OPTIMIZATION OF CONTROLLED LOW STRENGTH MATERIAL USING SPENT FOUNDRY SAND, GGBS, FLY ASH AND CKD

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Submitted by:
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DECLARATION

The author hereby declares that this thesis entitled "**OPTIMIZATION OF CONTROLLED LOW STRENGTH CONCRETE USING FOUNDRY SAND, GGBS, FLY ASH AND CKD**", in whole or part, has not been used to obtain degree in this, or any other institute. Except were references have been given in the text, it is entirely the authors own work.

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This is to certify that the thesis entitled "**OPTIMIZATION OF CONTROLLED LOW STRENGTH CONCRETE USING FOUNDRY SAND, GGBS, FLY ASH AND CKD**" being submitted by Mr. Sagar Tandon, Roll No. 801322017 in partial fulfillment for the award of degree of **Master of Engineering in Structural Enigneering** at **Thapar University, Patiala** is a bonafide work carried out by him at **Thapar Univeristy, Patiala,** under our guidance and supervision and that no part of this thes has been submitted for the award of any other degree.

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ABSTRACT

A Controlled low strength material (CLSM) is a highly flowable material which does not need any compaction and primarily comprises of sand, cement, water and other filler materials. The main implementation of CLSM is to replace soil backfill. The purpose of this project was to optimize a mix proportion for CLSM using various industrial by-products and to construct a material which does not have any commercial building material as its constituent. The recycling of such a waste materials will not only be having positive impact on the environment but will also lead to construction stability and economy. The mixes must possess the consistency, flowability and strength which is required for CLSM. This was achieved using trial mixing and new mixes were derived using the performance of previous pours. To investigate the properties of derived mixes tests for flowability, bleeding, density and compressive strength were performed.

An effort has been made to completely replace natural coarse sand with Spent Foundry Sand (SFS). It was also found that cement and sand mixes could not provide the highly flowable and consistent mixes with high water/fines required to achieve a low strength of not more than 2 MPa at 28 days. To rectify this, binary and ternary mixes were derived by incorporating Fly Ash (FA) and Ground Granulated Blast-Furnace Slag (GGBS) with cement and sand. Since production of cement leads to high CO_2 emission the cement in this project was also completely replaced with Cement Kiln Dust (CKD). The optimum pour with regards to both fresh and hardened properties was found to be made up of all the by-products without using any of the commercial building materials but very high water content was need for its generation.

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(SAGAR TANDON)

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CHAPTER 1

INTRODUCTION

1.1 GENERAL

Recently, the use of Controlled Low Strength Material (CLSM) has grown considerably as a cost and time efficient substitute of compacted fills. Many engineering facilities and construction require excavation and backfilling. The backfilled earth is the ultimate load bearing layer of the structure so its quality directly affects the safety of the structure (Wang, 2013).

CLSM is a cementitious fill in a flowable state at time of placement and is having a very low compressive strength to enable subsequent excavation. American Concrete Institute (ACI), Committee 229R, 1999 defined CLSM as a self-compacted, cementitious material used primarily as backfill and an alternative to compacted fill. CLSM is also referred to as flowable fill, unshrinkable fill, controlled density fill, flowable mortar, plastic soil-cement slurry, k-krete and by various other names. CLSM has gained appreciable recognition in the USA and Canada as a fill material because of its inherent advantages of flowing placement without segregation, self-consolidation, controlled density, controlled strength, ease of excavation and economy.

Development of CLSM has primarily centered on mixtures containing cement and sand. The inter-particle voids of sand are slightly over-filled with a fluid paste composed of cement and water, with the possible addition of other fillers such as FA, GGBS, CKD, Incinerator Ash, etc. Components of the CLSM paste are varied in quantity to achieve the required performance in terms of strength development, self-consolidation, flow behavior characteristics, durability, economy and ease of removal. Overseas experience has shown the sand filler mixtures to have performed well, helping in achievement of all the desired properties. It may be difficult to achieve satisfactory flowability and there may be severe bleeding in cement-sand slurries although fillers can be of assistance in obtaining properties of flowability resulting in the reduction in bleeding.

It can be understood that CLSM is a cementitious material which can be mixed, transported and delivered using normal ready-mix operation techniques and processes. The material does not look concrete but it performs in a similar manner since it has cementitious properties and, with time, will become quite hard. However, the latter must be controlled so that it does not become too hard. As with any concrete, strength is influenced by the quantity of water and cement. Very high water content (300 to 600 kg/m^3) and very low cement content (25 to 100 kg/m^3) are quite normal for CLSM. Sand, Fly ash, other fillers and in some cases coarse aggregates, are also selected for their ability to flow rather than for their contribution to strength properties. This implies that sand not suitable for regular concrete may perform quite well in CLSM. Control of the material on site is best achieved by a flow test. A cylinder or cone is placed on a flat hard surface and filled with the flowable mix. When the mould is lifted, the material will spread on the flat surface as shown in Figure 1.1. If the measured spread of the CLSM reaches the predetermined distance, the mix is considered to have acceptable flow.

Figure 1.1: Typical spread cone, slump and cylinder slump test (Sheen et al. 2013).

Where backfill may have to be excavated at a later date, the strength of CLSM must be limited. ACI Committee 229R (1999), defines, CLSM as a material having a maximum compressive strength as high as 8.3 MPa. However, most CLSM applications incorporated now days require compressive strength of 2.1 MPa (300 Psi) or less. This lower strength requirement is necessary to allow for future excavation of CLSM. CLSM with strength up to 2.3 MPa at 28 days can generally be excavated using normal construction equipment. As CLSM is a highly fluid material, consideration must be given to the lateral pressure exerted during placement; lightweight pipes, etc may need to be anchored to prevent flotation. CLSM mixes should be designed for the particular flowing characteristics required as well as the compressive strength necessary. As indicated previously, aggregates are chosen more for their compatibility with the CLSM's flowing characteristics than their contribution to strength.

A wide range of fine aggregates including sands, gravels, quarry waste material and industrial by-products may be used to produce desired CLSM mixes. Aggregates used in CLSM does not require to comply with codes required for normal concrete but aggregate should be free of reactive or expansive materials. Coarse aggregates are not normally included in CLSM. Where filler is used to improve flowability it should be noted that early strength may be reduced. CLSM is designed for a maximum 28-day compressive strength of 0.5 MPa where future hand excavation and 1.5-2 MPa for mechanical excavation is required. Slumps that will suit most application of CLSM are around 250 mm. Compacted soil-cement, as defined by ACI Committee on Soil-cement should not be confused as CLSM, which requires compaction (consolidation) or curing to achieve the desired strength.

1.2 APPLICATIONS OF CLSM

The primary application of CLSM is as a structural fill or backfill in lieu of compacted soil and is important to minimize settlement. CLSM needs no compaction and can be designed to be very fluid hence, it is ideal for use in tight or restricted-access areas, where placing and compacting natural fill is difficult. It is also advantageous for backfilling excavations in soil that are prone to collapse when normal compaction equipment is used. CLSM may also be used for foundation support for different structural systems. Compressive strength may vary from 0.345 to 8.3MPa depending upon application. Very high quantity of waste material or by products can be utilized in CLSM which could help in providing economic and environmental benefits. In case of weak soils, it can distribute the structure's load over a greater area. For uneven or non-uniform sub-grades under foundation footings and slabs, CLSM can provide a uniform and level surface.

CLSM provides an excellent bedding material for pipes; electrical, telephone and other types of conduits. The flowable characteristics of the material allow the CLSM to fill voids beneath the conduit and provide a uniform support. CLSM may be used in backfilling trenches, filling abandoned underground structures, e.g. tanks, sewers, tunnels, etc. Bridge abutments and retaining walls can also be backfilled using CLSM; CLSM can be designed to provide erosion resistance beneath the conduit, too. It has been proven through laboratories and field performance that CLSM resists erosion better than many other fill materials. Tests comparing CLSM with various sand and clay fill materials show that CLSM, when exposed to a water velocity of 0.52 m/s, was superior to the other materials, both in the amount of material loss and suspended material. Stilling basins below dam spillways are often filled with CLSM to hold rock pieces in place and prevent erosion (Siddique, 2009).

1.3 ADVANTAGES OF CLSM

Following benefits are observed while using CLSM as flow-able fill in lieu of compacted soil:

- **Can be excavated:** CLSM having compressive strength of 1 MPa to 2 MPa is easily excavated with conventional digging equipment yet is strong enough for most backfilling needs**.**
- **Easy to place:** Depending on the type and location of void to be filled, CLSM can be placed by chute, conveyor, pump or bucket. As CLSM is self-leveling, it needs little or no spreading or compacting. This speeds construction, reduces labor requirements and equipment cost.
- **Flowability:** The inherit ability of CLSM can be used to flow it into hard-to-reach places where compaction using conventional methods wouldn't be possible.
- **Requires less inspection:** During placement, soil backfill must be tested after each lift for sufficient compaction. CLSM self-compacts consistently and does not need this extensive field testing.

- **Reduce excavating costs:** CLSM allows narrower trenches because it eliminates having to widen trenches to accommodate compaction equipment.
- **Does not settle:** CLSM does not form voids during placement and will not settle or rut under loading. This advantage is significant if the backfill is to be covered by a pavement patch. Soil or granular fill, if not consolidated properly, may settle after a pavement patch is placed and form cracks or dips in the roads.
- **Versatile:** CLSM mix designs can be adjusted to meet specific fill requirements. Add more water to improve flowability. Add more cement or fly ash to increase strength. Admixtures can be added to adjust setting times and other performance characteristics. Adding foaming agents to CLSM produces a lightweight, insulating fill.
- **Strong and durable:** Load-carrying capacities of CLSM typically are higher than those of compacted soil or granular fill. With superior angle of shear resistance and cohesion intercept. CLSM also is less permeable, thus more resistant to erosion. For use as a permanent structural fill, CLSM can be designed to achieve 28-day compressive strength as high as 8 MPa.
- **Improves worker safety:** Workers can place CLSM in a trench without entering the trench, reducing their exposure to possible cave-ins.
- **Makes use of a waste by-product:** Fly ash is a by-product produced by power plants that burn coal to generate electricity. CLSM containing fly ash benefits the environment by making use of these industrial waste materials. Similarly for other by-products as GGBS, CKD, Foundry Sand and Limestone dust reducing demands on landfills.

1.4 DISADVANTAGES OF CLSM

Various difficulties observed while using CLSM in construction practices are presented as below:

- **Unreliable strength acquisition:** A CLSM mix has very low 7-day strength of 1 MPa, which is very difficult to predict.
- **High segregation:** The mixes are highly prone to segregation when not properly designed as they have a high water/fines ratio and low cement content.
- **Non-Uniformity:** Can be hard to mix uniformly due to high water content.

- **Bleeding:** It is susceptible to a very high degree of bleeding leading to volume loss and inaccurate finish levels.
- **Shrinkage:** Very high degree of shrinkage when high water/ cement ratio is used.
- **Mix design:** It is difficult to achieve the required low strength while maintain cohesiveness.

1.5 MATERIALS USED FOR MAKING CLSM

Portland cement, Supplementary Cementitious Materials (SCM), aggregates and water are the key ingredients of a CLSM mixture. Air entraining or water reducing admixtures can also be incorporated to control fresh, mechanical and durability characteristics. Fine aggregates or fillers are often used in larger quantities while coarse aggregates, though in much lesser quantity, may also be used. CLSM mix typically contains 80–85% fine aggregate (size ranging from 4.45 to 0.075 mm) or filler, 10–15% supplementary cementing materials, 5–10% cement by mass, 250–400 l/m^3 of water – but the actual mix proportion can vary depending on the application and type of SCM used (Lachemi et al. 2008).

Although sand is the most commonly used fine aggregate for making CLSM, however, other materials such as quarry fines, asphalt dust and recyclable aggregates have also been used [Katz and Kovler 2004]. Among supplementary cementing materials, fly ash, bottom ash, foundry sand, and wood ash are used in CLSM mixes (Naik and Singh 1997). Selection of materials is generally based on availability, cost, specific application and the necessary characteristics of the mixture. Typically, CLSM has a slump value of about 250 mm or more and a maximum compressive strength of 8.3 MPa (1200 psi). Current applications of CLSM used an unconfined compressive strength of 2.1 MPa or less to allow for future hand or mechanical excavation.

Since, the volume of waste materials and by-products being generated in society is increasing, there are numerous pressures and incentives to reduce, reuse and recycle. The use of wastes and by-products in the development of CLSM can help to decrease environmental hazards and provide economy which can lead to sustainable development. CLSM offers an excellent opportunity for the use of industrial by-products or recycled materials as fine aggregate and/or cementing materials (Naik and Singh 1997, Wang et al. 2013, Lachemi et al. 2008, Sheen et al.

2013, Kuo et al. 2013, Her-Yung 2009, Zhen et al. 2013, Naganathan et al. 2012, Lee et al. 2013).

Many studies have been carried out regarding the use of various industrial by-products in the production of CLSM. Large amounts of by-product materials such as fly ash (FA) and ground granulated blast furnace slag (GGBS) were utilized to lower the cost and to ensure the required maximum compressive strength. It is known that the utilization of fly ash in CLSM provides many advantages, such as good flowability, reduced segregation and bleeding, and in numerous cases, a reduced material cost (Lee et al. 2013). Other industrial by-products such as recycled glass, cement kiln dust, and spent foundry sand were also employed in the generation of CLSM.

1.6 OBJECTIVES

The main objective of the study is to evaluate fresh and hardened properties of CLSM with utilization of various industrial by-products. The aim here in was to have mixes with 28 day compressive strength less than or upto 2MPa. The following properties were found out for the CLSM mixes prepared in the laboratory.

- Slump flow and J Ring Diameter
- Fresh and Hardened Density
- Bleeding for various CLSM mixtures
- 28-day Compressive Strength testing on various CLSM mixtures.

CHAPTER 2

LITERATURE REVIEW

2.1 GENERAL

Sustainability is important to the well-being of the planet, continued growth of the society, and human development. Concrete is the most widely used construction materials in the world. However, the production of Portland cement, an essential constituent of concrete, leads to the release of significant amounts of Carbon Dioxide (CO_2), a greenhouse gas (GHG); production of one ton of Portland cement produces about 850kg of CO_2 and other GHGs. The environmental issues associated with GHGs, in addition to natural resources issues, will play a leading role in the sustainable development of the cement and concrete industry during this century.

To build structures and infrastructures that are cost-efficient, environmentally friendly, and durable, the impact of the building materials on local and worldwide air conditions must be examined (McDonough et al., 1992). At the current rate of increase of cement production worldwide cement production is expected to rise from about 3.2 billion tones in 2010 to about 4.8 billion tones by 2030. Thus, CO_2 emissions caused due to Cement production are expected to rise by 1.5 times from the current level by 2030 (Statista, 2015). The annual production of cement from 1990 to 2030 is shown in Figure 2.1. For each metric ton of Portland cement clinker, 1.5 to 10 kg of NO_x is also released into the atmosphere. If the challenges associated with reducting CO_2, NO_x and other GHGs are to be met, then the concrete industry must develop other materials to replace Porland cement (Naik, 2008).

Therefore, supplementary cementing materials, which are waste/co-products from other industries such as fly ash, limestone dust and ground granulated blast-furnace slag should replace large amounts of Portland cement in concrete. However, before any construction occurs, all aspects of the building materials to be used should be evaluated. The use of blended cements and organic chemical admixtures must be significantly increased for sustainability of the cement and concrete industries.

A proper disposal of waste materials that are produced from various industries is a serious problem in many countries. Generation of industrial waste materials and by-products is increasing as a result of industrialization as is the need for higher amounts of raw materials and fuel to accommodate the rapid increase in the world's population.

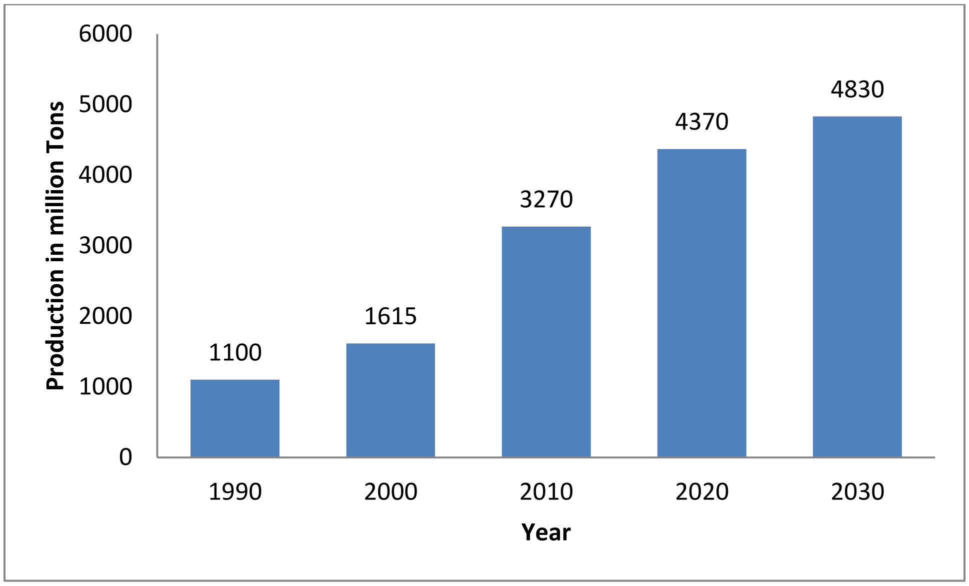


Figure 2.1: Annual Global Cement production from 1990 to 2030 (Statista, 2015)

This obviously causes many environmental problems in the form of waste generation and raises the potential to contaminate water, air and soil resources. The safe disposal of waste is costly, and there is a lack of disposal sites that are suitably designed to handle such materials without causing detrimental effects on the environment. Therefore, in recent years, research has been directed towards finding alternative methods of utilizing waste materials and industrial by-products, where their harmful effects are minimized or even eliminated. The construction industry is one of the areas where the safe use of waste materials could have a promising future (Taha et al., 2007)

A controlled low-strength material (CLSM) is a self-compacted, cementitious material used primarily as a backfill as an alternative to compacted fill. Several terms are currently used to describe this material, including flowable fill, unshrinkable fill, controlled density fill, flowable mortar, plastic soil-cement, soil cement slurry, and other various names. Controlled low-strength materials are defined by ACI 229R, 1999 as materials that result in a compressive strength of

8.3MPa (1200 psi) or less. Most current CLSM application require unconfined compressive strength of 2.1 MPa (300 psi) or less at 28 day. This low–strength requirement is necessary to allow for possible future excavation of CLSM. It costs more per cubic meter when compared with conventional soil backfill; however its advantages results in lower in-place costs. (ACI 229R, 1999). Since sand and cement are major components of CLSM; replacing the natural and cement with the waste materials is an attractive beneficial reuse option.

The primary application of CLSM is as a structural fill or backfill in lieu of compacted soil. As CLSM needs no compaction and can be designed to be fluid, it is ideal for use in tight or restricted-access areas where placing and compacting fill is difficult. If future excavation is anticipated, the maximum long-term compressive strength should generally not exceed 2.1 MPa (300 psi). The following applications are intended to present a range of uses for CLSM.

2.2 APPLICATIONS OF CLSM

2.2.1 Backfills

CLSM can be readily placed into a trench, hole or other cavity. Compaction is not required; hence the trench width or size of excavation may be reduced. Granular or site excavated backfill, even if compacted properly in the required layer thickness, may not achieve the uniformity of CLSM (Siddique, 2009).

2.2.2 Structural Fills:

The CLSMs with 10% and 20% slag have 28-day strength of 6.4 and 7.8 MPa, respectively. This makes the materials suitable for permanent structural fill where relatively high strength is required. The selection of the slag level (10% or 20%) would depend on the required strength (Achtemichuk et al., 2009). In case of weak soils, it can distribute the structure’s load over a greater area. For uneven or non-uniform sub-grades under foundation footings and slabs, CLSM can provide a uniform and level surface (Siddique, 2009).

