PERFORMANCE OF RC COLUMNS CURBED USING COLD FORM STEEL (CFS) CONSUMING NANOMETAKAOLIN AS CEMENTITIOUS RESOURCES

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The structural recital of axially loaded concrete containing Nano metakaolin (NMK) in filled steel composite columns is investigated. The ratio of height and breadth of the specimens are kept constant as 6.25 and M_{20} grade of concrete is used. The width to depth ratio is assumed to be taken as 1.00, 1.25, 1.50, 1.75 and 2.00. The foremost constraint of the task is to study the effectiveness of concrete in filled steel hollow sections with bolted connection incorporating NMK as cementitious substantial. The columns examined are different in cross-sectional dimensions. The axial load is provided to the core concrete alone and the behaviour of the confined cold form steel is studied, and axial load of reinforced concrete column and confined columns are compared. The optimal percentage at which cement can be substituted with Nano-Metakaolin is found to be 4 % and XRD analysis is carried out to predict the pozzolanic activity of cementitious materials. Also, consequences show that the column with greater cross-sectional area had higher load carrying capacity of about 33 kN while comparing to reinforced columns.

Keywords: *Metakaolin (MK), Nano Metakaolin (NMK), Cold-formed steel (CFS), Hat section, In-filled, Columns, Axial load*

1. Introduction

Researches recently challenge to reduce the environmental hazards caused by construction industry. Among those new attempts is to use green and available supplementary cementitious materials to reduce the negative consequences after cement manufacture. One of those supplementary on hand is Metakaolin. In the last few years, many studies have bean ran to find out the enhancement in the mechanical properties of the fresh and hardened concrete mix contains MK and its optimum dosage. However, studies of the structural routine of various reinforced concrete structural elements comprise MK are ongoing. The consequences of spatial distribution of lightweight aggregates (LWAs) on internal curing of concrete in replacements for normal aggregates, different sizes and amounts of natural pumice as LWAs were used as water reservoirs to provide internal curing in mitigating autogenous deformation [1].The ultimate aim is to construct structures without affecting the strength of concrete and taking this into account different admixtures have been used in concrete and provides a detailed review of various studies on concrete with admixtures over the years [2]. A survey of different waste material used in the concrete has been included in this work for gaining better knowledge regarding the effect of different waste materials on the properties of concrete. To achieve good strength, workability, and durability of concrete, we must partially replace all the material in concrete [3]. Supplementary cementing materials (SCM) have occupied an integral part of concrete mix design where else some of the commonly used SCM are fly ash, silica fume (SF), GGBS, rice husk ash and MK [4]. The cement blended with MK is also required as an alleviation to reduce the amount of CO_2 generation. [5]. Metakolin, a highly reactive pozzolona, reacts with the excess calcium hydroxide resulting from hydration of cement and produces calcium-silicate-hydrate (C-S-H) and calcium alumina silicate hydrates [6]. Cement Replacement Material (CRM) like Metakaolin is generally a new approach. It is found that partial replacement of cement with Nano -Metakaolin has a greater influence on structural elements to initiate initial crack, ultimate load, maximum defection, and toughness [7]. For each of grades of concrete, 10 %, 20 % and 30 % of cement was replaced with NMK. The particle size of nano-cement was determined using a Scanning Electron Microscope (SEM) [8]. The indirect method and direct method like Chapelle's method be appropriate to the determine the reactivity of pozzolanic lime utilizations. The greatest method is Chapelle's method to arrive lime pozzolan reaction which is used popularly in cement industry. The partial substitution levels were taken into an account of 10 %, 20 % and 35 % at the same level of Blaine fineness, having 63 samples in account [9]. The effect of fire flame exposure with different intensities of firing on the mechanical properties of a high strength concrete (HSC). Two types of coarse aggregate were used as natural crushed gravel and crushed dolomite rock with maximum size of 14 mm [10]. This cement content should be replaced with by-products like Micro-Silica (MS) to avoid the risk of greenhouse effect to some extent. The utilization of micro-silica in varying percentage like 5 %, 10 % and 15 % along with the appropriate dosage of chemical admixtures were experimentally investigated [11]. Modern construction makes use of a composite column

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called Concrete infilled steel tubular section (CFST). CFST column system is known to be the satisfied and most successful system, and the confinement of concrete by steel tubular sections amplifies the core's strength [12].

