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INFLUENCE OF METAKAOLIN IN CONCRETE AS PARTIAL REPLACEMENT OF CEMENT

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ABSTRACT

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 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. Also a relationship developed between the compressive strength and non-destructive tests. Based on the results, the performance of modified concrete is better than the normal concrete.

Key words: Supplementary Materials, Concrete, Non – Destructive test, Compressive Strength, Split Tensile Strength, Flexural Strength, Rebound hammer, Ultrasonic Pulse Velocity.

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1. INTRODUCTION

In the today's world concrete plays an important role in the construction works like dams, buildings, roads etc. It is made when cement, aggregates and water are mixed. These additives are natural, but the constant use of natural additives has led to exhausting of the natural sources and this will affect the global warming also. Thus the use of alternative / supplementary materials for both cement and aggregate is a step towards solving part of the depletion of natural sources, and these alternative / supplementary materials processed from waste materials would be an even more good solution. Concrete is very strong in compression and weak in tension. Concrete technologists are trying to improve the compressive strength of concrete by using supplementary materials i.e. mineral admixtures. Still researchers are trying different materials like fly ash, metakaolin, silica fume, blast furnace slag, recycled aggregates, plastic aggregates, etc., which can be used in place of cement and aggregates.

Utilization of metakaolin as a pozzolanic material in mortar and concrete studied by Sabir et.al. (2001). they reported that the use of metakaolin in concrete and mortar will help in the development of early strength. Also they reported that it greatly improves the resistance to transportation of water and diffusion of harmful ions which led to degradation of matrix. Venu and Rao (2010) investigated the usage of supplementary materials by replacing in both cement and fine aggregate with ground granulated blast furnace slag and robo sand respectively. From the experimental investigation they found that both can be used as supplementary materials for both cement and fine aggregate. An attempt have been made by Hemant et al (2011) to use industrial wastes like activated Fly ash, Iron Oxide and Metakaolin as supplementary cementitious materials in various proportions. Using these mineral admixtures with OPC cement, five different types of concrete mixtures were prepared and same were used to find compressive strength of concrete cubes at 3,7,14,28 and 56 days. They reported that it was possible to make the concrete economical by 42% replacement of cement with different percentages of mineral admixtures like Fly ash (30%), Metakaolin (10%) and iron oxide (2%). High performance concrete was prepared by partial replacement of Ordinary Portland cement with Metakaolin and Fly ash by Muthu priya et al (2011). The test results showed improvements in strength, brittleness and durability. The optimum replacement level for Metakaolin and Fly ash was reported as 7.5%. They reported that the compressive strength of high performance concrete containing 7.5% of Metakaolin was 12% higher than the normal concrete. Kannan and Ganesan (2012) investigated the effects of Rice husk ash, Metakaolin and their combinations when used as replacement for blending component in cement. The properties of blended cement mortar were investigated which included physical properties, chemical properties, setting time, compressive strength and saturated water absorption. Metakaolin is used in the development of self-compacting concrete (Poon et al. 2001; Basu 2003; Patil and Kumbhar 2012; Dvorkin et al. 2012) and it has given the good results. Zhiguang Shi et al. (2015) conducted the experiment on effect of metakaolin and sea water on performance and microstructure of concrete. They have used 0–6 wt% MK used in the study. The compressive strength at 28 days increased by 33% when addition of 5 wt% MK and by 22% when mixed with seawater. The combination of both increased compressive strength by 52%. The pore structure was refined under both conditions. Adel Al Menhosh et al. (2016) studied the effect of metakaolin additive and polymer admixture on the concrete strength properties. Different proportions of the combination using two different polymers, metakaolin, and recycled fiber reinforcement have been used in this study. They found that, the addition of 5% optimized polymer and 15% cement replacement using metakaolin generates an optimized concrete mixture for both strength and durability.

From the literature it is clearly shows the lot of research is going on the supplementary materials for cement and aggregates and very limited research on non-destructive evaluation of metakaolin concrete. Here an attempt has been made for the use of Metakaolin as a pozzolanic material and it impact on the mechanical properties of concrete.

2. MATERIAL PROPERTIES

The following are materials used for the entire investigation. The properties of these materials are given below.

