Evaluating effects of various mineral admixtures when replaced with a part of cement in concrete

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Abstract. With increase in the demand of concrete there is increase in demand of cement. Manufacturing cement leads to emission of harmful gases like carbon-di-oxide. This emission of harmful gases in environment led to global warming. On another hand increasing waste landfills of different materials such as brick-dust, ceramic-dust, husk-ash and many more leads to environmental pollution. Hence to save the environment from the harmful gases and also from increasing landfills we make use of various waste material termed as pozzolans. In the pre-requisite research we had taken three different pozzolans say china-clay, flue-ash and brick-kiln-powder. All the three pozzolans were replaced with the part of cement in concrete. The replacement was done to evaluate the pozzolans effect on concrete. The pozzolans are replaced in various set proportions. The replacement proportions were 3%, 6%, 9%, 12%, 15%, 18% and 21%. The concrete developed using various proportions of different pozzolans were tested for various test. The tests were done on fresh concrete and also after concrete get hardened. The tests conducted were C-S, S-T-T, and workability test. In total 189 cubes samples and 189 cylinder samples were casted. The investigation at last concluded that 12% of china clay, 21% of flue-ash and 18% of brick-kiln-powder separately when replaced with cement showed tremendous results as compared to normal concrete. Both C-S and S-T-S were seen to be increasing in same pattern. As the proportion of china-clay increases in concrete the value of slump tends to decrease. But in case of flue-ash it was increasing with increase in % replacement of flue-ash. The slump value in case of brick kiln powder assumed to be higher at 12% replacement. Hence, it was concluded that use of pozzolans in concrete in replacement to cement is good.

Keywords: China clay, Flue ash, Brick kiln powder, Environment friendly concrete and Compressive strength.

1. Introduction

“Concrete” a material of supreme importance in construction sector is a combination of various components such as cement, aggregate and water[1], [2]. Cement being one of the many key components used for concrete production, contributes to global warming[3]. Production of cement in various cement industry leads to production of carbon-di-oxide. The carbon-di-oxide present in the environment considered to be the major cause of global warming. Carbon-di-oxide in our surrounding stays in the environment for long time and also its molecules do not hold heat. Therefore, carbon-


dioxide is acknowledged as one of the largest contributors to global warming[4]. But, since cement helps in holding aggregates together, it is one of the most required materials. Therefore, to make concrete eco-friendly, we use various pozzolans in replacement to cement in concrete.

“Concrete” a word of Latin origin is a revolutionary material. This material is known to be most passable material in the infrastructure industry[5]. The word concrete is devised from another word concretus. Concretus means condensed or compact. Concrete is assumed to be the most historical material as evidence of its use by Romans were found in around 300 BC to 476 AD. Some evidences of concrete floors were also unearthed in the royal palace of Greece. When chemically inert materials like aggregates are mixed with cement and water it forms concrete[6]. Concrete being a most valuable structural material provides strength to the structure. Nowadays, due to emission of carbon-dioxide from cement, concrete researchers advising everyone to use pozzolanic concrete. As we know that cementitious concrete is a lime-based concrete and pozzolanic concrete is a silica-based concrete.

Cement is used as material that helps in binding the ingredients of concrete together. Cement provides both strong bond as well as strength to concrete. Amount of cement and formation of di-calcium silicate and tri-calcium silicate at the time when cement reacts with water is responsible for both early strength and long term strength. Depending upon its use cement is classified as ordinary-portland-cement, and pozzolanic-portland-cement. The Portland cement was pioneered by Joseph Aspdin in year 1824. Cement shows both adhesive as well as cohesive properties when reacts with water. Cement comprises materials like shale, clay, furnace slag, lime-stone, marl, and many other ingredients. Cement production emits enough amount of carbon-dioxide that acts a part to global warming. So to reduce some effect of global warming researchers advised to use pozzolans.

Pozzolanic concrete comprises of both cement and pozzolans. But when the concrete comprises only pozzolans it is named as geo-polymer concrete. Pozzolans are siliceous material which when reacts with hydrated product of cement i.e. lime acts as a binder to concrete. Using pozzolans as replacement to cement in concrete makes concrete economic and environment friendly. Pozzolans when used in concrete makes concrete structure durable.

The experimental investigation was done at site of TRIL IT city sector-59 Gurugram. According to literature review done it was noted that there are large sets of pozzolans available. Each pozzolan have its unique chemical composition and physical nature. So after reviewing the past researches I had chosen China-clay, fly-ash and brick-kiln powder. Out of all the three pozzolan fly-ash is a much known and easily available pozzolan. In the research cement is replaced in various proportions of 3%, 6%, 9%, 12%, 15%, 18% and 21% with China-clay, flue-ash and brick-kiln powder.

The research was done to compare the physical properties such as concrete workability, concrete C-S and concrete S-T-S of different pozzolanic concrete at different percentage replacements. Standard guidelines from Indian Standard Codes were referred to conduct all tests at specific temperature and humidity in the site laboratory of TRIL IT city sector-59 Gurugram.

2. Objectives of prerequisite research

In relation to previous researches as mentioned in literature review it was acknowledged that researchers are focusing on transforming cement based concrete to pozzolan based concrete. As per the data provided by various researches it can easily be understood that using cement to produce concrete is affecting the environments health. So as to make the concrete environment friendly we can use various pozzolans in place of cement. Those pozzolans can vary depending upon the availability and need. In the prerequisite research pozzolans such as metakaolin, flue-ash and brick-kiln powder are used as a cement replacement to make economic concrete.

The main aim to use the pozzolans is:

a. To get the same strength from pozzolanic concrete as we get from conventional concrete.

b. To reduce the waste amount, this contributes to landfills.

c. To make concrete environment friendly, so to reduce carbon-dioxide emission.

d. To develop a cost effective pozzolan based concrete.
3. Mineral admixtures incorporated in research

3.1. China-clay

China-clay is a form of metakaolin. It is a type of natural pozzolan[7]. It is obtained from kaolinite, a clay mineral. Kaolin being a most abundant clay mineral, when heated at a temperature of 650 to 900 degree Celsius forms metakaolin[8]. Using calcined clay a clay mineral similar to china-clay reduces concretes permeability, water-absorption and porosity[9]. When calcium-hydroxide released at the time of cement hydration when a source of china-clay reacts with meta-kaolin develops hydrated phase [10]. Metakaolin used to extract calcined clay becomes expensive when developed from high grade kaolin clay calcination[11]. Given below in table 1 and table 2 are the chemical composition and physical properties of china clay respectively.

| Chemical-Components | CaO | SiO$_2$ | Al$_2$O$_3$ | Fe$_2$O$_3$ | MgO | Na$_2$O + K$_2$O |
|---------------------|-----|---------|-------------|------------|-----|-----------------|
| Proportions         | 0.26| 53.7    | 42.8        | 0.53       | 0.29| 0.33            |

Table 2: Properties (Physical) of china-clay

| S.No. | Properties        | Results                    |
|-------|-------------------|----------------------------|
| 1     | Colour            | White + Cream              |
| 2     | China-clay specific gravity | 2.48 (gm/cm$^2$)      |
| 3     | Size of particle  | 0.0011 cm                  |

[12], author in his research studied the effect of kaolinite when replaced with cement to produce mortar and concrete. The research was done at various replacement % of 5, 10, 15 and 20. Author acknowledged that with the incorporation of kaolinite the consistency of the binder increases significantly. Both for concrete and mortar 15% of metakaolin incorporation was suitable and showed best results. In comparison with control mix concrete the concrete strength with metakaolin incorporated in it was more.

[13], the research was held using Lias delta clay and the same was calcined in kiln. The calcined clay used was having mean particle diameter as 12.5µm. The author from the research concluded that for maximum samples having calcined clay the initial strength increases at slow pace. But, it was acknowledged by the author that mixes having 20 to 25% of calcined clay show long-term effect on concrete’s strength. The strength of concrete having 20 to 25% of calcined clay was observed to be higher in comparison to conventional concrete. Reduction in consistency, bleeding and shrinkage was observed when calcined clay was in-corporate in cement.

[14], the author emphasized on the effect of metakaolin when it is used as partial supplement to cement. It was M30 grade on which experimental investigation was done. In the research author replaced metakaolin with cement in various set percentages such as 0, 3, 6, 9 and 12. After experimental investigation author concluded that 12% is taken as best replacement category. All in strength of concrete at 12% of metakaolin replacement was seen to high in comparison to normal conventional concrete

3.2. Flue-ash

Flue-ash is a product similar to fly-ash. It is obtained from coal burned at the time of manufacturing electricity at power generating plant [15]. Mostly used flue-ash ranges between ten micron to hundred micron and particles of flue-ash used is finer than those of ordinary cement [15]. As per ASTM the flue-ash is divided in various classes depending up-on the chemical composition say C, F and N [16]. Given below in table 1 and table 2 are the chemical composition and physical properties of flue ash respectively.
Table 3: Proportion of chemical compounds in flue-ash

| Chemical-Components | CaO  | SiO$_2$ | Al$_2$O$_3$ | Fe$_2$O$_3$ | SO$_3$ | MgO  | Na$_2$O | K$_2$O | LOI  |
|---------------------|------|---------|-------------|-------------|--------|-------|---------|--------|------|
| Proportions         | 15.62| 52.9    | 16.87       | 3.26        | 1.75   | 1.08  | 0.33    | 0.83   | 0.44 |

Table 4: Properties (Physical) of flue-ash

| S.No. | Properties                  | Results          |
|-------|-----------------------------|------------------|
| 1     | Colour                      | White + Grey     |
| 2     | Fly-ash bulk density        | 0.989 g/cm$^3$   |
| 3     | Fly-ash specific gravity    | 2.128            |
| 4     | Content of moisture         | 3.11             |
| 5     | Size of particle            | 0.0062 cm        |

[17], the author based on his literature survey concluded that fly-ash may be a polluting agent but it acts as a useful raw material in concreting. He concluded that using fly-ash as a binding agent in cement partially or fully can help in decreasing environmental problems. The carbon left unburned has ability to enhance the adsorption capacity of concrete.

[18], the author investigated the concrete by replacing cement in various percentages such as 0, 10, 20, 30, 40 and 50. From the results it was noted that replacing flue-ash with cement increases concrete’s strength. As per results 30% of flue-ash when replaced with cement in concrete increase concrete strength by 25% as compared to conventional concrete. It was also evidenced that increasing the percentage of flue-ash in concrete decreases the workability of concrete.

[19], the author from the research concluded that with the replacement of flue-ash with cement the flexural strength of concrete was increasing. The author in his research used fly-ash and hypo-sludge both. The fly-ash used for the investigation purpose was retained at sieve of size 45 micron. W/C ratio taken was 0.48. The author reported that 20% of fly-ash when replaced with cement increases the flexural strength of concrete to its maximum.

[20], the researcher replaced part of cement by part of fly-ash and silica fumes. Fly-ash used in experimental investigation was of Class C. M30 was the concrete grade on which testing for various strength parameters was done. Slump value for various proportions of replacement was also done. The strength of samples was acknowledged to be more when super-plasticizer was used. From the result it was concluded that in comparison to silica fumes, fly-ash shows tremendous results.

3.3. Brick-kiln-powder

Brick-kiln-powder, is a material taken either directly from the landfills in brick manufacturing plant or from demolished brick structures. Brick waste used to replace cement & aggregates. Since broken brick waste aggregate are less denser hence therefore when broken brick material is replaced with fine aggregate, the density of concrete decreases. Use of red coloured brick powder contains high silica content that results in high strength [21].

Table 5: Proportion of chemical compounds in brick kiln powder

| Chemical-Components | CaO  | SiO$_2$ | Al$_2$O$_3$ | Fe$_2$O$_3$ | SO$_3$ | MgO  | Na$_2$O | K$_2$O | LOI  |
|---------------------|------|---------|-------------|-------------|--------|-------|---------|--------|------|
| Proportions         | 12.67| 40.36   | 16.12       | 13.99       | 0.46   | 3.08  | 0.1     | 2.01   | 10.74|
Table 6: Properties (Physical) of brick kiln powder

| Properties (physical)          | Results                  |
|-------------------------------|--------------------------|
| Colour                        | Orange + Red             |
| Brick-powder bulk density     | 1.72 (gm/cm²)            |
| Brick-powder specific gravity | 2.571                    |
| Brick-powder fineness modulus | 1.69                     |
| Size of particle              | Less than 150 micron     |

[22], author in his study evaluated the effect of brick aggregate on the properties of concrete. Evaluation of various properties was done using brick aggregate as replacement to coarse aggregate. The author used two brick sample of brick aggregate. Both the brick aggregate samples were replaced in proportions say 15% and 30%. The research was conducted at two different w/c ratios say 0.45 and 0.50. The result shows similar pattern of stress-strain curve for both type of aggregate samples.

[23], the author reviewed various research papers and concluded that waste of brick in any form is taken to very viable material for replacement with cement. Brick waste can be in the form of dust (Surkhi), over burned bricks, broken bricks. Etc. Waste from brick can be used to replace fine aggregate, cement and also the coarse aggregate in concrete. Author also concluded that concrete gains strength in comparison to conventional concrete when brick waste is used in concrete.

[24], the researcher replaced brick-kiln-powder by weight with cement. Replacement of cement was done up to a replacement percentage of 20%. But the author made the conclusion that 10% by weight of brick-kiln-powder when replaced with cement showed increment in the compressive strength results. The powder of brick used as replacement consist up-to 60% of silica content and rest are alumina and lime. The grade of concrete used was M20.

[25], this research includes replacement of fine aggregate with crushed brick powder. The percent of replacement were 5, 10, 15 and 20. The author concluded that replacing brick powder with fine aggregate increases the concrete’s density and leads to decrease in pores with highly compacted concrete. The compressive strength and split-tensile strength result increases to a % replacement of 10%.

4. Ingredients detailing

4.1. Cement

Cement as a part of concrete is considered to be the material of utmost importance. It acts as strengthening agent of concrete. Taking concrete manufacturing in consideration when cement reacts with water it works as a binder to cement, fine aggregate and coarse aggregate. In accordance with Indian Standard Code (IS 8112: 1989), the code for 43 grade of Ordinary Portland cement is developed by any of the two manufacturing processes that are dry manufacturing processes and wet manufacturing process. Refer table 4 for chemical composition and physical properties of cement.

Table 7: Properties of cement (OPC-43)

| Specific Gravity | Setting Time | Consistency | Fineness of cement | Compressive Strength (Cement) |
|------------------|--------------|-------------|--------------------|------------------------------|
|                  | Initial Time | Final Time  |                    |                              |
| **3.11**         | 135 min     | 260 min     | 30.5%              | 48.39N/mm²                   |
Table 8: Cement chemical composition

| Compounds | CaO  | SiO₂ | Al₂O₃ | Fe₂O₃ | SO₃  | MgO  | Na₂O | K₂O | LOI |
|-----------|------|------|-------|-------|------|------|------|-----|-----|
| Proportions | 63.27 | 24.12 | 5.03  | 4.01  | 1.58 | 1.16 | 0.19 | 0.20 | 0.44 |

4.2. Aggregate

Concrete a hard core material of construction industry consists 70% to 80% of aggregate. Therefore, it becomes matter of importance and necessary to be studied in context of concrete. Aggregates majorly have influence on the properties of concrete. Generally in purpose of construction we use aggregates maximum of size 20mm. To determine the particle size we do sieve analysis. Depending on surface area, aggregate are further bifurcated as F.A. (Fine-Agg.) and C.A. (Coarse-Agg.).

4.3. Design detailing for M30 concrete grade

Mix design is nothing but the perfect method of finding exact quantity of various ingredients to be used in manufacturing of concrete. Mix design helps in setting the proportion of ingredients to get the desirable properties of fresh as well as hardened concrete. Indian Standard Codes (IS: 10262 and IS: 456) were referred in making of mix-design for M30 concrete.

Table 9: Mix design requirement detailing for concrete grade M30

| S.No. | Description               | Values       |
|-------|---------------------------|--------------|
| 1     | Concrete Grade            | M30          |
| 2     | Type of Cement            | OPC-43       |
| 3     | Nominal Aggregate Size (maximum value) | 20 milimeter |
| 4     | Cement Quantity (minimum requirement) | 320Kg/m³ |
| 5     | W/C Ratio (maximum value)  | 0.45         |
| 6     | Environmental Conditions  | Moderate     |
| 7     | Coarse Aggregate Shape    | Crushed Angular |
| 8     | Cement Quantity (maximum) | 450Kg/m³    |
| 9     | Admixture Used            | Super plasticizer |

Table 10: Results for different material properties

| S.No. | Description     | Values      |
|-------|-----------------|-------------|
| 1     | Cement          | 3.11        |
| 2     | Fine Agg.       | 2.41        |
| 3     | Coarse Agg.     | 2.67        |
| 4     | China-Clay      | 2.48        |
| 5     | Flue-Ash        | 2.13        |
| 6     | Brick-kiln Powder | 2.57     |
| 7     | Specific Gravity | Cement 0.1 mm |
| 8     | Particle Size   | Fine Agg. Less than 4.75 mm |
| 9     |                 | Coarse Agg. 20mm (max) |
Table 11: Proportion of various materials as per mix design

| Proportions                  | 0%     | 3%     | 6%     | 9%     | 12%    | 18%    | 21%    |
|------------------------------|--------|--------|--------|--------|--------|--------|--------|
| Cement (Kg)                  | 405.48 | 393.32 | 381.16 | 368.99 | 356.82 | 344.66 | 332.49 |
| China-clay Quantity (in Kg)  | 0      | 12.16  | 24.32  | 36.49  | 48.66  | 60.82  | 72.99  |
| Flue-Ash Quantity (in Kg)    | 0      | 12.16  | 24.32  | 36.49  | 48.66  | 60.82  | 72.99  |
| Brick Kiln Powder (Kg)       | 654.6  | 654.6  | 654.6  | 654.6  | 654.6  | 654.6  | 654.6  |
| C-A 20mm (Kg)                | 436.4  | 436.4  | 436.4  | 436.4  | 436.4  | 436.4  | 436.4  |
| 10mm (Kg)                    | 729    | 729    | 729    | 729    | 729    | 729    | 729    |
| Water (Kg)                   | 182.46 | 182.46 | 182.46 | 182.46 | 182.46 | 182.46 | 182.46 |
| Super plasticizer (Kg)       | 4.05   | 4.05   | 4.05   | 4.05   | 4.05   | 4.05   | 4.05   |

5. Results analysis and discussion:

The experiments were done on fresh as well as hardened concrete. The fresh China-clay based concrete was taken to test the workability using slump cone. Compressive-strength and split-tensile-strength both tests were done on hardened concrete cubes and cylinders respectively.

5.1. Discussion and detailing of compressive strength results

In the figure given below there are the results of compressive-strength of china-clay based concrete for various replacement percentages. As per the figure, 12% of china-clay is suitable for replacement with cement in concrete. The strength for all days of curing was first increase to a 12% replacement and then decreased. As per the results conventional concrete achieves its prescribed characteristic compressive strength at 14 days of curing only.

**Figure 1:** Graph showing relation between compressive-strength and % of china-clay replaced.

Figure above show the relation in compressive strengths of china-clay based concrete as various % replacements. As per the results strength of china-clay based concrete was 46.12% more than the required strength for M30 grade. In relation with strength of conventional concrete the strength at 12%
china-clay replacement was 22.83% more. Given below is the table showing results of compressive-strength of china-clay concrete in N/mm$^2$.

In the figure given below there are the results of compressive-strength of flue-ash based concrete for various replacement percentages. As per the figure, 21% of flue-ash is suitable for replacement with cement in concrete. The strength for all days of curing was keeping on increasing upto a level of 21%. As per the results conventional concrete achieves its prescribed characteristic compressive strength at 14 days of curing only.

![Flue-Ash Graph](image)

**Figure 2:** Graph showing relation between compressive-strength and % of flue-ash replaced.

Figure above show the relation in compressive strengths of Flue-Ash based concrete as various % replacements. As per the results strength of Flue-Ash based concrete at 21% replacement was 57.13% more than the required strength for M30 grade at 28 days of curing. In relation with strength of conventional concrete the strength at 21% Flue-Ash replacement was 32.1% more. Given below is the table showing results of compressive-strength of Flue-Ash concrete in N/mm$^2$.

In the figure given below there are the results of compressive-strength of brick kiln powder based concrete for various replacement percentages. As per the figure, 21% of brick kiln powder is suitable for replacement with cement in concrete. The strength for all days of curing was keeping on increasing upto a level of 21%. As per the results conventional concrete achieves its prescribed characteristic compressive strength at 14 days of curing only.

![Brick Kiln Powder Graph](image)

**Figure 3:** Graph showing relation between compressive-strength and % of brick-kiln-powder replaced.
Figure above show the relation in compressive strengths of Brick Kiln Powder based concrete as various % replacements. As per the results strength of Brick Kiln Powder based concrete at 18% replacement was 44% more than the required strength for M30 grade at 28 days of curing. In relation with strength of conventional concrete (CC) the strength at 18% Brick kiln dust replacement was 21.1% more.

5.2. Discussion and detailing of split tensile strength results

The split-tensile strength was increasing at same rate it was increasing in case of compressive strength. The results were best at 12% replacement. The split tensile strength results were seen to 10% to 12% of the compressive strength. Split-tensile strength for all percent replacement is given in the table below. The strength given in the table is in N/mm². The table shows that split-tensile strength at 12% of china-clay replacement is 4.865 N/mm². The highest values among all % replacement for 28 days cured samples.

![Figure 4: Graph showing relation between split-tensile-strength and % of china-clay replaced.](image4)

The split-tensile strength was increasing at same rate it was increasing in case of compressive strength. The results were best at 21% replacement. The split tensile strength results were seen to 11% to 12% of the compressive strength. Split-tensile strength for all percent replacement is given in the table below. The strength given in the table is in N/mm². The table shows that split-tensile strength at 21% of Flue-Ash replacement is 5.657 N/mm². The highest values among all % replacement for 28 days cured samples.

![Figure 5: Graph showing relation between split-tensile-strength and % of china-clay replaced.](image5)
The split-tensile strength was increasing at same rate it was increasing in case of compressive strength. The results were best at 18% replacement. The split tensile strength results were seen to 11% to 12% of the compressive strength. Split-tensile-strength at all percent replacement is given in the table below. The strength given in the table is in N/mm². The table shows that split-tensile strength at 18% of Brick Kiln Powder replacement is 4.753 N/mm². The highest values among all % replacement for 28 days cured samples.

![Graph showing relation between split-tensile-strength and % of brick-kiln-powder replaced.](image)

Figure 6: Graph showing relation between split-tensile-strength and % of brick-kiln-powder replaced.

5.3. Discussion and detailing of slump cone test results:

Workability means to make something practicable or feasible. In relation to concrete, workability means ease in placement. The table above shows that we had achieved the desired workability (100mm to 125mm slump) at 9% of replacement of china-clay with cement. But, the results for both compressive strength and split-tensile strength were best at 12% replacement. It can be acknowledged from the result that the workability at 12% replacement of china-clay is less than desired. Since the value of slump at 12% comes to be 98mm, therefore we can take it as suitable proportion for every property.

![Slump result for various % replacements](image)

Figure 7: Slump result for various % replacements
In relation to concrete, workability means ease in placement. The table above shows that we had achieved the desired workability (100mm to 125mm slump) at 3% of replacement of Flue-Ash with cement. But, the results for both compressive strength and split-tensile strength were best at 21% replacement. It can be acknowledged from the result that the workability at 21% replacement of Flue-Ash is in the desired range. Since the value of slump at 12% comes to be 127mm, therefore we can take it as suitable proportion for workability.

It can be acknowledged from the result that the workability at 18% replacement of Brick Kiln Powder is in the desired range. Since the value of slump at 3% comes to be 127mm, therefore we can take it as suitable proportion for workability. The graph showing that with increasing % replacement the value of slump was decreasing constantly.

6. Conclusion

The research concluded the importance and feasibility of various pozzolans as replacement to cement in concrete. Use of mineral admixtures such as china clay, flue-ash and brick kiln powder reduces the certain amount of cement to develop concrete. It was also noticed that addition of mineral admixture as replacement to cement in concrete increases the strength. The increase in strength of concrete was noticed to be more at different % replacement for different type of mineral admixture. In comparison to conventional concrete, concrete with mineral admixture should best result in term of strength increment even at their higher replacement percentages. The workability of concrete incorporated with china clay was seen to be decreasing. Whereas, the workability in case of both flue-ash and brick kiln powder increased up-to a certain level and then decreased. Hence, from the research it can be concluded that the entire admixture used in the research are better in case of replacement to cement in concrete.

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