OPTIMUM UTILISATION OF SPENT FOUNDRY SAND IN FLY-ASH BASED ALKALI ACTIVATED GEOPOLYMER CONCRETE

A PROJECT REPORT

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in partial fulfillment for the award of the degree

of

BACHELOR OF ENGINEERING

IN

CIVIL ENGINEERING

PSG INSTITUTE OF TECHNOLOGY AND APPLIED RESEARCH, COIMBATORE

ANNA UNIVERSITY: CHENNAI 600 025

APRIL 2019

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BONAFIDE CERTIFICATE

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ACKNOWLEDGEMENT

We express our whole-hearted indebtedness to our Management, for their warm blessings, moral support, constant encouragement at various stages of course study and providing all necessary facilities for completing this project work.

We sincerely express our thanks to our esteemed Principal **Dr.P.V.Mohanram** for his support and encouragement on this project. Also we extend our heartfelt thanks to our Vice-Principal**Dr.G.CHANDRAMOHAN** for his continuous support in all aspects

We also express our gratefulness to the Head of the Department and our project guide **Dr.M.I.ABDUL ALEEM** for providing valuable advice during the development of the project.

We express our sincere gratitude to **Mr.K.KAVIKUMARAN**, Research Assistant for providing valuable ideas and guidance throughout the project

It is a great pleasure to express our whole hearted gratitude to our project co-ordinator **Mr.S.ELAYARAJA** for his constant suggestions, encouragements and valuable guidance rendered to us in the preparation and completion of this project work.

We are committed to place our thanks to all our Faculty members, Non-Teaching Staffs, family and friends who played a supportive role throughout the project.

Abstract

In the recent times as there is scarcity in availability of river sand the need for the usage of M sand in modern construction is demanding.It is also to be noticed that wastage in sand particle from foundry is relatively high in order to overcome these two short comings,we have decided to incorporate the spent foundry sand in fly ash based alkali activated geo polymer concrete.the title of our project is “ To find optimum utilization of spent foundry sand in fly ash based alkali activated geo polymer concrete”.The aim of our project is to reduce the usage of cement ,to increase the sustainability in construction of buildings and to increase the utilization of waste materials.In this project instead of testing the cubes we decided to test the building elements.Form work and reinforcements were prepared.Geo polymer solution was prepared using NaOH and Sodium silicate.The elements were casted . The curing of those elements were done with the help of a hot air chamber for one day and ambient curing for 28 days.the hot air chamber was specifically designed for this project with electronic circuits ,so that temperature inside the chamber is automatically maintained uniformly.The elements were tested with the help of Universal Testing Machine.These process helped in nurturing our creativity,management skills and academic excellence.

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INTRODUCTION

Concrete, usually Portland cement concrete, is a composite material composed of fine and coarse aggregate which are bonded together with the help of cement paste.Concrete is the primary construction material used in the industry. In building construction, concrete is used for the construction of foundations, columns, beams, slabs and other load bearing elements. The demand for concrete in our country is increasing rapidly day by day. When aggregate is mixed together with dry Portland cement and water, the mixture forms a fluid slurry that is easily poured and moulded into shape. The cement reacts chemically with the water and other ingredients to form a hard matrix that binds the materials together into a durable stone-like material that has many uses.[4] Often, additives (such as pozzolans or super plasticizers) are included in the mixture to improve the physical properties of the wet mix or the finished material. Most concrete is poured with reinforcing materials (such as rebar) embedded to provide tensile strength, yielding reinforced concrete. Materials are mixed in specific proportions to obtain the required strength. Strength of mix is specified as M5, M10, M15, M20, M25, M30 etc., where M signifies Mix and 5, 10, 15 etc. as their strength in kN/m^2. Water cement ratio plays an important role which influences various properties such as workability, strength and durability. Adequate water cement ratio is required for production of workable concrete.

There are numerous positive aspects of concrete:

- It is a relatively cheap material and has a relatively long life with few maintenance requirements.
- It is strong in compression.
- Before it hardens it can be moulded into desired shapes.
- It is non-combustible.

Cement is an important constituent of concrete. When mixed with water cement acts a binding agent which helps in holding the aggregate together, resulting in providing the required strength to concrete. When mixed with water, cement undergoes certain exothermic reactions which provide the bonding property. Although the usage of cement causes some environmental effects which is to be noted.

The cement industry is one of the primary producers of carbon dioxide, a potent greenhouse gas.A single industry accounts for around 5 percent of global carbon dioxide (CO_2) emissions. Cement manufacturing is highly energy and emissions intensive because of the extreme heat required to produce it. Producing a ton of cement requires 4.7 million BTU of energy, equivalent to about 400 pounds of coal, and generates nearly a ton of CO_2..The manufacturing of cement, the main constituent of concrete contribute about 95% of the total greenhouse gas released per cubic yard of concrete produced (Obla, 2009). Worldwide, the cement manufacturing industry contributes nearly 7% of global greenhouse gas emissions. The emission of greenhouse gases to the atmosphere is responsible for global warming (www.ucsusa.org). As per Carbon Dioxide Information Analysis Centre (CDIAC) statistical data, CO2 emissions in India increased from 0.268 to 1.59 metric tons per capita in a period between year 1960 and 2013. CO2 emissions are expected to increase in future with increase in construction activities, increase in living standards, etc. However, CDIAC data (2013) reveals that in India, per capita CO2 emission is much lower compared to 16.39 metric tons per capita in USA. Given its high emissions and critical importance to society, cement is an obvious place to look to reduce greenhouse gas emissions. The heating of limestone releases CO_2 directly, while the burning of fossil fuels to heat the kiln indirectly results in CO_2 emissions.The production of cement releases greenhouse gas emissions both directly and indirectly:

The direct emissions of cement occur through a chemical process called *calcination*. Calcination occurs when limestone, which is made of calcium carbonate, is heated, breaking down into calcium oxide and CO_2. This process accounts for ~50 percent of all emissions from cement production.

Indirect emissions are produced by burning fossil fuels to heat the kiln. Kilns are usually heated by coal, natural gas, or oil, and the combustion of these fuels produces additional CO_2 emissions, just as they would in producing electricity. This represents around 40 percent of cement emissions. So the following effects has to be taken into account and the next suitable alternative has to be found.

The waste materials act as a suitable alternative for cement. The natural and industrial waste products can act as a alternative for cement. There are environmental benefits in reducing the use of Portland cement in concrete, and using a cementitious material, such as fly ash, silica fume, ground granulated blast furnace slag, metakeoline, rice husk ash, etc. as a partial substitute.

Fly ash or flue ash, also known as pulverised fuel ash in the United Kingdom, is a coal combustion product that is composed of the particulates (fine particles of burned fuel) that are driven out of coal-fired boilers together with the flue gases. Ash that falls to the bottom of the boiler is called bottom ash. In modern coal-fired power plants, fly ash is generally captured by electrostatic precipitators or other particle filtration equipment before the flue gases reach the chimneys. Together with bottom ash removed from the bottom of the boiler, it is known as coal ash. Depending upon the source and composition of the coal being burned, the components of fly ash vary considerably, but all fly ash includes substantial amounts of silicon dioxide (SiO_2) (both amorphous and crystalline), aluminium oxide (Al_2O_3) and calcium oxide (CaO), the main mineral compounds in coal-bearing rock strata.Coal contains trace levels of trace elements (such as arsenic, barium, beryllium, boron, cadmium, chromium, thallium, selenium, molybdenum and mercury many of which are highly toxic to humans and other life. Therefore, fly ash obtained after combustion of this coal contains enhanced concentrations of these elements and the potential of the ash to cause groundwater pollution is significant.In the USA there are documented cases of groundwater pollution that followed ash disposal or utilization without the necessary protection having been put in place. For example, a December 2008 Maryland court decision levied a $54 million penalty against Constellation Energy, which had performed a "restoration project" of filling an abandoned gravel quarry with fly ash; the ash contaminated area water wells with heavy metals. Another survey shows the total production of fly ash in the world is about 780 Million tons per year after. In India more than 100 million tons of fly ash is produced annually, out of which 17 – 20 % fly ash is utilized either in concrete as a part replacement of cement or workability improving admixture or in stabilization of soil. With silicon and aluminium as the main constituents, fly ash has great potential as a cement replacing material in concrete.

Waste foundry sand (WFS) is one such promising material which needs to be studied extensively as substitute of fine aggregates in concrete. It is a by-product from the ferrous and non-ferrous metal casting industries with ferrous foundries producing the most sand. It is characteristically sub-angular to round in shape and has high thermal conductivity which makes it suitable for moulding, casting operations. Moulding sands are recycled and reused multiple times during casting process. In due course, the recycled sand degrades to the state that it can no longer be reused in the casting process. Then, the old sand is dismissed as byproduct, and new sand is introduced into the cycle. Metal alloy casting industries only produce several million tons of by product in the world and waste foundry sand (WFS) is the major by-product. It has been successfully used as a land filling material since many years, but due to rising disposal costs, land filling is also becoming a problem. United States has about 3000 foundries which annually utilizes 100 million tons of sand for itsproduction and about 6–10 million metric tons of waste foundry sand is discarded per year, which goes into landfills [2,3]. With high national average tipping fee of foundry by-products landfilling has also not remained a feasible option. Indian foundry industry is the third largest casting manufacturer in the world after China and USA. With approximately 5000 foundries and installed capacity of 15 Million metric tons/annum the annual production of nearly 9.3 Million Metric tons is reported for 2012–13. The installed capacity and output could be actually higher than estimate since the sector is majorly (around 85%) unorganized that does not reports in public [4]. Waste produced (WFS) from these foundries is approximately 1,710,000 tons (1.71 MT) per annum [5]. In an effort to use the waste foundry sand in large volume, research is being carried out for its possible substantial utilization as partial replacement of fine aggregate in concrete. Also, foundries use high quality size-specific silica sands for use in their moulding and casting operations. Usually raw sand is of a higher quality than the typical bank run or natural sands used in fill construction sites [6]. Therefore, this can be a very competent material for sand replacement.

Geopolymers are inorganic, typically ceramic, materials that form long-range, covalently bonded, non-crystalline (amorphous) networks. Obsidian (volcanic glass) fragments are a component of some geopolymer blends.[1] Commercially produced geopolymers may be used for fire- and heat-resistant coatings and adhesives, medicinal applications, high-temperature ceramics, new binders for fire-resistant fibre composites, toxic and radioactive waste encapsulation and new cements for concrete. The properties and uses of geopolymers are being explored in many scientific and industrial disciplines: modern inorganic chemistry, physical chemistry, colloid chemistry, mineralogy, geology, and in other types of engineering process technologies. Geopolymers are part of polymer science, chemistry and technology that forms one of the major areas of materials science. Polymers are either organic material, i.e. carbon-based, or inorganic polymer, for example silicon-based. The organic polymers comprise the classes of natural polymers (rubber, cellulose), synthetic organic polymers (textile fibres, plastics, films, elastomers, etc.) and natural biopolymers (biology, medicine, pharmacy). Raw materials used in the synthesis of silicon-based polymers are mainly rock-forming minerals of geological origin, hence the name: *geopolymer*.

Geopolymer concrete is an innovative and eco-friendly construction material and an alternative to Portland cement concrete. Use of geopolymer reduces the demand of Portland cement which is responsible for high CO_2 emission. Geopolymer was the name given by Daidovits in 1978 to materials which are characterized by chains or networks or inorganic molecules. It is a new material in which cement is totally replaced by the pozzolanicmaterials that are rich in Silicon (Si) and Aluminium (Al) like fly ash. It is activated by highly alkaline liquids to produce the binder which binds the aggregates in concrete when subjected to elevated temperature. The chemical process involved in this case is polymerization.

ADVANTAGES:-

1. **High Strength** – it has a high compressive strength that showed higher compressive strength than that of ordinary concrete. It also has rapid strength gain and cures very quickly, making it an excellent option for quick builds.

Geopolymer concrete has high tensile strength. It is less brittle than Portland concrete and can withstand more movement. It is not completely earthquake proof, but does withstand the earth moving better than traditional concrete.

2. **Very Low Creep and Shrinkage** – shrinkage can cause severe and even dangerous cracks in the concrete from the drying and heating of the concrete or even the evaporation of water from the concrete. Geopolymer concrete does not hydrate; it is not as permeable and will not experience significant shrinkage.

The creep of geopolymer concrete is very low. When speaking of creep in concrete terms it means the tendency of the concrete to become permanently deformed due to the constant forces being applied against it.

3. **Resistant to Heat and Cold** – It has the ability to stay stable even at temperatures of more than 2200 degrees Fahrenheit. Excessive heat can reduce the stability of concrete

causing it to spall or have layers break off. Geopolymer concrete does not experience spalling unless it reaches over 2200 degrees Fahrenheit.

As for cold temperatures, it is resistant to freezing. The pores are very small but water can still enter cured concrete. When temperatures dip to below freezing that water freezes and then expands this will cause cracks to form. Geopolymer concrete will not freeze.

4. **Chemical Resistance** – it has a very strong chemical resistance. Acids, toxic waste and salt water will not have an effect on geopolymer concrete. Corrosion is not likely to occur with this concrete as it is with traditional Portland concrete.

1.1 AIM AND OBJECTIVE:-

To determine the optimum utilization of spent foundry sand by using fly ash based alkali activated geopolymer concrete in the building elements. In order to overcome the problem of river sand, now a days M-Sand is used. However M-Sand is also a non-renewable resource and therefore we would be sooner in need of an alternative, Spent foundry sand is the major end product coming from foundries and it is available in large quantities and it is very difficult to dispose so Spent foundry sand can be used as an alternative.

In geopolymer concrete M- Sand is partially replaced with spent foundry sand at different percentages in order to find the optimum percentage of spent foundry sand without compromising the strength and other parameters. Beams and columns being the basic structural elements of the building, these elements are casted in geopolymer concrete and they are tested in order to find out the strength.

Chapter-2

LITERATURE REVIEW

Joseph Davidovits (1994)carried out a Properties of Geopolymer cements. This paper focused on Geopolymer concrete has excellent properties and is well-suited to manufacture precast concrete products that are needed in rehabilitation and retrofitting of structures after a disaster. The concluded by introduced low – CO2 geopolymeric cements, not only for environmental uses, but also in construction, civil engineering would reduce CO2 emission caused by the cement and concrete industries by 80%.

VijayaRangan et al (2006) studied the behaviour of fly ash-based Geopolymer concrete and informed that the geopolymer concrete had an excellent compressive strength and is suitable for the structural applications. The elastic properties of the hardened concrete, as well as the behaviour and strength of the reinforced structural members were similar to those of Portland cement concrete. Therefore, the design provisions present in the current standards and codes can be used to design the reinforced fly ash-based geopolymer concrete structural members

Dr Abdul Aleem M.I and Arumairaj (2012)made an attempt to find out an optimum mix for the Geo-polymer concrete and they have casted concrete cubes of size 150 x 150 x 150 mm and cured under Steam curing for 24 hours based on the compressive strength. The optimum mix is Fly ash: Fine aggregate: Coarse aggregate (1:1.5:3.3) with a solution (NaOH& Na2SiO3 combined together) to fly ash ratio of 0.35. High and early strength was obtained in the Geo-polymer concrete mix.

RafatSiddique et al. investigated the mechanical properties of concrete mixtures in which fineaggregate was partially replaced by foundry sand at different weight percentages (10%, 20%, 30%).Tests were performed to find various properties of concrete like its compressive, split tensile, andflexural strengths, and its modulus of elasticity at 28, 56, 91, and 365 days. Test results showed thatthe increase in compressive strength varied between 8% and 19%, splitting tensile strength between6.5% and 14.5%, flexural strength between 7% and 12%, and the modulus of elasticity between 5%and 12%.

Siddique et al. (2007, 2009)reported that the use of SFS up to 30% as partial replacement of sand resulted in slight increase in compressive strength, splitting tensile strength, and modulus of elasticity of concrete. However, Guney et al. (2010) illustrated that the strength properties including modulus of elasticity of concretemade with SFS decreased with increase in the replacement level ofstandard fine sand. They also reported that concrete specimen with 10% SFS displayed similar compressive strength, tensile strength and modulus of elasticity results to that of control concrete. They observed that by carefully arranging the particle size distribution of SFS, it can successfully be used in manufacturing of high strength concrete.

Naik et al. evaluated the performance of foundry sand as a partial replacement (up to 35%) of the fine aggregate for masonry blocks and paving stones. Masonry blocks made with WFS passed ASTM requirements for compressive strength, absorption, and bulk density. Bakis explored the possibility of the reuse of WFS in asphalt concrete production by partially replacing fine aggregate with it [2]. The particle size distribution of the mixture with 10% WFS possibly gives sufficient adherence than the other mixtures with WFS.