2.2.3 Conduit Bedding:

CLSM provides an excellent bedding material for pipes, electrical, telephone and other types of conduits. The flowable characteristics of the materials allows the CLSM to fill voids beneath the conduit and provide a uniform support. CLSM can be designed to provide erosion resistance beneath the conduit. Encasing the entire conduit in CLSM also serves to protect the conduit form future damage. If the area around the conduit is being excavated at a later date, the obvioud material change in CLSM versus the surrounding soil or conventional granular backfill could be recognized by the excavating crew, alerting them to the existence of the conduit. Coloring agent have been used in mixtures to help identify the presence of CLSM (Siddique, 2009).

2.2.4 Erosion Control:

It has been proven through laboratory and field performance that CLSM resists erosion better than many other fill materials. Tests comparing CLSM with various sand and clay fill materials showed that CLSM, when exposed to a water velocity of 0.52m/s, was superior to the other materials, both in the amount of material loss and suspended material. Rip rap for embankment protection and installing basins below dam spillways are often filled with CLSM to hold rock pieces in place and prevent erosion. Flexible fabric mattresses used along embankments for erosion protection are filled with CLSM to provide strength and weight to the fabric revetments. In addition to providing erosion under culverts, CLSM is used to fill voids under pavement, sidewalks, bridges and other structures where natural soil or non- cohesive granular fill has eroded away (Siddique, 2009).

2.2.5 Void Filling

In filling old tunnels and sewers, it is important to use a highly flowable mixture. A constant supply of CLSM will help keep the material flowing and make it flow greater distances. Unwanted basements are often filled-in with CLSM by pumping or conveying the mixture through an open window or doorway. CLSM has been used to fill abandoned underground tanks (Siddique, 2009).

2.2.6 Groundwater Cutoff

CLSM mixes are extensively used as a means of groundwater cut off. It can control seepage beneath dams and contain polluted groundwater which arises from the presence of insanitary landfills. CLSM can provide this function due to its low permeability. Usually, bentonite, which is sodium clay that expands when wet, is added to the CLSM mix which lowers its permeability significantly to the order of 10^{-9} m/s. Essentially, the ‘flowcrete’ acts as barrier against contaminated water (Siddique, 2009).

2.2.7 Pile Driving

CLSM mix can be used in driving the sheet pile through the fill, for which the strength should be less than 1MPa at 7-day.

2.2.8 Road Bases

The CLSM mix can be made with resistance of soil–cement to freezing/thawing and wetting/drying cycles, both mixtures are suitable for road bases where high durability against freezing and wetting is required (Achtemichuk, 2009)

2.2.9. Repairs of road sections

It is often required to complete road repairs within a short period of time to minimize the impact on traffic. In such situations, fast hardening time is often required. Some CLSM mixes are observed with a setting time as low as 5hrs. This makes the mixtures suitable for such repair works where the CLSM serves as a road base or a temporary road surface.

With regard to CLSM, one can efficiently use by-products and waste materials within the mix to reduce the cost of its production (Nataraja et al., 2007). The efficient disposal of waste can be costly ad can have negative impacts on the environment due to the generation of this waste. As a result of this, research has been carried out in the last number of years on ways to make use of these waste materials. It has been found that the construction industry is a sector in which the safe use of these by-products may have considerable commercial potential (Taha et al, 2007).

The proper disposal of waste materials that are produced from various industries is a serious problem in many countries. The generation of industrial waste materials and byproducts is increasing as a result of industrialization as is the need for higher amounts of raw materials and fuel to accommodate the rapid increase in the world’s population. This obviously causes many environmental problems in the form of waste generation and raises the potential to contaminate water, air and soil resources. The safe disposal of waste is costly, and therefore, in recent years, research has been directed towards finding alternative methods of utilizing waste materials and industrial by-products, where their harmful effects are minimized or even eliminated. It has been well known from decades, that the use of industrial by-products such as fly ash (FA), silica fume, pulverized-fuel ash and granulated blast furnace slag (GGBS) as a partial replacement of cement improves the durability of concrete structures and may also enhance the properties of both fresh (e.g. Workability, bleeding, etc.) and hardened (e.g. strength) concrete. This is well documented in various codes of practice. Another application where such materials can be re-used beneficially is as flowable fills or controlled low strength materials (CLSMs). Originally a CLSM was slurry consisting of a mixture of cement, sand, water and FA. Since sand and cement are the major components of CLSM, replacing the cement and/or natural sand with waste materials is an alternative beneficial reuse option and helps to keep the strength down.

CLSM mixes should be designed for the particular flowing characteristics required as well as the compressive strength necessary while remaining cohesive and stable in the fresh state. The aggregate are chosen more for their compatibility with the CLSM's flowing characteristics than their contribution to strength. A wide range of fine aggregates including sands, gravels and quarry waste materials can be used to produce satisfactory CLSM mixes. It is not necessary for aggregates to comply with codes. Aggregates should however, be free of reactive or expansive materials. Coarse aggregate are not normally included in CLSM as they impart strength to the CLSM mix. Where fly ash is used to improve flowability it should be noted that early strength will be reduced. Maximum 28-day strength of 0.5 MPa is suggested where future hand excavation is likely and 1.5-2 MPa for mechanical excavation. A flow diameter in the flow tube test should be between 600-700 mm.

2.3 PRIMARY CONSTITUENT OF CLSM

Water is one of the primary constituents present in the mix which significantly affects the production of CLSM. When the clinker is in contact with water, a series of chemical reaction take place. Hydration occurs where a Calcium-Silicate-Hydrate (CSH) gel forms rapidly on the surface of cement grains and begins to bind the aggregates together. The water is also necessary to achieve adequate flowability and workability. Water contents in CLSM mixes vary from 190 to 340 kg/m^3 however, in the presence of fly ash (FA), the water content may be reduced as the FA improves the flowability of the material and reduces the water demand.

The most common fine aggregate found in CLSM is sand. Sand makes up approximately 75% of the CLSM. Its proportion in the mix can vary between 1200 kg/m^3 and 1840 kg/m^3 (Gabr et al., 2000).

Coarse aggregates such as gravel are not commonly used in CLSM mixes, as they provide strength to the concrete. However, for CLSM mixes one wants to deliberately make concrete weak, so the use of coarse aggregates will not be needed.

2.4 FLY ASH (FA)

The common by-product found in CLSM mixes is Fly Ash (FA). FA can be defined as “the finely divided residue resulting from combustion of ground or powdered coal” (ASTM C 618:2003). It is essentially a by-product of a coal fired electricity generating plant. As well as providing environment advantages, PFA will also improve the performance and quality of the CLSM due to the rounded particle shapes of the FA which improves the flowability of the material. The typical chemical composition of Class F and C fly ash is shown in Table 2.1.

Table 2.1: Classification of fly ash (ASTM C 618:2003).

Class	**Sio_2**	**Al_2O_3**	**Fe_2O_3**	**CaO**
Class F	>50%	20-30%	20%	<5%
Class C	>30%	15-25%	<10%	20-30%

FA looks like cement to the naked eye if slightly darker but it is slightly finer than cement, and has a lower density, where the specific gravity for FA ranges from 1.9 to 2.4 whereas for cement, it is 3.15 approximately.

Although the chemical constituents compound of FA are similar to that of cement but not in same proportion, one can’t however completely replace the cement content with FA. The reason for this is that once the Portland cement mixes with water, a process called hydration starts; this is where calcium-silicate-hydrate (C-S-H) gel forms rapidly on the cement grains. This is the component that binds the aggregates together and provides the concrete with its strength. As well as this, Calcium Hydroxide is also formed during the hydration of the cement. It is the constituent that the FA reacts and forms additional C-S-H gel. From this conclusion, one can see that there is a difference between water/cement ratio and water/binder ratio.

The introduction of FA will reduce the early strength of the CLSM because the rate of hydration of FA is slower. This suppresses the initial reaction of C_3S (alite), which is the compound that provides a significant proportion of early age strength to the concrete. However, the presence of FA will also increases its long term strength meaning the cement content may also be reduced accordingly. This happens because the FA consumes the weak CH over time and replaces it with hard stable calcium silicates and aluminum hydrates. (Gabr et al., 2000). According to the European standards IS EN 206, they suggest a 10% increase in the 28 day strength of Ordinary Portland cement/FA mix.

Flowability is an important characteristic for CLSM mixtures; this is because one wants the mix to be able to flow into the available space but, with the presence of FA in the mix it was found that a desired flow can be achieved with a lower water/cement ratio. This is due to the reduced water demand provided by the presence of the FA and by the spherical nature of the FA particles (Nataraja and Nalanda, 2008). The presence of FA will also increase long term strength leading to reduction in the cement content.

Compressive strength of CLSM are usually limited to 2MPa to allow for future excavation. It is observed that for CLSM mixes consisting of FA/cement, strength rises as age increases, however after 7 days the increase in strength is only marginal due to the reduced pozzolanic activity of the cementitious materials (Nataraja and Nalanda, 2008).

The current trend of burning coal to make steam, power turbines, and generate electricity for new coal power plants is to use circulating fluidized bed combustion (CFBC) because the CFBC process emphasizes the optimization of coal and air interactions in the combustion chamber to maximize combustion efficiency. Furthermore, it attempts to vastly decrease the emission of combustion pollutants to the atmosphere to satisfy the enhanced Environmental Protection Agency (EPA) regulation. The introduction of ground limestone into CFBC chamber minimizes the release of sulfur oxides into the atmosphere, thus resulting in fly ash containing high lime and sulfate contents. Moreover, the combustion at relatively low temperature (i.e., 1200–1250 ^{o}C) produces particles with leafy-flake shaped irregular morphologies as opposed to spherical shaped particles in conventional fly ashes. Because of these abnormal physical and chemical characteristics, the CFBC ashes do not meet ASTM 618 (2003) requirements to qualify as Class

C or Class F fly ashes. (Shon et al., 2010), evaluated the potential use of stockpiled circulating fluidized bed combustion (CFBC) ashes in developing controlled low strength material (CLSM) in which stockpiled CFBC ash was partially or fully replaced with Class F fly ash. Prior to develop CLSM mixture, basic material characterization of stockpiled CFBC ash was executed to identify the physical, chemical, and mineralogical changes due to aging process of the stockpiled ashes. For CLSM mixture, stockpiled CFBC ash was replaced with five different percentages of Class F fly ash by weight (20%, 40%, 60%, 80%, and 100%). Tests were performed to measure fresh and hardened properties of CLSM mixtures. It was found that the stockpiled CFBC ash can be effectively used in developing CLSM mixtures with restricted use of portland cement and fly ash in the direction of sustainable development.

Qian et al. (2015), conducted laboratory experiment to characterize various properties and performance of fresh and hardened controlled low-strength materials (CLSM). The laboratory tests used for characterization of CLSM included flow, segregation, compressive and split tensile strength, resilient modulus, and freeze–thaw tests. The results from the laboratory tests show that water solid ratio and fly ash had significant effects on the flow, segregation, strength, and freeze–thaw resistance whereas cement exhibited little effect on the flow. The results also show that coarse sand caused CLSM more susceptible to segregate. Finally, the correlations between different mechanical properties of CLSM were explored.

2.5 GROUND GRANULATED BLAST FURNANCE SLAG (GGBS)

Ground granulated blast-furnace slag (GGBS) can also be used in CLSM in combination with other cementitious materials such as Portland cement. GGBS is similar to FA, in that it is a by-product of iron, copper and steel making process. The molten slag lying on the top of molten iron in the blast furnace comprises silicates (glass) which is the raw material for GGBS cement. The molten slag is cooled and then finely ground to form GGBS cement. GGBS is a recycled product and as it has the same but not identical chemical constituents as Portland cement, and unlike PFA it can replace it on a one-to-one basis.

GGBS is frequently used in mix designs for concrete, and form comparing the strength versus time graph for mixes for Portland cement on its own and a GGBS/Portland mix, it has been found that the GGBS/Portland cement mix will gain its strength much more slowly when compared with that of Portland cement mix. This lower strength is desirable for CLSM mixes, however the ultimate compressive strength of a GGBS/ Portland cement mix has also been found to be higher. The reason for this is due to the fact that there is a higher content of Calcium-Silicate-Hydrate (CSH) gel and a lot less calcium hydroxide (lime) in the resulting concrete.

The CSH gel is the binder that holds the aggregate and provides the concrete with its strength whereas the lime provides a small amount of strength to the concrete. The GGBS consumes this weaker CH over time and replaces it with more stable CSH gel. For this reason the 28 day cube strength may not be an accurate reflection of its long term strength, so a 56 day cube test is recommended (Taha et al., 2007). Similarly with FA, by replacing the content of Portland cement, it will reduce the amount of CO_2 which would need to be emitted when producing Portland cement. The job requirements may allow the need for Portland cement to be eliminated completely from the mix.

Copper Slag being utilized as full substitute for cement (no cement being used) showed very low strength of 0.135MPa implying that copper slag is not pozzolanic material when used alone as full substitute for cement i.e. cement is still needed for the reactivity of the material. Highest unit weight of the mix containing copper slag was observed, since copper slag was having highest specific gravity of 3.45 when compared with cement, CKD and incinerator ash (Taha et al. 2007).

Mixtures of RCA (Recycled Concrete Aggregate) and slag or HCFA (High Calcium Fly Ash) were produced and found to gain strength without the need to add Portland cement. The compressive strength of the slag/RCA mixtures was higher than that of HCFA/RCA mixtures. For both types of SCM (Supplementary cementing material), the strength of mortar cubes increased with increasing SCM content in the mixtures. Both slag and HCFA produced strength due to their hydraulic and pozzolanic reactions. The latter is believed to be promoted by the alkalis released from the residual paste in RCA. The strength development resulting from the hydration of unreacted PC particles in the RCA was evaluated and found to have minor effect on strength development. Two types of CLSMs were developed in this study: one type with fine RCA for use in narrow and restricted locations, and another type with fine/coarse RCA for use as permanent structural fills and road bases where relatively high strength (up to 8.3 MPa), high resistance to freezing/thawing and wetting/drying and short hardening times are required. For CLSM with fine RCA, a slag content of 20%, expressed as percentage mass of RCA, was found to produce cohesive mixtures with low subsidence and high resistance to cycles of freezing/ thawing and wetting/drying. However, the strength was relatively high which renders the mixture not suitable for applications that require future excavation. At the lower slag contents (5% and 10%), the strength met the range required for future excavation (<2.1 MPa), but the mixtures had high subsidence. (Achtemichuk et al. 2009).

Sheen et al. (2013), examined the engineering properties of soil-based controlled-low strength material (CLSM) containing blast furnace slag cement as cement substitute and residual soil as aggregate. By conducting an experimental program, twelve CLSM mixtures made with blast furnace slag partially replace for Portland cement of 10%, 20%, and 30% by weight and three sand–soil combinations, e.g. sand–soil proportion of 6:4, 5:5, and 4:6. The engineering parameters of CLSM, such as slump flow, setting time, ball-drop value, compressive strength, pulse velocity, and modulus of reaction subgrade were determined in according with ASTM procedures. Testing results indicate that the proposed mix proportion are almost met the requirements of excavatable CLSM. In addition, with slag replacement to cement would effectively improve the flowability, significantly delay setting time, and noticeably reduce compressive strength, pulse velocity under water-to-binder ratio being fixed. Moreover, the findings also exhibit that an increase in soil content in composition could lead to affect obviously on the CLSM’s performances. Furthermore, an exponential formula was also successfully established based on experimental data to express the relationship between compressive strength and ultrasonic pulse velocity, from 01 to 91 days. Finally, as regards geotechnical property, the applied load–deflection curves for CLSM have been plotted and thereby the modulus of reaction subgrade reaction was further estimated.

Sheen et al. (2014), used stainless steel reducing slag (SSRS), a by-product generated from stainless steel making process, as a cement substitute in production of soil-based controlled low-strength material (CLSM). In the present work, surplus soil and concrete sand were blended well together with a sand–soil proportion of 6:4 by volume in order to produce fine aggregate. Totally, twelve mixtures were prepared for experiment when we changed in turn percentages of Portland cement replacement with SSRS of 0%, 10%, 20%, and 30% by weight and the water-to-binder ratio of 3.4, 3.6, and 3.8. Meanwhile, the binder content in each mixture was fixed at 100 kg/m^3. Fresh and hardening properties of the CLSM were experimentally investigated via flowability, hardening time, ball drop, compressive strength, and pulse velocity test. Testing results indicate that SSRS with the specific surface area of 4551 cm^2/g can substitute for Portland cement up to 30% in production of excavatable CLSM, commonly classified by the 28-day compressive strength of 1.034 MPa or less. In addition, increasing SSRS substitution level would result in effectively improving workability, extending setting time, decreasing pulse velocity, as well as reducing gradually compressive strength, being necessary to control the excavatability of CLSM. Moreover, based on the testing data, an analytical model for predicting compressive strength of the CLSM from one to 56 days has been developed with high reliability.

2.6 CEMENT KILN DUST (CKD)

Cement Kiln Dust (CKD) or Cement By-pass Dust (CBPD) is a by-product of the manufacture of Portland cement. It is generated during the calcining process in the kiln. As the raw material are heated in the kiln dust particle are produced and then carried out with the exhaust gases at the upper end of the kiln. These gases are cooled and the accompanying dust particles are captured by efficient dust collection systems. Composition of CKD is quite variable from one source to another due to raw material and process variations. The high alkali content (K_2O) in CKD can cause alkali silica reaction in concrete. However, the addition of very small amount of CKD in flowable fill mixtures is not expected to cause ASR (Alkali Silica Reaction) especially when the sand used in the mix is free from reactive materials. The use of CKD as a complete replacement of cement with mix composition of CKD, sand and water at 296, 1503 and 333 kg/m^3 has shown 28 day compressive strength results with in recommended limits (0.35-3.5 MPa) using various water types (Al-Harthy et al., 2005).

With the use of CKD content of about 62 kg/m^3 with incinerated ash and copper slag a very low compressive strength of about 0.327 MPa was observed. This implies that mixes having cement as their main ingredient would produce higher strength than other mixes (Taha et al. 2007).

Lachemi et al. (2010), evaluated the potential use of cement kiln dust (CKD) together with slag to replace the use of cement in the production of controlled low-strength material (CLSM). The low strength requirements of CLSM compared to conventional concrete enable the use of industrial by-products for the production of CLSM. In this study, the workability-related fresh properties of CLSM mixtures were observed through slump flow diameter, V-funnel flow time and filling capacity. Setting times, temperature rise, air content and unit weight of CLSM mixtures were also determined as part of fresh properties. The hardened properties that were monitored for 28 days included the unconfined compressive strength. The test results presented herein show that a combination of less than 50 kg/m^3 slag and up to 300 kg/m^3 CKD provides a good mix that satisfies the requirements of a CLSM with similar or better properties to that of CKD-based CLSM mix containing Portland cement. Suitable CLSM mixtures with reasonable fresh and hardened properties could also be developed by using CKD alone. However, reduced strength in such CLSM mixtures may limit their field application. The slag significantly assisted in increasing compressive strength of CKD based CLSM mixtures. A CLSM mix containing a combination of slag and CKD was shown to have excellent characteristics for flowable backfill and excavatable base material. Therefore, producing CKD/slag based CLSM through the use of co-generated products from the cement and iron manufacturing processes can provide leadership for the construction industry in the transition for sustainable development.

2.7 SPENT FOUNDARY SAND (SFS)

Spent foundry sand is high quality silica sand that is a byproduct from the production of both ferrous and non-ferrous metal castings. Foundries use high quality size-specific silica sands for use in their molding and casting operations. The raw sand is normally of a higher quality than the typical bank run or natural sands used in fill construction sites. In the casting process, molding sands are recycled and reused multiple times. Eventually, however, the recycled sand degrades to the point that it can no longer be reused in the casting process. When it is not possible to further reuse sand in the foundry, it is removed from the foundry and is termed as spent foundry sand. The physical and chemical characteristics of foundry sand will depend in great part on the type of casting process and the industry sector from which it originates. Classification of foundry sands depends upon the type of binder systems used in metal casting. Two types of binder systems are generally used, and on the basis of that foundry sands are categorized as: clay-bonded sands (green sand) and chemically-bonded sands.

