International Journal of Recent Technology and Engineering (IJRTE)
ISSN: 2277-3878, Volume-7, Issue-6C2, April 2019

Mechanical and Durability Properties of Limestone Calcined Clay Cement (Lc^3)

J. Lavanya, V. Ranga Rao

Abstract: : Limestone calcined clay cement (LC^3) is a new type of cement blended with 15% limestone,50% clinker,5% gypsum and 30% clay. The production of LC^3 can reduce CO_2 emissions up to 30% as compared to that of OPC. The utilization of calcined kaolinite clay as alternative material for bond is a choice to relieve the ecological effect. In this work, Mechanical properties of LC^3 like fineness, consistency, initial and final setting time, compressive strength with different clinker proportions (40%, 50%, 60%) at different calcined kaolin clay (40%, 30%, 20%) at a temperature 450ºC were studied by casting mortar cube specimens and concrete cubes were tested and the results were compared with strength of OPC mortar and concrete cubes. For durability study of LC^3 concrete, LC^3 and OPC concrete cubes were exposed to chloride attack (NaCl) and sulphate attack ($MgSO_4$) and the results were compared.

Index Terms: Calcined kaolin clay, clinker, compressive strength, Gypsum, Limestone.

I. INTRODUCTION

The utilization of supplementary cementitious materials (SCMs) to replace some portion of the clinker in cement is the best system to decrease CO_2 emissions in the worldwide cement industry. In any case, the limited supply of SCMs in many countries and regions is an obstacle to more extensive use. Today>80% of SCMs used to decrease the clinker factor in cement or limestone, fly ash or slag. Calcined clays, especially in blend with limestone can possibly expand the utilization of beneficial cementitious materials as a partial substitution of clinker in cement and concrete. This paper mainly focuses on the Limestone calcined clay cement (LC^3).

Revised Manuscript Received on April 09, 2019.
J. Lavanya, P. G. Student, Koneru Lakshmaiah Educational Foundation, Vaddeswaram, Guntur district, Andhra Pradesh, India.
V. Ranga Rao, Professor, Koneru Lakshmaiah Educational Foundation, Vaddeswaram, Guntur district, Andhra Pradesh, India.

The materials present in this cement are clinker, limestone, gypsum, kaolin clay.

Limestone is also known as calcite, marble, chalk, aragonite in few places.

In LC^3 production, a new type of ternary blend cement, containing 50% clinker, 30% calcined clay, 15% limestone, 5% gypsum was carried out in India. Calcination of clays was carried out in static kilns used in fire potteries and ceramics. Crushing and blending of cement was done at a cement grinding unit.

In LC^3, by adding large amount of calcined clay and ground limestone to concrete mixtures, the aluminates obtained in clay interact with calcium carbonates from the limestone

In the environmental point of view, limestone calcined clay cement is a low-carbon alternative when compared to Portland cement. It can reduce CO2 emissions in the manufacturing of cement by reducing the clinker content, replacing it with limestone and calcined clay. Low grade kaolin clays can be utilized for the production of LC^3 and are abundantly available at various places of world. It is cost effective and does not require capital investments and can be obtained in existing plants.

A. Clinker

In the manufacture of cement, clinker forms as lumps. Clinker comprises of different calcium silicates including alite and belite. Tricalcium aluminate and calcium aluminoferrite are different common components. These components are frequently created in-situ by heating different clays and limestone. Portland cement clinker is made by heating homogeneous blend of raw materials in rotary kiln at high temperature.

B. Limestone

The principle particle of limestone is calcium carbonate ($CaCO_3$). Limestone can be directly prepared into aggregated rock and calcined into quicklime. Lime are of 2 types: Quicklime and slaked lime. The main component of quicklime is CaO, when it is with high purity it looks white and when it is impure, it looks pale grey or faint yellow.

