Literature Review on Self Compacting Concretes Containing Metakaolin

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Abstract-*The cement and fine aggregate are the most commonly used materials for concreting, plastering and masonry work. The use of Metakaolin can be used as a partial replacement material for cement in the production of concrete where service environments, exposure conditions or life cycle cost considerations define the use of Self Compacting concrete. Metakaolin is used in concretes to improve the compressive, flexural strength and reduces the permeability of the hardened concrete. In this paper an overview on the literature on mechanical and durability behaviour of self-compacting concrete with partial replacement of cement by metakaolin is carried out based on recent research studies*

Keywords-Self compacting Concrete, Compressive strength, Split tensile strength, Durability, metakaolin

I. INTRODUCTION

Cement is the most commonly used material in concrete. Use of concrete is increasing day by day due to increase in the construction works. Usually Concrete is compacted by vibrations in order to expel entrapped air, making it denser and homogeneous because compaction is necessary to produce durable concrete. In location where heavy reinforcement is provided, compaction of concrete is very difficult and to provide proper compaction without segregation in such areas self-compacting concrete (SCC) is used. Self-compacting concrete (SCC) can be defined as a concrete which can be placed with its own weight with or without vibration. SCC facilitates proper filling and good structural performance of heavily reinforced congested members.

II. SELF COMPACTING CONCRETE

Self compacting concrete (SCC) was first developed in 1986 in Japan to achieve durable concrete structures . SCC is defined as a type of high performance concrete that gives excellent deformability in the fresh state and high resistance to segregation, and can be placed and compacted under its own weight without applying vibration. Due to its excellent deformability, low risk of blockage, and good stability to ensure high filling capacity of the formwork it is widely used in construction especially in places where heavy reinforcement is provided.

Durability properties of Self Compacting Concrete were evaluated by conducting various tests such as open porosity, sorptivity, water penetration test, gas permeability, carbonation resistance and electrical resistance etc. Durability of the cement concrete is defined as the ability to resist weathering action, chemical attack, abrasion or any other process of deterioration. The durability of a concrete structure is associated to the permeability of the surface layer, it shouldlimit the ingress of substances that can initiate or propagate possible deleterious actions .

III. REVIEW OF LITERATURE

3.1 Durability Study on concrete with Metakaolin

Badogiannis(1) et.al (2014) examined the durability of metakaolin based self-compacting concrete. In this study concrete was prepared by replacing cement with metakaolin. The properties such as open porosity, sorptivity, water and gas permeability and chloride permeability were evaluated in their study against control mix. Fresh properties of SCC such as slump flow value, V funnel and L box permeability testetc were evaluated. The effect of metakaolin as a replacement material had an enhanced effect in the chloride penetration resistanceand it did not enhance surface water permeability.

Ramezanianpour(2)et.al(2012) investigated the performance of concrete mixtures containing local metakaolin in terms of compressive strength, water penetration, sorptivity, salt ponding, Rapid Chloride Permeability Test (RCPT) and electrical resistivity at 7, 28, 90 and 180 days. In addition, microstructure of the cement pastes incorporating metakaolin was studied by XRD and SEM tests. The percentages of metakaolin replacing PC is at 0%, 10%, 12.5% and 15% by mass. The water/binder (w/b) ratios used in this study were 0.35, 0.4 and 0.5 having a constant total binder content of 400 kg/m3. Fick's second law of diffusion and crank's solution were used to determine the diffusion coefficient and the surface concentration. The following equation were used to determine the chloride concentration at different depths.

$\frac{dC}{dt} = D\frac{d^2C}{dx^2}$………………….. (1)

Where C is the concentration of ions as a function of distance x, at anytime t and D is the diffusion coefficient.

$C_{x,t} = C_0[1 - \text{erf}\left(\frac{x}{2\sqrt{Dt}}\right)]$…………..(2)

Where$C_{x,t}$is the chloride concentration at depth x and time t, C_0 is the chloride concentration at surface (x= 0), 'erf' is the error function and D is the diffusion coefficient .

