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EFFECTS OF PARTIAL REPLACEMENT OF CEMENT BY METAKAOLIN POWDER AND SAND BY WASHED BOTTOM ASH ON THE PROPERTIES OF CONCRETE

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Abstract- *Concrete is a composite material consisting of cement, fine aggregate, and coarse aggregate, and demand for it is increasing due to construction practices at a large scale. As of now, we are able to use waste material such as fly ash in the manufacturing of cement, but fine aggregate and coarse aggregate are made available from natural resources and are getting depleted day after day. So, the need of an era is to find out some more waste material that can be used in place of these materials or can be replaced in a suitable amount. So, the material used for replacement in this research is washed bottom ash in place of sand and metakaolin powder in place of cement. The main objective of this research is to determine the workability, compressive strength, split tensile strength, and flexure strength of concrete prepared by using washed bottom ash and metakaolin powder. The test will be conducted to determine the compressive strength, split tensile strength, and flexure strength. Based on previous research, a comparison of strength and properties of concrete made with replacement compared to the standard concrete is made. Cement is replaced by metakaolin powder by 6%, 12%, 18%, 24%,30%, and natural sand is replaced by washed bottom ash by 9%, 18%, 27%, 36%, 45%. Based on the properties of the materials, the M35 grade of concrete mix is prepared. Different specimens of the material are tested for strength. The result shows that concrete workability is fine and within limits after replacing cement with metakaolin powder and natural sand by washed bottom ash. So, after this research work, we find out that the replacement can be done to some extent.*

Keywords-Washed Bottom Ash, Metakaolin Powder, Compressive Strength, Flexural Strength, Split Tensile Strength.

1. INTRODUCTION

Concrete consists of cement, fine aggregate, and coarse aggregate and plays vital roles in construction work today. Sand and cement are the prime material for the preparation of mortar and cement. Properties of material play a significant role in preparing a design mix. Sand in concrete occupies space between the coarse aggregate and cement acts as a binding material between fine aggregate and coarse aggregate. About 80% of the total volume of concrete consists of coarse aggregate and fine aggregate. Nowadays due to the construction boom demand for this material increasing day by day for construction activities worldwide, for rapid growth in infrastructure, consumption of natural sand is increased which lead to the continuous extraction of natural sand from the river bed. This extraction is causing severe damage to the natural resources, which poses a severe threat to the environment, such as loss of aquatic life, losing water retaining soil strata, causing bank slides, loss of vegetation on the banks of rivers, and the society, etc. Due to these adverse effects, different states have imposed bans on the natural extraction of sand. Also, natural sand is very costly nowadays which makes the construction uneconomical so in this situation, the need arises to find some readily available alternative that can also reduce the cost of construction. The manufacturing of cement poses a severe threat to the environment. It is estimated that nearly 1 tonne of CO_2 gas gets emitted during 1 tonne of Portland cement production. Since WBA is a waste product and metakaolin is cheaper than cement and also increases the strength of cement concrete. The use of these products in concrete makes the work economical and using these materials in the construction practices, the disposal problem of these materials can be reduced to a large extent. The other factor that contributes to their use in the concrete is their low cost. So, the use of these waste materials as an alternative material makes the project economical.

1.1 Washed Bottom Ash (WBA)

India produces approximately more than 100 million tonnes of coal ash annually. Coal-based thermal power plants all over the world face serious problems of handling and disposal of the ash produced. The utilization of fly ash is about 30% as various engineering properties requirements that is for low technical applications such as in the construction of fills and embankments, backfills, pavement base and sub-base course. Washed bottom ash is nearly 20% of the residual material of coal combustion in a power plant, boiler, furnace, or incinerator. The portion of the ash that escapes the chimney is referred to as fly ash (80%), and the clinkers that fall under their weight in the bottom hopper is termed as bottom ash (20%) which is cooled by water washing and is termed as Washed Bottom Ash (WBA). India currently generates 100 million tonnes of coal ash annually, of which 15-20% is bottom ash. Non-natural lightweight aggregate built on bottom ash has a lot of promise for usage in construction projects. Bottom ash has shown to be a cheap material since it has benefits for constructability in addition to good engineering properties Bottom ash is a versatile material that can be used in a variety of civil engineering projects that call for sand, gravel, or crushed stone The washed bottom ash in the form of fine aggregates is shown in Fig.1.