The comparison of experimental results with numerical analysis by application of ANSYS on the buckling behaviour of medium height light gauge steel rectangular hollow column and in-filled column with plain cement concrete and steel fiber reinforced concrete subjected to concentric and eccentric loads [13]. Compressed stabilized earth blocks (CSEBs) are in comparison with new earth-based materials like rammed earth, adobe, and bricks. In addition to this, CSEBs can overcome the issues of fired bricks. The stabilizers were sort out with Lime percentages of 5 %, 10 %, and 15 % by weight [14]. Concrete-filled hollow steel sections are known to be more and more often used as compression members in structures these days. To explore the effect of high-volume replacement level of cement with fly ash on the strength of concrete filled steel tubular short columns. The replacement for cement or as an additional cementations material in concrete can be done with Fly ash. [15]. The behavioral performance of the square concrete-filled cold-formed steel tube (CFST) columns under axial cyclic loading. The analytical results were observed to be fairly close in agreement with experimental results in terms of buckling mode, load-deformation response, the tension capacity and the decreasing compression capacity under cyclic load when considered [16].Clay pozzolan is produced as a supplementary cementitious material by the common and usual method in which clay is treated through calcination process at high temperature [17].The absolute energy parameter in the assessment for establishing the damage level in Reinforced concrete RC structure. This primary issue being addressed, it is believed that this study can further help in improving the effectiveness of the AE technique for Structural Health Monitoring (SHM) in civil engineering [18]. Cold-formed steel (CFS) sections can be designed in many configurations and the outcome is found to be more efficient in comparison with hot-rolled steel elements and this leads economic design solutions. The investigation of the effects of bolt arrangement, cross-sectional shape, gusset plate thickness and cross-sectional slenderness on the seismic performance of CFS connections under cyclic loading is made with the model [19]. The concrete filled tubular columns using varying steel materials under axial loading is done to carry out for casting and testing the cube, cylinders and Concrete filled tubular specimens. During testing, are slight local bulking and weld failure are the common modes of failures that have been observed in the columns [20]. Cold-formed steel construction can yield more efficient designs in comparison with hot-rolled steel members because of its high strength, light weight, ease of fabrication, and flexibility in their cross-section profiles [21]. The confinement provided by steel tubes in Concrete filled Steel tubular (CFT) Columns is found to be vital in the enhancement of structural properties of such columns [22]. It is convinced that the central concrete can be optimally replaced by another hollow steel tube with smaller area to form double-skinned concrete-filled-steel-tubular (CFDST) columns [23].

A Concrete filled rectangular tube column consists of a steel tube filled with concrete. Concrete core adds stiffness and compressive strength. Steel tube acts as longitudinal and lateral reinforcement-resists tension, bending moment and shear, confines concrete. In composite column the steel provides external reinforcement and support several levels of construction prior to concrete being pumped. The rectangular concrete in-filled hollow section includes a thin steel section covering the rectangular concrete fill. These thin steel sections are cold formed, i.e., their manufacturing process involves forming steel sections in a cold state without application of heat from steel sheets of uniform thickness.

2. Investigational analysis

2.1 Materials and Mix Design

The Ordinary Portland Cement of grade 53 used as cementitious constituents and purchased from Ravi traders, Coimbatore and conforming to IS 12269- 2013 [24]. The Specific gravity of the cement used in this investigation is 3.21. The Standard consistency of cement is 32 %, initial and final setting time used in this research are 42 minutes (conforming IS 1489-2015) [25] and 340 minutes (conforming IS 1489-2015) [25]. The average compressive strength of cube for 28 days is 59.65 N/mm^2. The chemical composition of the ordinary Portland cement (OPC), Metakaolin (MK) and Nanometakaolin (NMK) are designed in Table.1

