Study on Behavior of Flyash based Geopolymer Concrete Incorporated with M sand and Bottom Ash

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Abstract — In the modern era, global warming becomes a critical environmental issue. Each passing year, the amount of green house gas emission to the atmosphere is in an increasing trend. Carbon dioxide (CO2) remains the ace green house gas which cause significant influence on global warming. CO2 contributes about 82% of the total green house gas emission. Cement industries are one of the major emitters of CO2. India is the world's second-largest cement producer next to China to reduce the utilisation of cement in concrete. In the prospects and perspectives of waste reutilization and eco-sustainable concrete production, the feasibility of total replacement of cement with fly ash and partial replacement of natural river sand with M-Sand (manufactured sand) in geo-polymer concrete was investigated in this research. Usage of this type of concrete can reduce the usage of cement and also the CO2 emission. Variations in compressive strength of geopolymer concrete with respect to various molarities of alkaline activators were studied. The optimal molarity ratio was identified as 12M and the optimum molarity ratio was kept constant for partial replacement of river sand with M-Sand. It was observed that better compressive strength (7 and 28 days) was attained for the eco-friendly concrete upto 40% replacement of river sand with M-Sand. Further more with 40% replacement of M.sand for river sand as constant, partial replacement of bottom ash for river sand at 40% was found to be optimum. The strengths of concrete are considered as the key factors for quality assurance of concrete. In this research a data driven model, Utilization of industrial by-products as aggregate in concrete becomes current need of the hour owing to its environmental importance. The ANN model was developed using experimental data and the data gathered from the past research literature. Totally 70 set of data's were used for ANN modelling, 80% in the training phase, and 10% in the testing phase and remaining 10% for validation phase. To develop the model, 8 input parameters namely fly ash, sodium hydroxide, sodium silicate, M-Sand, bottom ash, water, river sand and coarse aggregate were used to attain three output parameters. Compressive, flexural and split tensile strength of geopolymer concrete containing M-Sand and bottom ash was considered as output for respective neural network model. The results obtained in the training, testing and validation phases strongly show the potential use of ANN to predict 28 days compressive strength, split tensile strength and flexural strength of geopolymer concrete containing M-Sand and bottom ash.

Keywords: Global Warming, Alkaline Activators, Eco-Friendly Concrete, M-Sand and Bottom Ash

I. INTRODUCTION

Concrete is construed as a globally preferred building material and it plays an inevitable role in the construction arena. Though concrete comprises of several ingredients, cement is considered as a key ingredient in the concrete which gives binding property. In recent years, the cement production has grown very rapidly all over the world due to the huge requirement of cement for multi-various construction purposes. Worldwide the Portland cement production increases 9% annually. India stands second in the world cement production and produces 6.9% of world"s cement output. One tonne of cement production emits equal amount of CO2 to the atmosphere. Carbon dioxide is a primary greenhouse gas which contributes to global warming.

Cement industries are the third largest source of CO2 emissions and they account for 8% of the total greenhouse gas emissions to the atmosphere. Greenhouse gas emission causes a serious threat to the environment (Asokan 2005; Bednarik et al. 2000). In World, nearly 12 billion tonnes of concrete is produced for construction every year. Owing to the huge requirement of concrete this quantity may increase in the forthcoming years. Over-exploitation of natural resources and unused waste industrial byproducts generation causes serious jeopardy to the environment. So an alternate technology should be used in construction which reduces the usage of cement in concrete. Geopolymer concrete is an appropriate technology to utilize the industrial by-products and also the usage of cement can be completely eliminated.

Power generation in India predominantly depends on coal based power plants. In thermal power plants, during the production of power, high heat is generated through the burning of coal; due to this process, enormous quantity of fly ash and bottom ash is produced as waste by-products. Yearly 131 million tonnes of fly ash is produced and only 60% of total production is used for other purposes. Remaining is unutilized. Similarly, ample quantity of bottom ash is also formed during the coal combustion. Fly ash is obtained in fine powdery form and bottom ash as coarser ash particles. Improper disposal of fly ash and bottom ash in open spaces causes environmental pollution. Over exploitation of river sand for construction activities results in natural resources depletion. In order to maintain the sustainable development, it is necessary to find alternative material for the conventional concrete ingredients (Raijiwala & Pat 2010; Rangan 2008). Pozzolanic property of fly ash and grain size of bottom ash and M-Sand gives a greater scope to use these by-products as an alternative material for cement and river sand in concrete. Geopolymer concrete is predominantly made by utilizing industrial by-products such as fly ash or Ground Granulated Blast furnace Slag (GGBS). Due to abundant quantity of fly ash, it is the most preferred pozzolanic material to produce geopolymer concrete. In this research an attempt has been made to investigate the feasibility of utilization of fly ash as an alternate to cement, M-Sand and bottom ash as substitute materials for River sand to produce geopolymer concrete.