Fig.-1: Washed Bottom Ash

1.2 Metakaolin Powder

By using additives in place of cement, which increases CO2 emissions in the construction industry, these emissions are reduced. Cement can be replaced with metakaolin, also known as calcined kaolin, which is created via calcination. Due to their advantages for the economy and ecology, supplemental cementitious elements are utilized in concrete all over the world and have received a lot of attention recently. The more popular SCMs are mineral admixtures such fly ash, rice husk ash, silica fume, etc. They aid in achieving increased efficiency and performance. One such unconventional substance that can be used to good effect in the construction sector is metakaolin.

The most effective pozzolanic substance for use in concrete is metakaolin, a kind of pozzolan. It is created when china clay, a mineral called kaolin, is heated to a temperature between 600 and 800 ºC, making it a manufactured good intended for use as opposed to a byproduct. Its manufacturing process includes quality control, producing a material that is far less variable than industrial pozzolans, which are by-products. Metakaolin was successfully included into the concrete when it was first used in the 1960s to build a number of significant dams in Brazil with the initial goal of preventing any harm brought on by the alkali-silica reaction. As with other mineral admixtures, metakaolin is made up of silica and alumina in an active form. When combined with calcium hydroxide at room temperature, it forms calcium silicate hydrate (C-S-H)-gel, which raises the density and lowers the porosity of concrete. As a result, the concrete becomes more durable and its permeability is reduced. Now, when it is added to concrete, it will function as a filler, saturating the spaces between cement particles and making the concrete more impermeable. It is neither a by-product of industry nor a natural product it is obtained by calcination of pure kaolinite or china clay at a temperature of 650 to 800^{0}C. Once the burning process is completed is grinded properly to that particle size for which it is used and fulfills the strength and property parameter of cement in motar and concrete. Metakaolin Powder is shown in the Fig.2.

Fig.-2: Metakaolin Powder

2. OBJECTIVE

a. To perform the following test and to compare the results with and without replacement of washed bottom ash and metakaolin powder.

- Compressive Strength Test.
- Flexural Strength Test.
- Split Tensile Strength Test.

b. To reduce the overall environmental effects of concrete production using washed bottom ash and metakaolin powder as partialreplacement.

c. Workability of concrete.

3. LITERATURE REVIEW

Meghana. K et al. (2019): The M30 grade of concrete is used in this investigation for the experiment. 0 percent, 20%, 40%, 60%, 80%, and 100% of the bottom ash is added in place of the sand. The silica fume is added to replace 20% of the cement's weight in cement in a partial replacement. Additionally, the strength characteristics of concrete, including its impact, flexural, shear, and tensile strength, are investigated.

M. Narmatha, Dr. T.Felixkala (2016): This study aims to describe the effect of the replacement of metakaolin powder in cement. Metakaolin is a supplementary cementitious material for high- performance concrete. Properties of concrete with metakaolin are mostly preferred additives in high- performance concrete. The replacement proportion of metakaolin to be used was 5%, 10%, 15%, and 20% by the weight of cement.

4. MATERIAL AND PROPERTIES

4.1 Cement

When combined with water to create mortar or when combined with sand, gravel, and water to create concrete, cement is a dry, powdery material. It serves as a binder. Cement provides sufficient strength once it has hardened. Lime is the main chemical component of cement. Depending on the demand and required strength, there are many different types of cement available on the market. The cement we'll use in this study is 43 Grade Ordinary Portland Cement that complies with IS: 8112 and goes by the brand name Ambuja Cement. The relevant lab has provided information on the cement's physical qualities

Fig-3: 43 Grade OPC Cement

Table-1: Properties of Cement

S.No.	Properties	Test Results	IS: 8112-1989
1.	Normal Consistency	32%	<34%
2.	Initial Setting Time	45 min	>30 min
3.	Final Setting Time	350 min	<600 min
4.	Specific Gravity	3.15	
5.	Fineness	4%	<10%

4.2 Fine Aggregate

Fine aggregate consists of crushed sand particles or natural river sand passing through a 4.75mm sieve. In general, river sand is used as a fine aggregate having a particle size of 0.07mm. The extraction is done from rivers, lakes or seabed's. Fine aggregate that was present at the site was extracted from Akhnoor Jammu. Sieve analysis would be done to find out the zone conforming IS: 383-1970. The physical properties of sand were provided by the

concerned lab. It conforms to IS 383 1970 comes under zone II.

Fig.-3: Fine Aggregate

4.3 Coarse Aggregate

Aggregate which has a size larger than 4.75 mm or which retrained on 4.75 mm IS Sieve are known as Coarse aggregate. Coarse aggregates must be tough, pristine, and devoid of any chemical coating of clay and dust on the surface in order to make a decent concrete mix. Although there are many different ingredients or components used to make concrete mix, coarse aggregate is frequently used because it is one of the most important elements of concrete and takes up a significant amount of the mixture. The most important function of fine aggregate is to help with mixing consistency and workability. In this investigation, coarse materials with angular shapes from the neighborhood crusher are used. Grading of coarse aggregate was done according to IS:383-1970. Aggregates of Nominal size 20mm & 10mm to form a graded aggregate. The concerned lab provided the properties of coarse aggregate.

