Experimental Study on Self-compacting Geopolymer Mortar with Partial Replacement of River Sand by Slag, Artificial, Wash Sands

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Abstract:

This paper deals with the study of replace natural sand with different sand with the help of self-compacting geopolymer mortar. The increase in construction activities is leading to the depletion and the exploitation of the natural river sand, causing adverse effects on the environment. Therefore there is an urgent need to find an alternative substitute or replacement of natural river sand and the major factor in the global warming is production of cement which releases CO_2 in the atmosphere. It is very necessary to reduce or replace the cement by other cementations material or industrial waste like fly ash. Geopolymer is a new development in the world of mortar in which cement is totally replaced by fly ash .experimental investigation has been carried out to study the effect of the different percentage of sand on compressive strength and geopolymer mortar. In this research some chemical admixture were used such as super plasticizer (sp), sodium silicate and 14 molar NaOHsolution. The workability properties such as filling ability, passing ability and resistance to segregation assessed using mini slump flow and mini v-funnel test methods. It was found that the essential workability requirements for self-compacting according to EFNARC were satisfied. Results showed that the workability and compressive strength improved with the increase in super plasticizer dosage as well as by using different sand with different percentage also improved the compressive strength.

Keywords – self compacting, geopolymer, fly ash, natural sand, NaOH, Na_2SiO_3, mortar.

I. INTRODUCTION

Geopolymerization is a developing field of research for utilizing solid waste and by-products. It provides a mature and cost-effective solution to many problems where hazardous residue has to be treated and stored under critical environmental conditions. Geopolymer involves the silicates and aluminates of by-products to undergo process of geopolymerization. It is environmentally friendly and need moderate energy to produce. Geopolymer is an inorganic polymer produced from two main constituents which are the combination of raw materials known as aluminosilicate source containing alumina (Al) and silica (Si) with alkaline activator. The combination of sodium silicate (Na_2SiO_3) and sodium hydroxide (NaOH) has been used widely as the alkaline activator to produce geopolymer. So in this we used some chemicals like sodium silicate and sodium hydroxide for casting purpose. Due to the global concern about CO_2 emissions nowadays, it is well accepted that a new kind of cement is in need to replace Portland cement with improved environmental, mechanical, and durability performance. Portland cement is responsible for 7% of total CO_2 because every ton of Portland cement releases roughly one ton of CO_2 emissions due to the high energy required for production. Alkali activated geopolymer is one potential alternative to Portland cement

A mix design procedure is proposed on the basis of quantity and finenessof fly ash, sand, quantity of water, Sodium silicate solution and sodium hydroxide solution having 14M concentration were maintained constantthroughout the experiment. Fly ash -to-sand ratio is 1:2 and sodium silicate-to-sodium hydroxide ratio of1:1 by mass were fixed on the basis of workability and cube compressive strength.Workability of geopolymer mortar was measured by mini slump flow and mini v-funnel test and Cubesof 70mm size were cast and tested for compressive strength after specified period ofoven heating. The temperature of oven heating was maintained at 90^0C for 24 hoursduration and tested 7 days after heating. It is observed that the results of workabilityand compressive strength are well match with the required degree of workability andcompressive strength. So, proposed method is used to design normal and standardgeopolymer.

II. OBJECTIVES OF WORK

For Characterization of self-compacting geopolymer mortar with replacement of different sands experimental work would be carried out to achieve following objectives

1) To study the workability properties of fresh self-compacting mortar with replacement of different sand.
2) To study the effect of on mechanical properties of self-compacting mortar with replacement of different sand.
3) To study the all properties as well as to check workability and effects

4) Find out the good replacement sand which helps in future
5) Replace sand easily available ecofriendly and cost effective.

III. Research Methodology

In present paper, research is carried out in following steps.

1) Study of research articles and codes based on self-compacting mortar and concrete.
2) Study of research articles based on geopolymerisation process.