C. Gypsum

It is a soft sulfate mineral consists of calcium sulfate dihydrate and having a chemical formula $CaSO_4.2H_2O$. Gypsum plays a vital role in controlling the rate of hardening of cement. Gypsum was used to control the setting of cement. Percentage of gypsum used in cement is about 2-8%, but typically 5%.

D. Kaolin clay

Kaolin is a hydrated aluminum silicate crystalline mineral (kaolinite), formed

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication

from weathered granite located beneath the earth's surface. The world's largest reserves of premium kaolin are situated in United States and Brazil.

II. RESEARCH SIGNIFICANCE

For every 20 tons of man-made CO_2 that enters into the atmosphere which was obtained from the kilns of cement factories. Emissions formed in cement production are of three ways:

a. From the production of electrical energy, raw materials and clinker were grind.
b. From the fuel burned to heat, the raw materials in a kiln at 1450ºC to form clinker.
c. When limestone is heated, it converts into lime and CO_2.
d. These emissions represent 60-65% of the total emissions were linked to cement production. So, by reducing the amount of clinker in cement, the amount of
e. CO_2 in atmosphere also reduces.
f. To reduce CO_2 emissions and the cost-effective cements - LC^3 was used.

III. MATERIALS

In this study the experimental work is done by using these materials.

1. Ordinary Portland cement
2. Clinker
3. Calcined clay
4. Limestone
5. Gypsum
6. Admixture
7. Coarse aggregate
8. Fine aggregate

A. Ordinary Portland cement

Ordinary Portland cement was used in this experimental work. OPC 53 grade was preferred. This grade was introduced in the country by BIS in 1987 and commercial production started from 1991. Appearance of this grade in the nation owes it to the enhanced innovation adopted by modern cement plants.

The experimental work was done with OPC 53 grade attains higher strength.

B. Clinker

Clinker product is collected from the cement factory which was collected in the form of lumps. These lumps were powdered by using Los Angles Abrasion testing machine. Then they obtained powder was sieved in 90 microns. This clinker powder was used in this experimental work.

C. Calcined clay

Kaolin clay was used in this work and it is in white color. This kaolin clay was heated to 450ºC in muffle furnace. When the clays are calcined then chemically attached hydroxyl groups were removed, making the clay amorphous and reactive.

D. Limestone

The main particle of limestone is calcium carbonate. Limestone used in the work was faint yellow color.

E. Gypsum

The chemical composition of gypsum is $CaSO_4.2H_2O$. It acts as a retarder. Gypsum delays the setting of cement in hot climates.

F. Coarse aggregate

The coarse aggregate was used from the batching plant in our university. Flakiness and elongation index were maintained. To arrest voids cubes were cast with a combination of 30% 10mm and 70% 20 mm aggregates. The specific gravity of coarse aggregate was 2.81.

G. Fine aggregate

River sand was used as fine aggregate which was from our batching plant according to the recommendation of IS-383. The specific gravity of fine aggregate was 2.6. Generally, zone -II sand was used.

H. Admixture

To increase the workability of concrete admixtures are used. Admixtures such as super plasticizer were used from our laboratory at a volume of 0.5%. This can be done according to ASTM C-494. These are high water reducing agents which reduces water up to 20%.

IV. EXPERIMENTAL WORK

The experimental work was carried out by casting motor cubes and concrete cubes. The dimensions of mortar cubes were 75x75x75 mm and concrete cube dimensions were 150x150x150 mm. the mix design was done on M30 grade of concrete which was done according to IS10262-2009. The mix proportions are as shown below.

Table I: Mix design

Grade	Cement (kg/m^3)	Fine aggregate (kg/m^3)	Coarse aggregate (kg/m^3)	w/c	*Sp* (kg/m^3)
M30	380	826.29	1010.56	0.45	1.9

A. OPC mortar cubes

For this mortar cubes, consistency test was carried out by taking 300gms of cement in vicat apparatus and add different percentages of water. After adding water to the cement, the cement test is mixed thoroughly and placed it aside for 3 to 5 minutes. Then that cement paste was placed in vicat mould. The water content was known by penetration of the plunger into the cement paste. The penetration should be of 5 to 7 mm from the bottom of the vicat mould.