Fig.-4: Coarse Aggregate

4.3 Metakaolin Powder

Metakaolin is a highly pozzolanic material. It is one of the most widely used mineral admixtures these days. Concrete containing metakaolin as cement replacement up to some percentage help concrete to obtain both high performance and economy. It is neither a by-product of industry nor a natural product it is obtained by calcination of pure kaolinite or China clay at a temperature of 650 to 800^{0}C. Once the burning process is completed is grinded properly to that particle size for which it is used and fulfills the strength and property parameter of cement in motar and concrete. Metakaolin, which contains silica and alumina in an active state, interacts with calcium hydroxide at room temperature to generate calcium silicate hydrate (C-S- H)-gel, increasing concrete's density and lowering its porosity.

As a result, the concrete becomes more durable and its permeability is reduced. As a filler, it will now penetrate the spaces (voids) between cement particles when employed in concrete, making the concrete more impermeable. Metakaolin is its high reactivity with calcium hydroxide, $Ca(OH)_2$, and its ability to accelerate cement hydration. Metakaolin is expected to be more significant due to its high concentration of silica and alumina. Specifically, the calcium to silicon (C/S) ratio of the produced calcium silica hydrates (C–S–H gel) is expected to be higher than of other SCM's

Table-2: Chemical Composition of Metakaolin Powder

Chemical Composition	Cement (%)	Metakaolin (%)
SiO_2	34	54.3
(Al_2O_3)	5.5	38.3
(CaO)	63	0.39
(Fe_2O_3)	4.4	4.28
(MgO)	1.26	0.08
(K_2O)	0.48	0.5
(SO_4)	1.92	0.22
Colour	Grey	Off White

4.4 Washed Bottom Ash

Washed bottom ash is nearly 20% of the residual material of coal combustion in a power plant, boiler, furnace, or incinerator. The portion of the ash that escapes the chimney is referred to as fly ash (80%), and the clinkers that fall under their weight in the bottom hopper is termed as bottom ash (20%) which is cooled by water washing and is termed as Washed Bottom Ash (WBA). The size of bottom ash ranges from fine sand to fine gravel and has a minimal amount of silt and clay. A large portion of bottom ash comprises fine particles. Coal bottom ash is generally falling in a well-graded sand group.

Table-3: Chemical Composition of WBA

Chemical Composition	Bottom Ash
SiO_2	68
Al_2O_3	25
Fe_2O_3	2.18
CaO	1.66
TiO_2	1.45
MgO	0.02
SO_3	Nil
Loss on Ignition	1.69

4.5 Water

Water is one of the main constituents in the production of concrete. The normal portable tap water must be used in the production of concrete. Water to be used must be free from impurities and unwanted particles. The ph of the water to be used must be in the desired range. Otherwise, the strength of concrete can get affected. The strength of concrete can also get affected by polluted water.

5. METHODOLOGY

5.1 Batching: It's a technique for calculating and combining the necessary concrete components by weight and volume in accordance with the design mix. In most cases, volume is used. In batching, accuracy is crucial. Instead of using volume batching, it is preferable to use weight batching.

Fig.-4: Mixing of Material

5.2 Casting: The workability of mixture is tested via slump test and then placed in a mould. Before putting concrete mix in mould the mould is greased or appropriately oiled. After placing the mixture in the mould, it is adequately compacted. The exact process is carried on for all specimens to be tested. Three samples are prepared for each mix

Fig.-5: Casting of Cube

5.3 Curing: Before removing the mould, it is dried for 24 hours, and then specimens are placed in a water tank made to cure specimens. The specimens must be marked for identification so that there must not be any error. The specimens are removed from the tank and dried before putting in the testing machine. The specimens are kept in the tank for 28 days.

Fig.-6: Curing

5.4 Slump cone test: The slump test of concrete is a laboratory or field test that is used to determine the workability of concrete. The slump test is simply a measure of the wetness or consistency of the mix. The equipment used to test the concrete slump is quite simple. It consists of a tamping rod of length 600mm and dia. 16mm and a truncated cone that's 300 mm tall, 100 mm in diameter at the top, and 200 mm in diameter at the bottom.

