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Mixture Proportioning Approaches For Self Compacting Concrete - A Review

Apeh J.A ,Okoli, G.O.
*Department of Building, Federal University of Technology, Minna,
** Department of Building, Faculty of Environmental Design, Ahmadu Bello University, Zaria
E-mail Id - *apehjoe@futminna.edu.ng, okoliog12@gmail.com*

Abstract

In the production and application of concrete, Mix design is a critical step. Many mix design methods have been proposed for Self – compacting Concrete (SCC); but these methods lacks a uniform criterion, specific design parameters of factors to evaluate their design process or procedures which makes it cumbersome to compare the effectiveness of these mix design methods and properties of SCC. This study is an in depth review on the mix design methods for SCC available in the literatures so as to evaluate progress made so far and thus provide valuable data to help select suitable mix design method(s) for SCC. On the basis of their principles, these approaches can be classified into five groups such as rational mixture proportioning method, compressive strength mixture proportioning method, aggregate packing mixture proportioning, statistical and rheology of paste model mixture proportioning method respectively. Each mixture proportioning method was discussed based on their procedure, pros and cons. To obtain high quality SCC with satisfactory properties, appropriate method should be chosen in accordance with actual situation.

Keywords – Concrete , material , segregation

INTRODUCTION

Self–compacting Concrete (SCC) is a high performance material which flows under its own weight without vibration to achieve consolidation by complete filling of Formworks, even when access is hindered by narrow gaps between reinforcement bars. This is due to its excellent deformability and cohesive enough to be handled without segregation or bleeding. In order to overcome the problem of vibrating concrete in highly congested reinforced concrete structures especially in seismic regions, SCC was developed first in Japan in the late 1980s. The durability of concrete Structures in Japan necessitates the requirement of adequate compaction by skilled labours. Consequently, the concept of SCC was first introduced by Okamura in 1988 or there about and then later developed (Okamura and Ouchi, 1999). Since its inception, it has been widely used in large construction in Japan, and has gained wide use in many Countries for different applications and structural configuration. Compared to conventional concrete, its advantages are numerous- Faster construction and reduction in labour cost, reduced Noise levels due to absence of vibration, improving filling capacity of highly congested structural members, improving the interfacial transitional zone between Cement paste and aggregate or reinforcement, decreasing the permeability and improving durability of Concrete, facilitating constructability and ensuring good structural performance (Shi *et al*, 2005; Shi and Wu, 2005).

Concrete mix design can be described as the selection of raw materials by optimum proportions to produce Concrete with required properties in fresh and hardened states for particular applications. SCC being different from normal concrete, has three key properties (Goodier, 2003): (1) Filling ability – the ability to flow into the formwork and completely fill all spaces under its own weight; (2) passing ability – the ability to flow through and around confined spaces between steel reinforcing bars without segregation or blocking; (3) segregation resistance – the ability to remain homogeneous both during transportation, placing and after placing. In addition to good self- compatibility, designed SCC also should meet the requirements for strength, volume stability and durability of the hardened Concrete at the same time (Liu *et al*, 2007). This has made SCC to be a research focus for many years as evidenced from the seven RILEM conferences and three symposiums on design, performance and use of SCC (Yu *et al*, 2005; Shi et al, 2009 and Shi *et al*, 2014).

The works of (Hu and Wang, 2011; Wang *et al*, 2014; Han and Wang, 2014) shows that factors like aggregate packing density, composition of raw materials, incorporation of chemical and mineral admixtures, water to cement ratio (W/C) and design methods significantly affects the properties of SCC in terms of rheology, strength, shrinkage and durability. Hu and Wang (2011) showed that graded aggregate could considerably reduce yield stress and viscosity of concrete. The work of Girish et al, (2000) also shows that increased paste volume could enhance the rheological properties of SCC. The consideration of these factors prior to starting the design mix process cannot be over emphasized. All mix design methods must ensure adequate yield stress and plastic viscosity of the concrete. Yahia et al, (1999) pointed out that a low yield stress is important for filling ability while high mortar plastic viscosity is needed for placement in highly congested sections and for mixtures with high coarse aggregate contents. High deformability can be achieved by limiting the coarse aggregate volume while segregation resistance can be achieved by controlling the mortar rheology through reducing the ratio of water to cementations' materials, increasing the powder content, or adding viscosity modifying agents (VMA).

