The Non-Carbon Kaolinite; Part Substituent of Cement in Concrete

ABSTRACT

Concrete lavishly used as an anthropogenic building material. Globally the cement sector emits about 8% of CO_2 (Carbon Dioxide), generated at a ratio of 1MT of CO_2 per1MT of cement clinker sintering. Environmental concerns for its degradation through cement and its products play a pivotal role in urban development. To restrict cement production, natural clay materials and wastes from industries are in to replace cement partly or wholly. The present search is the usage of Metakaolin (MK), an abundantly available clay in India, as a substituent for cement. The physical, chemical, and mechanical properties of the metakaolin concrete investigated using XRF spectrometer, Scanning Electron Microscopy and universal testing machine following laboratory procedures. The efficiency of MK-concrete at different percentage mixes (0-30%) of ordinary Portland cement replacement at water-cement ratio 0.48 for all the mixes observed. The results suggested that concrete strength reduced significantly during the initial hydration period, particularly at high MK content. The application of up to 15 per cent MK beyond 28 days curing triggers initial setting, time, rises in concrete strength, and increases durability and is also not affected by alkali-silica gel reaction, chloride and sulphate attack. Depending on the age of curing and the MK-concrete durability increases.

K**ey Words:** Metakaolin, Conventional Concrete, properties of concrete, XRF study, Durability of concrete, China clay

1. INTRODUCTION

Kaolin is $Al_2O_3{\cdot}2SiO_2{\cdot}2H_2O$ (the hydrated Aluminum Silicate. The Metakaolin (MK) is highly reactive calcined clay, produced by charring kaolinite at 600 to 900^{0}C. High-reactivity MK ($Al_2Si_2O_7$) is commonly available in market as china clay, used for pottery and glasses. It is one among the cementous constituents with pozzolanic properties used for high-performance concrete. As a good pozzolanic material, MK can replace cement (partly) in cement concrete (CC) and save the environmental degradation, Siddique et. al., (2009), Sposito G., (2012), and Khatib et al., (2018), Verma et al., (2021). MK optimized carefully for glazing colour, removing neutral crusts and varying particle size. The MK is extremely sensitive white powder, which is stable in look and performance. Metakaolin is in research interest for its highly cementous properties, suggesting the adaptation of Metakaolin as a supplementary cementing material (SCM). Like additional blending cementous materials, MK is a by-product or direct product obtained through the calcination of kaolin clay between 650 and 800^0 C whereas cement is processed at 1450^0C (so produce more CO_2), Glavind M., (2009).

Kaolin (a healing drug in Ayurveda) is a natural clay in (Kao-ling hill China) is safe in use as medicine during diarrhea, for sores and swelling of the mouth cavity, stops bleeding, filler for tablets, intestinal infections etc. *(Attarah, 2021*, NCBI -2021*)*. The industrial application of Kaolin is paper. ceramics, ink, paint, plastics, agro-chemicals, insecticides, soaps /detergents, rubber, ink, fiberglass, catalysts, and many other trades. The green MK-concrete, the Kaolinite swell, and act as diluent, disintegrating element, binder, amorphizing, particle film coating, emulsifying, pelletizing, granulating, and suspending agent, waterproof blockade that supports construction of sewerage systems, underground tanks, waste, and nuclear storing units, Murray, (1961), Bundy (1993),. *Awad et al., (2017), Boyer et al., 2021)*

2. LITRETURE REVIEW

Sahin et al, 2008, Holland et. al., 2016, 3. Dezfouli, A. A. 2021**,** have reported that Metakaolin as pozzolanic materials that would help to build early and long-term strength enhancing its resistance to water transportation and diffusion of harmful ions that lead to matrix degradation. Justice, et. al., (2005) mentioned that finer Metakaolin and Silica fume (8% by weight) can substitute of cement and portrays higher strengths and greater toughness, shrinkage, longevity than the standard mixes. The MK blended concrete is ecofriendly and environment sustainable material Sabir et. al., (2001), Glavind M. (2009) and Panser D. K. 2019.The Metakaolin and Fly ash (15% each by weight) have improved the concrete strength and durability Pacheco T. F. et al (2011). The Metakaolin decreases the concrete strength and workability and High Range Water Reduction Admixtures (HRWRA) are needed to achieve the required slump due to deflocculating properties of MK particles Paiva. H et al (2012). The Metakaolin-Ca $(OH)_2$-water and Fly ash-Ca$(OH)_2$-water has the overall rate of reaction is high in early OPC-MK concrete and initial stage there is a mild rate of action between Fly ash-Ca$(OH)_2$-water as compared with Metakaolin-Ca$(OH)_2$ and water Dojkov. I et al (2013). MK is a good pozzolanic material and can replace cement (partly) in cement concrete (CC), Siddique et. al., (2009), Sposito G., (2012) and Khatib et al., (2018). Blended cement concrete with MK can increases workability, performance (up to M70), self-compacting, quickly reduces initial setting time, and increases strength up to 10% replacement of cement Malagavelli et al., (2018). Metakaolin as small particle size as compared to OPC has (~1–2 μm) and higher surface area but larger in contrast to silica flume Keleştemur et al., 2010.