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A. An Overview of Geopolymer Concrete

In 1908, a German Engineer and chemist Kuhl is first patented his research work on alkali activated based binder materials. Later, Chemistry Professor Davidovit found the geopolymers to exemplify the class of inorganic polymers that endure polycondensation, which remains stable at temperatures upto 1250˚C and are non-inflammable. In 1972, a novel approach was established on the the geosynthesis of kaolinite which reacted with sodium hydroxide (NaOH) and polycondenses to Hydrosodalite at a temperature of 100oC to 150˚C. In 1973 – 1976, by using this technology building product of fire resistant chip board panel was developed and later prolonged to ceramic applications in 1978. Even though, it has excellent thermal and mechanical properties, the research work was restricted due to poor water absorption.

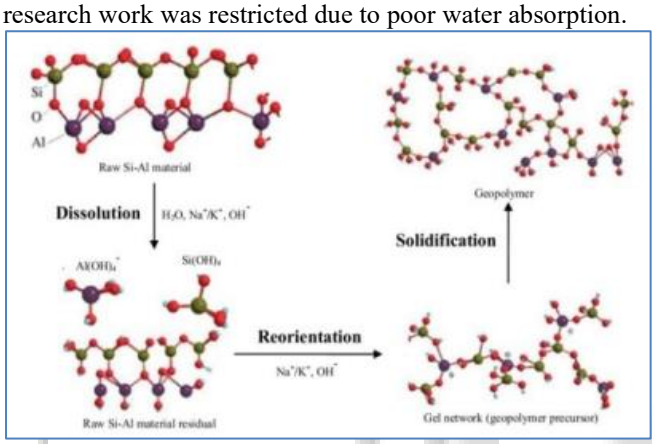


Fig. 1.1: Reaction mechanism of Geopolymerization

B. Source Materials for Geopolymer Concrete

1) Fly ash

In the recent decades, one of the main sectors which have high increase in the production of waste, specifically ash, are the hydro-electric power plants producing electricity to provide the requirements of the continuously increasing population. Coal ash is the material remaining the after the burning of coal at a temperature of 1500oC in suspended state and it together produces fly ash and bottom ash as by products. Bottom ash is collected in the boiler and whereas fly ash is collected in the chimney. From the year 2000, the coal ash has been shifted to "waste material" from the group of "hazardous industrial waste". It has become an accessible commodity.

2) Scenario of Fly Ash in India

The ash content present in Indian coal is upto 30 – 40% and its imported coals has 10 – 15% of ash content. It was found that, among the total ash generated only 80% of fly ash and 20% of bottom ash has been used and remaining has been dumped in open yard as landfills. The generation of fly ash increased year by year due to the electrical power requirement of the society. The awareness of utilizing Fly ash in construction industry is high when compared to bottom ash. In huge parts of coal ash, only the fly ash has been accepted as a basic material for production of geoplymers while the usage of bottom ash is less because of its maximum carbon content (Djwantoro Hardjito 2010; Si Hwan Kim et al. 2012; Singh & Siddique 2013).

3) Bottom Ash

Both the fly ash and bottom ash were collected from the same source, their phase and physical properties are dissimilar with bottom ash having a lesser amount of glassy constituent phase. Hence, bottom ash as collected has angular fragments and least spherical particles. So it has to be powdered finely similar to fly ash to enhance the pozzolanic activity for replacing Portland cement. The employment of bottom ash as replacement for cement has not been well recognized as it itself increases the water demand of the mixture and porous in nature. In the other hand, crushing of bottom ash has the significances of delayed setting time and decrease the workability of the mix. The presence of alumina and silica are rich in bottom ash and therefore production of geopolymer concrete by using bottom ash is not possible. Bottom ash also comprises of toxic elements like cadmium, lead and copper which leads to pollute the soil.

4) Depletion of River sand and its Disadvantages

The mixing of River sand for the production of concrete has some of the problems which are listed below.

From the environmental point of view:

- Removal of the river sand from river bed in huge amount resulted in biggest threat to the environment.
- In well foundations of bridges, due to the excess exploitation of river sand it affects the sub structure of the bridges.
- It reduces the water head because of the lesser amount of rain water percolates into the ground.
- The sand reduction in river bed results in the evaporation of water more owing to direct sun light.
- The filtration rate of water was affected by the sand shortage in river bed.

Considering the above aspects, intermittent limitations are being presented by government authorities against the mining of river sand. At the same time the cost of the river sand is increasing due to huge demand in the construction industry. So it is essential to identify alternative materials for river sand in concrete. The alternative materials should match with the properties of river sand.