Since sustainability is taking the center stage in construction now, waste materials such as fly ash (FA), rice husk ash (RHA), crushed limestone powder and waste glass powder can be used in the production of SCC as demonstrated by Shi et al (2004). Mermon et al, (2011) has reported the improvement in strength of SCC with increasing content of Super plasticizer (SP) when 10% RHA was incorporated. The work of Bouzuubaa and Lachemi (2011) has also shown that economical SCC could be developed successfully with 28-day compressive strength from 26 to 48 MPa with incorporation of 40 – 60% FA.

The principle of mix design is to select proper proportion of various materials so as to obtain concrete with workable fresh properties for casting and required functional properties especially strength and durability after hardening. Owing to a wide variety of raw materials used in SCC, various mix design methods or techniques are used in production of SCC. These methods can be broadly split between three approaches based on the method of achieving sufficient viscosity and segregation resistance: powder – type, VMA – type, and combination of powder and VMA type. In powder – type SCC, the powder content is high and W/P low. In VMA – type SCC, the powder content is reduced and the W/P is increased relative to powder – type SCC and a VMA is added to ensure segregation resistance. The paste volume, however may not change significantly between the two types. Combination – type SCC combines both moderately high powder content and the use of a VMA.

Owing to the complexity of SCC, many researchers all over the world have done a lot of work on its mix design. The work of Demone (2006) on the analysis of 68 case studies on mix design for SCC vary widely such that there is not a unique solution for any given application. The analysis found that coarse aggregate contents varied from 28% to 38 % of concrete volume, paste content varied from 30 to 42% of concrete volume, powder content ranged from 445 to 605 Kg/m^3, water- powder ratio ranged from 0.26 to 0.48 and fine aggregate content varied from 38 to 54 % of mortar volume. The majority of case studies used maximum coarse aggregate sizes of 16 to 20 mm. nearly all mixtures used some type of non- Portland cement powder with limestone powder the most common addition. In general the SCC mix design when compared to conventional, vibrated concrete were characterized by lower coarse aggregate contents, increased paste contents, higher powder contents, low water-powder ratios, high HRWRA dosages, and the use of VMA in some cases. Furthermore, a review of the work of the researchers on mix design of SCC shows that they proposed a variety of mix design methods based on different principles or control parameters. And for the mix design methods or guidelines used all over the world, there is a lack of uniform criterion, specific design parameters or factors to evaluate the SCC design process. This makes it cumbersome to compare to compare the effectiveness of different design methods and properties of SCC. This paper classified the mix design methods for SCC based on their design principles; The procedures, pros and cons of each method were highlighted and compared. This was done so as to review progresses made so far and thus provide valuable scientific data as a guide for selection of suitable mix design method(s) for SCC.

Mix design Methods

From literature, many mix design methods abound.. Domone (2009) in his work on proportioning of self-compacting Concrete developed a method – the UCL method. Petersson (1996) presented a model for mix design of SCC[1-11]. Su et al, (2001) on the other hand introduced a coefficient called the packing factor (PF) used to adjust the relative content of aggregates and pastes. Hwang et al, (2005) in their work on the effect of aggregate packing types on engineering properties of self compacting concrete developed an algorithm for a densified mix design, which was derived from the maximum density theory and excess paste theory. Saak et al, (2001) used rheology of paste model for the design of fiber – reinforced SCC. Ghazi et al, (2010) developed a new mix design method for SCC with specified compressive strength. Sebaibi et al, (2013) used the European standard (EN 206-1) to develop a new mix design method and so on[12-18]. Based on the design principles, these methods from literature were classified as follows: Rational mix design method, also known as empirical design method, statistical design of experimental approach, compressive strength method, packing method and rheology of paste model. These methods are discussed as follows:

Rational mix design method

A rational mix design method was proposed by Okamura and others (Okamura and Ozawa 1995; Okamura, 1997) which is a relatively simple method based on the principles of limited aggregate content, low water- powder ratio and use of s super plasticizer. The fundamental steps in the mix design procedure as stated by Okamura (1997) include:

1. Coarse aggregate content is fixed at 50 % of the solid volume of the concrete,
2. Fine aggregate content is fixed at 40 % of the mortar volume;
3. Water – cement ratio in volume is assumed as 0.9 to 1.0 depending on the properties of the cement and;

4. Super plasticizer dosage and the final water – cement ratio are determined so as to ensure sel-compatibility. In this rational design method, water – cement ratio is very low, 0.29 to 0.32 by mass corresponding to 0.9 to 1.0 by volume. Higher dosage of super plasticizer must be used to achieve higher deformability and moderate viscosity of the mortar as opined by Okamura (1997). Furthermore, in this method though easy to follow, no parameters describing the properties of aggregate is considered which makes it difficult to reach an optimal mixture proportion by this approach. Edamatsu et al, (2003) and Edamatsu, (1999) improved the method by fixing fine aggregate ratio, volumetric water-to-powder ratio and super plasticizer dosage. Compared with Okamura's approach, this method can be applicable to powder materials and aggregates of various qualities[19-25]. However, further work is required to characterize the properties of new materials, including the compatibility between powder materials and super plasticizers. Khaleel et al, (2014)'s method is similar to Edamatsu's approach, for self-compacting Metakaolin Concrete with coarse aggregates of different properties. Experiments were conducted on paste, mortar and concrete to facilitate the mix design process. The results indicates that this method is good in production of SCC with coarse aggregate of different qualities. This shows that the use of Metakaolin in concrete is not only a good choice for utilization of wastes and enhancing sustainability construction but also enhances properties of SCC. Domone (1999)'s method based on experience and understanding of the behavior of SCC was code named the UCL method. It estimated the mix design for a given set of required properties, then adjusted it by trial mixes. The mortar fraction of concrete was tested using spread and V-funnel tests to determine the water-to-powder ratio and super plasticizer dosage. In this method, only standard tests for fresh concrete are needed and other complicated tests such as rheology behavior of mortar or concrete are avoided. A significant advantage for the empirical design method is its simplicity. However, intensive laboratory testing is neede to obtain compatible behavior for available constituents and satisfactory mix design. Besides, changes in raw materials will need intensive re-testing and adjustments.

Statistical design of experimental approach

With this method, the effects of different key parameters such as the content of cement and mineral admixtures, water-to-powder ratio, volume of coarse aggregate, and dosage of SP e.t.c on workability and compressive strength of fresh and hardened SCC is determined. Reasonable ranges of each parameter are determined and the mix design for SCC is calculated in the same way as that of the mix design for conventional concrete. Khayat *et al,* (1999; 2000) selected five key mix design parameters that can have significant influence on mixture characteristics of SCC to derive statistical models. These five parameters used in their modeling include the contents of cementitious materials (CM), the ratio of water to cementitious materials (W/CM), the concentration of high-range water reducer (HRWR), the concentration of the viscosity enhancing agent (VEA), and the volume of coarse aggregate (V_{ca}). A $2^{(5-1)}$ statistical experimental design was used to establish models for describing relevant properties of SCC, including both the fresh and the hardened properties. The fresh properties were described by the slump flow, the rheological parameters including relative flow resistance and relative torque viscosity, the filling capacity, the V-funnel flow and the settlement. The hardened properties include 7-day and 28-day compressive strength. Thirty- two mixtures were used in their study to obtain the regression equations with the square of relative correlation coefficient, R^2 in the range of 0.76 (for the settlement) to 0.98 (for the relative toque viscosity). The advantage of the mix design using statistical models is that it can simplify the test protocol required to optimize a given mixture by reducing the number of trial batches needed to achieve a balance among mixture variables[26-28]. Establishment of statistical relationships needs, however intensive tests to renew the regression coefficients.