3. Reasons for study:

The current technological advancement should adhere to the sustainable development goal (SDG) prescribed in Parish Agreement-2015 for safe, reliable, affordable, resilient, and sustainable environment combating climatic impact. However, the excessive emission of greenhouse gases is the major challenge to achieve SDG-13. Cement production contributes to over 5% of the global carbon dioxide CO_2 emissions with environmental deterioration Damtoft et al., (2008).

The reason is the production of intensive high energy from calcined clinker and the removal of CO_2 from limestone materials. To reduce atmospheric degradation from cement factories; an innovative natural material like MK can be thought off.

Present work envisages finding the behavioral changes of concrete when replace cement partly by metakaolin. The research also includes the performance of concrete by using both metakaolin and admixture with respect to mechanical strength such as compressive, tensile and flexural.

4. Materials and Methods

Metakaolin (MK) used in preparation of china clay (ceramics) which is obtained when the kaolinite is dehydroxylated. To reduce the anthropogenic environmental footprint, the cement industries need replacement through other cementous materials as CO_2 production contributes 8% of total generation is from Cement Industries (IPCC 1997 and Gibbs et all 1999). India has produced 337.32MMT of cement during 2018-19, predicted to rise to 547MMT during 2020 (IBEF data 2019). To reduce the stress of CO_2 on the biodiversity, it is essential to replace cement by some iso-constituent materials. Different waste products like red mud, pumecrete, ground granulated blast furnace slags, fly ash etc. have been tried and partly successful (Nayak and Mishra, 2017, Majumdar and Mishra 2017, Das and Mishra 2020) which are industrial waste products and in addition add to environmental pollution during their disposal.

Kaolinite (alumina, (39.8 %); silica, (46.3 %); water (13.9 %) is an easily available soil as Kaolin along the east coast of India. It has cementous properties. To test the strength and durability of concrete, the cement can have replacement with Metakaolin fine aggregates (MKF) at various proportions. The properties were under investigation in the laboratory of Centurion University of technology management (CUTM). Without the presence of free calcium chloride, other technological advantages were under evaluation for the substituted MK-concrete and the similar mixes of conventional cement concrete (CC) mixes.

Present study envisions finding out the behavioral change of concrete when used with metakaolin to replace cement. Furthermore, this study also includes the performance of concrete by using both metakaolin and admixture with respect to mechanical strength such as compressive, tensile and flexural.

(A) Kaolin as Clay minerals India

India has produced 337.32MMT of cement during 2018-19, predicted to rise to 547MMT during 2020 (IBEF, 2019). To reduce the stress of CO2 on biodiversity, it is essential to replace cement with some iso-constituent materials. Different industrial waste products that create environmental pollution like red mud, pumecrete, ground granulated blast furnace slags, fly ash etc., have been tried and partly successful (Nayak and Mishra, 2017, Majumdar and Mishra 2017, Das and Mishra 2020). In addition, metakaolin can be preferred as an alternate source of SCM. Metakaolin used to prepare china clay (ceramics) when the kaolin is dehydroxylated. India has a potential of 29.35bnMT of kaolin in different pockets, and state wise resources depicted in **Fig.1.** From the figure, most of the states of India have sources for kaolin. Different cement factories in India use kaolin as raw materials, and the usage during 2013-14, 2014-15 and 2015-16 were 1.43MMT, 1.28MMT and 1.58MMT, respectively.

