STRENGTH ANALYSIS OF METAKAOLIN BASED CONCRETE IN PRESENCE OF WASTE FOUNDARY SAND

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ABSTRACT: The purpose of this study is to investigate the results that would be obtained by exchanging cement for metakaolin and fine aggregate for waste foundry sand. For the purpose of this inquiry, M-30 grade concrete is produced, and it is examined for characteristics of hardened concrete such as compressive strength. Samples with required dimensions were utilised with Metakaolin at a constant 10 percent, and the fine aggregate was replaced with waste foundry sand at weight percentages of 0, 10, 20, 30, and 40 percent. Based on the findings, it appears that improving the mechanical properties of concrete by mixing in Metakaolin and waste foundry sand is beneficial. The best results were obtained by replacing cement and sand with Metakaolin at a percentage of 10 percent and waste foundry sand at a percentage of 30 percent, respectively. The findings indicate that, up to a certain amount of Waste foundry sand and Metakaolin addition, there is a gain in mix strength; however, after that point, further addition of the Metakaolin and Waste foundry sand begins to lower mix strength. Despite the fact that adding Metakaolin and waste foundry sand up to a level of ten percent and thirty percent, respectively, helps in achieving higher strength than conventional concrete, the inclusion of these materials is not required. As a result, the use of metakaolin and waste foundry sand in place of traditional sand aids in the development of green concrete that is both kind to the environment and durable.
Keywords: Concrete, metakaolin, waste foundary sand, strength, environment.

1. Introduction

After water, concrete is the substance that is found all over the planet in the greatest abundance. Although the exact year it was first created is debatable due to the varying definitions of the word "concrete." In ancient times, crude cements were made by using either gypsum or limestone that had been crushed and then burned. Lime can also refer to limestone that has been crushed and then burned. As soon as sand and water are added to the cement, it is transformed into mortar; mortar is a plaster-like compound that is used to connect stones to one another. Concrete as we know it today is the product of a multi-thousand-year-long process that began with the production of its constituent parts independently, continued with their combination with those of other parts, and ultimately evolved into its present-day form. These days, Portland cement, coarse and fine stone and sand aggregates, together with water, are the components that are utilised in the production of concrete. Admixtures are chemicals that are added to the concrete mix after it has been prepared in order to change the setting properties of the concrete. This is done in order to achieve the desired end result. When pouring concrete in scenarios characterised by severe weather, such as extremely high or low temperatures, conditions characterised by wind, and so on, these are typically the settings in which they are used. Around the year 1300 B.C., architects in the Middle East made the discovery that covering the exteriors of their pounded-clay fortifications and residence walls with a thin, moist layer of burned limestone resulted in a chemical reaction with gases in the air that produced a hard, protective surface. This discovery was made by coating the exteriors of their pounded-clay fortifications and residence walls with burned limestone. This kind of response was known as a pozzolanic reaction back in the day. This was the beginning of the development of cement, even though at the time it wasn't anything like concrete.

Limestone that had been crushed into mortar, then burned, along with sand and water were the primary components of the first cementitious composite materials. These early cementitious composite materials were used for stone construction rather than casting the material in a mould, which is essentially how modern concrete is used, with the mould serving as the concrete forms. Rather than casting the material in a mould, these early cementitious composite materials were utilised for the construction of stones. In modern building, concrete is employed in a manner analogous to that of stone. Natural deposits were generated in what is now Israel about 12 million years ago as a result of spontaneous combustion interactions between limestone and oil shale. These interactions took place in the land that is now Israel. These interactions took place in the land that is now Israel. Cement, on the other hand, is not the same thing as concrete. The constituent parts of concrete, of which cement is only one, have undergone transformations over time and will continue to do so in the future. Concrete is a composite building material. There is a possibility that the concrete's performance attributes will change based on the forces that it is required to sustain. These pressures might be mild or severe, and they can come from the top (gravity), the bottom (soil heaving), the sides (lateral loads), or the sides in the form of erosion, abrasion, or chemical attack. The components of the concrete and the proportions in which they are used are referred to as the design mix.