A. Study of research articles and codes based on self-compacting mortar and concrete.

Dehestani, M., Nikbin, I., have reported effect of specimen shape and size on the compressive strength of self-consolidating concrete (SCC) in this study three mixes were proportionate to investigate the mechanical properties of self-compacted concrete cylinders and cubes. In this investigation natural sand and 12.5mm maximum size of course aggregates were used. Characterization tests were conducted are slump flow, T_{500}, V-funnel, and L-box. Results indicate that, effect of specimen size plays an important role in slenderness ratio of specimen of 0.5 and 1.0. Whereas for higher slenderness ratio, size effect is minimally affected by the concrete mix design. Results also indicate that, at the slenderness ratio (h/d=1), the square section exhibits better performance against the size effect and is less affected by the concrete mix design. In general, we can concluded that, at the slenderness ratio (h/d=1), compressive strength of the square section is higher than circular section and cross section effect on compressive strength is in significant. [12]

EFNARC- specifications and guidelines for self-compacting concrete reported introduction of SCC, scope for SCC, referenced standards, definitions requirements for constituent materials, requirements for self-compacting concrete and mortar, mix composition production and placing, quality control. This guide also, reported various workability test for self-compacting mortar and concrete such as slump flow, T_{50cm} slump flow, V- funnel, orimet tests to check filling ability of concrete. In this guide L-box, U-box, fill- box tests for passing ability of SCM are also included. GTM test, V- funnel at $T_{5minutes}$ for segregation resistance are also included. [6]

Khaleel, O. R., Razak, A., have developed mix design methods for self-compacting metakaolin concrete with different properties of coarse aggregate. This study was conducted in three phases, i.e. paste, mortar, and concrete. In this study, initial investigation on cement paste is carried out to basis for water-cement ratio and dosage of SPs. In this study metakaolin (MK) were used in mortar with replacement level 5%, 10%, 15%, 20% by weight of cement. Self-compacting mortar and concrete was achieved by adding suitable materials such as mineral admixture and superplasticizers. From results it can be concluded that, the optimum ML replacement level for cement was 10% from the view point of workability and strength. Results also indicate that, mixes which contain course aggregate with lower volume, small size, and continuous grading affected positively the fresh properties of SCM. [11]

B. Study Of Research Articles Based On Geopolymerisation Process.

Davidovits, J., studied global warming impact on the cement and aggregate industries. (1994) according to this study, alkalis are generally thought of as the cause of deleterious alkali aggregate reaction. As a consequence, the tendency has been to avoid any addition of alkali in OPC. However, geopolymeric cements, even with alkali content as high as 9.2% do not generate any dangerous alkali aggregate reaction. Geopolymeric cement is manufactured in a different manner than OPC. They do not require extreme high temperature kilns, with large expenditure of fuel, nor do they requires such a large capital investment in plant and equipment. Thermal power plant provides suitable geopolymeric raw materials. This technology reduces also energy consumption during cement manufacturing, [10]

P. Chindaprasirt, T. Chareerat, V. Sirivivatnanon, cement and concrete composites 29 (2009) reference page no. 224-229 have studied workability and strength of coarse high calcium fly ash geopolymer. In this paper, the basic properties i.e. workability and strength of geopolymer mortar made from coarse lignite high calcium fly ash were investigated. The geopolymer was activated with sodium hydroxide (NaOH), sodium silicate and heat. The results revealed that the workable flow of geopolymer mortar was in the range of 110 ± 5% – 135 ± 5% and was dependent on the ratio by mass of sodium silicate to NaOH and the concentration of NaOH. The obtained compressive strength was in the range of 10–65 MPa. The optimum sodium silicate to NaOH ratio to produce high strength geopolymer was 0.67–1.0. The concentration variation of NaOH between 10 M and 20 M was found to have a small Effect on the strength. The geopolymer samples with high strength were obtained when the delay time after moulding and before subjecting the sample to heat was 1 hour and the optimum curing temperature in the oven was 75^0C with the curing duration of not less than two days. Manufacturing of Portland cement is an energy intensive process and releases a large amount of greenhouse gas to the atmosphere. It has been reported that 13 500 million ton is produced from this process worldwide, which accounts for about 7% of the greenhouse gas produced annually therefore, researcher been made to promote the use of pozzolans to replace part of Portland cement. The work on this geopolymer so far has been based on the normally used type-F low calcium fly ash based on this data Improvements in the workability of the mortar could be achieved with addition of water or super plasticizer. However, the use of superplasticizer had an adverse effect on the strength of geopolymer.

