adjustments of quantities of aggregate and water. According to Mindess et al. [1], environmental and practical concerns frequently make it advantageous to retain some wash water in the mixer which must be taken into account during the batching operation; this necessitates material quantities to be measured to a high degree of accuracy and is best accomplished by mass proportioning. With well- maintained and properly functioning equipment, mass batching can result in a high degree of uniformity of successive batches of concrete (Kellerman [5]).

In respect of batching by volume, Kellerman [5] has stated that possible sources of errors are due to the bulking of sand ranging from 15% to 30% for coarse and fine sands respectively, the compaction of aggregates and the packing characteristics of the aggregate. Regarding the latter, rounder and more graded aggregates are liable to pack more closely than poorly shaped and single sized aggregates. Major errors also occur with volume batching of cement on account of changes in the loose bulk density as the cement becomes aerated when discharged. Consequently for the foregoing reasons it is generally recommended that volume batching be confined to non-structural works such as foundations for houses, and relatively unimportant construction not requiring usage of mass batching equipment (Kellerman [5]).

Despite the above observations and misgivings, the general tendency in many West African and particularly Nigerian construction sites is to adopt volume batching for the majority of concrete works, on the grounds of ease, simplicity and construction speed (Orumu [6]). This has been the case for both structural and non-structural concrete constructions which are in accordance with BS 8500-1:2002 [7]. Admittedly the problem here is compounded by the fact that a given project may specify nominal mix proportions and maximum coarse aggregate sizes to be employed, but the method of batching whether by mass or volume proportioning in order to achieve a specified characteristic strength is seldom stated. Furthermore on-site practices involve a visual assessment of the workability of the concrete as water is added and consequently, compressive strengths attained may be substantially lower than the specified characteristic strength and may differ from batch to batch of the concrete produced particularly where the consistency is not monitored (Olusola et al. [8]).

2. LITERATURE REVIEW

A review of the literature on the variations that occur in the properties of concrete when batching is carried out by volume as opposed to mass reveals surprisingly a dearth of results. Goldbeck and Gray [9] in their pioneering studies emphasized the necessity of establishing the mix proportions with the materials to be used on site. In contrast to the general practice of stipulating an unconfirmed mix ratio for a specified characteristic strength, they suggested that appropriate mix proportions should be arrived at after preliminary site tests.

Olusola et al. [8] investigated the influence of batching methods on the compressive strength and workability of concrete using five mix proportions of 1:1:2, 1:1.5:3, 1:2:4, 1:3:6 and 1:4:8, and water cement ratios varying from 0.35 to 0.95. In all cases batching by mass gave rise to higher slumps than volume proportioning, the percentage differences ranging from 4% to 30%, with most results in the range 4%-10%. With regards to the compressive strength, for ordinary structural mix ratio of 1:2:4 normally used for structural work in West Africa, concrete batched by volume resulted in 28th day compressive strengths which were about 14% lower than concrete produced by mass proportioning. They concluded that compressive strengths produced by volume batching on construction sites might not attain the designed target strengths.

Orumu [6] developed a modified volume batching method based on the complete removal of entrained air occurring in the traditional volume proportioning approach. He found that for a rich structural mix ratio of 1:1.5:3, concrete batched by the modified volume method had 65% and 22% compressive strength increase over concrete batched by the traditional volume approach for 7 and 28 days respectively. Additionally the modified volume batching method resulted in a more rapid strength development than that of the traditional volume proportioning. However he concluded that an increase of 20.9% in cement volume, a decrease of 24.6% in fine aggregate volume and an increase of 1.1% in coarse aggregate volume was required in contrast to the traditional volume proportioning method. For the purpose of the present study however, a modified volume batching approach has not been adopted.

In view of the scarcity of results found in the literature as enunciated earlier, the emphasis in the current investigation is on a comparison of the mass and volume batching methods with respect to their influence on the properties of the fresh and hardened concrete along the lines adopted by Olusola et al. [8]. However locally sourced materials in Botswana have been utilized for the present research in order to provide additional test results and thereby supplement the existing data relating to batching methods.