Metakaolin brought from Marvel industries, Tirunelveli is one of the supreme widely used by-product materials in the construction field approaching Portland cement. The specific gravity and specific surface area of MK used in this study is 2.45 and 12 m^2/g. Brightness appearance of MK specifies 83 Hunter L and powder is light white form. Metakaolin was used to condense the heat of hydration, permeability, and bleeding in concrete [5]. Metakaolin a cherished pozzolanic material, can react with the lime enlightened from the hydration of ordinary Portland cement [6]. The nano metakaolin (NMK) was prepared by thermal activation of kaolin clay for 3.5 hours at 780 ^{0}C The NMK was partially replaced by OPC of (1, 2, 3, and 4,5,6,7 %) by weight of cement. The picture of nano metakaolin taken by Scanning electron

Table 1

Chemical composition of OPC, MK and NMK

Constituents / Materials	SiO_2	CaO	Al_2O_3	Fe_2O_3	MgO	SO_3	Na_2O	K_2O	SiO_2
OPC (%)	31.3	63.12	5.5	2.9	1.3	2.5	0.03	0.02	31.3
Metakaolin (%)	53.7	0.8	40.8	1.6	0.3	0.2	0.16	0.04	53.7
Nanometakaolin (%)	50.2	0.05	30.8	0.06	0.35	0.20	0.04	0.03	50.2

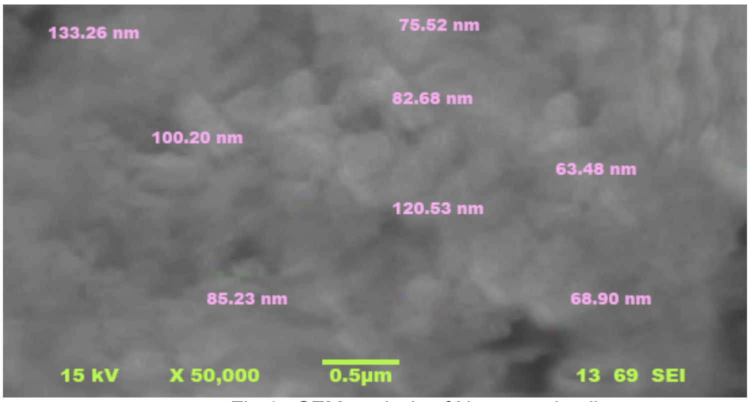

Fig.1 - SEM analysis of Nanometakaolin.

microscope (SEM) as confirmed [10] are shown in Figure 1. It is clearly showing that average particle size maintained in about 75 nm and Blaine surface area is about 350000 cm²/g.

The river sand used in this study having specific gravity of 2.59 and conforming to grading zone III. The water absorption and fine modulus for sand are 1.02 % and 2.69 and tested as per Indian Standard Specifications IS: 383-1970 [26]. The particle sizes were prescribed in Figure .2

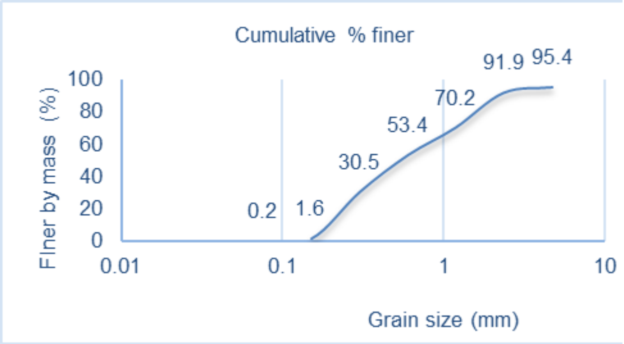

Fig.2 - Grain size distribution.

The locally available coarse aggregates were used of average maximum size of 20 mm brought from nearby quarry. The bulk density, specific gravity, fine modulus, and percentage of voids were 1568 kg/m³, 2.72, 6.9 and 43.2 % physical properties are used in study as conforming to IS 2386 (Part III): 1963 [27]. Normally available water having pH value of 6.5 used in this exploration for making concrete. Conplast 430 were used as chemical admixture to produce good workability confirming to IS: 9103-1999 as recommended with [28] and BS: 5075 as recommended with [29]. The concrete is designed for M20 grade as per IS10262:2009 [30]. The mix proportion of water, cement, fine aggregate, and coarse aggregates of 208 kg/m³, 416 kg/m³, 655.29 kg/m³, 1090.45 kg were taken as quantities to produce good concrete.