Bokyeong Lee, Gyuyong Kim, Raehwan Kim, Bongsuk Cho, Sujeong Lee, Chal Min Chon 151(2017) reference page no. 512-519 This paper aims to study the compressive strength of geopolymer paste was affected by the Si/Al ratio calculated by the combination of the amorphous Si and Al contents in the fly ash and the alkaline activator. Then the direct correlation between the polymerization reactivity of the geopolymer paste and the compressive strength could not be confirmed from the shift position in the broad hump peak in the X-ray diffraction pattern. And the compressive strength of geopolymer mortar with 20–40 wt. % sand confirms the availability as a construction material. Because geopolymers are materials that harden at low temperatures owing to the chemical reaction between the aluminosilicate material and an alkaline activator. Hence Experimental results confirm that the compressive strength of the geopolymer paste is greatly affected by the Si/Al ratio. The geopolymer paste also shows high polymerization reactivity at an early age. The strength development properties of geopolymer paste and mortar with 20–40 wt% of sand is analysed with respect to changes in the Si/Al ratio calculated from a combination of the amorphous Si and Al contents in fly ash and an alkaline activator.by using this information it is confirm that the possibility of using geopolymer mortar as a construction material. Author also concludes that the compressive strength development properties of the geopolymer paste can be confirmed from the combination of the amorphous Si and Al contents in the fly ash and the alkaline activators. The compressive strength was found to vary considerably depending on the combination of the alkaline activator. The method for deriving the compressive strength of the geopolymer by combining the amorphous content in the fly ash and the alkaline activator was found to be effective. [3]

U.S. Agrawal, S.P. Wanjari, D.N. Naresh construction and building materials 150 (2017) reference page no.681-688this paper gives information about replace fly ash sand as a natural river sand. In this with the increase in the construction activities, the demand for river sand has increased exponentially causing the depletion and exploitation of the natural sand thus resulting adverse effects on the environment such as sliding of the river shores, lowering water table, etc. Hence, there is an urgent need to find an alternative substitute or replacement of natural river sand. The increase in construction activities is leading to the depletion and the exploitation of the natural river sand, causing adverse effects on the environment. In this paper author highlights some point like new approach to replace the natural sand by artificial sand in the field of civil engineering. As well as Fly ash and geopolymer was utilized to prepare artificial sand known as geopolymer fly ash sand (GFS). And Different properties of geopolymer fly sand (GFS) were studied and compared with the natural river sand (NRS). Writer has mainly focused on replacement of sand. With this paper study author concludes that the geopolymer fly ash sand could be used as an alternative to natural river sand in construction activity. [2]

IV. Materials

A. Fly ash

In the experimental work, materials were selected according to the specifications that meet the requirement of British standards and EFNARC guidelines. Fly ash used in the research was class F with chemical compositions in this pozzocrete 60 and pozzocrete 100 is used. Fly ash procured from dirk India private limited, Nasik (NTPS) and class F as per IS 3812:1981 Table 1 shows the test results of basic properties of fly ash.

Table No. 1 properties of fly ash

Test no.	Test	Unit	IS specifications	Pozzocrete 60	Pozzocret 100
1	Fineness-specific surface by Blaine's permeability	m²/kg	320	368	638
2	Lime reactivity (min)	N/mm²	4.5	6.09	8.60
3	Moisture content (max.)	%	2	0.30	0.27
4	Autoclave expansion (max.)	%	0.8	0.030	0.024

B. Sand

Locally available river sand was used as filler material. Sand confirming to zone II with specific gravity 2.74, water absorption 3.41% and fineness modulus 3.039 as per IS 383:1970

C. WATER

The tap water should be used in the mortar. The demand of water increases with increase in fineness of source material for same degree of workability. So, the minimum quantity of water required to achieve desired workability is selected on the basis of degree of workability.

D. SUPER PLASTICIZER (SP)

Addition of the superplasticizers improves the workability of the geopolymericpaste by improving the plastic and hardening properties. Leading to higher compressive strength. Compressive strength value depends on the pore structure of the hardened super plasticizer Paste, which consists mainly of micro pores leading to a denser structure. In this work kemi flow SR-500 should be used. The new generation super plasticizers termed poly-carboxylates ethers is particularly useful for Self-compacting mortar.

