Development of high strength concrete by using metakaolin and Copper slag

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ABSTRACT

High strength concrete (HSC) is experimentally developed by using Metakaolin as a replacement of cement and copper slag as a replacement of sand. Nine concrete mixtures were prepared with different proportions of copper slag ranging from 0% (for the control mix) to 60%. And prepared with different proportions of Metakaolin ranging should be 0%, 5% and 10%. Concrete mixes were evaluated for workability, density, compressive strength and durability. The results indicate that there is a slight increase in the HSC density of nearly 5% with the increase of copper slag content, whereas the workability increased rapidly with increases in copper slag percentage. Addition of upto 50% of copper slag as sand replacement yielded comparable strength with that of the control mix. However, further additions of copper slag caused reduction in the strength due to an increase of the free water content in the mix. Mixes with 80% and 100% copper slag replacement gave the lowest compressive strength value of approximately 80Mpa, which is almost 16% lower than the strength of the control mix. The results also demonstrated that the surface water absorption decreased as copper slag quantity increases upto 40% replacement; beyond that level of replacement, the absorption rate increases rapidly. Therefore, it is recommended that 40% of copper slag can be used as replacement of sand in order to obtain HSC with good strength and durability properties.

KEY WORDS: strength, metakaolin, concrete.

1. INTRODUCTION

General: Concrete is one of the most extensively used construction material in the world with an approximate of about two billion tones placed worldwide per year. It is attractive in many applications because of its considerable strength at a relatively low cost. Concrete can generally be produced of locally available constituents and can be cast into a wide variety of structural configuration and requires minimal maintenance during service. However environmental concern is the emission of co_2 associated with cement manufacturing and hence has brought pressure to reduce the cement consumption with the, inventions and usage of Admixtures.

Objective: The main objective of this study is to achieve high strength concrete by using Metakaolin admixture and its durability. Also the other objective is to study the behavior of concrete by using copper slag as a substitute for sand and its durability. This study also includes the performance of concrete by using both Metakaolin and copper slag with respect to compressive strength, and its durability – a first of its kind. The proportions of both of these are chosen based on the available literatures as discussed in the below.

Admixture: Admixtures are ingredients other than water, aggregates that are added to the concrete batch immediately before or during mixing. A proper use of admixtures offers certain beneficial effects to concrete including improved quality, acceleration or retardation of setting time, enhanced frost and sulphate resistance, control of strength development, improved workability and enhanced finish ability.

Types: Chemical admixture, Mineral admixture.

Chemical admixtures are the ingredients in concrete other than Portland cement, water and aggregate those are added to mix immediately before or during mixing. These admixtures are added to ensure the quality of concrete during mixing transporting, placing and curing and to overcome certain emergencies during concrete operations

Classifications of Chemical admixtures:

Air entraining admixtures: These agents entrain small air bubbles in the concrete. The major benefit of this is to enhance durability in freeze-thaw cycles relevant in cold climates.

Water reducing admixtures: about 5 to 10 percent and consequently to produce high strength concrete without increase in the amount of cement.

Retarding admixtures: These admixtures which slow the setting rate of concrete are used to counteract the accelerating effect of hot weather on cornet setting. Retarders keep concrete workable during placement and delay the initial setting of concrete.

Accelerating admixtures: These admixtures are especially useful for modifying the properties of concrete in cold weather. They reduce the rate of early strength development and reduce the time required for proper curing and protection and speed up the start of finishing operations.

