CONSISTENCY, FLOW, STRENGTH AND DURABILITY (CFSD) ASSESSMENT ON CONCRETE USING SUPERIOR CEMENTITIOUS CONSTITUENTS

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This research mainly focuses on the durability of self-compacting concrete replaced with cement and Nano-metakaolin (NMK). NMK was prepared by heating kaolin at (760-780) °C sustaining for 2 hrs. NMK was used in this study by replacing cement by weight with 1, 2, 3, 4, 5 and 6 % individually. The optimal proportion of replacement of river sand by manufactured sand is 45 %. The consistency, initial and final setting of NMK were predicted and compared with ordinary Portland cement (OPC). Fresh concrete tests like slump flow, T_{50} cm, U Box, V-funnel, and hardened concrete tests like compressive tests were conducted at 7, 28, 60 and 90 days. Water absorption, Porosity test (Absorbency), Acid Attack, sulphate Attack, Indicator of Concrete's Capability to Attack Chloride Ion Penetration (RCPT) tests were conducted to observe the durability of Self-compacting concrete (SCC). From the analysis it is clear shown that addition of NMK increases with 7, 28, 60, 90 and 180 days compressive strength and the optimum level was found to be 4 %. The fissure width had diminished by the incorporation of Nanometakaolin while reducing the calcium hydroxide (CH) and mediating calcium silicates to calcium silicate hydrate (C-S-H). The final consequences of compressive strength, durability and flow property shows that 4 % of Nanometakaolin by weight of cement increases the workability, strength and compromises the durable properties.

Keywords: *Nanometakaolin, Self-Compacting concrete, Rapid chloride penetration test (RCPT), workability, Absorbency*

1. Introduction

Nano-metakaolin (NMK) acts as pozzolanic material with mechanical properties like compressive strength. NMK originates from kaolin rock and then thermal activation of kaolin clay is done at different temperatures for about 2 hours at (700-800 ^{0}C) is simultaneously crushed, ball milled for (40-60) hours and finally it acts as activator to support hydration process. It also fills in pores to increase strength properties and produce more C-S-H by absorbing calcium hydroxide ($CaOH_2$) crystals [1]. The multiwall carbon nanotubes (CNT's), Nano-silica (NS) and Nano-metakaolin (NMK) are used to improve mechanical properties of cement pastes. Some techniques like XRD, TG/DTG, and SEM analysis were done to explore the phase composition and the microstructure of concrete [2]. The preparation of concrete mix is done by replacing cement with 20 % Nano flyash (NF) and 10 % of Nano metakaolin following the concrete mix is added with 0.4 %, 0.8 %, 1.2 %, 1.6 %, 1.8 % and 2 % of activated carbon [3]. The replacement of Nano metakaolin (1 % by weight of cement) were consumed and variable among the mixtures were Nano metakaolin and SO_3 contents. From the results it is revealed that there is an optimum gypsum content present in sand (SO_3 = 0.5 % by weight of fine aggregate) [4]. The optimum percentage, the cement can be replaced with Nano-Metakaolin is observed to be 10 % to enable the compressive strength, split tensile strength and modulus of elasticity of concrete. Nano Metakaolin substitutes the cement at various percentages (2 %, 4 %, 6 %, 8 %, 10 %, 12 %, 14 %, 16 %, 18 % and 20 %) for cases like M20, M30, M40 and M50 grades [5]. The OPC-NMK mixes were made by the partial replacement of OPC by NMK (4, 6, 10 and 15 weight %). The fresh pastes were prepared with an initial water/solid (W/S) ratio of 0.27 by weight and is then hydrated for various time intervals. Few tests like X-ray diffraction (XRD), differential scanning calorimetry (DSC), scanning electron microscopy (SEM), free lime content, combined water content analysis was done to assess the property of NMK [6]. The optimal sacking temperature of MK is found to be 750 ^{0}C , thus produce Nano metakaolin and finest substitution of OPC named as NMK (750) was found to be 8-10 %. NMK (750) consumes more amount of calcium hydroxide gel and enormous volume of chemically contained water in all period of hydration. The SEM micrographs is obtained for the hardened OPC (93 %) and NMK (7 %) blended cement paste shows the formation of amorphous and microcrystalline C-S-H gel which fill the pores and produces more dense structure with higher hydraulic activity as compared to neat OPC paste [7]. Fresh concrete tests including slump flow, visual stability index, T_{50}, V-funnel, and L-box, were performed. Compression tests were executed to analyses the mechanical properties. The abbreviation of chemical compositions of cement, pumice and MK is given below:

$C = CaH = H_2OS = SiOA = Al_2O_3$ ---------- (1) [8]

$C_3S/ C_2S + H \rightarrow$ (fast) C-S-H + CH-------- (2) [8]

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Wherever C_3S and C_2S or cement react with water.