Concrete's versatility and application in the construction industry cannot be overstated. For more than two decades, researchers have been working on regular and high strength concrete. Ordinary concretes have a compressive strength of between 25 and 55 MPa, while high strength concretes have a compressive strength of more than 55 MPa, as stated in the IS: 456-2000 [Code of Practice for Plain and Reinforced Concrete]. The term "ultra-high strength concrete" refers to concrete that has a compressive strength of greater than 120 MPa. Many uses can be found for high-strength concrete globally, including towering skyscrapers, long span bridges, and buildings in harsh conditions. As a result, it is necessary to manufacture a high-strength concrete while simultaneously minimising waste by employing it as a constituent of concrete. The utilisation of waste foundry sand ash and metakaolin as partial replacements for fine aggregates and cement, respectively, is the primary emphasis of this investigation.

It is possible to recycle waste foundry sand by using it as fine aggregate in concrete for paving blocks. Because of the significant impact of discarding foundry sand after it has been used, the utilisation of scrap foundry sand is required. Different types of foundry sand Green sand and chemically bonded sand are the two categories of foundry sand. Clay is what holds green sand together as a cohesive material. It is composed of between 85 and 95 percent silica, between 0 and 2 percent clay, between 2 and 10 percent carbonaceous additives like sea coal, and between 2 and 5 percent water. Green sand is the type of sand that is most commonly used as a moulding material in foundries. The silica sand that makes up the majority of green sand is able to withstand high temperatures; the clay coating that covers it is what holds the sand together; water

contributes to the material's flexibility; and carbonaceous additives prevent the sand from melting into the casting surface. In chemically connected sand, the individual grains of sand are held together with the use of polymers. It is composed of between 93 and 99 percent silica and somewhere between 1 and 3 percent of a chemical binder. In a reaction that is started by a catalyst, the silica sand and the binder are thoroughly combined before the curing and hardening processes take place. Chemical binder systems like as phenolic-urethanes, epoxy-resins, and sodium silicates are utilised in the foundry industry. The focus of the ongoing study is on environmentally friendly WFS made with bentonite clay as a binder and chemically bonded WFS made with sodium silicate as a binder. The ferrous and nonferrous metal casting industries both produce sand from waste foundries as a byproduct of their respective processes. Sand can be recycled and reused multiple times in foundries with great success. Used foundry sand is sand that has been removed from a foundry after it has reached the point where it can no longer be used there. Research is being done to determine whether or not used foundry sand can be used on a wide scale to partially replace fine aggregate in concrete. This is being done in an effort to get the most use out of the sand that has already been used.
As a result, extensive research is required to improve the mechanical features of concrete, such as strength and durability, and to reduce waste created at the household and industrial levels. The purpose of this paper is to use Metakaolin and Waste Foundry Sand to replace cement and fine aggregate under regulated settings. It will aid in the reduction of concrete production costs as well as the efficient disposal of industrial waste. Additionally, using Metakaolin obtained from businesses as a replacement for cement helps to reduce CO2 emissions from cement manufacturers.

2. Experimental

Materials

The civil engineering laboratory was used to perform experiments in accordance with the applicable rules of practise on the physicochemical properties of the materials that are necessary for the production of the concrete mix. Cement (OPC grade-43), fine and coarse aggregates, water, Metakaolin, and waste foundry sand are the components that were employed in this research. Coarse aggregate used for the research work were procured from local seller, having maximum size of 20 mm. Before testing, the aggregates were properly washed to remove small debris and dust. After that they were placed in open for drying up to surface dry condition. The physical properties of aggregates were tested as per Indian standard specifications of IS: 383-1970 which are given in following table. In this research work, fine aggregate used were procured from local seller. The aggregates procured for testing were free from any waste and were sieved through 4.75mm sieve to remove coarse particles. The fine aggregates used for testing were of light brown in color. Fine aggregates used were tested as per IS: 383-1970 and results were tabulated in the following table. Clean and potable water available in civil engineering laboratory was used in making concrete mix. It was free from waste, debris, silt and organic materials conforming to IS: 456-2000. Same quality water was used for the curing of specimens.

Metakaolin used for the research work was prepared in laboratory by dehydroxylating the waste clay obtained in oven. It is a pozzolanic material and hence used in place of cement for preparing the concrete mix. After taking out the clay from oven, it was grinded into fineness for using as a replacement of cement. The chemical composition of Metakaolin is expressed in terms of the oxides determined by the help of x-ray fluorescence. Table 3.5 shows the different range of compounds present in Metakaolin prepared in civil lab. The Metakaolin obtained from waste are not of same quality and carried the same compounds. It carries a range of different compounds depending upon the location from where the waste is obtained. Its physical properties are listed in the following table.