Super plasticizer: These admixtures are added to concrete at the site as they last only for 30 to 60 minutes. They can be added to concrete with low to normal slump and low water-cement ration to make high-slump flowing concrete.
Mineral admixtures: Mineral admixtures are used in addition to the normal amount of Portland cement or a substitute for the portion of the cement depending on the required or specified properties of the concrete. The benefits of using these materials either separately or in various combinations include higher early strength, higher later age strength, reduced permeability, control of alkali-aggregate reactivity, lower heat of hydration or reduced costs.
Some of the Mineral admixtures:
Fly ash: Fly ash is frequently used in mass concrete as a cement replacement to reduce the heat of hydration which in turn reduces peak temperatures, temperature gradients and the likelyhood of thermal cracking. Fly ash reduces permeability and chloride diffusivity and increases resistivity and making it a beneficial material in concrete that is exposed to chlorides such as bridge decks etc.
Silica fume: Silica fume is a very fine pozzolanic material produced as a by-product in the production of silicon or Ferro-silicon alloys. Use of around 5 to 10 percentage of the total cementious materials will improve the early age strength development of concrete and is particularly beneficial in achieving high release strengths in precast, prestressed concrete beam.
Ground granulated blast-furnace slag: Ground granulated blast-furnace slag also called slag cement is made by rapidly quenching molten blast-furnace slag and grinding the resulting material into a fine powder. The usage of this slag lowers the concrete permeability and reduces the heat of hydration and thereby avoiding thermal cracking. Concrete strength is usually optimized when the slag is replaced by 40 to 50 percent of Portland cement.
Metakaolin: Metakaolin is classified as a Mineral Admixture in IS 456:2000 in clause 5.2.1.4
About metakaolin: Metakaolin is produced by heat treating Kaolin one of the most abundant natural minerals to a temperature of 600-800 degree Celsius. Kaolin is a fine white clay mineral that has been traditionally used. Metakaolin is produce under carefully controlled conditions and hence its composition, white appearance and performance are relatively consistent. It reacts rapidly with the calcium hydroxide in the cement paste, converting it into stable cementations compounds thus refining the microstructure of concrete thereby reducing its permeation properties. Due to its high surface area and high reactivity, relatively small addition rates of MK produce relatively large increases in strength, impermeability and durability while its light color gives it an aesthetic advantage.
About copper slag: It is also worth noting that every year large quantities of different industrial by products are being produced by various industries and the Government is seeking ways to reduce the dual problem of disposal and health hazard from the accumulation of these by products. Since the construction industry is already facing a scarcity of source of materials from natural resources such as sand, stone aggregate etc. The utility of industrial wastes will go a long way in promoting sustainable development of construction industry. It may be noted that rapid rate of growth of concrete utility in developing countries has created a huge demand for sand which cannot be met out by the available resources. New by products are being generated by various industries which could have a promising future in construction industry as partial or full substitute of either cement or aggregates either coarse or fine.

Copper slag which is by product of the manufacture of copper is one of the promising industrial by products among them. This slag is currently being used for many purposes ranging from land filling to grit blasting which are not very high value added applications. These applications utilize only about 15% to 22% of the copper slag generated and the remaining materials are being dumped as a waste which requires large areas of land and hence a fast diminishing high value asset. In addition there are apprehensions that are material could also cause environmental pollution.

In order to avoid such above discussed problems, copper slag can be utilized as a partial or complete substitute for fine aggregates in concrete and there by the excess digging of sand can be avoided and hence the ecology can be maintained. Many researchers have investigated the use of copper slag in the production of cement mortar and concrete as raw materials for clinker, cement replacement coarse and fine aggregates. The use of copper slag in cement and concrete provides potential environmental as well as economic benefits for all related industries particularly in areas where a considerable amount of copper slag is produced. Although there are many studies that have been reported by investigators from other countries on the use of copper slag in cement concrete not much research has been carried out in India. This project is taken up to generate specific experimental data on the potential use of copper slag as sand replacement in concrete along with the admixture Metakaolin.

2. LITERATURE OF MATERIALS

Metakaolin: Metakaolin is produced by heat-treating kaolin, one of the most abundant natural minerals. Kaolin is fine, white clay that has been traditionally been used in the manufacture of porcelain and as a coating for paper. The term Kaolin is derived from the name of Chinese town kao-ling that yielded the first Kaolin. The first documented use of MK was in 1962 when it was incorporated in the concrete used in the Jupia Dam in Brazil. It has been commercially available since mid-1990 and currently costs approximately Rs.30 per Kilogram in India. MK particles are generally one-half to five microns in diameter – an order of magnitude smaller than cement grains and an order of magnitude larger than silica fume particles. MK is white in color unlike silica fume which is typically dark grey or black.

Physical characteristics of selected pozzolans: The presence of MK has an immense effect on the hydration of Portland cement. When Portland cement alone hydrates typically 20% to 30% of the resulting paste mass is CH. However when MK is introduced it reacts rapidly with these newly formed CH compounds to produce supplementary calcium silicate hydrate(C-S-H).