Sonebi (2004) in his work used statistical factorial model and designed medium strength SCC with fly ash. He used a factorial design to mathematically reflect the influence of five key parameters on filling and passing abilities, segregation and compressive strength, which are important for the successful development of medium strength SCC incorporating pulverized fuel ash (PFA); The parameter include the contents of cement and PFA, water-to-powder (cement + PFA) ratio (W/P) and dosage of SP[29-35]. The responses of the derived statistical models are slump flow, fluidity loss, Orimet- time, V-funnel time, L- Box, J- Ring combined to the Orimet, J- Ring combined to cone, rheological parameters, segregation and compressive strength at 7, 28 and 90 days. Twenty – one mixes were prepared to derive the statistical models, and five were used for the verification and the accuracy of the developed models. The results showed that medium strength SCC with 28 –day compressive strength of 30 to 35 MPa could be achieved by using up to 210 Kg/m^3 of PFA. For this type of method, a central composite response surface is the most commonly used approach. Some prior knowledge of both the materials to be used and the SCC proportioning is required to select the values of factors used in the experiment design such that all or most mix design exhibit SCC or near-SCC flow characteristics. Although the absolute values of the modeled responses may change when different materials are used, the general relative trends illustrated for a certain set of materials and proportions may remain consistent when a different set of materials is used (Ghezal and Khayat, 2002).

Compressive Strength Method

With this type of mix design approach, cement, mineral admixtures, water and aggregate content are determined on the basis of the required compressive strength. In their work, Ghazi et al (2010) proposed a mix design method that is straightforward for SCC which is based on ACI 211.1-91 provisions for proportioning conventional concrete combined with EFNARC method for proportioning SCC. For this approach, the coarse aggregate content depended on the maximum aggregate size (MAS) and fineness modulus of the fine aggregate. The water content wa determined on the basis of both the maximum aggregate size and concrete strength. The W/C and the water-to-powder volume ratios were determined by the compressive strength of concrete. Though the original ACI 211.1M method covers the design of compressive strength from 15 to 40 MPa, this method expanded compressive strength range from 15 – 75 MPa for SCC, with maximum W/C as shown in table 1.0 taken from the work of ghazi and Jadril, 2010.This method presents a clear and precise procedure to obtain specific quantities of ingredients and minimizes the need for trial mixtures. Also, the proposed method takes cognizance of gradation of fine and coarse aggregates or the contribution of pozzolanic materials to the properties of concrete. However, one of the draw- back is that it requires adjustments to all ingredients like sand, coarse aggregate, super plasticizer and water, to achieve an optimal mix design. it also requires the use of data from the works of other researchers.

Table 1: *SCC Compressive strength versus W/c*

Fc (MPa)	15	20	25	30	35	40	45	50	55	60	65	70	75
W/C	0.8	0.7	0.62	0.55	0.48	0.43	0.38	0.35	0.34	0.33	0.32	0.31	0.21

Particle packing

For this approach, the mixture proportion is obtained depending on 'the least void' between aggregates which is based on a packing model and then pastes are applied to fill the void between the aggregates. There are many packing models such as the compressible packing model (De Larrard, 1999), used for SCC (Sedran et al 1996; Sedran and De Larrard 1999). Particle packing is the concept of grading aggregates so as to attain an optimal degree of packing leading to an optimal use of materials. In the mixture proportioning for SCC, due to the high requirements for workability without vibration, the entire system of the cement-aggregates-fillers-admixtures must be taken into consideration. Many particle packing models used for mixture proportions for SCC abounds. The earliest ones include Fuller's model (1907) which is for continuous grading of aggregates and that of Furna (1931), used for coarse, medium and fine aggregates in normal concrete. These models became obsolete with the development of high performance concrete (HPC) and SCC. which has more complex mix design. Some packing models have been reviewed and modified for better application to concrete mixture proportioning. The work of Jones et al (2002) and others such as Stoval et al, (1986), Glavind et al, (1993) and De Larrard (1999) on packing models showed that there is need for more hands to be on deck in the development of fundamental models. Thus, it is not unconnected with the fact that most of the models used in concrete mixture proportioning is based on the assumed spherical particle shape of aggregates, which is quite apart in comparison to real aggregates, crushed aggregates in particular.