E. SODIUM HYDROXIDE

Sodium hydroxide (NaOH) has been used widely as the alkaline activator to produce geopolymer. 14M of NaOH is the optimum compressive strength achieved. Sodium hydroxide is available in the local market in a solid state by means of pellets and flakes form. But here we used flakes form. Sodium hydroxide 97% purity were used for preparation of geopolymer solution. Sodium hydroxide solution was prepared by dissolving sodium hydroxide flakes in water at the rate of various molar concentrations. It is strongly recommended that the sodium hydroxide solution must be prepared 24 hours prior to use with mixing alkaline liquid. So the prepared solution should be used within this time. NaOH solids in flakes form per liter of the water, where 40 is molecular weight of NaOH.

F. SODIUM SILICATE

Sodium silicate is available in gel form or liquid form. It is commercially available in the market. Note that the mass of water is the major component in both the alkaline solutions.

V. Mix Proportion And Experimental Work

Table No. 2 Geopolymer mix design

Sands	Fly Ash to Sand Ratio	Na_2SiO_3 to NaOH Ratio	Sodium Hydroxide Concentration	Superplasticizer %	Curing Type	Curing Period °C
River Sand	1:2	1:1	14 M	2.5	Oven	90
Slag Sand	1:2	1:1	14 M	2.5	Oven	90
Wash Sand	1:2	1:1	14 M	2.5	Oven	90
Artificial Sand	1:2	1:1	14 M	2.5	Oven	90

A. Preparation of Sodium Hydroxide Solution:

Depending on the concentration of sodium hydroxide solution required, flakes of sodium hydroxide were added in a litre of distilled water instead of preparing one-litre solution. Then molarity was found from the laboratory measurements. For example, 14M sodium hydroxide solution consists of 14 × 40 = 560 grams of NaOH solids per litre of solution. But instead of that, 560 gm. sodium hydroxide flakes were added in a litre of distilled water. So the total volume of cube (1.319 ÷1000) in cubic meter. The solid contained in a litre of sodium hydroxide solution was estimated as (140×1.319÷1000) Therefore the molarity of solution is 0.18466 kg.Sodium hydroxide solution was prepared two days prior to the casting of mortar cubes so as to cool down the solution up to room temperature specifically in summer season.

B. Preparation of geopolymer mortar:

Geopolymer mortar is the combination of fly ash, sand and the chosen activator. For the geopolymer formulation, Mustafa discovered that 12M of NaOH is the optimum compressive strength achieved. In previous research by hardjito, it was also found that Na_2SiO_3/NaOH ratio 2.5 produced the best results. Geopolymer formulation determined by previous researchers was used in this study due to the same class and types of fly ash. However, the addition of sand in geopolymer improved the strength and exhibited different physical properties at different binder to sand ratio. The addition of sand as aggregates to polymer is not only economically favourable but also reduces pore density and promotes high strength.

C. Preparation of Geopolymer Mortar Mixes:

Geopolymerthe same amount of fly ash and activating it by alkaline solutionsof sodium hydroxide and sodium silicate.GeopolymerMortar cubes were prepared using 1: 2 proportions of fly ash and locally available sand graded similar to standard sand. Quantities of alkaline solution and water were calculated by considering solution-to-fly ash ratio of 0.35, 0.40, and 0.45, sodium silicate-to-sodium hydroxide ratio by mass of 1.1, and water-to-geopolymer solid ratio by mass of 0.2625 on the basis of past investigation. Calculated quantities of sodium silicate solution mixed with sodium silicate solution along with extra water if any in a glass bottle of capacity five litre and agitated gently as to give homogeneous solution. Prepared solution was kept aside for about 2 hours as to avoid any contamination during casting.