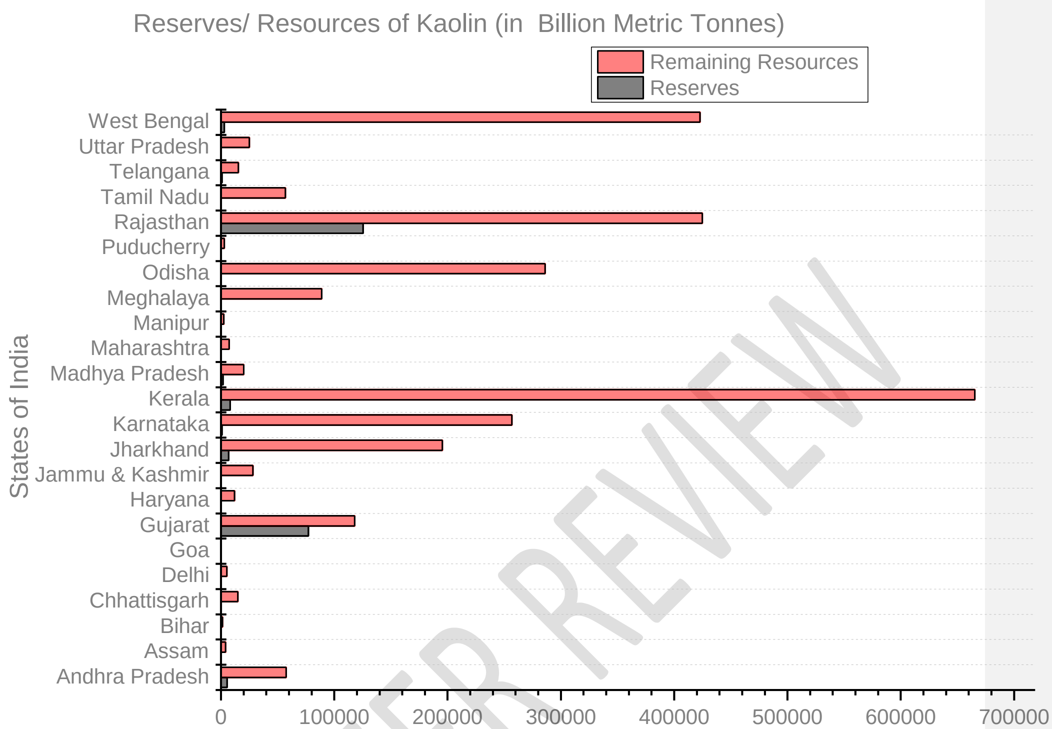

Fig 1: The state wise reserves and resources of Kaolin in India (20175); Sour: Indian Mineral book -2018 (57^{th} edition, Kaolin)

5. Materials and methods:

(A) Kaolin:

Kaolin ($Al_2Si_2O_5$ $(OH)_4$ with 0-4molecules of H_2O) is white soil available in the village Gaoling in Jianxi province, China. It was used in past for preparation of famous china pottery. Metakaolin, has the advantage of very fine particle size of ~ 1.0 to 2.0µm with large surface area which undergo quick pozzolanic reaction that lower the diffusion coefficient matched with OPC particle so keep MK in advantage position to replace cement. India has a potential of 29.35bnMT of Kaolin in different pockets and state wise resources is in **Fig 1.** Different cement factories in India are using Kaolinite as raw materials and their consumptions during 2013-14, 2014-15 and 2015-16 were 1.43mnMT, 1.28mnMT and 1.58mnMT respectively. They used not only in cement factories but also in ceramic, cosmetic, glass and many other factories. The kaolinite soil either powdered or pelleted is under heating up to 750^0 C by flash calcination or rotary kiln calcination yields Metakaolin (MK), (Verga G., 2007). On heating the Kaolinite clay gives of two water molecules to form Al2O3.2SiO2.2H2O and later the structure breaks down and forms Al2O3.2SiO2 and the process is called dehydro-oscillation, forming 39.5% Al2O3 and 46.5% SiO2 and rest water Bilijana et. al., (2010).

{Si4}Al4O10 (OH) 8, n (H2O) [n= 0to 4) → Al2O3.2SiO2.2H2O → Al2O3.2SiO2 + n H2O

$$\underset{\text{(Kaolin)}}{Al_2O_3\,(SiO_2)_2\,(H_2O)_2} \underset{750^0C}{\Rightarrow} \underset{\text{(Metakaolin)}}{Al_2O\,(SiO_2)_2\,(H_2O)_4} + (0\text{-}4)\,H_2O$$

India has a reserve of 2941.24MMT (2018) and state wise distribution comprises of Kerala (≈ 23%), followed by Rajasthan (19%), WB (14%), Odisha (10%) and Karnataka (9%). But the statewide exploration of Kaolin in India Gujarat (54%); Kerala (24%), Rajasthan (16%), WB (3%) and other states 3%. The high potential natural resource can be under best utilization if replaces cement in use as per Indian mineral yearbook 2018.

6. RESEARCH SIGNIFICANCE

To find out the mechanical strength such as compressive, tensile and flexural strength of concrete by substituting Mk by cement by proportion of 10%, 15%, 20% and 30%

Comment [I1]: Please explain the hypothesis of the researchers calling for the selection of these ratios

To study the behavioral change of concrete when used with metakaolin in replacement of cement.

To study physical properties of concrete like permeability, durability, flexibility etc.

Comment [I2]: No tests were performed for these properties to show the impact of cement replacement, Please attach the tests for that

To prepare a concrete with more advantages than the conventional concrete.

This study also includes the performance of concrete by using both metakaolin and admixture with respect to compressive strength, tensile strength and flexural strength.