Mix design method based on aggregate packing

The mix design method on the basis of aggregate packing determines mixture proportions by obtaining 'the least void' between aggregates based on packing model first, then applying pastes to fill the void between aggregates. Petersson et al, (1996) developed a model for the mix design of SCC taking into account the least amount of paste based on the void content and the blocking criteria. The first step is to find the minimal paste volume from the mixture between coarse and fine aggregate by measuring the void contents for different combinations of coarse and fine aggregate using the modified ASTM C29/C29M. The minimal paste volume should fill all voids between aggregate particles and also cover all surfaces of the particles. The blocking model used by Petersson et al, (1996) is based on the work of Ozawa et al, (1992) in which the risk of blocking was computed by the linear summation of the effect of each single size of aggregate as in equation (1).

Risk of blocking = $\sum$ (ns $\sqrt{}$nsbi) $\leq$ 1 (1)

Where ns and nsbi are the volume ratio of a single- size group of aggregate to total volume of concrete and nsbi is the blocking volume ratio of the single – size group of aggregate to total volume of concrete. This method is notable for its importance but is not that easy to apply. It enables one to develop a mix design for a specific bar spacing with sufficient lubrication between aggregates. However, there are no adequate methods to justify uniformity of the mixture. Su et al, (2001) proposed a mix design method for SCC using a packing factor (PF). The typical consideration of the method was to fill the paste of binders into voids of loosely pilled aggregate frame work. The packing factor (PF) of aggregate is defined as the mass ratio of tightly packed aggregate to that of loosely packed aggregate. Thus the content of fine and coarse aggregate can be calculated as follows;

$W_{\delta} = PF \; X \; W_{\delta l} \; X \; (1 - s/a)$ (2)

$W_s = PF \; X \; W_{sl} \; X \; s/a$ (3)

Where W_{δ} is the content of coarse aggregate in SCC (Kg/m3); Ws is the content of fine aggregate of loosely piled saturated surface dry coarse aggregates in air (Kg/m^3); Wsl is the unit volume mass of loosely piled saturated surface –dry fine aggregates in air (Kg/m^3); s/a is the volume ratio of fine aggregates to total aggregates, which ranges from 50 to 57 %. This method is simple and uses a small amount of binders. PF determines the aggregate content and influences the strength, flow ability and self-compatibility. However, how to determine the optimum sand to aggregate ratio or the packing factor is not explained. These two values are assumed empirically to carry out the mixture design.

Rheology of Paste Model

The mix design method of Saak et al,(2011) based on rheology of paste model proposed that the rheology of the cement paste matrix largely dictated the segregation resistance and workability of fresh concrete, given a specified particle size distribution and volume fraction of aggregate. The applicability of the method is tested by measuring the flow properties of fresh concrete. Additionally, it is proposed that a minimum paste yield stress and viscosity must be exceeded to avoid segregation under both static 9rest) and dynamic (flow) condition, respectively.

CONCLUSION

From the literatures reviewed so far on the mix design methods for SCC, they can be categorized as rational, statistical, packing and rheology of paste volume model approaches. The following conclusions can then be drawn:

1. The rational mix design method is the simplest approach; However, to obtain limiting values for a possible linear optimization, large tests in laboratory is required. Furthermore, if there are changes in raw material properties, more tests will be required to renew the limiting values. Basically, it is a ‘trial and error’ approach.
2. Among the methods reviewed, the compressive strength method ls the only approach whose procedure is clear and precise to obtain specific quantities of ingredients and thus, minimizes the need for trial mixtures. Another advantage is that the gradations of fine, coarse aggregates and contributions of Pozzolanic materials to the properties of SCC are given due consideration.. However, its draw- back is that to achieve an optimum mix proportioning mixture, it requires adjustments to all the ingredients.
3. The aggregate packing method requires small amounts of binders because it mainly considers the relationship between paste and aggregate. However, SCC produced on the basis of this method tends to segregate easily, which is a challenge to construction.
4. The statistical models approach has the capability to making the test protocol needed for the optimization of a given mixture by reducing the number of trial batches required towards achieving a balance among mixture variables, provided, the statistical relationships are established. However, the hitch is with the establishment of such relationships which requires much laboratory tests and also additional tests will be required if there are changes in raw materials properties

for the renewal of regression coefficients.
5. The method based on rheology of paste model can reduce the laboratory work and materials, and provide the basis for quality control and further development of new mineral and chemical admixtures.

To obtain a high quality SCC, mix design is a critical step. For any good mix design method, the following should be considered:
1. Wide applicability
2. The variable raw material should be strong and robust.
3. Technical requirements are imperative
4. Sustainability and cost.

So far, none of the mix design methods reviewed has fully met these requirements. Hence, appropriate model should be selected to meet specified requirement(s).

REFERENCES

1. OKAMURA, H and Ouchi, M. (1999). Self-compacting high performance concrete; structural engineering international J., 6(4), 269-270.
2. 2.SHI, C. (2005). Design and application of self- compacting lightweight concrete, In: SCC 2005-China: Ist international symposium on design, performance and use of self-consolidating concrete. RILEM Publications SAR1, 2005.
3. SHI, C; WU, Y. (2005): Proportioning and properties of Self-compacting Lightweight concrete containing Glass powder, ACI Mater 2005; 102(5).
4. LUI, Y.H; XIC, Y; and LONG, G.C. (2007): Development of self compacting concrete. Chin Ceram Soc. 2007, 35(5), 671 – 678.
5. ATTIOGBE, E.K; SEE, H.T, DACZKO, J.A (2002): Engineering properties of self consolidating concrete. In: proceedings of the first North American Conference on the design and use of self – consolidating concrete, 2002 November.
6. BILLBERG, P, (2005): Development of SCC static yield stress at rest and its effect on the lateral form Pressure. In : SCC 2005, Combining the second North American Conference on the design and use of self-compacting concrete and the fourth international RILEM Symposium on Self-compacting concrete, 2005, 583-589.
7. YU, Z.W, SHI, C. KHYAT, K.H. PRO 42: 1st international symposium on design, performance and use of self-compacting concrete. RILEM Publications, 2005.
8. SHI, C. YU, Z.W., KHAYAT, K.H. PRO 65: 2ND international Symposium on design performance ans use of self-consolidating concrete. RILEM Publications, 2009.
9. SHI, C. OU, Z.H., KHAYAT, K.H. PRO 93: 3rd international Symposium on design performance ans use of self-consolidating concrete. RILEM Publications, 2014.
10. HU, I., WANG, K (2011). Effect of coarse aggregate characteristics on Concrete Rheology. Constr Build Mater 2011: 25(3); 196 -204.
11. WANG, X.H. WANG, K.I, TAYLOR, P. and MORCUS, G. (2014); Assessing particle packing based on Self- consolidating concrete mix design method. Constr Build Mater 2014, 70, 439-452.
12. YAHIA, A., TANIMURA, M; SHIMABUKORO, A; and SHIMAYAMA, Y. (1999): 'Effect of rheological parameters on Self-compatibility of concrete containing various mineral admixture'. Proceedings of the first international RILEM Symposium on Self-compacting concrete. Stockholm, Sweden, 523- 533.
13. SHI, C. WU, Y. and RIEFLER, C. Use of crushed stone dust in production of self- consolidating concretes. In: LUi