Table 1 Physical characteristics of selected pozzolans

Material	Mean size(10^{-6})	Surface area(m^2/g)	Particle Shape	Specific Gravity
Portland cement	10-15	< 1	Angular, irregular	3.2
Fly Ash	10-15	1-2	Mostly spherical	2.2 to 2.4
Silica Fume	0.1-0.3	15 to 25	spherical	2.3
Metakaolin	1 to 2	15	Platy	2.4

The presence of MK has an immense effect on the hydration of Portland cement. When Portland cement alone hydrates typically 20% to 30% of the resulting paste mass is CH. However when MK is introduced it reacts rapidly with these newly formed CH compounds to produce supplementary calcium silicate hydrate(C-S-H).

Mechanical properties:

Compressive strength: Partial replacement with MK can improve concrete strength. It is determined that MK increases strength as much or more than silica fume and hence might find greater application in High Strength concrete and prestressed concrete in future. Vast majority of papers about MK incorporate some mention about the strength. Caladrone (1994) produced concretes with 5% and 10% MK by weight of cement with w/c as 0.40. His experiments showed enhanced strength at ages upto 365 days. These specimens showed strengths at an average of 10% more than concrete incorporated with the same amount of silica fume. Similar results were obtained and reported by wild (1996). He tested concretes ranging from one to 90 days in age produced at a w/c ratio of 0.45.He found that 20% replacement with MK was optimal for achieving maximum long-term strength enhancement. A summary of wild results is as shown.

Table: 2 Compressive strength of metakaolin concrete [Wild 1996]

MK %	Density (Kg/m^3)	Compressive Strength [N/mm^2]				
		1 Day	7 Days	14 Days	28 Days	90 Days
0	2490	19.07	50.23	57.10	62.60	72.43
5	2440	21.50	53.80	58.97	63.50	71.63
10	2460	22.43	62.30	69.23	71.00	80.07
15	2470	20.23	64.80	74.67	76.00	83.07
20	2480	19.33	66.47	75.73	82.47	85.13
25	2470	15.73	62.50	69.77	73.93	82.23
30	2480	14.53	60.53	72.33	76.73	81.80

MK used at 5% replacement of cement b weight will contribute to increased strength; reduced permeability; greater durability.

Durability: A concrete structure is considered to be of adequate durability if it performs in accordance with its intended level of functionality and serviceability over an expected or predicted life cycle. Durable concrete must have the ability to withstand the potentially deteriorative conditions to which it can reasonably be expected to be exposed. Concrete durability depends largely on the ease or difficulty with which fluids like water, co_2, and oxygen in the form of liquid or gas can migrate through the hardened concrete mass. The addition of MK is widely regarded as an effective means to increase concrete durability. This is achieved primarily in the Inter Transition Zone [ITZ] which is characterized by a higher porosity, a higher w/c ratio and differing mineralogical and chemical composition. The effect of MK in this regard in pronounced. The engineered particle size of MK serves as an effective micro-packing additive. Its average particle size being approximately on order of magnitude smaller than the average cement particle, will serve to fill the interstitial spaces between cement grains thus physically tightening the particle arrangement. In addition, the optimized reactivity of MK serves to chemically combine with calcium hydroxide. The alteration of lime is in a way a removal by substitution reaction where calcium hydroxide crystals are reacted by MK in the presence of aluminate hydrates. The physical and chemical effect of MK is of particular significance with regard to the paste-aggregate interfacial zones.

Water Absorption Test: This test is conducted on the specimen of size 100mm X 100mm X 100mm concrete cubes to study the percentage of water being absorbed and thereby estimating the durability of concrete. In this test the specimen is allowed to dry on room temperature and on getting the surface dried the specimen is weighed and placed in the oven for 24 hours by maintaining the temperature at 104 degree C. The dried specimen is taken out of the oven and allowed to cool for 2 hours and then weighed. The water absorption percentage is arrived from these two weights. Water Absorption is given by {[wt of wet specimen- wt of dried specimen]/ wt of wet specimen}* 100.

Copper slag: copper slag is a by-product material produced from the process of manufacturing copper. Copper slag used in this project study was brought from Sterlite Industries Ltd, Tuticorin, and Tamilnadu, India.

Utility: These high strength concrete can be utilized for components of bridges, prestressed members, nuclear projects, Airport runways, heavy containers yards, shotcreting, for railway sleepers etc where high strength concretes are found necessary.