5) Manufactured Sand (M - Sand)

M-Sand is a by product obtained in the crushing and screening process in the quarries. While crushing the rocks for obtaining aggregates, quarry generates significant amount of quarry fines. It is also called as stone sand, crushed rock sand, crushed river sands and crusher sand. Quarry fines comprises of mixed graded particles of fine sand, medium sand and coarse sand, including clay/silt fraction called as the filler grade. The particle size is less than 75 microns. The filler content plays a vital role in the technical properties. The restriction on the passing on 75 microns in code for river sand for concrete is a reaction to the existence of deleterious clay minerals within this fraction size. Clay minerals are likely to cause dusting, cracking and shrinkage in hardened concrete, and it increases the water demand in the mix design. While designing the concrete incorporated with river sand, it is essential to limit the passing 75 microns to a level that inhibits the probability of clay minerals being presence in quantities which is results in the potential issues. With the incorporation of M-Sand, there has been a steady acknowledgement that much of the passing 75 microns materials are ground into

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primary minerals and not as clay minerals. These materials act as filler and have benefits in the concrete mix.

C. Scope and Objectives of the research

This research mainly focuses on identifying the optimal replacement percentage of M-Sand and bottom ash to replace river sand in fly ash based geopolymer concrete of grade M30. The performance of geopolymer concrete will be analyzed by determining the mechanical properties such as compressive strength, flexural strength and split tensile strength, the durability properties by acid resistance and corrosion resistance tests. SEM analysis will be conducted to study the micro structural properties. ANN model will be developed to predict the compressive strength, flexural strength and split tensile strength of fly ash based geopolymer concrete.

The objectives of this research are,

- To identify the optimum molarity ratio to produce M30 grade of geopolymer concrete.
- To examine the fresh, mechanical properties of geopolymer concrete.
- To explore the feasibility of replacing M- Sand and Bottom Ash for river sand in geopolymer concrete.
- To study the durability properties by acid attack and corrosion resistance for various combinations of river sand, M-Sand and bottom ash as river sand in geopolymer concrete.
- To understand the micro structural properties using SEM analysis.
- To develop an ANN model to predict the compressive strength, split tensile strength and flexural strength of geopolymer concrete.

II. LITERATURE REVIEW

A. General

This chapter presents the detailed background of the past and contemporary research in the area of geopolymer concrete and geopolymer concrete with partial replacement of river sand using industrial by-products. The available literatures related to geopolymer concrete and river sand replacement were briefly reviewed.

B. Fly Ash Based Geopolymer Concrete

Bennet Jose Mathew et al. (2013) studied the economic influence and alternative on both OPC based concrete and geopolymer concrete. The comparative studies revealed that the geopolymer concrete can be manufactured at a reasonable cost with that of OPC concrete with reduction in carbon dioxide emissions to the environment. The energy of fly ash and GGBS based geopolymer concrete is 40 % less than that of OPC based concrete. Abdul Aleem & Arumairaj (2012) stated that geopolymer concrete is a new innovative material that can be manufactured by the chemical action of organic materials. Fly ash was used as binder material which is collected from thermal power station with alkaline activator solutions to produce alumino silicate gel. Because of its high early strength, they suggested that the geopolymer concrete can be utilized in precast construction work and other infrastructure projects.

Divya Khale & Rubina Chaudhary (2007) examined the mechanism of geopolymerization and the factors influencing the strength in the manufacturing of geopolymer concrete. The role and effect of the source materials, the chemical reaction, factors influencing the mix proportions such as curing time, curing temperature, alkali concentration, water solid ratio, ratio to silica and alumina was examined in this research. The authors concluded that the knowledge of geopolymerization could be developed to usage the by-products such as slag, fly ash and kiln dust. They also concluded that the geopolymer material reduces the CO2 emissions to the atmosphere by about 80% compared to that of ordinary Portland cement. Brooke et al. (2005) investigated the behaviour of geopolymer concrete beam column joints. The test results revealed that, similar behaviour was found to that of beam column joints members made of Portland cement. Application of geopolymer concrete members was well associated with concrete members made with OPC. Hardjito & Rangan (2005) studied the behaviour of fly ash based geopolymer concrete beam embedded with reinforcement. They found that, geopolymer concrete beam showed better performance than the Portland cement concrete. They reported that, flexural strength was increased upto 2.34% for the specimens cured at 60oC.

Van Jaarsveld et al. (2002) investigated the characteristics of fly ash based geopolymer. They reported that incomplete dissolution of the materials affects the properties of Geopolymer. The curing temperature and curing condition influenced the compressive strength. An extensive increase in the compressive strength was observed at 70oC for 24 hours and longer curing period reduced the compressive strength. Swanepoel & Strydom (2002) carried out a study by mixing fly ash, NaOH, Na2SiO3, kaolinite, and potable water to produce M40 grade of Geopolymer concrete. The study revealed that curing time and curing temperature influenced a lot in the compressive strength attainment of Geopolymer concrete. Optimum strength was attained when specimens were cured for 48 hours at 60oC. Xu & Van Deventer (2002) investigated the mechanism of geopolymerization of fifteen natural Al-Si minerals. From this research, they found that the mineral with greater dissolution after polymerization has excellent compressive strength. The results of this research revealed that the compressive strength of geopolymer concrete was influenced by calcium oxide (CaO), percentage of potassium oxide (K2O), the type of alkali, the molar ratio of Si/Al in the solution during dissolution and the molar ratio of Si and Al in the source material. Xu & Van Deventer (2000) studied about the geopolymerization of natural Al-Si minerals. They found that, minerals having higher extent of dissolution had better compressive strength and it was achieved when fly ash was used as a binder material. The percentage of calcium oxide (CaO), potassium oxide (K2O), the molar ratio of Si-Al in the source and in the solution had significant effect on the compressive strength. Higher compressive strength of 43 MPa was obtained in their study for the molarity ratio of 16.