7. MATERIALS USE IN EXPERIMENTAL INVESTIGATION

A CEMENT

Ultra Tech cement of 53 grades was in use in the MK-concrete design procedure. Specific gravity (Sp. Gr.) as 2.91, fineness modulus (FM) was 4.6%, found in the CUTM concrete laboratory.

B METAKAOLIN

The analysis of chemical composition of both metakaolin, and OPC conducted by the X-Ray Fluorescence Spectrometer (XRF) (Epsilon-1; PANALYTICAL). The chemical analysis exhibited that higher alumina and lower CaO was present in the metakaolin. In OPC sample calcium oxide is predominant (**Fig 2**). The Specific gravity of the cement and metakaolin were 2.91 and 2.8 respectively, and the fineness modulus (FM) of the cement and metakaolin were 4.6% and 5 respectively in close proximity. To test the mechanical strength and durability of concrete, the partial replacement of the cement by Metakaolin as fine aggregates (MKF) at various proportions tried. The longevity, durability, and strength properties tested in the laboratory of Centurion University of technology management (CUTM).

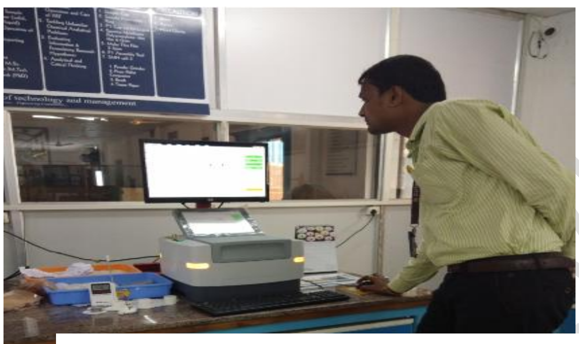

Fig 2: The chemical composition of cement and MK as determined from XRF

Table 1. Comparison of chemical composition of Metakaolin and OPC grade 53 (Ultratech)

Chemical composition (%)	SiO_2	Al_2O_3	CaO	Fe_2O_3	Mg O	K_2O	SO3	LOI
Metakaolin	53.7	39.1	0.7	4.7	0.41	0.48	0.25	0.65
Cement	21.37	5.71	55.41	3.65	1.73	0.45	1.55	3.87

(C) SEM photomicrographs of metakaolin

Field Emission Scanning Electron Microscopy (FESEM) coupled with Energy Dispersive Spectrometer (EDS) analysis was carried out for morphological analysis of metakaolin using Carl Zeiss, Germany (Model: Supra 55) (**Fig 3**). The obtained photomicrographs are in Fig.2. Inference from the figure, it can be observed that the sample comprised of higher alumina content. However, the deficiency of CaO in MK can be adjusted during partially substitute of cement in cement concrete as follows

$$\text{CaO (from cement)} + \text{Water} \rightarrow \text{C-S-H gel} + \text{Ca (OH)}_2$$

CaO (from cement) + Metakaolin (MK) → C-S-H gel

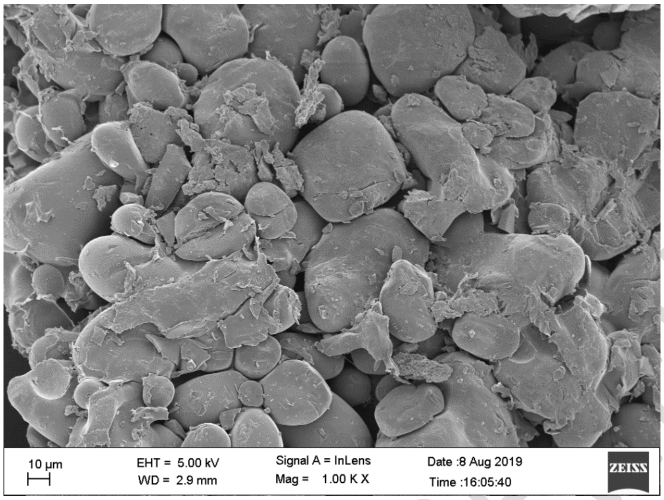

Fig. 3: SEM photomicrographs of metakaolin

(D) Advantages of MK cement concrete

1. Usage of metakaolin in concrete speeds up concrete's initial setting time.
2. Develop concrete's early age strength, allows early removal of the formwork, and thus enhances the rate of production.
3. Metakaolin absorbs calcium hydroxide thereby avoiding the alkali-silica gel reaction.
4. Metakaolin use increases resistance to sulfate attack, chemical attacks and freezing and thawing. This reduces the shrinkage and efflorescence Verma et al, (2021).