Clay-bonded sand also known as Green sand is composed of naturally occurring materials which are blended together; high quality silica sand (85–95%), bentonite clay (4–10%) as a binder, a carbonaceous additive (2–10%) to improve the casting surface finish and water (2–5%). It is black in color due to carbon content. Green sand is the most commonly used molding media by foundries. The silica sand is the bulk medium that resists high temperatures while the coating of clay binds the sand together. The water adds plasticity. The carbonaceous additives prevent the "burn-on" or fusing of sand onto the casting surface. Green sands also contain trace chemicals such as MgO, K_2O, and TiO_2. The green sand used in the process constitutes upwards of 90% of the molding materials used. Chemically bonded sands are used both in core making where high strengths are necessary to withstand the heat of molten metal, and in mold making. Chemically bonded sand consists of 93–99% silica and 1–3% chemical binder. Silica sand is thoroughly mixed with the chemicals; a catalyst initiates the reaction that cures and hardens the mass. There are various types of chemical binder systems used in the foundry industry. The most common chemical binder systems used are phenolic-urethanes, epoxyresins, furfyl alcohol, and sodium silicates. Chemically bonded sands are generally light in color and in texture than clay bonded sands.

Spent foundry sand is generally sub-angular to round in shape. Green sands are generally black, or gray, and chemically bonded sand is typically a medium tan or off-white color. The grain size distribution of spent foundry sand is uniform, with 85–95% of the material between 0.6 and 0.15mm, 5 to 12% of foundry sand can be smaller than 0.075mm. The specific gravity of foundry sand varies between 2.39 and 2.55 (Siddique and Noumowe 2008).

Naik et al. (2001) conducted tests for flow, temperature, unit weight, settlement, bleed water, shrinkage cracks and condition of setting of CLSM mixtures. They used a regular concrete sand and two types of foundry sands; clean foundry sand (FS1) and spent foundry sand (FS2), and two fly ashes (F1 and F2) for making CLSM mixtures. Fly ash F1 had CaO (8.5%), SiO_2 (48.4%), Al_2O_3 (27%) whereas fly ash F2 had CaO (3.2%), SiO_2 (46.1%), Al_2O_3 (24.4%). Total of 18 fly ash slurry mixtures were made. Of these, two were control mixtures (without spent foundry sand), and the remaining sixteen contained four different replacement levels of fly ash (30, 50, 70, and 85%) with two types of foundry sand (clean and spent). Unit weight of the slurry varied between 1570 and 2115 kg/m^3. Mixtures containing fly ash F1 and clean foundry sand (FS1) or spent foundry sand (FS@) showed some bleed-water at 1-h age, and the bleed-water decreased up to the age of 14 days.

In the case of mixtures made with fly ash F2 and clean foundry sand (FS1) or spent foundry sand (FS2), all the mixtures except the 85% foundry sand mixtures exhibited absence of bleed-water even at the 1-h age. This could be attributed to the greater fineness of fly ash F2 and the lower amount of water used in these mixtures compared with the fly ash F1 mixtures; (iii) all mixtures containing fly ash F2 along with clean foundry sand (FS1) or spent foundry sand (FS2) became hardened at the age of 5 days; (iv) there was slight increase in settlement up to 3 days, thereafter, the settlement became approximately constant. In general, total settlement was found to be less than 18mm for the F1 mixtures and 3.2 mm for the F2 mixtures with and without foundry sand up to 14 days. In order to have settlement less than or equal to 3 mm, the water content of the mixtures should be maintained so as to have a flow of 275 mm or less. All of the test specimens showed absence of shrinkage cracks up to the 14-day age. Compressive strength of CLSM mixtures was achieved between 0.17-0.76 MPa. Based on the investigation, they reported that (ii) compressive strength of slurry mixtures made with foundry sands and fly ash F1 and F2 increased with age (ii) generally compressive strength increased with an increasing amount of foundry sand up to certain limit, and then decreased. Excavatable slurry with up to 85% fly ash replacement with clear and spent foundry sand can be manufactured without significantly affecting the strength of the reference mixtures. the permeability of fly ash F1 slurry mixtures varied from 4.3×10^{-6} to 74.2×10^{-6} cm/s, and it was between 4.8×10^{-6} and 69.3×10^{-6} cm/s for fly ash F2 slurry mixture. The minimum permeability value was observed at 30% fly ash replacement level with foundry sand; (ii) permeability for both the fly ash mixtures was not significantly affected by increasing foundry sand content up to 70% fly ash replacement at the age of 30 days. However, it increased abruptly when the replacement levels for the fly ashes with foundry sand were increased to 80% from 70%. Spent foundry sand met all parameters of the Enforcement Standards (ES), but it exceeded the (Wisconsin Department of Natural Resources) WDNR, Preventive Action Limits (PAL) for lead and chromium. Spent foundry sand met all requirements, except for Fe, for public welfare-related Ground Water Quality Standards (GWQS).

2.8 LIMESTONE DUST

Another waste material that can contribute to sustainability is limestone dust. Limestone dust is produced during the rupturing of large stones in stone crushers for producing coarse aggregate in quarrying. It is a waste material that is locally available in Ireland and is made up of excess fines and is usually dumped in bulk quantities which causes environmental pollution. By using limestone dust in a CLSM mix, one can mitigate its negative environmental impact and also minimize the cost of producing CLSM (Naganathan et al., 2011). It does not have cementitious properties like that of PFA and GGBS, but it still can be used in a CLSM design mix as filler.

The limestone dust has the advantage of being cheap and can provide a workable/consistent mix. As the limestone dust is not a cementitious material, it will not provide any additional strength to the mix in the long term though it does assist in early age strength by providing nucleation sites for hydration. With the addition of quarry dust, there is a slight increase in compressive strength. A reason for this may be because of the high percentage of silica present in the quarry dust, which may produce more C-S-H gel during hydration which increases the strength gain (Naganathan et al., 2011). It was found that mixes containing quarry dust can achieve a desired flow with a lower water/cement ratio when compared with that of mixtures containing sand.

2.9 INCINERATOR ASH

The ash generated from the burning of domestic garbage collected from different locations is known as incinerator ash. Since incinerator ash is having very low specific gravity, the mix containing incinerator ash are observed to be having a low unit weight when compared with the mix containing only cement and sand. This is an advantage for the construction of fills on grounds with a low bearing capacity since settlement will be reduced. The mix generated lowest strength among the other when incinerated ash was considered as full substitute of cement implying it does not show pozzolanic properties when considered as full substitute of cement (Taha et al. 2007).

Naganathan et al. (2012), evaluated the properties of controlled low-strength material (CLSM) made using industrial waste incineration bottom ash and quarry dust. Various mix proportions of CLSM containing bottom ash and quarry dust were developed and the properties evaluated. Tests were performed on the CLSM in fresh and hardened states involving flowability, stability, setting time, segregation resistance, California bearing ratio (CBR), and corrosivity and the results discussed. Results indicated that the setting time of the CLSM mixtures tested ranged from 3.7 to 8 h, the fresh density from 1539 to 2100 kg/m^3, strength values from 0.22 to 11.42 MPa, mixtures were stable and no corrosively. It is shown that addition of quarry dust enhanced the performance of CLSM made using bottom ash with regard to stability, strength, and CBR and hence both the industrial waste incineration bottom ash and quarry dust are potential materials for use in CLSM.

Zhen et al. (2013), Explored the potential reuse of dewatered sludge (DS) and municipal solid waste incineration (MSWI) bottom ash as components to develop controlled low-strength material (CLSM). The effects of DS:MSWI bottom ash:calcium sulfoaluminate (CSA) cement ratio and thermal treatment of MSWI bottom ash at 900 ^{o}C on the mechanical and microstructural properties of CLSM were intensively studied to optimize the process. Results showed DS and MSWI bottom ash could be utilized for making CLSM. The CLSM prepared with milled MSWI bottom ash gave higher unconfined compressive strength (UCS) of 2.0-6.2 MPa following 1 year of curing at 1.0:0.1:0.9 $\leq$ DS:MSWI bottom ash:CSA $\leq$ 1.0:0.8:0.2. However, the corresponding strengths for CLSM containing thermally treated MSWI bottom ash ranged from 0.7 to 4.6 MPa, decreasing 26-65%. The microstructural analysis by X-ray powder diffraction (XRD), Fourier transforms infrared spectroscopy (FT-IR), as well as scanning electron microscopy (SEM) combined with an energy dispersive X-ray spectroscopy (EDS) revealed that ettringite ($C_3A \cdot 3CS \cdot H_{32}$, or AFt) crystals were the most important strength-producing constituents which grew into and filled the CLSM matrix pores. Milled MSWI bottom ash addition favored the formation of highly crystalline AFt phases and accordingly enhanced compressive strengths of CLSM specimens. In contrast, thermal treatment at 900 ^{o}C produced new phases such as gehlenite ($Ca_2Al_2SiO_7$) and hydroxylapatite ($Ca_5(PO_4)_3(OH)$), which deteriorated the pozzolanic activity of bottom ash and caused the strengths to decrease. Leaching tests evidenced that leachable substances from CLSM samples exhibited negligible health and environmental risks. The results of this study suggested that MSWI bottom ash can be effectively recycled together with DS in developing CLSM mixtures with restricted use of CSA cement.

Lee et al. (2013), conducted series of characterization tests to systematically investigate the characteristics of alkali-activated, cementless, controlled low-strength materials (CLSM) utilizing industrial by-products in the present study. Three different industrial by-products (fly ash, slag and bottom ash) were used as component materials in the CLSM mixture. The flow, bleeding, settlement and air content of fresh CLSM mixture were measured, and hardened CLSM mixtures were tested to measure their compressive strength and density. The results showed that NaOH solution as an alkaline activator had very little effect on the flowability of CLSM mixtures, whereas an increase in the amount of bottom ash (fine aggregate) resulted in a considerable reduction in the flowability of CLSM mixtures. An increase in the amount of slag resulted in a reduction of the bleeding rate. The solid NaOH amount which satisfies the maximum strength requirement for future re-excavation as suggested in ACI 229R (1999) was found to be 1.5–2.5% by weight in the CLSM mixture when a bottom ash/total binder ratio and a slag/total binder ratio were 1.5 and 0.2, respectively.

Yan et al. (2014), designed controlled low strength material using municipal solid waste bottom ash and dredged sediment as raw materials. Up to 80% of waste utilization by mass was achieved with all requirements fulfilled as general CLSM. The compressive strength of CLSMs made with bottom ash is generally higher than that of sediment. The formation of C–S–H gel contributes to the strength development and heavy metal immobilization from wastes. The heavy metal concentrations in the TCLP leachates of CLSM are far below the U.S.EPA regulatory standards, and the CLSMs are suitable for a wide range of construction applications.

2.10 WASTE GLASS POWER

Glass is unstable in the alkaline environment of concrete and could cause a deleterious alkali–silica reaction (ASR). However, such a problem can be overcome by grinding it into fine glass powder (GLP) for incorporation into concrete as a pozzolanic material. Laboratory experiments have shown that fine GLP can suppress the alkali reactivity that is present in coarser glass particles, as well as that of natural reactive aggregates. GLP undergoes beneficial pozzolanic reactions in the concrete and can replace up to 30% of cement in some concrete mixes with satisfactory strength development. Although fine GLP has been utilized as a pozzolanic material as early as the 1970s, its use has become more widespread only in recent years, mainly because of the continual accumulation of waste glass and its consequential environmental problems. Using waste glass to replace aggregates in concrete mixing offers a number of advantages due to its impermeability, enhanced flow properties, and higher strength at elevated temperatures when used in low replacement proportions (Her-Yung, 2009).

(Her-Yung, 2009), replaced fine aggregates with LCD glass-sand at a substitution of 10%, 20% and 30% and it was found that in case of W/B(water/binder) ratio of 1.3 and 1.5, an increase in the glass-sand replacement from 0 to 30%, the slump was increased from 410 to 450mm and from 420 to 560mm, respectively, indication the property of high fluidity. Regarding the initial setting time for W/B ratios of 1.1%, 1.3%, and 1.5%, the 10% glass–sand replacement sample was the fastest while the 30% one was the slowest. However, the initial setting time of the three W/B ratios was slower than the control group, indicating that increasing the addition would result in a longer initial setting time. In the case of the early-high strength concrete, the one with 10% replacement was the fastest, setting time being less than the general strength CLSM by 80–130 minutes. The compressive strength was reduced by 4–10% when the replacement level reached 30%, indicating that increasing the glass–sand replacement would result in a decrease in compressive strength. the ultrasonic pulse velocity of the general strength and early-high-strength specimens was 1267–3200 m/s and 1767–3202 m/s, respectively. In both cases, the velocity was higher when the glass–sand replacement was 30%. And when the replacement increased from 0 to 30%, the ultrasonic pulse velocity increased by 8% and 16%, indicating that the early-high-strength specimen was denser than the general strength one. the electrical resistivity varied relatively little for various W/B ratios when the aging time was less than seven days, and it gradually became obvious after 28 days. Among the various aging times, the one with the 30% replacement had higher electrical resistivity, followed by the 20%, 10%, and 0% replacements. This may be due to the high resistance of glass. Moreover, at different W/B ratios (W/B = 1.1, 1.3, and 1.5), when the replacement increased from 0 to 30%, the electrical resistivity grew by 4%, 8%, and 16%, respectively, indicating that the electrical resistivity grows when the W/B ratio decreases. The permeability ratio rises with increasing W/B ratios. The permeability ratios of the early-high-strength specimen were 0.75–0.35%, indicating that the permeability ratio of the early high- strength specimen was lower than the general strength one.

2.11 RECYCLED CONCRETE AGGREGATES

Recycled concrete aggregate (RCA) is an example of a common construction waste that is produced from demolishing concrete structures as they approach the end of their service life. Construction and demolition waste in Canada amounts to 15–20% of all landfill materials. In terms of using RCA in structural concrete, research has shown that the use of 30% RCA and 70% natural aggregate in high strength concrete produces concrete of similar strength as that containing only natural aggregates. However, concrete mixtures made with laboratory crushed RCA as the only source of aggregate show a strength reduction of 10% when compared to conventional concrete (Achtemichuk, 2009).

Miren et al. (2013), analysed the use of recycled fine aggregates for Controlled Low Strength Materials (CLSMs) production. Self-compacting and flowable CLSM material was composed of cement, fine aggregates, water and an air-entrained admixture. Adequate mix proportions of CLSM material produced with recycled fine aggregates were validated according to the minimum requirements of ASTM and the results obtained by CLSM produced with natural fine aggregates. Bleeding and penetration resistance for fresh state and density, porosity and absorption in hardened strength of optimum mix proportions of all CLSM mixtures with recycled aggregates were also validated.

2.12 WASTE TYRE RUBBER AGGREGATES

Due to the highly developed automobile industry and the popularization of transportation vehicles, the production of tyres has been substantially increasing. The total number of registered motor vehicles in Taiwan reached 221.7 million at the end of March 2012. As a result, there are a considerable number of waste tyres in existence. In the past 5 years, the annual average recycled waste tyres have amounted to more than 100,000 metric tons. Waste tyres are difficult to decompose and the disposal of waste tyres by landfill will shorten the service life of the landfill site, and thus, this disposal method is not economically reasonable. In addition, the long-term land filling of waste tyres often results in exposure of the ground surface to waste tyres or damage to the leakage-preventing coated layer of the landfill site. The willful disposal of the waste tyres may create a hotbed for vector mosquitoes and other pests, causing harm to the environment and posing the risk of environmental damage due to the dioxin generated from the combustion of waste tyres. Hence, the impact of the disposal of waste tyres on the environment is significant (Wang et al. 2013), Fresh properties and 1 day-aged compressive strength of controlled low-strength rubber concrete (CLSRC) and controlled low-strength rubber lightweight aggregate concrete (CLSRLC) with five waste-tyre rubber replacement of 0%, 10%, 20%, 30% and 40%, respectively were studied. Experimental results showed that the slump, slump flow and tube flow value of each mix proportions is greater than 190, 400 and 150 mm, respectively. The fresh properties of CLSRLC are slightly better than CLSRC. The unit weight and initial setting time are affected by the amount of rubber particles that have been substituted for natural aggregate. An average 10% increase in the amount of rubber particles decreased the unit weight by approximately 69 kg/m^3, while the initial setting time was approximately 35 minutes. The compressive strength of CLSRC and CLSRLC decrease while the amount of rubber replacement increases, respectively. Before the rubber replacement reaches 20%, the early-stage (1d) compressive strength of CLSRC and CLSRLC is greater than 0.7 MPa. The optimal rubber replacement of 20% is suggested for concerning about construction and safety in situ. By comparison with CLSRC, CLSRLC has the number of advantages such as the workability, low cost and environment-friendly.

2.13 OTHER FILLER MATERIALS

An alternative to CLSM mixes is Foamed concrete which is expensive in comparison. The most basic definition of foamed concrete is that it is ‘mortar with air bubbles in it’. The air content of foamed concrete may be upto 75% by volume. In general terms, foamed concrete can be described as a lightweight, free flowing material which is ideal for wide range of applications. It can have a range of dry densities, typically from 400 kg/m^3 to 1600 kg/m^3 and a range of compressive strengths from 1 MPa to 15 MPa.

Bentonite, which is a fine material with a high water absorbing capacity, acts as an excellent workability agent where the optimum quantity found lies in range 50-70 kg/m^3. But the major drawback of bentonite is that it could not be used for the project where high quantities of CLSM are required as it is prohibitively expensive.

Kuo et al. (2013), evaluated the practical application of waste oyster shells (WOS) as controlled low-strength materials (CLSM), using a reference sample and four fine aggregate replacement

5%, 10%, 15% and 20% WOS sand, and the cement was replaced by 20% fly ash of the materials were tested. The hardened properties and the durability are tested and other various engineering properties are investigated. The experimental results demonstrate that there was no significant reduction in the compressive strength up to 20% of dosages of WOS sand instead of sand, and a proper amount of fly ash material and WOS sand for the replacement of the fine aggregate in cement mortar fills material pores, reduces the absorption rate. WOS sand can be resources of pure calcareous materials and effective in replacement of sand, indicating appropriate application of oyster shells, it is feasible to use in CLSM.

2.14 MODELING OF CLSM MIXES

Alizadeh et al. (2014), described the design of an optimized CLSM mixture that was used as a structural fill for construction of a bridge abutment. The main performance criteria for selection of a potential CLSM mixture were compressive strength to support the bridge loads, excavatability and flowability to fill the entire abutment in one continuous pour. Several CLSM mixtures were developed and tested in the laboratory for engineering properties including flowability, density, compressive strength and stress–strain behavior. Since it was a critical area of concern in design of the CLSM bridge abutment, the bond strength performance of the CLSM to steel anchors was also investigated. In pullout tests, a CLSM mixture with higher compressive strength resulted in higher bond strength and more brittle slippage. A numerical simulation of pullout tests indicated that the bond strength decreases with increase in bar size and embedment length.

Blanco et al. (2014), proposed a general methodology for the design of optimised CLSM that includes the definition of the mechanical requirements through numerical simulations with FEM and an experimental procedure to define the mix by optimising the aggregate skeleton, the content of cement and the use of admixtures and additions. Moreover, the methodology is applied to the backfill of narrow trenches.

Bassani et al. (2015), studied the long-term stiffness characterisation of Controlled Low-Strength Materials (CLSMs) for pavement applications in substitution of granular fill materials. Three alternative CLSM mixtures, two with ordinary Portland cement and a third one with an ultra-rapid sulpho-aluminate cement, were examined. Two different sample aspect ratios were considered and the samples were subjected to different testing conditions in terms of saturation, loading time and repetition. The investigated CLSMs are insensitive to variations of loading frequency and to water saturation, and sensitive to sample aspect ratio. They exhibit a significant increase in stiffness under repeated load triaxial testing and a low permanent strain accumulation. Finally, they exhibit an increase in resilient modulus when the deviatoric stress increases.

CHAPTER 3

MATERIALS AND METHODS

3.1 GENERAL

The aim of this work is to optimize the mixture proportions for CLSM using various industrial by-products as fillers and cementitious materials. An effort has been made to generate a mix of CLSM made by replacing conventional building materials with industrial by-products. The objective is to obtain a CLSM that satisfies all the fresh and hardened state properties desired for CLSM.

