Replacement of Cement with Metakaolin, Marble Dust, and Slag Sand for Properties of Concrete using Correlation Coefficient

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ABSTRACT
In the construction industry, sand, marble, and cement are highly regarded. It is rising at a rapid rate, mainly in infrastructure development areas such as highways, airports, power stations, bridges, etc. Concrete is a good construction material due to its versatility for different applications as well as its ability to attain different shapes according to architectural requirements. The modernization and industrialization of the country have initiated a huge number of construction activities. Given that these natural resources are exploited and used to the greatest extent, pollution is increasing and resources are deprived. Environmental compliance costs are large throughout the industrial sector, including the concrete industry. Marble Dust (MD) is a byproduct of the marble industry resulting from the sawing, shaping, and polishing of stone. In this paper, correlation was employed as an analytical tool to study both the strength and degree of relationship between green concrete properties and the percentage replacement of cement with engineering materials. Both the Pearson product-moment method and Spearman's correlation coefficient were extensively used to show how correlation analysis can be practically applied in green concrete research. To satisfy the demands, an alternative material, artificial sand, was used. Slag sand is used as a complete replacement for river sand and has found its strengths. Tests for compressive strength, split tensile strength, and flexure strength were conducted on the sample with the replacement percentages of Metakaolin: 0%, 5%, 10%, 15%, and 20%. Marble dust 0%, 10%, and 20%, and slag sand as a complete replacement. This study intends to investigate the compressive strength, flexibility strength, and split tensile strength acquired by the curing at 3 days, 7 days, and 28 days, respectively. The goal was to assess the strength of the cement mix while being substituted with metakaolin.

Keywords: **Metakaolin, Marble Dust, Pearson and Spearman's Correlation**

1. INTRODUCTION

India is estimated to have the third-largest cement and concrete industry in the world. [13] The nation's construction sector is expanding quickly, mostly in the areas of infrastructure development such ports, highways, airports, power plants, bridges, etc. [12] Concrete is a good building material since it can be used for a variety of purposes and may take on various shapes to meet architectural specifications. Large amounts of concrete will be needed for the majority of the new projects. [8] Since new concrete structures will be utilizing the nation's priceless non-renewable resources, it would be imperative from a sustainability standpoint to guarantee that these structures remain robust. The building sector understands how important it is to make notable advancements in product quality, energy efficiency, and environmental performance. Costs associated with environmental compliance are high in the industrial sector as a whole, including the concrete sector [9],[10]. A by-product of the marble industry, Marble Dust (MD) is created when stone is sawed, shaped, and polished. Because MD has a high concentration of silica and calcium oxide, two components that are necessary for cement, it can be utilized to increase the strength of concrete. Natural resources can be preserved when MD is used in concrete in place of cement. Kaolin is heated between 600 and 800 degrees Celsius to create metakaolin. Early strength is improved by raising the heat of hydration rate because metakaolin has a larger specific surface area. [14],[15],[16]. Metakaolin alone does not possess cementitious properties, but in combination with cement and water, it catalyzes and advances these reactions. The process of making marble results in the creation of marble dust. Because it is created as dust during procedures like polishing and sawing, it is produced in enormous quantities. When it is exposed to the elements, the powder mixes with the water and increases turbidity. It also releases a significant amount of solid waste. All materials, including marble dust, slag sand, and metakaolin, are therefore used. The compaction factor and slump value are calculated for every combination of samples.

2. MATERIALS AND METHOD

2.1 Metakaolin

The clay mineral kaolinite is transformed into a different form called metakaolin. A useful additive for concrete and cement applications is metakaolin. China clay, also referred to as kaolin, is the term for kaolinite-rich rocks that are traditionally utilized in the production of porcelain. Metakaolin's particles are not as fine as silica fume, but they are still smaller than those of cement and their properties as shown in Table 1. A relatively new addition to the concrete industry, metakaolin effectively improves the air-void network, lowers sulfate attack, and increases strength. It released the composition of Calcium Hydroxide (CH) and extra Calcium Silicate Hydrate (C-S-H), pozzolanic reactions alter the microstructure of concrete and the chemistry of hydration products, improving durability by reducing porosity and increasing strength. [6],[7]