(E) Physical and chemical differences between MK and OPC

The physical properties scaling for Specific Gravity and Fineness Modulus are nearly equal. The X-Ray Fluorescence Spectrometer (XRF) (Epsilon-1; PANalytical) have been used to find the metal oxides present in both the OPC cement and the Metakaolin (MK) sample. After comparison, higher alumina and lower CaO percentage observed in the MK **(Table - 2).**

Table2: The difference in physical properties of cement used and the Meakaolin

Chemical Composition	Formulae	Metakaolin %	OP Cement (%)
Physical Form	Powdered Form	Powdered	Powdered
Colour		Off white	Cement colour
Specific Gravity		2.8	2.91

When MK partially substitutes cement, the deficiency of CaO, the process of adjustment of CAO in gel formation reaction is as follows

$$CaO \text{ (from cement)} + Water \rightarrow C\text{-}S\text{-}H \text{ gel} + Ca(OH)_2$$

$$CaO \text{ (from cement)} + Metakaolin (MK) \rightarrow C\text{-}S\text{-}H \text{ gel}$$

(F) Setting Time

One of the additions of water to dry concrete mix, it hydrates and changes its plastic stage to hardened stage. IS: 4031 (Part 5):1988 specify that the complete cycle starts 30mnts as IST (initial setting time) after start of hydration reaction and final loss of plasticity as FST (final setting time) which takes 10hours (Table 3).

Table-3 Initial and final setting times of Metakaolin concrete at various mix. proportions

% of MK in mortar	Std consistency (%)	I.S.T	F.S.T
N(MK0)	35	33min	8hr55min
MK10	37	8min	8hr30min
MK15	39	5min	8hr15min
MK20	41	4min	8hr2min
MK30	43	4min	7hr50min
MK: Metakaolin; Std: Standard; I.S.T. (initial set time) F.S.T; (Final set time)			

The advantage of adding MK concrete at various grades have shown that the IST and FST is much earlier than the conventional cement concrete. So, the MK concrete is best applicable for underwater concreting, closure of dams etc.

(G) Fine and Coarse Aggregates

Daya River sand was in use as fine aggregates of specific gravity of 2.64 confirming to IS 383 1970 (revised 2016) on passing through 4.75 mm sieve. Mechanically crushed black hard granite stone chips (12mm to 20mm) was in use in manufacturing in M25 Cement Concrete.

(H) Super-Plasticizer

Armix EmmeCrete PC10 (Supper arment) is a high performance super-plasticizer (carboxylic ether polymer with long lateral chains) used in this concrete mix with pH 6.0, specific gravity 1.20kg/lit. Armix EmmeCrete PC 10 have applications like achieving early strengths (compressive, flexural), eco-friendly, less permeable, reduced creep and shrinkage, highly durable and workable. The plasticizer used in high performance durable concrete for manufacture of paver blocks, Hume pipes and electric poles. The photograph of cement, Metakaolin and Armix EmmeCrete PC10 are in **Fig 4; (a), (b) and (c).**

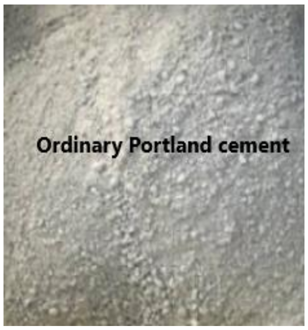

Fig 4(a). Cement Fig 4(b): Metakaolin Fig.4(c): Super Plasticizer

8. <u>DESIGN MIX CALCULATIONS</u>

The concrete grade M25 was prepared as per standard concrete mix (IS10262-2019 & IS456-2000). For M25 design mix, the targeted compressive strength (f'_{ck}) uses the formulae as per IS-456: 2000.

$$f'_{ck} = fck+1.65 *S = 25 + 1.65* 4 = 31.6N/mm^2$$

where the standard deviation (S) = 4N / mm), for f'_{ck} , the Target Mean strength of concrete cube (average) after curing for 7, 14 and 28 days, fck = Compressive strength of the cube after curing for 28 days. The water cement (WC) ratio = 0.48. The quantity of ingredients were Ultra Tech cement= 400 kg / m3, Local tap water=191.5ltr / m3, fine aggregate (Daya river sand) = 646.27kg / m3, HG chips (12mm to 20mm) as coarse aggregate (black hard granite of size 12mm to 20mm) = 1240.32 kg\m3. Proportion by weight of the final design mix was 0.47:1:1.615:3.10 whereas by material weight of water, Cement, Sand and BHG chips were 191.58liters, 400kg, 646.27kg and 1240.32kg for finding the M-25 concrete. Water, Ultra Tech Cement, River sand, and HG chips respectively. Test cubes, test cylinders, and specimen beams were casted and were cured for different mixes and submerged in portable supply water for 7, 14, and 28days.