Fig.-7: Slump Test

5.5 Compressive Strength Test: Compressive strength of the concrete is measured in UTM using mould that may be of cubical, trapezoidal, cylindrical in shape. Generally, cubical mould of size 150mm are used if the maximum nominal size of the aggregate is greater than 20mm and if it is less than 20m then mould of size 100mm can also be used. It is defined as the capacity of the concrete to resist the loads tending to reduce its size. By this test characteristic compressive strength of concrete is determined. This test performed only in the lab.

Fig.-8: Compression Test

5.6 Flexural Strength Test: Flexural strength is defined as the capacity of the beam or slab to resist failure in bending. Flexural strength of concrete is tested indirectly by finding the modulus of rupture for which mould of size 15cm x 15cn x70cm is prepare if maximum nominal size of the aggregate is greater than 20mm and of size 10cm x 10cm x 50cm is prepare if the maximum size of the aggregate is less than 20mm.

Fig.-9: Flexural Strength Test

5.7 Split Tensile Strength Test: Tensile strength of a concert can be tested using the splitting cylindrical test, which consist of a cylindrical mould which is loaded horizontally in between the plates of universal testing machine The tensile strength of concrete significantly affects the cracking in the structure. As we know, the concrete is weak in tension, so concrete generally develops cracks when tensile forces exceed the tensile strength of the concrete. This test can be performed on the universal testing machine. The apparatus consists of: tamping rod of 600mm length and 16mm dia., a weighing balance, a cylinder of size 15 x 30cm, a testing machine and a trowel.

Fig.-10: Split Tensile Strength Test

6. RESULT AND DISCUSSION

6.1 Concrete Mix Design

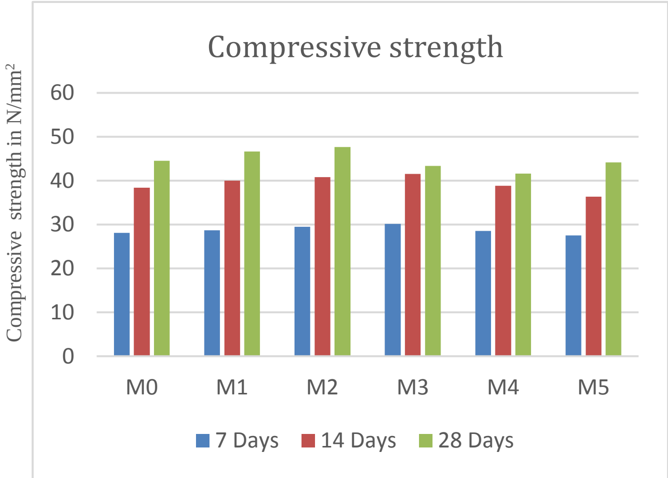
Based on trial mixes for different proportions of ingredients,the final design mix was prepared for M35 grade of concreteas per IS 10262:2009. The concrete mix proportion and w/cratio was considered as 0.44 and with varying percent of metakaolin powder and washed bottom ash and design was done. The different specimens as per the requirement for test were casted. The specimens were tested after 28 days of curing. In each category the specimens to be tested and average value is reported in the form of graphs.

6.2 Compression Test

The total of 54 cubes was tested at 7 days, 14 days, 28 days. The value of each test is provided in the table below:

Table-4: Compressive Strength Results

Mix	Specimen Details	Compressive Strength (N/mm²)		
		7 Days	14 Days	28 Days
M0	Convention Concrete	28.13	38.36	44.51
M1	6% MP + 9% WBA	28.67	39.97	46.63
M2	12% MP + 18% WBA	29.46	40.8	47.63
M3	18% MP + 27% WBA	30.16	41.54	43.37
M4	24% MP + 36% WBA	28.54	38.86	41.57
M5	30% MP + 45% WBA	27.51	36.37	44.14



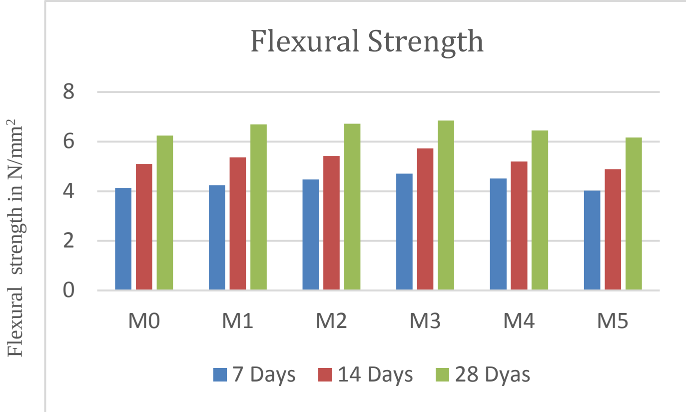
Graph-1 : Compressive Strength Results

6.3 Flexural Strength

Results including the flexural strength (for fractured samples) and the yield strength (samples that did not fracture). The test results conducted for 28 days are tabulated below.