3. EXPERIMENTAL PROGRAMME

In this section a description is given of the different materials employed in the current study and how the mix proportions were arrived at. The procedure for casting of the concrete specimens as well as the methods employed for the tests subsequently carried out on the fresh and hardened concrete are outlined.

3.1 Materials, Mix proportions and Casting

Ordinary Portland cement of specification 42.5 N CEM 1 and manufactured by PPC Ltd. was utilized for the study. This cement is suitable for the production of all reinforced concrete work and mortars requiring high initial strength. It has ready application in a great variety of reinforced and prestressed construction. The cement has an initial setting time ≥ 60 minutes and final setting time of approximately 110 minutes, with a 7 day compressive strength of 29 MPa and 28 day compressive strength of 42.5 MPa. The coarse aggregate utilized was 13.2 mm maximum size silica stone, while the fine aggregate employed was 4.75 mm maximum size crusher sand. The loose bulk densities of the fine and coarse aggregates were approximately 1,600 kg/m^3 and 1,440 kg/m^3 respectively. The aggregates were sourced from Kgale Quarries in Gaborone. The particle size distributions for the fine and coarse aggregates are shown in Figures 1 and 2 respectively.

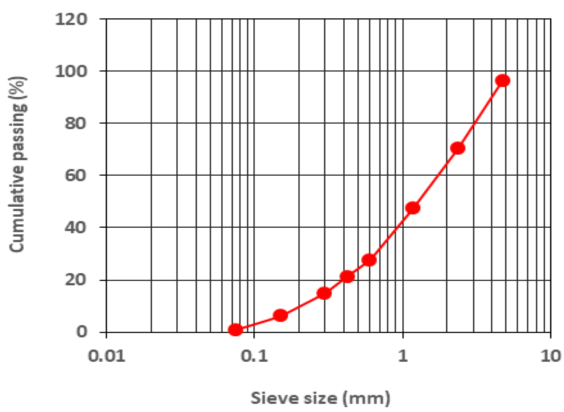


Fig. 1: Particle size distribution for fine aggregate

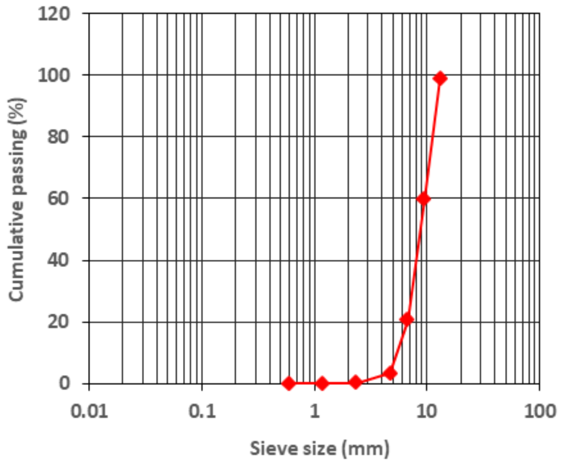


Fig. 2: Particle size distribution for coarse aggregate

The Cement and Concrete Institute method of mix design derived from ACI Standard 211.1-91 as described by Addis and Goodman [10] was adopted to determine the quantities of the different materials needed. The selected characteristic strength was 42.5 MPa at 28 days. Parameters such as the compacted bulk density and relative density for the cement, crusher sand and silica stone were taken from the suppliers guidelines in order to obtain reasonable estimates of material characteristics for the mix design. Three water-cement or w/c ratios of 0.5, 0.55 and 0.65 were adopted. Trial mixes were carried out to arrive at the mix proportions shown in Table 1.