Ordinary Portland Cement (OPC) of 53 grade has been used. River sand has been used as fine aggregate having specific gravity 2.68. The sample is confirming to zone II and fineness modulus is 3.18. Coarse aggregate of 10 mm and 20mm crushed gravel of 2.71 specific gravity was used. The coarse aggregate was air-dried in the laboratory and sieve analysis was carried out.

2.1. Metakaolin

The raw material in the manufacture of Metakaolin is kaolin clay. Kaolin is a fine, white, clay mineral that has been traditionally used in the manufacture of porcelain. Metakaolin is neither 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 colour, remove inert impurities, and tailor particle size such, a much high degree of purity and pozzolanic reactivity can be obtained. The chemical equations describing this process is $Al_2O_3.2SiO_2.2H_2O = Al_2O_3. 2SiO_2 + 2H_2O$ (g). The physical and chemical properties are shown tables 1 and 2.

Table 1 Physical properties of metakaolin

Specific Gravity	2.40 to 2.60
Physical Form	Powder
Colour	Off white, Grey to Buff
Specific Surface	8– 15 m2 /g.

Table 2 Chemical properties of Metakaolin

SiO2	51-53 %	CaO	< 0.20%
Al2O3	42-44 %	MgO	< 0.10%
Fe2O3	< 2.20%	Na2O	< 0.05%
TiO2	< 3.0%	K2O	< 0.40%
SO4	< 0.5%	L.O.I.	< 0.50%
P2O5	< 0.2 %		

2.2. Super Plasticizer

The excellent dispersion properties of VARAPLAST PC 432 make it the ideal admixture for ready mixed concrete where low water cement ratios. The use of VARAPLAST PC 432 gives a combination of excellent initial workability and workability retention over a long period in cementitious rich compositions of concrete. Specific gravity of super plasticizer1.10 at 20 °C, Air entrainment is less than 1% additional air is entrained and setting time is 1 - 4 hours retardation depending on dosage and climatic conditions.

3. MIX PROPORTIONS

The investigation was aimed to study the mechanical properties of M35 grade Concrete. The mix proportions are calculated based on the IS 10262 [10] and SP 23 [11]. The mix proportions for M35 concrete are 1:1.725:2.475 with w/c ratio 0.3. Super plasticizer was 3 kg/m^3 used in the all concrete mixes. The percentage of metakaolin is varies from 0 to 20 % with as increment of 5% used in the concrete.

3.1. Mixing, Casting and Curing

All the materials are mixed in pan mixer. Firstly coarse aggregate, fine aggregate are mixed thoroughly in the mixer for about 2 minutes and then added cementing material, mixed around one minute then 1/3 of water added to dry mix and allow to mix for one minute, add another 1/3 of water to the mix. Super plasticizer was added to the remaining 1/3 of water so that it will disperse equally throughout the mix after adding the concrete. The all ingredients are mixed thoroughly for five minutes so that it will have a homogeneous mixture. Slump test has been performed to know the workability of the concrete.

Cube specimens of 150X150X150mm, Cylinder specimens 300X150mm and Beam specimens 100X100X500mm were casted for determining the mechanical or strength properties of modified concrete for the ages of 7 and 28 days. The specimens were kept at room temperature for 24 hours and then immersed in water.

4. MECHANICAL PROPERTIES

Fresh properties of concrete like workability has performed using slump test. Slump of the modified concrete increased when compared to normal concrete.

Compression testing machine of 2000kN used for the compression and split tensile test and 100kN Flexural Testing Machine has been used for the split tensile test and flexural strength test.

The compressive strength (f_{ck}) results shown the Fig.1 for all modified concretes for both 7 and 28 days. The seven days compressive strength varies from 23.9 to 28.5MPa and 28 days strength varies from 47.3 to 55.2MPa. All modified concrete and controlled concretes achieved the target strengths of 35MPa in 28 days. The compressive strength of modified concrete is increased by 7% and 16.75% with the addition of 5% and 10% metakaolin in the cement. Similarly for 15% and 20% of addition of metakaolin the compressive strength is increased by 11.42% and 6%. This clearly shows the optimum percentage of metakaolin used in the concrete is 10%.

The main reason for improving the strength concrete with metakaolin is, Silica present in metakaolin will reacts with Calcium Hydroxide (Ca (OH)2 : by product of hydration process of cement) and it forms the additional Calcium Silicate Hydrate (C-S-H) gel which is main gel for the development of strength. This process will continue till the saturation point in this study it is 10% beyond this metakaolin will act like a filler material only.