Waste foundry sand used in the research work was obtained from “Precision Industries” which is located at Goyal compound, Industrial area, Tansen road, Gwalior (M.P). The sample obtained from industry was of black in colour & have rough texture. The physical properties obtained and sieve analysis test results are shown in following table.

Table 3.1. Physical properties of cement

Sr. No.	Physical Properties	Results obtained	IS limits
1	Specific gravity	3.13	3.15
2	Initial Setting time	51 Minutes	>30 Minutes
3	Final Setting time	214 Minutes	<600 Minutes
4	Normal consistency (%)	32%	---
5	Color	Grey	Grey
6	Expansion- Le Chatelier apparatus (mm)	3mm	<10mm
7	Fineness (retained on 90 µm sieve)	3.40%	10%

Table 3.2. Physical properties of coarse aggregates

Sr. No.	Physical Properties	Results obtained
1	Specific gravity	2.67
2	Water absorption	0.81%
3	Maximum nominal size	20 mm
4	Color	Grey
5	Shape	Crushed Angular type
6	Fineness Modulus	6.74
7	Aggregate impact value	26%

.Table 3.3. Physical properties of fine aggregates

Sr. No.	Physical Properties	Results obtained
1	Specific Gravity	2.61
2	Fineness Modulus	2.73
3	Water absorption (%)	1.50%
4	Clay Lumps and fiberable Particles	Nil
5	Color	Light Brown

Table 3.4. Sieve analysis of fine aggregates

Sr. No	Sieve Size (mm)	Weight of fine Aggregate Retained	Percentage Retained	Cumulative Percentage retained	Percentage Passing
1	4.75 mm	750	15	15	85
2	2.36 mm	790	15.8	30.8	69.2
3	1.18 mm	490	9.8	40.6	59.4
4	600 µm	645	12.9	53.5	46.5
5	300 µm	1610	32.2	85.7	14.3
6	150 µm	540	10.8	96.5	3.5
7	Pan	175	3.5	100	0

Table 3.5. Chemical composition of Metakaolin

Sr.No.	Name of chemical compound	Chemical composition (%)
1	SiO_2	52.1
2	Al_2O_3	46.3
4	Na_2O	0.19
5	K_2O	0.17
6	SO_3	0.1
7	MgO	0.11
8	CaO	0.04

Table 3.6. Physical properties of Metakaolin

Sr. No.	Physical properties	Results obtained
1.	Specific Gravity	2.50
2.	Water absorption	Less than 2%
3.	Color	Light Brown
4.	Texture	Rough

Table 3.7. Chemical composition of Waste Foundry Sand

Sr.no.	Name of chemical compound	Chemical composition (%)
1.	SiO_2	87.91%
2.	Al_2O_3	4.70%
3.	MgO	0.30%
4.	CaO	014%
5.	Na_2O	0.19%
6.	K_2O	0.25%
7.	SO_3	0.09%
8.	Loss on ignition (LOI)	5.15%

Table 3.8. Physical properties of waste foundry sand

Sr. No.	Physical properties	Results obtained
1.	Specific Gravity	2.2
2.	Water absorption (%)	1.3%
3.	Fineness Modulus	2.57

4.	Material Finer than 75µ (%)	8%
5.	Clay Lumps and fiberable Particles (%)	Nil

Methods

The ingredients obtained from different sources like cement, fine and coarse aggregates, water, Metakaolin and waste foundry sand were mixed in proper proportions and in a better way to get a homogeneous concrete mix. Quantities of different materials for making concrete mix were evaluated. First of all, the materials were properly weighed and then mixed in dry form as specified. Mixing was done manually on a dry platform and then water was poured on the dry mix. The concrete cube moulds used were of standard size of 150×150×150mm as prescribed by Indian Standard specifications. Before starting the work, the concrete cubes were properly washed to remove any debris and dust. Every time there inner part were oiled properly before filling the cubes with concrete. The oil was applied to prevent the concrete from sticking with the mould and after hardening, they can be easily removed. Corrosion from nuts and bolts of the mould was removed by washing them with oil properly. After casting the concrete in concrete cube moulds, they were left for hardening upto 1-2 hours. After the concrete sufficiently, they were marked with a specific number with the help of a sharp tool for 7, 14 and 28 days testing. After 24 hours concrete specimens were taken out from the moulds and submerged fully into a water tank for curing and the temperature of the tank was maintained at 27 ^{o}C for effective curing. At the end of the 7, 14 and 28 days the cubes were taken out of the water tank and left in shade for drying. Then concrete cubes were taken for testing in compression testing machine.