2.2 Preparation of Nanometakaolin and microstructure analysis

Metakaolin which is white slight off in color purchased from solvents chemical industries which is in Coimbatore which is used to formulate Nanometakaolin (NMK) as cementitious materials. NMK is prepared from industry waste metakolin by thermal activation of clay maintained 770-790 °C in furnace for about 2-2.3 hours and crushed very serenely. The ball mill technique used to reduce the particle size Nanometakaolin for about (30-60) hours. The average size of the particle received after the process will be 70-95 nm, consistent and spherical rounded in shape. The optimal percentage of NMK observed from compression test is 4 % with particle size of 80 nm is maintained. The most commonly used method used in construction industry will be Chapelle´s method and results were obtained with one gram of lime (as specified in 9). The calcium consumption of metakaolin as the base material tested with 1g of CaO mg/g per sample (160 tests) taken from values [9] for the medium, maximum and minimum value will be approximately 857, 876,833 and 11 respectively and similar to $Ca(OH)_2$ mg/g per sample will be 1131,1156, 1100 and 0 are observed. The results clearly indicate that CaO consumption in metakolin increases instantaneously. Finally, XRD analysis is commonly used method to envisage crystal structures was carried out between particles to observe phase relationship in pozzolanic materials. The metakolin powder sample were analyzed by XRD analysis indexing cement content was measured and peak values is observed on database. The samples like M00, M01 and M02 are tested and XRD pattern implies that the phase of calcium hydroxide, silica and partial water content were present. In another assorted phase relationship SiO_2 , CaO Al_2 , and H_2O were found .Metakolin increase with increase in percentage the first phase relationship also will increase and with rather increase in percentage of metakaolin there will be slight decrease in optimum percentage of metakaolin increases .The increase in age of hydration there is a slight decrease in calcium hydroxide content at the peak level decrease in crystallinity degree to CH gel. The quantity amount of CH consumed in the pozzolanic reacts with NMK exceeds with amount of ordinary Portland cement hydration so that there will a decrease in amount of CH gel in peak concentrations of 60 and 90 days hydration. The compressive strength of metakolin increases up to optimum limit and beyond limit it decreases due to over dosage of calcium and silica content, the maximum compressive strength obtained from the results were 22 % more than while comparing to normal concrete

2.3 RC Column dimensions and materials specification

A total of 30 columns were casted in which 15 specimens were of reinforced concrete columns (3 specimens for each size) and 15 specimens (3 specimens for each size) were confined columns. The ratio of height and breadth of the specimens are kept constant as 6.25. The height and breadth of the specimens were 500 mm and 80 mm. The width to depth ratio is assumed to be taken as 1.00, 1.25, 1.50, 1.75 and 2.00 as shown in Figure 3 (a) and assembled of hat sections are as shown in Figure 3(b) The reinforcement of about 6 mm diameter bars of total 4 number were used and also 6 mm diameter bars are used as stirrups at spacing of 80 mm. The yield strength of the reinforcement steel is 500 MPa. The thickness of cold form steel is 1 mm, and the yield strength of the cold form is 250 MPa. The cold form steel is coated with Zinc-Chrome primer to avoid the corrosion of steel from the external environment. Bolts and nuts are used for connecting the two hat sections to provide confinement. The HSFG bolts were used. The diameter of the bolts is about 6 mm and the diameter of the bolt hole is about 8 mm. The pitch distance of bolts is 50 mm, and the edge distance is 25 mm

2.4 Casting of Specimens

After mixing of the concrete, it is placed in the prepared rectangular mould (column specimen), before initial setting of cement. The compaction or consolidation of concrete is started immediately after placing the concrete in position. Compaction is carried out in three layers each