The 28 days split tensile strength (f_{st}) and flexural strength (f_{fx}) of modified concretes is presented in the Fig.2 and Fig.3 respectively. With the addition of 5%, 10%, 15% and 20% of metakaolin in the concrete the split tensile strength increased by 2.66%, 7.1%, 4.73% and 2.66%, and flexural strength increased by is 3.31%, 7.88%, 5.39% and 2.69% respectively. From these strength properties, the optimum use of metakaolin in the concrete is 10%. Fig.4 and Fig.5 represents the relationship between compressive strength to split tensile and flexural strengths.

$$f_{st} = 0.6164\, f_{ck}^{0.4411} \quad and\ R^2 = 0.9952 \tag{1}$$

$$f_{fx} = 0.7224\, f_{ck}^{0.492} \quad and\ R^2 = 0.9993 \tag{2}$$

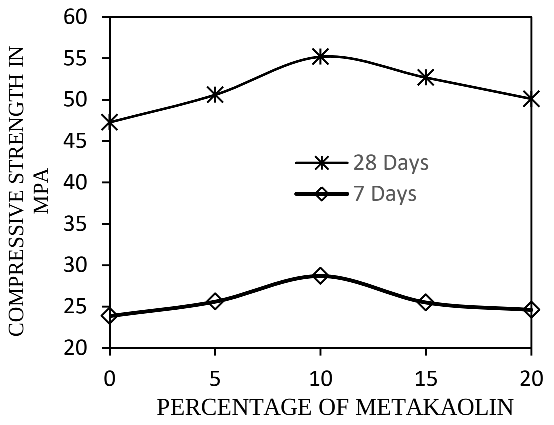

Figure 1 Compressive Strength of Concrete at the age of 7 and 28 Days

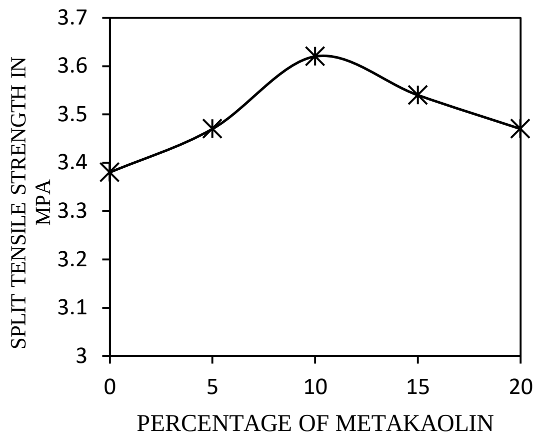

Figure 2 Split Tensile Strength of Concrete at the age of 28 Days

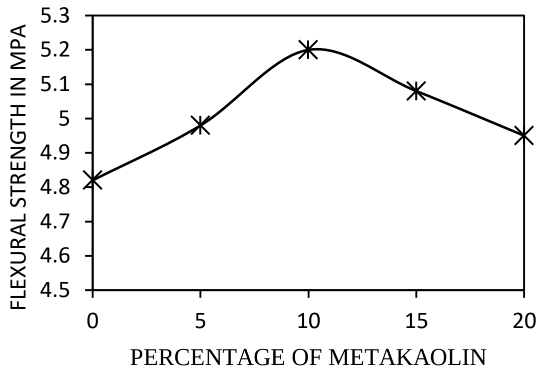

Figure 3 Flexural Strength of Concrete at the age of 28 Days

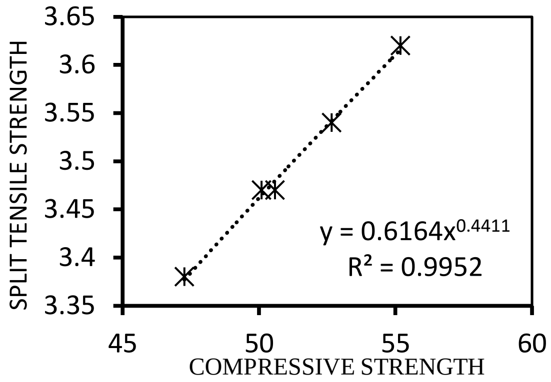

Figure 4 Relationship between Compressive Strength and Split Tensile Strength of Concrete