Table 1: Mix proportions (in kg.) for 1m^3 of fresh concrete

Water	Cement	Silica stone	Crusher sand	w/c ratio
168.6	337.2	1,011	842.9	0.50
185.5	337.2	1,011	842.9	0.55
219.2	337.2	1,011	842.9	0.65

When batching by mass, the constituents of the concrete were weighed separately using a well calibrated scale balance. Specifications generally require that materials be measured in individual batches within the percentages of accuracy of 1% for cement, 2% for aggregates and 1% for water. For the case of volume proportioning, a specially constructed gauge box shown in Figure 3 of internal dimensions 350 mm x 200 mm x 250 mm was employed to measure the volumes of the different constituents. Prior to casting of the cubes, slump tests were carried out for all the different concrete mixes.

A total of one hundred and eight (108) concrete cubes of 150 mm sizes were cast for the compressive strength tests. Due to uncertainties at this stage regarding the variations that would occur particularly in respect of volume proportioning, it was decided to utilize the results of six cubes rather than the widely adopted or standard three cubes, in order to assess the compressive strength at any given time. The moulds for all cast specimens were vibrated by means of a vibrating table and subsequently covered with wet hessian or translucent plastic sheet for 24 hours. The cubes were then de-moulded and placed in a constant temperature curing bath for a total of 7, 14 or 28 days as deemed necessary, prior to testing.

Fig. 3: Constructed gauge box for volume batching

3.2 Testing Procedures

The testing of the hardened concrete cubes was carried out at 7, 14 or 28 days after curing for each cube irrespective of the batching method employed. A well-maintained compression test machine shown in Figure 4 was utilized for this purpose. Loading was applied at a constant rate up until failure in accordance with the South African standard SANS 5863: 2006 [11]. Any unusual behaviour of the test specimens during crushing was noted and analysed subsequently. As mentioned earlier, the compressive strength at any given occasion was taken as the average of six test results.

Fig. 4: Compression test set-up

4. RESULTS AND DISCUSSION

In this section the detailed results of the slump tests on the fresh concrete, compressive strength tests on the hardened cubes and the observed variations in the cube strengths with respect to the batching methods used are presented. An attempt is also made to correlate the results of the study with previous findings presented in the literature.

4.1 Effect of batching method and w/c on slump

The comparison of slumps for concrete batched by volume in contrast to mass proportioning is presented in Table 2. The results demonstrate that slumps for concrete batched by mass were generally higher than those for materials proportioned by volume for all water-cement ratios, probably due to the greater consistency in measuring materials by mass as opposed to volume. There were no changes in slump for concrete batched by volume for all w/c ratios in the range 0.5 to 0.55. However there was a shear slump for a w/c ratio of 0.65, indicating that the mix was too wet. The flow test would have been more appropriate to measure the workability of such mix. In comparison, for concrete proportioned by mass, slumps of 8 mm and 20 mm were obtained for w/c ratios of 0.55 and 0.65 respectively, although these results indicate that the mixes were relatively dry. It should be borne in mind here however that the range and number of tests conducted were limited as compared to those of Olusola et al. [8].

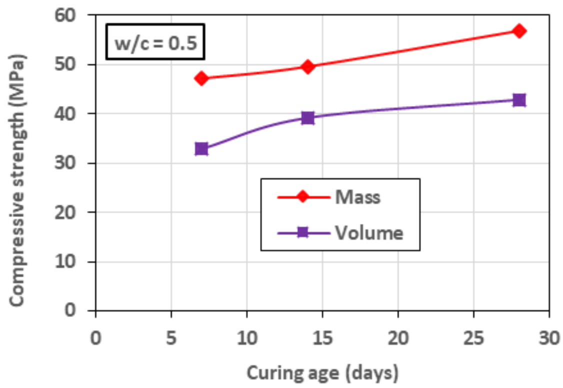
Table 2: Variation of slump (in mm.) with batching method

w/c ratio	Slump		Slump class*	
	Volume	Mass	Volume	Mass
0.50	0	0	–	–
0.55	0	8	–	–
0.65	Shear slump	20	–	S1