Table-5: Flexural Strength Results

Mix	Specimen Details	Flexural Strength (N/mm²)		
		7 Days	14 Days	28 Days
M0	Convention Concrete	4.12	5.09	6.24
M1	6% MP + 9% WBA	4.24	5.37	6.7
M2	12% MP + 18% WBA	4.48	5.42	6.72
M3	18% MP + 27% WBA	4.7	5.73	6.85
M4	24% MP + 36% WBA	4.51	5.2	6.45
M5	30% MP + 45% WBA	4.02	4.89	6.17



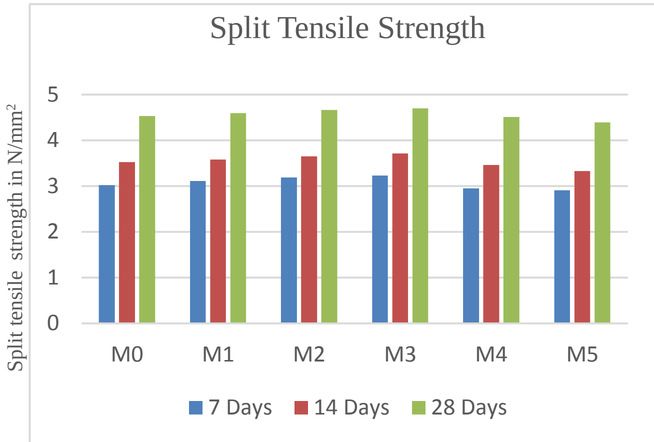
Graph-2: Flexural Strength Results

6.3 Split Tensile Strength

A standard test cylinder of concrete specimen is placed horizontally between the loading surfaces of compression testing machine. The compression load is applied diametrically and uniformly along the length of cylinder until the failure of the cylinder along the vertical diameter. The test results conducted for 28 days are tabulated below.

Table-6: Split Tensile Strength Results

Mix	Specimen Details	Split Tensile Strength (N/mm²)		
		7 Days	14 Days	28 Days
M0	Convention Concrete	3.02	3.52	4.53
M1	6% MP + 9% WBA	3.11	3.58	4.59
M2	12% MP + 18% WBA	3.19	3.65	4.66
M3	18% MP + 27% WBA	3.23	3.71	4.70
M4	24% MP + 36% WBA	2.95	3.46	4.51
M5	30% MP + 45% WBA	2.91	3.33	4.39



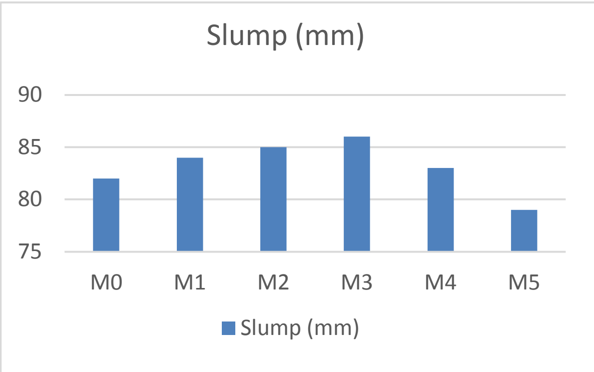
Graph-3: Split Tensile Strength Results

6.4 Slump Test

The results of the slump cone test performed on different mixes of M35 grade concrete are shown in the table:

Table-7: Slump test Results

Mix	Specimen Details	Slump (mm)
M0	Convention Concrete	82
M1	6% MP + 9% WBA	84
M2	12% MP + 18% WBA	85
M3	18% MP + 27% WBA	86
M4	24% MP + 36% WBA	83
M5	30% MP + 45% WBA	79



Graph-4: Slump Test

7. CONCLUSION

Based on the experimental investigation carried out on the strength behavior of Partial replacement of fine aggregate with washed bottom ash and cement with metakaolin powder, the following conclusions are drawn:

- Workability results show that if we replace cement with metakaolin powder up to 18% and sand with washed bottom ash up to 27%, there is no significant decrease in the workability.
- Compressive Strength is maximum at 18% metakaolin powder and 27% washed bottom ash replacement.
- Flexural Strength is maximum at 18% metakaolin powder and 27% washed bottom ash replacement.
- Split Tensile Strength is maximum at 18% metakaolin powder and 27% washed bottom ash replacement.

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