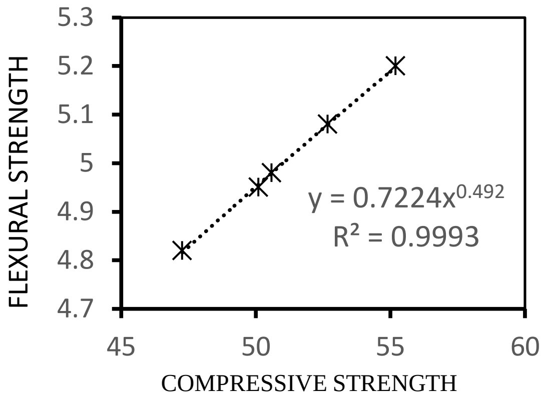

Figure 5 Relationship between Compressive Strength and Flexural Strength of Concrete

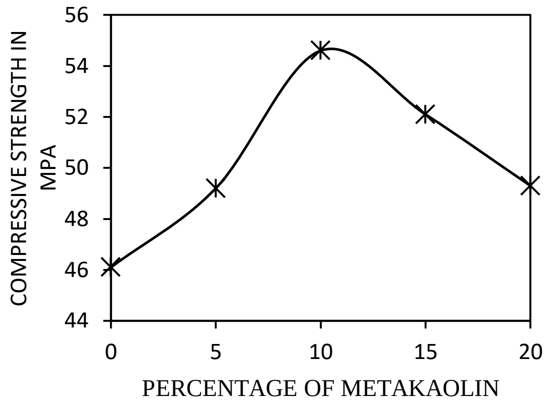

Figure 6 Rebound hammer Strength of Concrete at the age of 28 Days

4.1. Non – Destructive Evaluation of Concrete

Non – destructive evaluation of concrete has performed by using rebound hammer and ultrasonic pulse velocity tests. The results of both the tests are explained below.

4.2. Rebound Hammer Test

The rebound hammer test was carried out in accordance with IS 13311 [12]. The test can provide a fairly accurate estimate of concrete compressive strength. The cube specimens were tested as per the standard procedure and the test data is shown in Fig.6. The test results of Rebound Hammer Test are in agreement with the compression test results. A relation has been developed by using regression analysis for compressive strength and rebound number (f_{rn}) as shown in Fig.7.

$$f_{rn} = 0.654\, f_{ck}^{1.1033} \quad and\ R^2 = 0.9933 \qquad (3)$$

4.3. Ultrasonic Pulse Velocity (UPV) Test

Ultrasonic Pulse Velocity (UPV) testing of concrete is based on the pulse velocity method to provide information on the uniformity of concrete, cavities, cracks and defects. The pulse velocity in a material depends on its density and its elastic properties which in turn are related to the quality and the compressive strength of the concrete. It is therefore possible to obtain information about the properties of components by sonic investigations. The test was carried out in accordance with IS 13311(Part 2): 1992.