Table 1: Composition of both Cement and Metakaolin

Chemical Composition	Cement %	Metakaolin %
Silica	34	54.3
Alumina	5.5	38.3
Calcium oxide	63	0.39
Ferric oxide	4.4	4.28
Magnesium oxide	1.26	0.08
Potassium oxide	0.48	0.50
Sulphuric anhydride	1.92	0.22
Specific gravity	3.15	2.5
Color	Grey	Off white
Physical form	Fine powder	Powder

2.2 Marble Dust

As a byproduct of making marble, one might obtain marble dust. It is among the solid wastes discharged into the surroundings. Large amounts of it are obtained during the marble's polishing and sawing processes. Although marble dust doesn't have cementitious qualities, it helps the concrete mix by filling in the gaps. Because marble dust contains a large amount of lime, its reactivity is enhanced, which benefits its compressive strength and their properties as shown in the Table 2. Benefits to the environment also result from our ability to free up some areas from the accumulation of solid waste, which enhances soil fertility and ensures that nutrients are retained in the soil.[4]

Table 2: Properties of Marble Dust

S. No	Properties	Results
1	Fineness Modulus	3.36 m
2	Bulk Density	1336Kg/m^3
3	Specific Gravity	2.58

2.3 Fine Aggregate- Slag Sand

An alternative to river sand is slag sand. The quick mining of river sand, which is used extensively in the construction industry much like cement, is delicately upsetting natural resources. The compressive strength of natural sand is lower than that of slag sand. The type of stones utilized affects the bonding strength. The mix needs to be changed frequently since the truck's fineness modulus varies when it does. The iron and steel industry are the final source of slag sand and their properties as shown in Table 3. It is created by putting molten iron slag from a blast furnace in steam or water, letting it cool, and then grinding it into a fine powder. It is not a product made of metal. The main component of slag sand, Calcium oxide raises compressive strength. Slag sand's main benefit is that it restricts temperature growth and slows down the heat of the hydration process.[5]

Table 3: Properties of Slag Sand

S. No	Properties	Results
1	Specific Gravity	2.65
2	Bulking of Sand	46.15%

2.4 Coarse Aggregates:

Aggregates rank among the most important components of concrete, after cement. They create the binding and sticky quality of the matrix. They comprise 60–70% of the whole. Aggregates are taken to determine bonding efficiency between 20 mm and 12 mm. Coarse aggregates are available from the adjacent quarry and its properties as shown in Table 4.

Table 4: Properties of Coarse Aggregates

S. No	Properties	20mm	12mm
1	Specific Gravity	2.90	2.55
2	Water Absorption	0.25%	1.0%
3	Flakiness Index	10	18
4	Elongation Index	17.3	21
5	Fineness Modulus	5.61	3
6	Bulk Density	1566.3Kg/m^3	1553.14Kg/m^3

2.5 Casting:

The process of using concrete for constructing items or structures is known as concrete casting. The steps in the procedure are setting up the mold adding the concrete, and making it cure. The subsequent stages of the concrete casting process preparation as shown in fig 1.

i. preparing the formwork
ii. Mixing the Concrete
iii. Placing the concrete in the formwork
iv. Finishing the surface
v. Curing the concrete
vi. Removing the formwork

Fig.1: Preparation of Concrete block using casting method

2.6 Compressive strength:

Concrete's compressive strength is its ability to support weights before breaking. The compressive strength test is the most crucial of the various tests conducted on the concrete since it provides insight into the material's properties. as shown in fig 2.

Fig.2: Compressive test

2.7 Compaction Factor:

The laboratory workability test for concrete is called the compaction factor test. The weight ratio of partially compacted to completely compacted concrete is known as the compaction factor. It was created by the UK's Road Research Laboratory and is used to assess whether concrete is workable as shown in fig 3.

Fig.3: Compaction factor test

3. CORRELATION ANALYSIS:

A correlation demonstrates the degree and direction of a relationship between two variables. It serves as a gauge for the type and degree of correlation that exists between the variables. It merely quantifies the link to extreme values of its coefficient, not the causative relationship. There are two types of correlation are

a) Pearson's product-moment correlation

$$r=\frac{\varepsilon xy}{\sqrt{(\mathcal{E}x)^2(\mathcal{E}y)^2}} \quad (1)$$

were,

r = Pearson's coefficient of correlation

X = value of the deviations of coordinate x from X (their mean value).