The study concluded that concrete incorporating metakaolin have higher compressive strength and metakaolin enhanced the durability of concretes and reduced the chloride diffusion. The below mentioned figure shows a linear relationship between chloride permeability and compressive strength of concrete. The sorptivity test results showed that with the addition of metakaolin at 10% gives a better result.

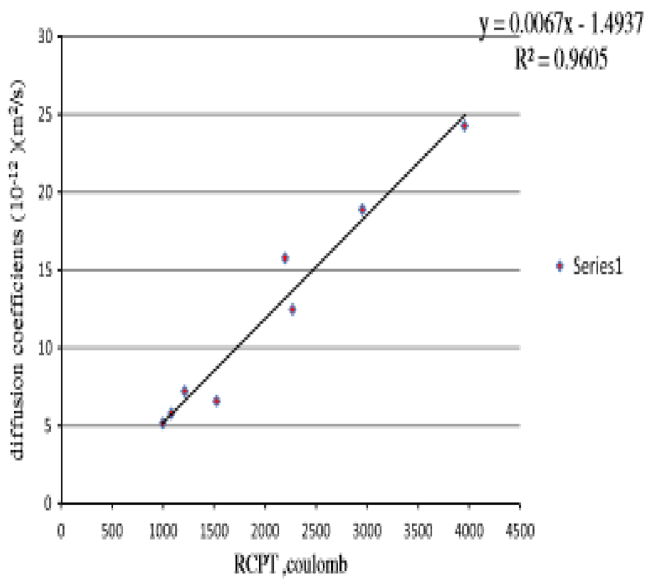

Fig 1. Correlation between diffusion coefficient and RCPT (Source: Ramezanianpour et.al (2012))

Kelestemur[3] et.al (2015) investigated the mechanical and physical properties of structural lightweight concrete (SLC) specimens produced by replacing cement with metakaolin (MK) at various percentages such as 5%, 10%, 15% and 20% w/w were examined, and the corrosion behaviour of the reinforcing steel bars embedded in these specimens were analyzed. Corrosion rates of the bars were determined by using galvanic current measurement method. Furthermore, the corrosion potential of the steel bars in these specimens was measured daily for a period of 90 days based on ASTM C876 standard test method. As a result of this study, it was found that the metakaolin improved the mechanical and physical properties of the SLC.

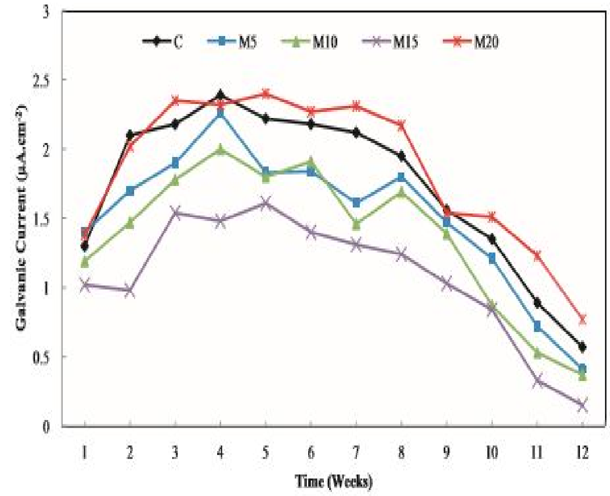

Fig 2. Changes in the galvanic current along with time (Source: Kelestemur et.al (2015))

Al-alaily[4] et.al (2016) investigated the concrete quality and time by maintaining the environmental conditions constant. Fifty-three concrete mixes were tested based on a refined statistical analysis. The authors proposed response surface method (RSM) to study the most significant factors that affecting the chloride diffusion at different ages. Bulk diffusion test was adopted for two years to determine the time-dependent coefficient m of chloride diffusion for all mixtures based on the error function solution to Fick's law. The investigation also includes experimental relationships between the rapid chloride permeability test (RCPT), chloride diffusion coefficient, and compressive strength results based on equation 3.