T. editors. Recycling concrete and other materials for sustainability development. ACI SP- 219. American concrete Institute Farmington Hills, MD 48333, May, 2004, p 115-129.
14. MERMON, S.A., SHARICH, M.A, AKBAR, H. Utilization of rice husk ash as viscosity modifying agent in self compacting concrete. Constr Build mater, 2011, 25 1044—1048.
15. BOUZUUBAA, N., LACHEMI, M., Self- compacting concrete, incorporating high volume of class F fly ash preliminary results. CEM CONC Res 2001.413-420.
16. DOMONE, P.L. (2006). 'Self-Compactiing concrete: an analysis of 11 years of case studies'. Cement and Concrete Composites, 28, 197 – 208.
17. DOMONE, P (2009): Proportioning of self –compacting concrete- UCL method, 2009.
18. PETERSSON, O. BILLBERG, P. and VAN, B.K. (1996): A model for self-compacting concrete. 1996.
19. SU, N, NSU, K, CHAI, H. A Simple mix design method for Self-Compacting Concrete. Cem Concr Res 2001.; 31(12); 1792- 1807.
20. HWANG, C. TSAI, C. Effect of aggregate packing types on engineering properties of Self-compacting Concrete. In: Zhiwu Yu et al editors SCC 2005- China : 1st international symposium on design, performance and the use of Self-compacting Concrete. RILEM Publications SARI, 2005.
21. SAAK, A.W., JENNINGS, H.M. SHAH, S.P. New methodology for designing self- Compacting concrete, ACI Mater journal, 2001, 98(6).
22. GHAZI, F.K., JADIRI, A.I. New method for proportioning Self-compacting concrete based on compressive strength requirements. ACI Mater J. 2010; 107
23. SEBAIBI, N. et al, Composition of Self-compacting Concrete (SCC) using the compressible packing model, the Chinese method and the European standard. Constr. Build Mater, 2013; 43; 382 -388.
24. OKAMURA, H. 'Self-Compacting High performance Concrete, Concrete International, July (1997), 50 -54.
25. EDAMATSU, Y. NISHIDA, N. and OUCHI, M. A rational mix design method for self-compacting concrete considering interaction between coarse aggregate and mortar pareticles. In: proceedings of the first international RILEM Symposium on self-compacting Concrete, Stockholm, Sweden, 1999.
26. KHALEEL, O.R, ABDUL, R.H. Mix design method for self- Compacting Metakaolin Concrete with different properties of coarse aggregate. Mater Des 2014; 53; 691-700.
27. DOMONE, P.L.; JUI, J. and CHAI, H.N. Optimum mix proportioning of Self-Compacting concrete ; In: innovation in Concrete structures: design and construction; proceedings of creating with concrete, university of Dundee, Dundee, Sept. 1999, 277-285.
28. KHAYAT, K.H. GHEZAL, A and HADRICHE, M.S.; 'Factorial design models for proportioning self-consolidating Concrete, mater strut, 32 (1999), 679-686.
29. KHAYAT, K.H. GHEZAL, A and HADRICHE, M.S.; 'Utility of statistical models in proportioning self-consolidating Concrete, mater strut, 33 (2005), 338-344.
30. GHEZAL, A.F and KHAYAT. K.H. (2002); 'Optimizing self- consolidating concrete with Limestone filler by using statistical factional design methods'; ACI Materials Journal, 99(3), 264- 272.
31. EFNARC: Specification and Guidelines for self compacting concrete, 2002.
32. SONEBI, M. Medium strength Self-Compacting concrete containing fly

ash: 'Modeling using factorial experimental plans' Conc Res 2004.; 34(7); 1199- 1208
33. STOVAL, Y. DE LARRARD, F. and BUIL, M. 'Linear packing density model of grain mixtures, power tech, 48(1986), 1-12.
34. GLAVIND, M. OLSEN G.O, and MUNCH-PETERSSON, O.'Packing calculations and Concrete mix design, Nordic Concr, Res. Publ no 13. (1993), 21 -34.
35. DE LARRARD, F. 'Concrete mixture proportioning: A scientific approach, E & FN Spon, 1999.