The water content was calculated and then mortar cubes were cast by using three types of sands, one is passing through 2.36 mm sieve and retains on 1.18 mm sieve, another sand was passed through 1.18 mm sieve and retains on 500 microns sieve, and the last type of sand is passing through 500 microns sieve and retains on 90 microns sieve as per IS 4031-part 4.

For the casting of mortar cubes (shown in Figure 1) for every type of sand 200gms of

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication

sand is collected and 200gms of cement was collected. This cement and sand were mixed thoroughly and then add water of 90ml and mixed thoroughly. After applying grease to the mortar mould place

the mould on vibration testing machine then add this mortar into the mould by tamping each layer. These mortar cubes were cured and tested for 3, 7 and 28 days.

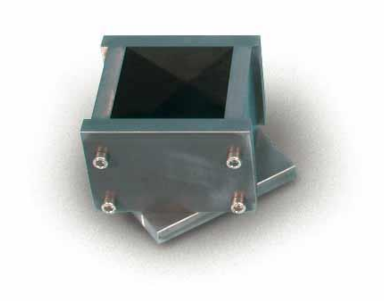

Figure 1: Mortar cube mould

B. Workability

For the workability of concrete slump cone test was conducted. According to IS 456-2000 code, the workability obtained was 100 as shown Figure 2 below.

Figure 2: Slump cone test

C. PC concrete cubes

OPC concrete cubes were cast. While casting the concrete mix was placed in the cubes specimen (Figure 3) in three layers. Every layer is compacted by tamping rod of 16 mm diameter and 610 mm length should be tamped evenly with 25 strokes per layer. After casting was completed then these cubes were cured for 7, 28 days.

Figure 3: Concrete mould

For LC^3 cement different proportions were used by varying clinker and kaolin clay percentages and limestone and gypsum percentages were maintained constant. The mix proportions were noted below:

Table II: Mix proportions

Mix	Clinker	Kaolin clay	Limestone	Gypsum
1	40%	40%	15%	5%
2	50%	30%	15%	5%
3	60%	20%	15%	5%

D. LC^3 mortar cubes

Mix-1: The consistency test was same as OPC. The slight variation is cement. This mix consists of 40% of clinker, 40% of kaolin clay, 15% of limestone, and 5% of gypsum. To this mix water was added and mixes thoroughly and places it in vicat mould. Then by the penetration of plunger water content for mortar cubes were noted. For this mix mortar cubes were cast.

Mix-2: The consistency test was same as OPC. The slight variation is cement. This mix consists of 50% of clinker, 30% of kaolin clay, 15% of limestone, and 5% of gypsum. To this mix water was added and mixes thoroughly and places it in vicat mould. Then by the penetration of plunger water content for mortar cubes were noted. For this mix mortar cubes were cast.

Mix-3: The consistency test was same as OPC. The slight variation is cement. This mix consists of 60% of clinker, 20% of kaolin clay, 15% of limestone, and 5% of gypsum. To this mix water was added and mixes thoroughly and places it in vicat mould. Then by the penetration of plunger water content for mortar cubes were noted. For this mix mortar cubes were cast.