Table 3 Physical properties of slag

Specific gravity [SSD] : 4.12, Bulk density [SSD] : 2.31 gm/cc				
Fineness Modulus : 3.0, Deleterious Materials : Not present				
IS Sieve No	**Wt. retained [gm]**	**Cumulative % Wt. retained [gm]**	**Cumulative % Wt. retained**	**Cumulative % passing**
4.75mm	--	--	--	--
2.36mm	85.00	85.00	17.00	83.00
1.18mm	154.00	239.00	47.80	52.20
600 microns	166.00	405.00	81.00	19.00
300 microns	72.00	477.00	95.0	4.60
150 microns	16.42	493.42	98.684	1.316
% passing	6.58	500.00	100.00	0.000
		Fineness Modulus	**3.40**	

Chemical composition of Copper slag: Chemical composition of copper slag as reported by the Sterlite Ltd is given below

Table 4 Chemical composition of Copper slag

Composition	% by mass
Fe_2O_3	55-60
Fe_3O_4	< 10
SiO_2	27-33
CaO	1-3.5
S	0.2-1.5
Cu	< 1
Al_2O_3	< 3

Table 5 Chemical analysis

Chemical analysis	Typical
SiO_2	52-54%
Al_2O_3	40 to 42%
Fe_2O_3	0.35%
TiO_2	0.90 to 1.2%
CaO	0.016%
MgO	0.065%
K_2O	0.20%
Na_2O	0.13%
L.O.I	≤ 1-2%
Application: Rubber, Ultramarine Blue, Construction	

The specific gravity for copper slag is 4.12 and has bulk density of 2.31 gm/cc which is higher than that for normal river sand [2.6, 1.53] which may result in production of concrete with higher density. Also the measured water absorption for copper slag was 0.40% as compared with 0.70% for sand.

This suggests that copper slag has less apparent porosity and would demand less water than that required by sand in the concrete mix. Hence when copper slag is partially replaced instead of sand the workability increases and because of less water the w/c ratio required is less and hence the possibility of increased strength.

Tests conducted: The high strength behavior of concrete and the durability enhancement of the concrete using the above said admixture and the copper slag over the control concrete are being studied by performing the following tests.

- Compression test of concrete on 28 days
- Water absorption test

Materials used:

Ordinary Portland cement: Conforming to IS 43 Grade OPC [Ultratech cement]

Metakaolin: Metakaolin received from Koat manufacturing company, Vadodara, Gujarat India-390001

Graded Fine aggregates: Local clean river sand conforming to IS 383-1970 Copper slag received from Sterlite Ltd, Tuticorin, India.
Graded coarsed aggregates: Locally available well graded Aggregates of normal size Greater than 4.75mm and less than 20mm.

Table 6 Manufacturer's specification of metakaolin:

Origin	India
Mineralogical composition:	Kaolinite- ($Al_2O_3SiO_2$)
Packaging:	Powder 25 kgs
Physical properties	**Typical**
Pozzolan reactivity mg $Ca(OH)_2$/gm	900-1050
BET surface area m^2/gm	12-18
Average particle size	1.5-2.5 micron
Residue(> 45 micron)(max%)	0.5-2%
Brightness	75±1
Bulk density (gms/ltr)	300 to 320
Specific gravity	2.5

Table 7 Mix proportion

Water (Liters)	Cement (kg)	FA (kg)	CA (kg)
140	350	773.6	1262.2
0.4	1	2.21	3.60

3. RESULTS

The concrete mix proportion is 1:2.21:3.60, With a W/C ratio of 0.4 & suitable dosage of admixture.

Types of mixes: For achieving high strength concrete the control mix is chosen as M40.Over this control mix sand is being replaced by copper slag at the order of 40%, 50% and 60% by the weight of sand. The influence of Metakaolin over the control mix is further studied and based on the literature it is decided to replace cement by Metakaolin at the rate of 5%, 10% and 15% by weight of cement is used. Similarly, the influence of copper slag over the above said mixes at the rate of 40%, 50%, 60% replacement of sand is also experimental for the first time. Hence the following table shows the various combinations of mixes carried out for this study.