Water absorption, electrical resistivity, and rapid chloride permeability (RCP) tests were carried out to examine durability properties of concrete [8]. There is a variation in compressive strength and microstructure while adding fly ash-based geo polymer mortar with 14 M molar concentrations of alkali activator solution. The various substitution levels of NMK like (0 %, 2 %, 4 %, 6 %, 8 % and 10 % of fly ash) were considered. The mixture of sodium hydroxide (NaOH) and sodium silicate (Na_2SiO_3) in the ratio of 1:2:5 was taken as an alkaline activator solution. Geo polymer mortar with 4 % nano-metakaolin shows considerable development in compressive strength at all curing stages [9]. Mortars, in which cement was partially replaced with 0, 1, 2, 3, 4, and 5 % weight of Nano metakaolin and (10 -12) % MK were done. The compressive strength of mortar increases when the exfoliated NMK was found to be highly effective and concluded with the optimum replacement of NMK is 3 % [10]. The effect of nano-silica as a tallying on new concrete called (SCC) fresh properties like slump flow, U-Box test and J-ring tests were unwavering for hardened concrete properties like split tensile strength are reviewed. The consumption of micro-silica in unpredictable proportions like 5 %, 10 % and 15 % along with the suitable dosage of chemical admixtures were investigated. The result shows that 10 % Micro silica improved the workability to 3.8 %, the tensile improvement to 22.82 % [11]. The influence of Nano metakaolin on the fresh and mechanical belongings which is drawn from the tests like slump flow, T_{50} cm, L-Box, V-funnel, compressive and flexure strength. The consequence shows that the SCC with 5 % of NMK gives excellent increase in strength parameters and partial replacement by weight of cement [12]. Nano Silica gives high compressive strength concrete and delivers high workability with reduced water cement ratio [13]. Nano metakaolin substitutes the fine aggregates at various percentages 8 %, 10 %, 12 %, 14 %, for M60 grade and confirmed as per IS 10262 – 2009. A similarity between the cost of Normal Concrete and concrete with Nano Metakaolin is estimated [14].Cement content of 500 kg m^{-3} was taken into account, on the other hand the MK was used to replace cement by 5, 10 and 15 % weight to determine the fresh concrete properties tests like slump flow, T_{50} cm time, V-funnel flow times, L-box and blocking ratio were carried out [15].The faults occurring in concrete such as honey combing, segregation, voids, capillary can be overcome by using M-Sand for M-30 grade of concrete. Here concrete mixes with river sand were replaced by M-sand by a constant percentage and cement by metakaolin in various percentages such as 5 %, 10 %, 15 %, and 20 % to enhance compressive, split tensile and flexural strengths of concrete [16]. The partial replacement of cement has been done at 0 %, 3 %, 5 %, 9 %, 12 % and 13 % with Metakaolin (MK) and 0 %, 10 % (constant) with MP (Marble powder). The compressive and tensile strength of concrete made with MK-MP has been compared with conventional concrete of grade M30. Both compressive as well as split tensile strength achieved the optimized strength value of concrete at 9 % MK and 10 % MP [17]. The compressive and tensile strength is made to ascertain the properties of HPC M40 grade concrete by using metakaolin as partial cement replacement and quarry dust as partial fine aggregate replacement [18]. The Chapelle's method is one of the direct techniques to accomplish pozzolanic lime, the limited replacement considerations were taken as 10 %, 20 % and 35 % and 63 samples were measured [19]. The main objective of this investigational work is to study the variations in Consistency-Flow-Strength-Durability (CFSD) of concrete mix by partial replacement of Nanometakaolin (NMK) ($Al_2Si_2O_7$) as cementitious materials along with superplasticizer. Workability test is used to assess the flow ability characteristics of Self-Compacting concrete using Nanometakaolin.

2.Materials and methods

The ordinary Portland cement (OPC) 53 grades used in this research, conforming to IS: 12269-1987 [20] brought from STS traders, Coimbatore. The colour of cement was uniform Gray with light greenish shade and chemical composition of cement were listed in Table 1. Locally available river sand used as fine aggregate (FA) conforming to IS: 383-1987 [21] of size less than 4.75 mm. Coarse aggregate (CA) having size ranges from 0-12 mm and shape was rounded and graded. The physical properties of fine aggregate, coarse aggregate is listed in Table 2. Quarry dust (Manufactured sand) having specific gravity of 2.63 along with Bulk density of 15.1 kN/m^3 are used as partial replacement for river sand. The Special Cementitious materials (SCM) used in this study were NMK of Blaine surface area ≈ 25300 cm^2/g and of average dimensions of 195 x 110 x 16 nm. Specific gravity of Nanometakaolin was found to be 2.7.

Super plasticizer (SP) (IS 9103: 1999) [22] Fosroc Conplast SP 430 brought from Sri Sarovel Chemicals was used as a chemical admixtures for concrete mixtures to improve workability. Water the tab water having pH 6.20 is used in concrete. The viscosity modifying agent (VMA) is added in concrete to alter the rheological possessions of fresh concrete and optimum percentage of (1.2 % – 1.4 %) is maintained (12 -15 liters) normally added with water.

Table 1

Chemical composition of Cement and Nanometakaolin

Constituents/Materials	SiO_2	Al_2O_3	CaO	Fe_2O_3	MgO	SO_3	Na_2O	K_2O	MnO	LOI
OPC (%)	22.1	4.30	63.12	3.69	2.06	3.12	0.02	0.01	0.09	1.49
NMK (%)	60.6	35.6	0.05	0.40	0.06	0.25	0.08	0.10	<0.01	2.85

Table 2

Physical properties of Fine aggregate and coarse aggregate

Constituents / Properties	Maximum Aggregate (mm)	Specific Gravity	Bulk density (kg/m^3)	Fineness modulus	Coefficient of uniformity (C_u)	Coefficient of curvature (Cc)	Voids (%)
River sand	0 - 4.75	2.62	1409	3.76	2.39	1.25	46.29
Crushed stone	10 - 12	2.70	1569	7.20	3.33	0.91	42.10