For the fresh state of CLSM, it must possess sufficient flowability, consistency and density while avoiding heavy bleeding as well as any significant segregation. Flowability is particularly an important aspect of CLSM as it allows the materials to be self-compacted, so that it can readily flow into and fill voids. Flowability of a CLSM mix is measured by means of flow table test; wherein the adequate target flow from the test should be between 550 to 650 mm (according to the ENFARC 2005 guidelines for the SCC). The mix is appropriate for unreinforced or slightly reinforced concrete structures that are cast from the top with free displacement from the delivery point, casting by a pump injection system (e.g. tunnel linings), sections that are small enough to prevent long horizontal flow (e.g. piles and some deep foundations). The fresh state density of CLSM mix is between 2100 to 2350 kg/m^3. The consistency of the mix is equally important. This aspect will heavily depend on the quantity of fines present in the mix. The finer a material is, the greater is surface area to volume ratio, which means there is more surface area available to hold and absorb water in the mix. Fineness is measured in terms of surface area per unit mass.

Although guidelines for CLSM suggests that the 28-day compressive strength of CLSM can be as high as 8 MPa, but the objective for the developed mix was to be used as material which can be excavated easily by normal hand or mechanical operations. Hence, the desired 7-day and 28-day compressive strength was targeted as less than or upto1 MPa and 2 MPa, respectively.

3.2 MATERIALS

The basic materials for a CLSM mix are same as the materials in conventional concrete i.e. cement, fine aggregate and water. As stated by ACI 229R (1999), coarse aggregates are generally not used in CLSM mixes. In this study, fine aggregates were substituted with Spent Foundry Sand (SFS), whereas Fly Ash (FA), Cement Kiln Dust (CKD) and Ground Granulated Blast-Furnace Slag (GGBS) were used as full or partial substitute of cement. The basic properties of all the materials are discussed here under.

3.2.1 Cement

Cement is a binding material that sets and hardens when water is added to it causing initiation of hydration reaction, which further results into formation of CSH gel around other particles which acts as link between them and can bind them together. Other supplementary cementing materials can also be used with cement but cement is considered necessary component for the initiation of the hydration reaction without which other pozzolonas cannot show any binding property.

Figure 3.1: OPC Cement used in the present study.

In the present study, 43-grade Ordinary Portland Cement (OPC) manufactured by JK Lakshmi Cement Company was used. Figure 3.1 shows the cement used for developing different mixes.

Various physical properties of cement are shown in Table 3.1. It can be observed from the table that the physical properties of the cement complies with the specifications of IS 8112: 1989. XRF (X-Ray Florescence) was performed on the sample of cement and different compounds with their percentage. The chemical composition of cement used is presented in Table 3.2.

Table 3.1: Physical properties of Cement used in the study

Property	**Value**	**IS 8112:1989 Specifications**
Grade	OPC-43	OPC-43
Specific Gravity	3.14	3.10-3.25
Initial Setting time	152 minutes	30 minutes, minimum
Final Setting time	262 minutes	600 minutes, maximum
Blaine Fineness	3250 cm^2/g	2250 cm^2/g
28-Day Compressive Strength	47.3 MPa	43-58 MPa

Table 3.2: Chemical composition of cement observed present study.

Constituent	**Cement Used**	**IS 8112:1989 Specifications**
CaO	63.49 %	-
SiO_2	21.25 %	-
Al_2O_3	4.74 %	-
Fe_2O_3	4.30 %	-
SO_3	2.92 %	Max. 3.5%
MgO	1.02 %	Max. 6%
K_2O	0.78 %	-
TiO_2	0.36 %	-
BaO	0.32 %	-
Na_2O	0.30 %	-
P_2O_5	0.21 %	-
Cl	0.09 %	Max. 0.1%
MnO	0.08 %	-
SrO	0.04 %	-
Ratio of aluminia to iron oxide	1.12	Min. 0.66%

3.2.2 Cement Kiln Dust (CKD)

CKD is the byproduct of cement manufacturing process, collected from the exhaust gases of the calcination of raw material using ESP's (Electro Static Precipitators). It is a fine powdery material which is very similar to cement. The physical and chemical properties of CKD vary from plant to plant, depending upon the type of raw material used for production of clinker, the method used for heating the kiln and type of pollution controlling device used for its collection. However, the dust collected from the same plant generated during the manufacturing of same type of cement shows similar properties. The coarser particles of CKD consist of free lime which could be collected closet to the kiln and finer particles mainly consist of sulfates and alkalis. It is lime and silica which contribute to provide cementing capacity to CKD. As suggested by Siddique 2009, CKD can be successfully applied in CLSM due to its low cementing capacity. It has also been observed that CKD has higher water demand.

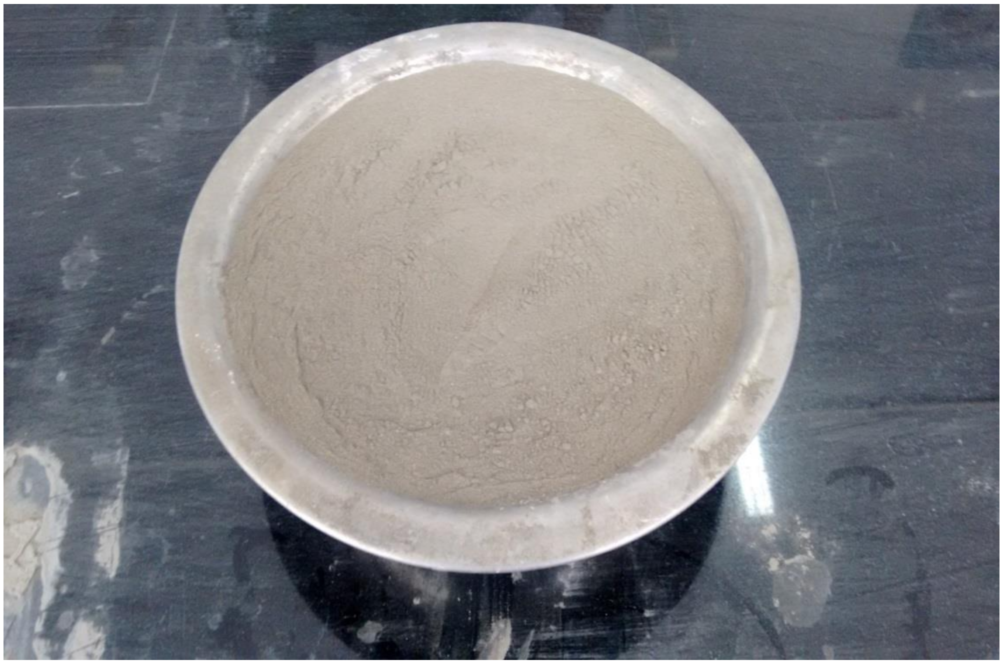


Figure 3.2: CKD used in the study

CKD from the cement manufacturing plant of Ambuja Cement, Suli, Himachal Pradesh was collected and used throughout the study. CKD was used as a complete replacement to cement because of its cementing capacity and presence of free lime which could help in initiation of hydration reaction. Figure 3.2 shows the CKD used in the study. The specific gravity of CKD was 3.05 and has a Blaine's fineness value of 4050 cm^2/g. The amount of CaO and SiO_2 present in CKD as observed by the EDX (Energy-dispersive X-ray spectroscopy) analysis performed was 54.29 and 25.84%, respectively. The quantity of CaO and SiO_2 are comparable to the quantity of these compounds in cement hence indicating that the behavior of CKD will be somewhat same as cement. Various constituents with their proportions and composition from different sources are given in Table 3.4. Figure 3.3 shows the SEM (Scanning Electron Microscopy) image of the sample of CKD at 50μm scale. SEM shows that the particles of CKD are angular in nature. Peaks observed for different elements caused by X-rays given off as electrons return to the K electron shell are shown in Figure 3.4. The XRD (X-Ray Diffraction) patron for the material is also shown in Figure 3.5.

Table 3.3: Composition of CKD used in present study and from different sources.

Constituents	Present Study	Zhu et al. 1999	Lachemi et al. 2010
SiO_2	25.84	14.66	13.1
CaO	54.29	41.52	58.1
Al_2O_3	6.84	3.94	4.2
Fe_2O_3	3.33	1.38	2.3
MgO	2.89	1.4	3.3
SO_3	5.74	6.09	10.6
Na_2O	0.15	0.45	0.7
K_2O	0.59	2.44	2.8
TiO_2	0.32	-	0.3

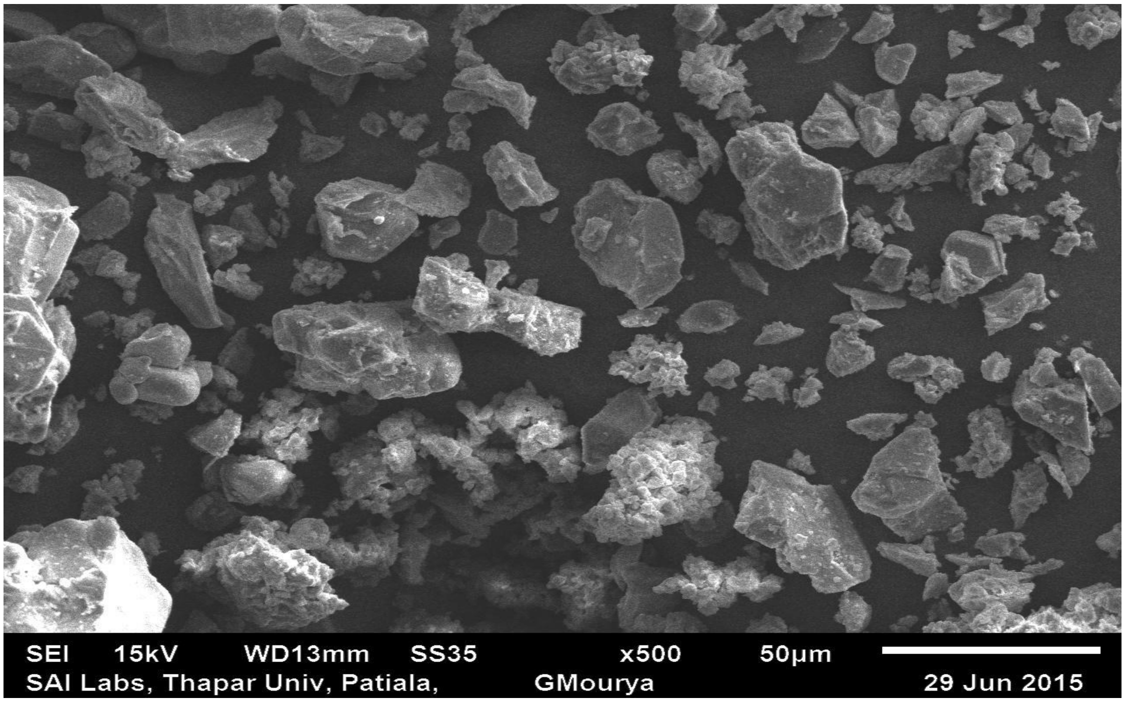


Figure 3.3: SEM image of sample of CKD at 50μm scale.

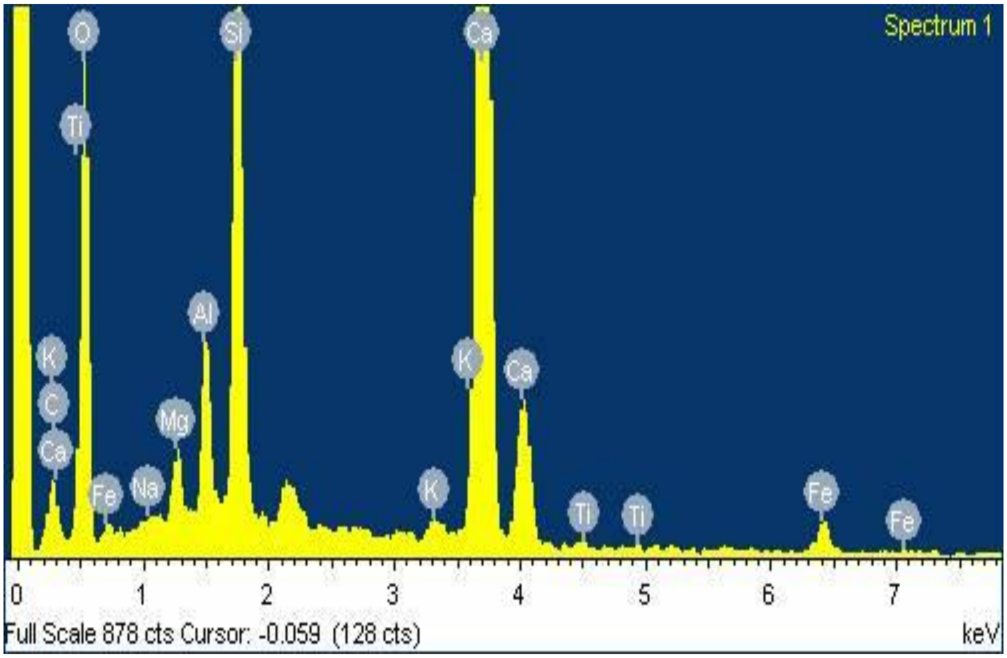


Figure 3.4: Peaks obtained for different compounds on sample of CKD using EDX analysis.

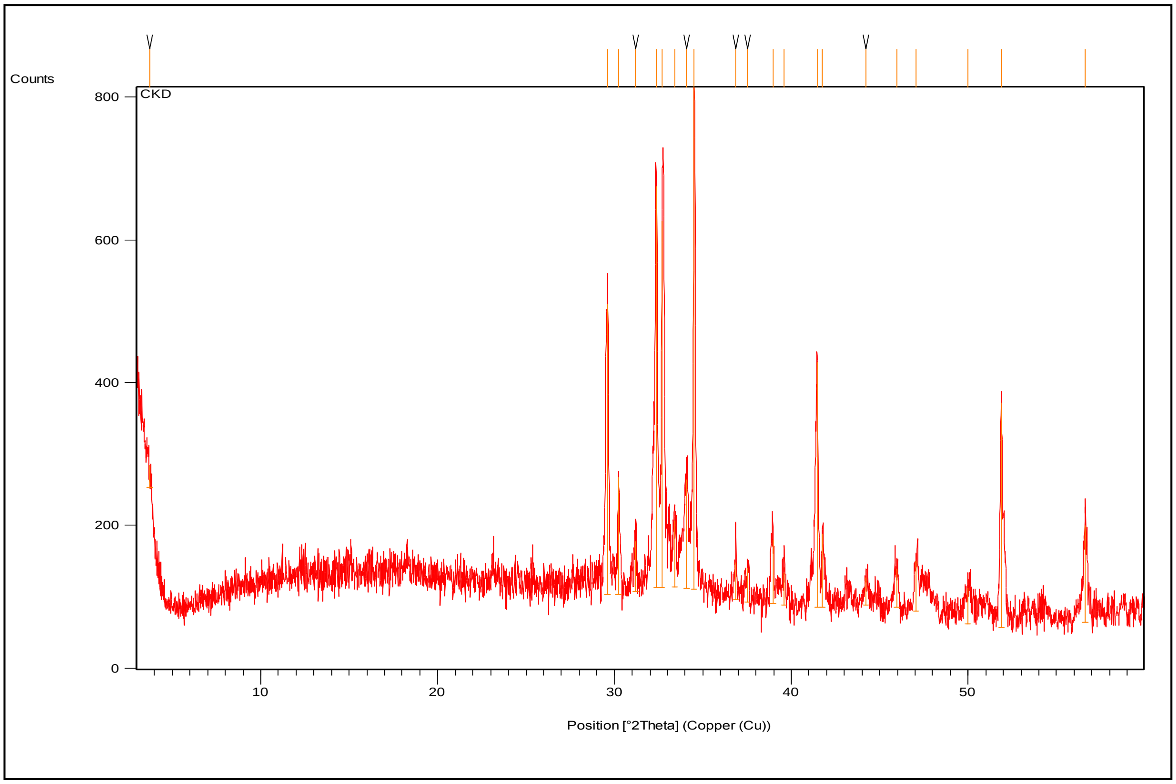


Figure 3.5: Counts observed for the sample of CKD in XRD analysis

3.2.3 Fly Ash

Fly ash is a finely divided residue that results from the combustion of ground or powdered coal and that is transported by flue gases in the thermal power plant. Coal burning power plants annually produce millions of tons of FA as a waste product world-wide. According to ACI 229R (1999), Fly ash used in production of CLSM mixes do not need to conform to either class F or C as described in ASTM C 618 (2003).

In the present study fly ash obtained from Guru Nanak Thermal Power Plant, Bathinda, Punjab was used as a partial replacement of cement. Fly Ash used in this study is shown in Figure 3.6. The fly ash was having specific gravity of 2.36 and a Blaine's fineness value of 3527 cm^2/g. The SEM (Scanned Electron Microscope) image of fly ash at a scale of 50μm used in the study is given in Figure 3.7 showing the particles glassy and round in nature. The EDS (Energy-dispersive X-ray spectroscopy) on the raw sample of fly ash revealed the presence of SiO_2 as 66.96 and CaO as 9.04%, conforming to be termed as Class F fly ash. Various constituents found in the fly ash are given in Table 3.4. Peaks observed during EDS analysis for various elements caused by X-rays given off as electrons returns to their K electron shell (Figure 3.8) revealed the presence of high quantity of silica and alumina in the raw sample of fly ash. Figure 3.9 shows XRD graph of FA at reference angles (2θ) varying from 20^o to 80^o and it was found from the results that fly ash was containing mainly two compounds SiO_2 and Aluminum silicon oxide with SemiQuant of 78 and 22%, respectively.

Table 3.4: Chemical composition of fly ash used.