Davidovit (1994) proposed a controversial theory that was acknowledged in a book and has gained extensive support and recognition. He proposed that the great pyramids of Egypt blocks were cast in place and then allowed to set, creating an artificial zeolite rock with geopolymerization

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technology. He gathered a huge amount of supporting findings from ancient Egyptian researches. Based on that, many researchers started their studies on geopolymer. Davidovits (1988) coined the term 'Geopolymer' in 1978 to represent the mineral polymers consequential from geochemistry. He documented that, geopolymer is an inorganic alumina-silicate polymer, and it is produced from predominantly silicon (Si) and aluminium (Al) material. During the synthesized process, silicon and aluminium atoms were combined to form the building blocks that are chemically and structurally comparable to those binding the natural rocks. Most of the literature available on this material deals with geopolymer pastes. The author also reported that geopolymers were members of the family of inorganic polymers similar to natural Zeolite materials. Geopolymer materials with a low Si:Al ratio normally 2 would be suitable concrete production.

C. M-SAND As River Sand in Concrete

Gui Feng Liu et al. (2011) experimentally studied the properties of concrete made with manufactured sand under the conditions freeze-thaw. They reported that, if 100% replacement is made with M-Sand, strength and elastic modulus of concrete has decreased evidently. The durability of concrete was weakened due to freeze-thaw cycle. The alkali and acid resistance decreased with increase in time of freeze-thaw cycle, and the acid resistance has also decreased.

Mahendra Chitlange & Prakash Pajgade (2010) investigated the steel fiber added concrete with M-Sand as river sand. 3 grades for compressive strength of 20, 30 and 40 MPa were designed and reinforced with steel fibers at volume fraction of 0.5,1.0, 1.5 and 2.0 %. The specimens were tested for compressive, flexural and split tensile strength. The author reported that sufficient strength was attained for steel fiber reinforced artificial sand concrete (SFRASC). LiBeixing et al. (2009) studied the properties of M-Sand with the increasing methylene blue value. They found that methylene blue value is the key index which reflects the quality of M-Sand. Test results showed that increase in methylene blue value tends to decrease workability, flexural strength. But compressive strength at 7 days and 28 days was not reduced. Test results indicated that 7% methylene blue value addition of M-Sand showed better performance in all the aspects. Jiliang Wang et al. (2009) made an attempt to replace M-Sand for river sand in concrete. The effects of M-Sand on the workability and crack propagation characteristics were studied by them; similarly they studied the mechanical properties and dry shrinkage of the hardened concrete. The experimental results showed that upto 50% of M-Sand can be replaced for river sand. Increase in M-Sand content beyond 50% tends to reduce the workability, flexural and compressive strength.

Cortes et al. (2008) studied the workability, stiffness and strength of concrete incorporated with 50% of M-Sand with respect to void ratio. The results revealed that workability and compressive strength were attained for the maximum void ratio of the river sand. Ilangovan et al. (2008) studied the feasibility of using of manufactured sand as substitute for river sand by 100% replacement in concrete. Tests were conducted to determine the strength of concrete made with manufactured sand and results were compared with concrete made of river sand. They found that the compressive and flexural strength of concrete made with manufactured sand were nearly 10% higher than that of concrete made with river sand. Sunilaa George et al. (2008) proposed a mix design for M30 grade of concrete using manufactured sand by replacing the river sand. Manufactured sand was partially replaced by 30%, 40%, 50% and 60% to test the effect of manufactured sand in concrete. Test results were compared with the control concrete. The strength of the concrete was improved at 50% replacement by M-Sand. Li Zhi-cheng et al. (2006) investigated the effects of the water to binder ratio on fly ash concrete incorporated with M-Sand; they reported that, water to binder ratio extremely affects the performances of concrete. The results showed that water to binder ratio below 0.35 cause adverse effects in strength. Concrete composed of 40% manufactured sand and 30% fly ash showed better performance. O'Flynn (2000) test verified the feasibility of replacing manufactured sand for natural river sands in concrete. Based on the obtained results, they concluded that upto 60% of river sand can be partially replaced with M-Sand and this was not affecting the physical and chemical characteristics of the concrete.