9. <u>EXPERIMENTAL INVESTIGATION & RESULT</u>

Comment [I3]: I suggest separating the method of work from the results to be more accurate and clear

The specimen cubes possessed target strength in excess of 31.6 N/mm2 for the control mixture at 7, 14 and 28 days. The details of the mixture (MK10, MK15, MK20, and MK30,) were in adaptation to examine the impact of small w/c ratio on CC containing Metakaolin on the spatial strength and durability properties. Concrete put in three layers in regular molds, and the tamping rod compacts each layer and vibrates on the table vibrator for 10 to 15 seconds for full compaction. For smooth surface, finally the top surfaces of concrete specimens were completed. Cubes (150x 150 x 150mm), cylinders (150 x 300mm), beams (100x 100 x 500mm) of standard sizes have been cast and tested for a water submerged period of 28 days and tests for comp. strength, (STS) split tensile strength & density are tabulated in T**ables -4**.

Table-4: Mix Proportions of various weight percentage of MK in cement concrete grade

	PERCENTAGE OF METAKAOLIN				
	0%MK	10%MK	15%MK	20%K	30%MK
	MIX DESIGN				
Ingredients	MIX-M0	MIX-M1	MIX-M2	MIX-M3	MIX-M4
Cement (ultra Tech) (kg/m³)	400	360	340	320	280
Metakaolin(kg/m³)	0	40	60	80	120
Fine Aggregates (kg/m³)	646	646	646	646	646
Coarse Agg. 20mm (kg/m³)	1240	1240	1240	1240	1240
Super plasticizer (% of binder)	0	1.5	1.75	2.0	2.25
Slump (mm)	78	85	87	91	96
Water (liter)	191	191	191	191	191

Compressive strength

The compressive strength of the cube increased with the addition of metakaolin in the mixture initially. The maximum compressive strength achieved when 15% metakaolin (MIX-M2) was present in the mixture (Fig 5). The results specify that the compressive strength of the cube increased with the increase in weight percentage of metakaolin in the mixture up to 15% and after that decreased with the further addition of metakaolin in the mixture. Thus, the compressive strength of the cube varied between 19.25 to 22.10 N/mm^2. The attributable reason for reaching the maximum compressive strength when cement partly substituted by MK is due to the ultimate hydration reaction of the green concrete. The increase in metakaolin percentage shall weaken the Vander wall forces and retards the hydration reaction (Shown in Fig 5).

Table 5. Compressive strength results of cube (UTM results)

Mix Proportions	**Compressive strength of cube after curing (N/mm^2)**		**% increase/decrease in strength**
	7 days	28 days	
MIX-M0	19.28	30.97	
MIX-M1	20.97	34.18	10.36%

MIX-M2	21.62	35.25	13.82%
MIX-M3	22.18	36.18	23.28%
MIX-M4	19.95	33.18	07.14%

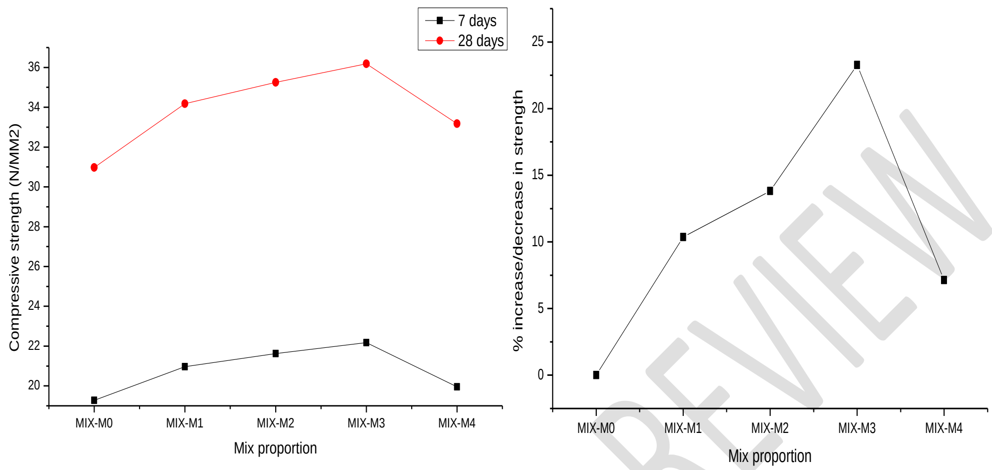

Fig 5(a) compressive *strength* of MK-conc. cube; Fig 5(b); % of increase/decrease in strength

Split tensile strength

Initially the split tensile strength of the cylinder increased with the addition of metakaolin in the mixture up to 15% weight of the mix and after that decreased with the further addition of metakaolin in the mix.

