Sustainable Infrastructure in Kenya; Effect of local mixing methods on properties of concrete with low water/binder ratio

Kiburi Isaiah Achini
achinikpa@gmail.com

Abstract

Construction of infrastructure is a key pillar of Vision 2030 with the most common material of construction being concrete. One of the major causes of flawed structures in the industry is poor concrete preparation methodology. Traditional concrete preparation and particularly mixing practices have numerous shortcomings. The amount of water used in concrete mixing is often reduced to a minimum required to hydrate the cementing paste, which increases its strength and durability. Workability is enhanced by addition of an admixture. Any loss of moisture during mixing can result in incomplete hydration of paste and loss of strength. On the other hand, effectiveness of the mixing method affects the homogeneity of the mix and affect its hardened characteristics such as strength. Loss of moisture and homogeneity of the mix reduces the initial workability increasing plasticizer demand. This paper explores effects of common mixing methods on initial workability and strength of concrete of low water/binder ratio. The effects of a paddle or active mixer and a rotating drum or a passive mixer are also investigated. Results show that concrete mixing, sequence of loading, and type of mixer used all have significant effect on initial workability and strength. In general, lower workability and strength were obtained when a rotating drum mixer was used.

Keywords: Mixing methods, Workability, Mixer types

1. Introduction.

Proper mixing of materials is particularly of great importance for concrete of low water/binder ratio in order to achieve the durability and workability requirements as well as resistance to various stresses and protection of steel from rust [1]. During mixing, the reduction of water/binder ratio increases both the strength and durability of the resulting concrete by reducing porosity arising from the evaporation of excess water. Addition of a plasticizing admixture then becomes necessary to bring the concrete to a desired level of workability. Under such circumstance, any loss of moisture during mixing can result in incomplete hydration of the paste and loss of strength. On the other hand, the effectiveness of the mixing affects the homogeneity of the mix and can also affect the strength. Various methods of mixing concrete have been outlined in existing design codes. Traditional concrete mixing sequences in many construction projects in Kenya are derived from these design codes. In this study, a testing programme was developed so that effects of these mixing methods could be assessed in respect to the properties of low water/binder ratio concrete.

Most of the available previous research concerns the mixing of normal concrete as opposed to low water/binder ratio concrete. Though opinion on optimum charging sequence of concrete constituents into mixers during mixing varies, there is consensus among many authors that mixing methods affect various properties of the resulting concrete [4], [5], [6]. The most preferred method of mixing concrete using large mixers is by adding layers of coarse aggregate, followed by cement and then fine aggregate [7].

In Kenya most of the small to medium scale construction projects depend on concrete mixed on site. Data from the National Construction Authority (NCA) indicate that over 80% of construction projects registered in the year 2018 were categorized as low-impact projects implemented by contractors registered in lower categories [8]. It is common to find organized concrete mixing groups commonly known as ‘gangs’ in many construction projects who specialize in mixing of concrete and supply of concrete materials. To a big extent, these ‘mixing gangs’ determine the final quality of concrete on site and regrettably, due to poor supervision, they directly contribute to poor quality of structures. Unlike large scale projects which have higher economies of scale, majority of small scale projects are only able to afford concrete mixed on site. In many construction sites, workability enhancing admixtures are increasingly being used to improve performance of concrete in the fresh and hardened state. Additionally, infrastructure development in the counties has contributed to increased consumption of construction materials such as cement as the devolved governments come into effect in accordance with the new constitution. Use of traditional concrete mixing methods in Kenya has led to various challenges including poor strength, high porosity and permeability, susceptibility to chemical attacks and rebar corrosion.

Fig 1.1: Concrete mixing gangs in a construction site (Ruaka, 2018)

In this study, the sequences of mixing individual components of concrete i.e. cement, fine and coarse aggregates, water and superplasticizer, were systematically varied in accordance with four methods of mixing using both an active (forced action) and a passive (free fall) concrete mixer. Three mixing sequences compiled from suggestions made in existing design codes namely Indian Standard (IS) mixing method [2], American Concrete Institute (ACI) Code [3] and British Standard (BS) Code [4] were used. Additionally, a method involving progressively making paste followed by aggregate also known as Paste-mortar-concrete (PMC) was used. In all these methods, results obtained using both passive and active mixers were compared. The study aims at highlighting the significance of mixing methods outlined in three existing design codes and a fourth method suggested by the author on the rheological and hardened characteristics of low water/binder concrete.