Constituent	Class F Fly ash (%)	ASTM C 618 (2003):Requirements
SiO_2	68.95	-
Al_2O_3	17.41	-
Fe_2O_3	1.28	-
SiO_2+Al_2O_3+Fe_2O_3	87.64	70 minimum
CaO	9.04	-
MgO	3.17	5 maximum
Na_2O	0.15	1.5 maximum

Figure 3.6: Fly Ash used in the study

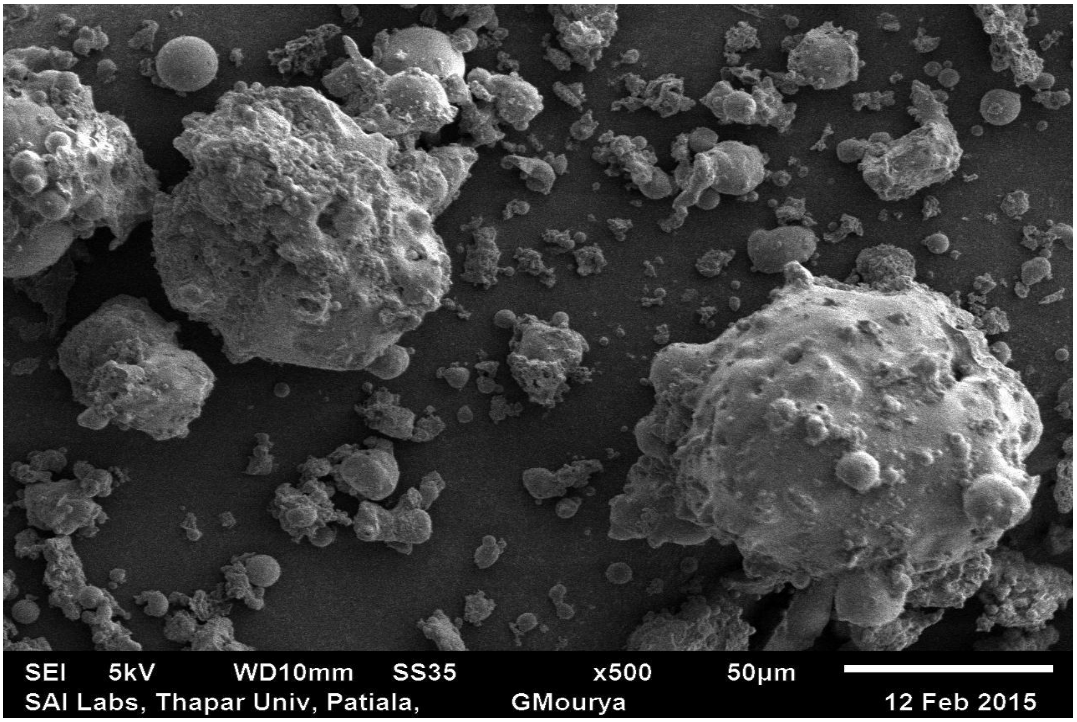


Figure 3.7: SEM image of Fly Ash at 50µm scale

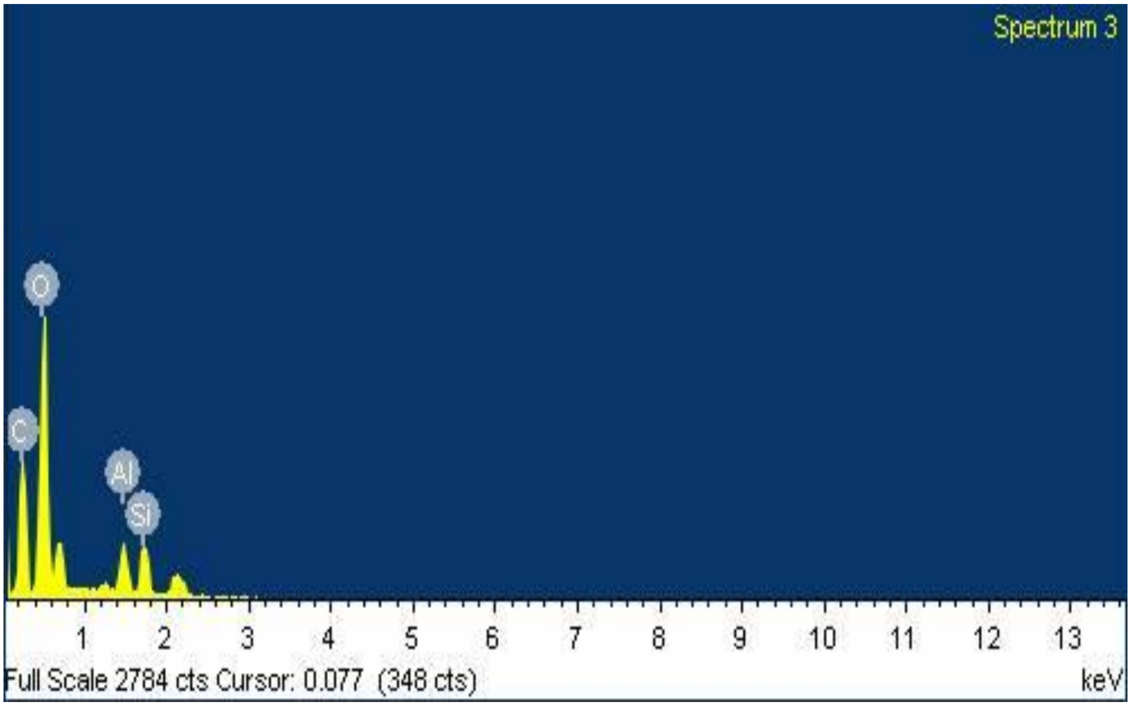


Figure 3.8: Concentrations of various elements in the Fly Ash (EDX).

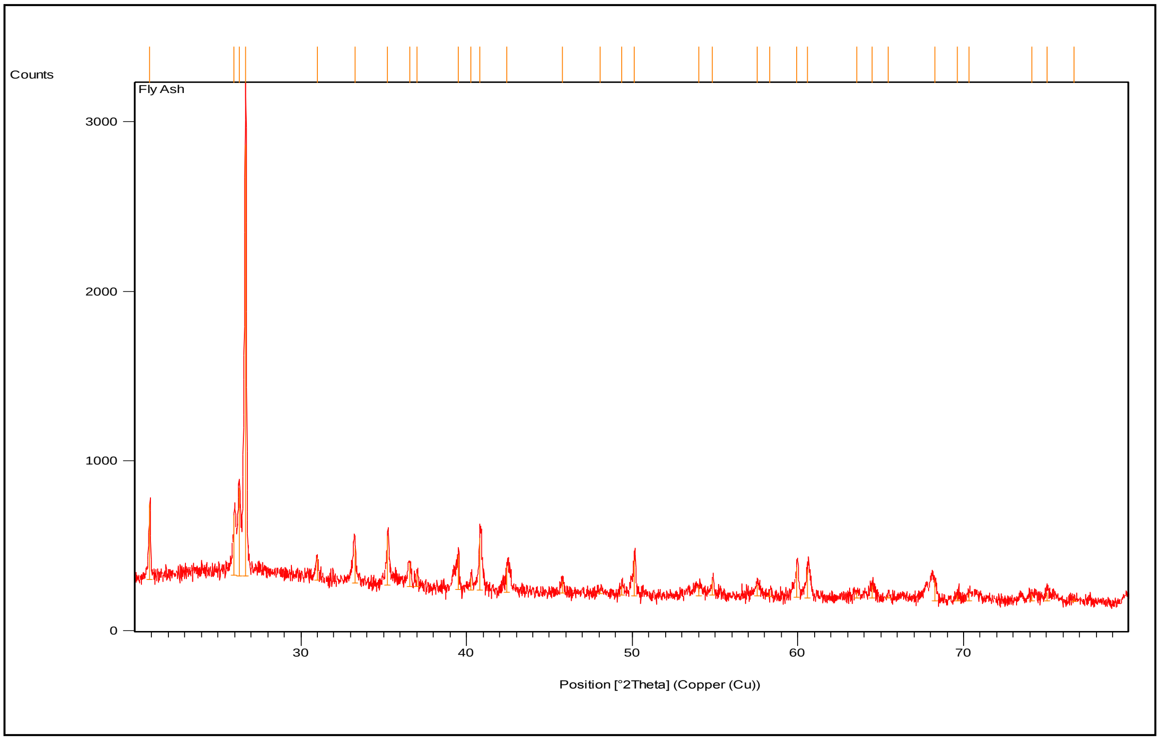


Figure 3.9: XRD graph of Fly Ash at various reference angles (2θ)

3.2.4 Ground Granulated Blast-furnace Slag (GGBS)

GGBS is a by-product obtained from the blast furnace in the production of iron, copper and steel. When molten slag is quickly quenched from a high temperature with water in pond or powerful water jets, most of the lime, magnesia, silica and alumina are held in non-crystalline or glassy state. This GGBS should be finely grounded into particle size of less than 45μm (Sheen et al. 2013) to be used for replacing cement. GGBS is commonly used as a cementitous material and may be used as substitute of Portland cement from 10% to 90% (Buokini et al. 2009) to enhance the workability and durability properties. The use of blending cement in construction is widely agreed to provide an important benefit of environmental protection.

Figure 3.10: GGBS used in the study

In the present study, a product Alcofine of Counto Microfine Products Pvt. Ltd., has been used as is shown in Figure 3.10. The GGBS was having a specific gravity of 2.9 and Blaine's fineness value of 4490 cm^2/g. The SEM image of the GGBS shown in Figure 3.11 indicates that particle size of GGBS is less than 45μm. As shown in Table 3.5, GGBS was having a high SiO_2 content of 73.47% and lime (CaO) as 12.40%. Figure 3.12 indicates peaks observed for different elements when their electrons returned to their K shell. Figure 3.13 shows XRD graph of GGBS at reference angles (2θ) varying from 20^o to 80^o and it was found from the results that GGBS was containing Fe_3Si, AlFe and $FeAl_2Si$ with a SemiQuanit of 6%, 17% and 77%, respectively.

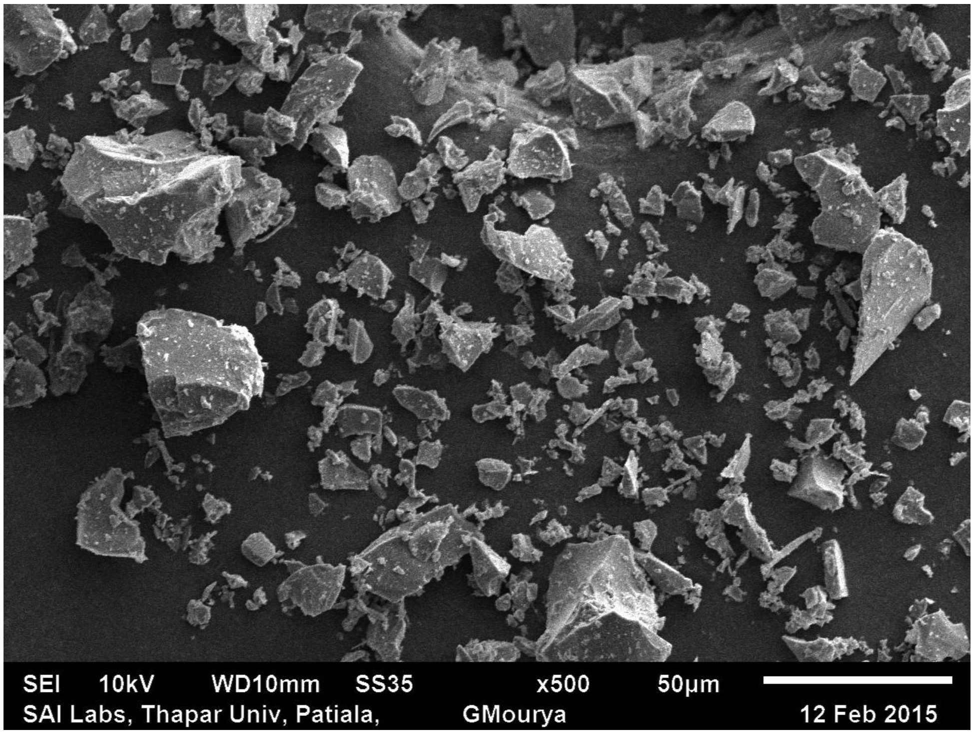


Figure 3.11: SEM image of the GGBS at 50µm scale

Table 3.5: Chemical composition of GGBS

Constituent	Composition (%)
CaO	12.40
SiO_2	73.47
Al_2O_3	4.35
SiO_2	5.48
MgO	2.14

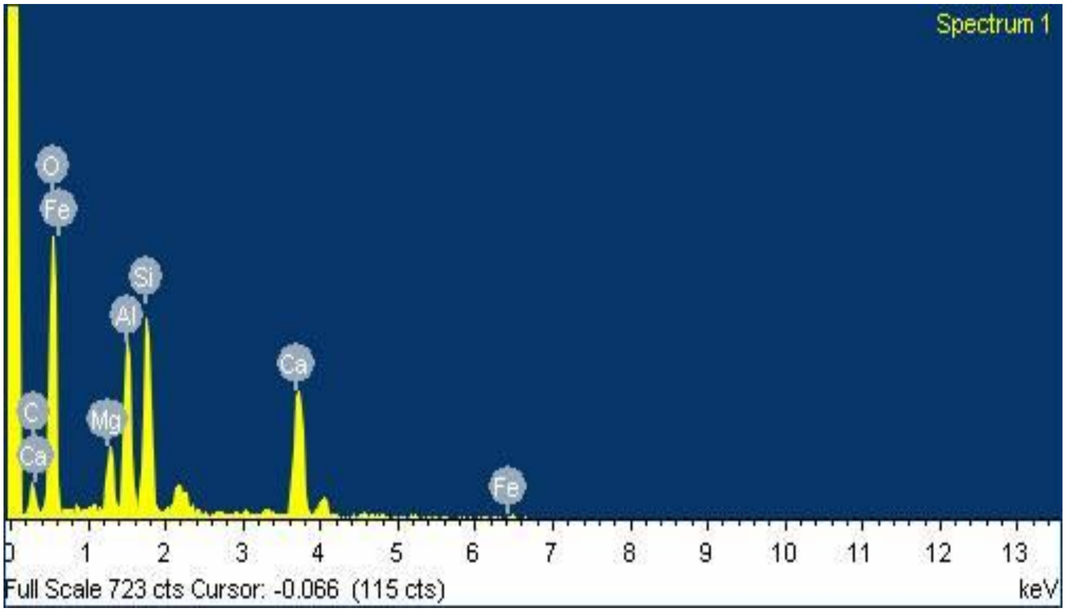


Figure 3.12: Peaks observed for the sample of GGBS under EDX.

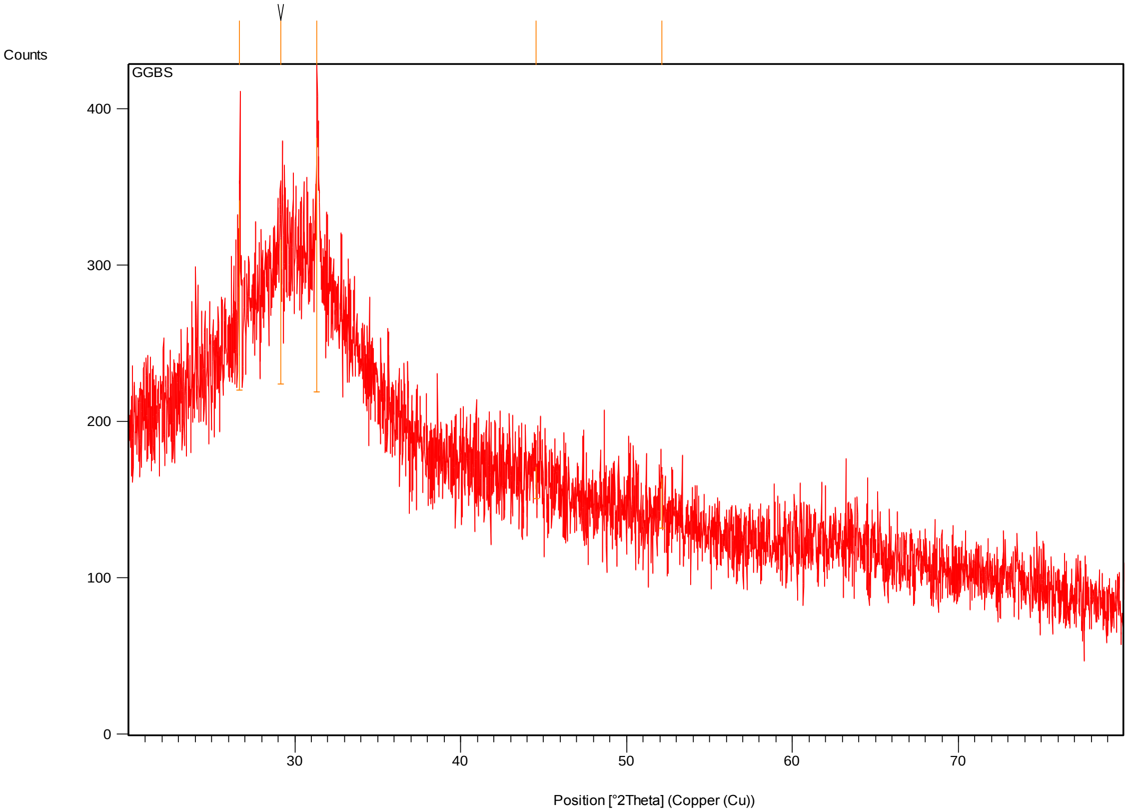


Figure 3.13: XRD graph of GGBS at various reference angles (2θ)

3.2.5 Fine Aggregates

An important factor considered to control the behavior of CLSM is the type and size of fine aggregates used in the mix. As approximately 75% of the CLSM is made up of fine aggregates only, the properties of fine aggregates used affect the properties of the resulting CLSM mix. Two types of fine aggregates were used in this study, Natural River Sand (NS) and Spent Foundry Sand (SFS).

a) Natural River Sand

River sand from Pathankot as shown in Figure 3.14 was used as one of the fine aggregates in this study. Sand was classified as coarse sand. The sand was having grain size distribution curve as shown in Figure 3.15 which is conforming to the ASTM C33 (2003). The river sand had a specific gravity of 2.59, fineness modulus of 2.45 and water absorption of 1.63%. Fine aggregates were used in oven dry condition to check the change in moisture content of sand due to various environmental factors. CLSM mixes were prepared with river sand to evaluate the effect of change in the type of fine aggregate while moving from conventional building materials to industrial by-products.

Figure 3.14: River Sand used in the study

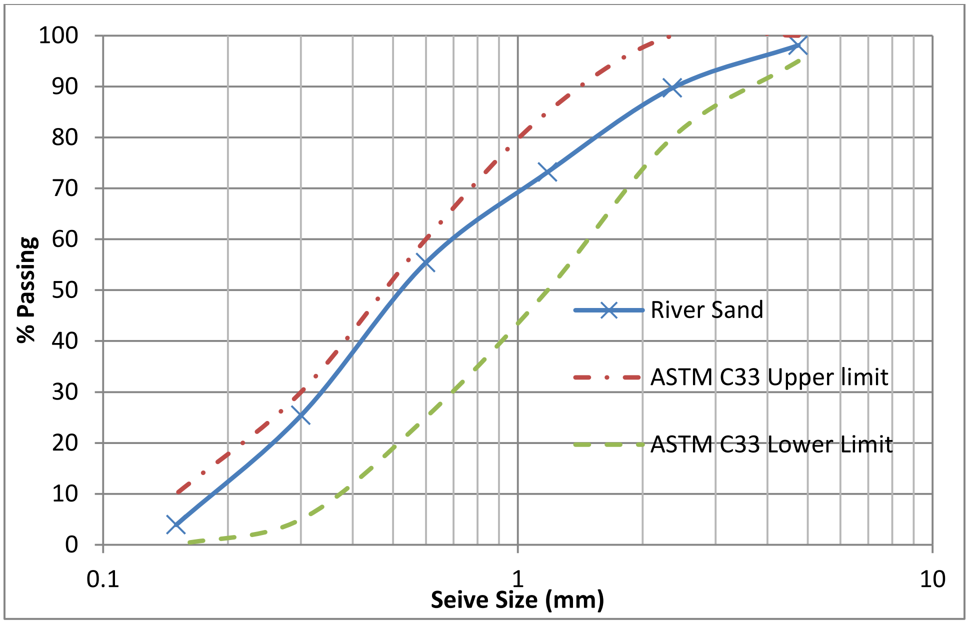


Figure 3.15: Particle size distribution curve for natural river sand.

b) Spent foundry sand

Spent foundry sand (SFS) is a by-product from the production of both ferrous and nonferrous metal castings. High quality size-specific silica sands are used by the foundries in their molding and casting operations. Spent foundry sand is removed from the foundry when it is not possible to further reuse the sand. Spent foundry sand (SFS) is also known as Waste foundry sand (WFS) or Used foundry sand (UFS). On the basis of the type of binder system used in metal castings, waste foundry sand is categorized as clay bonded sand and chemical bonded sand.

Clay-bonded sand also known as green sand is composed of naturally occurring materials which are blended together; high quality silica sand (85–95%), bentonite clay (4–10%) as a binder, a carbonaceous additive (2–10%) to improve the casting surface finish and water (2–5%). It is black in color due to presence of carbon content. Chemically bonded sand consists of 93–99% silica and 1–3% chemical binder. It is thoroughly mixed with the chemicals; a catalyst initiates the reaction that cures and hardens the mass. The most common chemical binder systems used are phenolicurethanes, epoxy-resins, and sodium silicates. Chemically bonded sands are generally light tan in color and clay bonded sands are black in color.

Figure 3.16: Spent Foundry Sand used in the study

SFS was used as complete replacement of natural river sand in the mixes of CLSM. SFS was obtained from a metal tools manufacturing industry at Jalandhar, Punjab. SFS used in the present study is shown in the Figure 3.16 being tan in color can be classified as chemically bonded sand. As observed from the previous research findings (American foundry men's society, and Siddique et al. 2010), SFS consists of high quality of silica which can be observed in Table 3.3 showing a SiO_2 content of about 77.17%. The grain size distribution curve for SFS used for carrying out various tests is shown in Figure 3.17. The graph shows that SFS does not lie in the range of ASTM C33:2003 for its gradation but as suggested by ACI 229R (1999), fine aggregates need not to conform to standard codes for their application in CLSM. The sub rounded particles of SFS can be seen in the SEM (Scanned Electron Microscopy) image of the sample at 100µm scale (Figure 3.18). SFS was having a specific gravity of 2.52 and water absorption of 4.43%. Figure 3.19 show peaks observed for various elements as electrons returns to K shell, while conducting EDX (Energy Dispersive X-ray spectroscopy) on the sample of spent foundry sand indicating a high content of silica in the material. Figure 3.20 shows XRD (X-Ray Diffraction) graph of SFS at reference angles (2θ) varying from 20^o to 80^o and it was found from the results that Quartz was the main compound having chemical formula SiO_2 with SemiQuant of 100%. XRD results indicated high percentage of Silica in SFS.