Khatib and Baig et al.studied fresh and hardened properties of concrete containing wastefoundry sand (WFS) replaced with fine aggregate at 0 to 100%, maintaining the W/C ratio constantthroughout the study. Testing on the hardened properties of concrete was conducted at 14, 28, and 56days. Results showed that the incorporation of waste foundry sand in concrete causes a decrease inworkability, ultrasonic pulse velocity, and strength, but an increase in water absorption and theshrinkage of concrete. They also reported that an acceptable concrete strength can be achieved using foundry sand.

T.R. Naik et al. conducted an investigation evaluate the performance of foundry by-products in concrete & masonry products. Based on the test results they concluded that, (a)The addition of foundry sand caused a decrease in concrete workability. (b) Compressive strength of concrete decreased slightly due to the replacement of regular coarse aggregate with foundry slag. However, compressive strength observed for both 50 and 100 percent slag mixes were appropriate for structural uses. (c) The modulus of elasticity of the 100 percent slag mix was the highest of all the three mixes evaluated. (d) All the masonry blocks made with 35 percent new/used foundry sands passed ASTM requirements for compressive strength, absorption and bulk density.

Singh and Siddique observed enhancement in strength of concrete with increase in WFS content replacing natural sand by different proportions (5%, 10%, 15% and 20% by mass). Compressive strength of concrete at 28-day increased by 8.25–17%.Beyond 15% WFS there wasn't significant increase in strengthwhich is attributable to increase in surface area of fine particles which may have led to reduction of water cement gel in matrix hence led to inadequate binding. The factors responsible for strength reduction are the poor workability of the matrix and the existence of binder (i.e., very fine powder of carbon and clay) in WFS which stick to sand particles and prevents strengthening bond between the cement paste and the aggregate. Siddiqueand Kadri reported improvement in strength by the addition of mineral admixture i.e. Metakaolin (MK) of concrete containing WFS.

Bikas et alincorporated used foundry sand in asphalt concrete with 4%, 7%, 10%, 14%, 17%, and 20% replacement of fine aggregate. Their tests measured the flow values and Marshall stability of the asphalt concrete. The results showed that a 10% replacement of fine aggregate with used-foundry sand is most suitable for asphalt concrete mixtures. Additionally reported is that used-foundry sand did not affect the environment around the deposition.

Siddique et al.reported an increase in compressive strength,splitting-tensile strength, flexural strength and modulus of elasticity of with an increase in used foundry sand content. The fine aggregate replacement used in their study consisted of three percentages (10%, 20% and 30%). The increase in compressive strength varied from 8% and 19% depending upon the used-foundry sand replacement and the age of the specimens. The percent increase for the splitting-tensile strength varied from 6.5% to 14.5% and 7% and for the flexural strength. Lastly the recorded performance increase for the modulus of elasticity varied from 5% to 12%.

Bikas et al.incorporated used foundry sand in asphalt concrete with 4%, 7%, 10%, 14%, 17%, and 20% replacement of fine aggregate. Their tests measured the flow values and Marshall stability of the asphalt concrete. The results showed that a 10% replacement of fine aggregate with used-foundry sand is most suitable for asphalt concrete mixtures. Additionally reported is that used-foundry sand did not affect the environment around the deposition.

Fiore et al.conducted a report on the reuse of foundry sand and recycling of various sizes. Their findings grouped used foundry sand into three categories according to particle size dimensions: less than 0.1 mm (0.0039 in.), between 0.1 mm (0.0039 in.) and 0.6 mm (0.023 in.), and above 0.6 mm (0.023 in). The fraction above 0.6 mm (0.023 in.) (metallic iron) may be reused in furnaces, while the fraction between 0.1 mm (0.0039 in.) and 0.6 mm (0.023 in.) may be reused in cores production, after retreatment. The smaller fraction, less than 0.1 mm may be recycled for use in the concrete industry. Additionally, the Fiore et al. [13] reported that the fraction below 0.025 mm could be reused in green moulding operations, pending retreatment.

Qasrawi et al.uses both recycled concrete aggregate (RCA) and steel slag aggregate (SSA) as partial replacement in concrete. The results show a decrease in strength with full replacement;however a 67% replacement of SSA increased the properties of normal strength concrete. The use RCA had some adverse effects on the concrete such as workability, air content and modulus of elasticity, whereas the SSA replacement did not.

Yuksel et al.used both bottom ash and non-ground blastfurnace slag as 10%, 20%, 30%, 40% and 50% fine aggregate replacement, respectively. The results showed that both additives positively affect the durability properties of concrete, such as the resistance to high temperature and surface abrasion. This is due to the chemical and physical properties of the bottom ash and slag, as revealed by Scanning Electron Microscope (SEM) imaging. This work ultimately demonstrates that durable concrete can be produced with the addition of non-ground blast furnace slag and bottom ash.

Gurpreet Singh and RafatSiddique performed experimental investigations to evaluate the strength and durability properties of concrete mixtures, in which natural sand was partial replaced with (WFS). Test results obtained shown that, (a) Concrete mixtures made with WFS exhibited higher compressive strength than control concrete. From the results, it was found that 28 day compressive strength increased by 8.25%, 12.25%, 17% and 13.45% for mixtures M-2 (5%WFS), M-3 (10% WFS), M-4 (15% WFS) and M-5 (20% WFS) respectively than control mixture M-1 (0% WFS). Comparative study of compressive strength at 28 and 91 days indicate that % increase in compressive strength decreases with the increase in WFS content at 91 days in comparison to 28 days, it was decreased by 7% to 1.98%. (b) Splitting tensile strength of concrete mixtures increased with the increase in WFS content. Splitting tensile strength of control mixture M-1 (0% WFS) was 4.23 MPa at 28 days. It was increased by 3.55%, 8.27%, 10.40% and 6.38% of M-2 (5% WFS), M-3 (10% WFS), M-4 (15% WFS) and M-5 (20% WFS) respectively. Higher value of splitting tensile strength was observed at 15% WFS.(c) Ultrasonic pulse velocity test was performed on concrete containing 0%, 5%, 10%, 15% and 20% of WFS at the age of 28 and 91 days. Test results shown that USPV value increased with the increase in waste foundry content in concrete mixtures and it also increases with age. USPV value for concrete mixture containing WFS was found more than control concrete mixture M-1 (0% WFS).

Konapure et al. researched M20 & M30 grade concrete with mix proportions of 1:2.09:3.02 &1:1.98:3.88 with respective water-cement ratios of 0.45 & 0.42 when evaluating basic fundamental properties of concrete (compressive strength, split tensile strength, flexural strength). The data obtained from their research can be analysed& a comparative study can be done with mixes using foundry sand [FS]. This relationship is governed by workability, compressive strength, split tensilestrength, and flexural strength, hence this data can be represented both mathematically & graphically.Test results showed that a 20% substitution of foundry sand results in an increase in compressive strength for both the M20 & M30 grade concrete when compared to mixes with natural sand, and then decreases as the replacement percentage increases.

Vijai et al (2010) conducted tests on Geopolymer concrete cubes, cylinders and prism specimens by using fly ash and aggregates and also using the ordinary Portland cement along with the fly ash and aggregates. It was inferred that the density of GPC ranges from 2336 to 2413 kg/m3 and density of GPCC ranges from 2356 to 2424 kg/m3. They also reported that Geopolymer Concrete has two limitations such as delay in setting time and necessity of heat curing to gain strength.

Krauthammer(1984) presented a method for the analysis of reinforced concrete (RC) box-type structures under the effects of severe dynamic loading conditions and Krauthammer (1986) demonstrated it by employing it for the analysis of seven different events and the evaluated it’s accuracy by comparing numerical and experimental results. And then, the dynamic responses of RC beams under the dynamic loading condition were farther studied with the rate-dependent model and compared with the rate-independentmodel (Beshara 1992; Al-Haddad 1995; Farag 1996; Kulkarni 1998). Kunnath (1990) presents anefficient model for inelastic biaxial bending interaction of reinforced concrete sections and the validityof the proposed scheme was demonstrated through the analytical simulation of available biaxial experiments on reinforced concrete columns and comparison with other analytical models.

Kaur et al. added fungal (Aspergillus spp.) (fungal culture at about 5% (w/v)) treated 20% WFS as sand replacement and reported 15.6% increase in 28 day compressive strength of concrete. Incorporation of fungal treated WFS showed improvement in strength due to plugging of pores within concrete by deposition of fungal spores or biomineral in pores of cement sand matrix. The fungal culture (Aspergillus spp.) increased the ability of cement to react properly with foundry sand and hence increased the formation of C–S–H gel. Kaur et al, showed similar results supported by XRD analysis exhibiting some extra peaks of calcium aluminium silicate (gismondine) in the concrete containing fungal treated WFS (20%).This confirmed the formation of new phases of silicates within the matrix of this mortar material, which caused an improvement in the strength of the material.

Salokhe et al.concluded that concrete with WFS from ferrous foundries performed better than concrete with non-ferrous WFS in case of strength gain. Inclusion of both sands gave dense concretes at 20% replacement. Basar and Aksoy investigated the potential reuse of WFS in ready mix concrete production by studying five different replacement percentages (0, 10, 20, 30 and 40%) of regular sand by WFS. The concrete having 20% WFS exhibited almost similar results with the control one along with similar micro-structural properties and morphological characterization. The concretes produced with WFS were lighter than the conventional concrete due to lower density of WFS but still its density was within the range 2000–2600 kg/m3, valid for normal concrete class.

Siddique et al.reported consistent increase in strength of concrete with WFS, when added up to 30% as sand replacement, attributing to densification of concrete matrix due to finer WFS particles and also presence of silica content which would havehelped in the formation of C-S-H gel. Similar results of consistent increase in strength at even higher replacement levels i.e.up to 60% of WFS have been summarized by Pathariya et al. with maximum strength shown by mix with 60% WFS. Similarly, Siddique et al. reported strengths of mixes with 30%, 40% and 50% of WFS higher than control concrete at the curing ages of 28 days, 90 days and 365 days. The rate of strength gain for normal concrete (with slump near 75 mm) between 7 and 90 days is found as 72% which is characteristic of normal concrete. The rate of strength gain for all WFS concrete mixes was closer to control mix at 90 days, whereas, it was found higher at 365 days. The effect of increase in WFS replacement on 28 day strength of concretes as reported by various researchers Siddique et al.; Aggarwal and Siddique; Prabhu et al; Khatib et al.

Prabhu et al. used WFS prior washed four times to remove ash and clay particles and thereafter sun dried for two days. They concluded a comparable compressive strength to that of control concrete by replacing 20% WFS as fine aggregate replacement. However, a slight decrease was observed at 30% replacement leveland beyond that the strength decreased drastically i.e. at 50% replacement the decrease in strength was up to 23.95% to that of control concrete. Concrete with adequate strength was achievable even when fine aggregates were fully replaced by WFS with strength nearly 50% of the strength of control concrete.

Siddique et al.investigated the use of WFS as partial replacement of fine aggregate in concrete by 10, 20 and 30% and observed consistent increase insplit tensile strength than control concrete by up to 12, 14 e replacing natural sand withWFSby different proportions (5%, 10%, 15% and 20% at respective replacement ratio. Similar observations were made elsewhere. Marginal increase of 3.6–9% in splitting tensile strength was reported with increase in WFS content at 28 days curing age, depending upon level of replacement (10%, 20% and 30%). Guney et al. reported increase in strength up to 10% replacement by WFS then it decreased further at 15% substitution. Similar results were reported elsewhere which show enhancement in splitting tensile strength by 3.6–10.4% for concretand 20% by mass). Concretes with WFS of M20 grade showed higher values of splitting tensile strength than M30 grade at all WFS percentage levels and at all curing ages. Correspondingly, SCC concrete with 15% WFS content showed higher values of splitting tensile strength when studied for replacement level up to 20%. Ferrous WFS concrete performed slightly better than non-ferrous WFS concretewith 20% addition gave maximum strength value.

Siddique et al.observed that mixes with 30%, 40% and 50% WFS showed higher strength at 28 days, 90 days, and 365-days.Whereas mixes with 10%, 20% and 60% WFS showed 11.5%, 4.8% and 17.30% decrease in strength respectively, in comparison with the strength of the control mix. An increase in split-tensile strength values by 24.03%, 19.23%, and 14.42% was observed for 30%, 40% and 50% replacement levels respectively at 28-day curing age. Aggarwal and Siddique investigated the effect of waste foundry sand and bottom ash in equalquantities as partial replacement of fine aggregates in various percentages (0–60%), on concrete properties. Splitting tensile vary from 0.062 to 0.080; 0.062 to 0.078; 0.061 to 0.076 and 0.052 to 0.075 times the compressive strength, at ages of 7, 28, 90 and 365 days, respectively. Olutoge et al. concluded that the split tensile strength increases as the percentages of sand replaced with foundry sand increases. The split tensile strength increased by 11.91%, 17.44%, 20%, 20.85%, and 25.53% for 20%, 40%, 60%, 80%, and 100% sand replacement with foundry sand respectively when compared to a conventional concrete mix with natural sand as fine aggregate.

Prabhu et al. found results of concrete mix up to 20% replacement level of WFS (prewashed four then sun dried) comparable to control mix, however, beyond 20% slight decrease in strength was observed up to 30% replacement and it further decreased at higher replacement levels of WFS. A decrease of 19.32% in tensile strength was observed as compared to control mix at 50% replacement level of WFS.

Zanetti and Godio (2006) also presented their research into the recovery of foundry sands and iron fractions from an industrial waste landfill. They tried to recover this by-product in three ways: (i) thermal process, which carries the risk of strong environmental impact and costs about €30-40 per ton. (ii) Wet mechanical treatment, which involves a noticeable sludge production and costs about €20-30 per ton. (iii) dry mechanical process, which – to comply with the core making operations necessitates a unique study for each plant of the organic additives mixture and costs €10 per ton. Theyalso concluded that the European price of virgin silica sand nearly equalled the price of recovery offoundry sand. For instance, in Italy the price is about €40 per ton while, i.e. in Belgium andNetherlands the same product is sold at about €10 per ton (Zanetti and Godio 2006). Therefore, many foundries are reluctant to reclaim spent foundry sand and instead prefer to replace it with virgin sand and discard large quantities of this spent foundry sand, namely waste foundry sand (WFS).

Guney et al. (2006) evaluated the environmental behaviour of WFS amended with lime and cement. They claimed that water passing through WFS or WFS-based mixtures did not become contaminated with metallic compounds, due to fact that the measured concentrations were apparently lower than the U.S. EPA limits. In other words, if utilized and if there is contact between the WFS and water that has been discharged directly to the environment (e.g., drainage through asphalt pavement), the quality of the water will not be affected by any metals leached from the WFS or WFS-based mixtures.

Javed et al. (1994) conducted similar experiments on asphalt concrete samples containing WFS. They found that an amount up to 15% was the maximum amount of WFS that could be allowed to replace conventional sand content in asphalt concrete. However, in the light of their experiments on samples having 0, 4, 7, 10, 14, 17 and 20% replacement of fine aggregate with WFS, Bakis et al. (2006) suggested that using WFS as a partial replacement for fine aggregate in asphalt concrete should be limited to a maximum of about 10% in practical applications. They made this determination based on the fact (i) that, as shown in Figure 4, flow decreased parallel to the increase in the percentage of added WFS (ii) as the percentage of WFS added to the asphalt cement increased from 0 to 20% and the Marshall stability value decreased from 12.1 to 9.7 kN. However, when the WFS content was limited to a maximum of 10% of the whole aggregate weight, the Marshall stability value was 10.9 kN. Which is a fairly good result; (iii) similarly the indirect tensile strengths of the asphalt cement samples displayed an almost linear decrease as the percentage of WFS material was increased, resulting in values of 13.9 kPa with 0% WFS, 11.8 kPa for 10% WFS and 9.4 kPa with 20% WFS added. (iv) it is well-known that the measured density value of asphalt cement concrete is 2.4 g/cm3. However, they measured this value as 2.28 g/cm3 for asphalt cement concrete sample including 20% WFS. Hence, it is clear that the density of the mixture decreases as the percentage of WFS in the asphalt cement concrete increases.