Casting of geopolymer mortar is similar to that of cement mortar in which dry mixture of fly ash and graded sand was made in a bowl of capacity 6 kg and then alkaline solution is added to it and thoroughly mixed for 2 to 3 minutes so as to give homogeneous mix. It was found that the fresh fly ash based geopolymer mortar was viscous, cohesive, and dark in colour. After making the homogeneous mix, workability of fresh geopolymer mortar was measured by flow table apparatus as per IS 3812-1981 and IS 383-1970. Then for every concentration of sodium hydroxide, 3 cubes of size 70.7mm × 70.7mm × 70.7mm were cast in three layers. Each layer was well compacted by tamping rod of diameter 20mm. After compaction of mortar, the top surface was levelled using Trowel and the sides of mould were gently tapped to expel air, if any, present inside the mortar. All cubes were removed from moulds after 24 hours of casting and then placed in an oven for thermal curing (heating).To avoid the sudden variation in temperature, the mortar cubes were allowed to cool down up to room temperature in the oven itself. After 24 hours, specimens were removed from the oven and the weight of each specimen was taken for determination of mass density and then tested for compressive strength after 7 days of heating. Testing procedure is similar to that of cement mortar as mentioned in IS 4031 (part-VI)-1981. Three cubes were cast and tested for compressive strength for each curing period.

VI. Experimental Study

A. Testing of Self-Compacting Geopolymer Mortar Cubes

In present study, workability of self-compacting mortar geopolymerwere measured in term of flowing and filling ability by using following standard tests.

Workability test for Self-Compacting Geopolymer Mortar

The workability of SCGM is checked based on two tests: mini slump cone test and mini V- funnel test.

1) **Mini slump cone test:**The workability of SCGM is examined by mini slump cone test. Fig. shows the dimensions of mini slump cone which is used for the testing.
   Procedure
   About 6 litre of concrete is needed to perform the test, sampled normally.
   Moisten the base plate and inside of slump cone,
   Place baseplate on level stable ground and the slump cone centrally on the base plate and hold down firmly.
   Fill the cone with the scoop. Do not tamp, simply strike off the concrete or mortar level with the top of the cone with the trowel.
   Remove any surplus concrete or mortar from around the base of the cone.
   Raise the cone vertically and allow the concrete or mortar to flow out freely.
   Simultaneously, start the stopwatch and record the time taken for the concrete or mortar to reach the 500mm spread circle.
   Measure the final diameter of the concrete or mortar in two perpendicular directions.
   Calculate the average of the two measured diameters. (This is the slump flow in mm).

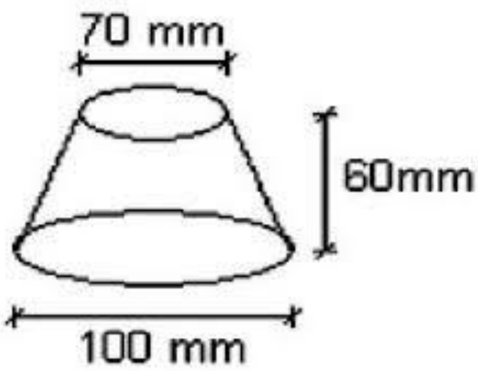

Figure 6.1: Dimensions of mini slump cone (Source: ASTM C 1437:2013)

2) **Mini V- funnel test:**this test covers the determination of filling ability of self-compacting mortar in the laboratory or field.
   Procedure
   About 12 litre of concrete is needed to perform the test, sampled normally.
   Set the V-funnel on firm ground.
   Moisten the inside surfaces of the funnel.
   Keep the trap door open to allow any surplus water to drain.
   Close the trap door and place a bucket underneath.
   Fill the apparatus completely with concrete without compacting or tamping, simply strike off the concrete or mortar level with the top with the trowel.
   Open within 10 sec after filling the trap door and allow the concrete or mortar to flow out under gravity.
   Start the stopwatch when the trap door is opened, and record the time for the discharge to complete (**The Flow time**). This is taken to be when light is seen from above through the funnel.
   The whole test has to be performed within 5 minutes.