Table 3

Compositions of different mixes and their designation

Materials/ Mix No.	**CM (%)**		**FA (%)**		**CA**	**w/c ratio**	**SP (%)**	**VMA (%)**
	C	**NMK**	**RS**	**MS**				
Z01	**100**	**0**	**100**	**0**	100	0.55	0.4	1.2
ZO2	100	0	55	45	100	0.50	0.4	1.2
ZO3	99	1	100	0	100	0.47	0.4	1.2
ZO4	98	2	100	0	100	0.47	0.4	1.2
ZO5	97	3	100	0	100	0.47	0.4	1.2
ZO6	96	4	100	0	100	0.47	0.4	1.2
ZO7	95	5	100	0	100	0.47	0.4	1.2
ZO8	94	6	100	0	100	0.47	0.4	1.2
Z09	97	3	55	45	100	0.49	0.4	1.2
Z10	96	4	55	45	100	0.49	0.4	1.2
Z11	95	5	55	45	100	0.49	0.4	1.2
Z12	94	6	55	45	100	0.49	0.4	1.2

3.Production of Nanometakaolin and microstructural analysis

Nanometakaolin was prepared from Metakaolin (MK) was slight off- white and purchased from Solvents chemicals industries by thermal activation of clay maintaining (760-780) ^oC in heating furnace for about 2 hours then crushed dried and ball mill technique is used for about (35-60) hours to reduce the particle size of NMK .The average particle size of 75-80 nm is maintained for NMK having the shape is spherical and regular.XRD study is carried out for metakaolin a pozzolanic materials to observe phase relationship between the particles. Based on database analysis, the metakaolin powder is analysed by XRD for samples like Y10, Y11, Y12 along with results shows that calcium hydroxide, silica content and water content were presented. In another set of samples, phase relationship like SiO_2 , CaO Al_2 and H_2O were found. The increase in proportion of adding metakaolin will increase in age of hydration, there will be slight decrease in Calcium hydroxide content at greatest level of metakolin. The CH consumed in the NMK increases with crystalline materials and amount of OPC consumes CH gel decreases in peak value of intensities for about 60 and 90 days of hydration. Finally, the compressive strength of concrete comprising metakaolin increases up to zenith level. It decreases due to over quantity of calcium content present in concrete merged with 26 % is the maximum strength obtained from test results compared to standard concrete. The results of Chapelle ‘s method is attained with one gram of lime (as mentioned in 19), the calcium utilization substance present in metakolin as source material tested with results 1g of Cao mg/g per sample (155 tests approximately) were seized from [19] and values obtained starts from medium to minimum value will be about 856-11 consistently. The outcomes clearly show that CaO consumption present in metakaolin rapidly increases constantly and both XRD analysis and indirect method is compared.

4. Mix proportion and behaviour of fresh SCC using NMK

Twelve similar mixes named (Z01-Z12) are casted for different types of proportions on durability of concrete are given in Table 3. The control mix was prepared for the M25 (Z01-Z02) grade concrete without cement replacement and partial replacement of M sand with river sand about 45 % respectively. In mixes (Z03-Z08), NMK was partially replaced with 1 %, 2 %, 3 %, 4 %, 5 % & 6 % with

Table 4

Mix proportion for SCC (kg/m^3)

Materials/ Mix No.		ZO1	ZO2	ZO3	ZO4	ZO5	ZO6	ZO7	ZO8	ZO9	Z10	Z11	Z12
CM	Cement	342	342	338.58	335.16	331.74	328.32	324.9	321.48	331.74	328.32	324.9	321.48
	NMK	0	0	3.42	6.84	10.26	13.68	17.10	20.52	10.26	13.68	17.1	20.52
FA	RS	1063	585.5	1064	1064	1064	1064	1064	1064	585.5	585.5	585.5	585.5
	MS	0	478.8	0	0	0	0	0	0	478.8	478.8	478.8	478.8
CA		836	836	836	836	836	836	836	836	836	836	836	836
Water		188	172	159	157.5	155.9	154.3	152.7	151	162.5	160.8	159.2	157.5
SP		1.34	1.34	1.34	1.34	1.34	1.34	1.34	1.34	1.34	1.34	1.34	1.34
VMA		12	12	12	12	12	12	12	12	12	12	12	12

weight of cement. Finally Mixes (Z09-Z12) river sand is partially replaced with manufactured sand and cement is replaced with NMK for about 3 %, 4 %, and 5 %. All the specimens are casted in the 150 mm cube.

Within the particle size and dosage range examined at all curing ages, the strength generally increases with the addition of NMK, the optimum percentage of NMK is (4 %) with 75 nm particle size gives the highest strength of SCC mixture. The water cement ratio and superplasticizers are used for about 0.47 and 4 % by weight of cement conforming as per IS 9103: 1999 [22]. Super plasticizer acclaims dosages of 12 gram per kg of OPC, which will reduce 32 % of water without loss of workability. The detailed mix proportions of SCC are prearranged in Table 4. In this experimental work, preliminary tests like consistency, initial and final setting time tests are done to predict the variations in adding cement paste with Nanometakaolin. Slump flow, T50 cm, V-funnel and U box tests were carried out to ensure that the mixes satisfy the requirements of SCC and hence all mixes were satisfied to the requirements of (EFNARC, 2005) [23]. To ensure the properties and durability of nano concrete, compression strength of cubes with optimum replacement of 4 % Nanometakaolin that has been immersed in water absorption test, Porosity test (Absorbency), HCL (Acid attack), Na_2SO_4 (sulphate test), Rapid chloride penetration test (RCPT) are done.