2. Experimental Materials and Methodology.

2.1 Materials

The binder used was CEM IV/B-P 32.5R manufactured by a local company to KS EAS 18 which is derived from EN 197[9] and having the properties shown in Table 2.1. Fine aggregate was river sand of fineness modulus 2.76. Coarse aggregate was crushed stone of maximum aggregate size 12.7 mm obtained from a quarry in Nairobi area. Ordinary tap water from the city mains was used for concrete mixing, and a polycarboxylate super-plasticizer marketed locally was used for workability enhancement.

Table 2.1: Chemical and physical properties of cement.

Composition	Parameter	CEM IV/B-P 32.5R
Chemical (%)	Loss on ignition (LOI)	4.56
	Insoluble residue (IR)	35.20
	SiO_2	34.23
	Al_2O_3	6.71
	Fe_2O_3	4.69
	CaO	47.15
	MgO	0.41
	SO_3	1.97
	N_2O	1.10
	K_2O	1.52
	Cl^-	< 0.01
Physical	Specific surface (cm^2/g)	48.56
	Initial setting time (min.)	214
	Final setting time (min.)	279
	Soundness (mm)	0.8
	Mortar prism strength at 2 days (N/mm^2)	15.10
	Mortar prism strength at 7 days (N/mm^2)	26.80
	Mortar prism strength at 28 days (N/mm^2)	36.90
	Density (g/cm^2)	2.99

2.2 Material Preparation and Preliminary Tests

2.2.1 Fine aggregate

Fine aggregate was oven dried at 105°C for 24 hours to minimize the influence of moisture content on the water-cement ratio of concrete. Grading of the aggregate was done according to ASTM C136 requirements as shown in Figure 2.1. Specific gravity and water absorption of the aggregate were carried out with the results shown in Table 2.2.

Table 2.2: Physical properties of fine aggregate

Property	**Value**
Specific gravity	2.55
Water absorption (%)	0.7
Fineness Modulus	2.76
Maximum size (mm)	4.75

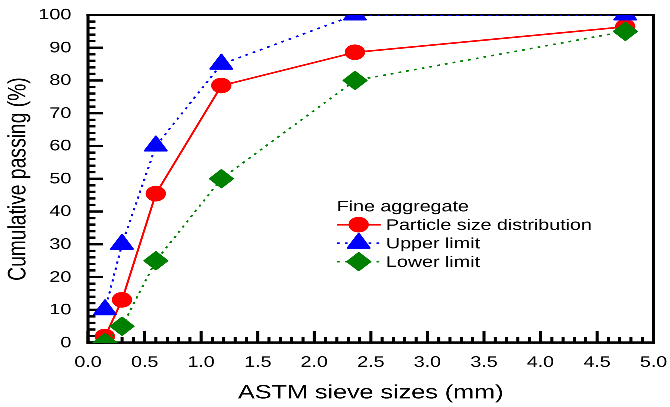


Fig. 2.1: Particle size distribution of fine aggregate.

2.2.2 Coarse aggregate

Coarse aggregates grading was carried as shown in Figure 2.2. The Specific gravity, water absorption and bulk density of the aggregates were determined as summarized in Table 2.3.

Table 2.3: Physical properties of coarse aggregate

Property	**Value**
Specific gravity	2.58
Water absorption (%)	0.5
Bulk density (kg/m^3)	1,527
Maximum size (mm)	12.7

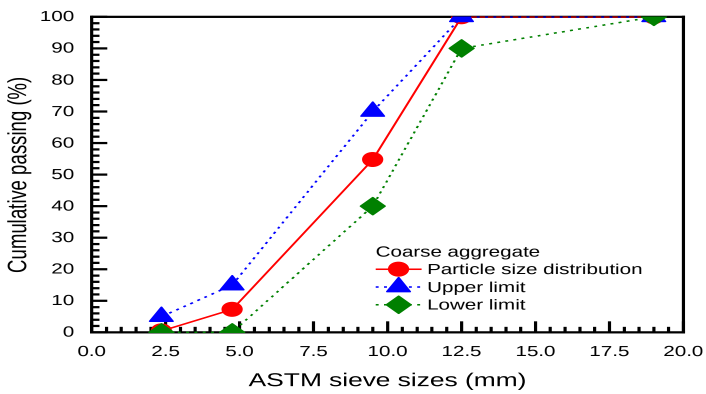


Fig. 2.2: Particle size distribution of coarse aggregate.