Table 8 Different combinations of mixes

Trail mix	Mix details (cement+MK)	Fine aggregate (sand+slag)
Mix 1	100%Cement+0% MK	Sand + 0% Slag
Mix 2	95%Cement + 5%MK	Sand + 0% Slag
Mix 3	90%Cement +10%MK	Sand + 0%Slag
Mix4	100%Cement + 0%MK	50% Sand+50%Slag
Mix5	100%Cement+0%MK	40%Sand+60%MK
Mix6	95%Cement+5%MK	50%Sand+50%MK
Mix7	95%Cement+5%MK	40%Sand+60%MK
Mix8	90%Cement+10%MK	50%Sand+50%MK
Mix9	90%Cement+10%MK	40%Sand+60%MK

Schedule of casting:

Table 9 Details of specimens

Details of sample	Number of specimen cast
150mm*150mm cube	54 nos
100mm*100mm cube	27 nos

Casting details: Ultratech cement of 43 grade OPC cement is used for the casting. Metakaolin is received from Koat Manufacturing company, 27, Vraj Sidhi Towers, Vadodra, Gujarat, India 390 001. Metakaolin was purchased at the rate of Rs 25/ kg at factory. Around 40 kg of Metakaolin is used for this thesis.
Different moulds are used for casting to study the properties of the concrete. The details are as follows.

a) Compressive test 150mm*150mm
b) Water absorption test 100mm*100mm

The carefully weighed materials are loaded in a mixing drum and the required amount of water as per the design is added. As the W/C adopted is 0.40. We need to increase the workability of concrete and hence super plasticizer is added to bring to the normal workable condition. Admixture Techo mix 550 is used. The demolded and numbered specimens should immediately laid in the curing yard filled with normal water and can be stacked in such a way that the 7 days specimen and 28 days specimen can be easily identified.

Compression test: Testing place: Ready-mix plant at Siruvachur.

The compressive strength of concrete is one of the most important and useful properties of concrete. In most structural applications concretes are employed primarily to resist compressive stresses. Concrete cube specimens of 150mm*150mm*150mm were cast with different combinations as mentioned earlier. After 24 hrs. of setting, the specimens were demolded and were cured for 7 days and 2 days in a curing tub in normal water. After the curing period was over the specimens were tested for compression strength in UTM compression concrete testing machine. Triplicate specimens were cast and average compressive measurements were reported. The specimens are carefully weighed in a digital weighing balance. The ultimate compressive load is noted carefully and noted according to the number of the specimen.

Water absorption test: This test is conducted on 100m x 100mm x 100mm concrete specimen. The 28days cured cubes are taken out from the curing yard and allowed to dry at atmospheric temperature. These specimens are carefully weighed and the initial weight is note (W1). After noting down the initial weight these specimens are dried in an oven for 24 hours and temperature in the oven is maintained at 110 c. After 24 hours the dried specimens are taken out of the oven and allowed to cool at normal room temperature. These specimens are weighed carefully and the weights are noted. (Wf). The water absorption percentage is then calculated as follows:

Water absorption percentage = [{Wi - Wf}/Wi] x 100

Discussions: In this thesis it is aimed to study the behavior of concrete using the mineral admixture Metakaolin as a replacement for cement and copper slag as a replacement of sand. In order to study the behavior we need to have the control mix as the datum to study the behavior of concrete on the quantum of replacements of cement and sand.

Table 10 Control mixes

Control Mix 1	Cement	Sand	Aggregates
Control Mix 2	Cement	50% Sand + 50% Slag	Aggregates
Control Mix 3	Cement	40% Sand + 60% Slag	Aggregates

Table 11 Compressive testing results for control

Mix No	Description	Weight in Kg	Compressive Stress 7 days	Compressive Stress 28 days	% increase W r t control
1	0% MK, 0% SLAG	8.968	26.88	47.55	1.2
4	0% MK, 50% SLAG	9.600	34.66	51.11	2.86
5	0% MK, 60% SLAG	9.490	39.11	55.55	7.3