5.Results and Discussion

5.1. Consistency & Setting time of Nanometakaolin

The standard consistency value for normal cement is 30 %. Consistency value for 5 % NMK replacement gives 34.5 % and consistency value increases up to 42 % with replacement up to 6 %. Meanwhile consistency value for 4 % gives 31.2 % along with 3 % NMK produce 32 % consistency. There is a margin value between 3 % & 4 % replacements and satisfies IS 4031-4 (1988) [24]. The amount of water required to produce a cement paste of consistency with the cement that can be partial replaced with Nanometakaolin are performed. The initial and final setting time for normal cement paste would be 45 minutes and 510 minutes. By replacing 3 % NMK into cement the initial setting time was found to be 75 minutes while adding 4 % NMK gives 55 minutes. Up to 4 % the initial setting time to be decrease when the cementitious content percentage increases rather beyond 5 %, 6 % of NMK the value may be get increase maximum of 110 minutes. NMK percentage 3 % - 6 % of mixes showed less than 550 minutes of final setting time satisfies the standard. As per Indian standard (IS: 4031-PART 5-1988) initial and final setting time for the cement should not be less than 30 minutes and not more than 600 minutes [24]. Finally, the replacement data (Z06 and Z10) satisfies the IS requirements.

5.2. Fresh SCC tests

The slump-flow test is appreciated for signifying the capability of concrete to distort under its own weight in contradiction of friction. All SCC combinations unveiled acceptable tests like slump flow ranges from 650 mm – 800 mm, (2-5) sec for T_{50} , U funnel grab from 6 mm – 12 mm and U box lies with 0 – 30 mm as proposed by European federation dedicated to specialist construction chemicals and concrete EFNARC (2005). It can be clearly notice that replacement of NMK with cement tends to increase in flow ability in the range of 740 mm (mix Z06) compared with reference mix (Z01 & Z02) having slump value of 680 mm and 700 mm which shows valuable flow ability. Further increase the slump-flow diameter while adding NMK from (5 -6) % MK. With the addition of M sand with (mix Z10) exhibits good flow ability having value increased up to 755 mm henceforth flow diameter is increased wherever viscosity of concrete is decreased. The reference mix (Z01 & ZO2) reveals flow time for about 4.6 s & 4.5 s where sample containing cementitious mix (Z06 & Z10) shows nethermost flow time 2.9 s & 3 s, respectively. Commonly U box is developed to measure filling capability of SCC occasionally denoted as box shaped test and appropriate to extremely flow able concretes. For the replacement mixes (Z03- Z06), (Z07-Z12) & conventional mix (Z01 & Z02)

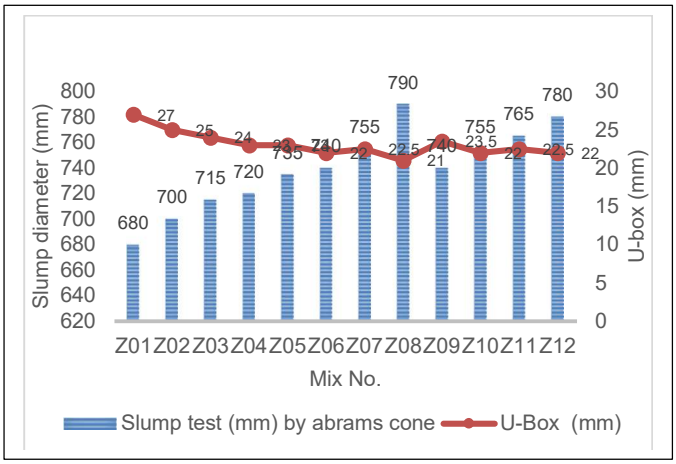

Fig 1 – Abrams cone Diameter (mm) versus Mix no. versus U-box (mm)

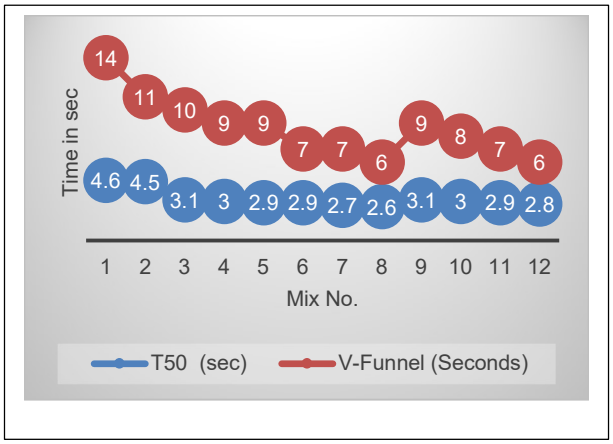

Fig 2 - .T_{50} (Sec) versus Mix No. versus V funnel (Sec)

difference between the heights was measured. The difference between the heights aimed at conventional mix was perceived to be 27 mm & 25 mm and for additional replacement mix was observed by 22 mm for (Z06 mix) and 22 mm for (Z10 mix). Along with addition of 4 % NMK gives greater flow ability which improves the transient ability of SCC.U box tests also meets the acceptance criteria [23]. The slump flow, U box resulted values were presented in Fig.1.The slump diameter influences 50 cm (T_{50}) was measured with 4 % replacement of NMK gives good workability and does not revelation segregation or bleeding during session and satisfies EFNARC specifications. The V funnel tests is done to estimate the filling ability of concrete in control specimens and specimen containing cementitious materials. The V funnel flow were measured as 14 s & 11 s for reference mix (ZO1 & Z02) similarly mix containing NMK measured as 7 s & 8 s (Z06 & Z10).It can be clearly observed that addition of NMK gives results in increasing flow ability confirms enlightening workability of SCC and fulfills the acceptance criteria .The Figure 2 clearly specifies the variance between T_{50} and V funnel (Sec) to measure the time in flow in terms of seconds.

