Scholarly Article Template

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This paper presents a mixture design method using the cementitious material for the design of concrete mixtures to assess early age strength and self-compactability. The proposed method adopted strength based mixture design method in addition to the packing theory to achieve target strength; enhanced durability and minimum paste volume. Packing theory was adopted to determine the aggregate proportions, binder paste is then filled in voids between aggregates to tightly pack concrete. The factors that influence the strength and durability of concrete are the amount of supplementary cementitious material (SCM), cement, and water. Compressive strength and water to cementitious material relationship were introduced depending on data from previous literature on concrete. Water to cementitious material ratio is used in place of water to cement ratio, early strength could be achieved in SCMs concrete. The optimal percentage of SCM for use in concrete was assessed using strength efficiency method. Using the proposed mixture design method, it was found that self-compacting concrete (SCC) made with an optimal percentage of metakaolin as SCM achieved the expected strengths of 60, 90 and 120 MPa at 28 days of curing.

# 1. Introduction

In recent years,SCC played the most significant role in construction industry. In early 1990’s Self compacting concrete with fresh and hardened properties were introduced in concrete technologyDomone[1].The property of SCC to flow in formwork by filling gaps, corners, around the reinforcement without the need of vibration or bleeding makes it significant to use Valcuende and Gómez[2].The use of mineral additiveis involved in development of SCCthat can be fly ash, silica fume, limestone filler; the powder composition for SCC should satisfy both performance and requirements at hardened and fresh state respectivelyEsmaeilkhanian et al. [3].

Metakaolin confirms to ASTM C 618 [], Class N pozzolan specifications Caldarone et al.[4].In construction industry metakaolin Al2Si2O7 is used as a SCMAkhras[5].It is a pozzolanic material that is used now days used as amineral additive in the development of SCCHubertova and Hela[6]. Generally, pozzolans such as fly ash, silica fume, ground granulated blast furnace slag (GGBS) are secondary products or by-products but metakaolin is a primary product Badogiannis et al.[7]. It is a thermally activated aluminosilicate material thatis produced after calcination of purified kaolinite clay at temperature of 700-8500C to form calcium silicate and calcium aluminate hydrate. It is a highly reactive material which contains SiO2 and Al2O3 in 50-55% and 40-45% respectivelyPoon et al.[8].

And flash metakaolin also to be discussed.

Metakaolin is a white powder, poorly crystallized material with an average size between 1.5 and 2.5 µm and specific surface area 12000 m2/kg Caldarone et al.[4].It is lighter in color which makes it suitably fit with concrete in aesthetics Dinaker et al.[9].As compare to silica fume, metakaolin has been claimed to have more engineering properties Caldarone et al. [4]. It has been reported that use of metakaolin refines the pore structure of cement paste matrix of concrete Ambrosie et al. [10]; Wild et al. [11]. Ample research has been reported for metakaolin and its properties such as compressive strength, shrinkage cracking, flexural strength, porosity and pore size distribution Khatib and Wild [12];Coleman and Page [13]; Curcio and DeAngelis [14];Sabir et al. [15]; Ding and Li [16].Moreover, texture of metakaolin is creamier, generates less bleed waterCaldarone et al. [4]; Balogh [17], it is considered sustainable material as it emits limited CO2 while production, while replacement with Portland cement, reduction in emission of CO2 was achieved Badogiannis and Tsivillis [18].There are a small number of studies reported on development of SCC using metakaolin. Strength efficiency of metakaolin for compressive strength(on rheological and strength properties) was studied earlier which showed that with the increase in replacement of metakaolin the compressive strength and other parameters increasesHassan et al [19]. From Dinakar 2014

In another studies, SCC attained very high compressive strengths at 28 days and 90 days. (Incomplete)

The primary restraint in development of SCC is the mixture proportion which can provide appropriate durability and mechanical properties. To avoid bleeding or segregation and for proper self-compaction, the paste must be fluid and viscous Yahiaa et al. [20]; Ye et al. [21]. The metakaolin act as pozzolanic material, during cement hydration it reacts calcium hydroxide and form C-S-H, aluminosilicate hydrates and calcium aluminate Caldarone et al. [4]. Moreover, particles of metakaolin acts as a filler material and fresh properties of SCCmixture can be enhanced by using adequate superplasticizerKumar et al. [22]; Vejmelková [23]; Madandoust and Mousavi [24]; Melo and Carneiro [25]

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2.

Nowadays, many researchers from various fields such as metallurgy, ceramics, concrete technology,etc. are attracted towards theory of particle packing. The theory is based on a concept of minimization of voids. In the field of concrete technology, particle packing is used to attain dense structure in concrete. It is a virtual stage where concrete is isolated and fully packed.The fresh and hardened properties of concrete are results of interaction between aggregates, cement, SCMs and/or mineral additives and superplasticizers. The size, shape and type of parent rock of aggregate plays a vital role for obtaining maximum packing density. The packing characteristics of one aggregate and its influence on the packing of mixture of aggregates are the bases for this method. To evaluate packing density, proper proportion of fine and coarse aggregates mixture is necessary. In this process, voids between coarse aggregates are filled by fine aggregates that will result in increase in packing density with minimized voids. Thereafter, reducing cementitious materials and water content.

*1.1.* **Review of earlierparticle packing based mixture design methods**

Mixture designmethod was first developed in 1995 by Okamura and Ozava[1] to attain self-compactability in concrete by keeping water to cement/powder ratio variable with fixedfine and coarse aggregates contents. Later this model was improved in 2003 by Edamatsu et al.[2], by fixing water to powder ratio, superplasticizer dosage and fine aggregate ratio. The methodology has been modified by various researchers with different models.In year 1996 a method based on blocking criteria was developed by Petersson et al.[3]in which concrete was considered as a solid aggregate phase in liquid paste phase, voids between aggregates were filled by paste formed of powder, water and chemical admixtureproviding lubricating coat between particles. A simple method was suggested by Su et al. [4]in 2001 based on packing factor in which quantity of fine aggregates increased but total content of aggregates including coarse aggregates decreased that lead to increased passing ability. Su and Miao[5] in 2003 prepared paste with fly ash and GGBS to fill voids between aggregates and achieved required strength and workability. Brouwers and Radix[6], 2005 suggested lowest powder contents in their study with the combinations of three sands, gravel, superplasticizer and slag blended cement, analyzed viscosity of slurry minimum with constant water content that resulted in tighter packing.Hwang and Tsai[7]in 2005 used densified mixture design algorithm (DMDA) approach in which fly ash was used as a fine powder to fill the voids between the aggregates. Hwang and Hung [8]in 2005 proposed a mixture design method for light weight concrete according to ACI 318[9] code which combines aggregate packing with lubrication technique. Sedran and Larrard[10]in 1999, presented the compressible packing model to determine virtual packing density for solid particles of varying sizes. In 2017, Chand et al used the compressible packing method (CPM) developed by Larrard[11]to determine packing density of recycled aggregate SCC without and with steel fibers. Sebaibi et al.[12]determined packing factor in 2013 usingcompressible packing model, the Chinese method and EN 206-1[13]standard was used to determine mixture design of concrete. Chen et al. [14]used densified mixture design algorithm in 2013 to analyze performance of concrete containing fly ash and slag with different water to cementitious materials ratios and different cement paste contents.Kandasan and Razak[15]in 2014 prepared mixture design with use of palm oil clinker aggregate as binder was prepared satisfying fresh and hardened properties of concrete. In another approach, Wang et al.[16]in 2014 improved particle packing approach and reduced paste quantity while maintaining quality and performance of concrete.

**2.** **Strength based design method**

There are number of classical mixture design approaches for SCC such as empirical method, statistical method, method based on rheology and particle packing method.However, no standard procedure is suggested in these methods to attain required strengthlike in conventional concrete. These methods gives general standards and guidelines on quantities of concrete ingredients and are based on trial mixtures to correct deviation in properties of fresh and hardened concrete. While designing SCC main focus was towards passing ability, segregation resistance and filling ability but fresh and hardened properties of concrete were generally not considered. Thestrength based design method gives clear standards and specifications to determine required strengths with variable mixture designs. Moreover, trial mixtures are minimized with the use of compressive strength methods.

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