In the present research work, the concrete cubes were tested in compression testing machine. The concrete cubes of different proportions of Metakaolin and waste foundry sand were tested on different days and the average of three cubes for each proportion was taken for getting accurate results. After that the results obtained are listed in table to evaluate the effect of current replacements.

For evaluating the compressive strength of cubes of size 150×150×150mm, proper test procedure was followed. The concrete cubes of size 150×150×150mm filled with fixed %age of Metakaolin (10%) and varying percentage of waste foundry sand (0,10,20,30 &40%) replacement were already casted and cured. For split tensile strength measurements, cylinders of dia 150 mm and height of 300 mm were casted and for flexural strength test, beam moulds of size 10x10x50 cm were prepared. Test procedure was conducted according to IS: 516-1959 (reaffirmed 1999).

In this research work first of all the ingredients including cement, fine and coarse aggregates, Metakaolin and waste foundry sand were mixed in dry form as specified and then water was added. The concrete cube moulds were cleaned with oil from inner surface and then concrete was poured into it. After 24 hours, the cubes were taken out from mould and submerged into water for curing. After that the concrete cubes were taken out from water for 7, 14 and 28 days testing in compression testing machine. The load was applied gradually and truly vertical without any jerk till the specimen crushed. The load was applied at the constant rate per minute till the specimen fails. After that load value was taken from dial gauge and divided by area of specimen to get the strength of that specimen. In the same way the other specimens were tested and their average compressive strength was evaluated for getting accurate results.

Table 3.9. Mix design of Concrete Mixtures

Sr. No.	Materials	Units	Material quantities					
			M0	M_1	M_2	M_3	M_4	M_5
1.	Cement	Kg/m^3	422.0	379.80	379.80	379.80	379.80	379.80
2.	Metakaolin	Kg/m^3	-	42.20	42.20	42.20	42.20	42.20
3.	Fine aggregate	Kg/m^3	621.0	621.0	558.90	496.80	434.70	372.60
4.	Waste Foundry Sand	Kg/m^3	-	-	62.10	124.20	186.30	248.40
5.	Coarse aggregate	Kg/m^3	1284.0	1284.0	1284.0	1284.0	1284.0	1284.0
6.	Water	lit/m^3	148.0	148.0	148.0	148.0	148.0	148.0
7.	Admixture	lit/m^3	5.064	5.064	5.064	5.064	5.064	5.064

3. RESULTS AND DISCUSSION

The results obtained after testing the concrete cubes for 7 and 28 days of testing in compression testing machine are compared. The results obtained are for different proportions of waste foundry sand and fixed %age of Metakaolin. In this paper graphs are plotted to specify the optimum values of Metakaolin and waste foundry sand which gives the maximum compressive strength.

3.1. COMPRESSIVE STRENGTH

The compressive strength results obtained by testing of concrete cubes for different proportions of Metakaolin and waste foundry sand were compared with that of normal concrete testing results. The results shows that increase in strength with the increase in content of waste foundry sand and Metakaolin at optimum level is approx. 14% and 16% for 7 and 28 days respectively. After optimum level is reached, the compressive strength starts decreasing and become lower than the normal concrete.