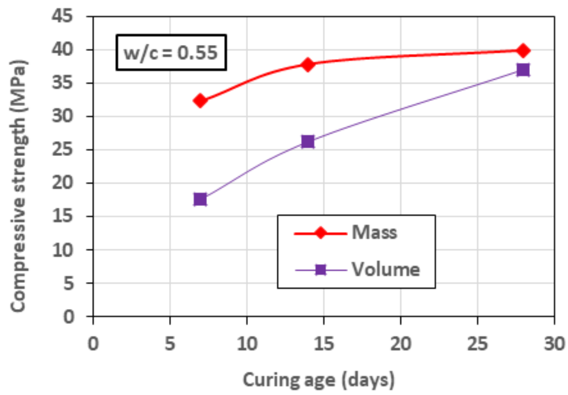
*S1 (≥ 10 ≤ 40) according to BS EN 206-1: 2000 [12]

4.2 Effect of batching method on cube strength

Figures 5(a) to (c) show the results of the compressive cube strengths for the different methods of batching and w/c ratios. It is apparent that there is an increase in compressive strength with increase in testing age. In addition there is a decrease in compressive strength with increase in w/c ratio. These trends are not surprising and are well documented in the literature. In all cases higher compressive strengths were obtained for concrete batched by mass as opposed to volume. For example for a w/c ratio of 0.5, the 28th day compressive strength for concrete proportioned by mass was 32.6% higher compared to that proportioned by volume. With a w/c ratio of 0.55, the difference in compressive strength was 7.8% which was quite modest. However for a w/c ratio of 0.65, the strength difference peaked at 70.6%. Such trend of compressive strength in relation to the batching method was also found by Olusola et al. [8] although their margins of differences were not as pronounced compared to the present study. Nevertheless the results of both investigations support the view that there is a high probability that most concrete produced on construction sites in West African countries in general might not meet the designed target strengths.



(a)



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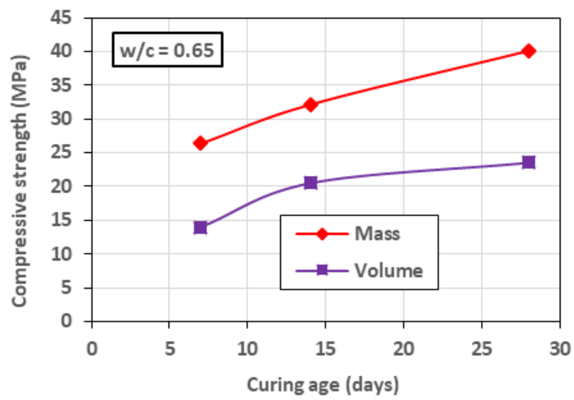

(c)

Fig. 5: Variation of compressive strength with age for various w/c ratios

4.3 Variation in compressive cube strengths

With regards to the issue of variation in the compressive strength results, in most cases the coefficient of variation for cubes batched by volume was significantly higher than for specimens proportioned by mass regardless of the age of testing or the w/c ratio. For example, for the 14th and 28th day compressive strengths with a w/c ratio of 0.5, volume batching produced variations of 11.6% and 12.1% respectively. The corresponding values for mass proportioning were 6.3% and 4.5% respectively. With a w/c ratio of 0.65, volume batching resulted in a coefficient of variation for the 14th and 28th day compressive strengths of 6.1% and 23.8% respectively. The corresponding values for mass proportioning were 4.1% and 4.5% in that order. These results demonstrate that it is prudent as suggested in the literature (see Kellerman [5] for example) to restrict concreting batched by volume to minor and non-structural works, or construction requiring very little or minimum supervision.

5. CONCLUSIONS

The work carried out in the present study was executed in order to determine the influence of the method of batching on the properties of concrete in both the fresh and hardened states. The particular characteristics of interest herein were the workability of the fresh concrete as assessed by the slump, and the compressive strength of the hardened concrete. A single mix proportion was used, however three water-cement ratios of 0.5, 0.55 and 0.65 were employed. Based on the investigations carried out, the following conclusions have been drawn.