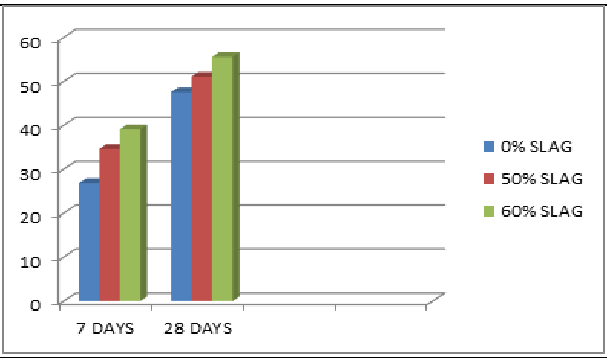

Figure 1 Compressive testing results for control

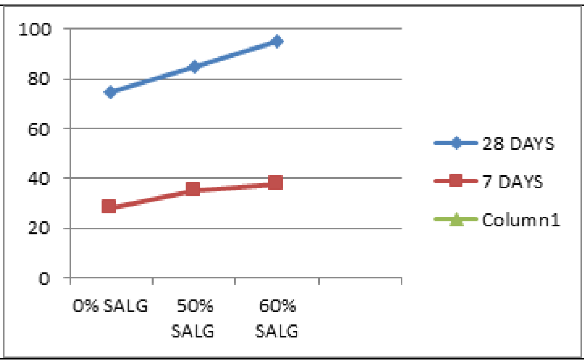

Figure 2 Graph showing the results of Compressive strength of control

Observation: Here on seeing the 28th day results we find there is an appreciable increase of around 5% to 10% in the compressive strength when slag is replaced by cement and it also to be noted that the increase is more when the replacement is about 50%.

Study of behavior of Metakaolin from Control Mix I: To study the influence of the admixture Metakaolin with the cement, cement is replaced by 5%, 10% and its behaviors are studied.

Table 12 Compressive Testing results of 0% slag

Mix No	Description	Weight in Kg	Compressive Stress 7 days	Compressive Stress 28 days	% increase With respect to control
2	5% MK, 0% SLAG	9.294	29.77	46.66	0.3
3	10% MK, 0% SLAG	8.865	32.44	48.88	0.63

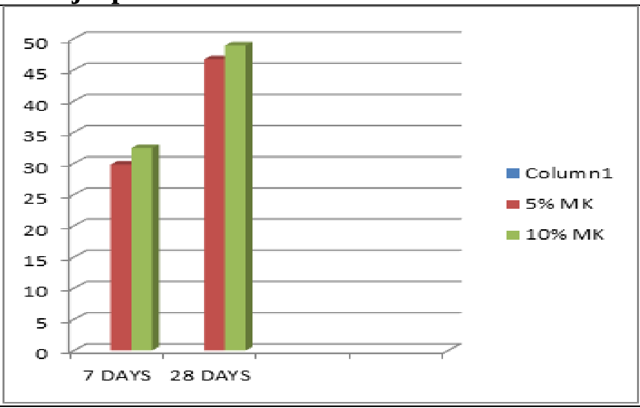

Figure 3 Compressive testing results of 0% slag

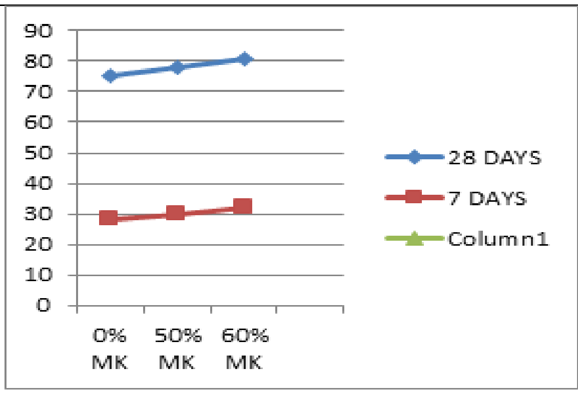

Figure 4 Graph showing the results of Compressive strength of 0% slag

The value above indicates that there is an increase in compressive strength of concrete to a range of 6.5 to 13.4% is observed and is maximum at a replacement of 10% MK.

Study of behavior of Metakaolin and Copper Slag from Control Mix: To study the influence of Metakaolin over the 50% replacement of sand in the concrete the following combination od cubes are made and tested for 7days strength and 28 days strength.

Table 13 Compressive test result for 50% slag:

Mix No	Description	Weight in Kg	Compressive Stress 7 days	Compressive Stress 28 days	% increase Wrt control
4	0% MK, 50% SLAG	9.600	34.66	51.11	6.12
6	5% MK,50% SLAG	9.650	42.66	59.55	8.44
8	10% MK,50% SLAG	9.620	45.33	62.22	11.11