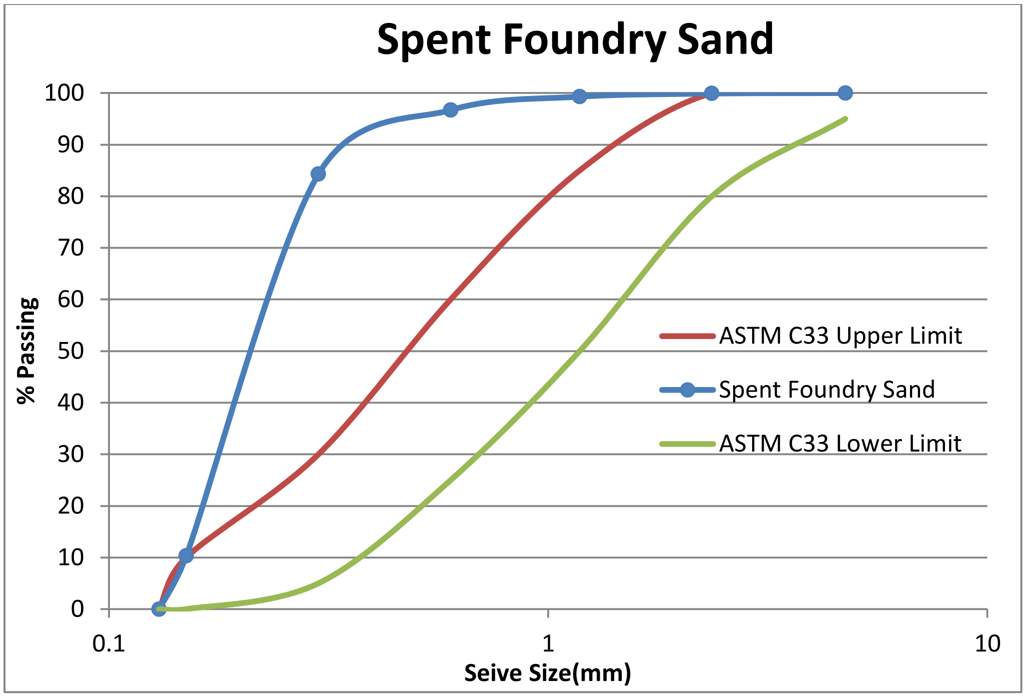


Figure 3.17: Particle size distribution curve for spent foundry sand.

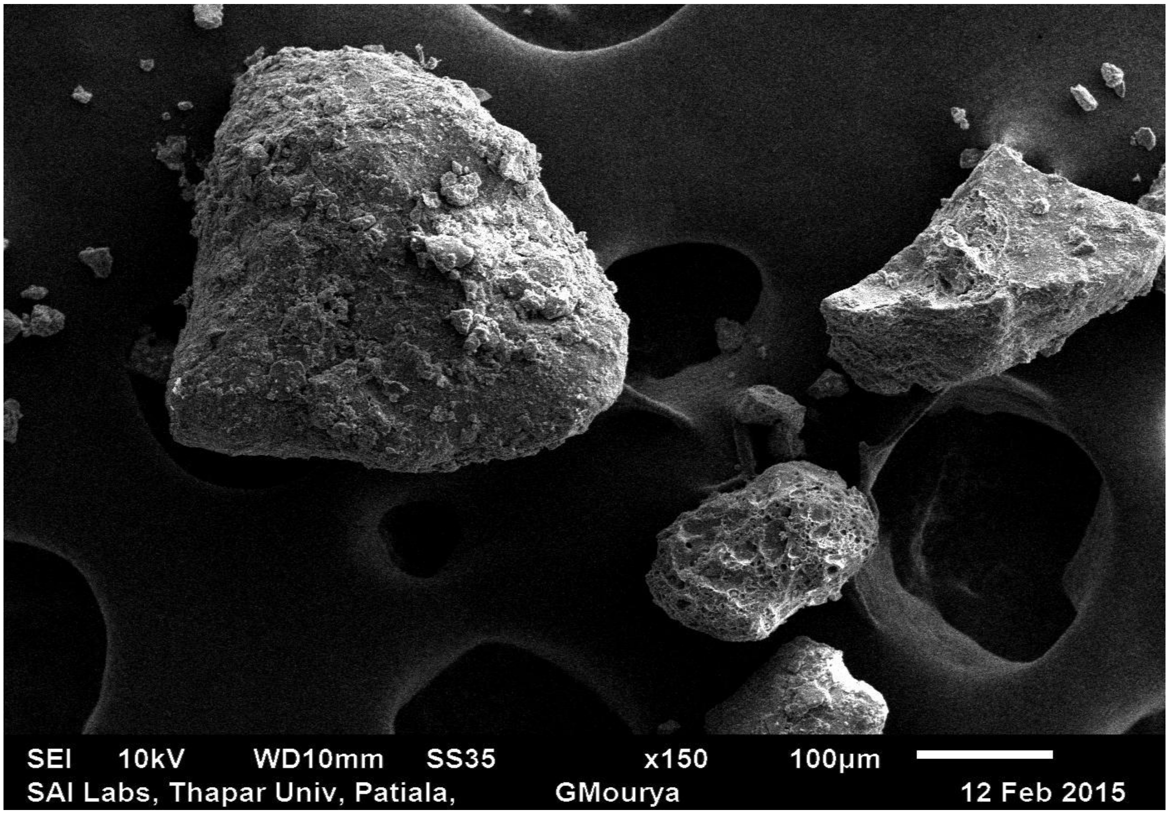


Figure 3.18: SEM image of the foundry sand at 100µm scale

Table 3.6: Constituents in SFS (in %) as in present study and in previous research work

Constituents	Present Study	American Foundry men's Society(1991)	Siddique et al. 2011
SiO_2	77.17	87.91	78.81
Al_2O_3	4.99	4.7	6.32
Fe_2O_3	0.69	0.94	4.83
CaO	1.29	0.14	1.88
MgO	3.4	0.3	1.95
SO_3	-	0.09	0.05
Na_2O	2.18	0.19	0.1
K_2O	1.36	0.25	-
TiO_2	-	0.15	-
Mn_2O_3	-	0.02	-
SrO	-	0.03	-

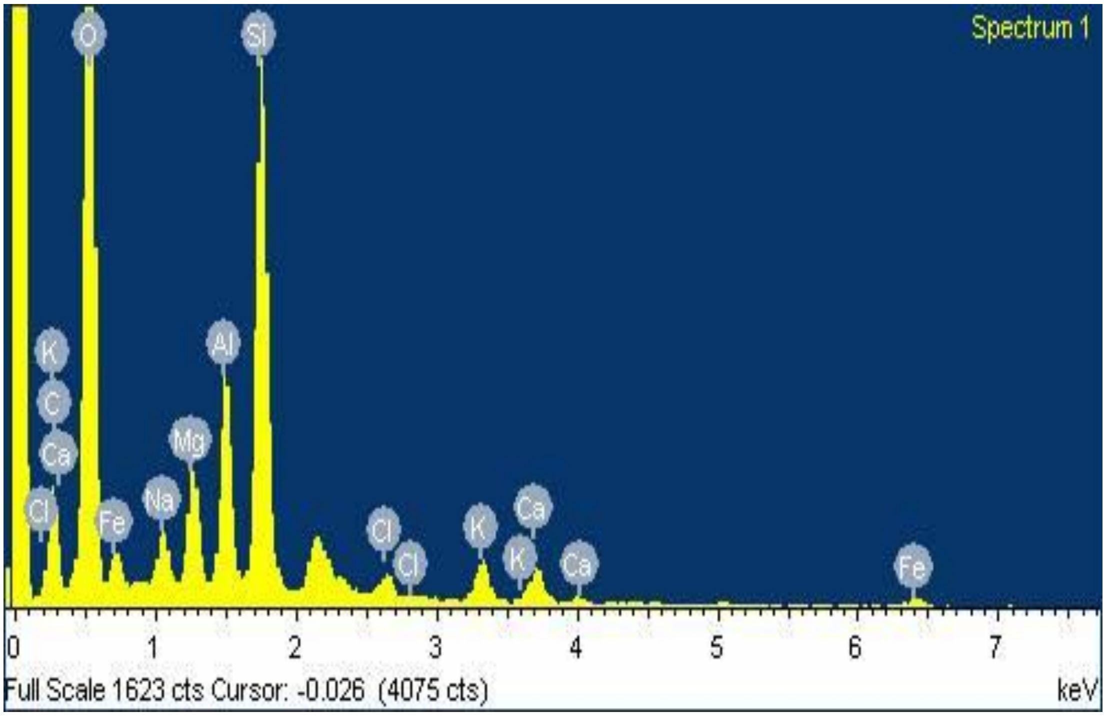


Figure 3.19: Peaks for various elements observed while conducting EDX on SFS sample.

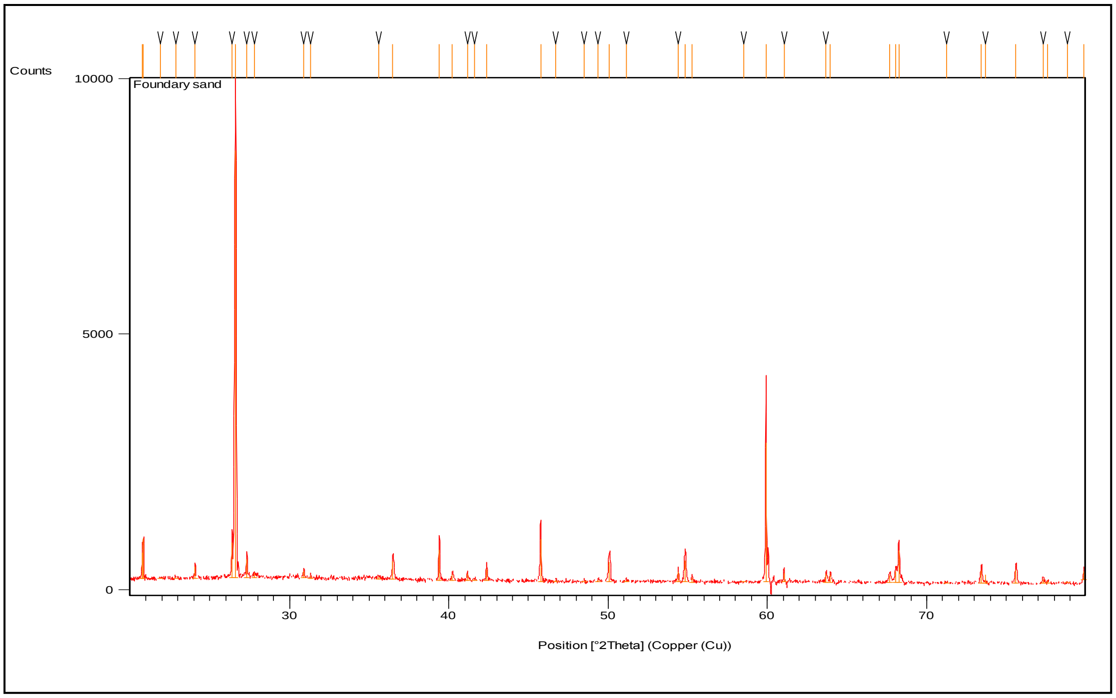


Figure 3.20: XRD graph of Foundry Sand at various reference angles (2θ)

3.3 MIXES

The various mix combinations of the different filler and cementitious materials were made in order to achieve the optimized CLSM mix. The trial mixes can be clubbed in following three categories.

3.3.1 Base Mixes

It included four mixes; one set of mixes contained cement as binder with river sand and spent foundry sand as fine aggregates and the other contained CKD as binder with river sand and spent foundry sand as fine aggregates. The list of combinations for preparation of base mixes is presented as below:

- Cement/River Sand (RS)
- Cement/Spent Foundry Sand (SFS)
- CKD/River Sand (RS)
- CKD/Spent Foundry Sand (SFS)

3.3.2 Binary Mixes

It included three types of mixes; one contained cement as binder, GGBS as filler and river sand as fine aggregate. The second binary mix contained cement as binder, GGBS as filler and spent foundry sand as fine aggregate and the last one contained CKD as binder, GGBS as filler and spent foundry sand as fine aggregate. The list of various combinations for the preparation of binary mixes is described as below.

- Cement/GGBS/River Sand
- Cement/GGBS/Spent Foundry Sand
- CKD/GGBS/Spent Foundry Sand

3.3.3 Ternary Mixes

For the generation of ternary mixes, GGBS in above described binary mixes was replaced with fly ash at different volume fraction and various fresh and hardened properties were evaluated. The list of combinations of materials used for preparation of ternary mixes is shown as below.

- Cement/GGBS/Fly Ash/River Sand
- Cement/GGBS/Fly Ash/Spent Foundry Sand
- CKD/GGBS/Fly Ash/Spent Foundry Sand

The above mixes were tested in the Structural Laboratory of Thapar University, Patiala. The idea was to get the complete replacement of conventional construction materials with the industrial by-products and finding the best combination of these materials to make the mix more economical, and environmentally friendly.

The performance of the CLSM was to be optimized by varying the quantites of each constituent. Numerous pours had to be carried out for each mix in which the performances and observations were to be recorded. As the pouring program proceeded, subsequent mix designs were then varied depending on the results of the previous pour. This method of optimization is known as “Trial Mixing”.

This procedure is also adopted by other researchers, it is mentioned by ACI 229R (1999) that “Trial mixtures are evaluated to determine how well they meet certain goals for strength, flowability, and density. Adjustments are then made to achieve the desired properties.”

3.4 MIX PROPORTIONS

Mix Proportioning for the basic, binary and ternary mixes was started by studying the results from previous research work already done. From the results of each trial, further adjustments were made to improve the properties of CLSM i.e. consistency, flow ability and low compressive strength. The details of all mixes are discussed here under.

3.4.1 Base Mixes

Base mixes were prepared to study the behavior of the CLSM when only cement or CKD was used as binder and river sand or spent foundry sand was used as fine aggregate. The comparison of the results from these trials could help in finding the effect of each material on the property of the CLSM as a whole.

a) Using cement as binder

The base mixtures were prepared using both river sand and spent foundry sand to evaluate the behavior of the CLSM when used only with cement. Table 3.7 shows various single binder mixtures prepared using cement.

Table 3.7: Mix proportions for base mixes with cement as binder

MIX	**Type of Sand**	**Mix proportions (kg/m^3)**	
		Cement	**Sand**
C/R	Natural Sand	140	1790
C/F	Spent Foundry Sand	140	1630

b) Using CKD as binder

Similarly base or singular binder mixtures were also prepared using CKD as shown in Table 3.8. From literature, it was found that CKD provides very low strength which may be below the strength requirements of CLSM. Hence, higher quantity of CKD was used as compared to the amount of cement used in the corresponding mixes.

Table 3.8: Mix proportions for base mixes with CKD as binder

MIX	**Type of Sand**	**Mix proportions (kg/m^3)**	
		CKD	**Sand**
K/R	Natural Sand	300	1750
K/F	Spent Foundry Sand	300	1510

3.4.2 Binary and Ternary Mixes

The binary and ternary mixes were considered using cement/CKD as binder, GGBS/FA as filler and RS/SFS as fine aggregate. The ratios of GGBS and Fly ash was kept as 100/0, 80/20, 60/40, 40/60, 20/80 and 0/100 by volume. The initial quantity of cement and GGBS was taken as 50 and 200 kg/m^3, respectively. The mixture proportions used for cement and CKD with natural and spent foundry sand are discussed as below.

a) Using cement as binder and natural sand as fine aggregate

The initial quantity of cement was taken as 50 kg/m^3 and the initial quantity of GGBS was taken as 200 kg/m^3: subsequently, then GGBS was replaced with fly ash, in terms of specific gravity by considering ratio of GGBS/Fly ash as 100/0, 80/20, 60/40, 40/60, 20/80 and 0/100, respectively. When initial slump was conducted for the binary mixes of cement as binder and GGBS as filler, along with natural sand, shear slump was achieved with the use of GGBS at 200 kg/m^3. Hence, new set of trials were done and the amount of fines were increased to achieve true slump and with number of trials, true slump was achieved at a GGBS content of 400 kg/m^3. The mix proportions used with cement as binder are shown in Table 3.9. In the table, the mixes marked as ‘A’ are trial mixes and were used only for initial trials, while mixes marked as ‘B’ are final mixes used in the study.

Table 3.9: Mix proportions for binary and ternary mixtures with cement as binder and River Sand (RS) as fine aggregates.

MIX	**Type of Sand**	**Mix proportions (kg/m^3)**				**GGBS/FA**
		Cement	**GGBS**	**Fly Ash**	**RS**	
C/R/G$_{100A}$	Natural Sand	50	200	0	1740	100/0
C/R/G$_{80A}$	Natural Sand	50	160	34.2	1740	80/20
C/R/G$_{100B}$	Natural Sand	50	400	0	1660	100/0
C/R/G$_{80B}$	Natural Sand	50	320	68.4	1660	80/20
C/R/G$_{60B}$	Natural Sand	50	240	136.4	1660	60/40
C/R/G$_{40B}$	Natural Sand	50	160	205.24	1660	40/60
C/R/G$_{20B}$	Natural Sand	50	80	273.86	1660	20/80
C/R/G$_{0B}$	Natural Sand	50	0	342	1660	0/100

b) Using cement as binder and spent foundry sand as fine aggregate

Similarly initial trials mix were prepared with cement as 50 kg/m^3 and GGBS as 250 kg/m^3 and for each mix, GGBS was replaced with Fly Ash by volume in the ratios 100/0, 80/20, 60/40, 40/60, 20/80 and 0/100, respectively. Another batch was made by increasing the quantity of GGBS by 50 kg/m^3 to evaluate the effect of increase in the quantity of pozzolanas on various properties of CLSM as shown in Table 3.10. For this second batch the quantity of cement was reduced to 25 kg/m^3. Mixes marked as 'C' were having quantity of cement as 50 kg/m^3 and initial quantity of GGBS as 250 kg/m^3. Mixes marked as 'D' were having quantity of cement of 25 kg/m^3 and initial quantity of GGBS as 300 kg/m^3.

Table 3.10: Mix proportions for binary and ternary mixtures with cement as binder and spent foundry sand as fine aggregate.

MIX	**Mix proportions (kg/m^3)**				**GGBS/FA**
	Cement	**GGBS**	**Fly Ash**	**SFS**	
$C/F/G_{100C}$	50	250	0	1450	100/0
$C/F/G_{80C}$	50	200	42.75	1450	80/20
$C/F/G_{60C}$	50	150	85.5	1450	40/60
$C/F/G_{40C}$	50	100	128.25	1450	60/40
$C/F/G_{20C}$	50	50	171	1450	80/20
$C/F/G_{0C}$	50	0	213.75	1450	100/0
$C/F/G_{100D}$	25	300	0	1530	100/0
$C/F/G_{80D}$	25	240	51.3	1530	80/20
$C/F/G_{60D}$	25	180	102.6	1530	60/40
$C/F/G_{40D}$	25	120	153.9	1530	40/60
$C/F/G_{20D}$	25	60	205.2	1530	20/80
$C/F/G_{0D}$	25	0	256.5	1530	0/100

Table 3.11: Mix proportions for binary and ternary mixtures with CKD as binder and spent foundry sand as fine aggregate.