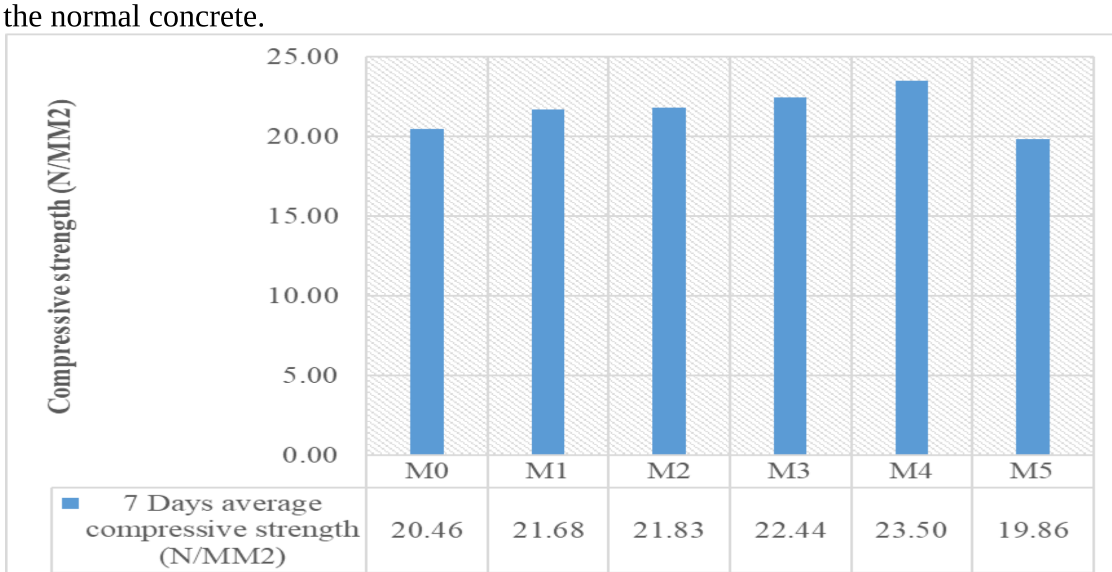

Figure 4.1. 7 days compressive strength

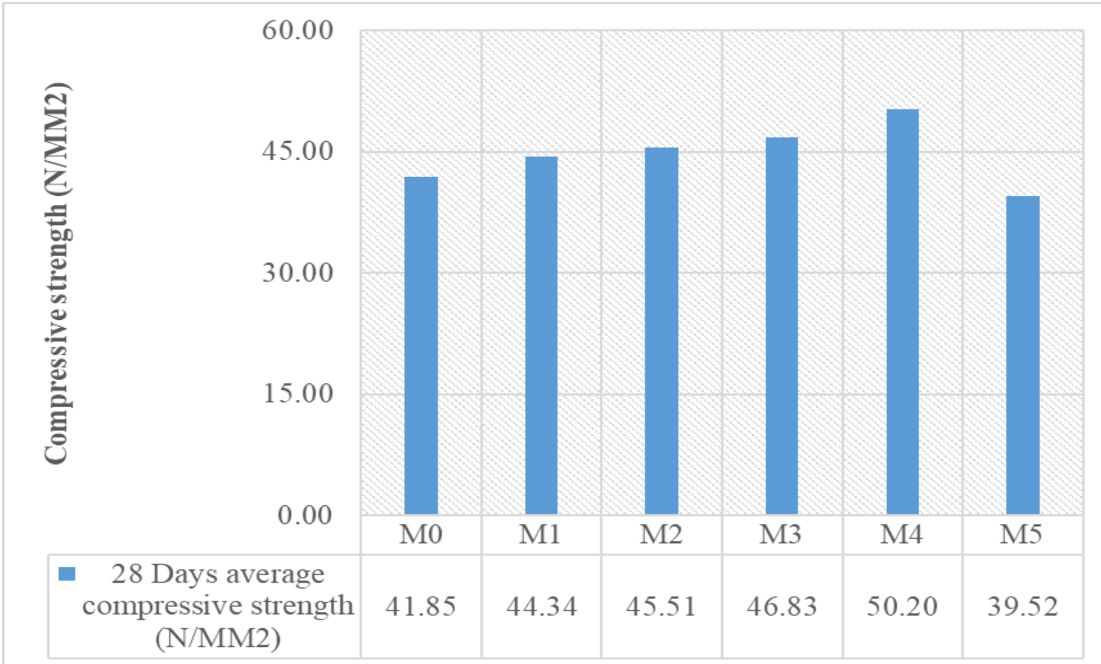

Figure 4.2. 28 days compressive strength

3.2. SPLIT TENSILE STRENGTH

It was discovered that the split tensile strength increases with an increase in MK concentration, but after that its value increases with an increase in the amount of WFS. It decreases further due to the unreactivity of excess WFS, which rather fills the pores up to a certain extent known as the optimized amount.