Khatib and Ellis (2001) investigated concrete samples containing three types of foundry sands as apartial replacement of fine aggregate: white fine sand without the addition of clay and coal; foundry sand before casting process (virgin); and foundry sand after casting process (WFS). In order to determine the optimum amount of these materials, the standard sand was partially replaced by 0%, 25%, 50%, 75%, and 100%. Their results indicated that (i) the strength of concrete reduced as the amount of replaced sand increased; (ii) concrete samples containing white sand had similar strength to those including WFS at all replacement levels; (iii) concrete with high amounts of virgin sand had lower strength compared with concrete incorporating white sand or WFS; and (iv) increase in strength was not observed at low replacement levels (less than 50%). The tests on shrinkage up to the age of 60 days were also performed, and according to the results, they indicated that (i) length change of concrete increased as the replacement amount of standard sand with the three types of sand increased; (ii) WFS based concrete had higher drying shrinkage values; however, white sand based concrete had lower values. (iii) Expansion was mostly lower in white sand based concrete compared with the other two types (virgin and WFS) at a low sand replacement level of 25% (Khatib and Ellis 2001).

Another research was conducted by **Siddique et al. (2009)** on concrete samples containing threedifferent percentages of WFS (10%, 20%, and 30%) substituted for the fine aggregate. They explained that; (i) as seen in Figure 5, an increase in compressive strength was observed due to the fact that WFS is finer than conventional sand. Additionally, it is clear in Figure 6 that higher splitting-tensile strength was observed due to silica content present in the WFS. Likewise, flexural strength, and modulus of elasticity of WFS based concrete increased in line with the increase in foundry sand content as shown in Figure 7 and 8; (ii) compressive strength, splitting-tensile strength, flexural strength, and modulus of elasticity of concrete mixtures increased with age for all the WFS contents as seen in Figure 5, 6, 7, and 8. (iii) increase in compressive strength varied between 8% and 19% depending upon WFS percentage and testing age, whereas it was between 6.5% and 14.5% for splitting-tensile strength, 7% and 12% for flexural strength, and 5% and 12% for modulus of elasticity.

In an environmentally-focused study, **Siddique et al. (2018)** showed that the use of WFS as replacement of conventional sand did not only lead to a decline in the cost of concrete, but also to a considerable reduction in CO2 emissions. In another similar study, leach ability characteristics of the concrete specimens with WFS at different pH conditions representing variant natural cases revealedthatWFS could be utilized in the production of concrete with no hazardous effects in terms of the topic's environmental aspects (Basar and Aksoy 2012).

Siddique (2009) noticed innumerate advantages of this material: its generation from by-products (especially from WFS), its fast manufacture, self-compaction, simple excavation, and its utilization in confined spaces. Kennedy and Linne (1987) specified that WFS is a convenient material for CLSM production due to its performance, lower cost, and availability. In order to validate the incorporation of WFS into CSLM from an environmental perspective material leaching analyses are required. To this end, Deng and Tikalsky (2008) conducted extensive experiments and showed that the toxicity of CLSM specimens with WFS was below regulated criteria without posing any environmental hazard with regard to toxic metals. Additionally, the U.S. EPA accepted ferrous WFS as a suitable CLSM material (Environmental Protection Agency 1998). To date, several studies have been conducted on the issue of replacing WFS with natural fine aggregate. Tikalsky et al. (1998) investigated both green and chemically bonded WFS in CLSM and compared results with CLSM containing uniformly graded crushed limestone sand. According to their results, CLSM containing WFS gave similar or better results in terms of strength than CLSM containing crushed limestone sand. WFS supported strength retention from exceeding the desired upper limit of 700 kPa. However, when compared to each other, chemically bonded WFS performed better than green WFS in CLSM on the issue of fluidity (Tikalskyet al. 2000).

Kumbhar et al. investigated the various mechanical properties of concrete containing used foundry sand. The concrete was produced by replacing natural sand with UFS in various percentages (10%, 20%, 30%, and 40%). Based on the test results they concluded that (i) workability decreases with an increase in UFS content, (ii) at 28-days, the compressive and splitting tensile strengths for different replacement levels of UFS increased, whereas flexural tensile strength decreased for a UFS content of more than 20%, (iii) at 28-days, the modulus of elasticity values increase with a replacement of UFS up to 20%. They also concluded that UFS can be utilized in place of regular sand in concrete in up to about 20%.

Ranjitham et al. investigated strength properties like compressive, split tensile and flexuralstrengths of M75 grade of mixtures at 10% to 30% replacement of fine aggregate by foundry sand,along with cement replacement by mineral admixtures such as fly ash and GGBS slag at a water binder ratio of0.3. Based on the results shown, a replacement of 30% UFS with 3% super plasticiser exhibited superior strength characteristics. They conclude that by varying the super plasticizer dose, workability can be reached. Mixes with 30% fly ash and 30% GGBS replacement showed better workability compared to other percentage replacements. The use of foundry sand and mineral admixtures improves the strength properties of concrete. A combination of UFS+GGBS showed better overall performance than UFS and fly ash.

Jay Pandya et al. investigated durability of concrete using supplementary materials such as foundry sand & slag. The alccofine is used in 10% and 15% by replacement of cement, and, the same time, the sand will be replaced with foundry sand at 10%, 20%, 30%, 40%, and 50% for all experimental work. Durability tests like RCPT, sulphate attack, sorptivity, rebound hammer, UPV, and compressive strength tests were carried out at 7, 28, and 56 days. Results showed that foundry sand increases the strength up to 20% replacement; as the percentage of foundry sand then increases, the strength and durability of the concrete decreases.

Gurumoorthy et al.investigated and found that UFS in concrete without proper treatment will reduce the binding and strength properties. In order to minimize iron content, the UFS was treated with acid. From this treatment, the silica in the foundry sand had been enriched - this is called Treated Used Foundry Sand (TUFS). This paper presents the results of an experimental investigation carried out to evaluate the microstructural and mechanical properties of concrete mixtures in which fine aggregate (river sand) was partially replaced with TUFS. Test results indicate a marginal increase in the strength properties and good microstructural properties of plain concrete with this inclusion of TUFS as a partial replacement of fine aggregate (sand). This will pave the way for making high quality concrete and convenient disposal of the UFS safely without disturbing the environment.

PranitaBhandari et al. investigated how to produce low-cost concrete. An experimental investigation was carried out on concrete containing waste foundry sand at 0%, 10%, 20%, 30%, 40%, 60%, 80%, and 100% replacement by weight for M25 grade concrete. Concrete containing foundry sand was tested and compared against conventional concrete in terms of workability, compressive strength, and acid attack performance. Cubes were cast and a compression test wasperformed on 3-, 7-, and 28-day old specimens for a mix of 1:1.01:2.5 at a w/c of 0.4. Through theobtained experimental results we conclude that after a 20% partial replacement of foundry sand compressive strength decreases with each increase in the percentage of replacement. The aim of this research is to evaluate the mechanical properties of concrete after adding an optimum quantity of WFS in different proportions. Per this study, maximum compressive strength was obtained at 20% replacement of fine aggregate by waste foundry sand.

JayanthiSingaram et al. investigated masonry units which are extensively used nowadays to reduce CO2 emissions and embodied energy rates. Long-term performance of such structures has become essential for sustaining construction technologies. This study aims to assess the strength and durability properties of concrete prepared with unprocessed bagasse ash (BA) and silica fume (SF). A mix proportion of 1:3:3 was used to cast concrete cubes 100 mm in size. Results showed that there was a slight difference in mass loss before and after exposure to a chemical attack in all the cases examined. Though the appearance was slightly different than the normal concrete, residual weight was not affected. The compressive strength for 10% bagasse ash (BA) replacement with 10% SF as an admixture resulted in better strength than that of normal concrete.

SaveriaMonosi, Daniela Sani and Francesca Tittarelli,investigated the properties of mortars and concretes containing different dosages of used foundry sand (UFS) as partial replacement of sand in both fresh and hardened conditions. According to the obtained test results, they concluded that, (a) UFS reduces the workability when added as natural sand replacement (at same w/c); higher amount of super-plasticizer is required in order to maintain the same workability. The control mortar sample with w/c equal to 0.50 requires an addition of 0.5% by cement weight, while mortars containing UFS need an addition up to 1.8%. Similarly, concrete mixture containing UFS needs a super-plasticizer dosage. (b) Fresh mixture unit weight (UNI EN 12350-6) andentrapped air content (UNI EN 12350-7) do not point out any relevant differences with and without foundry sand. (c) Despite the absolute value of compressive strength, the negative influence ascribed to the presence of UFS in reducing the compressive strength seems greater when lower w/c is adopted. Although the absolute value of the compressive strength is high at low w/c ratio, as usual, it achieves negligible advantages when w/c is lower than 0.50.

Khatib et al.investigated some mechanical and fresh properties of concrete containing waste foundrysand (WFS). With reference to the properties investigated, they reported that (a) there is systematic loss in workability as the foundry sand content increases which was found by observing the percentage decrease in slump with increase in WFS. (b) All the mixes (with and without WFS) show an increase in strength with curing time. (c) The compressive strength of concrete also decreases with increasing amounts of WFS. This decrease is systematic. (d) The control mix shows the least water absorbed and generally the water absorption increases as the WFS in the concrete increases. (f) The shrinkage increases as the WFS in the concrete increases and this increase is systematic.

Chapter-3

MATERIALS AND ITS PROPERTIES

3.1GEOPOLYMER CONCRETE:

Geopolymer concrete is an innovative construction material which shall be produced by the chemical action of inorganic molecules. Fly Ash, a by-product of coal obtained from the thermal power plant is plenty available worldwide. Fly ash is rich in silica and alumina reacted with alkaline solution produced aluminosilicate gel that acted as the binding material for the concrete. It is an excellent alternative construction material to the existing plain cement concrete. Geopolymer concrete shall be produced without using any amount of ordinary Portland cement.

The geopolymers depend on thermally activated natural materials like Meta kaolinite or industrial by-products like fly ash or slag to provide a source of silicon (Si) and aluminium (Al). These Silicon and Aluminium is dissolved in an alkaline activating solution and subsequently polymerizes into molecular chains and become the binder. The polymerization process involves a substantially fast chemical reaction under alkaline conditions on silicon-aluminium minerals that results in a three-dimensional polymeric chain and ring structure. The ultimate structure of the geopolymer depends largely on the ratio of Si to Al (Si:Al), with the materials most often considered for use in transportation infrastructure typically having an Si:Al between 2 and 3.5 5 &6 . The reaction of Fly Ash with an aqueous solution containing Sodium Hydroxide and Sodium Silicate in their mass ratio, results in a material with three dimensional polymeric chain and ring structure consisting of Si-O-Al-O bonds.

Water is not involved in the chemical reaction of Geopolymer concrete and instead water is expelled during curing and subsequent drying. This is in contrast to the hydration reactions that occur when Portland cement is mixed with water, which produce the primary hydration products calcium silicate hydrate and calcium hydroxide. This difference has a significant impact on the mechanical and chemical properties of the resulting geopolymer concrete, and also renders it more resistant to heat, water ingress, alkali–aggregate reactivity, and other types of chemical attack . In the case of geopolymers made from fly ash, the role of calcium in these systems is very important, because its presence can result in flash setting and therefore must be carefully controlled. The source material is mixed with an activating solution that provides the alkalinity (sodium hydroxide or potassium hydroxide are often used) needed to liberate the Si and Al and possibly with an additional source of silica (sodium silicate is most commonly used). The temperature during curing is very important, and depending upon the source materials and activating solution, heat often must be applied to facilitate polymerization, although some systems have been developed that are designed to be cured at room temperature.

3.1.1 PROPERTIES OF GEOPOLYMER CONCRETE

The superior properties of Geopolymer concrete, based on Prof. B. VijayaRangan and Hardijito,

1. sets at room temperature
2. non-toxic, bleed free
3. long working life before stiffening
4. impermeable
5. higher resistance to heat and resist all inorganic solvents
6. higher compressive strength

Compressive strength of Geopolymer concrete is very high compared to the ordinary Portland cement concrete. Geopolymer concrete also showed very high early strength. The compressive strength of Geopolymer concrete is about 1.5 times more than that of the compressive strength with the ordinary Portland cement workability as of the ordinary Portland cement.

3.1.2APPLICATIONS:

In the short term, there is large potential for geopolymer concrete applications for bridges, such as precast structural elements and decks as well as structural retrofits using geopolymer-fibre composites. Geopolymer technology is most advanced in precast applications due to the relative ease in handling sensitive materials (e.g., high-alkali activating solutions) and the need for a controlled high-temperature curing environment required for many current geopolymer. Other potential nearterm applications are precast pavers & slabs for paving, bricks and precast pipes.

3.1.3 LIMITATIONS:-

The followings are the limitations

1. Bringing the base material fly ash to the required location
2. High cost for the alkaline solution
3. Safety risk associated with the high alkalinity of the activating solution.
4. Practical difficulties in applying Steam curing / high temperature curing process

Considerable research is on-going to develop geopolymer systems that address these technical hurdles.

3.2 CONSTITUENTS OF GEOPOLYMER CONCRETE :-

The following are the constituents of Geopolymer concrete

- Fly Ash- rich in Silica and Aluminium
- Sodium Hydroxide or Potassium Hydroxide
- Sodium Silicate or Potassium Silicate.

3.2.1 FLY ASH:-

Fly ash or flue ash, also known as pulverised fuel ash , is a coal combustion product that is composed of the particulates (fine particles of burned fuel) that are driven out of coal-fired boilers together with the flue gases. Fly ash is a by-product from the combustion of pulverized coal, and is widely used as an ingredient in hydraulic-cement concrete. Because it improves many desirable properties of concrete, it is introduced either as a separately batched material or as a component of blended cement. Fly ash reacts with the hydrating hydraulic cement to form a cementing medium. Fly ash use in concrete improves the workability of plastic concrete, and the strength and durability of hardened concrete. Fly ash use is also cost effective. When fly ash is added to concrete, the amount of Portland cement may be reduced.Fly Ash has very small particles which makes the concrete highly dense and reduces the permeability of concrete. It can add greater strength to the building. The concrete mixture generates a very low heat of hydration which prevents thermal cracking.

There are two types of fly ash

1) Class C Fly Ash
2) Class F Fly Ash

Class F Fly ash:-

The burning of harder, olderbituminous coal and anthracite typically produces Class F fly ash. This type of fly ash is pozzolanic in nature, and contains less than 7% lime (CaO). Because of the presence of pozzolanic properties, the alumina and glassy silica from the fly ash needs to be activated by a cementing agent, such as quicklime, hydrated lime or Portland cement. These cementing agent when mixed with water reacts and produces cementitious compounds. Alternatively, this can also be activated by adding a chemical activator such as Sodium Silicate to form a geopolymer.

Class F Fly ash requirements as per IS 3812.1.2013:-

Characteristic	Requirements
Silicon dioxide(SiO_2) plus Aluminium oxide(Al_2O_3) plus Iron oxide(Fe_2O_3) in percent by mass, Min.	70
Silicon dioxide(SiO_2) in percent by	35

mass, Min.	
Reactive Silica in percent by mass, Min.	20
Magnesium oxide(MgO) in percent by mass, Min.	5.0
Total sulphur as sulphur trioxide(SO_3) in percent by mass, Max.	3.0
Available alkalies as equivalent Sodium oxide(Na_2O) in percent by mass, Max.	1.5

Table 1: Constituents of class F Fly ash

Advantages:-

When used as a portland cement replacement, Class F fly ash offers the following advantages

- Increased late compressive strengths (after 28 days)
- Increased resistance to alkali silica reaction (ASR)
- Increased resistance to sulfate attack
- Less heat generation during hydration
- Increased pore refinement
- Decreased permeability
- Decreased water demand
- Increased workability

Class C Fly ash:-

Fly ash which is produced from the burning of sub-bituminous coal or younger lignite, has self–cementing properties in addition to pozzolanic properties. Class C Fly ash hardens and gets stronger over time in the presence of water. It contains more than 20% lime (CaO). Unlike Class F Fly ash, Class C Fly ash does not require an activator because of the presence of high calcium content.Class C Fly ash requirements as per IS 3812.1.2013:-

Characteristic	Requirements
Silicon dioxide(SiO_2) plus Aluminium oxide(Al_2O_3) plus Iron oxide(Fe_2O_3) in percent by mass, Min.	50
Silicon dioxide(SiO_2) in percent by mass, Min.	25
Reactive Silica in percent by mass, Min.	20
Magnesium oxide(MgO) in percent by mass, Min.	5.0
Total sulphur as sulphur trioxide(SO_3) in percent by mass, Max.	3.0
Available alkalies as equivalent Sodium oxide(Na_2O) in percent by mass, Max.	1.5

Table 2: Constituents of class C Fly ash

Advantages:-

When used as a portland cement replacement, Class C fly ash offers the following advantages,

- Increased early and late compressive strengths
- Less heat generation during hydration
- Increased pore refinement
- Decreased permeability

- Decreased water demand
- Increased workability

In this project we have used fly ash of class F

Fig 1: Fly ash of class F

3.2.1.1 SEM AND EDAX REPORT FOR FLYASH:

Scanning Electron Microscope (SEM) is a type of electron microscope that uses focused beam of electron to scan the surface of the sample and produce the images of the sample. These electrons produces various signals by interacting with the atoms in the sample, these signals contain information about composition of sample and the surface topography. The electron beam scans and captures in the rectangular pattern (raster scan) and position of beam combines with intensity of detected signal to produce the image in the television. Everhart-Thornley detector detects the secondary electrons emitted by atoms. The SEM has capability to produce the very high resolution images of the surface of sample of size less than 1 nm. Some applications of SEM imaging are

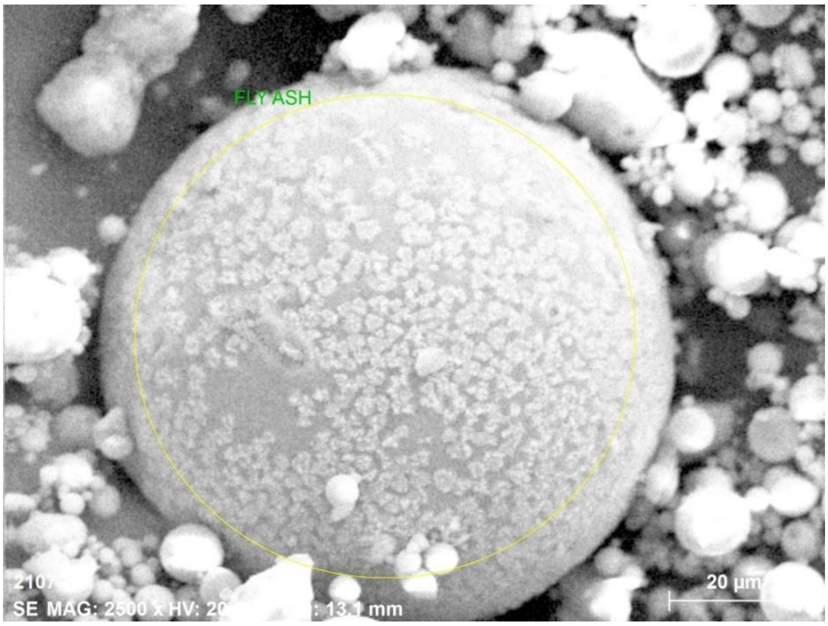
1) To acquire elemental maps or to spot chemical analyses by using Energy Dispersive X-Ray Spectroscopy (EDS).
2) Phases discrimination based on, mean atomic number by using Back Scattered Electron Detector (BSE).
3) Compositional maps based on difference in the trace elements using CL.