Y = value of the deviations of coordinate from Y (their mean value).

The Pearson's coefficient of correlation, or "r," has values between +1 and -1, and its meaning can be understood as follows.

Character of the correlation: An inverse correlation is represented as a negative correlation for "r," whereas a positive correlation denotes a direct correlation.

b) Spearman's correlation coefficient

Spearman's correlation is also called as "Rank order correlation coefficient. Here "r_s" is Spearman's correlation.

$$r_s = 1- (6\ \mathcal{E}\ D^2)/\ (n\ (n^2 -1) \quad (2)$$

were

r_s =Spearman's correlation coefficient

D= difference between the two ranks of each observation

n = number of observations

4. METHODOLOGY

4.1 Workability:

The ease with which the mix can be moved, compacted, and placed is known as workability. The workability tests listed below are carried out.

4.2 Slump Cone Test:

From Table 6. One of the simplest and most fundamental tests for determining workability is the slump test. It can be carried out outdoors or in a lab. It consists of a slump cone that is 300 mm tall overall, with a top diameter of 100 mm and a bottom diameter of 200 mm. The sample mix is layered three times inside the cone. A concrete slump is the height at which the concrete mix sinks when the cone is elevated. For very wet or extremely dry mixes, it is not the best option.

Table 6: Slump Cone Test Results

S.NO	Cement (%)	Metakaolin replacement (%)	Slump (mm)	Marble Dust replacement (%)
1	100	0	112	0
2	90	0	110	10
3	80	0	107	20
4	85	5	104	10
5	75	5	100	20
6	80	10	98	10
7	70	10	97	20
8	75	15	95	10
9	65	15	91	20
10	70	20	89	10
11	60	20	85	20

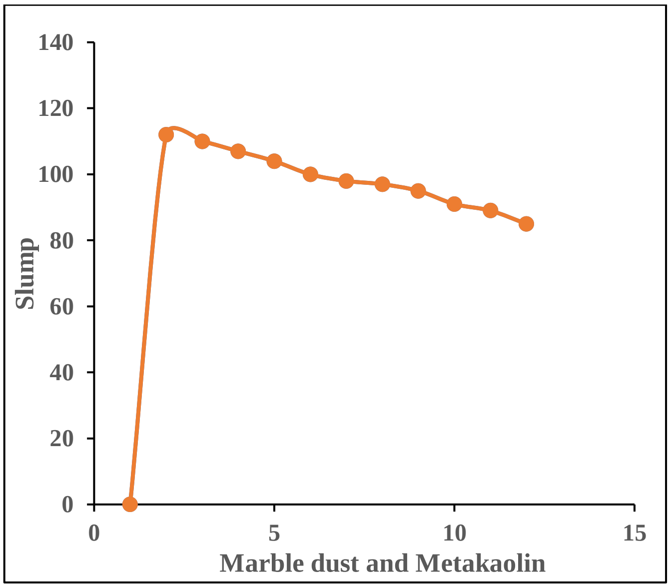

Fig.4: Marble dust and Metakaolin vs Slump test results

The maximum slump value was 0% replacement, while the lowest slump value was 20% replacement. The overall average slump recorded was 98mm. The droop ranged from 120mm to 80mm. The mix had a minor decline as shown in fig 4.

5. Compaction Factor Test Results:

Fig 5. The greatest value is seen at 0% replacement. The last value was recorded at 20% replacement. The range was between 0.920 to 0.814. Because the values are limited, the mix is extremely easy to handle, and compacting was not difficult. The compaction factor test is completely lab-based. The cement's densification and compacting are influenced by this and results as shown in Table 7. The compaction factor is calculated as the weight ratio of partly compacted concrete to fully compacted concrete.