2.3 Concrete Mix Design

Concrete mix design targeting a 28-day average strength of 60 MPa was carried out to ACI 211.4R-08 in order to proportion concrete constituent materials based on desired properties such as strength and workability. On this basis, the design targeted a concrete slump range of between 40 and 55 mm and water/cement ratio below 0.35 upon which the quantities indicated in Table 2.4 were obtained.

Table 2.4: Material proportions (kg/m^3)

Coarse aggregate	Fine aggregate	Cement	Water	Super-plasticizer
1,088	780	616	196	23

2.4 Mixer Loading Sequence and Mixing

For each of the mixing method used, the sequences of loading various materials into the mixers were varied as follows:

2.4.1 Method 1 – (ACI/ASTM Method)

Approximately 10% of coarse aggregate and 1/4 to 1/3 of the mixing water were placed in the mixer drum to prevent materials such as sand and cement from packing in the drumhead. Sand and cement ware then added followed by 2/3 to 3/4 of mixing water mixed with liquid chemical admixtures and mixing was started. Remaining coarse aggregates were added, and mixing was continued. Remaining 1/4 to 1/3 of the water was added just before discharge.

2.4.2 Method 2 – (BS Method)

Dry mixing with half of the coarse aggregates and fine aggregates was started for approximately half a minute. Remaining coarse aggregates were added, and mixer allowed to run for between 15 to 30s. Half of mixing water was then added, and mixing continued for a total of 2 to 3 min. Cement was spread in a layer over the mixed aggregate and the remaining mixing water with liquid chemical admixture were added. Mixing was continued for 30 seconds to ensure proper uniformity.

2.4.3 Method 3 – (IS Method)

In this method, cement and sand were thoroughly mixed first in the mixer followed by fine and coarse aggregates. Mixing water mixed with admixtures were added and mixing was continued until a uniform color was obtained throughout the mix.

2.4.4 Method 4 – (PMC Method)

Mixing water and liquid chemical admixture were first added into the mixer. Cement was added and mixed thoroughly to make a uniform paste. Fine aggregates were added and mixed to make mortar. Coarse aggregates were then added, and mixing continued until the concrete mix was homogeneous.

In all the above methods, mixing was first done using an active (paddle) mixer and repeated using a rotating drum (passive) mixer. The two types of mixers used are illustrated in Figure 2.3.

(a). Active mixer. **(b). Passive mixer.**

Fig.2.3: Forced action (active) and rotating drum (passive) mixers.

2.5 Preparation and Curing of Test Specimens

A minimum of three samples from each batch were taken for testing for all the mixing methods. In total, 144 samples for compressive strength testing were prepared using both passive and active mixers. The specimens were cured in saturated lime water bath until the time of test.

2.6 Initial Workability

Tests on fresh concrete included slump and slump flow diameter for each mixing sequence which was noted in the beginning. This test was used to determine the rheological characteristics and check the consistency of fresh concrete by assessing amount of water added into the mix. Slump tests were carried out before cubes were cast. The spread of the concrete was measured and recorded.

2.7 Compressive Strength Test

Compressive strength of concrete was determined at 3, 7, 14, 28, 56, and 90 days according to procedures outlined in BS EN 12390-3. The consideration to test concrete strength beyond the 'standard' 28 days was based on recommendations by Tamimi & Ridgway [10]. The mode of failure for all specimen was also noted and an image record was kept.

3. Results.

3.1 Effect of Mixing Methods on Initial Workability

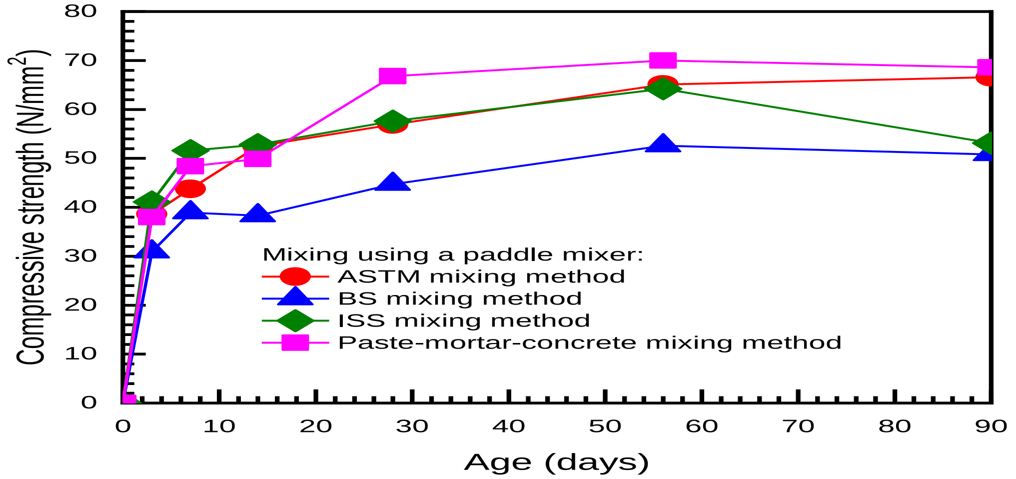
The slump obtained for all samples ranged from 35mm to 180mm as shown in Table 3.1. Paste-mortar-concrete (PMC) and IS methods gave improved results of workability over concrete prepared using ACI and BS mixing methods which exhibited poorer workability characteristics. The same trends were echoed in the results of flow table test. When BS and ACI methods were used, the resulting mix was slightly thick with sticky consistency. The PMC method resulted into concrete with a runnier consistency by the time mixing was complete.