(1) Slumps for concrete batched by mass were generally higher than those for concrete proportioned by volume for all water-cement ratios utilized. However the concretes produced by volume batching were considered to be rather wet, while those manufactured by mass proportioning were adjudged to be relatively dry for the limited number of tests conducted.

(2) The compressive strengths for concrete produced by mass batching were higher than those for concrete manufactured by volume proportioning at all ages of testing and for all w/c ratios, With reference to the 28th day strength the margin of difference was 32.6% for a w/c ratio of 0.5 and 70.6% for a w/c ratio of 0.65.

(3) There is a high likelihood that concretes proportioned by volume on construction sites, as prevalent in several West African countries, might not meet their designed target strengths.

(4) In respect of the compressive strength of concrete, the coefficient of variation for cubes batched by volume was significantly higher than that for specimens proportioned by mass regardless of the age of testing or the w/c ratio. This lends credence to the widely held conviction to restrict concreting batched by volume to minor and non-structural works in the construction industry.

(5) The major findings from the investigations conducted in the current study are in broad agreement with the results of previous research found in the literature.

ACKNOWLEDGEMENT

The work contained in the present study was carried out in the Civil Engineering Department of the University of Botswana, Gaborone, under the leadership of the first investigator. The authors would wish to thank Professor Goitseone Malumbela of the Botswana International University of Science and Technology for his useful advice and suggestions during the course of the research. In addition the assistance of the technical staff of the Materials and Structures laboratories of the Civil Engineering Department are hereby acknowledged.

REFERENCES

[1] S. Mindess, J.F. Young and D. Darwin "Concrete", 2nd Edition, Prentice Hall/Pearson Education Inc., New Jersey, USA, 2003, 657 pp.

[2] F.K. Kong and R.H. Evans, "Reinforced and Prestressed Concrete", 3rd Edition e-book, CRC Press, London, U. Kingdom, 2017, 528 pp.

[3] M.S. Shetty and A.K. Jain, "Concrete Technology – Theory and Practice", 8th Revised Edition, S. Chand and Co. Ltd., New Delhi, India, 2019, 664 pp.

[4] P.K. Mehta and P.J.M Monteiro, "Concrete: Microstructure, Properties and Materials", 3rd Edition e-book, McGraw-Hill, New York, USA, 2006, 684pp.

[5] J. Kellerman, "Manufacture and Handling of Concrete", In: Fulton's Concrete Technology, 9th Edition, G. Owens (Ed.), Cement and Concrete Institute, Midrand, South Africa, 2009.

[6] S.T. Orumu, "Modified Volume Batching Method of Concrete", Journal of Civil Engineering, Vol. 11, No. 1, 2016, pp. 1-9.

[7] British Standards Institution, "Concrete – Complementary British Standard to BS EN 206-1 – Part 1: Method of Specifying and Guidance for the Specifier, BS 8500-1: 2002", BSI, London, U. Kingdom, 2003.

[8] K.O. Olusola, A.J. Babafemi, A.A. Umoh, and B.J. Olawuyi, "Effect of Batching Methods on the Fresh and Hardened Properties of Concrete", International Journal of

Research and Reviews in Applied Sciences, ARPA Press, Vol. 13, Issue 3, 2012, pp. 773-779.

[9] A.T. Goldbeck and J.E. Gray, "A Method of Proportioning Concrete for Strength, Workability and Durability", National Crushed Stone Association, Engineering Bulletin No. 11, 1968, 37 pp.

[10] B. Addis and J. Goodman, "Concrete Mix Design", In: Fulton's Concrete Technology, 9th Edition, G. Owens (Ed.), Cement and Concrete Institute, Midrand, South Africa, 2009.

[11] South African Bureau of Standards, "Concrete Tests – Compressive Strength of Hardened Concrete, SANS 5863: 2006", SABS Division, Groenkloof, Pretoria, South Africa, 2002.

[12] British Standards Institution, "Concrete – Part 1: Specification, Performance, Production and Conformity, BS EN 206-1: 2000", BSI, London, U. Kingdom, 2003.