Table 7: Compaction factor results

S.NO	Cement (%)	Metakaolin (%)	Marble Dust (%)	Compaction factor
1	100	0	0	0.92
2	90	0	10	0.894
3	80	0	20	0.862
4	85	5	10	0.859
5	75	5	20	0.853
6	80	10	10	0.851
7	70	10	20	0.849
8	75	15	10	0.847
9	65	15	20	0.839
10	70	20	10	0.827
11	60	20	20	0.814

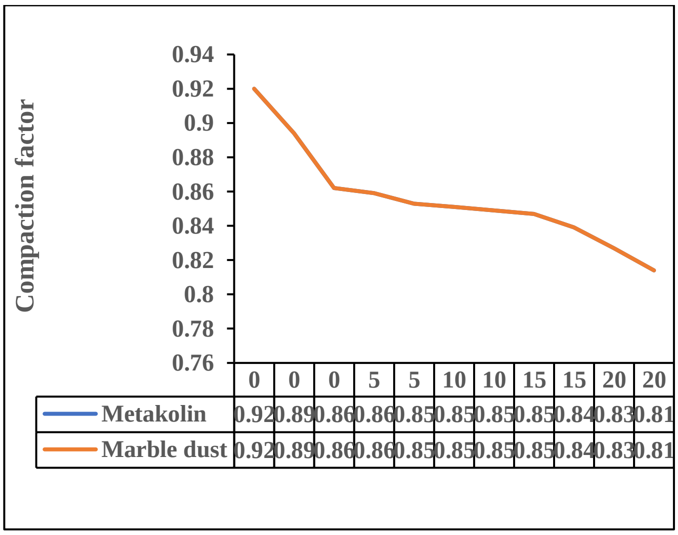

Fig.5: Metakaolin and Marble dust of compaction factor

6. Compressive Strength Test Results:

After 3,7,28 days of curing, the sample's compressive strength is determined [3]. Early strength is defined as having been developed after three days, first-stage strength as developed after seven days, and characteristic compressive strength as developed after 28 days. After 28 days, the strength attained is 99% of the desired strength. Standard-sized 150 x 150 x 150 mm cubes are taken. From Table 8 all samples of compressive strength and no of days as shown. Samples are taken out of the curing tank and allowed to air dry in the sun. The sample is then put beneath the apparatus used for compressive testing.

Table 8: Compressive Strength Test Results

Materials			Compressive strength		
S.NO	Metakaolin (Mk)	Marble Dust (MD)	3 days	7 days	28 days
1	0	0	23.39	38.1	66.9
2	0	10	23.51	38.3	67.1
3	0	20	23.62	38.4	67.5
4	5	10	23.96	38.9	69.5
5	5	20	24.04	39.1	69.8
6	10	10	24.22	39.3	71.4
7	10	20	24.56	39.8	73.6
8	15	10	25.17	41.9	76.2
9	15	20	24.51	39.9	74.2
10	20	10	23.23	38.4	71.2
11	20	20	23.17	37.6	69.7