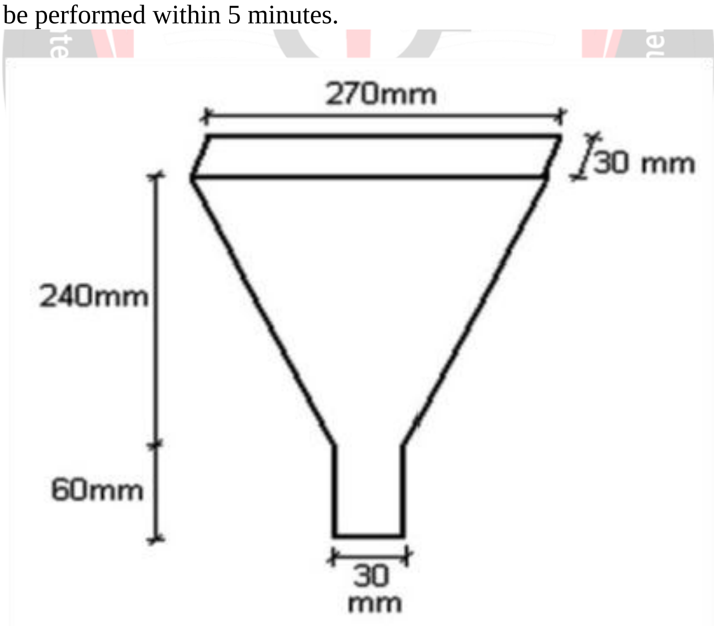

Figure 6.2 Dimensions of mini V- Funnel (Source: ASTM C 1437:2013)

VII. Results And Discussion

A. WORKABILITY TEST FOR SELF- COMPACTING GEOPOLYMER MORTAR (SCGPM)

The workability of SCGPM was checked on mini slump cone test and mini V –funnel test. Results of workability test are shown in figures 7.1, 7.2 and in 7.3.

B. TEST FOR COMPRESSIVE STRENGTH

The mortar cube of size 70 X 70 X 70mm After casting, all cubes were removed from mould after 24 hours of casting and placed in an oven for heating After 24 hours, specimens were removed from the oven and the weight of each specimen was taken for determination of mass density and then tested for compressive strength after 7 days of heating. Compression strength test is carried out on geopolymer mortar cubes after a test period of 7 days. Results of workability and compressive strength test are shown in figures.

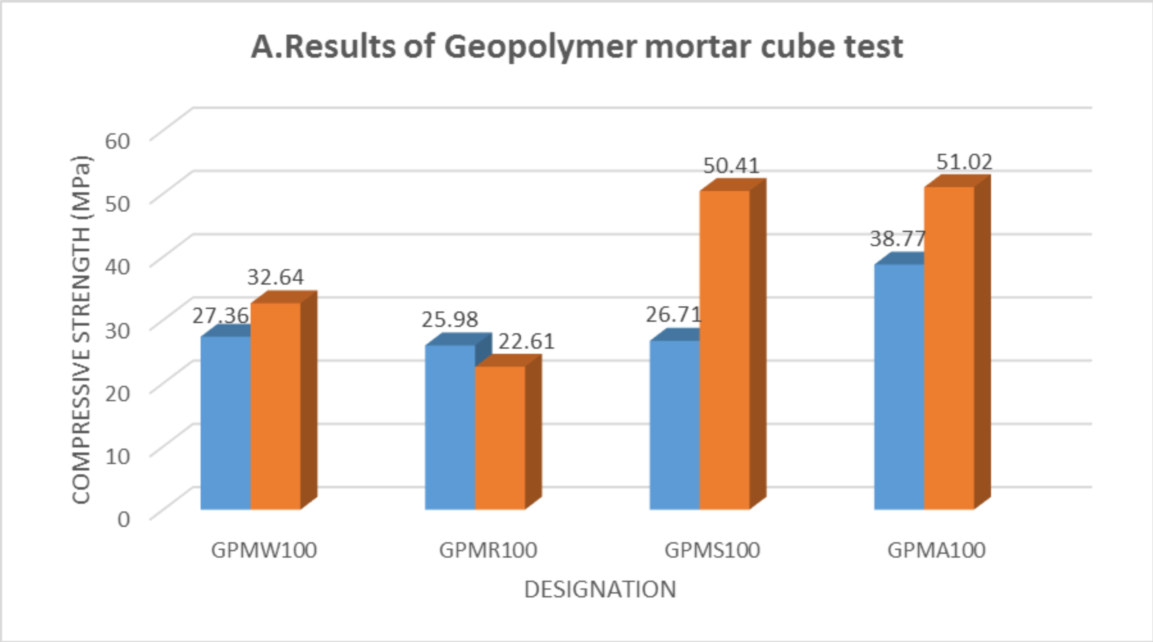

Figure 7.1: correlation between compressive strength and designation

In this correlation, test results of compressive strength of SCGPM indicates that, the compressive strength of SCGPM cubes of different sand gives good results which were cured at 90^0C in oven. Seven days compressive strength of SCGPM was in range of 20 to 50 MPa.in temperature curing mode compressive strength of SCGPM was increased in 20% and different sand gives good strength as compare to river sand it means wash sand, slag sand and artificial sand gives good strength and percentages also increased.in this correlation artificial sand and slag sand achieved more strength than river sand. It concludes that these sand are beneficial for future work.

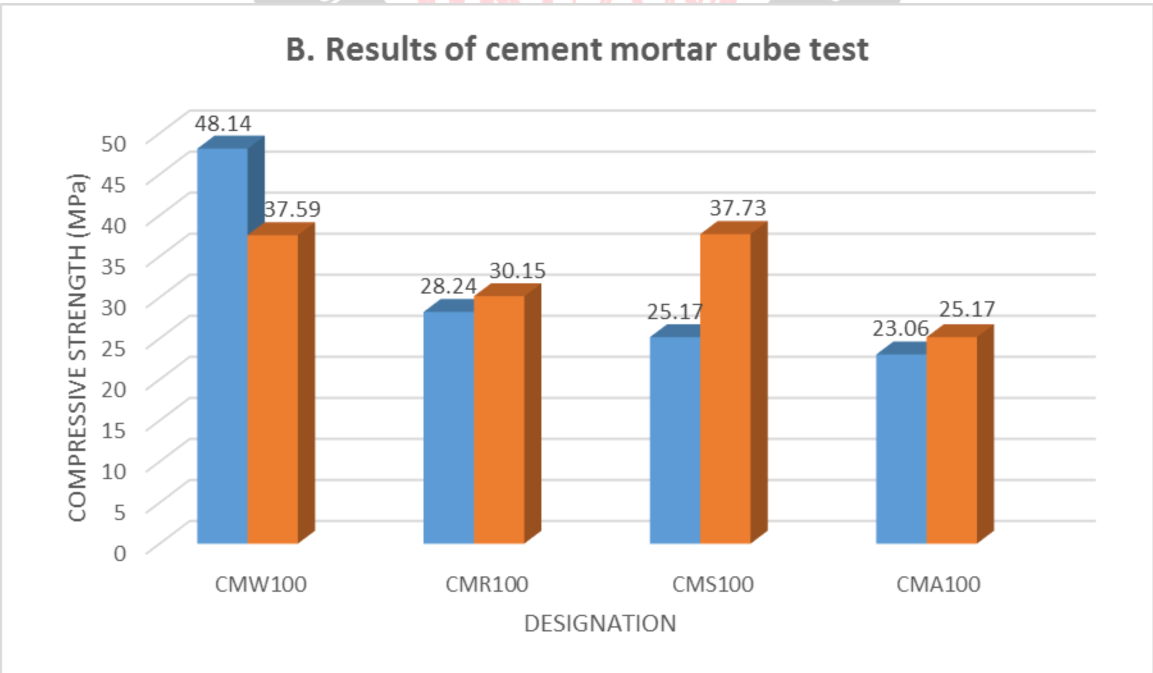

Figure 7.2 correlation between compressive strength and designation

In this correlation, test results of compressive strength of cement mortar indicates that, the compressive strength of cement mortar cubes of different sand gives same or little more results which were cured in water tank for Seven days. The compressive strength of cement mortar was in range of 20 to 50 MPa. In this mode compressive strength of cement mortar was increased in different percentage and different sand gives good strength as compare to river sand it means wash sand, slag sand and artificial sand gives good strength and percentages also increased. In this correlation wash sand achieved more strength than other sand. It concludes that these sand are beneficial for future work. But SCGPM also gives good results as compare to cement mortar.

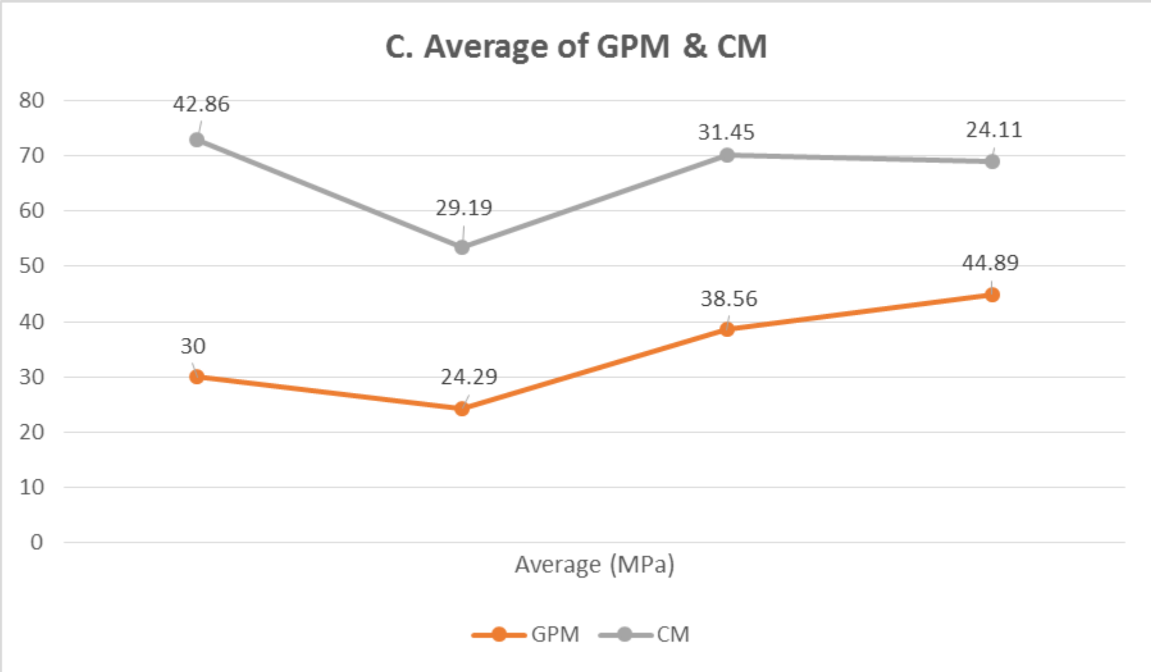

Figure 7.3 Average comparison of GPM &CM

In this correlation, we calculate the average of SCGPM and cement mortar through this test results average compressive strength of SCGPM is high for some sand such as artificial sand and slag sand and average compressive strength of cement mortar is high for only one sand that is for wash sand. So through this average graph we can compare more and more graph with different property and study and we can find out the best solution. But in both case that is SCGPM and cement mortar river sand is in the range of 20 to 30. It concludes that these sand are beneficial for future work. But SCGPM also gives good results as compare to cement mortar.

VIII. CONCLUSION

On the basis of results obtained during the experimental investigations, following conclusion were drawn:

1. The compressive strength of the fly ash based geopolymer mortar is more than cement mortar in some cases by observation it is concluded that result of slag sand and artificial sand average compressive strength is 38.56 and 44.89 in geopolymer mortar and 31.45 and 24.11 in cement mortar it means geopolymer mortar achieved more strength than cement mortar.

2. Geopolymer mortar achieved more compressive strength in minimum days or in 7 days as compare to cement. Cement mortar required more time or 28 days for the strength. Hence geopolymer is always preferable as compare to other.

3. Through results it is also concluded that river sand can easily replace by different sand such as slag sand, artificial sand results of this sand achieved more compressive strength than river sand. Hence it can be considered as eco-friendly material and economical also.

4. The compressive strength of the fly ash based geopolymer was found to be greatly affected by the relationship between the curing temperature and the curing period.

5. Geopolymer mortar utilizes the industrial waste for producing the binding material in mortar, hence it can be considered as eco-friendly material and gives more strength. The environmental issues associated with the production of OPC are too many responsible for some of CO_2 emissions, so there must be an alternative to OPC. The reduced CO_2 emissions of geopolumer mortar make them a good alternative to OPC.

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