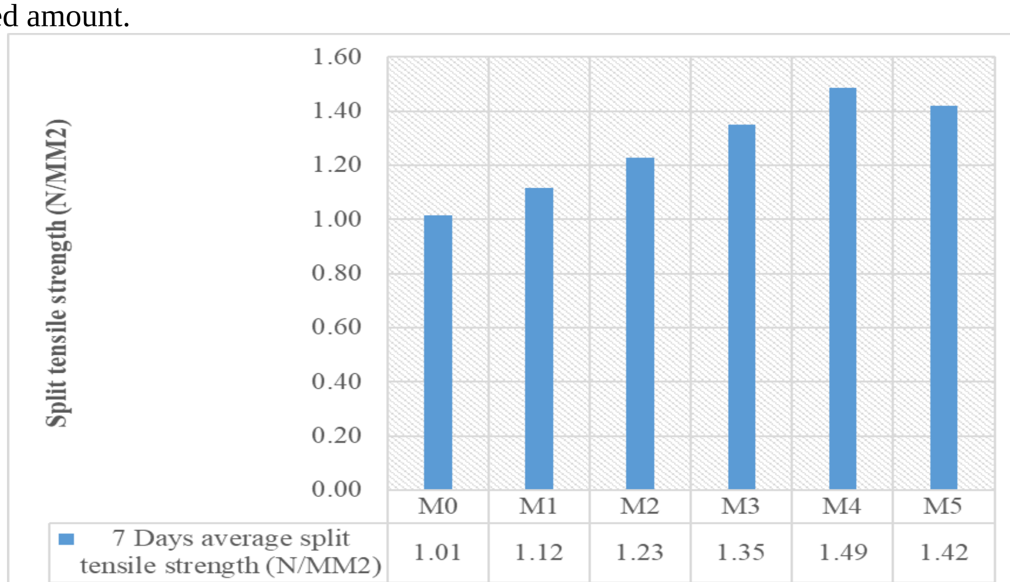

Figure 4.3. 7 days split tensile strength

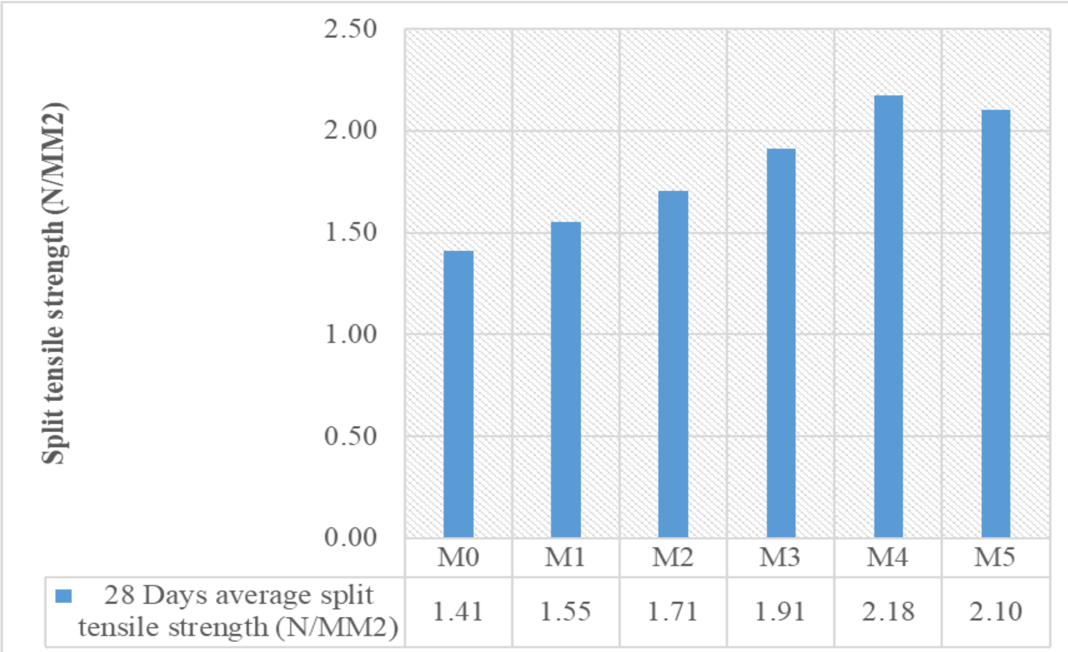

Figure 4.4. 28 days split tensile strength

3.3. FLEXURAL STRENGTH

It is clear from the result that there flexural strength of concrete increases when the MK dosage is added. The flexural strength of concrete also increases with age but the percentage increase in flexural strength was more at early ages than at later ages. Strength also increases with increase in WFS content till 30% and afterwards a slight decrease is observed.