MIX	**Mix proportions (kg/m^3)**				**GGBS/FA**
	CKD	**GGBS**	**Fly Ash**	**SFS**	
$K/F/G_{100}$	200	100	0	1400	100/0
$K/F/G_{80}$	200	80	16.98	1400	80/20
$K/F/G_{60}$	200	60	33.97	1400	60/40
$K/F/G_{40}$	200	40	50.96	1400	40/60
$K/F/G_{20}$	200	20	67.95	1400	20/80
$K/F/G_{0}$	200	0	85.5	1400	0/100

c) *Using CKD as binder and foundry sand as fine aggregate*

Minimum quantity of CKD which was used to initialize the hydration reaction as seen from the literature was 200 kg/m^3. Hence, same amount of CKD was used for present study with the quantity of GGBS as 100 kg/m^3. Further, for subsequent mixes 20% of GGBS was replaced by fly ash showing a mix ratio of 100/0, 80/20, 60/40, 40/60, 20/80 and 0/100, respectively. The mix proportion used in the present study is shown in Table 3.11. In all the mixes containing CKD as binder, the slump obtained was true slump. So, no trial mixes were prepared for these set of mixes.

3.5 EXPERIMENTAL PROGRAMME

The primary purpose of this study is to design a set of CLSM mixes using the materials mentioned with a compressive strength of not more than 2.0MPa at 28-day. The mixes must also have sufficient flowability for a successful concreting operation as well as having moderate effects of bleeding and eliminating the occurrence of segregation. This objective was achieved using trial mixes.

The desired properties of CLSM evaluated as a part of the program include Cylinder Slump flow, Slump Cone test, J-ring test, Bleeding and fresh density in fresh state; hardened density and compressive strength in hardened state. Cylinder slump flow and slump cone test are performed to evaluate the fluidity of the CLSM for the use as backfill or structural fill. J-ring is performed to evaluate the passing ability of the CLSM. Bleeding can be understood as the degree of subsidence i.e. reduction in the volume of CLSM which depends on the extent of quantity of water released from the CLSM mixture. Fresh density and hardened density tests were performed to evaluate the effect of various materials used on the density of the CLSM. Unconfined compressive strength test was carried out to check if the mix lies in the strength range of CLSM considered in this project i.e. the 28-day compressive strength values lying between 0.345 MPa (50 psi) to 2.1 MPa (300 psi). All these tests were performed for all mixes defined in the previous section. The details of the tests are described hereunder.

3.5.1 Flowability

Flowability is the ease with which a material could be transported and placed. It can be used to evaluate the consistence of the CLSM mix. If consistence is not correct, the concrete will not have the desired qualities. Following three tests were performed to evaluate the flowability of various CLSM mixes.

a) Cylinder Flow Test

The flowability of CLSM can be evaluated using the slump flow test (ASTM D 6103:1997). For the test 75 mm diameter and 150 mm height cylinder (Figure 3.21) was placed on a level surface. Then, the mix was poured into the cylinder. The top surface of the cylinder was leveled and then, the cylinder was lifted vertically without any twist. When the cylinder was lifted CLSM subside resulting in formation of a spread. Diameter of this spread was measured in two perpendicular directions and mean of these values was considered as cylinder slump flow. As stated by ACI 229R (1999), good flowablitiy is achieved, where, there is no noticeable segregation and at least 200mm diameter spread is formed for the mix.

This test was used to find the initial amount of water to be added to the mix. Since the amount of material required for carrying out this test was very less (about 1.5-2kg), this test is most suitable for initial iterations. The typical spread is shown in Figure 3.22.

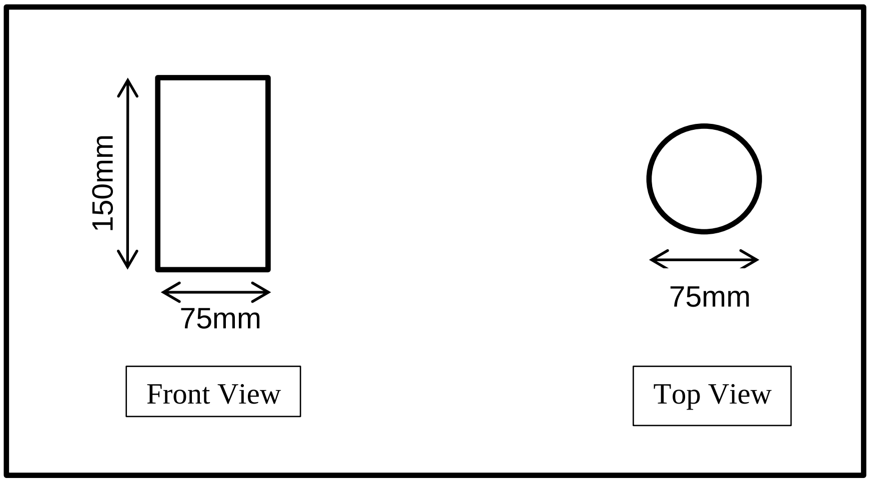


Figure 3.21: Cylinder Slump flow apparatus (ASTM D6103:1997)

An initial water content of 300 kg/m^3 was used for the mix containing river sand and 450 kg/m^3 was for the mix containing spent foundry sand. Trials were done to achieve a required spread of 200 mm. The amount of water was increased as 15kg/m^3 in each step till a spread of 200 mm was achieved. The quantity of water obtained for each mix was finalized from this test and the same was used in other tests. The quantity of water content observed from cylinder slump test is stated in the succeeding chapters.

Figure 3.22: Cylinder slump flow test performed on C/R/G_{100B} mix

b) Slump Cone Test

The test was carried out using a mould known as a slump cone or Abrams cone (BS EN 12350-2:2009). The standards specify a slump cone of height 300 mm, a bottom diameter of 200 mm and a top diameter of 100 mm as shown in Figure 3.23. The cone was placed on a hard non-absorbent surface. This cone was filled with fresh CLSM without compaction to the top of the mould. The mould was carefully lifted vertically upwards, so as not to disturb the CLSM cone and the mix subsides. The diameter of the spread was measured as slump flow. This value was noted for all the mixes.

In this study, a slump flow of 550-650 mm as per EFNARC (2005) is considered as the required flow. The mix with this flow is considered appropriate for unreinforced or slightly reinforced concrete structures that are, cast from the top with free displacement from the delivery point, cast by a pump injection system (e.g. tunnel linings), or for sections that are small enough to prevent long horizontal flow (e.g. piles and some deep foundations). Figure 3.24 shows the cone slump flow observed for C/F/G_{80A} mix.

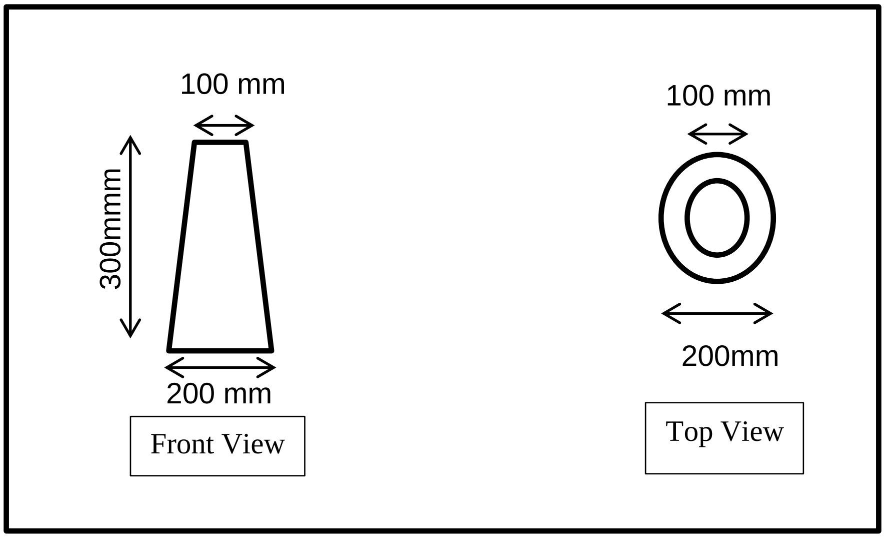


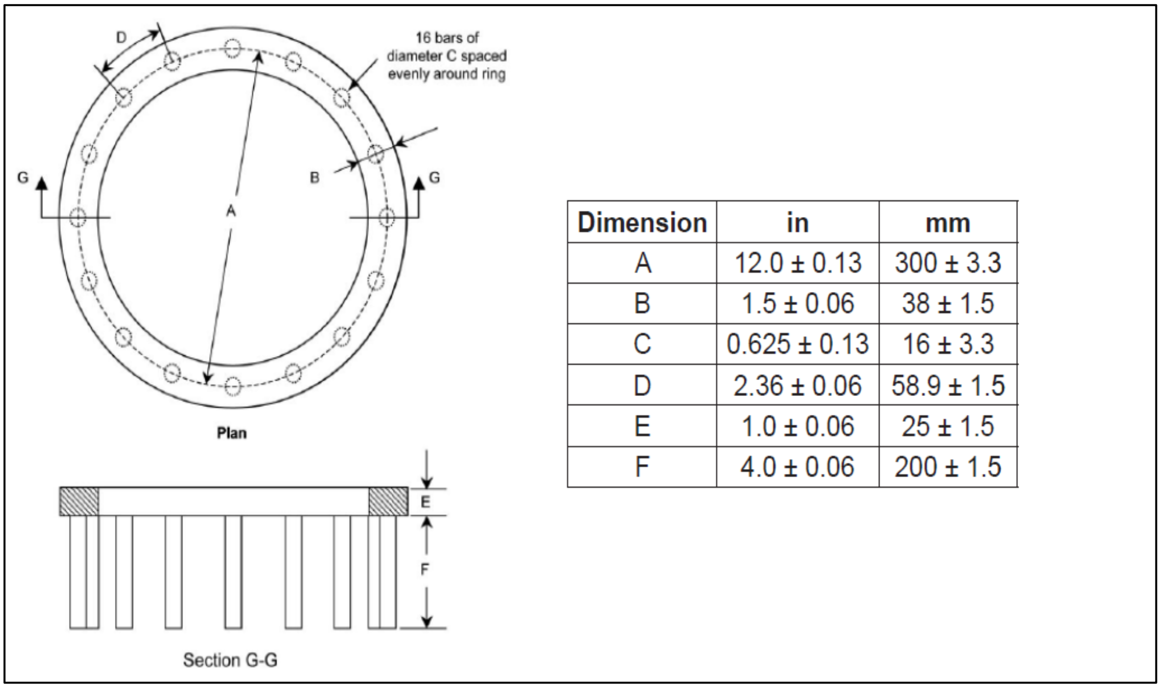
Figure 3.23: Slump cone or Abram's cone (BS EN 12350-2: 2009).

Figure 3.24: Flow table diameter observed for C/F/G_{80A} mix

c) J-ring test

Same Abram’s cone is used as described in previous test with addition to a J-ring which acts as an obstruction to the free flow of mix. J-ring consists of a non-absorbent, rigid material ring measuring 300 mm in diameter at the center of the ring and 25 mm in thickness and sixteen 16 mm diameter smooth rods spaced evenly around the ring measuring 100 mm in length as shown in Figure 3.25. The J-ring test can be used to determine the passing ability of self-consolidating concrete (ASTM C1621:2013). It is applicable for laboratory use in testing different concrete mixtures for passing ability or can be used in field as a quality control test.

The slump cone was placed in the middle of the J-ring on a non-absorbent, leveled and hard surface. The cone was filled with fresh CLSM without compaction to the top of the mould. The mould was carefully lifted vertically upwards, so as not to disturb the CLSM cone and the mix subsides (Figure 3.26). The diameter of the spread was measured as total flow for J-ring. This value was noted for all the mixes. Larger value of total flow indicates higher workability. In terms of the J-ring, a minimum diameter (total flow) of 400 mm is recommended (EFNARC, 2005) for a mix, so as to behave as a self-compacting material.



Dimension	in	mm
A	12.0 ± 0.13	300 ± 3.3
B	1.5 ± 0.06	38 ± 1.5
C	0.625 ± 0.13	16 ± 3.3
D	2.36 ± 0.06	58.9 ± 1.5
E	1.0 ± 0.06	25 ± 1.5
F	4.0 ± 0.06	200 ± 1.5

Figure 3.25: J-ring Apparatus for measuring passing ability (ASTM C1621:2013).

Figure 3.26: J-Ring total flow observed for the mix C/F/G_{40A}

3.5.2 Density

Density of the material is the mass per unit volume of the material. It is the measure used to classify a material as heavy or light. In this study, both the fresh and hardened density of CLSM was noted to evaluate the change in the density with different proportions of materials used.

a) *Fresh state density*

The density of CLSM was determined by filling a measure of known volume with CLSM. The mass of the filled measure was obtained to an accuracy of 10 gms. The density was then calculated by dividing the mass by the volume (ASTM D 6023:2002). A cylindrical container made of steel or other suitable metal can be used. It should be watertight and sufficiently rigid to retain its form and calibrated volume under rough usage. Measures that are machined to accurate dimensions on the inside and provided with handles are preferred.

b) Hardened density

Hardened density was measured at 28 days. For this, fresh CLSM mixtures were introduced into 150 × 150 × 150 mm cubic moulds without compaction. The hardened CLSM samples were demoulded after 7 days and stored into plastic bags at room temperature. The hardened CLSM samples were removed from the plastic bags after 28-day of casting. These samples where weighed on an electronic balance to the accuracy of 0.5 g. The ratio of mass of the sample to its volume was taken as density. Average of three samples was noted down.

3.5.3 Bleeding

Subsidence refers to the reduction in volume of CLSM, and its extent is dependent upon the quantity of water released from the CLSM mixture. Bleeding is commonly used to quantify the degree of subsidence for CLSM and was measured in this study according to ASTM C 940. A 1000 ml-graduated cylinder was filled with 800 ml of fresh CLSM mixture and then covered with a plastic Para film to prevent evaporation. The volume of bleed water which accumulated at the surface of the CLSM was recorded at a regular interval of 15 minutes. The final reading was taken as the one after which no further accumulation of water at the top was observed. The bleeding was expressed as a percentage with the volume of bleed water over the initial volume of CLSM mixture. CLSM is considered stable with bleeding less than 5% by volume at 2 h (Gabr, 2000 and Yan, 2014).

3.5.4 Compressive Strength

Fresh CLSM mixtures were introduced into 150 × 150 × 150 mm cubic moulds without compaction. The hardened CLSM samples were demoulded after 7 days and stored into plastic bags at room temperature. The hardened CLSM samples were removed from the plastic bags after 28-day of casting.

The unconfined compressive strengths of the CLSM samples having size 150 × 150 × 150 mm were determined at 28 day of casting. Universal Testing machine as shown in Figure 3.27 was used for this purpose. The machine had a stroke rate of 10 kN and a maximum capacity of 1000 kN. Cubes were subjected to compression at a constant loading rate of 0.1 kN/sec. The unconfined compressive strengths of three identical CLSM samples were measured and the experimental data points were plotted with error bars to show their reproducibility and reliability. The measurements are reported in terms of the mean ± standard deviation.

Figure 3.27: CLSM cube tested in UTM at pace rate of 0.1 kN/sec.

CHAPTER 4

PROPERTIES OF BASE MIXES

4.1 GENERAL

The objective of the present study was to make use of various industrial by-products and evaluate their effect on the behavior of CLSM mixes. The basic mixes in this chapter comprising cement/sand and CKD/sand were monitored for fresh and hardened properties and, based on these observations, further mixes were prepared. The objective is to control the behavior of the material by varying the constituent's proportions through trial mixing based on the results from literature and proceeding mixes.

4.2 BASE MIX - CEMENT AS BINDER

Cement is the binder and acts as a substance that sets and hardens independently and can bind other materials together. The cement used in this study was Ordinary Portland Cement(OPC) from J. K. Lakshmi cement complying with IS 8112: 1989, the Indian standard specification for 43-grade OPC.

The basic concrete mix with cement alone was tested just to understand the baseline properties of the mix without any filler material. Two different types of mixes were prepared using either, Natural River Sand (RS) or Spent Foundry Sand (SFS) as fine aggregate. The Natural river sand was from Pathankot, Punjab. The river sand was conforming to ASTM C33:2003 for the particle size gradation. Foundry sand used in the study was from a metal tools manufacturing industry in Jalandhar, and was a type of chemically treated sand.

Only one type of sand was used in the base mixes i.e. first set of mixes consisted of cement or CKD as binder and river sand as fine aggregates in the mix, whereas second set consisted of cement or CKD as binder and spent foundry sand as fine aggregate. The mix proportions of the base mixes were finalized based on the literature available for CLSM.

The basic mix can be used to compare the variation in the fresh and hardened properties of material when cement is incorporated with different types of sand. The mix proportions used for finalized base mixes with cement as binder are shown in Table 4.1. The amount of water to be added to each mix was decided using cylinder slump test with a desired spread of 200 mm (ACI 229R:1999). To achieve this, for cement binder mix containing river sand a trial was started at 300 kg/m^3 of water and then an increment of 15 kg/m^3 was given till a slump of 200 mm was achieved. However, when spent foundry sand was used as fine aggregates resultant mix was observed to be very harsh. Therefore, trials were started from 450 kg/m^3 of water with an increment of 15 kg/m^3. As can be seen in the Table 4.1 cement/foundry sand mix required more water in the mix to be workable. It can be due to higher water absorption of spent foundry sand (4.43%) compared to the river sand (1.6%). Along with this, the particle size of spent foundry sand is very small as compared to river sand causing increase in the surface area to be wetted in the mix.

After finalizing the mix properties i.e. water content of the mix, other properties were monitored which include slump cone diameter, J-ring total flow, bleeding, fresh state density, hardened density and 28-day compressive strength. The properties monitored are shown in Table 4.2 and are described as under.

Table 4.1: Base mix proportions with cement as binder.

MIX	**Type of Sand**	**Mix Proportions (kg/m^3)**		
		Cement	**Sand**	**Water**
C/R	Natural River Sand	140	1790	436
C/F	Spent Foundry Sand	140	1630	584

Table 4.2: Results of basic mix proportions with cement as binder.

MIX	**Slump Flow(mm)**	**J Ring (mm)**	**Fresh Density (kg/m^3)**	**Bleeding (%)**	**Hardened Density (kg/m^3)**	**Compressive Strength (N/mm^2)**
C/R	530	490	2020	4.1	2131	8.32±0.25
C/F	575	520	1614	5.5	1773	4.39±0.05

a) Flow Table Test

From Table 4.2, it can be seen that mix C/R showed a moderate flowability of 530 mm which is below the target flowability of 550 mm. The poor flowability of the mix is due to the presence of coarser particles and the absence of filler material to hold water and a low water quantity present in the mix. A high flowability of 575 mm has been observed in case of mix C/F which is in the range of our target flowability of 550 to 650 mm. The above observation could be due to the increase in the number of fines that makes the mix homogeneous, hence allows for the better flow of the mix. However, both the mix showed high segregation.

b) J –ring Test

As shown in Table 4.2, for mix C/R a total flow in J-ring has been observed as 490 mm and for C/F as 520 mm. Higher passing ability has been observed in case of mix C/F containing foundry sand when compared with mix C/R made up of natural river sand. It can be attributed to the presence of coarser particles of natural river sand, which cause increase in friction, thereby reducing the passing ability of the mix.

c) Bleeding

The percentage bleeding observed for Mix C/R is 4.1% and for Mix C/F is 5.5%. The CLSM mixes are considered stable when bleeding is less than 5% by volume at 2h. High bleeding occurs in the mixes when the cohesive fines in the mix are not sufficient to hold the water which may also lead to excessive segregation. In both C/R and C/F mixes, the fines are contributed only by cement. Since the amount of fines is very low, bleeding is high. Further, in C/F mix bleeding is exceptionally high due to large amount of water added to maintain flowability. This high amount of water was first needed to wet the surface area of the smaller particles in spent foundry sand in the mix but due to lesser number of cohesive fines, it became difficult for the same mix to hold this water, when left undisturbed for some time.

d) Fresh state density

Mix C/R has observed a fresh state density of 2020 kg/m^3 which is comparable to the results from previous research (Alizadeh et al. 2014) findings, whereas Mix C/F has shown a lower fresh state density of 1614 kg/m^3. The reduction in the density of the mix containing spent foundry sand may be due to the lower specific gravity of spent foundry sand and higher amount of water used in the mix.

e) Hardened Density

It has been observed that mix C/R and C/F were having hardened density of about 2131 and 1773 kg/m^3, respectively. There is an increase in the hardened density as compared to the fresh state density of the mix. It can be attributed to the fact that due to bleeding, subsidence has occurred in the mix causing reduction in the volume and increase in the density.

f) 28-day compressive strength

Cubes having size 150 mm were cast for the mixes and were de-molded after 7 days of casting. These cubes were cured in plastic bags till 28 days as it was suggested by Taha et al. 2007 that water curing should be avoided due to disintegration of cubes after immersion in the water because of their very low strength. These cubes were tested on Universal Testing Machine (UTM) at a pace rate of 0.1 kN/sec. The Unconfined Compressive Strength (UCS) of 150 mm cubes of mix C/R and C/F at 28th day was observed as 8.32 and 4.39 N/mm^2, respectively. This reduction in the compressive strength by using spent foundry sand as fine aggregate may be due to the fact that spent foundry sand mixes were having high amount of water, which may have caused formation of the voids in the matrix of the cube. Both the mixes however had strength much higher than 2MPa, which is above the main replacement of CLSM mixes.

