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An Experimental Study to Investigate Strength Properties of Concrete with Partial Replacement of Cement with Metakaolin and Ceramic Powder

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ABSTRACT

Concrete is the prime material used in any RCC structure. In this generation, we can observe the rapid urbanization and industrialization which was leading to the increase in the construction of the projects. So, in the construction of any structure concrete is main material to be used in completion of structure. Concrete is a mixture of several ingredients but the main ingredient is cement which helps to bind together of remaining ingredients. But, the cost of cement is high but it is important in concrete. So, in order to fulfill the requirement the cement can be replaced with cementitious material i.e. metakaolin and ceramic powder. In this research work, the concrete specimens are casted and cured with portable water. An experimental study is made on the nature of metakaolin and ceramic powder and its influences on the properties of fresh and hardened concrete. In the present study, an attempt has been made to investigate the strength parameters of concrete made with partial replacement of cement by metakaolin and ceramic powder. Moreover, no such attempt has been made in substituting metakaolin and ceramic powder with cement for medium grade concrete i.e M30. The compressive, tensile and flexural strength are investigated when 5%, 10%, 15%, 20%, 25%, 30% and 40% replacement of cement by metakaolin and ceramic powder in weight. The specimens are cured for 7days, 28 days and are tested for compressive, tensile and flexural strength. The obtained results are compared with the conventional concrete mix.

1. INTRODUCTION

Concrete is a supreme material for the construction and majorly used worldwide which has resulted in large scale manufacturing of cement. It is proven through various researchers that production of cement produces heavy environmental pollution because of the emission of CO2 gas. This is quite hazardous. Hence it became crucial and essential for the researchers tofind a better alternative that can be eco-friendly and reasonable in every way.Hence, they have started working on the economical and eco-friendly substitute of cement which can partially supplement to cement minerals or raw materials without compromising the strength parameter. We can call such kind of material as supplementary cementing materials or a pozzolanic or mineral admixture. In this generation, we can observe the rapid urbanization and industrialization which was leading to the increase in the construction of the projects. So, in the construction of any structure concreteis main material to be used in completion of any RCC structure.

Concrete is a composite material composed of water, aggregate, and cement. Concrete is used in large quantities; almost everywhere mankind has a need of structure. It is very tough to find an option for concrete in construction,which ismain ingredient is cement which helps to bind together of remainingingredients. But, the cost of cement is high but it is important in concrete. inordertofulfilltherequirementthecementcanbereplaced withcementitious material i.e. Metakaolin and ceramic powder.

Indian ceramic production is 100 Million ton per year. In ceramic industry, about 15%-30% waste material generated from the total production. This waste is not recycled in any format present. However, the ceramic waste is durable, hard and highly resistant to biological, chemical, and physical degradation forces. The Ceramic industries are dumping the powder in any nearby pit or vacant spaces, near their unit although notified areas have been marked for dumping. This leads to serious environmental and dust pollution and occupation of a vast area of land, especially after the powder dries up so it is necessary to dispose the Ceramic waste quickly and use in the construction industry. As the ceramic waste is piling up every day, there is a pressure on ceramic industries to find a solution for its disposal. The use of this material as replacement offer cost reduction, energy savings, arguably superior products, and fewer hazards in the environment.

Use OfCementatious Material In Concrete:

The threat to the ecology has lead to lot of investigation to the utility of industrial by product as supplementary cementations material for making concrete. Fly ash, Rice husk ash and Silica fume, metakaolin and ceramic powder are well known industrial by product that are being extensively used as supplementary cementations materials. The advancement in the cement technology has resulted in the development of high grade of cement which has enable engineers to use of lesser cement. This is possible by the use of the supplementary cementations materials. The use of metakaolin and ceramic powder as a mineral admixture in the concrete has been increasing. It is known that concrete incorporating metakaolin and ceramic powder restrain heat of hydration and has superior resistance to alkali-silica reaction,chloride ion penetration and sulphate attack.

A well-proportioned mixture generallyshows improved mobility,cohesiveness, strength and durability. The beneficial effects of these materials are well documented. Water cement ratio is a 3 important factor in mix design. Primary requirement of good concrete is a satisfactory compressive strength in its hardened state.

Necessity Of the Present Work:

As per the literature available it is said that in near future there will be shortage of cement itself. Hence cement will not be available for concreting purpose as extraction of rock materials leading to the pressure on the earth's surface.

The world at the end of the 21st century that has just been left behind was very different to the world.

The construction industry has been no exception to these changes when onelooks at the exciting achievements in the design and construction of buildings, bridges, offshore structures, dams, and monuments, such as theChannel Tunnel and the Millennium Wheel. But this process of the evolution

of the industrial and information technology era has also, however, been followed, particularly during the last four to five decades, by unprecedented social changes, unpredictable upheavals in world economy, uncompromising social attitudes, and unacceptable pollution and damage to our natural environment.

2. LITERATURE REVIEW

Earlier studies on utilization of ceramic powder &metakaolin in civil engineering works:

P. Dinakar*, Pradosh K. Sahoo, and G. Sriram (2013)) This study presents the effect of incorporating metakaolin (MK) on the mechanical and durability properties of high strength concrete for a constant water/binder ratio of 0.3.MK mixtures with cement replacement of 5, 10 and 15 % were designed for target strength and slump of 90 MPa and 100 ± 25 mm. From the results, it was observed that 10 % replacement level was the optimum level in terms of compressive strength. Beyond 10 % replacement levels, the strength was decreased but remained higher than the control mixture. Compressive strength of 106 MPa was achieved at 10 %

replacement.Splitting tensile strength and elastic modulus values have also followed thesame trend. In durability tests MK concretes have exhibited high resistance compared to control and the resistance increases as the MK percentage increases. This investigation has shown that the local MK has the potential to produce high strength and high performance concretes.

VenuMalagavelli, SrinivasAngadi and J S R Prasad (2018), (IJCIET) Concrete is a basic material for the construction industry. Due to infrastructure development in the developing countries, consumption of concrete is very high. The consumption of cement is also very high to meet the requirements. So there is a need to look after the supplementary / alternative materials for the cement, fine aggregate and coarse aggregate. The present work aims to look after the supplementary materials in the concrete. In this 6 paper, supplementary materials like metakaolin has been used in the concrete. Concrete having compressive strength 35 MPa is used in the experimental investigation. Mechanical properties like compressive strength, split tensile strength and flexural strengths are compared with modified concrete. Apart from that, the modified concrete has been evaluated using non-destructive tests like rebound hammer and ultrasonic pulse velocity.

SamaTarekAly; Amr Salah El-Dieb, M.ASCE; and Mahmoud RedaTaha(2019),(ASCE) A Numerous regulations have been imposed worldwide by governments and environmental organizations in order to reduce the negative environmental impact resulting from large numbers of solid waste landfills. Recycling of industrial by-products is a step toward sustainablewaste management. By utilizing ceramic waste powder (CWP) as a partial cement replacement, the construction industry can play a significant role inenergy conservation and limit future generations of CO2. This paperexamines the feasibility of producing self-compactingconcrete (SCC)mixtures yielding acceptable fresh and hardened concrete characteristics with the inclusion of high-volume CWP as partial replacement of cement. Theslump flow, J-ring, column segregation,funnel, and L- box). Theinvestigations show a slight reduction in the slump flow but with anenhancement of 7 the other fresh properties. In addition, the use of CWPslightly reduces compressive strength.

Z. Abdollahnejad; T. Luukkonen; M. Mastali; P. Kinnunen; and M. Illikainen(2018),(ASCE) Alkali-activated binders have received substantial attention due to their excellent potential in enabling the reuse and recycling of industrial solid wastes and by-products. One-part or just- addwater alkali-activated binders are an approach to reduce the negative aspects of using an alkali solutionduring the preparation of traditional two-part alkali-activated binders. The work aims to utilize the maximum content of ceramic wastes in alkali- activated blast-furnace slag/ceramic binders. The ground granulated blast- furnace slag was partially replaced [10%, 20%, and 30% in weight (wt.)%] by two types of ceramic wastes (porcelain and raw; i.e., fired and unfired). Moreover, the coarse particle size of porcelain ceramic waste was used as recycled aggregate. The specimens were cured under two different curing regimes: (1) sealing with plastic; and (2) using thermal curing conditions for 3 h in 60°C after demolding and then sealing until the testday. Mechanical testing and microstructural analysis were used to characterize the effects of different curingregimes and differentceramic sources

3. METHODOLOGY & MATERIALS

The Raw materials that are used in the production of concrete are mentioned below.

- Coarse aggregates
- Fine aggregates
- Cement
- Metakaolin
- Ceramic waste
- Portable water

Coarse aggregate:

The material whose particles are of size are retained on IS sieve of size 4.75mm is termed as coarse aggregate and containing only so much finer material as is permitted for the various types described in IS: 383-1970 is considered as coarse aggregate. Aggregates are the major ingredients of concrete. They constitute 70-80% of the total volume, provide a rigid skeleton structure for concrete, and act as economical space fillers. Because at least three-quarters of the volume of the concrete is occupied by aggregate,it is not surprising that its quality is of considerable importance. Theproperties of aggregate greatly affectthe durability andstructuralperformance of concrete. Aggregate was originally viewed as an inert material dispersed throughoutthe cement paste largely for economic reasons. It is possible, however, totake an opposite view and to look on aggregate as a building materialconnected in to a cohesive whole by means of the cement paste, in a mannerphysical, thermal and sometimes also 11 chemical properties influence the performance of concrete. Aggregate is cheaper than cement and it is, therefore, economical to put in to the mix as much of the former and as little of the later possible.

Fig1:coarse aggregates

Fine aggregate:

The size of the fine aggregate is below 4.75mm. Fine aggregates can be natural or manufactured. The grade must be throughout the work. The moisture content or absorption characteristics must be closely monitored. The fine aggregate as shown in Figure 3.2 used is natural sand obtained from the river Godavari conforming to grading zone-II of Table 3 of IS: 10262- 2009. The results of various tests on fine aggregate are given in Table 3.2. The fine aggregate shall consist of natural sand or, subject to approval, other inert materials with similar characteristics, or combinations having hard, strong, durable particles. The use of concrete is being constrained by urbanization, zoning regulations, increased cost and environmental concern

Fig2:Fine aggregate

Cement:

The cement is to be tested in the laboratory for its quality requirement limitations as per Indian Standards. The cement used was ordinary Portland cement of OPC 53 grade (KCP 53 grade) as shown in Figure. Confirming to IS: 12269-2013.n Various tests are conducted to know the physical properties of cement and the results are tabulated below in Table 3.1. All 16 the tests conducted are as per the norms of standard specifications given in IS 4031 and the results are tabulated.

The following tests as per IS: 4031-1988 is done to ascertain the physical properties of the cement. The results of the tests are compared to the specified values of IS: 4031-1988.

Table 1: properties of cement

S.NO	property	values
1	normal consistency	31%
2	Specific gravity	3.14
3	Initial setting time	94 minutes
4	final setting time	197 minutes

Metakaolin:

Metakaolin is a high-quality pozzolanic material. Metakaolin is one of the most widely used mineral admixtures these days. It helps concrete obtain both higher performance and economy. Unlike others, it is neither the by- product of an industrial process (like GGBS) nor entirely a natural product. It is specially produced from high quality Kaolin. Metakaolin is produced by the calcinations of pure or refined kaolinite clay at a temperature between 650°C to 850°C. Once the burning process gets completed it is properly grinded to achieve desired fineness to improve various strengths and property parameters of cement mortar and concrete.Metakaolin consist of silica and alumina in an active form and as other mineral admixtures, it reacts with the calcium hydroxide at room temperature and form calcium silicate hydrate (C- S-H)-gel which increases the density of concrete and reduces porosity. Thus, it decreases permeability and 16 increase durability of the concrete. Now, when it is used in the concrete, it will act as filler penetrating into the voids (space) between cement particles thereby resulting into a more impermeable concrete.

Fig4: Metakaolin

Table 2: physical properties of metakaolin

S.NO	property	values
1	Physical form	Powder
2	Colour	Off white, gray
3	Specific gravity	2.60
4	fineness	8000kg/m2

Table 3: chemical properties of metakaolin

S.NO	Chemical compound(%)	Amount
1	Silicon dioxide (Si 2)	53
2	Aluminium oxide (Al2O3)	44
3	Iron oxide (Fe2O3)	3
4	Calcium Oxide (CaO)	20
5	Magnesium oxide (MgO)	0.4
6	Sulphite (SO3)	0.5
7	Sodium oxide (Na2O)	0.2
8	Potassium oxide(K2O)	40
9	Loss on ignition	0.50

CERAMIC POWDER:

Ceramic powder is obtained by grinding the discarded tiles made only with the ball clay from the Ceramic industry. Firstly the tiles were collected and made into powder and checked for the chemical composition. The chemical combination complies with ASTM C 618 code. After chcking with its compliance to be used as a pozzolana material, it is incorporated in concrete as partial replacement to cement.

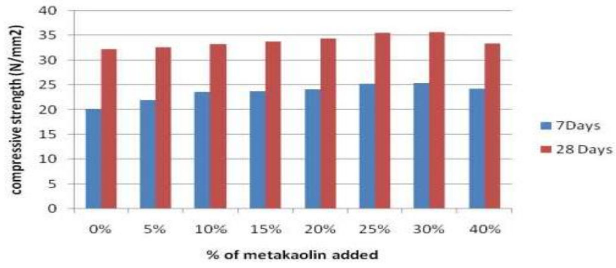
Table 4:Chemicalcompositionofceramicwaste

MATERIALS	CERAMICPOWDER(%)
SiO2	65
Al2O3	18
Fe2O3	0.5
CaO	4.5
MgO	0.72
P2O5	0.16
K2O	3.5
Na2O	0.75
SO3	0.10
CL	0.005
TiO2	0.7
SrO2	0.02
Mn2O3	0.05
L.O.I	4

Fig5:ceramic powder

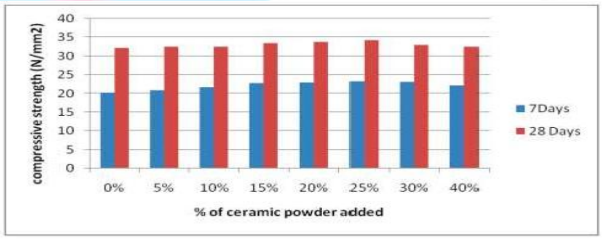
4. RESULTS

Compressive strength:



Graph1: Compressive StrengthTest Resultsof M30grade of metakaolinmix

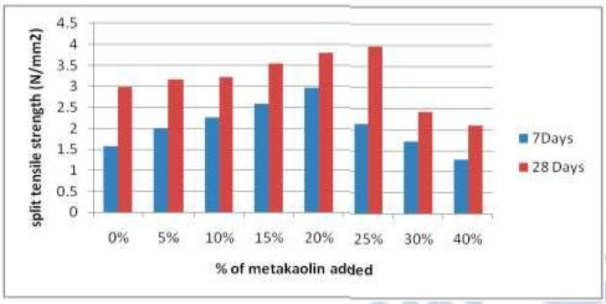
Above figure shows the variation of compressive strength of concrete with different replacement levels of metakaolin with cement. It can be observed that the compressive strength of concrete increase up to 30% of metakaolin. Then after, the compressive strength decreases. The compressive strengthmetakaolin cured with potable water. The normal mix strength was observed that the Compressive Strength of cured concrete at the age of 7 days is 20.21 N/mm2 and 28days is 32.24 N/mm2 . By using metakaolin it was observed that the Compressive Strength obtained at every percentage is more than the nominal mix. The maximum value attained at the 30 % replacement.



Graph 2: Compressive Strength Test Results of M30 grade of ceramic powder mix

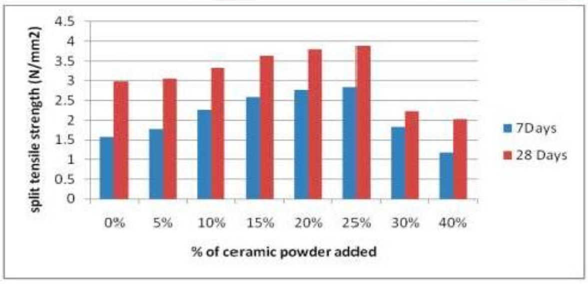
Above figure shows the variation of compressive strength of concrete with different replacement levels of ceramic powder with cement. It can be observed that the compressive strength of concrete increase up to 25% of ceramic powder. Then after, the compressive strength decreases. The compressive strength values obtained by testing standard cubes made with various percentage of ceramic powder cured with potable water. The normal mix strength was observed that the Compressive Strength of cured 38 concrete at the age of 7 days is 20.21 N/mm2 and 28days is 32.24 N/mm2 . By using ceramic powder it was observed that the Compressive Strength obtained at every percentage is more than the nominal mix. The maximum value attained at the 25% replacement.

Split tensile strength :



Graph 3: split tensile Strength Test Results of M30 grade of metakaolin mix

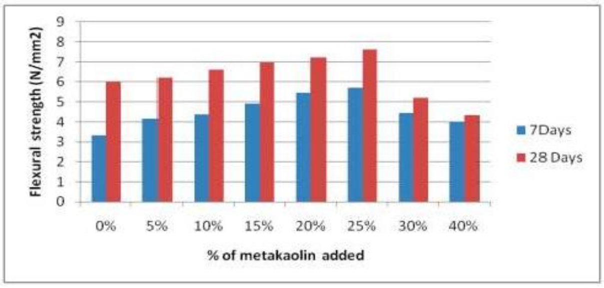
Above figure shows the variation of split tensile strength of concrete with different replacement levels of metakaolin with cement. It can be observed that the split tensile strength of concrete increase up to 25% of metakaolin. Then after, the split tensile strength decreases. the split tensile trength values obtained by testing standard cylinders made with various percentage of metakaolin cured with potable water. The normal mix strength was observed that the split tensile Strength of cured concrete at the age of 7 days is 1.58 N/mm2 and 28days is 2.99 N/mm2. By using metakaolin it was observed that the split tensile Strength obtained at every percentage is more than the nominal mix. The maximum value attained at the 25 % replacement.



Graph 4: splitting tensile Strength Test Results of M30 grade of ceramic powder mix

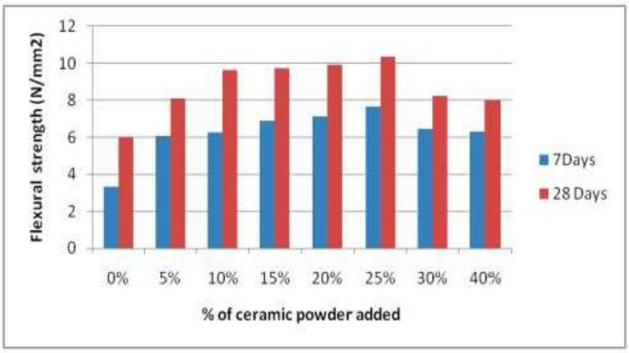
Above figure shows the variation of split tensile strength of concrete with different replacement levels of ceramic powder with cement. It can be observed that the split tensile strength of concrete increase up to 25% of ceramic powder. Then after, the split tensile strength decreases. The split tensile strength values obtained by testing standard cylinders made with various percentage of ceramic powder cured with potable water. The normal mix strength was observed that the split tensile Strength of cured concrete at the age of 7 days is 1.58 N/mm2 and 28days is 2.99 N/mm2 . By using ceramic powder it was observed that the split tensile Strength obtained at every percentage is more than the nominal mix. The maximum value attained at the 25% replacement.

Flexural strength:



Graph 5: Flexural strength Test Results of M30 grade of metakaolin mix

Above figure shows the variation of flexural strength of concrete with different replacement levels of metakaolin with cement. It can be observedthat the flexural strength of concrete increase up to 25% of metakaolin. Thenafter, the flexural strength decreases. The flexural strength values obtained by testing standard beams made with various percentage of metakaolin cured with potable water. The 42 normal mix strength was observed that the flexural Strength of cured concrete at the age of 7 days is 3.32 N/mm2 and 28days is 6.00 N/mm2 . By using metakaolin it was observed that the flexural Strength obtained at every percentage is more than the nominal mix. The maximum value attained at the 25 % replacement.



Graph 6: flexural strength Test Results of M30 grade of ceramic powder mix Above figure shows the variation of flexural strength of concrete with different replacement levels of ceramic powder with cement. It can be observed that the flexural strength of concrete increase up to 25% of ceramic powder. Then after, the flexural strength decreases. The flexural strength values obtained by testing standard cylinders made with various percentageof ceramic powder cured with potable water. The normal mix strength was observed

that the flexural Strength of cured concrete at the age of 7 days is

5.32 N/mm2 and 28days is 6.00 N/mm2 . By using ceramic powder it was observed that the flexural Strength obtained at every percentage is more than the nominal mix. The maximum value attained at the 25% replacement.

5. CONCLUSIONS

In this study series of the experiments have been conducted on concrete with the addition of metakaolin and ceramic powder as partial replacement of OPC. In the metakaolin and ceramic powder was used as partial replacement of OPC in different percentage that is 0%, 5%, 10%, 15%, 20%, 25%, 30% and 40% of the dry weight of the cement. the experiments were conducted on M30 grade of concrete as per relevant IS code practice based on the test results obtained from this study the following conclusion can be drawn.

From the compressive strength test results for both concrete grades i.e. M30, it is found that the with the addition of metakaolin and ceramic powder the strength is increased than the conventional concrete.

There is strength reduction with the addition of more than 30% of metakaolinand ceramic powder.From the above finding we can conclude that there is noremarkable variation in the compressivestrength calculated by usingcompression testing machine.The maximum value obtained for M30 grade of metakaolin concrete is at 30% replacement with cement. And the replaced strength values are more when compared with conventional mix.The maximum value obtained for M30 grade of ceramic powder concrete mix is at 25% replacement with cement. And the replaced strength values are more when compared with conventional mix.

Conflict of interest statement

Authors declare that they do not have any conflict of interest.

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