D. Bottom Ash as River Sand in Concrete

Malkit Singh et al. (2016) studied the effect of Coal Bottom Ash (CBA) on strength properties of concrete. Sand is replaced with CBA in the replacement percentages 20, 30, 40, 50, 75 and 100. They studied the relation between compressive and splitting tensile strength. At 30% replacement of CBA, compressive and splitting tensile strength got decreased at early curing. After 90 days of curing age, compressive and splitting tensile strength was almost on par to that of control concrete. Yogesh Aggarwal & Rafat Siddique (2014) investigated on mechanical properties of concrete made with bottom ash for partial replacement of river sand. The test results revealed that the mechanical properties such as compressive strength, splitting tensile strength and flexural strength of bottom ash added concrete specimens were lower than that of control concrete specimens at all the ages. It was also observed that the mechanical properties continued to get increased with age for all the bottom ash contents. Dilip Kumar et al. (2014) carried out a research in bottom ash utilization in concrete for M30 Grade. Ordinary Portland cement of 43 Grade was used to prepare concrete by mixing bottom ash as river sand. Bottom Ash was replaced by 10%, 20%, 30%, 40% and 50% for river sand in concrete. They reported that upto 40% bottom ash can be replaced for natural river sand.

Ilker Bekir Topcu & Mehmet Ugur Toprak (2011) examined the properties of bottom ash based geopolymer mortar under a curing the temperature of 80˚C. The study results revealed that ambient curing contributes to increased strength at later ages than direct curing because it cause's significant amount of water evaporation at a very early age. Mohd syahrul et al. (2010) investigated on performance of concrete made with partial replacement of washed bottom ash for river sand. The test results revealed that, the partial replacement of 10% of washed bottom ash for river sand exhibits the lower strength and cannot be used in concrete. But 30% of partial replacement of washed bottom ash was found to be optimum percentage to attain the required

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strength of 35 MPa. Djwantoro Hardjito & Shaw Sheng Fueng (2010) studied the mechanical properties of fly ash based geopolymer mortar with bottom ash as replacement for sand. They concluded that increase in bottom ash content resulted in decrease in the compressive strength of geopolymer mortar. Compressive strength of geopolymer mortar with 10% bottom ash is similar to that without bottom ash. But increase in curing temperature increased the compressive strength. Increase in bottom ash content increased the workability upto 75%. Djwantoro Harjito (2010) investigated the effect on the workability and mechanical properties of fly ash based geopolymer mortar with partial replacement of bottom ash as river sand. Partial replacement of bottom ash upto 50% did not show any increase in water demand but beyond 50% water demand increased. Increase in percentage of super plasticizer and extra water content resulted in the enhanced workability but the addition of super plasticizer showed superior properties in terms of 28 days of compressive strength. The test results also stated that the increase in alkaline liquid to fly ash ratio increases the workability. With the addition of extra potassium hydroxide (KOH) increased the compressive strength in turn. The separate mixing of fly ash with KOH had an adverse effect on the compressive strength of geopolymer mortar.

Andrade et al. (2009) investigated the influence of coal bottom ash as partial placement for natural river sands in concrete in the fresh state. The test results showed that the initial setting time of the bottom ash concrete was affected by replacement of 25% of bottom ash in the concrete. The strength properties of concrete was not affected when bottom ash was replaced at 25% for natural river sands. Slavik et al. (2008) studied the performance of geopolymer concrete produced with Fluidized Bed Combustion- Bottom Ash (FBCBA). They concluded that the concrete produced using FBCBA (Fluidized Bed Combustion- Bottom Ash) as river sand achieved a compressive strength of 50 MPa after 90 days of curing.

E. Concrete Strength Prediction Using Ann Model

Faezehossadat Khademi & Sayed Mohammadmehdi Jamal (2016) predicted the compressive strength of recycled aggregate concrete for 28 days. They considered 14 input parameters; both non-dimensional and dimensional parameters. They developed a neural network model and the input parameters were considered in the network to predict the 28 days compressive strength. They concluded that ANN model can be used for the strength prediction of concrete with higher accuracy. Deshpande et al. (2014) used ANN to predict the 28 days compressive strength of recycled aggregate concrete. The input parameters were different proportions of cement, recycled aggregates, river sand, coarse aggregates, admixture and water. They concluded that ANN performs superior in considering non-dimensional parameters like Sand–Aggregate ratio, Water–total materials ratio, Aggregate–Cement ratio, Water–Cement ratio and replacement ratio for the strength prediction of recycled aggregate concrete. Adriana Trocoli Abdon Dantas et al. (2013) developed a model using Artificial Neural Networks (ANN) for predicting the compressive strength of concrete containing construction and demolition waste after 3, 7, 28 and 90 days of curing. In their study totally 1178 data's were considered for modelling. 77.76% of data's were considered in training phase, remaining 22.24% of data's were considered in the testing phase. The results showed the use of ANN in predicting the compressive strength of construction and demolition waste incorporated concrete after 3, 7, 28 and 90 days of curing was good and effective.

Duan et al. (2013) carried out a study on predicting the compressive strength of recycled aggregate concrete using ANN. They constructed, trained and tested the ANN model using 146 available sets of data's collected from 16 literature sources. 14 input parameters were considered to develop the ANN model. From the test results they concluded that ANN is more effective in predicting the compressive strength of recycled aggregate concrete. Akhmad Suryadi et al. (2011) predicted the setting time of selfcompacting concrete using ANN. Totally 250 different data sets were collected and network was trained. They considered 120 data sets in the training and the remaining data' were considered in testing and validation phase of the network. The results indicated that the predicted results using ANN showed a dependable correlation between the input data and the targeted output. Nath et al. (2011) developed a model to predict the compressive strength of concrete using neural network. In order to predict the compressive strength of the concrete they developed computer code using MATLAB. They concluded that ANN can be effectively used in prediction of compressive strength of concrete. Vahid Alilou & Mohammad Teshnehlab (2009) predicted the 28 days compressive strength using Artificial Neural Network. They used multi input single adaptive system to predict the compressive strength. Out of 432 specimens, they used 300 samples data's for training, for validation they considered 66 samples data's and finally for testing they considered 66 samples data's. The simulations were based on real data from the experimentation which indicated the cogency of the proposed tool.

III. METHODOLOGY

In this research, geopolymer concrete incorporated with M-Sand and bottom ash was produced and its behavior was studied. The detailed methodology followed in this research is shown in Figure 3.1

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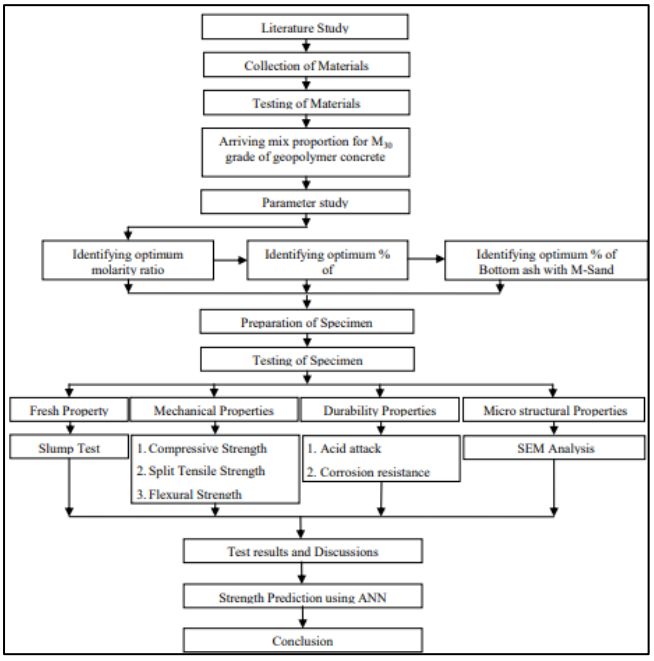


Fig. 3.1: Methodology of the study

A. Material Properties

The materials used for the M30 grade Geopolymer concrete was fly ash as 100% cement replacement, bottom ash and M-Sand as partial replacement for river sand, coarse aggregate, alkaline activator solution such as sodium hydroxide and sodium silicate with water. The properties of different constituent materials are also tested and their values are presented.

Sand are crushed river sands produced from hard granite stones which are in cubical shaped with grounded edges, washed and graded with consistency to be used as a substitute for river sand. ottom ash used in this research was collected from Thermal Power Station. Bottom ash particles were received from the boilers, possessed a glassy structure and shape was angular. Aggregates of 20mm size were used as coarse aggregate for preparation of geopolymer concrete specimens in this research. Figure 4.4 shows the coarse aggregate used in this research. The fineness modulus, specific gravity and water absorption of coarse aggregate were determined as per IS 2386: 1963 (Part 1) and (Part 3). Locally available potable water was used for preparation of geopolymer concrete specimens. Table 4.10 presents the parameters tested and permissible limits as per IS 456 – 2000. Generally the sodium hydroxides are available in solid state by means of pellets and flakes. In this research, sodium hydroxide in pellet form with 97-98% purity which is commercially available is used in this research. Sodium silicate is also known as water glass or liquid glass, available in liquid (gel) form. In the present investigation, ratio between Na2SiO3 and SiO2 is used as 2. As per the manufacturer, silicate was supplied to the detergent company and textile industry as bonding agent. The same sodium silicate was used for the preparation of alkaline activator solution for producing geopolymer concrete specimens. Alkaline activator in the form of liquid was prepared by mixing sodium hydroxide and sodium silicate together at least 24 hours prior to use. In this research, the concentration of molarity was taken as 10 for all the mixes. For example, to prepare 8M of NaOH solution, 320 grams of NaOH pellets were dissolved in one litre of distilled water. The sodium silicate solution with sodium hydroxide ratio by mass of 0.35 is used. M30 grade of concrete was designed in this research which is shown in appendix 1 to study the behaviour of geopolymer concrete incorporated with fly ash as 100% replacement for cement. M-Sand and bottom ash as partial replaced with for river sand, coarse aggregate, alkaline activator solution and water were used to produce geopolymer concrete. The specimens were cured at ambient temperature of 25oC + 2 oC and 65 + 5% relative humidity.

B. Test on the Concrete

Slump cone test was performed to find out the workability of concrete at fresh stage. The test was performed in accordance with IS 1199- 1959. By performing this test, the influence of different substitute materials on workability of geopolymer concrete was examined. The Compressive strength of concrete is considered as the key factor for quality assurance of concrete. Compression strength test was performed as per IS 516-1959 to determine the compressive strength of geopolymer concrete incorporated with M-Sand and bottom ash. Cubic samples with the dimensions of 100 mm x 100 mm x 100 mm were cast to determine the compressive strength of concrete. The compressive strength of concrete was tested at the age of 7 and 28 days. Three identical samples were cast for each mixing ratio and for each curing spell. An average compressive strength of three samples for each mixing ratio and for each curing spell was taken to assess the compressive strength of geopolymer concrete. Cylindrical samples with the dimensions of 150 mm diameter and 300 mm height were cast and tested for split tensile strength. Split tensile test was performed as per the test procedure specified in IS 516-1959. Test specimens were cured at ambient temperature. After 7 and 28 days of curing, split tensile strength of geopolymer concrete was determined. Flexural strength test was performed as per IS 516-1959 to determine the flexural strength of geopolymer concrete incorporated with M-Sand and bottom ash. Prismatic beams with dimensions of 100 mm x 100 mm x 500 mm were cast and tested for flexural strength. The system of loading used to determine the flexural strength was central point loading. Flexural strength of geopolymer concrete incorporated with M-Sand and bottom ash samples were tested after 7 and 28 days of curing. The test results were compared with control concrete. The cubic samples of size 100 mm x100 mm x 100 mm were used in acid attack test. The acid resistance of geopolymer concrete samples against sulphuric acid (H2SO4) was determined. M-Sand and bottom ash incorporated geopolymer concrete samples were immersed in 1% of H2SO4 solution. Figure 4.10 shows the specimens immersed in H2SO4 solution. Weight losses due to sulphuric acid after 30, 60 and 90 days of immersion in acid solution were studied. Based on the percentage of weight loss the acid resistance of the concrete samples were calculated. The micro structure of M-Sand and bottom ash incorporated geopolymer concrete was studied using Scanning Electron Microscope (SEM) analysis. Scanning electron microscope generates images of the samples by scanning the surface with the help of focused electron beams. The electrons act together with the atoms present in the sample and signals are generated. Based on the

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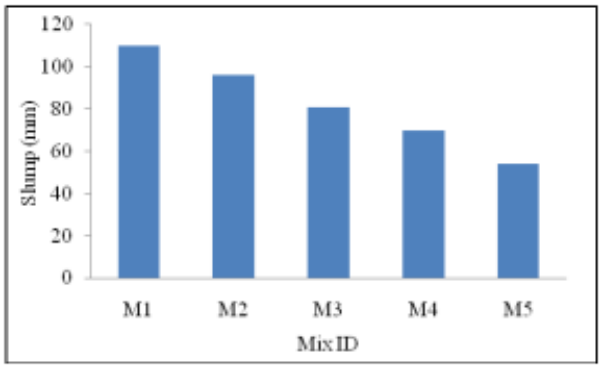
obtained signals various information of the samples were collected. In micro structural study of concrete matrix, SEM images give a clear picture about the internal bonding characteristics of different ingredients in the concrete matrix.

IV. Results and Discussion

This chapter deals with the test results and discussions on identifying the optimum molarity ratio, identifying the optimum percentage of M-Sand for partial replacement to river sand and identifying the optimum percentage of bottom ash for partial replacement for river sand with optimum percentage of M-Sand. The test result includes fresh property such as workability, mechanical properties such as compressive strength, split tensile strength and flexural strength. This chapter also discusses the acid resistance, corrosion properties and micro structural study of geopolymer concrete replaced with M-Sand and bottom ash for river sand.

A. Optimum Molarity Ratio and its influences

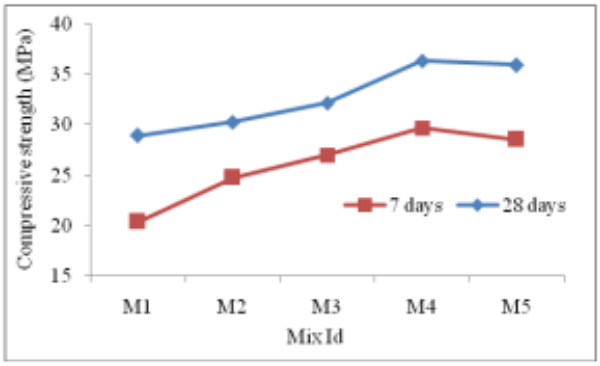
Alkaline activators such as sodium hydroxide (NaOH) and sodium silicate (Na2SiO3) are used to activate the pozzalonic activity of fly ash in the geopolymer concrete. Sodium hydroxide solution with molarities of 6M, 8M, 10M, 12M and 14M were used in trial and error basis with sodium silicate solution to identify the optimal molarity proportion of alkaline activator in the geopolymer mix. The influences of various molarities of NaOH solution in workability of geopolymer concrete are presented in Table 5.1. Workability of geopolymer concrete was measured in terms of its slump using slump cone apparatus. Due to the presence of sodium silicate, the mix was cohesive in nature. The measured slump values were less than 100 mm except for M1 sample and generally mixtures were stiff in nature due to the higher molarity. Increase in concentration of alkaline activator tends to decrease the workability of geopolymer concrete. The test results revealed that increase in concentration of NaOH increases the total solid content there by it reduces the water content of the mix.



Effect of alkaline activator concentration on workability of geopolymer concrete

The influence of various molar ratios of alkaline activators on the compressive strength attainment of geopolymer concrete at the age of 7 and 28 days are presented in Table 5.2. The average compressive strength ranges from 20.36 MPa to 29.66 MPa at the age of 7 days and 28.93 MPa to 36.33 MPa at the age of 28 days.

Mix Id.	Molarity	Avg. Compressive strength (MPa)	
		7 days	28 days
M1	6M	20.36	28.93
M2	8M	24.73	30.26
M3	10M	26.96	32.13
M4	12M	29.66	36.33
M5	14M	28.53	35.90



The highest value of compressive strength was obtained as 36.33MPa at the age of 28 days for the M4 specimen. The optimum percentage of molarity was 12. The test results revealed that the increases in molarity increases the compressive strength upto some extent, after attaining the optimum level the compressive strength of geopolymer concrete was reduced. Figure 5.2 represents the Compressive strength variation for different molarities at the age of 7 and 28 days of curing. The strength development at the age of 28 days was similar to strength development at the age of 7 days. Maximum strength was achieved at molarity 12. The influence of molarity ratio on split tensile strength was determined at the age of 7 and 28 days. The split tensile strength ranges from 1.36 MPa to 1.98 MPa at 7 days, 2.17 MPa to 2.97 MPa at the age of 28 days. The highest split tensile strength value of 2.97 MPa was obtained for 12M at the age of 28 days. Table 5.4 presents the average split tensile strength of geopolymer concrete for various molarity ratios.

Split tensile strength of geopolymer concrete for various molarity ratios

Mix Id.	Molarity	Avg. Split tensile strength (MPa)	
		7 days	28 days
M1	6M	1.36	2.17
M2	8M	1.51	2.33
M3	10M	1.77	2.60
M4	12M	1.98	2.97
M5	14M	1.42	2.30

The flexural strength of geopolymer concrete was tested for different molarity ratios and the optimum flexural strength value of 4.8 MPa was attained for molarity of 12. Table 5.4 presents the average flexural strength of geopolymer concrete at the age of 7 and 28 days for different molarity ratios.

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Mix Id.	Molarity	Avg. Flexural strength (MPa)	
		7 days	28 days
M1	6M	3.02	4.11
M2	8M	3.36	4.43
M3	10M	3.49	4.68
M4	12M	3.67	4.80
M5	14M	3.29	4.37

V. Conclusion

An experimental investigation was carried out on M-Sand and bottom ash incorporated fly ash based geopolymer concrete in order to study the combined effect of M-Sand and bottom ash. The fresh, mechanical, durability and micro structural properties of specimens were assessed. Based on the test results obtained from the experimental investigations, the following conclusions were drawn. The optimum molarity ratio was found to be 12. The different test values of geopolymer concrete revealed as under. Slump value decreases with increase in molarity ratio. With 12 molarity ratio, the required strength for M30 grade was achieved. When higher percentage of M-Sand was added, the slump value was reduced considerably. The slump value was reduced when higher percentage of bottom ash was added. The optimum percentage of M-Sand for partial replacement of river sand was found to be 40%. The tests on fresh and mechanical properties revealed that the maximum of 40% bottom ash can be used as partial replacement for river sand. The weight loss test results revealed that with increase in time, the percentage of weight loss got increased. The same pattern was also observed for optimum percentages of M-Sand added geopolymer concrete (with12M) and bottom ash added geopolymer concrete (with 12M + 40% M-Sand as partial replacement for river sand). The half cell potential tests revealed that the geopolymer concrete added with 12M plus 40% M-Sand as partial replacement for river sand plus 40% bottom ash as partial replacement for river sand resulted with lesser probability for occurrence of corrosion. The comparative study of SEM image showed that geopolymer concrete with 12M plus 40% M-Sand as partial replacement for river sand plus 40% bottom ash as partial replacement for river sand was found to be denser.

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