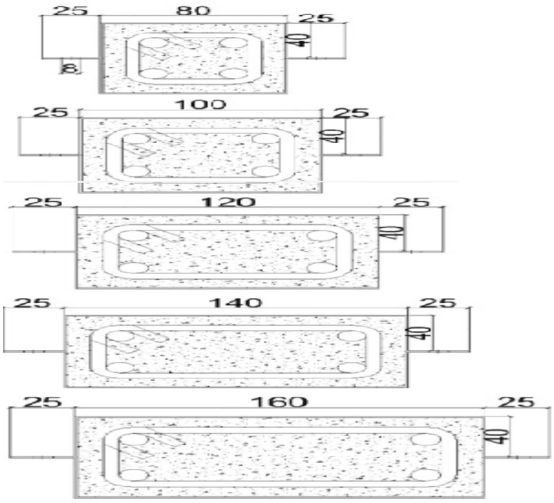

Fig.3 (a) - Cold form specimen dimensions.

Fig.3 (b) Assembled of hat sections

1/3rd of its height. The purpose of consolidation is to expel or eliminate the air bubbles from the concrete mass to the maximum extent to achieve maximum density of concrete. The improvement in density of concrete will ensure both, the higher desired strength as well as permeability. Compaction are carried out by hand. Hand compaction is carried out by tampering, hammering.

2.5 Test Setup

The specimens were loaded using the loading frame of 80-ton capacity. The load cell is placed above the plates. The test set up includes a concrete in-filled rectangular hollow steel section (rectangular column) in a which a steel plate of certain thickness say 25 mm is placed over the concrete core (not on the steel). Meanwhile, steel plate is also provided at the bottom of the column section to maintain the boundary condition (i.e., equilibrium condition is to be maintained). The entire load is provided to the concrete alone. The

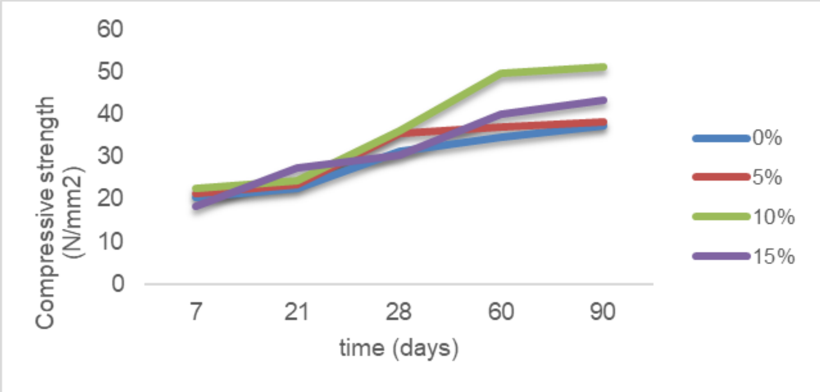

Fig.4 - Compressive strength of concrete containing metakaolin.

Table 2

Compressive Strength of concrete comprehending Nano Metakaolin

Days / (% of replacement)	1 %	2 %	3 %	4 %	5 %	6 %
7	18.7	20.4	22.8	24.6	23.8	20.4
21	28.0	30.6	34.2	36.9	35.3	32.5
28	31.2	33.6	35.5	37.9	36.9	33.8
60	35.6	41.2	44.6	47.8	46.4	44.5
90	39.8	42.7	45.8	55.6	51.2	48.9

support conditions taken in hinged –hinged type. The load is applied to the concrete core and the specific load is noted from the load cell. The process is repeated for all type of specimens. The behaviour of specimens of different sizes are studied and tabulated

3. Summary and Discussion

3.1 Compressive strength of concrete encompassing NMK

The metakaolin is used as cementitious material with different percentages to concrete for 7,21,28,60, and 90 days. The optimum replacement of 10 % metakaolin to cement the compressive strength of concrete at 28, 60 and 90 days is 36.2 N/mm^2, 49.6 N/mm^2, 51.2 N/mm^2 and there is an upsurge of increase in compression strength by 5.5 %. While moving beyond extend to 15 % metakaolin to concrete there is a slight decrease in strength up to 3.1 % From the strength data clearly shows that metakaolin beyond 10 % usage may decrease in strength. Figure 4 noticeably shows the compressive strength of concrete containing metakaolin.