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication

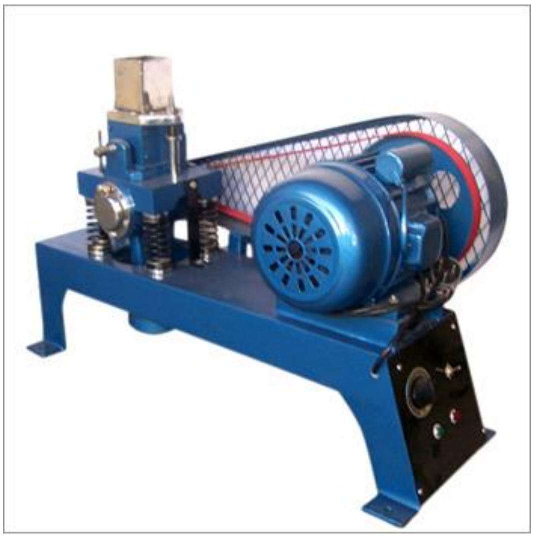

Figure 4: Vibration testing machine

E. LC³ concrete cubes

LC3 concrete cubes were cast by placing concrete mix in the cubes in three layers. By placing each layer and then place the mould on vibrator as shown in figure 4 for less than 1 minute.

For the three mix proportions, concrete cubes were cast by varying the clinker and kaolin clay contents. These cubes were cast and cured for a period of 7 and 28 days

V. RESULTS AND DISCUSSIONS

For LC³ and OPC, the properties like standard consistency, initial and final setting time were noted below.

Table III: Physical properties of cements

Property	Mix-1	Mix-2	Mix-3	OPC
Standard consistency (%)	40	36	30	33
Initial setting time (minutes)	90	90	90	90
Final setting time (minutes)	180	180	180	190

Table IV: Specific gravity of materials

OPC	LC³	Coarse aggregate	Fine aggregate
3.14	2.7	2.81	2.6

A. Compressive Strength

The tests were performed under the compressive testing machine for cubes. For ultimate failure of the specimen this compressive strength test was most commonly used and then strength acquired by the specimen has been noted. At 7 days and 28 days testing the average results were recorded.

The OPC and LC³ mortar cubes were tested under the compressive testing machine and the compressive strength results were noted for 3 days, 7 days, and 28 days. As shown in Table V to VIII.

Table V: Compressive strength for OPC mortar cubes

Trial	Compressive strength for OPC		
	3 days	7 days	28 days
1	12.4	19.5	28.48
2	16	21.3	32
3	19.5	24.8	28.4
Average	15.9	21.867	28.96

Table VI: Compressive strength for LC³ mix-1 mortar cubes

Trial	Compressive strength for LC3		
	3 days	7 days	28 days
1	10.66	12.4	17.7
2	8.8	14.2	19.5
3	7.11	16	23.1
Average	8.85	14.2	20.1

Table VII: Compressive strength for LC³ Mix-2 mortar cubes

Trial	Compressive strength for Mix-2		
	3 days	7 days	28 days
1	11.15	14.2	19.55
2	10.76	16.54	21.06
3	9.16	17.88	24.99
Average	10.35	16.20	21.86

Table VIII: Compressive strength for LC³ Mix-3 mortar cubes

Trial	Compressive strength for Mix-3		
	3 days	7 days	28 days
1	13.23	17.52	24.11
2	15.56	18.24	25.28
3	14.21	20.55	26.29
Average	14.33	18.80	25.66

Figure 5 shows the compressive strength values for OPC and different LC³ mixes were shown that compressive strength of OPC will give better results compare to mix-1, mix-2, mix-3 for different curing's of 3 days, 7 days, and 28 days.

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication

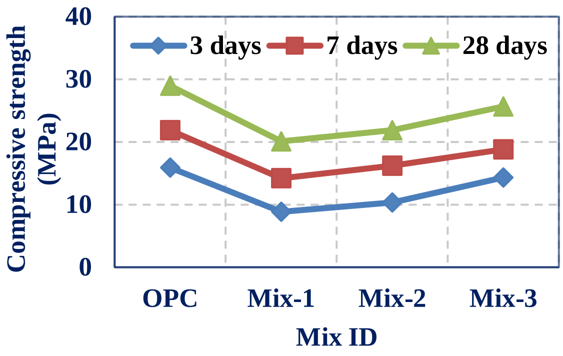

Figure 5: Mortar cube compressive strengths for different mixes

Similarly Table IX shows the compressive strength of OPC and LC^3 for 7 days and 28 days curing period.