Table 3.1: Effect of mixing method on initial workability.

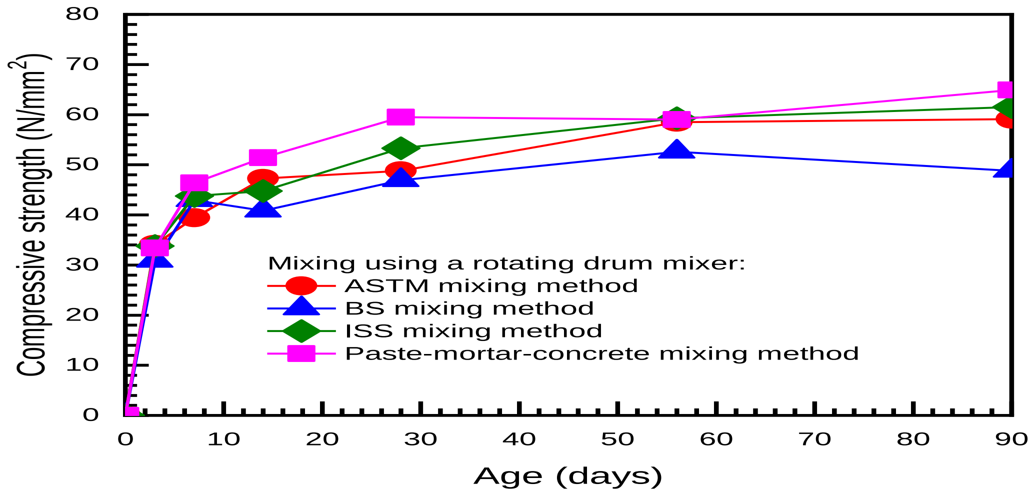
Method	Active mixer		Passive mixer	
	Slump (mm)	**Slump diameter** (mm)	**Slump** (mm)	**Slump diameter** (mm)
ACI/ASTM	70	475	50	335
BS	55	350	35	320
ISS	120	580	100	380
Paste-mortar-concrete	180	700	140	420

3.2 Effect of Mixing Methods on Compressive Strength

The Paste-mortar-concrete (PMC) method recorded highest compressive strength of 69.7 MPa at 90 days while BS mixing method recorded the lowest compressive strength of 53 MPa on the same day. In the early age of testing up to day 7, the results for ACI method very closely followed a similar format with the results for BS method. In the same manner, the trend of results for PMC and IS were similar. This shows that the mixing method of concrete influences the overall compressive strength with time. Concrete mixed using BS and ACI methods gained strength at a higher rate in the early age but slowed down after day 7 and 14 respectively. However, compressive strength increased for the two methods, albeit slowly, up to day 90 as shown in Figure 3.1.



(a) Active mixer.



(b) Passive mixer.

Fig. 3.1: Effect of mixing method on compressive strength.

3.3 Effect of Mixing Methods on Concrete Density

Concrete density results for samples prepared using various mixing methods are presented in Figure 3.3. PMC and IS mixing methods recorded highest densities of 2378 Kg/ m^3 and 2371 Kg/ m^3 on day 90 respectively. BS and ACI mixing methods had approximately the same value of density on day 90. The ACI and BS mixing methods gave results exhibiting similar trends except on day 28. However, the rate of density change with time for all the mixing methods was low at 12%. This agreed with findings by Shohana [17]. The slight reduction in densities for the PMC mixing method on day 7 was rather erratic and could be an outlier error caused by experimental variations.