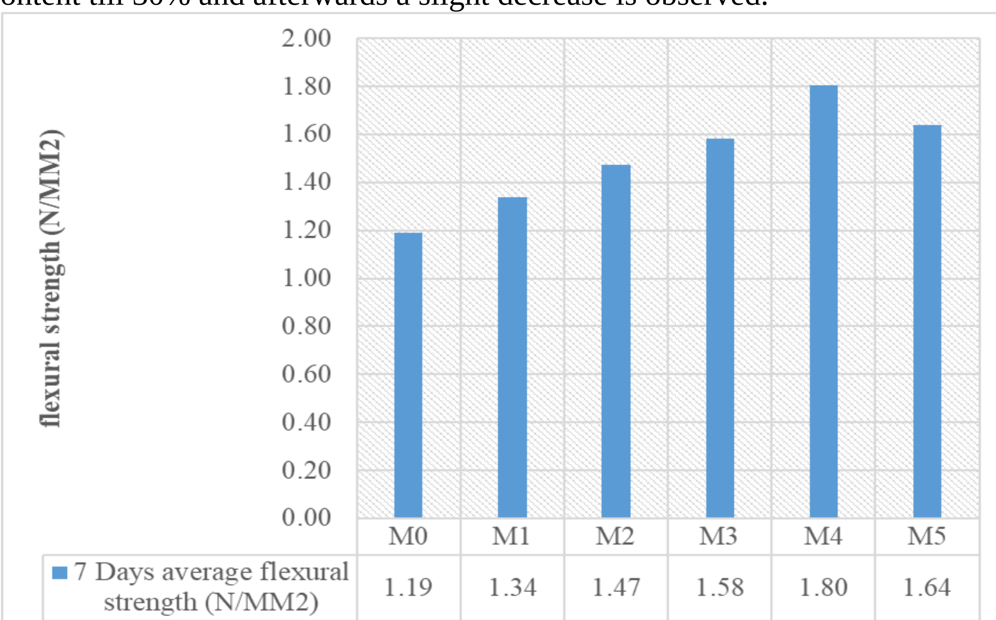

Figure 4.5. 7 days flexural strength

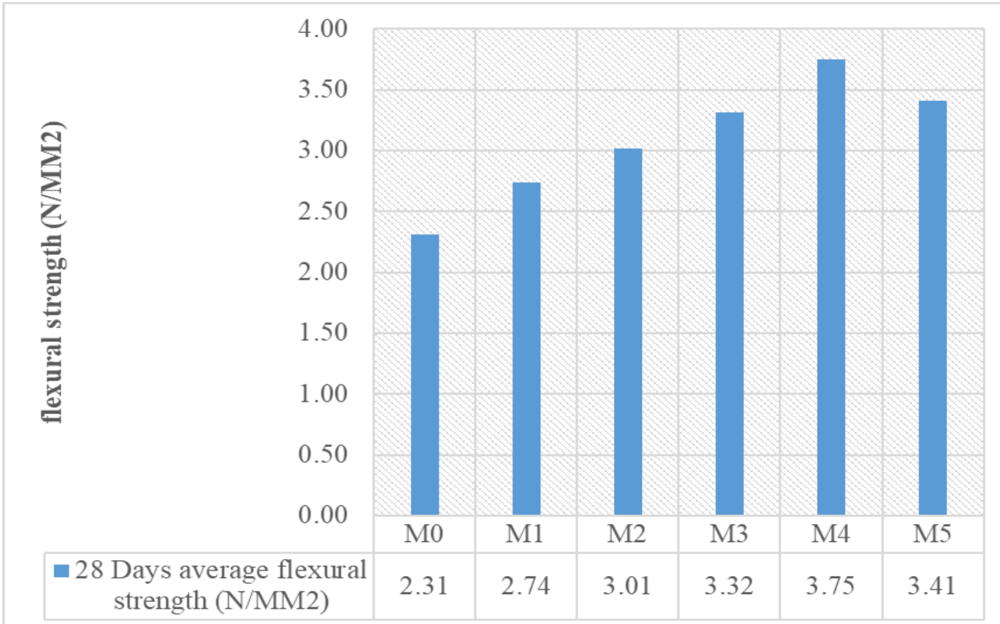

Figure 4.6. 28 days flexural strength

An explanation of the different ways in which pozzolanic ingredients can influence the properties of concrete provides an outline of the influence that pozzolanic elements have on the properties of concrete. In cement concretes that contain metakaolin, the metakaolin not only contributes to the strength of the concrete when it is young, principally through the filling effect, but it also contributes to the strength of the concrete when it is older as a result of the quick pozzolanic reaction. This effect is the primary factor that accounts for the early contribution that metakaolin makes to the strength of the concrete. Metakaolin can be included into concrete, which can lead to the manufacturing of high-strength concrete. The addition of MK to concrete, as stated by a number of papers, is said to result in an increase in the material's strength, particularly in the earlier phases of the material's hydration process. After the concrete has been cured for a period of 14 days, the contribution that MK gives to the strength of the concrete will begin to lessen. It is believed that the filling effect, in which MK particles fill the space between cement particles, the acceleration of cement hydration, and the pozzolanic reaction of MK are responsible for the increase in compressive strength that MK concrete possesses. Additionally, it is believed that the pozzolanic reaction of MK is responsible for the increase in tensile strength that MK concrete possesses. This effect is analogous to that which is brought on by breathing in crystalline silica fume. However, the pore structure of the paste is observed to become more refined, despite the fact that there is only a slight increase in the pore volume in pastes that include MK. When the percentage of MK that is used to partially replace PC in a paste is increased to at least 20 percent, the paste's pore structure experiences an improvement, which in turn leads to an improvement in the paste's overall quality.

4. Conclusion

The purpose of this study was to explore the changes made in concrete by substituting metakaolin for cement and waste foundry sand for fine aggregates. Both waste foundry sand and metakaolin are examples of materials that are generated as a byproduct of industrial processes. This research aims to demonstrate that the utilisation of these two materials helps in the manufacture of green concrete that has the requisite compressive strength and provides environmentally friendly solutions. The purpose of this research is to demonstrate this. A comprehensive analysis of the prior study was carried out in order to investigate the properties of metakaolin and residual foundry sand, as well as their possible use in the production of concrete that is less expensive. The findings of this study are encouraging because they point to an increase in compressive strength while showing no evidence of any adverse consequences. According to the results of the compressive strength tests, foundry sand and metakaolin can be utilised in the production of concrete. From the results, we were able to derive the following conclusions:

1. Using waste foundry sand as a replacement for fine aggregates gives positive results and helps to minimise the problem of natural sand depletion caused by mining. This is because waste foundry sand has a finer grain size than fine aggregates.
2. The results of the strength test on metakaolin and waste foundry sand indicate that the ideal values for each are 10 and 30 percent, respectively. After that point, there will be a reduction in the compressive strength of the concrete mix.
3. The workability of the concrete mixture deteriorates as the amount of unused foundry sand in the mixture grows. This effect is also caused by the presence of metakaolin, which is more powdery than cement.
4. A high early strength was achieved in a variety of different concrete mixes as a result of the addition of metakaolin to the concrete mix.
5. When compared to all of the other proportional mixes, it was determined that Blend-M4 is the most effective mix.
6. When compared to regular vibrating concrete that does not contain any replacement, the strength of concrete Mix-M4 is approximately 14 percent and 16 percent greater after 7 and 28 days, respectively.
7. The use of waste foundry sand at a greater replacement percentage may help in the efficient use of waste material while also presenting a solution to numerous environmental challenges such as the depletion of natural sand due to mining. This could be a solution to a number of environmental problems.

In conclusion, we are able to state that the utilisation of residual foundry sand in conjunction with metakaolin as a partial replacement for fine aggregates and cement delivers effective and favourable outcomes without causing any unfavourable side effects. However, after a certain point, both the strength and the workability started to deteriorate, which was caused by the fact that the increase in compressive strength that was caused by their replacement under controlled conditions was only temporary.

The presence of metakaolin in the concrete contributed to the surface's silky smoothness. The manufacture of green concrete that is kind to the environment benefits from the use of foundry sand that has been left over as a replacement for fine aggregate. In addition to this, it serves to reduce the problem of natural sand scarcity while at the same time making the production of concrete more cost-effective.

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