Table 2 shows the discussion on compressive strength on concrete containing nano metakolin. The results shows that optimum percentage of 4 % replacement the compressive strength of 7, 21, 28, 60 and 90 days are 24.6 N/mm^2, 36.9 N/mm^2, 37.9 N/mm^2,47.8 N/mm^2, 55.6 N/mm^2.This shows confirms that optimum percentage of replacement of NMK is 4 %. Increase in strength varies between 18 % - 27 % in the range of 3 % - 5 % in replacement of NMK and decreases maximum dosage of NMK concrete beyond 6 %. The NMK increases, strength also gets increased while comparing to normal concrete and fill the voids with reducing passage pores in concrete which results in microstructure of concrete dependably increases strength in concrete. Nanometakaolin reacts with lime contented Ca $(OH)_2$ progressive during hydration of cement to harvest C-S-H gel (conforming to SEM analysis) [8, 15]. Figure 5 (a) and Figure (b) show the testing photos of RCC column and composite column testing in loading frame.

The above Figure 6 (a) and Figure 6 (b) shows that the RC columns having less longitudinal deflection than the confined columns. The five groups of reinforced column of sizes (78 x 80 x 500 mm, RCK) , (98 x 80 x 500 mm, RCL), (118 x 80 x 500 mm, RCM), (138 x 80 x 500 mm, RCN), (198 x 80 x 500 mm, RCO) and five groups of Infilled concrete composites column of sizes like (80 x 80 x 500 mm, RCCK), (100 X 80 X 500 mm, RCCL) , (120 x 80 x 500 mm,RCCN), (140 x 80 x 500 mm,RCCN) ,(160 x 80 x 500 mm, RCCO) are tested under axial load in testing frame.. The tests were conducted for the specimens on which three number of specimens for each size. The samplings were placed centrally on the bench of the mechanism and measure the axial restriction and strain devices are fixed at the longer face of the sampling. The percentage of higher load carrying capacity for the column having the width to depth ratio of 1.00, 1.25, 1.50, 1.75 and 2.00 are 68 %, 40 %, 23 %, 35 %, 31 %. The longitudinal dislodgment with respect to load for composite column and Reinforced concrete column (80 x 80 x 500 mm) is strategized in a single graph (Load vs axial shortening of RCK and RCCK) as shown in Figure 7.

Fig 5 (a) - Test setup for RCC column testing in loading frame.

Fig 5 (b) - Test setup for Composite column testing in loading frame.

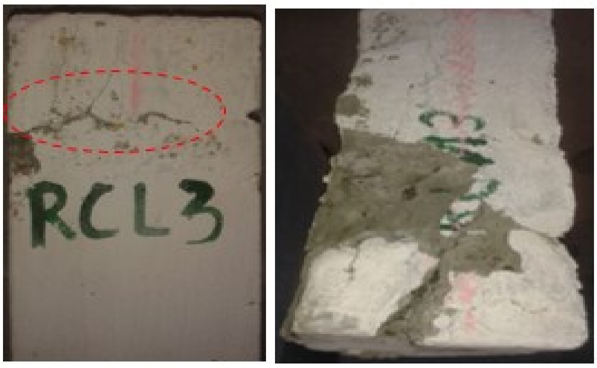

Fig 6 (a) - Failure of Specimens (RCL3).

Fig 6 (b) - Failure of Specimens (Composite)