Table IX: Compressive strength of different mixes

Trail	Compressive strength							
	OPC		Mix-1		Mix-2		Mix-3	
	7D	28D	7D	28D	7D	28D	7D	28D
1	21.3	40	4.4	8	9.7	16.3	15.5	20
2	29.1	51.5	4.4	6.2	16.8	18.6	14.6	21.3
3	29.2	50.2	5.3	7.1	13.3	22.2	15.5	24.4

The compressive strengths for concrete cubes were shown in Figure 6

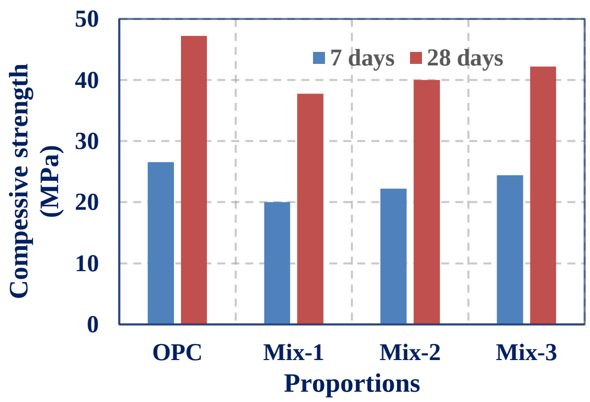

Figure 6: Comparison of different proportions on compressive strength

Figure 7: LC^3 Mix 1 cubes

Figure 8: LC^{3}Mix 2 cubes

Figure 9: LC^3 Mix 3 cubes

The concrete cubes were cast and shown in Figure 7, Figure 8, and Figure 9 for Mix-1, Mix-2 and Mix-3 respectively. And the cubes were tested on compression testing machine was shown on Figure 10.

Figure 10: Cube on compression testing machine

B. Durability

Table X: Compressive strength for exposed specimens

Designation	Mix-1	Mix-2	Mix-3	Mix-4
Conventional	47.25	37.77	40.01	42.22
Chloride attack	46.66	36.72	39.52	41.38
Sulphate attack	45.67	35.25	38.29	40.63

Table X shows the compressive strength of concrete cube specimens for 28 days curing exposed to chloride and sulphate attack. Compare to chloride attack specimens with specimens of sulphate attack is gives better strength

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication

values are graphically shown in Figure 11 below.

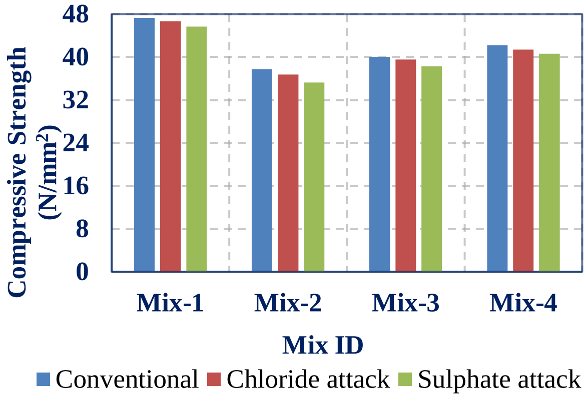

Figure 11: 28 days durability values

Table XI: Specimen weights exposed to chloride attack

Chloride attack				
Weight before dipping	8.498	8.585	8.596	8.608
Weight after dipping	8.365	8.49	8.51	8.53

Table XI shows that specimen's weighs exposed to chloride attack gives that reduction of weight for Mix-3 is very low compare to Mix-2, Mix-1, and OPC are graphically show in Figure 12 below.