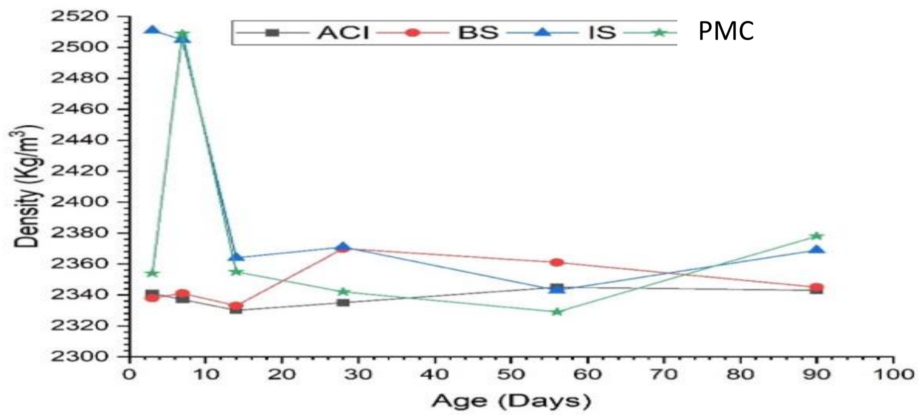


Fig 3.3: Average density of concrete mixed using various methods

4. Discussion.

The PMC method involved initial preparation of a homogeneous cement paste before adding aggregates. In this method, the mix was wet enough to allow the superplasticizer to act effectively and deflocculate cement grains prior to addition of the aggregate. However, when BS and ACI methods were used, the mix consistency was much stiffer implying that the deflocculating effect of the superplasticizer may have been inhibited leading to the low workability results. The low results could also be related to the possibility of poor interlocking between binder particles and coarse aggregate during mixing using the procedures outlined in the two methods [11], [12]. The results further show that IS and PMC methods produced by far the largest flow values. In the two methods, aggregates were added after cement and superplasticizer pastes hence minimizing loss of free water which enhances concrete fluidity. The tests also demonstrated that adding superplasticizer in the early stages of mixing ensued in adequate flow values agreeing with Abibasheer et al [13] and Tarek [6]. The improved workability exhibited by PMC method could also be explained by dispersion of concrete constituents with fine cement particles absorbing mixing water during the initial stages of mixing and later forming a lubrication zone around the aggregates in the later stages of mixing resulting in a more workable mix.

The PMC and IS mixing methods were somewhat similar as far as coarse aggregate charging into the mixer was concerned. This implies that compressive strengths were very much influenced by changes to the binder aggregate interface. In the case of PMC method, a rich paste of mixing water, admixture and cement promoted a more intimate mixing of all the particles with an improved efficiency of hydration. This resulted in more rapid strength development at early ages using the active mixer and eventually gave better overall strength results.

The results obtained agreed with observations made by Aitcin and Neville [14] that various pozzolanic materials in blended cements participate in different ways though at different rates in the hydration process and in creating bonds that determine the final strength of the concrete. A homogeneous paste therefore creates a good environment for particles blending to take place. In the case of BS method, aggregates were first added into the mixer followed by cement then mixing water and admixtures. This could explain the low strength results obtained since the interface between aggregates and cement paste was not strong enough. The weak bond formed between cement paste and aggregate resulted in lower values of compressive strength for the hardened concrete [15], [16].

In both mixers, PMC method of mixing in which a homogeneous paste was prepared before adding aggregates gave the highest density results. For the BS and ACI mixing methods which gave the lowest values of density on the same day, the sequence of mixing entailed pouring of aggregates in the mixer first, followed by cement and mixing water. This influenced the overall density of concrete drawing a close similarity with trends of earlier results for other concrete parameters investigated. Similarly, the results obtained using IS mixing method were 40% higher than ACI method on day 28. This could be explained by proper condensation of cement and sand which are thoroughly mixed before adding coarse aggregate in the case of IS mixing method [18].

In general, properly mixed concrete mix has better density due to ability of smaller particles fitting within the larger particles and bridging the voids during mixing process. Effective concrete mixing also enhances the pozzolanic reactions of nanoparticles from chemical admixtures further improving the filling effect and reducing pores for a dense concrete [19].