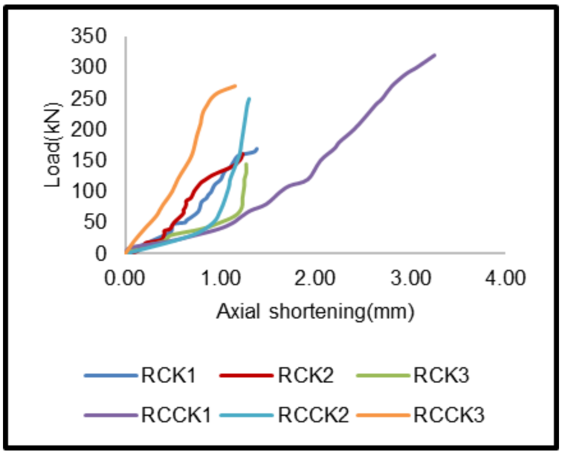

Fig. 7 - Load vs Axial Shortening of RCK and RCCK

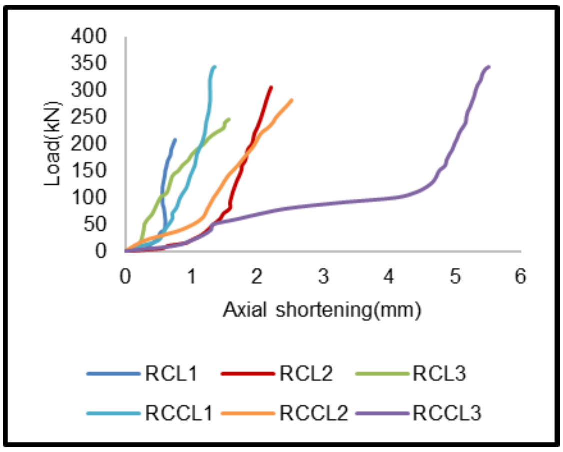

Fig. 8 - Load vs Axial Shortening of RCL and RCCL

The load vs axial restriction of RCL and RCCL with respect to load for composite and RC column (80 x 100 x 500 mm) is displayed in Figure 8. It was perceived that the CC in filled columns were taking 56 % more load than the normal RC columns. It is seen that after the failure of concrete the load get transferred to the steel confinement provided to the columns. The bulging of column takes place at the top of the column and at the bottom small amount of bulging takes place. The axial capacity of the RC columns and Confined columns were compared, and the results shows that the axial capacity of confined column are higher than the RC column.

The longitudinal supplanting with respect to load for composite column and RC column (80 x 120 x 500 mm) of RCM and RCCM are plotted in Figure 9. It shows that confined columns have higher axial shortening shows the effect of confinement. In the RC columns the failure takes place with cracks. For the confined column, the failure takes place in the form of bulging at the top of the column. Using Nano-Metakaolin with 4 % enhancing the properties of used concrete for initial crack, ultimate load, maximum defection, and toughness of composite sections are determined.