5.3 Compression strength Test:

Concrete cubes of sizes 150 mm × 150 mm × 150 mm were tested in compression testing machine for crushing strength. Freight at which failure separated by area of segment gives the compressive strength of concrete. The cube compressive strength is calculated by using σ_c= (P/A) N/mm^2. Compressive strength tests were conceded out on the hardened (100 % replacement of OPC) and (1 %, 2 %, 3 %, 4 %, 5 %, 6 % replacement of NMK) of 7, 28, 60, 90 & 180 days. The compressive strength increases constantly from 7 days with increase in age of hydration up to 90 and 180 days depends upon mix proportions. Consequently, for the pastes containing 4 % to 6 % NMK (Z07 –Z09) a slender reduction in compressive strength was detected at the later age of hydration (90 and 180 days). The compressive strength increases by 14 % compared to control one for 90 and 180 days formerly there is a slight variation in 180 days. For mix made up (4 % NMK+ 96 % OPC) Z06 which gives increase in compressive strength. There is a slight drop in the strength of the SCC paste made of mixes having (6 % NMK + 94 % OPC) Z07 & Z08 mixes may fill the enduring amount of NMK which act as weaker interfacial plaster agent between aggregate and cement paste in concrete. The strength consequences are accurately represented in Figure.3. From the upshots it clearly shows that hydration age the strength increases with the NMK substitution up to 4 % and the decrease of the compressive strength while NMK (5-6) % is mainly due to over interfacial covering between cement and aggregate in SCC. As the percentage of NMK increases, strength gets increased while comparing to conventional part. NMK reacts with lime content Ca $(OH)_2$ enlightened during hydration of cement to produce C-S-H gel (conforming to SEM analysis) [8] especially appreciable in cementitious materials. NMK elements fill the voids and reduce passageway pores in concrete which results in microstructure of SCC concrete consistently increases strength in concrete. Hence, the concentrated enhancement in the compressive strength of the hardened OPC & NMK was found at 4 % NMK as a partial substituent of OPC. The optimum percentage of 4 % NMK were inveterate in compression testing machine as shown in Figure.4 The Multiple linear regression analysis for compressive strength of concrete cubes having replacement of cement by NMK and manufactured sand (mix Z01-Z12) cured for 7, 28, 60, 90,180 days are obtained and the value for Multiple R is 0.78881 and square of R is 0.622226 adjusted value is found to be 0.3074150 and standard error is 3.00060 for about 12 (Z01-Z012 mix) observations. The coefficient values for

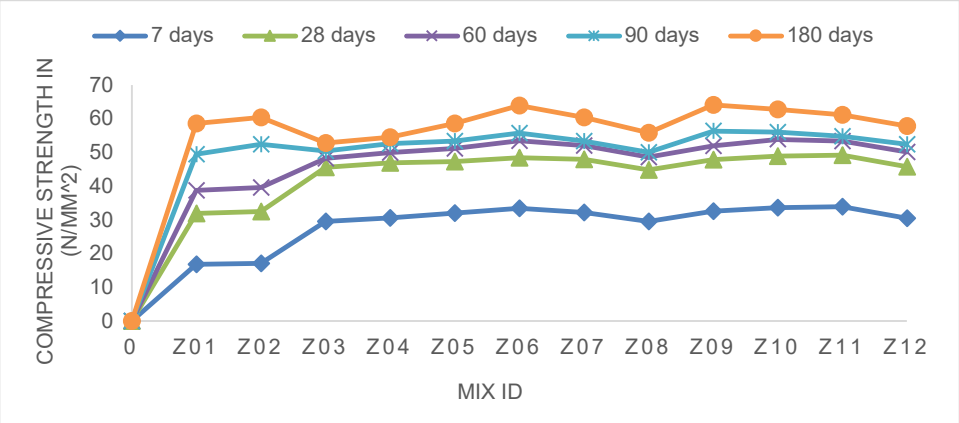

Fig 3 - Compressive strength versus Mix No.

Fig.4 - NMK with 4 % specimen testing in CTM.

Table 5

Multiple Regression analysis coefficients for compressive strength

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	37.504054	76.13408639	0.492605294	0.639796899	148.789	223.7974523	148.789	223.7975
7 days	3.27615097	4.521973451	0.724495844	0.496029654	7.78872	14.3410214	7.78872	14.34102
28 days	3.485697021	4.29383739	0.811790644	0.447911848	13.9923	7.020944576	13.9923	7.020945
60 days	0.821873708	2.665676822	0.308317085	0.768264774	-5.7008	7.344549916	-5.7008	7.34455
90 days	0.073542101	1.456231607	0.050501652	0.961361885	3.63681	3.489728277	3.63681	3.489728
180days	0.127487881	1.017897878	0.125246239	0.904419716	2.61819	2.363218501	2.61819	2.363219

compressive strength using multiple regression analysis is given in Table 5.