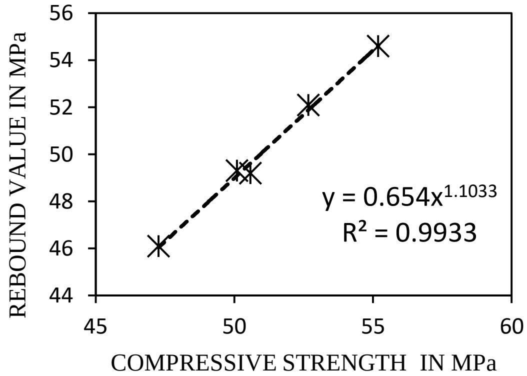

Figure 7 Relation between Compressive strength and Rebound hammer value

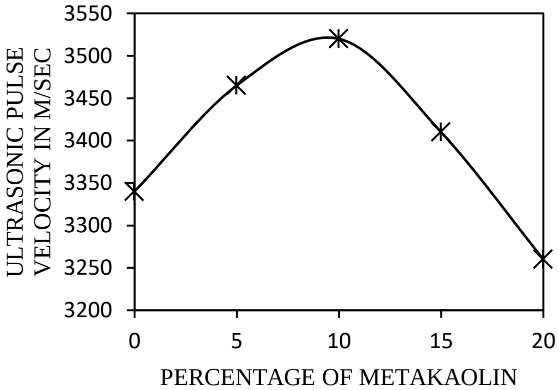

Figure 8 Ultrasonic Pulse Velocity of Concrete at the age of 28 Days

Figure 9 Test setups

Fig.8 represents the ultrasonic pulse velocity variation of modified concrete. The ultrasonic pulse velocity Test results shows that the strength of concrete increases as the percentage of Metakaolin increases up to 10%. The rebound hammer and ultrasonic pulse velocity tests further confirm that the modified concrete specimens although being sound and of good quality have increased strength when compared to the control concrete. Fig.9 shows the test setups for the experimental investigation.

5. CONCLUSIONS

From the experimental investigation the following conclusions can be drawn.

- Supplementary materials like metakaolin can be used in concrete in place of cement.
- The maximum of 10% can be replaced by cement with metakaolin.

- Fresh properties like workability is increases as the percentage of metakaolin increases.
- The percentage increment in strength properties are 16.75, 7.1 and 7.88 in compressive strength, split tensile strength and flexural strength respectively.
- There is a good correlation between non-destructive tests and destructive tests.

REFERENCES

[1] Adel Al Menhosh, YanWang and YuWang, 2016, The Mechanical Properties of the Concrete Using Metakaolin Additive and Polymer Admixture, journal of Engineering, 2016: 1- 6

[2] Basu, P. C., High performance concrete, 2003, In Proceedings INAE national seminar on engineered building materials and their performance, 426–450.

[3] Dvorkin, L., Bezusyak, A., Lushnikova, N. and Ribakov, Y., 2012, Using mathematical modelling for design of self-compacting high strength concrete with metakaolin admixture", Construction and Building Materials, 37: 851–864.

[4] Hemant Chauhan, 2011, "Effect of Activated Fly ash in Metakaolin based cement", Proceedings of National Conference on Recent Trends in Engineering & Technology, BVM Engineering College, Gujarat, India.

[5] IS 383 – 1970: Specification for Coarse and fine Aggregates from Natural Sources for Concrete.

[6] IS 2386 – 1963: Methods of Test for Aggregates for Concrete.

[7] IS 10262 – 2009: Recommended Guidelines for Concrete Mix design.

[8] IS 13311(Part 2) – 1992: Method of non-destructive testing of concrete methods of test.

[9] Kannan V and Ganesan K, 2012, "Strength and water absorption properties of ternary blended cement mortar using rice husk ash and metakaolin", Scholarly J. of Engg. Research, 1(4): 51-59.

[10] Muthupriya P, Subramanian K and Vishnuram B.G, 2011, "Investigation on behavior of high performance reinforced concrete columns with metakaolin and fly ash as admixture", International J. of Adv. Engg. Tech., 2(1): 190-202.

[11] Pal, S. C., Mukherjee, A. and Pathak, S. R., 2001, "Development of high performance concrete composites using high volume cement replacement with supplementary pozzolanic and cementitioius solid waste", Proceedings of SEC, recent developments in structural engineering: 215–229.

[12] Patil, B. B. and Kumbhar, P. D., 2012, "Strength and durability properties of high performance concrete incorporating high reactivity metakaolin", International J. of Modern Engg. Research, 2(3): 1099–1104.

[13] Poon, C. S., Lam, L., Kou, S. C., Wong, Y. L., and Wong, R., 2001, "Rate of pozzolanic reaction of metakaolin in high-performance cement pastes", Cement and Concrete Research, 31(9): 1301–1306.

[14] Sabir, B.B., Wild, S. and Bai, J., 2001, "Metakaolin and calcined clay as pozzolans for concrete: a review" Cement and concrete composites, 23: 441-454.

[15] SP – 23: Hand Book on Concrete Mixes.

[16] Venu Malagavelli and Rao, P.N., 2010, "High Performance Concrete with GGBS and ROBO sand", International J. of Engg. Sci. and Tech., 2(10): 5107-5113.

[17] Zhiguang Shi, Zhonghe Shui, Qiu Li and Haining Geng, 2015, Combined effect of metakaolin and sea water on performance and microstructures of concrete, Construction and Building Materials 74:57–64