Some abbreviations in SEM imaging,

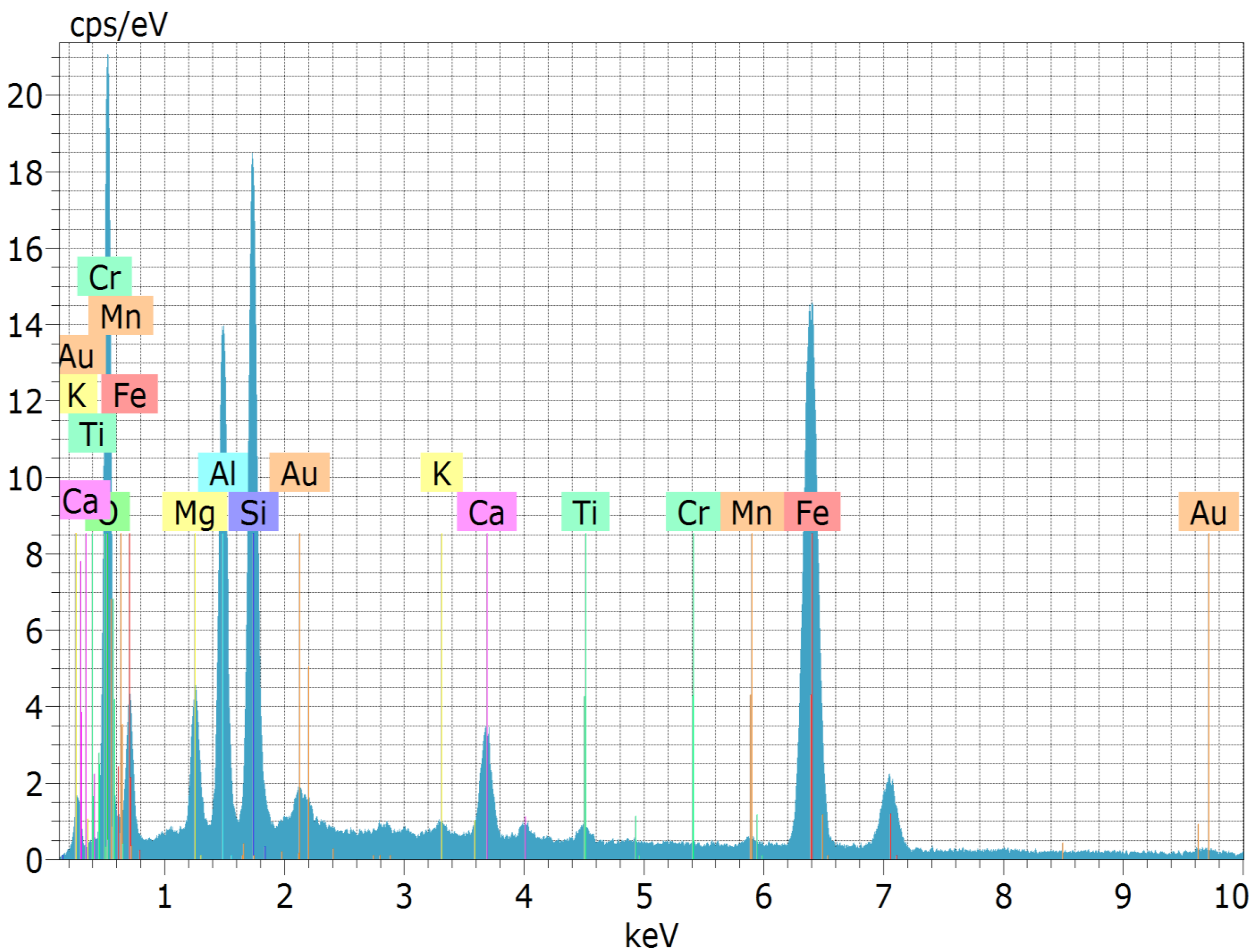
- EHT- Electron High Tension
- WD- Working Distance
- Mag- Magnification

Energy-dispersive X-ray spectroscopy (EDX):-

It is an analytical technique used for chemical characterization or elemental analysis of a sample. It relies on interaction on X-ray excitation and sample. The fundamental principle is that the each element has a unique atomic structure allowing the unique set of peaks in its electromagnetic emission spectrum. The high energy beam of charged particles such as protons or electrons or a beam of X- rays are focused into the sample being tested. These beams are helpful in stimulating the emission of Characteristic X-ray from the specimen. During rest, atom in the sample is at ground state in discrete energy levels. The incident beam is used to excite an electron in inner shell therefore ejecting it from shell thereby creating an electron hole where the electron was. Then the electron from the outer higher energy shell fills the hole and the difference between lower energy shell and higher energy shell will be released in the form of X-ray. Energy dispersive spectrometer is used to measure the number and the energy of X-ray emitted from the specimen. As the energy of X-rays are characteristic of difference in energy between atomic structure of emitting element and the two shells Energy-dispersive X-ray spectroscopy allows measuring of elemental composition of specimen. It is used to determine the abundance of the chemical present in the sample. Nature of the sample affects the accuracy of the measured composition.



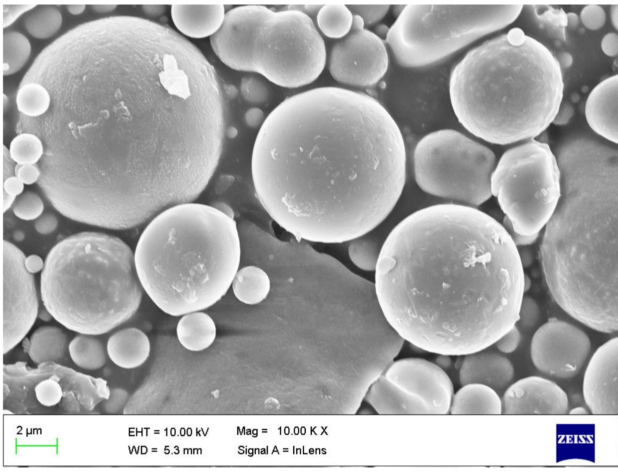
The figure shows the sem image of fly ash particles .These images were taken using a Scanning Electron Microscope

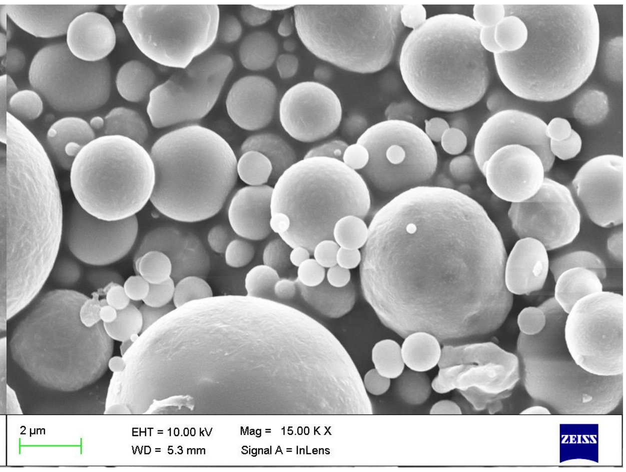


Spectrum: FLY ASH

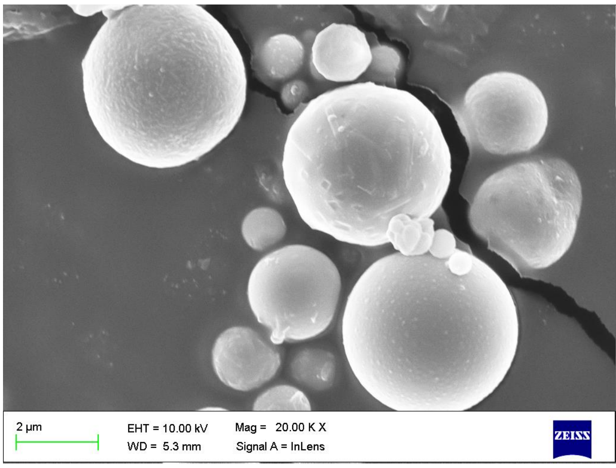
Element	Series	unn.C [wt.%]	norm.C [wt.%]	Atom. C [at.%]	Error (3Sigma) [wt.%]
Oxygen	K-series	25.25	32.68	56.46	9.56
Magnesium	K-series	2.25	2.91	3.30	0.47
Aluminium	K-series	6.77	8.77	8.98	1.07
Silicon	K-series	7.15	9.25	9.10	1.01
Calcium	K-series	1.93	2.50	1.72	0.26
Titanium	K-series	0.19	0.25	0.14	0.11
Iron	K-series	30.66	39.68	19.64	2.56
Gold	L-series	2.91	3.76	0.53	0.51
Potassium	K-series	0.01	0.01	0.01	0.08
Manganese	K-series	0.13	0.17	0.09	0.10
Chromium	K-series	0.03	0.04	0.02	0.09
Total:		77.28	100.00	100.00	

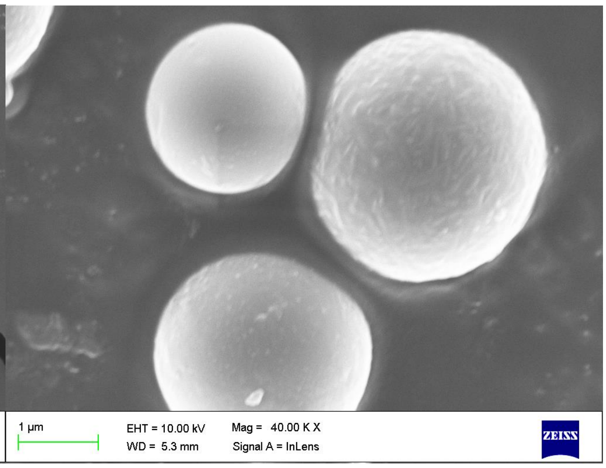
3.2.1.2 SEM IMAGES OF FLY ASH:



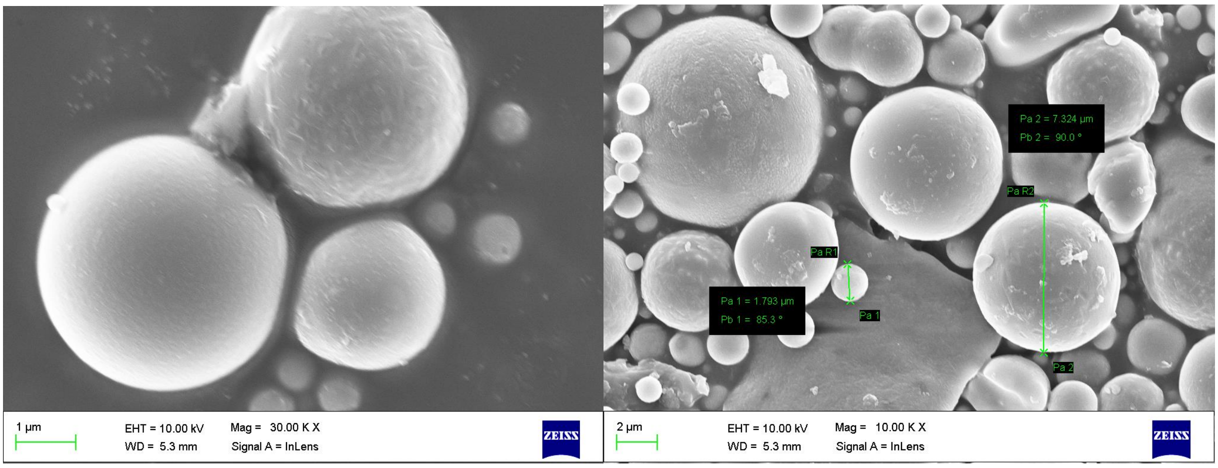


These are some sem images taken using lens whose magnitude is of 10,000 KX and 15,000 KX





These images are taken using a electron microscope whose lens is of magnitude 20,00 KX and 40,000 KX



These images are taken using a lens whose magnitude is of 30,000 KX and 10,000 KX.

3.2.2 SODIUM HYDROXIDE:-

Sodium hydroxide or caustic soda is obtained in the form of pellets. Sodium hydroxide is a strong base. Sodium Hydroxide is a strong irritant and corrosive to the skin. It is observed that the higher concentration of sodium hydroxide solution resulted in higher flow for alkaline solution-to-fly ash ratio of 0.35 and 0.40. It means that the flow of geopolymer mortar increases with increase in concentration of sodium hydroxide solution. It is due to a very viscous mix formation at higher concentration of sodium hydroxide which creates compaction problem. It is also observed that the mild concentration of sodium hydroxide solution gives poor strength.

3.2.3 SODIUM SILICATE:-

Sodium silicate is obtained in liquid form. Sodium silicate is also the technical and common name for a mixture of such compounds, chiefly the metasilicate, also called waterglass, water glass, or liquid glass. The product has a wide variety of uses, including the formulation of cements, passive fire protection, textile and lumber processing, manufacture of refractory ceramics, as adhesives, and in the production of silica gel.

3.3 SOLUTION PREPARATION:-

It is prepared by mixing Sodium hydroxide, Sodium silicate and water. It is observed that the compressive strength of geopolymer concrete increases with increase in concentration of sodium hydroxide solution and or sodium silicate solution with increased viscosity of fresh mix. The 10M solution is prepared. It is prepared by mixing 1 litre of water with 400 gms of sodium hydroxide and they are mixed until the solution becomes crystal clear. Now, the solution is weighed, and the sodium silicate solution is taken equal to 2.5 times of the weight measured and mixed with the already prepared solution in flocculator for about 30 mins. The solution prepared should not be used immediately, it should be used only after a gap of 24 hours. After 24 hours before using the solution it should be stirred well.