5.4 Water absorption test

The Water permeability tests was conducted for cube of size 100 x 100 x 100 mm. As per American society for testing and materials (ASTM 642:2006) [25], cubes were casted for all mix proportions, water cured for about 28 , 90 and 180 days are dried at 105°C.The weight of cubes were taken after specimen were permissible to cool at normal temperature and weighed. Yet again the specimen is engrossed in water and weighed, and percentage of water fascinated is determined by given formulations. Water preoccupation (%) = (W_2 − W_1) / W_1 x 100 (%) , Wherever W_1 = mass of oven dried sample (in terms of gram) W_2 = mass of surface dried sample (in terms of g). From the results it observed that water absorption values range from 1.95 % to 4.30 % for 28 days, 1.06 % to 3.5 % for 90 days and for 180 days 6.2 % reduction in water content while comparing to other two, respectively. The loss of weight due to cementitious materials (mix Z06) having very less water absorption to conventional part. With the addition of NMK with M sand (mix Z10), it was clearly notice that there is reduction in water absorption due to C-S-H gel was formed while associating to mix (Z01 & Z02). Apertures content is more in reference mix, but it stimulates the crusade of water. SCC containing gel was formed consistent through specimen which engages less amount of water in concrete and gratifies the specification.

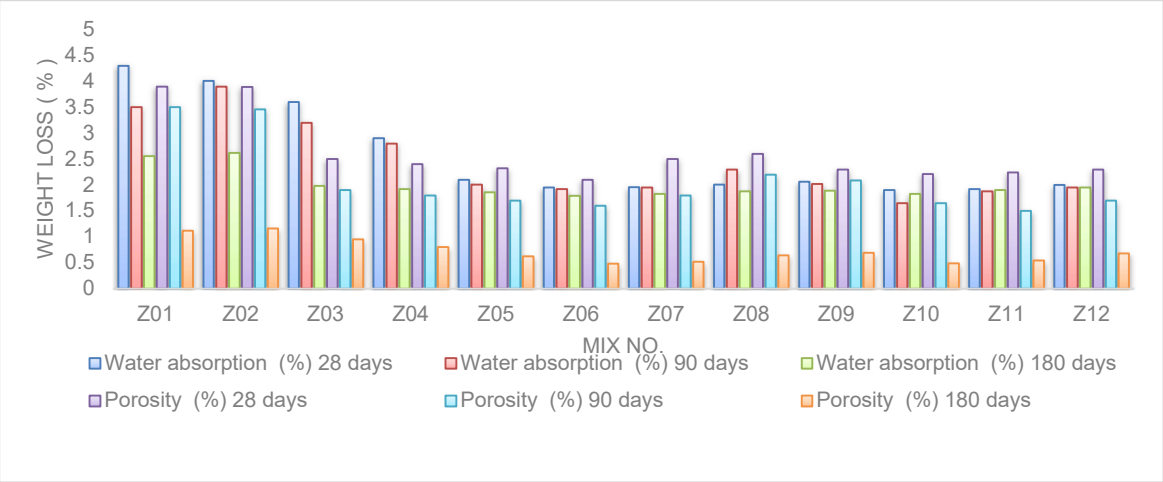

Fig.5 - Percentage of Water absorption & porosity versus Mix No.

5.5 Porosity test (Absorbency)

ASTM has delivered testing procedures for porosity in materials relating to concrete. The amount of aggregate that cannot hold to define arrangement and vulnerable to compaction. The high number of apertures present results in feebler in concrete strength. The percentage of pores present in total volume of concrete is measured by using this relation Porosity (%) = $\{(W_2 - W_1) / V\} \times 100$, Wherever W_1 – mass of oven dried section (in terms of g) W_2 – mass of surface dried section (in terms of g), V – Volume of the concrete model. For the conventional mix (Z01 & Z02) porosity value increased from 6.5 % - 7.9 % similarly pores space in concrete reduced while adding NMK as substituent of OPC. The Mix (Z06 & Z10) shows decrease in porous level for about 2.9 % -3.2 % correspondingly. The weight loss for water absorption and absorbency are given in Figure 5, perceptibly validations of results in terms of percentage. The results clearly show that however associating to conventional mix a smaller number of pores settled in concrete containing NMK.

5.6 Resistance against Acid Attack Test

The cubes of size 150 mm x 150 mm x 150 mm were casted and cured for 28 and 90 days. After 28 and 90 days of curing specimen with different percentage were taken out and allowed for drying for about 24 hours and after that weight were taken. Then cubes were immersed in 5 percentage of Hydrochloric acid for about 28, 90 and 180 days, respectively. Same concentration should be maintained during this period. After the interval period the specimen were taken out from hydrochloric acid solution dried and weights were measured. Finally, the percentage of weight loss are measured. From the test results, conclusion drawn for conventional concrete weight loss is more while comparing to cementitious materials. Meanwhile weight loss for conventional concrete with river sand and M sand are 4.63 % and 4.75 % for 28 days moreover 90 days 4.32 % and 4.46 % and for 180 days 3.86 % and 3.74 % respectively. The loss of weight for cementitious material containing NMK with optimum percentage of 4 % gives very less value comparing to other mix. Percentage of loss for mix (Z06) 2.24%, 2.02 % for 90 days and 1.68 % for 180 days and similarly for combination of manufactured sand gives better results than conventional percentage loss will be 2.23 % and 2.06 % for 28, 90 days and there is not much difference in the mix from Z09-Z12 for 180 days due to silica content expose to atmosphere conditions confirming [6 & 18]. Figure 6 obviously confirms the weight loss for acid and sulphate attack in terms of percentage. Calcium hydroxide crystal binds the property of specimens to form CSH gel in concrete and it clarifies that NMK increase the durability of concrete.

5.7 Resistance against Sulphate Attack Test

The confrontation of concrete to sulphate incidences was premeditated by determining the loss of compressive strength of 150 mm size after 28, 90 and 180 days of water curing and then dehydrated in sunlight for one day were engrossed in 5 % Na_2SO_4 and 5 % $MgSO_4$ added water for 28 ,90 and 180 days separately. After the break period the specimen were taken out from solution desiccated and weights were measured. Finally, the percentage of weight loss are measured. The tests consequence of acid tests and sulphate attack are inculcated in Figure.6. From the trials results weight loss in conventional concrete is more comparing to supplementary cementitious materials. From (Z03 - Z05) and (Z07-Z11) there is increase and decrease before and after optimum level reaches indicates clearly and compared to conventional concrete. For cementitious mix (Z06 & Z12) loss of weight found to be 1.95 %, 1.90 %, 0.98 % for 28, 90 and 180 days. The percentage of loss for conventional mix (Z01 & Z02) found to be 4.30 % , 3.50 % , 2.12 % for given 28 , 90 & 180 days and there is very less amount of water seepage in concrete containing

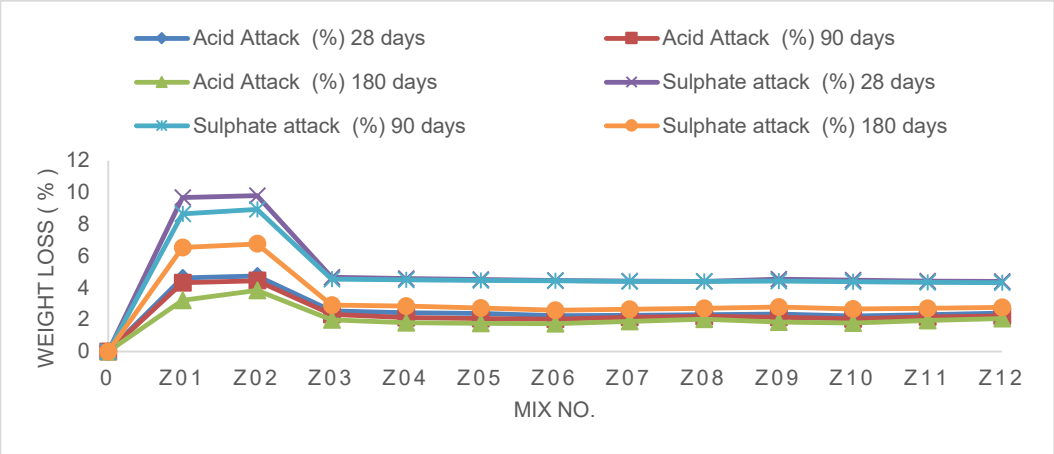

Fig. 6 – Weight loss of Acid attack & Sulphate attack versus Mix No.

Table 6

Chloride Permeability Based on Charge Passed (per ASTM C1202) [24]

Charge Passed (coulombs)	< 100	100-1,000	1,000-2,000	2,000-4,000	> 4,000
Chloride Ion Penetrability	Negligible	Very Low	Low	Moderate	High
Mix ID	Z01 & Z02	Z03	Z04	Z05	Z06
Charged passed (coulombs)	1698 (Low) & 1509 (Low)	712(Very low)	584(Very low)	502(Very low)	455(Very low)
Mix ID	Z07& Z08	Z09	Z10	Z11	Z12
Charged passed (coulombs)	488(Very low) & 512(Very low)	526(Very low)	460(Very low)	590(Very low)	639(Very low)

NMK and M sand . The property of specimens binds calcium hydroxide crystal form CSH gel in concrete and simplifies that NMK upsurges the durability of concrete.

5.8 Indicator of Concrete's Capability to Attack Chloride Ion Penetration (Rapid Chloride Permeability Test)

The standard method used to govern chloride permeability of concrete is RCPT and was implemented by American Association of State Highway and Transport Officials (AASHTO) and the technique is given by ASTM C1202-19 [26]. Chloride ion penetration was carried out for 90 days, respectively. The customary samples of size 100 mm in diameter and 50 mm thick concrete specimen are passed to 60 V DC voltage for about 6 hours. In one end the sample is dipped in 0.3 molarity of Sodium hydroxide (NaOH) solution and other end 2.4 Sodium chloride (NaCl). The samples were retained between the cells without any airgap and wrapped fully to seizure leakage of chemicals solutions. The percentage reduction in chloride ion diffusion for dissimilar replacement levels of cement with NMK was compared with conventional one. Chlorides infiltrate free from concrete like capillary preoccupation, hydrostatic burden, dispersal, and evaporative conveyance. The total amount of charge passed, in terms of coulombs, was used as a pointer of the confrontation of the concrete to chloride ion permeation. Total charge conceded is firm and progression the concrete according to ASTM C 1202 are mentioned. Current elegant through one cell is calculated by using in relations of coulombs trapezoidal imperative as given by ASTM C 1202 are I = 900 x (Io + i360) x 2 x (Icumulative) coulombs.