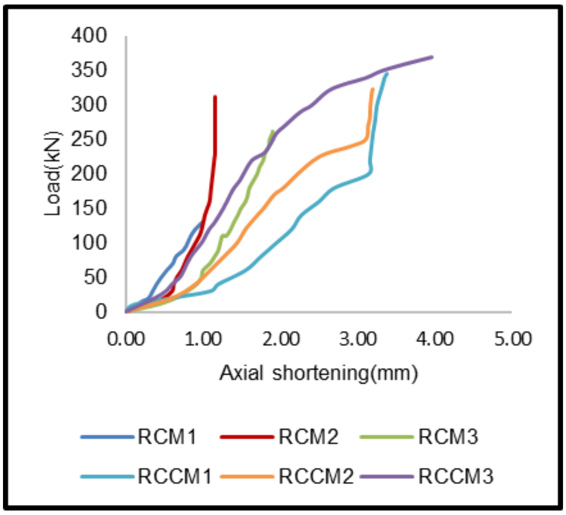

Fig. 9 - Load Vs Axial Shortening of RCM and RCCM

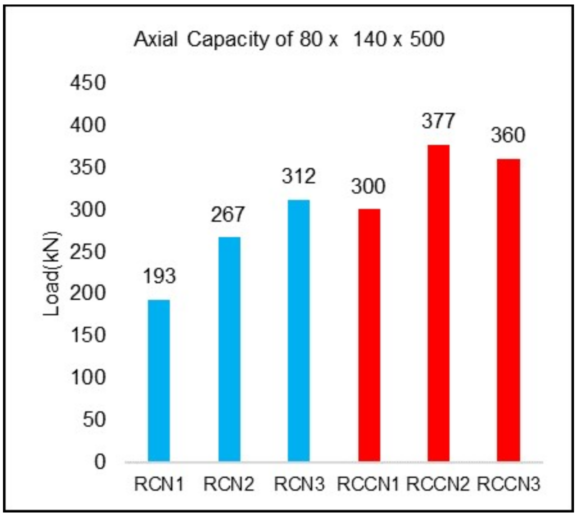

Fig. 10 - Load Vs Axial Shortening of RCN and RCCN

Finally, the column of size load versus axial shortening of RCN and RCCN (80 x 140 x 500 mm), load Vs axial shortening of RCN and RCCN (80 x 160 x 500 mm) are arranged in Figure 10 and Figure 11. The sample peak value for axial capacity of size 80 x 160 x 500 with load displacement of 406 highest value and lowest value of 304 as shown in Figure 11. All cross-section columns clearly show that composite column takes more load while comparing to RC columns. The confined column has more load carrying capacity while comparing to Reinforced concrete columns for all sections

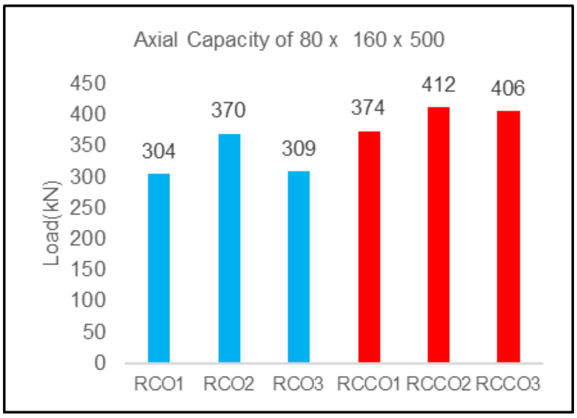

Fig. 11 - Load vs Axial Shortening of RCO and RCCO

4. Conclusion

1.A good quality concrete mix with 10 % MK and 4 % NMK exhibits greater mechanical properties and is selected as the optimum percentage of metakaolin and Nanometakaolin and it exceeds beyond 12 % and 4.5 % of MK and NMK value decreases due to over dosage content.

2. The peak proportion at which cement can be substituted with Nano-Metakaolin is 4 %. It is found that partial replacement of cement with Nano-Metakaolin has a greater influence on the strength parameters of concrete. Hence Nano-Metakaolin may be adopted as an effective pozzolanic material to partially replace cement in concrete.

3. The compressive strength of the blended cement pastes at all hydration times is increased on adding NMK for about 28 % while comparing to normal cement concrete is 16 % respectively

4.It came to observe that the phase work for CaO Al_2 SiO_2 H_2O in a sample M00, M01 and M02 results in increase in compressive strength and optimum percentage recommended used in concrete will be 10 %

5.XRD results obtained for pozzolanic materials like metakaolin indicates the formation of calcium silicates, silica content, and reasonable amount of water content with calcium silicates and calcium carbonates are observed and predicted

6. Composite column with MK and NMK has more load carrying capacity of 33 kN and 28 kN more than while compared with reinforced concrete column 18 kN as shown in Figure 5a.

7.The load deflection pattern of MK and NMK of composite column (Figure 7-11) clearly indicates greater load carrying capacity and energy dissipation is more while related to RCC column

8.Minimal number of fine cracks are observed from composite column as specified in sample Figure 6 a) intermingled OPC mixes with NMK show relatively lower values of total porosity compared to that of the control mix.

9. The column with greater cross-sectional area 12 % had higher load carrying capacity. Hence greater cross-sectional area larger is the load carrying capacity and compared with RCC column with and without NMK.

10. According to Figure 6(b), In addition to NMK, as it significantly improves the performance

of concrete mixes; it controls shear cracks and upsurges shear capacity in the bottom of the column.

11. Practice of concrete with NMK has no significant effect on column miscarriage mode and outrageous spacing is lesser in NMK concrete compared to normal concrete specified in Figure.4.

12. Composite columns has more deflection than reinforced concrete column because the core concrete fails indicated in Figure 5(b) and crushes very fastly.

13. At last workmanship is very much reduced and the process is simple when compared to the reinforced concrete columns during practising in laboratory sessions.

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