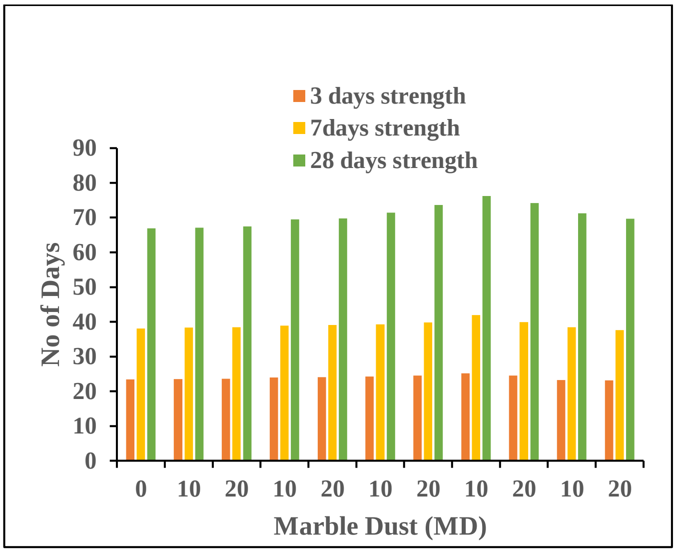

Fig.6: Compressive Strength Test of Marble Dust of 3,7,28 days strength

Fig 3. Additional cementitious materials including metakaolin and marble dust are used in this study. Early in the cement's hydration reaction, calcium silicate and hydrate combine to form C-S-H gel. The pozzolanic reaction between metakaolin and cement initiates the production of the secondary calcium silicate hydrate or C-S-H gel ettringite. It is less dense than the primary C-S-H gel and can be used to reduce the total permeability of cement-based composites, generate a packed structure, and fill and segment large capillary pores into small, discontinuous capillary pores by pore size refinement [1]. With its smaller particle size (1 m) than cement (12 m), metakaolin provides more nucleation sites, which promote quicker hydration, better packing, and a higher density of pore structure in the cement matrix. Consequently, the incorporation of Metakaolin enhances both mechanical characteristics and strength. Tricalcium aluminate, one of the primary bogue compounds in cement, combines with the calcium carbonate in marble dust to form calcium carbo aluminate, which helps to accelerate the hydration rate and development of compressive strength. Marble dust has a higher degree of fineness than other dusts, which makes concrete more cohesive. It also reduces water absorption and porosity when added to concrete, increasing the material's compressive strength [2]. Therefore, in the early phases, compressive strength begins to gradually grow and reaches an optimal proportion at 10% marble dust and 15% metakaolin, respectively. According to the data above, the replacement level of 10% marble dust and 15% metakaolin is the most appropriate for giving the mixture strength. Thus, it proved to be a sustainable and environmentally friendly material.

7. Correlation Coefficient of Compressive Strength Results

$$r = \frac{\varepsilon xy}{\sqrt{(\varepsilon x)^2(\varepsilon y)^2}} \quad (3)$$

Table 9: Correlation Coefficient Relation

X	Y	X=x-X	Y=y-Y	XY	X^2	Y^2
0	23.39	-20	0.006	-0.12	400	0.000036
10	23.51	-10	0.126	-1.26	100	0.015876
20	23.62	0	0.236	0	0	0.055696
30	23.23	10	-0.154	-1.54	100	0.023716
40	23.17	20	-0.214	-4.28	400	0.045796

$$X = \frac{\varepsilon X}{n} = 100/5 = 20$$

$$Y = \frac{\varepsilon y}{n} = 23.384$$

$$r = \frac{-6.066}{20*23.384} = -0.012$$

Table 9. The value of Pearson's correlation coefficient "r" showed a weak relationship between the concrete compressive strength and the percentage of cement with metakaolin and marble. It means the compressive strength of concrete will drastically reduce with an increase in the percentage of replacement cement with metakaolin along with marble.[11]

8. Spearmen Coefficient of Compressive Strength Results

Table 10: Correlation Coefficient Relation

X	Y	Rank X	Rank Y	D=[x-y]	[D]2
0	23.39	1	2	1	1
10	23.51	2	3	1	1
20	23.62	3	4	1	1
30	23.23	4	5	1	1
40	23.17	5	1	4	16

$$r_s = 1 - (6\,\mathcal{E}\,D^2)/\,(n\,(n^2-1)$$

$$r_s = 1 - \frac{6(20)}{5(25-1)} = 1 \quad (4)$$

The value of the spearmen coefficient "rs" also showed a very strong relationship between the concentric compressive strength and percentage replacement of cement with metakaolin and marble.

CONCLUSION

Correlation was the statistical tool analysis to find the mechanical and durability properties of concrete. The use of these analytical tools showed the degree of relationship and the results of a correlation positive relationship between metakaolin and marble.

Every sample mixture is meticulously produced. Strength increased from 0% to 15% in the Metakaolin and at 10% replacement of marble dust. A decrease in strength was seen during the 20% replacement of the Marble Dust stage. At 0% replacement, compressive strength was first measured at 66.9 N/mm2. At 15%MP+10%MK, the strength climbed to 76.2 N/mm2, and from 15%MK+20%MD, it began to decrease. Finally, with 20%MK+20%MD replacement, there was a total decline. Significantly less solid waste enters the environment when cement is substituted with marble dust and metakaolin.

Even though it might be on a small scale when we use tiny kilos of cement, if we were to produce tons of cement, we would need to replace massive kilograms of marble dust and kaolin. When cement is produced in large quantities, the impact of replacement is very noticeable.

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