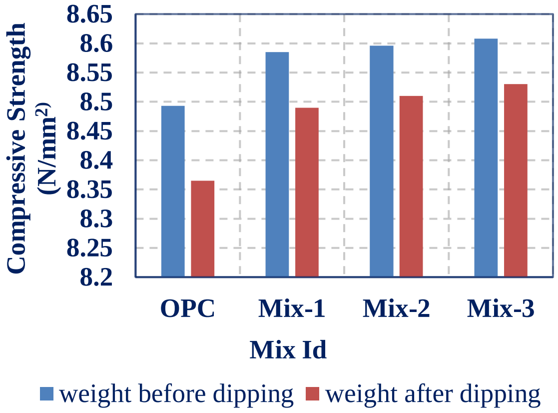

Figure 12: Specimen weights exposed to chloride attack

Table XII: Specimen weights exposed to sulphate attack

Sulphate attack				
Weight before dipping	8.475	8.568	8.59	8.61
Weight after dipping	8.38	8.508	8.526	8.542

Table XII shows that deducted weights of specimens subjected to sulphate attack gives the weight reduction of Mix-3 is very low, when compare to Mix-2, Mix-1, and OPC specimens are graphically shown in Figure 13 below.

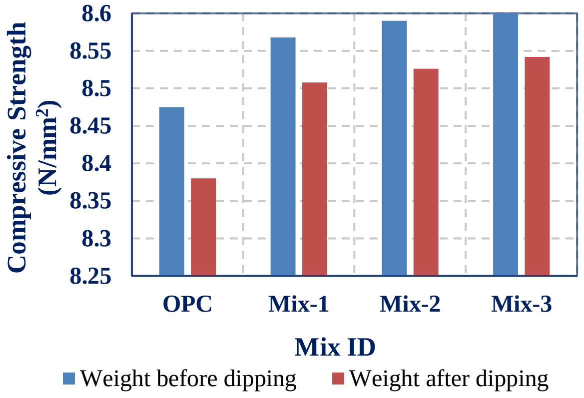

Figure 13: Specimen weights exposed to sulphate attack

VI. CONCLUSIONS

After performing the experimental work the following conclusions were made.

- It was observed that the compressive strength value was more for mix-3.
- When clinker content increases and clay content decreases then the strength increases.
- For durability point of view mix-1 was having low sulphate attack and chloride attack.
- When compared to OPC, LC3 was having low strength when calcinations were at 450°C.

ACKNOWLEDGMENT

The authors greatly acknowledge the concrete technology laboratory technicians for utilizing the lab equipment's and would like to acknowledge the transportation laboratory for using Los angles abrasion testing machine and to environmental engineering laboratory for using muffle furnace.

REFERENCES

1. WBCSD, Cement Sustainability Initiative, Getting the numbers right.
2. K.L. Scrivener, "Options for the future of cement", *Indian Concrete*, vol. 88, issue 7, 2014, pp. 11–19.
3. Karen Scrivener, Auelie Favier (Eds.), "Calcined Clays for Sustainable Concrete", *RILEM Book series*, vol. 10, Springer, 2015.
4. R. Snellings, "Assessing, understanding and unlocking supplementary cementitious materials", *RILEM Technical Letters*, [S.l.], vol. 1, 2016, pp. 50–55.
5. T. Matschei, B. Lothenbach, F.P. Glasser, "The role of calcium carbonate in cement hydration", *Cem. Concr.* Vol. 37, Issue 4, 2007, pp. 551–558.
6. Figures compiled by Ruben Snellings, fly ash figures are based on the production figures of the *World Coal Association, combined with ECOBA data* "to estimate the amount of fly ash produced per unit of coal combusted", published as a graphical abstract in to vol. 4.
7. IEA, WBCSD, "Cement technology road-map 2009 carbon emissions reductions up to 2050", *OECD/IEA; WBCSD, Paris; Conches-Geneva, Switzerland*, http:// wbcsdcement.org/pdf/techno