Table 6. Split tensile strength of specimen cylinder (results of UTM)

Mix Proportions	Spilt tensile strength of cylinder after curing (N/mm^2)		% increase/decrease in strength
	7 days	28 days	
MIX-M0	2.12	3.22	0.00%
MIX-M1	2.28	3.45	7.14%
MIX-M2	2.29	3.68	14.28%
MIX-M3	2.36	3.88	20.50%
MIX-M4	2.15	3.35	4.04%

The maximum compressive strength achieved when 15% metakaolin (MIX-M2) was present in the mix. This is in agreement with the study conducted by Ayobami et al., 2019. Dinakar et al., 2013 suggested that the split tensile strength of metakaolin is variable according to the rise in the compressive strength of the mixture.

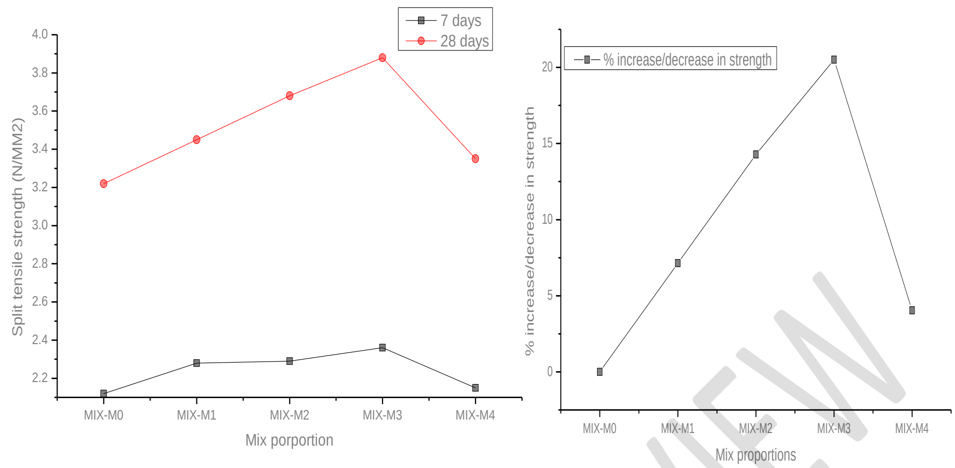

Fig 6(a). Spilt tensile strength of cylinder; Fig 6(b). Percentage increase/decrease of spilt tensile strength

Flexural strength

The flexural strength properties enhanced initially when partly replaced by metakaolin (until 15% MK addition) (shown in Table 8). It is due to the Pozzolanic and filler reactive properties of the cementitious materials. The gain in strength properties results from a faster hydration reaction between Ca $(OH)_2$ and the metakaolin when water is present. It can be asserted that the presence of alumina in metakaolin enhances the cementitious properties (C-S-H gel formation), which converted into calcium aluminates hydrates and alumina silicate hydrates (Lal and Bishnoi, 2015). After reaching the optimum mixing percentage, the strength properties deteriorate gradually due to the reduced extent of Ca $(OH)_2$ for cementitious reactions [Table 7, Fig 7 (a) and Fig (b)].

Table 7. Flexural strength of beam (UTM results) of various mix MK concrete

Mix Proportions	**Flexural Strength of beam after curing (N/mm^2)**		**% increase/decrease in strength**
	7 days	28 days	
MIX-M0	2.45	3.37	0.00%
MIX-M1	2.78	3.67	8.90%
MIX-M2	3.32	3.74	10.98%
MIX-M3	3.16	3.86	14.54%
MIX-M4	2.57	3.52	4.50%

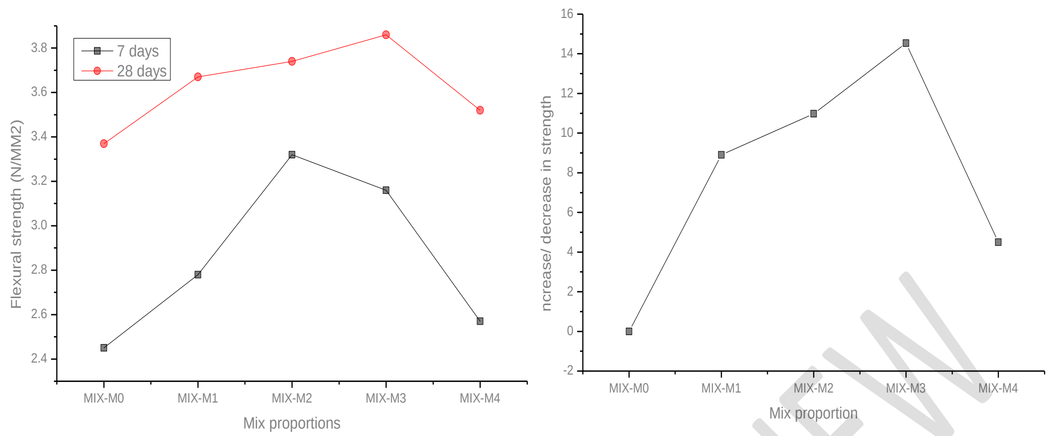

Fig 7(a). Flexural strength of beam; Fig 7(b) Percentage increase/decrease of flexural strength

Non-destructive Rebound Hammer test

Before conducting destructive tests in UTM machine a non-destructive test conducted by rebound hammer and the test results are as follows (presented in Table 8). The non-destructive test results exhibit that the MK-concrete satisfies the required compressive strength as per the design mix.

Comment [I4]: Please explain the reason for adding a non-destructive test while the results of the compressive strength test are present

Table 8: The rebound hammer test conducted before conducting by Universal testing machine

Sl No	Type of MK concrete	Test results of rebound hammer (28days curing) in N/mm^2
1	MIX-M0	29.90
2	MIX-M1	33.10
3	MIX-M2	35.20
4	MIX-M3	36.10
5	MIX-M4	33.10

10. **Discussion:**

India has old history of using Kaolin or metakaolin as use as medicine, pottery and other industrial uses. The cement industry consumes 45% of metakaolin trailed by ceramic (42%) in India. Apart from the lion's share of use, the industries like paper, ceramics, rubber, paint, plastics, agro-chemicals, insecticides, soaps /detergents, ink, fiberglass, catalysts Pesticide, *etc.* put away the residual 13%. The BIS (Bureau of Indian Standards) enforced of some codes for different uses of metakaolin. They are IS:2840-2002 (2nd Revision, Reaffirmed 2008) for ceramic; IS:68-2006 for paint; [IS: 505-1995; (3rd Rev., Reaffirmed 2011)] for paper, rubber and textile industries, [IS: 1463-1983 (3rd Rev., reaffirmed 2000)] for cosmetics, [IS:7589-1974, (Reaffirmed 2011)] for Explosive & Pyrotechnic Industry, as per 57th edition Indian mineral year book 2018(part III).

However, the use in quantities of Kaolin in domestic/health care sector and metakaolin in industries is so less that it can have direct partial replacement of cement in concrete. It is advantageous to replace metakaolin in high grade concrete and have successful performances like improved, strength, durability, quick in setting, safe from chloride attack, and sulphonation. Blended MK concrete can reduce environmental pollution in coming days Wang et al., 2021[46].

Use of concrete in ever-increasing building construction is as old from Greek/Roman civilization. The present generation of GHG gasses and high-energy consumption from cement and building materials, allied industry has made the products responsible for environmental deterioration. Innovative advancement in construction has developed various types of concrete like quick/delayed setting, high strength, high performance, and self-compacting concrete. On replacing cement by metakaolin in concrete uses can enhance the strength properties, like compressive strength by (+23.28%), and split Tensile strength by (+20.50%), and in flexural strength as (14.54%). The blended concrete can modify the concrete characteristics, lowers cost, reduce cement consumption, enhance durability and a novice way to waste disposal. MK concrete has lower cost, as the kaolin is plenty in availability in India can be the best choice for replacement.

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I suggest replacing it with an alternative paragraph that really discusses the results

11. CONCLUSION

The strength of meta-kaolin-concrete with at 15% replacement of cement gives best result among all trial percentages of substitute. The meta-kaolin, (blending at 15%), the compressive strength increases by (+23.28%), and split Tensile strength by (+20.50%), and in flexural strength as (14.54%) at the age of 28 days of curing period.The following conclusions inferred from the investigation based on the impact in concrete of partial substitution of cement with Metakaolin;

Kaolin can by a suitable natural replaceable substitute for traditional concrete after calcination to metakaolin and production of Mk-Concrete.MK-concrete significantly increases the comp. and flexural strength as opposed to traditional concrete. As per literature they are durable, quick setting properties without being affected by chloride, sulphate. Workability decreases as percentage of blending beyond 15% by Metakaolin in cement concrete surges. The admixture quantity needs snowballing gradually with increase in

Comment [I6]: Why are there characteristics in the conclusion that are specific to other literature?
I suggest moving it to the introduction with an explanation of this literature

percentage of Metakaolin. The optimized strength increases with increase in Metakaolin content up to 15% replacement of cement. Controlled use of MK in cement concrete can reduce the burden of CO_2 loading the Indian upper atmosphere.

COMPETING INTERESTS DISCLAIMER:

Authors have declared that no competing interests exist. The products used for this research are commonly and predominantly use products in our area of research and country. There is absolutely no conflict of interest between the authors and producers of the products because we do not intend to use these products as an avenue for any litigation but for the advancement of knowledge. Also, the research was not funded by the producing company rather it was funded by personal efforts of the authors.

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