$D_{28}(m^2/s) = -4.484*\text{Ln}(f_c(\text{ MPa}))+ 21.28$ ….(3)

Equation gives the relationship between 28 day compressive strength and chloride diffusion coefficient

The results showed that the values of the chloride diffusion indicated a general reduction from 28 days to 760 days of testing when metakaolin is used as a partial replacementmaterial for cement.

Seshagiri[5] et al (2015) conducted a study on properties of self compacting concrete with metakaolin replacing sand with Granulated Blast Furnace Slag (GBFS). In the experimental work concrete was prepared by replacing cement with 38% of fly ash and 10% Meta kaolin whereas river sand was replaced with 40% GBFS. In the present experimental work M40 grade of SCC was considered. The study was conducted on different mix proportions with 0% GBFS and replacement of cement by 0% metakaolin, 40% GBFS and 0% Meta Kaolin, 40% GBFS and 10% Metakaolin with constant of 0.28% of fly ash and constant water/powder ratio of 0.38. The mechanical and durability properties such as compressive strength of cubes, cylinders, split tensile strength and water absorption were evaluated.The physical and chemical properties of GBFS are suitable for the production of concrete mix. The compressive strength and split tensile strength are higher for replacement of sand with 40% of GBFS and replacement of cement with 10% Meta Kaolin. The compressive strength and split tensile strength are lower for 0% replacement. The results showed that using metakaolin and increasing percentage of fly ash with GBFS made an improvement in the impermeability of concrete. Percentage of water absorption gradually decreased with the use of GBFS along with Metakaolin. The results showed that replacement of cement by metakaolin leads to decrease in pore space.

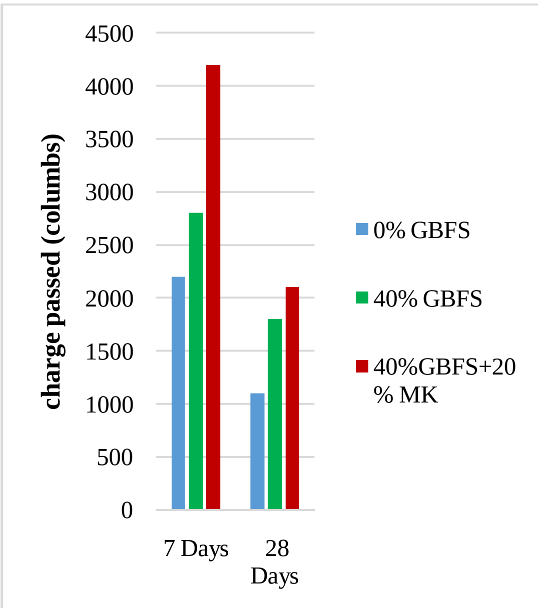

Fig 3 RCPT for M40 grade concrete
(Source: Seshagiriet.al(2015))

Singh[6] et.al conducted a study on carbonation and electrical resistance of self compacting concrete made with recycled coarse aggregates as a partial replacement material for coarse aggregate andmetakaolin as a partial replacement material for cement. In this study they prepared self compacting concrete by replacing natural aggregates with recycled coarse aggregates at 0, 25, 50, 75 and100%. To study the carbonation resistance of SCC made with recycled coarse aggregate, accelerated carbonation tests were conducted for an exposure periods of 4, 8, 12 and 16 weeks. Electrical resistivity tests was conducted by using four probe method. The results showed that compressive strength of SCC made by replacing natural aggregate with recycled coarse aggregate was rapidly decreasing with increase in recycled coarse aggregate content. With the addition of metakaolin the loss of electrical resistivity was compensated on account of replacing natural aggregates with recycled coarse aggregate.