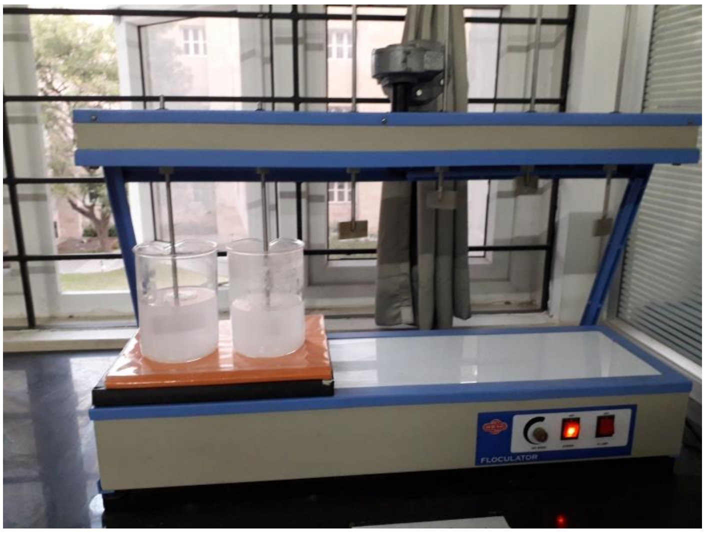


Fig 2:Solution Preparation

3.4 FINE AND COARSE AGGREGATE:-

3.4.1FOUNDRY SAND

Foundry sand is clean, uniformly sized, high quality silica sand, used in foundry casting processes. The sand is bonded to form moulds or patterns used for ferrous (iron and steel) and non-ferrous (copper, aluminium, brass) metal castings. Although these sands are clean prior to use, after casting they may contain Ferrous (iron and steel) particles. The automotive industry and its parts suppliers are the major generators of foundry sand. Most foundry sand is of high quality silica sand with uniform physical characteristics. It is a by-product of the ferrous and nonferrous metal casting industry, where sand has been used for centuries as a moulding material because of its unique engineering properties. In modern foundry practice, sand is typically recycled and reused through many production cycles. The sand is mainly used in the foundries for metal casting and this process is known as sand casting.

Fig 3: Waste Foundry sand

The various types of moulding sand are

1. Green sand
2. Dry sand
3. Loam sand
4. Parting sand
5.Facing sand
6.Backing sand
7. System sand
8. Core sand

1. Green Sand:-

- Green sand is a mixture of silica sand and clay. It constitutes 18 % to 30 % clay and 6 % to 8 % water.

- The water and clay present is responsible for furnishing bonds for the green sand.
- It is slightly wet when squeezed with hand. It has the ability to retain the shape and impression given to it under pressure.
- It is easily available and has low cost.
- The mould which is prepared in this sand is called green sand mould.
- It is commonly used for producing ferrous and non-ferrous castings

2. Dry Sand:-

- After making the mould in green sand, when it is dried or baked is called dry sand.
- It is suitable for making large castings.
- The moulds which is prepared in dry sand is known as dry sand moulds.
- If we talk about the physical composition of the dry sand, than it is same as that of the green sand except water.

3. Loam Sand:-

- It is a type of moulding sand in which 50 % of clay is present.
- It is mixture of sand and clay and water is present in such a quantity, to make it a thin plastic paste.
- In loam moulding patterns are not used.
- It is used to produce large casting.

4. Parting Sand:-

- Parting sand is used to prevent the sticking of green sand to the pattern and also to allow the sand on the parting surface of the cope and drag to separate without clinging.
- It serves the same purpose as of parting dust.
- It is clean clay free silica sand.

5. Facing Sand:-

- The face of the mould is formed by facing sand.
- Facing sand is used directly next to the surface of the pattern and it comes in direct contact with the molten metal, when the molten metal is poured into the mould.
- It possesses high strength and refractoriness as it comes in contact with the molten metal.

- It is made of clay and silica sand without addition of any used sand.

6. Backing Sand

- Backing sand or flour sand is used to back up facing sand.
- Old and repeatedly used moulding sand is used for the backing purpose.
- It is also sometimes called black sand because of the addition of coal dust and burning when it comes in contact with the molten metal.

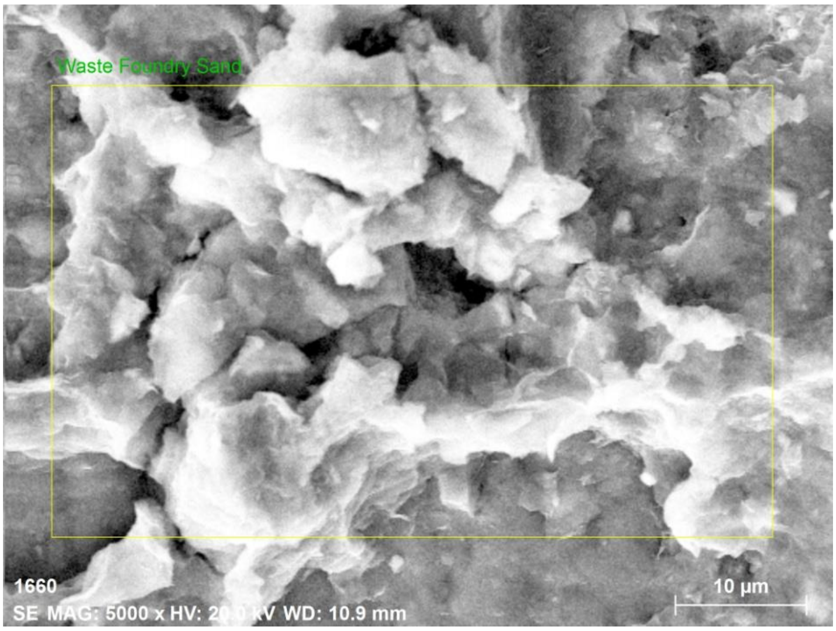
7. System Sand

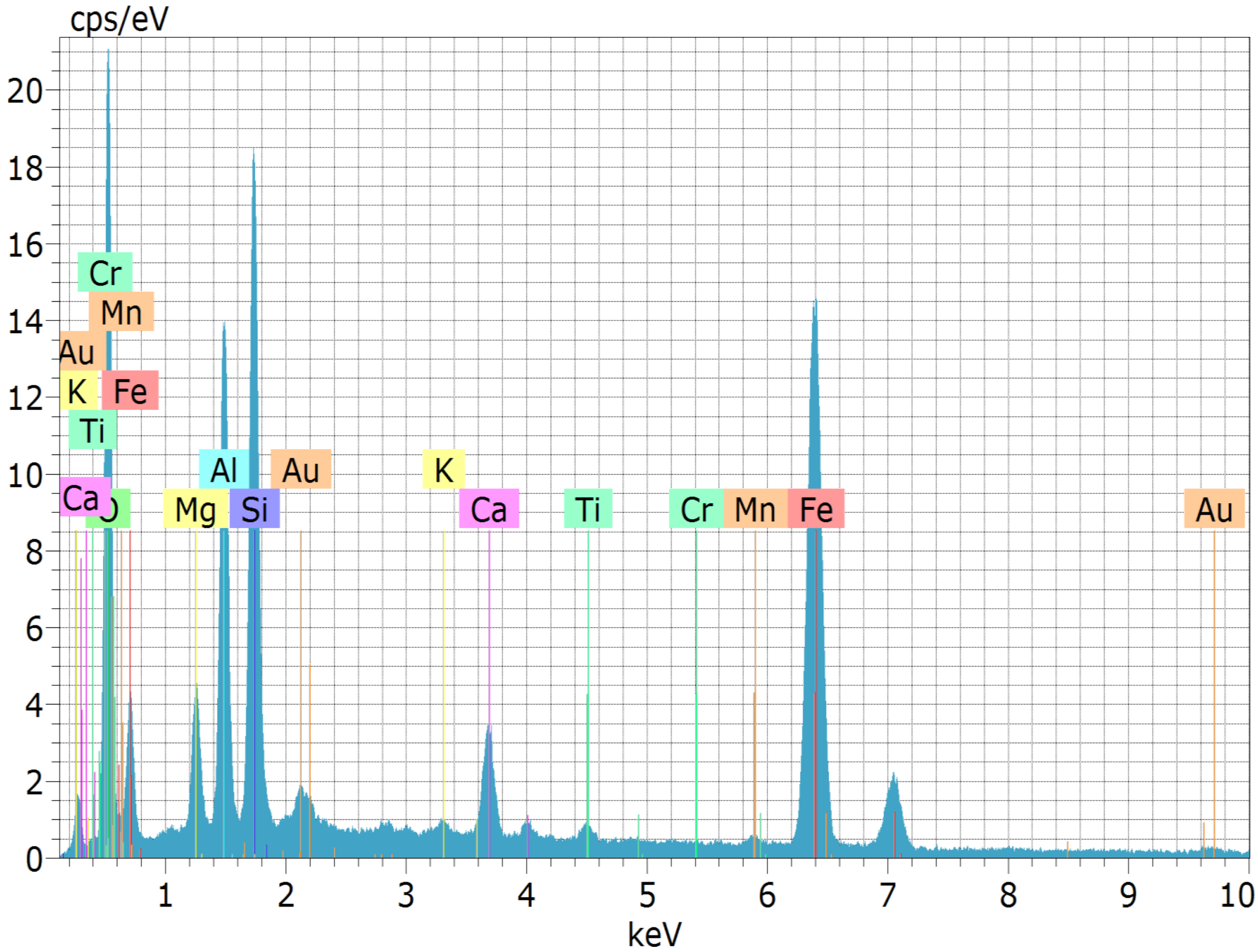
- In mechanical sand preparation and handling units, facing sand is not used. The sand which is used is cleaned and reactivated by adding of water, binder and special additives. And the sand we get through this is called system sand.
- System sand is used to fill the whole flask in the mechanical foundries where machine moulding is employed.
- The mould made with this sand has high strength, permeability and refractoriness.

8. Core Sand

- The sand which is used to make core is called core sand.
- It is also called as oil sand.
- It is a mixture of silica sand and core oil. Core oil is mixture of linseed oil, resin, light mineral oil and other binding materials.
- For the sake of economy, pitch or flours and water may be used in making of large cores.

3.4.1.1 SEM AND EDAX REPORT FOR FOUNDRY SAND:

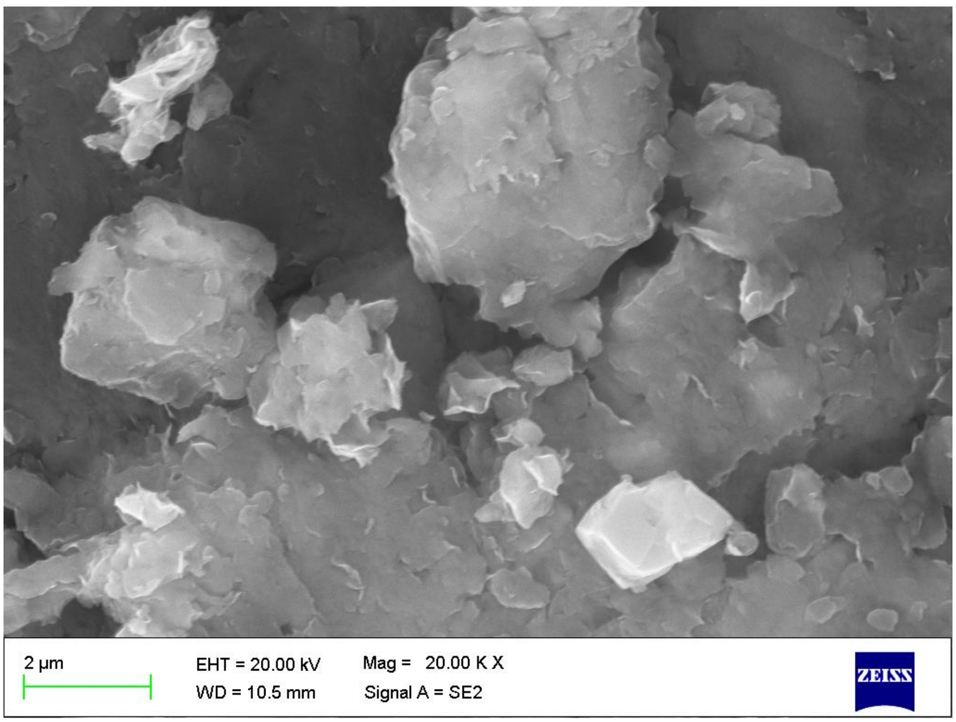




Spectrum: Waste FoundrySand

Element	Series	unn.C [wt.%]	norm.C [wt.%]	Atom. C [at.%]	Error (3Sigma) [wt.%]
Oxygen	K-series	23.26	38.18	46.27	8.86
Silicon	K-series	12.65	20.77	14.34	1.70
Carbon	K-series	10.06	16.51	26.66	5.15
Iron	K-series	7.95	13.05	4.53	0.75
Aluminium	K-series	4.37	7.17	5.15	0.71
Sodium	K-series	0.99	1.62	1.37	0.29
Magnesium	K-series	0.83	1.36	1.09	0.23
Calcium	K-series	0.43	0.71	0.34	0.13
Titanium	K-series	0.38	0.63	0.26	0.13
Total:		60.92	100.00	100.00	

3.4.1.2 SEM IMAGES OF FOUNDRY SAND:



This figure is a sem image of waste foundry sand taken using a lens whose magnitude is 20,000 KX

3.4.2FINE AGGREGATE:-

Fine aggregates(i.e.), manufactured sand proposed to be used shall be produced from a Vertical Shaft Impact (VSI) crushers and shall conform to the requirements of

Zone-II (in most of the cases) as per IS 383-1970 (Reaffirmed in 2007) and particles finer than 75 µm shall not exceed 15 %. Special efforts on the part of M-sand manufacturers (such as washing of sand by water or dry washing by air) is required to restrict particles finer than 75 µm to 15%.**Sand** in **concrete** serve several purposes. Because they act as filler, they also add more volume to the **concrete**. More volume means less air and a stronger product. The size of the gravel also helps to determine the **concrete's**strength

3.4.3 COARSE AGGREGATE:-

Those particles that are predominantly retained on the 4.75 mm (No. 4) sieve and will pass through 3-inch screen are called **coarse aggregate.** Here we use two types of aggregates (10 mm and 20 mm).

Coarse aggregate provides the required strength to the concrete.They help in binding the mortar properly. The coarser the aggregate, the more economical the mix. Larger pieces offer less surface area of the particles than an equivalent volume of small pieces.**Aggregate in concrete** is structural filler, but its **role** is more important than what that simple statement implies. ... The composition, shape, and size of the **aggregate**all have significant impact on the workability, durability, strength, weight, and shrinkage of the **concrete**.

Chapter-4

INTRODUCTION OF WORK

4.1 CASTING OF BUILDING ELEMENTS:-

Since cubes were casted and tested using geopolymer in many papers and previous research works, we decided to go with building elements.

So beams and columns were casted and tested using geopolymer concrete.

4.1.1 FORMWORK:-

The formwork was made of wood of size 1 m in length and cross sectional area of 200mm x 150 mm.

Fig 4:Form work of beam

4.1.2 REINFORCEMENT DETAILING:-

4.1.2.1 BEAMS:-

For beams the reinforcement was detailed as per IS 456: 2000.

2 nos. of 12 mm diameter bars were used at bottom and 2 nos. of 10mm diameter bars were used at top.

Stirrup's of 8mm diameter @ 150 mm c/c spacing were designed.

We provided a cover of 25 mm.

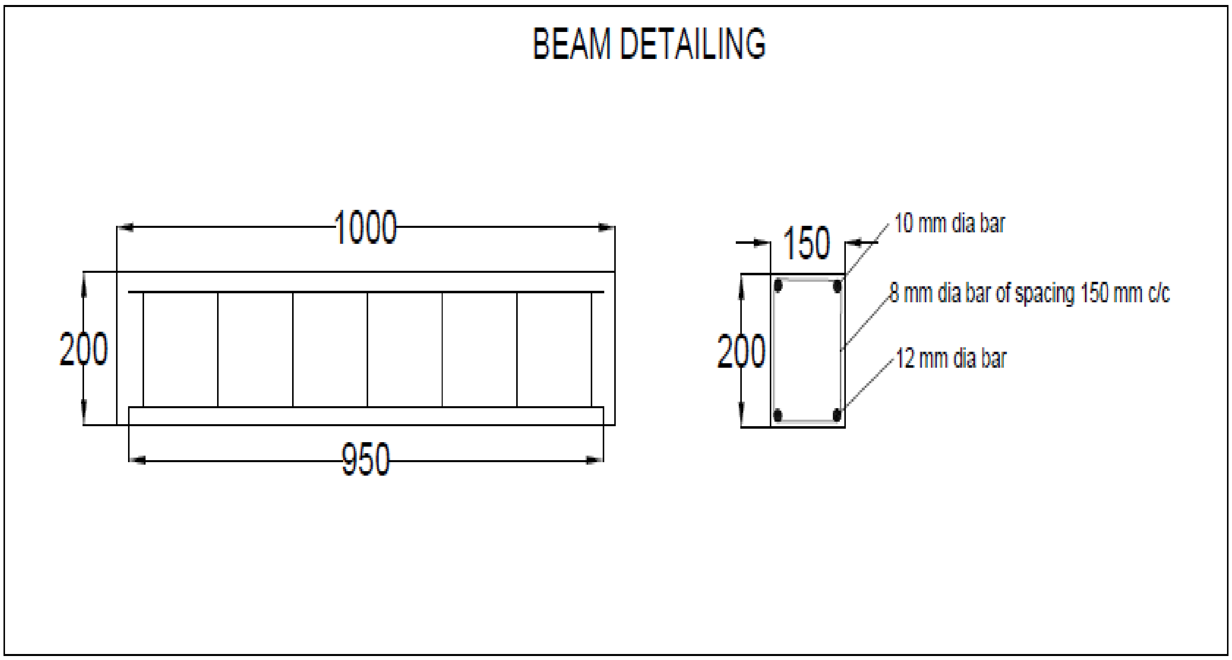


Fig 5 :Beam Detailing

Fig 7:Beam reinforcements

4.2 MATERIALS AND MIX PROPORTIONS:-

For beams , the mix proportion of 1:1.5:3.3 was adopted.

This mix proportion was adopted from the paper published by Dr Abdul Aleem M.I and Arumairaj (2012)

Percentage replacement of M sand by foundry sand	Fly ash (kg)	10 mm aggregate(kg)	20 mm aggregate (kg)	M sand (kg)	Foundry sand (kg)	Alkali activated solution (kg)
0 %	11.97	11.9	27.7	17.99	0	6
25 %	11.97	11.9	27.7	13.50	4.49	6
30 %	11.97	11.9	27.7	12.60	5.40	6
35 %	11.97	11.9	27.7	11.70	6.30	6
40 %	11.97	11.9	27.7	10.80	7.20	6

*materials were calculated with contegencies of 5%.

Table 3: Materials taken

Fig 8:Materials taken

4.3 Curing:-

Both Chamber and Steam curing were adopted for all the structural elements which were casted.

The beams were kept in a steam chamber for a period of 24 hours .

The chamber curing is done with the help of a steam chamber which was assembled for this purpose alone.

This chamber was assembled using an iron framework , GI sheet, glass wool, polycarbonate sheet.The glass wool was sandwiched between the GI sheet and the polycarbonate sheet in order to provide complete heat insulation.

An electric room heater was used to supply heat to the chamber and an electric circuit set was set up in order to control the temperature.It was designed to cut off the supply of heat when it reaches the targeted temperature and again switch on when there is a drop in temperature.The circuit was designed using LM 35 sensor(temperature sensor),arduino micro controller,opto coupler,bread board,single strand wires,heat sleeve.

After a period of 24 hours in the chamber, all the elements were placed in an open atmosphere for ambient curing.It was done for 28 days so that all the moisture contents were removed.The faces of the elements were turned periodically so that all the faces ofthe element gets periodically exposed to sunlight.

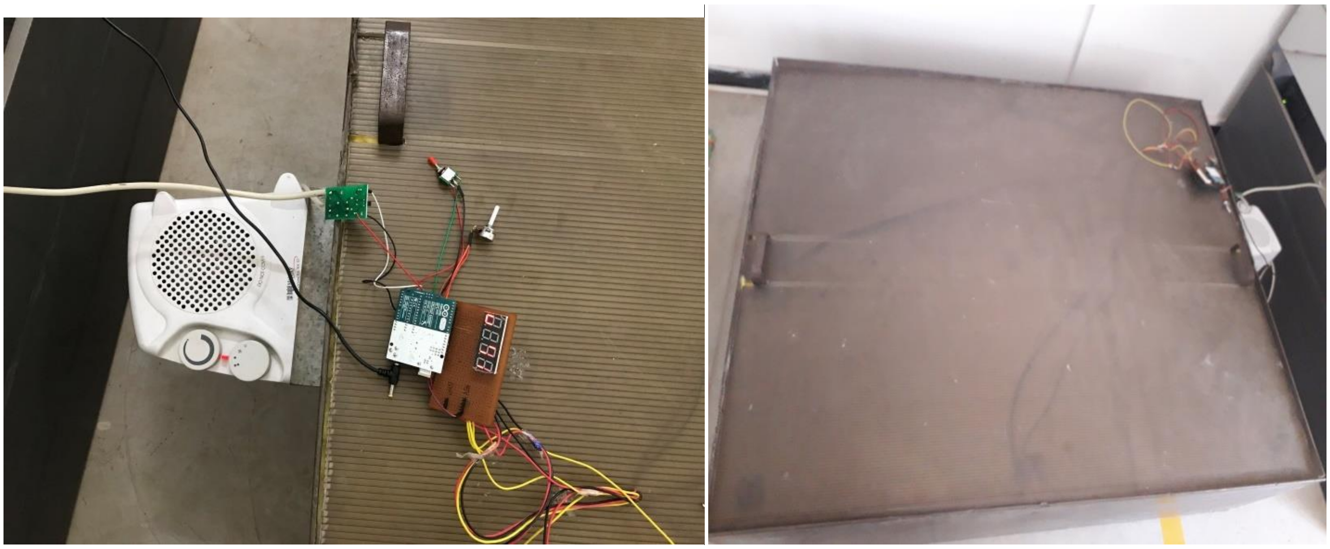


Fig 9: Chamber curing

Fig 10: Ambient curing

After curing for 28 days the building elements are then taken for testing.

Chapter-5

TESTING OF MATERIALS

5.1 VARIOUS TEST ON MATERIALS:

Following tests for determining the properties of the ingredients, fresh concrete and hardened concrete were performed:

- **Tests on coarse aggregate**
  - Specific gravity test
  - Water absorption test
  - Impact test
  - Density
  - Flakiness and elongation index
- **Tests on fine aggregate**
  - Specific gravity test
  - Sieve analysis
  - Density
- **Tests on fly ash**
  - Specific gravity test
  - Density
- **Test on fresh concrete:**
  - Slump Flow test
- **Tests on hardened concrete:**
  - Flexural and shear strength test(Experimental results)

5.1.1 SPECIFIC GRAVITY OF COARSEAGGREGATE AND FINE AGGREGATE

Specific gravity is defined as the ratio of the mass of a given volume of solids to the mass of an equal volume of water.

The empty weight of pycnometer was taken (W_1). Then 1/3 of height of pycnometer was marked. Pycnometerwas filled with aggregate sample up to the marked level and the weight was taken (W_2). Water was filled up to the marked level, and then weight of water along with sample was taken (W_3). Finally the weight of pycnometer fully filled with water was taken (W_4). Specific gravity was determined using the formula given below.

Specific gravity = $(W_2 - W_1) / ((W_2 - W_1) - (W_3 - W_4))$

W_1 = Empty weight of pycnometer

W_2 = Weight of pycnometer,and aggregate

W_3= Weight of pycnometer, aggregate and water

W_4 = Weight ofpycnometer and water

5.1.2 SPECIFIC GRAVITY OF FLY ASH:

Density bottle was used to determine the specific gravity of fly ash. The empty weight of density bottle was taken (W_1). Density bottle was filled with fly ash up to 1/3 height and the weight was taken (W_2). Water was filled up to the 1/3 rd height and then weight of water along with fly ash was taken (W_3). Then the weight of density bottle along with water was taken (W_4).Specific gravity was determined using the formula given below.

Specific gravity = $(W_2 – W_1) / ((W_2 – W_1) – (W_3 – W_4))$

W_1 = Empty weight of density bottle

W_2 = Weight of density bottle and fly ash

W_3 = Weight of density bottle, fly ash and water

W_4 = Weight of density bottle and water.

5.1.3 IMPACT TEST:

Empty weight of the cylinder is taken(W1). The cylinder is filled in three layers with each layer being tapped for 25 times. The weight of the cylinder along with coarse aggregate is taken(W2).

The weight of the aggregate is taken (i.e.) A= W2-W1. The metal weighing about 13.5 to 14 kg is raised to a height of about 380 mm and allowed to fall on the aggregate. This is repeated for 15 times. Now the test sample is taken and it is sieved through 2.36 mm IS sieve. The weight of the material passing through the sieve is taken as B.

Aggregate impact value = $\frac{B}{A}$ x 100

5.1.4 DENSITY TEST:

Empty weight of the mould is taken as W1. The mould is filled with aggregate and it is compacted using the relative density apparatus. The weight of the mould along with compacted aggregate is taken as W2. Then the mould is emptied and again filled with aggregate. The weight of the mould along with uncompacted aggregate is taken as W3. The volume of the mould is measured and taken as V.

Compacted density = $\frac{W2-W1}{V}$

Uncompacted density = $\frac{W3-W1}{V}$

5.1.5 WATER ABSORPTION TEST:

The oven dry weight of the coarse aggregate was taken (W1).Then the specimen was immersed in water for the time period of 24 hours. After 24 hours the coarse aggregate was taken out and wiped with the cloth and the wet weight of the specimen was taken (W2). The water absorption of coarse aggregate was determined by the following formula.

Water absorption = $\frac{w2-w1}{w1}$

5.1.6 FLAKINESS AND ELONGATION INDEX:

Arrange the IS sieves according to sizes 63, 50, 40, 31.5, 25, 20, 16, 12.5, 10, 6.3 mm from top to bottom. 3kg of coarse aggregate(W) is taken and it is passed through the sieve with the help of sieve shaker. The coarse aggregate retained in each sieve is taken separately. The aggregate retained in each sieve is taken separately. The retained mass is made to pass through the respective openings in the thickness gauge. The weight of the aggregate passing through the hole is noted and taken as W1.Simliarly the aggregate retained in each sieve is made to pass through the respective sizes in the length gauge.

The weight of the aggregate which do not pass through the length gauge are weighed as W2.

Flakiness index = $\frac{W1}{W}$ x 100

Elongation index = $\frac{W2}{W}$ x 100

5.1.7 FINENESS MODULUS OF AGGREGATE

It is defined as an empirical figure obtained by adding the total percentage of the sample of an aggregate retained on each of a specified series of sieves, and dividing the sum by 100. The sieve sizes are 150µ, 300µ, 600µ, 1.18 mm, 2.36 mm, 4.75 mm, 10 mm, 12.5 mm, 20 mm, 40 mm and 80 mm. The set of sieves were arranged in order and shaken well. The weight retained on each set of sieves was noted. Then the fineness modulus is determined by the formula given below.Fineness modulus = F / 100F = cumulative percentage of weight retained on each of a specified series of sieves.

5.1.8 SLUMP FLOW TEST

The slump flow is used to access the horizontal free flow of concrete in the absence of obstructions. The test method is based on the test method for determining the slump. The diameter of concrete is a measure for the filling ability of concrete. It is the most commonly used test, and gives a good assessment of filling ability. It gives no indication of the ability of the concrete to pass between reinforcement without blocking, but may give some indication of resistance to segregation.

The mould was in the shape of truncated cone with internal dimensions 200 mm diameter at the base, 100 mm diameter at the top and a height of 300 mm. The concrete needed to perform the test was taken. The base plate and the inside of slump cone were moistened. Then the concrete was completely filled in the mould and then the mould was removed.

The height of slump formed is then measured.

Fig 11: Slump Cone test

5.1.9 FLEXURAL AND SHEAR STRENGTH TEST :

To study the flexural behaviour, totally ten reinforced concrete beams of length 1000mm and cross sectional area 150 mm X 200 mm were casted.Two 12 mm diameter Fe 415 grade steel bars were used as tension reinforcement and two numbers of 10 mm diameter bars were used as hanging bars.Two legged 8 mm diameter stirrups were provided at 150 mm spacing throughout the length of the beam for shear.The beams were simply supported and subjected to two point loading. The loading was applied using universal testing machine.The deflection of the beams were recorded.The loading was applied in a two point loading format using a spliter.For flexural strength test the spacing between the loading point is 150 mm and for shear strength test the spacing between the loading point is 300 mm.

Fig 12: Flexural and Shear Strength test(UTM)

Chapter-6

RESULTS AND DISCUSSIONS

6.1 RESULTS

Tests were conducted to determine the physical properties of materials used in concrete and the properties of fresh and hardened concrete. The results obtained from the testes are discussed in the chapter.

6.1.1 SPECIFIC GRAVITY TEST RESULTS:-

Table shows the values of specific gravity of fly ash,Foundry sand,fine and coarse aggregate.

Table Specific Gravity

Particulars	Specific Gravity
Fly ash	2.28
Fine aggregate	2.8
Foundry sand	2.43
Coarse aggregate	3.06

Table 4: Specifiv Gravity test results

Specific Gravity is the ratio of the weight of a given volume of aggregate to the weight of an equal volume of water. It is the measure of strength or quality of the specific material. Aggregates having low specific gravity are generally weaker than those with higher specific gravity values.

6.1.2 IMPACT TEST ON COARSE AGGREGATE:

Table shows the impact test value of coarse aggregate

Particulars	IMPACT VALUE
Coarse aggregate	21.4%

Table 5: Impact value test results

The aggregate impact test is carried out to evaluate the resistance to impact of aggregates. Aggregates to be used for wearing course, the impact value shouldn't exceed 30 percent. For bituminous macadam the maximum permissible value is 35 percent. For Water bound macadam base courses the maximum permissible value defined by IRC is 40 percent

6.1.3WATER ABSORPTION TEST RESULTS:-

Table shows the water absorption values of coarse aggregate.

S.NO	W1 (g)	W2 (g)	Absorption %
	2000	2046	2.3
	2000	2090	4.5
	2000	2105	5.25
		Average	4.01

Table 6: Water absorption test results

For good aggregates the water absorption should be low . It genereally varies between 3 – 5 %.

6.1.4 TEST RESULTS FOR DENSITY :

Table shows the values of density for fly ash,foundry sand,fine and coarse aggregate.

S.NO	**Materials**	**Uncompacted Density(kg/m^3)**	**Compacted Density(kg/^{m3})**
1	Fly ash	916.6	1246.6
2	Fine Aggregate	1390	1423
3	Foundry sand	1546.6	1800
4	Coarse Aggregate	1420	1563

Table 7: Density test results

Density is defined as mass per unit volume . The density test results are used mainly to calculate the materials needed for the work .The density test results plays a vital role in determining the quantity of materials.

6.1.5 TEST RESULTS FOR ELONGATION AND FLAKINESS INDEX:

Table shows the values of Elongation and Flakiness index of coarse aggregate

S.NO	ELONGATION INDEX	FLAKINESS INDEX
Coarse Aggregate	15.9%	11.15%

Table 8: Elongation and Flakiness index results

Elongation index of an aggregate is the percentage by weight of particles whose greatest dimension (length) is greater than one and four-fifth times (1.8 times or 9/5 times) their mean dimension. Flakiness Index is the percentage by weight of particles in it, whose least dimension (i.e. thickness) is less than three-fifths of its mean dimension.

6.1.6 FINENESS MODULUS TEST RESULTS:

The values of fineness modulus of fine aggregate

Sieve opening	Mass of sieve	Mass of sieve + soil	Mass of soil retained	Percentage retained	Cumulative percentage retained	Percentage finer
mm	g	g	G	%	%	%
4.75	410	439	290	2.9	2.9	97.1
2.36	390	411	210	2.1	5	95
1.18	490	631	231	23.1	28.1	71.9
0.6	390	711	321	32.1	60.2	39.8
0.3	360	668	298	29.8	90	10
0.15	370	459	89	8.9	98.9	1.1
0.075	350	358	8	0.8	99.7	0.3
pan	450	453	3	0.3	100	0

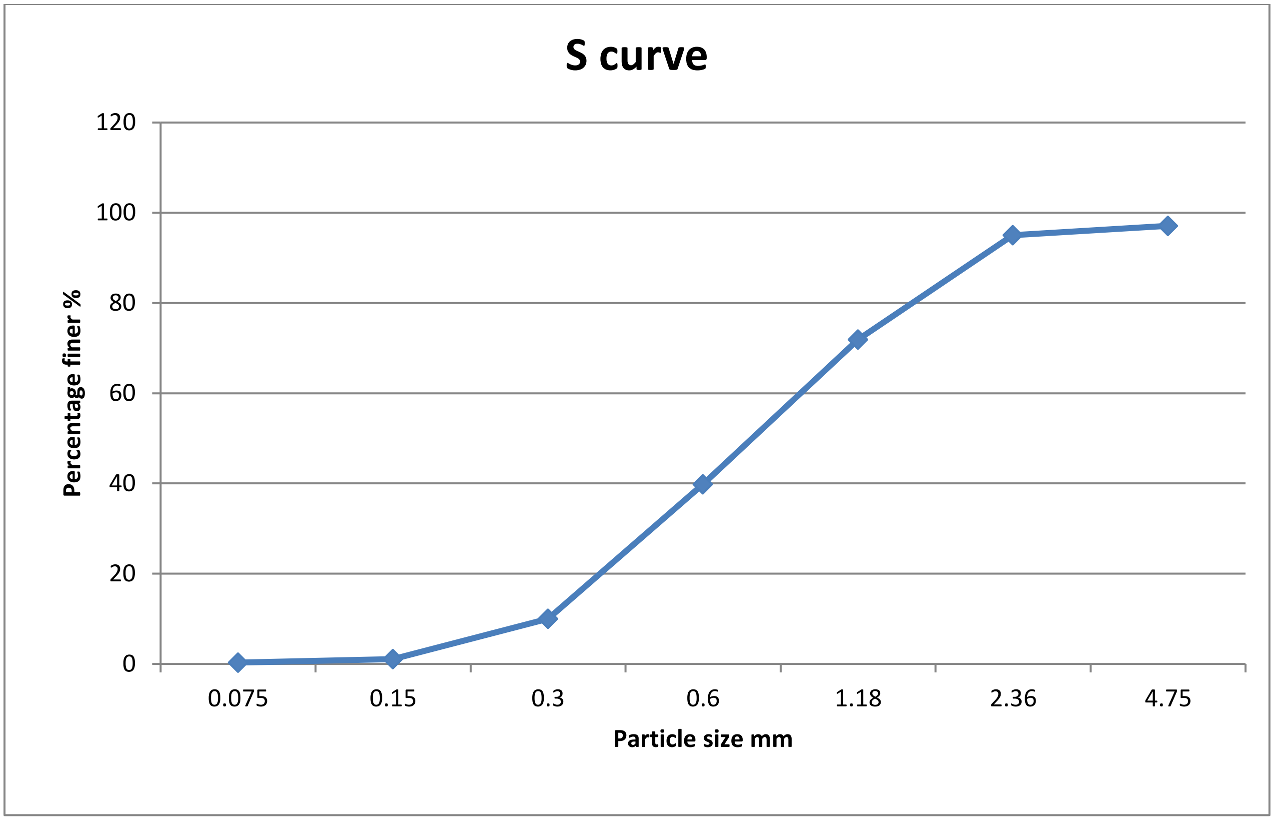
Table 9: Grain size distribution

The table shows the grain size distribution of soil particles by sieving the sand with the help of various IS sieves of standard dimensions.

Particulars	Fineness Modulus
Fine aggregate	3.84

Table 10: Fineness modulus value

The Fineness modulus (FM) is an empirical figure obtained by adding the total percentage of the sample of an aggregate retained on each of a specified series of sieves, and dividing the sum by 100



Graph 1 : S curve for grain size distribution

The S curve is obtained by plotting the point between the sieve size and percentage finer.From the graph we infer that it is a well graded soil.

6.1.7 FLEXURE AND SHEAR STRENGTH TEST:

The following tables show the experimental test results of the beams which were tested for shear and flexure using Universal Testing Machine.

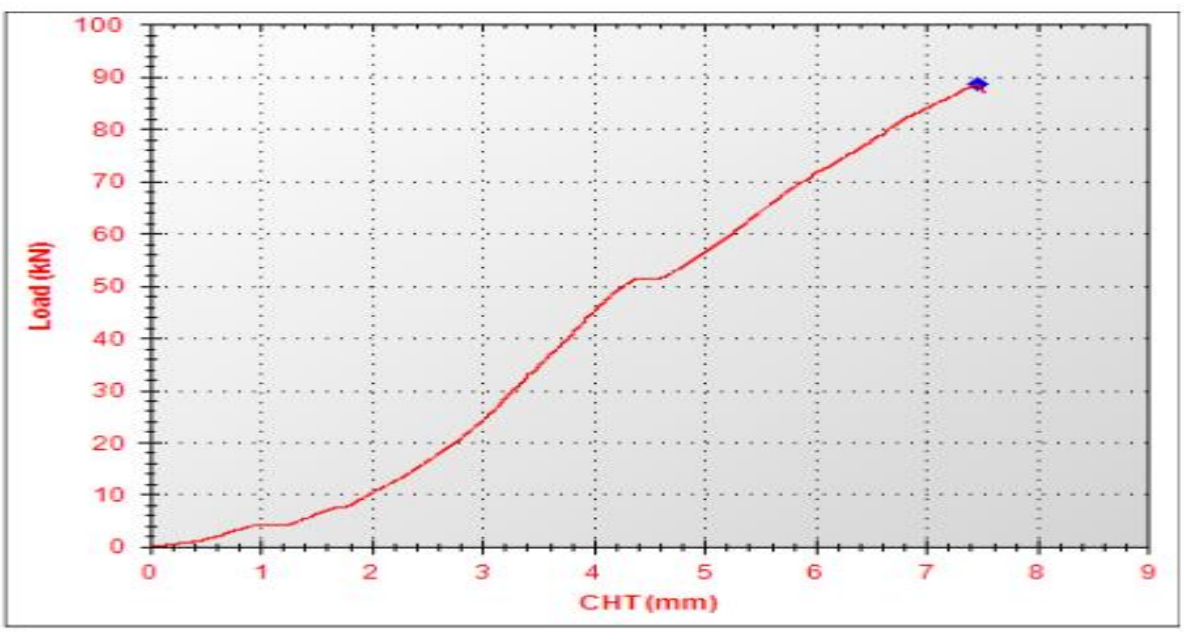
S.NO	Beam Designation	Breadth b (mm)	Depth d (mm)	Ast (mm^2)	WFS Replacement(%)	Shear span(mm)	$\frac{span}{depth}$ ratio
1	GPCB 1	150	200	226.08	0	250	1.55
2	GPCB 2	150	200	226.08	25	250	
3	GPCB 3	150	200	226.08	30	250	
4	GPCB 4	150	200	226.08	35	250	
5	GPCB 5	150	200	226.08	40	250	
6	GPCB 6	150	200	226.08	0	325	2.01
7	GPCB 7	150	200	226.08	25	325	
8	GPCB 8	150	200	226.08	30	325	
9	GPCB 9	150	200	226.08	35	325	
10	GPCB 10	150	200	226.08	40	325	

*GPCB-Geo Polymer Concrete Beam

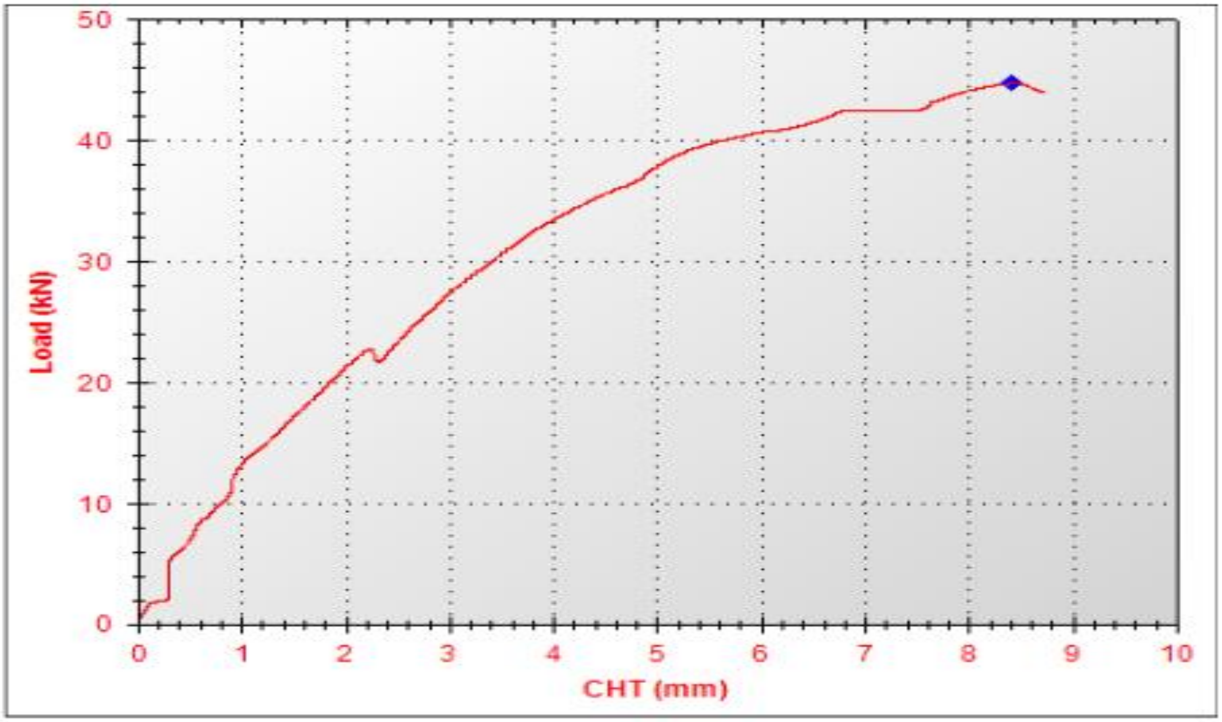
Table 11: Details of elements tested

S.NO	Beam Designation	D.O.C	D.O.T	W_{cr} (kN)	W_u (kN)	Deflection (mm)	Mode of Failure
1	GPCB 1	18 Feb	19 Mar	34	88.5	7.4	Shear
2	GPCB 2	19 Feb	20 Mar	24	44.68	8.6	
3	GPCB 3	20 Feb	21 Mar	19	57	2.93	
4	GPCB 4	21 Feb	22 Mar	18	56.37	6.98	
5	GPCB 5	22 Feb	23 Mar	12	44.40	7.55	
6	GPCB 6	18 Feb	19 Mar	39	102	11.25	Flexure
7	GPCB 7	19 Feb	20 Mar	34	70.7	8.19	
8	GPCB 8	20 Feb	21 Mar	33	91.56	6.44	
9	GPCB 9	21 Feb	22 Mar	25	60.26	13.2	
10	GPCB 10	22 Feb	23 Mar	12	32.63	9.73	

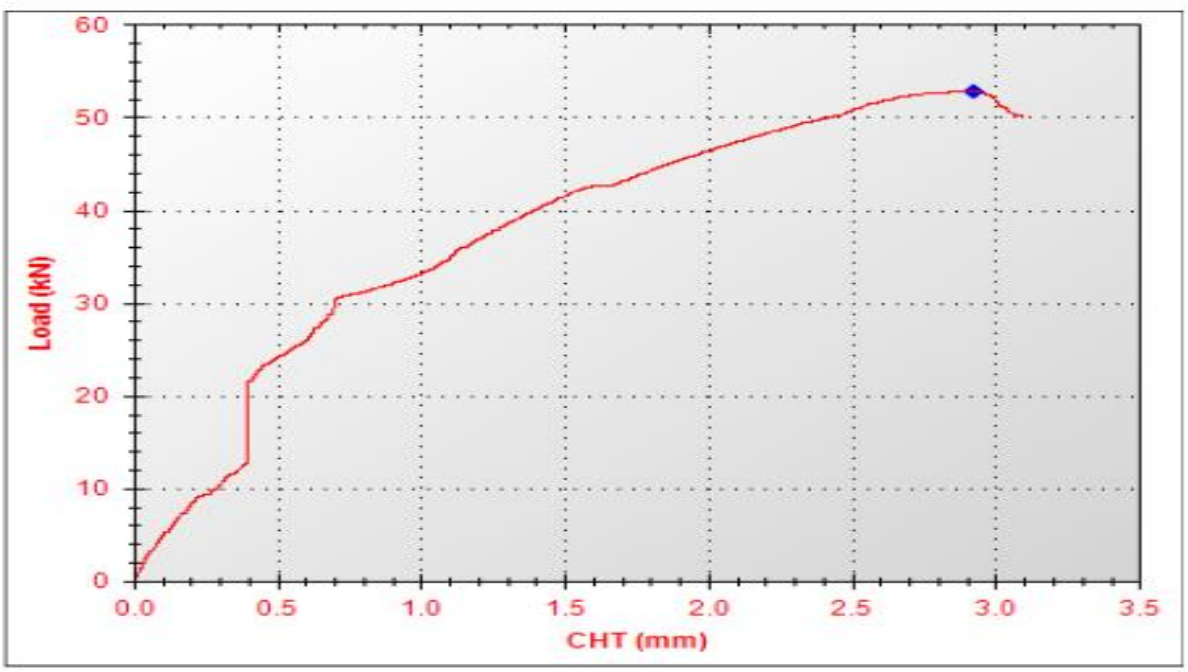
Table 12: Experimental test results



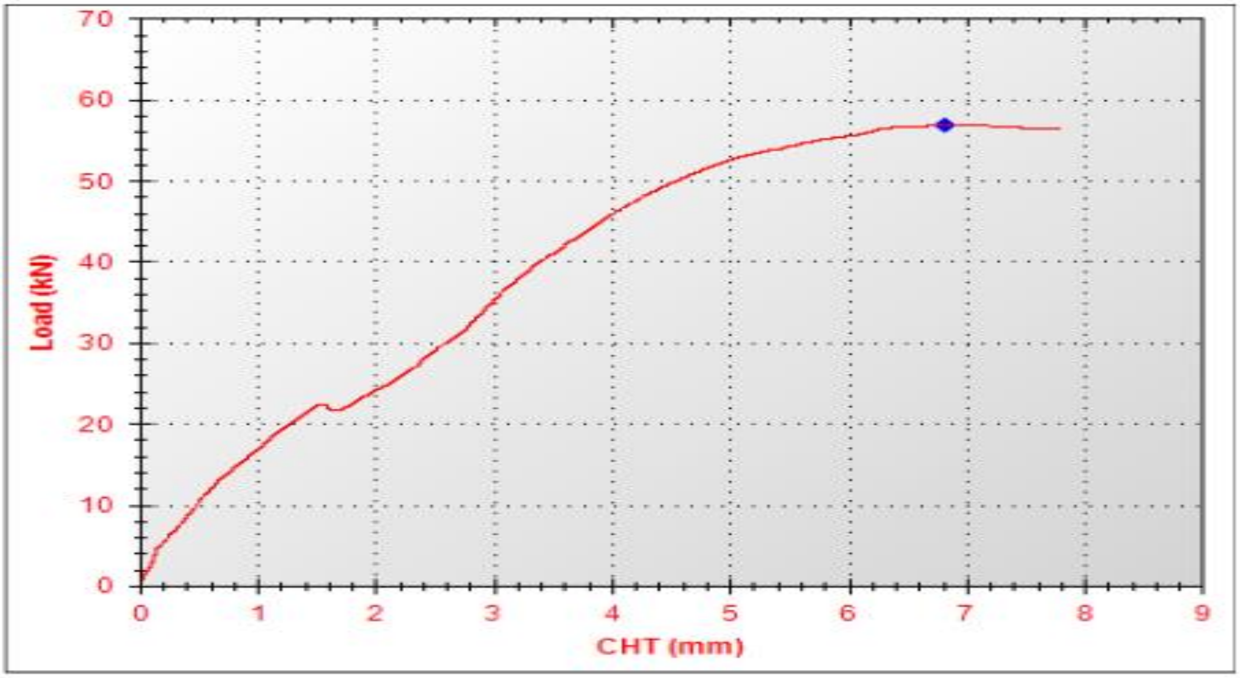
Graph 2: Load deflection for GPCB 1



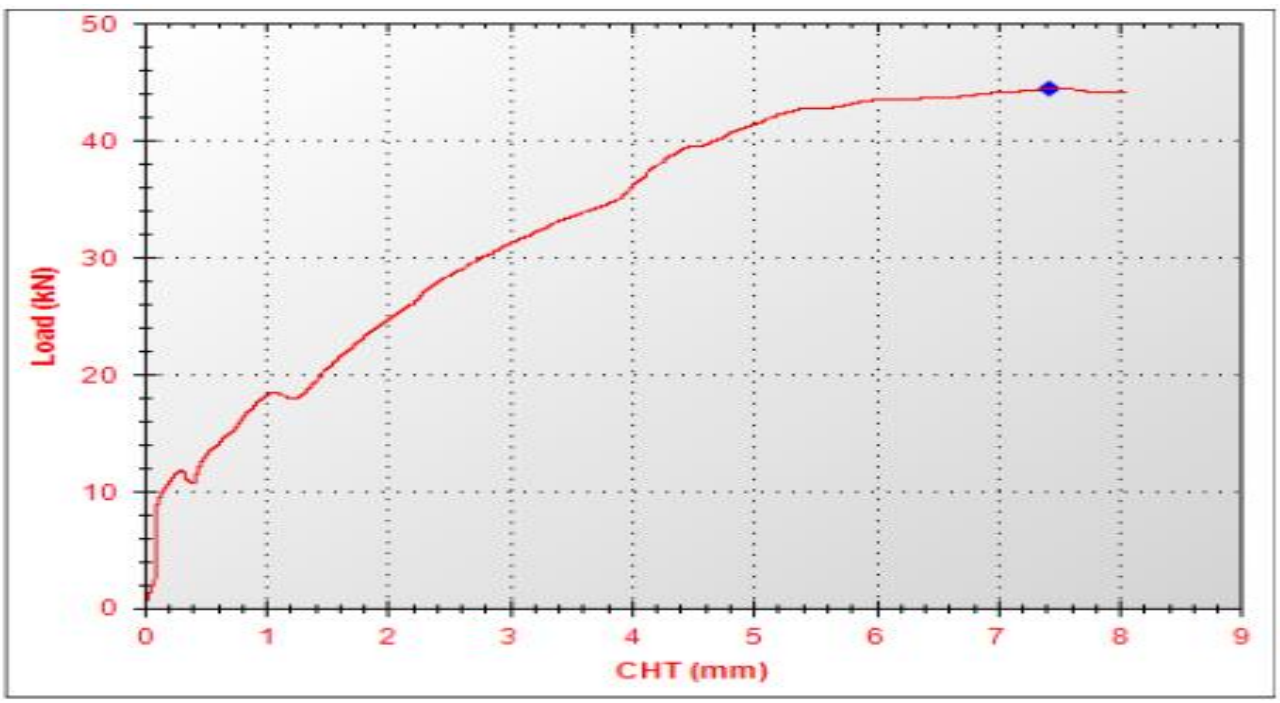
Graph 3: Load deflection for GPCB 2



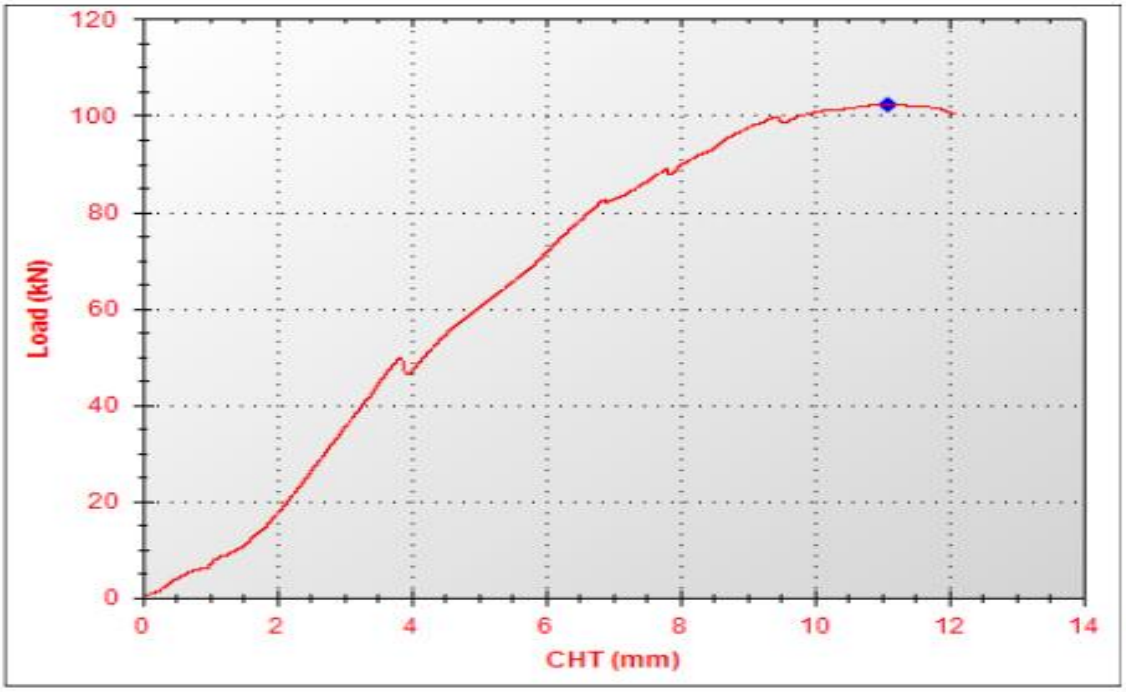
Graph 4: Load deflection for GPCB 3



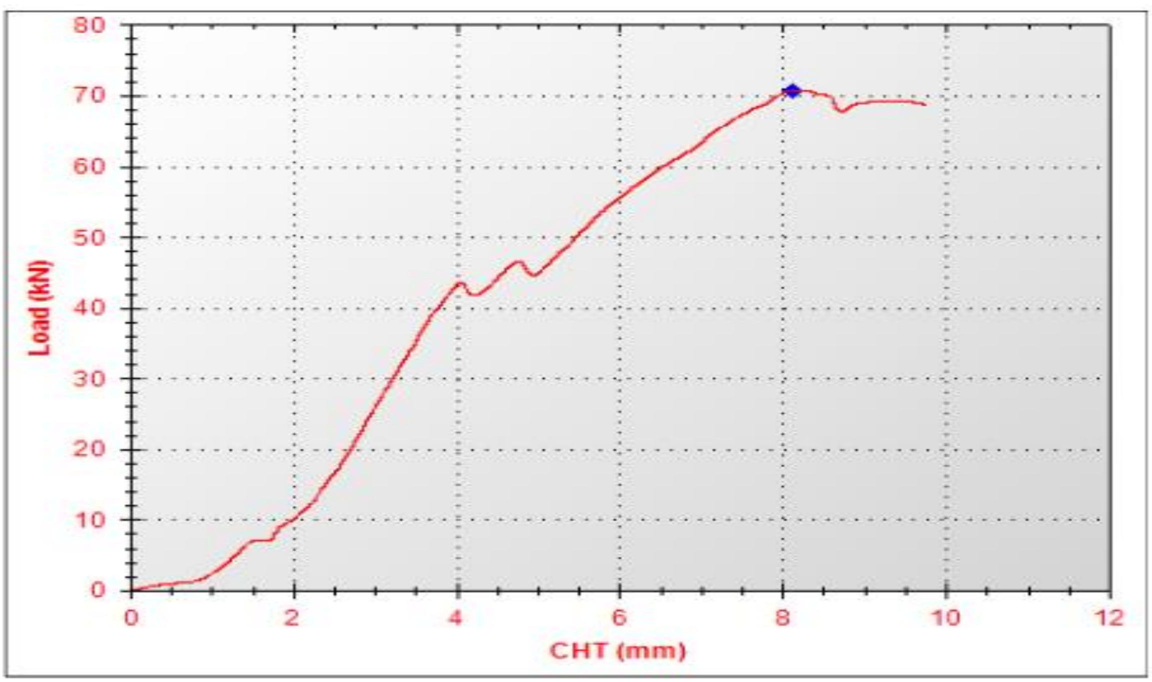
Graph 5: Load deflection for GPCB 4



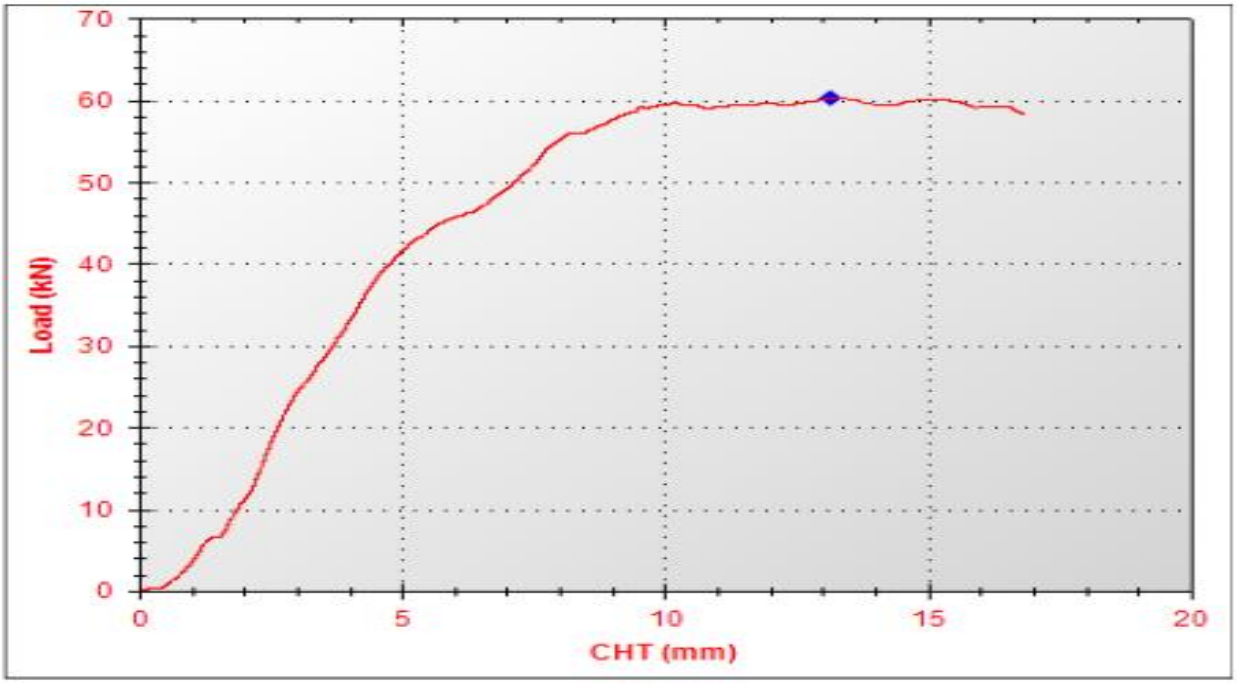
Graph 6: Load deflection for GPCB 5



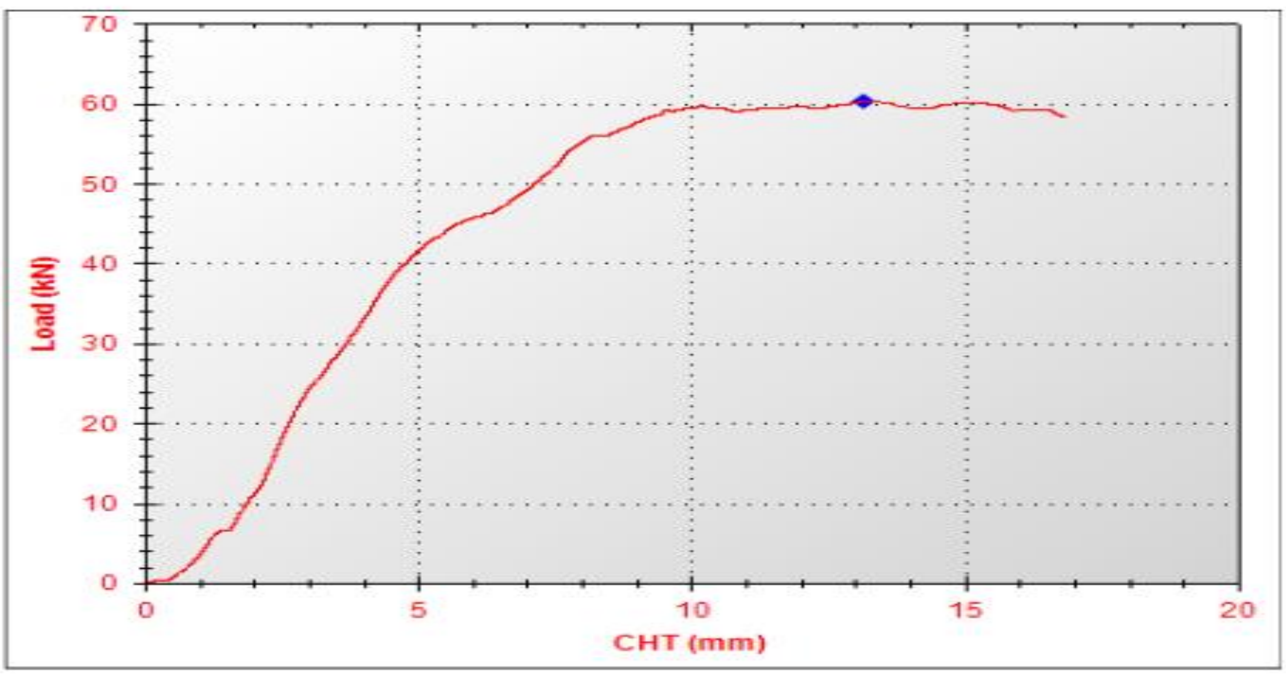
Graph 7: Load deflection for GPCB 6



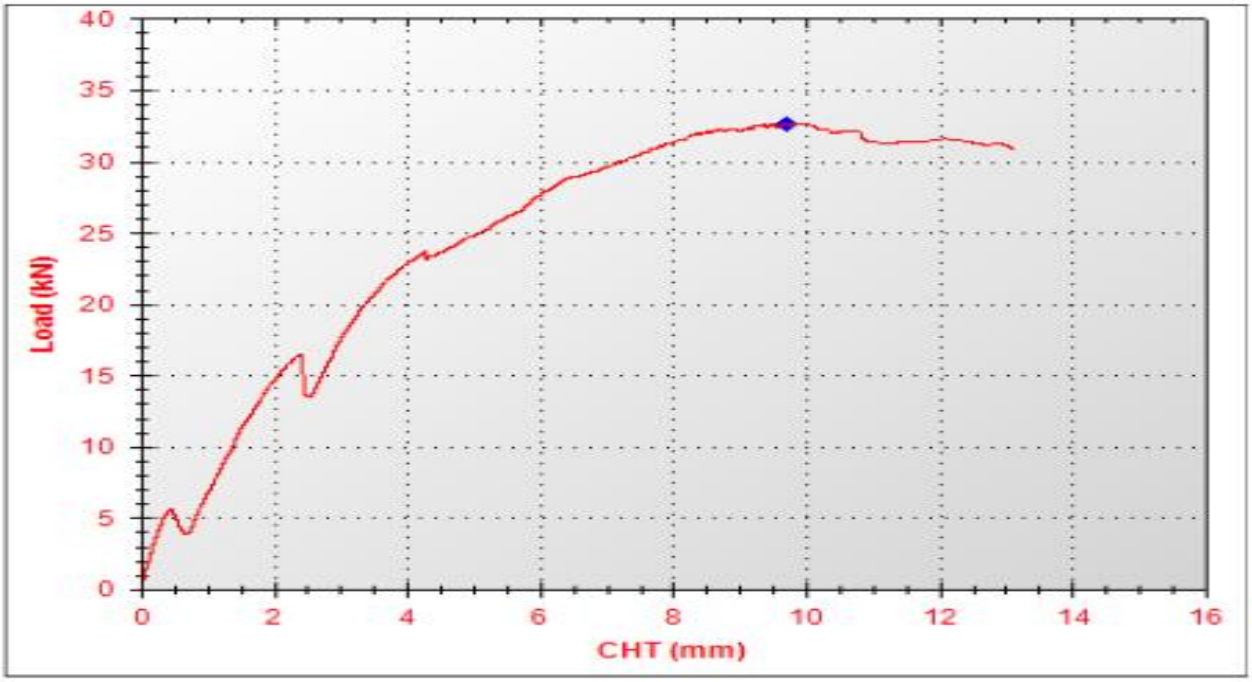
Graph 8: Load deflection for GPCB 7



Graph 9: Load deflection for GPCB 8



Graph 10: Load deflection for GPCB 9



Graph 11: Load deflection for GPCB 10

Fig 13: Crack pattern developed in a beam

CHAPTER 7

CONCLUSIONS:

1. It has been found that the beam undergoes shear failure when two point loads are applied at a distance of 150 mm from the centre on each side.
2. It has been found that the beam undergoes flexure failure when two point loads are applied at a distance of 75 mm from the centre on each side.
3. When Shear span / effective depth ratio in the beam is 1.55 then the failure is by Shear.
4. When Shear span / effective depth ratio in the beam is 2.01 then the failure is by Flexure.
5. The beam can withstand a maximum load in shear failure when 0% Waste foundry sand is added. Keeping in mind the environmental factors, the optimum utilization is obtained at 30% replacement of waste foundry sand.
6. At 30 % the beam which fails by shear have a minimum deflection of 2.93 mm which is 60.5% less than that of the deflection in controlled beam.
7. At 30% the maximum load carrying capacity (Shear failure beam) is 35% less than that of the maximum load carried by controlled beam.
8. The beam can withstand a maximum load in flexure failure when 0% Waste foundry sand is added. Keeping in mind the environmental factors, the optimum utilization is obtained at 30% replacement of waste foundry sand.
9. At 30 % the beam which fails by flexure have a minimum deflection of 6.44 mm which is 42.8% less than that of the deflection in controlled beam.
10. At 30% the maximum load carrying capacity(Flexure failure beam) is 8.97% less than that of the maximum load carried by controlled beam.
11. With above reference we can infer that the optimum utilization is achieved when 30% of M sand is replaced with waste foundry sand.

Chapter-8

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