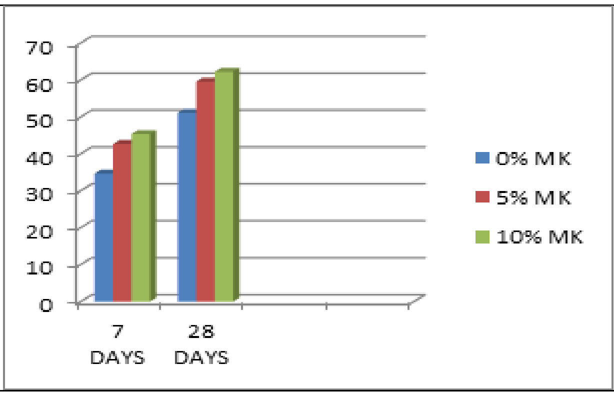

Figure 5 Compressive strength

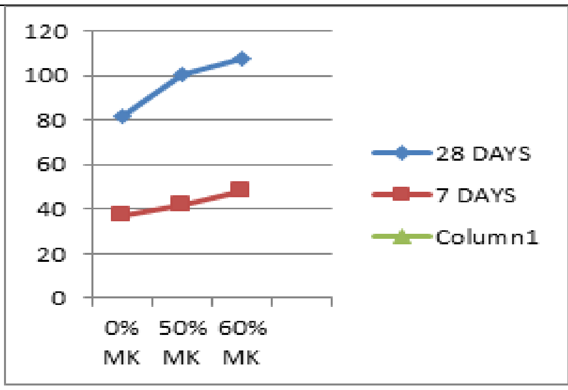

Figure 6 Graph showing the results of Compressive strength of 50% slag

From the above results it is observed that by keeping the slag constant and by increasing the replacement of MK, the compressive strength is proportionately increasing with the increase of MK and by increasing the percentage of Metakaolin replacement are tested and shown below.

Table 14 Percentage of Metakaolin replacement

Mix No	Description	Wt. Kg	Compressive Stress 7 days	Compressive Stress 28 days	% increase Wrt control
5	0% MK, 60% SLAG	9.490	39.11	55.55	5.1
7	5% MK,60% SLAG	9.730	43.10	63.11	7.56
9	10% MK,60% SLAG	9.294	48.88	70.66	15.11

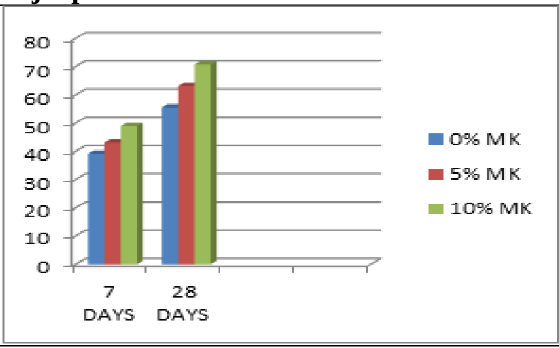

Figure 7 Comparative Study on Compression strength with respect to replacement of Metalaolin

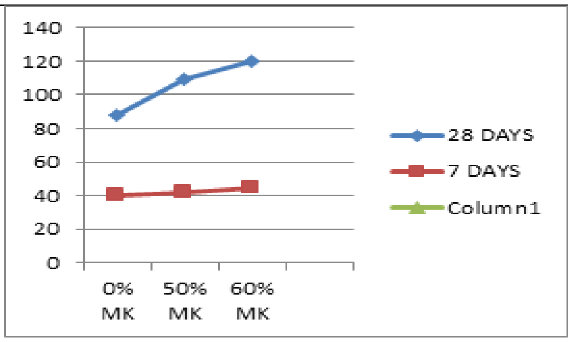

Figure 8 Comparative Study on Compression strength with respect to replacement of Metalaolin

From the above study and observation it is observed that the addition of admixture increases the concrete. Also by replacing the sand with 50% and 60% Slag is observed that compressive strength further increases with the replacement of sand with slag over the respective control mixes.

Comparative Study:

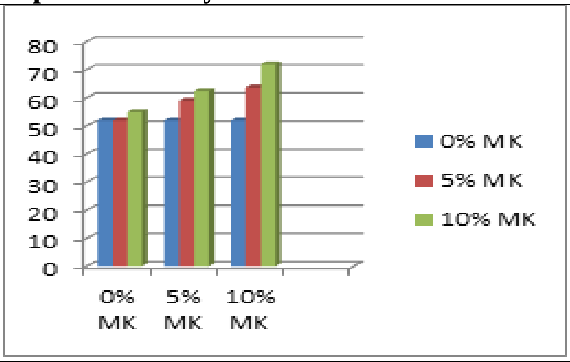

Figure 9 Comparative Study on Compression strength with respect to replacement of Metalaolin