logy/WBCSDIEA_Cement%20Roadmap.pdf, 2009.
8. R. Fernandez, F. Martirena, K.L. Scrivener, “The origin of the pozzolanic activity of calcined clay minerals: a comparison between kaolinite, illite and montmorillonite”, *Cem. Concr*vol, Vol. 41, Issue 1, 2011, pp. 113–122.
9. F. Wang, K. Kovler, J.L. Provis, A. Buchwald, S. Kamali-Bernard, L. Courard, K. Sideris, “Metakaolin as an effective supplementary cementitious material”, *Chapter in State-of-the-Art Report from Rilem TC SCM*, (to be published).
10. A. Alujas, R. Fernández, R. Quintana, K.L. Scrivener, F. Martirena, “Pozzolanic reactivity of low grade kaolinitic clays: influence of calcination temperature and impact of calcination products on OPC hydration”, *Appl. Clay Sci*, Vol. 108, 2015, pp. 94–101.
11. F. Avet, R. Snellings, A. Alujas Diaz, M. Ben Haha, K. Scrivener, “Development of a new rapid, relevant and reliable (R3) test method to evaluate the pozzolanic reactivity of calcined kaolinitic clays”, *Cem. Concr*, Vol. 85, 2016, pp. 1–11.
12. European Standard EN 196-1, “Methods of testing cement - part 1: determination of strength”.
13. M. Antoni, J. Rossen, F. Martirena, K. Scrivener, “Cement substitution by a combination of metakaolin and limestone”, *Cem. Concr*, Vol. 42, 2012, pp. 1579–1589.
14. L. Vizcaíno-Andrés, S. Sánchez-Berriel, S. Damas-Carrera, A. Pérez-Hernández, K. Scrivener, M.-H. Fernando, “Industrial trial to produce a low clinker, low carbon cement, Mater”. *Constr*, Vol. 65, Issue 317, 2015.
15. S. Bishnoi, S. Maity, A. Mallik, S. Joseph, S. Krishnan, “Pilot scale manufacture of limestone calcined clay cement: the Indian experience”, *Indian Concr*, Vol. 88, Issue 7, 2014, pp. 22–28.
16. A. Emmanuel, P. Halder, S. Maity, S. Bishnoi, “Second pilot production of limestone calcined clay cement in India: the experience”, *Indian Concr*, Vol. 90, 2016, pp. 57–64.
17. F. Avet and K.L. Scrivener, “Investigation of the calcined kaolinite content on the hydration of Limestone Calcined Clay Cement (LC3)”, *Cem. Concr*.
18. H. Maraghechi, F. Avet, H. Wong, H. Kazemi, K. Scrivener, “Resistance of limestone calcined clay binders with various kaolinite contents against chloride transportation”. (In preparation).
19. ASTM, C1543-10a, “Standard Test Method for Determining the Penetration of Chloride Ion into Concrete by Ponding”, *ASTM International, West Conshohocken, PA*, 2010.
20. M. Antoni, “Investigation of Cement Substitution by Blends of Calcined Clays and Limestone”, *EPFL thesis*, 2013, pp. 6001.

AUTHORS PROFILE

J. Lavanya is doing his Master of Technology in Structural Engineering at KoneruLakshmaiah Education Foundation (Deemed to be University), Vaddeswaram, Guntur district, Andhra Pradesh, India.

V. Ranga Rao is working as Professor in Department of Civil Engineering at KoneruLakshmaiah Education Foundation (Deemed to be University), Vaddeswaram, Guntur district, Andhra Pradesh, India. He is pursuing Doctorate from Ph. D. on "**Conventionally reinforced concrete columns with cement from industrial wastes under uniaxial bending**" from Andhra University, awarded in the year 1999, and M. E. on Structural Engineering from Annamalai university, awarded in the year 1990 with First class,and M. Tech. on C. S. C. from Vinaya Mission, awarded in the year 2007 with first class, andB. Tech on Civil Engineering from NIT-Bhopal, awarded in the year 1985 with first class.Hepublished 20 journalsin International and national. He is having 28-years of teaching experience. His research area is concreteStructures and Building materials.

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication