EXPERIMENTAL STUDY ON HIGH STRENGTH CONCRETE USING CRETACEOUS CLAY AS REPLACEMENT OF CEMENT.

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Since the infrastructure is developing tremendously day by day, the use of cement is highly used. India is developing as a major hub for service industry, automobile industry and for which the infrastructure development plays an important role. So the necessity of high strength concrete is increasing. In all construction work concrete is mostly used and it is costly which governs the total cost of the project. Since cement emits carbon dioxide both at the time of its production and consumption, we need to replace cement with other material to enhance its property. Some of the most commonly used material to enhance the property of concrete are metakaolin, silica fumes, fly ash etc. Cement is replaced to reduce its consumption to avoid the environmental pollution and save nature. It makes the cost efficient and enhances the compressibility and durability of MK concrete. Metakaolin is a unique in its very own form as it is not the by-product of an industrial process nor it is entirely natural. It is derived from naturally occurring minerals, and is manufactured specifically for cementing applications. Metakaolin has pozzolanic properties bringing positive effects on resulting properties of concrete. Metakaolin is manufactured by cretaceous clay which is kaolin. This clay is usually found at the bank of certain rivers. The metakaolin is manufactured by heating cretaceous clay under the temperature of 500 – 800 °C for 3-5 hours by the process of calcination. This results in change of kaolin into metakaolin. The resultant metakaolin has high pozzolanic characters and it increases durability and stability (mainly physical properties) when partially replaced with Ordinary Portland Cement. This Project deals the study of effect of Calcined kaolinite clay when partially replaced with cement with different percentage (10%, 15%, 20% and 25%). The compressibility and durability of the concrete is studied. It was found that the maximum compressive strength was at 15%.

Introduction:-
Concrete is probably the most extensively used construction material in the world. It is only second to water as the most heavily consumed substance. Concrete is generally classified as normal strength concrete (NSC), high strength...
concrete (HSC) and ultra high strength concrete (UHSC). There is no clear cut boundary for the above classification. IS: 10262-1985 recommends method of mix design by denoting the boundary of 35MPa between NSC and HSC. The high strength level is applied to concrete having strength above 40MPa, more recently the strength level value is rose to 55MPa as per IS 4562000. HSC differ from ordinary concrete with respect to its performance in fresh and hardened state that are mainly driven by exceptional material component and mixture proportion. It includes higher quantity of binder, lower water content, a greater fine aggregate contain and lesser amount and size of course aggregate. The water binder ratio of HPC (.30 TO.40) is lower than that of ordinary concrete. Pozzolanic materials including silica fumes, fly ash, slag, Rice Husk Ash and Metakaolin have been used in recent years as cement replacement material for developing HSC with improved workability, strength and durability with reduced permeability.

Metakaolin, which is a relatively new material in the concrete industry is effective in increasing strength and also reducing sulphate attack. Pozzolanic reactions change the microstructure of concrete and chemistry of hydration products by consuming the released calcium hydroxide (CH) and production of additional calcium silicate hydrate (C-S-H), resulting in an increased strength and reduced porosity and therefore improved durability. The test relating to strength are compressive strength and tensile strength and the test relating to durability test are freezing thaw test, salt ponding test, alkali silica reaction test, and chloride permeability test.

Use of Metakaolin in construction industry as partial replacement of cement started in the 1960’s and the interest in this material has considerably increased in recent years. Metakaolin has pozzolanic properties bringing positive effects on resulting properties of concrete. Pozzolanic properties cause chemical reaction of active components with calcium hydroxide (portlandite), which is formed as a product of cement hydration. This reaction leads to formation of binding phases of following types: secondary C-S-H gel, C4AH13, C3AH6 and C2ASH8.

Metakaolin is not the by-product of an industrial process nor is it entirely natural. It is derived from naturally occurring mineral and is manufactured specially for cementing applications. Metakaolin is produced under carefully controlled conditions to refine its color, remove inert impurities, and tailor particle size such, a much high degree of purity and pozzolanic reactivity can be obtained. Metakaolin is white, amorphous, highly reactive aluminiumsilicate pozzolans forming stable hydrates after mixing with lime stone in water and providing mortar with hydraulic properties. Heating up of clay with kaolinite Al2O3.2SiO2.2H2O as the basic mineral component to the temperature of 500 °C - 600°C causes loss of structural water with the result of deformation of crystalline structure of kaolinite and formation of an anhydrate reactive form – so-called metakaolinite. The chemical equations describing this process is

\[ \text{Al}_2\text{O}_3.2\text{SiO}_2.2\text{H}_2\text{O} = \text{Al}_2\text{O}_3.2\text{SiO}_2 + 2\text{H}_2\text{O (g)}. \]

The majority of the cementitious binders used in concrete are based on Portland cement clinker, the production of which is an energy-intensive process. In addition, it produces a large amount of greenhouse gas emissions, mostly CO₂, from limestone in the pyro-processing of clinker. On the other hand, the concrete industry is one of the major consumers of natural resources. In order to reduce energy consumption, CO₂ emission and increase production, cement plants produce blended cements, comprised of supplementary cementitious materials such as metakaolin, silica fume, natural pozzolans, fly ash and limestone should be used. The Meta prefix in the term is used to denote change. In case of Metakaolin, the change that is taking place is dehydroxylization, brought on by the application of heat over a defined period of time. Dehydroxylation is a reaction of decomposition of kaolinite crystals to a partially disordered structure. The results of isothermal firing show that the dehydroxylation begins at 420°C. At about 100-200°C clay minerals lose most of their adsorbed water. The temperature at which kaolite loses water by dehydroxylation is in the range 500-800 °C. This thermal activation of a mineral is also referred to as calcining. Beyond the temperature of dehydroxylation, kaolinite retains two dimensional order in the crystal structure and the product is termed Metakaolin. The temperature range varies in accordance with the kaolin found on different sites.

Metakaolin concrete has several advantages over the normal mix concrete as the initial possesses high compressive strength parameters and also increased durability. It also reduces the amount of cement in the formation of concrete, especially in concrete with high requirements for water resistance. The replacement of cement with metakaolin varies from 5%, 10%, 15%, 20%, 25% and 30% and compressive strength test are carried out for 3,7,28,90 and 180 days. There is also a peculiar characteristic that compressive strength increases from 3 to 28 days and then there is slight decrease in strength values till 90 days. After 90 days the strength increases and has a maximum constant value. Further metakaolin having pozzolanic character causes the resistance to concrete to action of harmful solutions.
Benefits Of Cretaceous Clay:-
High Strength Concrete with Metakaolin as admixtures offers many advantages. Some of these are as follows –
1. Facilitate finishing concrete surfaces by rubbing and smoothing due to the lack of stickiness of concrete to the tool and good thixotropy.
2. It reduces the amount of cement in the formation of concrete, especially in concrete with high requirements for water resistance.
3. Can significantly increase the residual strength of refractory concrete after firing, typically lose 50% of its strength after heating to 800°C.
4. The strength and durability of concrete increases.
5. Use of clay accelerates the initial set time of concrete.
6. Compressive strength of concrete increases @ 20% with clay.
7. The cross sectional areas of structural members can be reduced safely, so saving in concrete and can be economically used for high rise buildings, dams, bridges etc.
8. It imparts improved water-tightness, so safely used for water retaining structure, off shore structure etc.
9. Confers high early strength, allows a quicker reuse of formwork, and thus enhances the production rate.
10. Ecofriendly
11. Cretaceous increases resistance to chemical attack and prevention of Alkali Silica Reaction.
12. Clay disperse more easily in the mixer with less dusting
13. Cretaceous clay reduces heat of hydration leading to better shrinkage and crack control. p)Better Sprayability
14. Lesser Rebound so used in shotcrete with reduced wastage.

Drawbacks:-
1. High cost of clay and the extracting and calcinating process is cumbersome.
2. With the introduction of clay the heat and water demand increases.
3. Much capital investment is needed to initiate commercial production.
4. Limit of its availability

Literature Survey:-
B.B Sabir, S. Wild, and J. Bai they tested the compressive strength values for 5% and 10% replacement. The result showed that compressive strength increased till 14 days but beyond 14 days the strength which is enhanced began to decline. But after 90 days it again gained strength values. In this the temperature that was adopted for heating for kaolin was 650°C to 800°C. The best result was found at 10% MK. Hong-Sam Kim, Sang-Ho Lee and Han-Young Moon, and they found out that the maximum compressive strength value was obtained for a substitution rate of metakaolin of between 10% and 15%. Here they adopted the heating of kaolin clay at range of 700 to 800°C. They carried out test to determine the compressive strength, tensile strength at 1,3,7,28, and 91 days as per KSF2405. We found that both compressive strength and tensile strength gave maximum value for replacement at 10%. The compressive strength value for 10% MK at 28 days was 61MPa and at 90 days, it was 75MPa. Further the tensile strength value for 10% MK at 28 days was 3.9MPa and at 91 days it was 4.8MPa. A.A. Ramezanianpour, and H. Bahrami Jovein and they carried out test for 7, 28, 90 and 180 days with MK replacement at 10%, 12.5% and 15% by mass. Here the temperature range that was adopted was 700°C to 800°C. Concrete cubes of 100mm*100mm*100mm were cast for compressive strength at 7, 28, 90 and 180 days as per ASTM-C 150 type 1. The MK 12.5% gave the maximum value as 81.6MPa for water binder ratio 0.35. The MK 12.5% value for water binder ratio for 0.5 gives 50.5MPa and for 0.4 it gives 72MPa. Hence it is clear that increase in water binder ratio decreases the compressive strength. Rafat Siddique and Juvas Klaus found metakaolin at temperature range of 500°C to 800°C. They demonstrated on the properties of compressive strength. Metakaolin had 99.9% particle size less than 16um with a mean size of particle about 3um. They found out compressive strength of three different replacement of metakaolin, namely MK5, MK10, and MK15. MK5 had compressive strength value of 91.5MPa, MK10 having the greatest value of 104MPa while MK15 slightly lower value at 103.5MPa. The values of tensile strength were also checked at 5%, 10%, and 15% replacement. The data summarized are 3.58MPa for 5%MK; for 10% the value was 3.88MPa and at 15%MK the value was 4.29MPa. Hence it is quite clear that on increase in percentage of replacement of metakaolin with OPC increases the tensile strength.

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80MPa for 180 days. A.A. Ramezanianpour, and H. Bahrami Jovein carried out test for 7, 28, 90 and 180 days with MK replacement at 10%, 12.5% and 15% by mass. Here the temperature range that was adopted was 700$^\circ$C to 800$^\circ$C. Concrete cubes of 100mm*100mm*100mm were cast for compressive strength at 7, 28, 90 and 180 days as per ASTM-C 150 type 1. The MK 12.5% gave the maximum value as 81.6MPa for water binder ratio 0.35. The MK 12.5% value for water binder ratio for 0.5 gives 50.5MPa and for 0.4 it gives 72MPa. Hence it is clear that increase in water binder ratio decreases the compressive strength.

Physical And Chemical Properties Of Metakaolin:-

**Physical Properties of Metakaolin:-**

![Figure 1: Metakaolin](image)

**Table 1:- Physical Properties**

| Property             | Value          |
|----------------------|----------------|
| Specific Gravity     | 2.40 to 2.60   |
| Physical Form        | Powder         |
| Color                | Off white, Gray to Buff |
| Brightness           | 80-82 Hunter L |
| BET                  | 15 m$^2$/gram  |
| Specific Surface     | 8 – 15 m$^2$/g.|

**Chemical properties of metakaolin**

**Table 2:- Chemical Properties**

| Property | Value          |
|----------|----------------|
| SiO$_2$  | 51-53%         |
| Al$_2$O$_3$ | 44-48%      |
| Fe$_2$O$_3$ | <2.20%       |
| TiO$_2$  | <3.0%          |
| SO$_4$   | <0.5%          |
| P$_2$O$_5$ | <0.2%        |
| CaO      | <0.20%         |
| MgO      | <.10%          |
| Na$_2$O  | <0.05%         |
| K$_2$O   | <0.40%         |
| L.O.I    | <0.5%          |
| P$_2$O$_5$ | <0.2%        |

**Result and Discussion:-

Water Absorption:-**
The water absorption of calcinated concrete was measured and presented. The water absorption of concrete has gradually reduced the increase in the percentage of natural calcinated. The concrete with 25% natural calcinated has shown water absorption less than that of control at the age of 14 and 28 days.

**Table 3:- Water absorption of concrete incorporated with Calcined clay**

| Mix Code | Water Absorption (%) |
|----------|----------------------|
|          | 7 days     | 14 days | 28 days |
| 0%       | 1.986      | 1.465   | 1.225   |
| 10%      | 3.124      | 2.901   | 1.213   |
| 15%      | 2.983      | 1.801   | 1.166   |
| 20%      | 2.64       | 1.277   | 1.123   |
| 25%      | 2.60       | 1.187   | 1.003   |
Compressive Strength:-
The concrete cubes made with incorporation of natural calcinated were tested at the age of 7, 14, and 28 days and the results are presented in table.

Compressive Strength = Crushing Load / Area N/M²

Table 4: Compressive strength of concrete incorporated with Calcined Clay

| Mix code | Compressive Strength (N/mm²) |
|----------|-----------------------------|
|          | 7 days | 14 days | 28 days |
| 0%       | 22.3   | 25.1    | 33.5    |
| 10%      | 23.6   | 27.4    | 37.4    |
| 15%      | 26.6   | 32.3    | 40.1    |
| 20%      | 22.7   | 26.1    | 34.4    |
| 25%      | 22.1   | 25.8    | 33.9    |

It is observed that calcined clay has significant effect on strength of concrete. The increase in the replacement level up to 15% of cement has significantly increased the strength. The concrete made with 20% has yielded less compressive strength than the concrete with 15% However, even concrete with 20% has shown significantly higher than control.

Flexural Strength Of Concrete Incorporated With Calcined Clay:-
The concrete prisms made with incorporation of calcinated clay were tested at the age of 7, 14, and 28 days and the results are presented in table

Flexural strength = P x L / BD² N/mm²

P=load, L= length, B= breadth, D= depth

Table 5: Flexural strength of concrete incorporated with Calcined Clay

| Mix code | Flexural Strength (N/mm²) |
|----------|--------------------------|
|          | 7 days | 14 days | 28 days |
| 0%       | 2.52   | 2.68    | 2.81    |
| 10%      | 3.46   | 3.62    | 4.24    |
| 15%      | 4.41   | 4.51    | 5.54    |
| 20%      | 3.22   | 3.56    | 3.8     |
| 25%      | 2.64   | 2.82    | 3.27    |

It is observed that calcined clay has significant effect on flexural strength of concrete. The increase in the replacement level up to 15% of cement has significantly increased the strength. The concrete made with 20% has yielded less flexural strength than the concrete with 15% However, even concrete with 20% has shown significantly higher than control.

Conclusion:-
In the present work, an attempt has been made to study the suitability of Calcined cretaceous clay as partial replacement for cement, and its effect on physical properties and compressive strength of concrete. The following are the conclusions drawn.

1. The cement blended with Calcined clay has shown higher consistency than the control. The increase in Calcined clay has gradually increased the consistency. It must be due to the higher specific surface area of calcinated.
2. The initial and final setting times of cement blended with Calcined clay are higher than the control. The increase in content of Calcined clay in binder has marginally shortened the initial and final setting times to some extent. The incorporation of calcinated in cement has significantly altered the settings.
3. The concrete incorporated with Calcined clay has shown significantly higher water absorption than control at early age of 7 days. The increase in Calcined clay from 10% to 25% in concrete, the water absorption has gradually reduced to the level of control or even beyond 14 days.
4. The W/C ratio of concrete incorporated with Calcined clay was higher than that of control to achieve the slump value of 65± 5mm.
5. The incorporation of Calcined clay in concrete has remarkably improved the compressive strength and it is significantly higher than control. The strength has gradually increased with Calcined clay content from 10% to 15% and thereafter reduced.

6. The incorporation of Calcined clay in concrete has remarkably improved the flexural strength and it is significantly higher than control. The strength has gradually increased with Calcined clay content from 10% to 15% and thereafter reduced.

7. The improvement in the strength of concrete incorporated with Calcined clay must be due to filler effect, acceleration of PC hydration and also pozzolanic reaction.

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