$$C_{cumulative} = I_{30} + I_{60} + I_{90} + I_{120} + I_{150} + I_{180} + I_{210} + I_{240} + I_{270} + I_{300} + I_{330}$$

I = charge conceded in terms of coulombs, I_0 = current (amp) instantaneously after voltage is applied

I_t = currently (amp) at t minutes after voltage is smeared

The Table 6 clearly shows that NMK content present in concrete using both river sand and manufactured sand where chloride penetration is less. SCC with NMK with or without river sand prevents corrosion hence it is reacted with calcium hydroxide crystal present in concrete forms C-S-H compound gel which gives reduction in permeability and increase durability of concrete. From the consequences observed that when age increases, the chloride penetration decreases. The quality of concrete is lower, the current at which the given voltage is greater where energy produced is more. Graphs are drawn between RCPT values (charges passed in coulombs) and percentage replacement of cement (Mix id) with Nanometakaolin as shown in Figure 7.

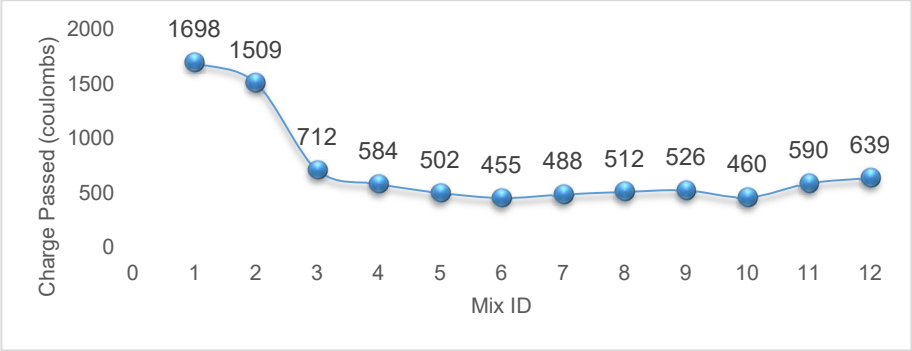

Fig. 7 – Rapid chloride permeability charged passed (Coulombs) vs Mix No.

6. Conclusion

The Persistence of this work is to regulate the effects of addition of Nano metakaolin to the concrete mix.

1.To measure the consistency of NMK, 31.2 % for 4 % optimum gives good results while comparing to standard OPC, initial and final setting of NMK comes under the limit which is better substituent replacement of Ordinary Portland cement.

2.The workability of concrete as measured from sump flow, T_{50} cm, V-Funnel and U Box tests as optimum percentage of NMK in concrete increases. As likened with conventional mix (Z01 & Z02) has a reduction in slump flow where workability of concrete decrease as optimum percentage of NMK in concrete increases.

3.The U Box tests done to know the passing ability of SCC with addition of 4 % NMK (Optimum percentage (Z06 & Z10) gives better workability without any segregation and practical difficulties.

4.While adding cementitious materials in SCC concrete from 1 % to 6 %, the compressive strength of concrete for 7, 28, 60, 90 & 180 days increases with increase in NMK content for 4 % and there is a trivial decrease in strength for ratios of 5 % And 6 %. The compressive strength of concrete cubes increases by the accumulation of NMK acts a pozzolanic materials and proves better results compared with control mix (Z01 & Z02).

5.Resistance against water absorption and porosity of concrete decreases in NMK from 1 % to 6 % for 90 and 180 days. The loss of weight in terms of percentage is calculated where else weight loss factor for conventional concrete is 1.15 % and NMK as 0.02 %. It was also observed that replacement of cement with Nano Metakaolin showed reduction in water assimilation and hence porous in nature.

6.Resistance against acid and sulphate attack shows better results, the loss of weight for acid attack will we be reduced to 3.26 % for 90 and 180 days and similar to sulphate attack the weight loss will be 2.94 % (Z06 & Z10) while comparing to conventional part.

7.The electrical resistivity of mix Z06 (96 % OPC+ 4 % NMK+ 100 % river sand) over 100 % higher than that of the conventional mix, and other hand Z10 (96 % OPC 4 % NMK + 45 % manufactured sand + 55 % river sand) are also compared with conventional part.

8.The dragging of NMK resulted in a very slight decrease in the density of mixes (Z03-Z12) comparing to conventional mixes.

9.The auxiliary of cement by NMK occasioned in a slight reduction in the water absorption (Z04-Z08) capacity of all mixes

10.In addition, the refined pore structure of NMK blended SCC shows reduced permeability (Z06 & Z10) and slows down ingress (Z07-Z09) & (Z11-Z12) of harmful chloride ions.

11.NMK alters the pore structure of concrete greatly and thus improves the resistance to the transportation of water and diffusion of chloride ions, which leads to degradation of the matrix. SCC containing 4 % NMK exhibited excellent durability to acid attack, sulphate attack, chloride penetration and water permeability.

12.The maximum strength is obtained by interpolating 4 % of NMK. This is the optimum percentage of NMK available to react with calcium hydroxide which accelerates the hydration of cement and forms C-S-H gel.

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