Table 1. Durability property results of SCC with metakaolin

Sl.No.	**Author**	**Type of study**	**Duration(days)**	**Result**
1	Badog-iannis et.al (2012)	Open porosity	28	Highest reduction with 14% metakaolin
		Sorptivity	28	Increased upto 14% metakaolin
		Gas permebility	28	Decreased with addition of metakaolin
2	Kelestemur et.al (2015)	Ultrasonic pulse velocity (UPV)	90	Increase in metakaolin content increased UPV
		Sorptivity	90	Sorptivity decreased
		Porosity	90	Decreased porosity
3.	Seshagiri et.al (2015)	RCPT	28	Impermeability improved
		Water absorption	28	Decreased
4	Singh et.al (2016)	Carbonation resistance	120	Carbonation depth decreased with addition of metakaolin & increases with the addition recycled coarse aggregate
5	Al alaily (2016)	Chloride permeability and chloride diffusion	90	Decreased continouslyupto 25% metakaolin

3.2 Strength Properties on SCC with metakaolin

Ramezanianpour[1] et.al(2012) analyzed the performance of concrete mixtures containing metakaolin as a partial replacement material for cement in terms of compressive strength, water penetration, sorptivity, salt ponding. The mixes were prepared by replacing cement with metakaolin at 0%, 10%, 12.5% and 15%. The experimental work was conducted on different water/binder (w/b) ratios such as 0.35, 0.4 and 0.5 having a constant total binder content of 400 kg/m^3. From the studythey concluded that concrete incorporating metakaolin as a partial replacement material for cement at 10% have higher compressive strength.

Dadsetan[2]et .al (2017) investigated the mechanical and microstructural properties of SCC containing the supplementary cementatious materials such as metakaolin, and fly ash. Mechanical properties were evaluated against a control mixture. Microstructural properties were studied using SEM and XRD analysis. Mechanical properties of SCC were evaluated at different w/c ratios. Study shows that properties of SCC were improved with the incorporation of metakaolin and GBFS.

Siddique[3] et al.(2017) investigated the strength characteristics and micro structural properties of self compacting concrete containing metakaolina as a partial replacement material for cement and rice husk ash as a partial replacement material for fine aggregate. SCC mixes were prepared by replacing cement with metakaolin by weight in three proportions of 5,10 and 15% and fine aggregate were replaced by rice husk ash in percentages of 10, 20 and 30. The fresh properties tests such as slump flow, L-box, U- box and V- funnel tests etc. were conducted. Tests such as compressive strength, split tensile strength and microstructural analysis were conducted upto 365 days. The strength properties of SCC were improved by the replacement of cement with metakaolin and fine aggregate with rice husk ash.

Seshagiri[4] et al (2015) investigated the properties of self compacting concrete with metakaolin as a partial replacement material for cement and sand is replaced partially with GBFS. In the present experimental work M40 grade of SCC was considered. Here tests were conducted on specimens prepared by replacing sand by 0% GBFS and replacement of cement by 0% metakaolin, 40% GBFS and 0% Meta Kaolin, 40%GBFS and 10% Meta Kaolin with constant of 0.28% of fly ash at constant water/powder ratio of 0.38. The mechanical properties such as compressive strength of cubes, split tensile strength and water absorption etc were examined.The physical and chemical properties of GBFS are suitable for the production of concrete mix. The compressive strength and split tensile strength are higher for replacement of sand with 40% of GBFS and replacement of cement with 10% Meta Kaolin. The compressive strength and split tensile strength are lower for 0% replacement of cement and strength increased at 10% metakaolin which is used as a partial replacement material for cement.

Barbhuiya[5] et.al (2015) evaluated the microstructure, hydration and nanomechanical properties of concrete containing metakaolin. The properties of concrete containing metakaolin at 0%, 5%, 10% and 15% by mass of cement were studied for their compressive strength, sorptivity and carbonation resistance at two different water–binder ratios. He found that 10% of the Portland cement could be beneficially replaced with the metakaolin can improve the sorptivity and carbonation resistance of concrete. The microstructure properties of concrete were analyzed by using different analytical techniques such as XRD and MIP. Nano indentation studies were also carriedout on cement paste samples. The results showed that the incorporation of metakaolin modifies the cement paste.

Kavitha[6] et. al (2013) conducted a study to evaluate the e□ects of Metakaolin (MK) and Alkali resistant glass fibers on the performance of SCC. In this study rheological properties (such as L-Box, slump flow, T50), mechanical properties (such as compressive, splitting tensile and flexural strength), and durability properties (such as chloride ion penetration and water absorption) properties were investigated. It was observed from the test results that there was a reduction in workability with an increase in fiber content. It was found that glass fibers did not impart positive e□ect on the compressive strength of concrete. The split tensile and flexural strength of glass fibered SCC increased with increase in fiber dosage. The durability studies show that inclusion of GF marginally reduces the resistance to chloride ion and water absorption of concrete. With the addition of both metakaolin and Glass Fibre at optimal percentages on concrete can improve the mechanical properties and durability of self-compacting concrete significantly.

Chow[7] et al.(2014) investigated the microstructure, hydration and nanomechanical properties of concrete containing metakaolin as a partial replacement material for cement. The experimental investigation was carried out to evaluate the microstructure, hydration and nanomechanical properties of concrete containing metakaolin. The properties of concrete containing metakaolin at 0%, 5%, 10% and 15% by mass of cement were studied for their compressive strength, sorptivity and carbonation resistance at two different water–binder ratios. The sorptivity and carbonation resistance of concrete can be improved at 10% replacement of cement with metakaolin. In order to have a better understanding of the microstructure, hydration and nanomechanical properties various analytical techniques such as XRD, MIP and nanoindentation studies were carried on cement paste samples (with and without 10% MK). The results showed that the compressive strength was found to increase with an increase in the metakaolin content upto 10% replacement.

Table 2 Results of mechanical properties evaluated in concretes containing metakaolin

Sl. No.	Author	% replacement of metakaolin	Test results	
			Compressive strength (Mpa)	Split tensile strength (Mpa)
1	Ramezanianpour (2012) et.al	0	35.5	-
		10	41	
		12.5	40	
		15	40	
2	Chow et al(2014)	0	60	-
		5	62	
		10	64	
		15	66	
3	Dadsetan et al(2017)	0	40	-
		10	70	
		20	78	
4	Siddique et al (2017)	0	41.4	
		5	45.5	
		10	47.9	
		15	51.7	
5	Seshagiri et al (2015)	0	47	4.49
		10	54	4.66

Shepur[8] et.al (2014) conducted an Compacting Concrete by incorporating metakaolin and polypropylene fibre. The SCC was prepared by replacing cement with metakaolin at 10, 20 and 30%.mechanical properties such as compressive strength, flexural strength and split tensile strength were computed at 7 and 28 days. Results showed that compressive strength, split tensile strength and flexural strength were increased with the addition of metakaolin as a partial replacement material for cement. Optimum percentage at which metakaolin gives maximum strength is at 20%.

IV. CONCLUSION

In this paper a review on self compacting concrete containing metakaolin as a partial replacement material for cement is presented. From this detailed review it is revealed that

- Mechanical properties such as compressive strength, split tensile strength etc were improved by the incorporation of metakaolin as a partial replacement material for cement.
- Compressive strength of SCC was found to be more for the addition of 10% metakaolin by the volume of concrete.
- Durability studies on SCC containing metakaolin as a partial replacement material for cement showed that incorporation of metakaolin improve chloride penetration resistance, reduce the chloride diffusion and improves the impermeability of concrete and it also decreases the pore space.

The effect of sulphate on self compacting concrete were not examined and a study has to be conducted on SCC with metakaolin as a partial replacement material for cement to analyze its sulphate resistance behavior

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