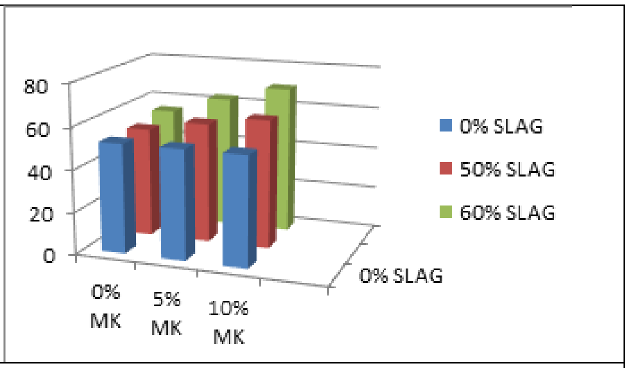

Figure 10 Comparative Study on Compression strength with respect to replacement of Slag

From the above bar chart and graph it is interesting to note that the compressive strength of the concrete is increasing by the replacement of cement with Metakaolin and also by the replacement of sand with Copper slag. It is also observed that replacement of copper slag over and above 50%, Shows reduced compressive strength than that of 50% replacement.

Study on the durability enhancement: The durability tests are also conducted on the combination of cement and Metakaolin and slag over their respective controls.

Water absorption test: This test is conducted on 100m x 100mm x 100mm concrete specimen. The 28days cured cubes are taken out from the curing yard and allowed to dry at atmospheric temperature. These specimens are carefully weighed and the initial weight is note (W1). After noting down the initial weight these specimens are dried in an oven for 24 hours and temperature in the oven is maintained at 110 c. After 24 hours the dried specimens are taken out of the oven and allowed to cool at normal room temperature. These specimens are weighed carefully and the weights are noted. (Wf). The water absorption percentage is then calculated as follows

Water absorption percentage = [{Wi - Wf}/Wi] x 100

Table 14 Percentage of Water absorption test

Mix No	Description of Mix	Water Absorption Percentage %
1	0% MK-0% Slag	2.94
3	0% MK-50% Slag	3.71
4	0% MK-60% Slag	3.87
5	5% MK-0% Slag	2.87
6	10% MK-0% Slag	2.63
9	5% MK-50% Slag	2.98
10	5% MK-60% Slag	2.77
12	10% MK-50% Slag	2.39
13	10% MK-60% Slag	1.91

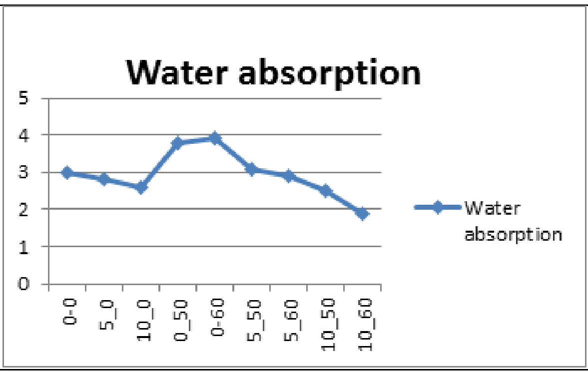

Figure 11 Percentage of water absorption

4. SUMMARY AND CONCLUSIONS

Summary: This is carried out to study the enhanced strength of concrete and its durability by Replacing cement with Metakaolin –a mineral admixture, Replacing fine aggregate (sand) with Copper slag, Replacing both cement and fine aggregate with Metakaolin and Copper slag.

Conclusion: Based on the experimental study the following conclusions are made:

- The addition of Metakaolin along with cement has increased the compressive strength of the concrete when compared to the control mix.
- The more effective percentage of replacement seems to be between 10 – 15%.
- The replacement of Copper slag in fine aggregates has increased the compressive strength of the concrete when compared to the control mix.
- The more effective percentage of replacement seems to be between 50-60%.
- The addition of slag have shown increased water absorption percentage when compared to control.
- The durability test conducted on the concrete specimens using both MK and slag have shown much improved result than that of their respective controls.
- By replacing the cement with metakaolin and copper slag, we can reduce the consumption of cement. By reducing the consumption of cement, the ecology of the earth can be improved and the air pollution due to the production of cement can be reduced.

Scope for further work: Based on studies and experiment done in this thesis it is inferred that the concrete mix using 10%MK & 50% slag using 15% MK, 50% slag are shown enormous increase in compressive strength and can be designed further. The cost of replacement is proved to be low. Though concrete have more density than the normal concrete this aspect can be further studied to make advantages in Nuclear Reactors, High traffic Pavements, railways sleepers etc.

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