5. Conclusion

- Mixing methods significantly affect strength, workability and the overall rheological behavior of freshly mixed low water/binder ratio concrete. PMC method produced low water/binder ratio concrete which was homogeneous and having enhanced flowability.
- Influence of mixer type on strength characteristics of low water/binder ratio concrete was also noticeable in this study. From the results, it can be safely stated that the best mixer for workability and strength of low water/binder ratio concrete was the active mixer.
- The stage of adding various concrete constituents into the mixer, particularly water and admixture, was found to influence concrete properties. The clearest indication from the results obtained in this research was that incorporating additives at the start of the mixing process and latter adding aggregates was beneficial in achieving concrete with good strength characteristics.
- There is need for more investigation to quantify effects of parameters such as mixing time, mixer power, size of the batch during mixing on the overall characteristics of low water/binder ratio concrete.
- As a recommendation, the construction industry anticipates heightened post_ Covid 19 construction activities. There is need to emphasize on proper concrete mixing methods for small to medium scale construction projects. Adoption of the Paste-Mortar-Concrete method of mixing low-cement/binder concrete in low-to medium construction projects in Kenya will enhance realization of steady and sustainable economic development. The changeover from traditional mixing methods of concrete use will require retraining of various players in the construction industry and improving our research and teaching institutions. This will result in durable structures and reduced maintenance burden for investors with scarce resources.

Acknowledgement

During the writing of this paper the author consulted Prof. David Koteng' of Technical University of Kenya and Dr. John Mwero of University of Nairobi, Department of Civil & Construction Engineering. Their contribution is acknowledged with gratitude.

6. References.

1. Chang, P. K., & Peng, Y. N. (2001). *Influence of mixing techniques on properties of high performance concrete*. Cement and Concrete Research
2. IS 456 (2000): *Plain and Reinforced Concrete - Code of Practice*, Bureau Of Indian Standards.
3. ACI 304R-00 (2000), *Guide for Measuring, Mixing, Transporting, and Placing Concrete*, ACI, Michigan
4. BS 1881-125 (2013), *Testing concrete: Methods for mixing and sampling fresh concrete in the laboratory*, BSI, London
5. Aguwa, J.I. (2010). *Effect of hand mixing on the compressive strength of concrete*. Leonardo Electronic Journal of Practices and Technologies,
6. Tarek Uddin Mohammed, Tanvir Ahmed, Shibly Mostafiz Apurbo, (2017) *Influence of Chemical Admixtures on Fresh and Hardened Properties of Prolonged Mixed Concrete*, Advances in Materials Science and Engineering, vol. 2017
7. Neville, A.M. (2011). *Properties of Concrete*, 5th Edition. Pearson Education Limited, London
8. National Construction Authority, (2018). *Construciton Industry Policy*, *1st Edition*, Accessed from www.nca.go.ke
9. EN 197-1, (2000). *European Standard on Cement Part 1: composition, specifications and conformity criteria for common cements.* European Committee for Standardization
10. Tamimi, A. K., and Ridgway, P., (1996), *Effects of Two-Stage Mixing Technique on Strength and Micro-hardness of Concrete*, ACI Journal
11. Amr H. (2015). *Concrete Mix Design Methods Verification Study. Proceeding of Symposium on Mix Design and Quality Control of Concrete,* Cement and Concrete Association
12. Nuraan Ebrahim, (2017). *Using Superabsorbent Polymers in High Performance Concrete to mitigate Autogenous and Plastic Shrinkage while observing the Compressive Strength*, Faculty of Engineering,University of Stellenbosch, 2017
13. Abibasheer Basheerudeen and Sivakumar Anandan (2015), *Simplified Mix Design Procedures for Reinforced Self Compacting Concrete* Engineering Journal Volume 19
14. Aitcin, P. C. and Neville (1993), *High performance Concrete Demystified*. Concrete International, pp 21-26
15. Rana, N., Tiwari, A., & Srivastava, A. K. (2016). *High Performance Concrete and its Applications in the Field of Civil Engineering Construction*. International Journal of Current Engineering and Technology

16. Ferraris, C.F. (2001). *Concrete Mixing Methods and Concrete Mixers: State of the Art.* Journal of Research of the National Institute of Standards and Technology
17. Shohana Iffat (2015), *Relation Between Density and Compressive Strength of Hardened Concret*e, Concrete Research Letters
18. J Fládr, P Bílý, (2017). *Influence of mixing procedure on mechanical properties of high-performance concrete,* IOP Conference
19. Ferraris, Chiara (1999), *Measurement of the Rheological Properties of High Performance Concrete: State of the Art Report*, Journal of Research of the National Institute of Standards and Technology, Vol 104