4.3 BASE MIXES - CKD AS BINDER

Cement Kiln Dust (CKD) is the by-product of cement manufacturing process obtained from the exhaust gases during the cancellation of cement. In this study, CKD was used as complete replacement of cement. It has been studied by various researchers (Al-Harthy et al. 2005, Taha et al. 2007 and Lachemi et al. 2010) that CKD can be used as complete replacement of cement since it has the binding properties just like cement because CKD is the unreacted raw material of cement manufacturing process. However, larger amount of CKD is required for the mix as compared to the amount of cement used in the corresponding mixes (Kartz and Kovler 2004 and Lachemi et al. 2010).

The base mixes were finalized based on the literature survey on CLSM. It was been found that the amount of CKD to be used in CLSM should lie between 200 to 300 kg/m^3 to satisfy the desired requirements. In the present study, the mixes with CKD as binder were developed using 300 kg/m^3 of CKD as against 140 kg/m^3 of cement in base mixes with cement as binder. The base mixes containing CKD were prepared with two types of sand as shown in Table 4.3. Only one type of sand was used in each of the base mix i.e. first mix (K/R) consisted of CKD as binder and river sand as fine aggregate in the mix whereas second mix (K/F) consisted of CKD as binder and spent foundry sand as fine aggregates. The amount of water to be added in each mix was calculated using Cylinder slump flow test.

Table 4.3: Basic mix proportions with only CKD as binder.

MIX	Type of Sand	Mix Proportions (kg/m^3)		
		CKD	Sand	Water
K/R	River Sand	300	1750	488
K/F	Spent Foundry Sand	300	1510	634

Table 4.4: Results of basic mix proportions with CKD binder.

MIX	Slump Flow(mm)	J Ring (mm)	Fresh Density (kg/m^3)	Bleeding (%)	Hardened Density (kg/m^3)	Compressive Strength (N/mm^2)
K/R	510	450	1961	3.5	1992	2.05±0.02
K/F	580	540	1481	3.5	1628	1.43±0.10

An initial water content of 300 kg/m^3 and 450 kg/m^3 was used for the mix containing river sand and foundry sand, respectively. Higher quantity of initial water was used in foundry sand as at water content of 300 kg/m^3, the mix was very harsh and dry. This higher water requirement was due to the higher water absorption of foundry sand (4.43%) as compared to river sand (1.6%) and smaller particle size of foundry sand. The amount of water used in cylinder slump test was increased at the rate of 15 kg/m^3 till the required flow of 200 mm was achieved. This amount of water was used for carrying out further testing on CLSM i.e. slump flow, J-Ring total flow, bleeding, fresh state density, hardened density, compressive strength. The various tests performed on the base mixes of CLSM containing CKD as binder are discussed as under and their results are compiled in Table 4.4.

a) Flow Table Test

Similar results have been seen as in the mix containing only cement as binder. Mix K/R showed a moderate flowability of 510 mm which is below the target flowability of 550 mm. The poor flowability of the mix is due to the presence of coarser particles and the absence of filler material to hold water. A flowability of 580 mm has been observed in case of mix K/F which is in the range of our target flowability. As the particle size of foundry sand is smaller than natural river sand, the mix could hold more water and show better flow. The mix K/R was observed to be highly segregated and showed shear slump, whereas, mix K/F was more stable and lesser segregation was observed.

b) J –ring Test

For mix K/R a total flow in J-ring has been observed as 450 mm and for K/F as 540 mm that is higher passing ability has been observed in case of mix K/F containing foundry sand when compared with mix K/R containing natural river sand. This may be due to the presence of coarser particles causing increase in the friction and hence reducing the passing ability of the mix.

c) *Bleeding*

The percentage bleeding observed for both mixes was 3.5%. The bleeding in both the above mixes has been considerably reduced when compared with the mixes containing cement as a binder only due to the fact that more quantity of fines have been used for the mix containing only CKD binder. The mix containing foundry sand has shown same amount of bleeding when compared with the mix containing natural river sand even if more water has been used to get the required slump. This may be due to the presence of fine sand in the mix containing spent foundry sand.

d) Fresh state density

Mix K/R has observed a fresh state density of 1961 kg/m^3 which is comparable to the results from previous research findings whereas, Mix K/F has shown a lower fresh state density of

1481 kg/m^3. The reduction in the fresh density of the mix containing spent foundry sand may be due to the lower specific gravity of spent foundry sand and higher amount of water used in the Mix K/F.

e) Hardened density

Hardened density of mix K/R and K/F were observed as 1992 and 1628 kg/m^3. The hardened density of mix containing SFS is lower as compared to the density of mix containing river sand which can be attributed due to the lower specific gravity of SFS as compared to the RS. Moreover, higher water content was used in the mix containing RS. The increase in the hardened density of both the mixes when compared with the fresh state density can be due to the fact that bleeding of water caused excessive subsidence resulting in reduction in the volume of the mix and hence leading to the increase in density.

f) 28-day compressive strength

The Unconfined Compressive Strength (UCS) of 150mm cubes at 28th day was observed as 2.05 and 1.43 N/mm^2. This reduction in the compressive strength occurred due to presence of more water in SFS mixes, which on evaporating led to the formation of higher number of voids.

4.4 COMPARISON OF BASE MIXES

The effect of change in the type of binder was also studied. The results from various tests conducted on the CLSM mixes, containing cement and CKD as binder were compared. These mixes are comparatively discussed in succeeding subsection.

a) Water content

The water content obtained from cylinder slump test to achieve the desired flow of 200 mm for the mix C/R, C/F, K/R and K/F was 436, 584, 488 and 634 kg/m^3, respectively (Figure 4.1). It was found that the mix containing CKD required more water as compared to the mix containing cement. This can be due to the fact that there were more number of cohesive fines in the mix, since mix containing cement as binder, contained only 140 kg/m^3 of cement with respect to the mix containing CKD as binder, which had 300 kg/m^3 of CKD causing mix to be lesser cohesive and lower amount of water was able to produce desired flow values.

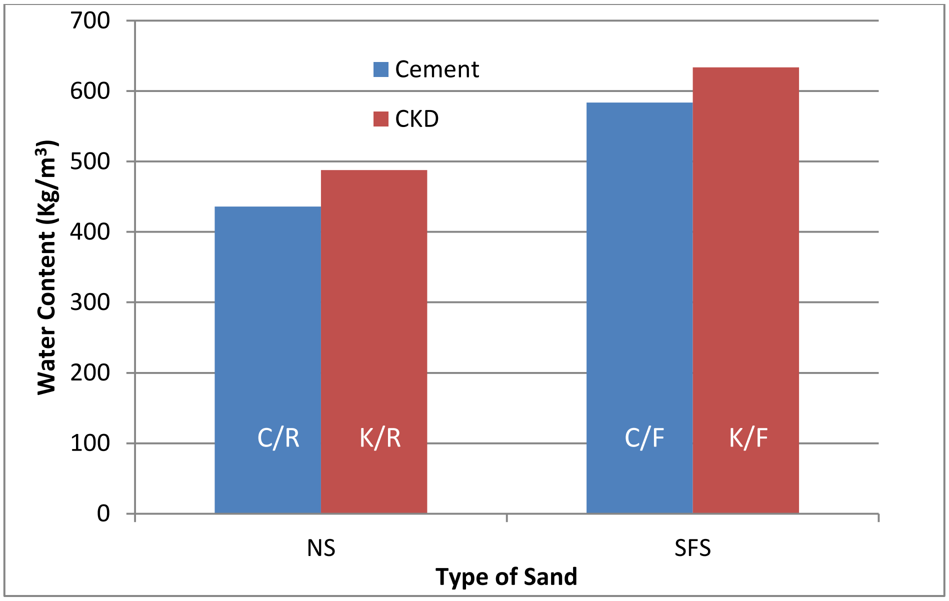


Figure 4.1: Water content obtained for C/R, C/F, K/R and K/F mixes using Cylinder Slump Test.

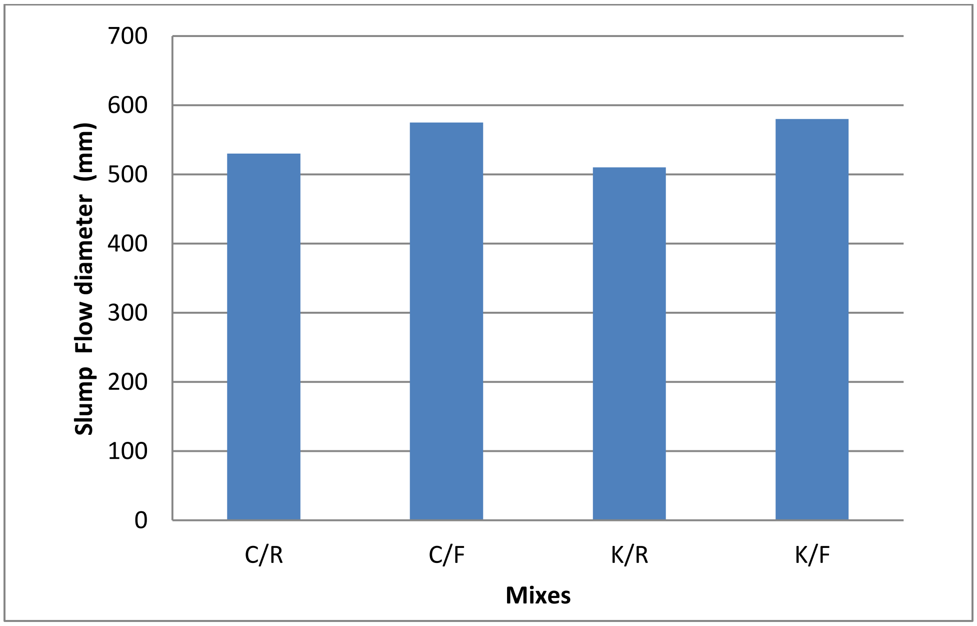


Figure 4.2: Slump flow values using Abram's cone for mix C/R, C/F, K/R and K/F.

b) *Flow table test*

The comparative results of slump flow test for the base mixes are shown in Figure 4.2. Slump flow for the mixes C/R, C/F, K/R and K/F was observed as 530, 575, 510 and 580 mm, respectively. In case of natural sand reduction in the value of slump flow was observed for mix containing CKD (K/R) when compared with mix containing cement (C/R) even if higher amount of water is used, since the cohesion in the mix would have increased due to addition of more number of fines. Same amount slump has been observed in the case of mix containing spent foundry sand with cement (C/F) as binder and CKD (K/F) as binder with higher amount of water used in the mix containing CKD as binder.

c) *J-ring test*

The results of J-Ring total flow are shown in the Figure 4.3. A total flow of 490, 520, 450 and 540 mm has been observed for the mix C/R, C/F, K/R and K/F, respectively. It is observed that is for a high increase in water content, while changing our binder from cement to CKD, a reduction in total flow has been observed for the natural sand whereas, in case of foundry sand only a slight increase has been observed.

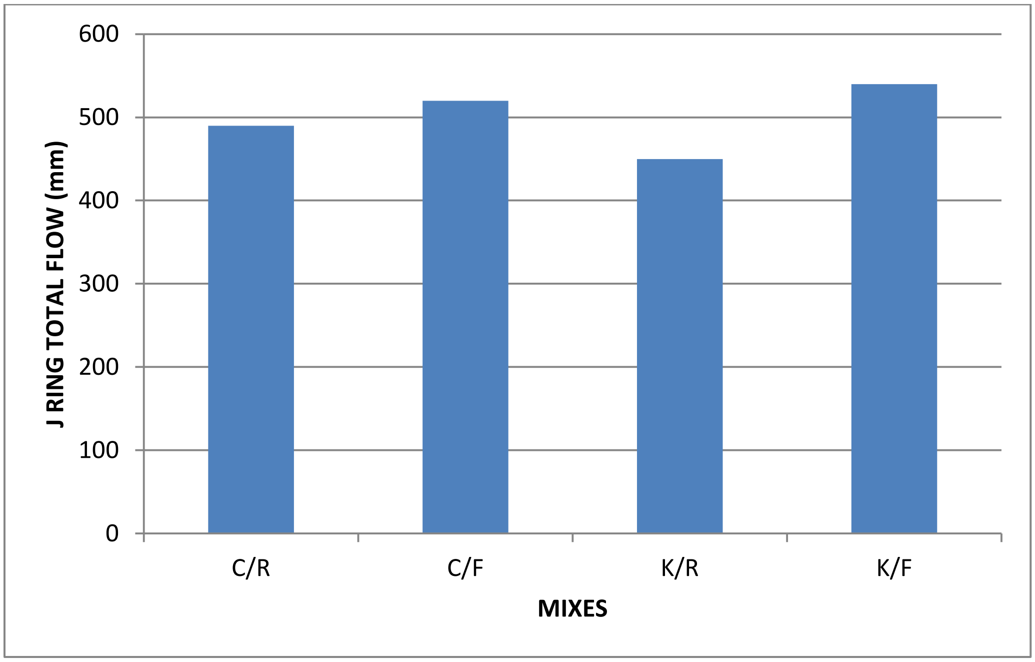


Figure 4.3: J-ring total flow for mix C/R, C/F, K/R and K/F.

d) *Bleeding*

The bleeding for the mix C/R, C/F, K/R and K/F was observed as 4.1%, 5.5%, 3.5% and 3.5%, respectively. The mix containing CKD (K/R and K/F) was observed to have lower bleeding as compared to the mix containing cement (C/R and C/F) with higher amount of water in the mix which may be attributed to the increase in the number of fines in the mix.

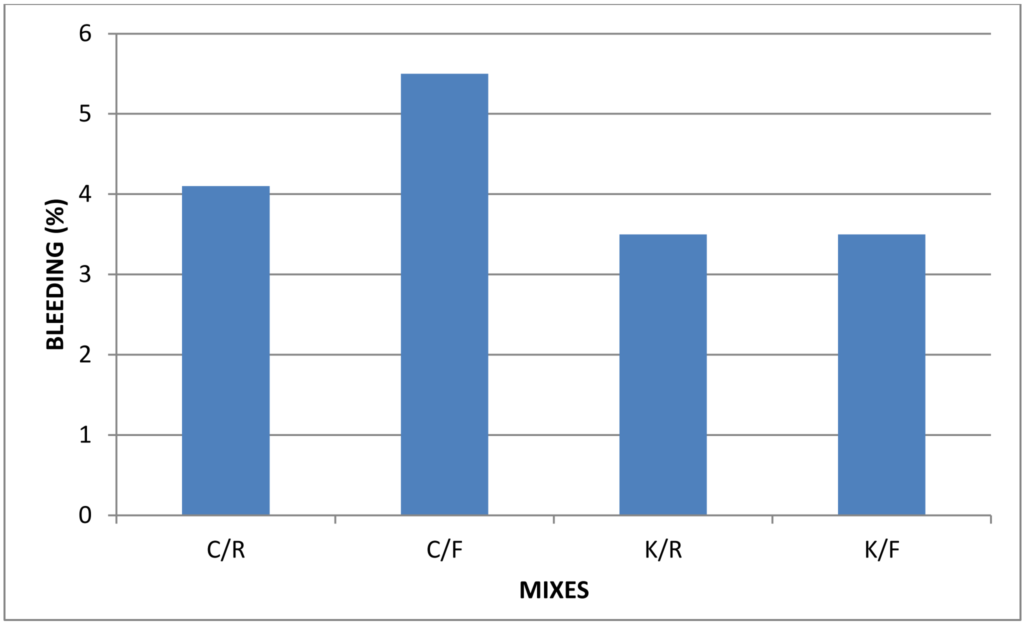


Figure 4.4: Bleeding for the mix C/R, C/F, K/R and K/F.

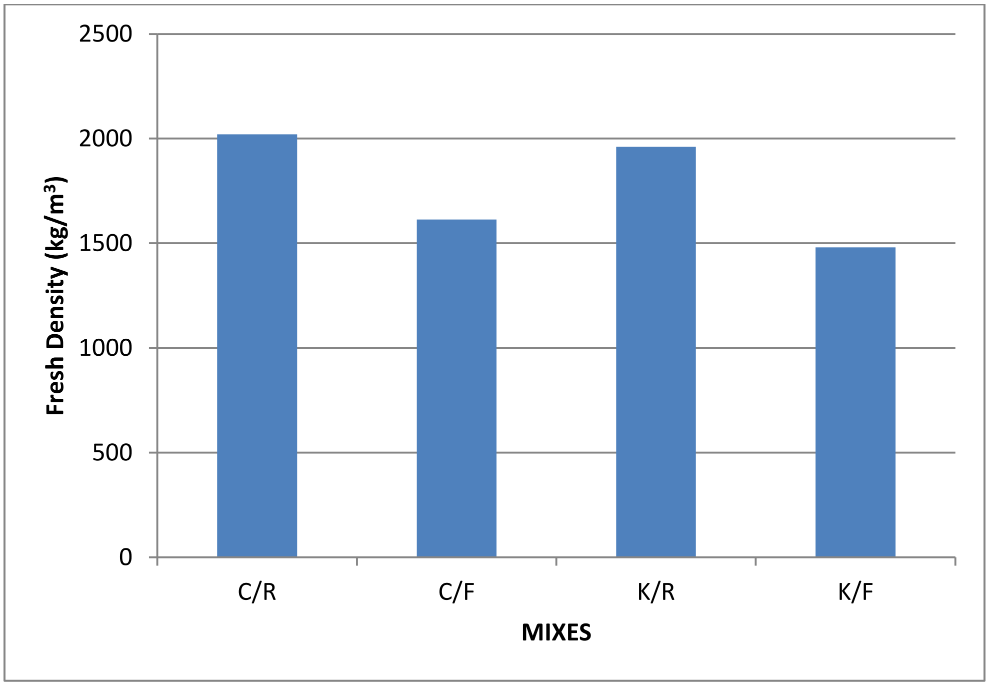


Figure 4.5: Fresh Density for mix C/R, C/F, K/R and K/F

e) *Fresh state density*

The fresh state density of the mixes C/R, C/F, K/R and K/F have observed as 2020, 1614, 1961 and 1481 kg/m^3, respectively, i.e. a reduction in the fresh state density has been observed for the mix containing CKD (K/R and K/F) as binder when compared with the mix containing cement (K/R and K/F) as binder for the same kind of sand used in the mix. This reduction may be due to the fact that specific gravity of CKD is less as compared to cement and the amount of water used for in the mix containing CKD was more as compared to the mix containing cement. The variation in the fresh density for base the mix containing cement and CKD is shown the Figure 4.5.

f) *Hardened density*

The variation in the hardened density of all the basic mixes has been shown in the Figure 4.6.

It was observed that the mixes C/R, C/F, K/R and K/F have a hardened density of 2131, 1773, 1992 and 1628 kg/m^3, respectively. The mixes containing CKD (K/R and K/F) as a binder are having a lower density as compared to the mix containing cement (C/R and C/F) as binder for same type of sand used in the mix. This trend was similar to the trend of fresh density. The hardened density was observed to be more as compared to the fresh density which is due to the fact that considerable subsidence had occurred due to bleeding in the mix.

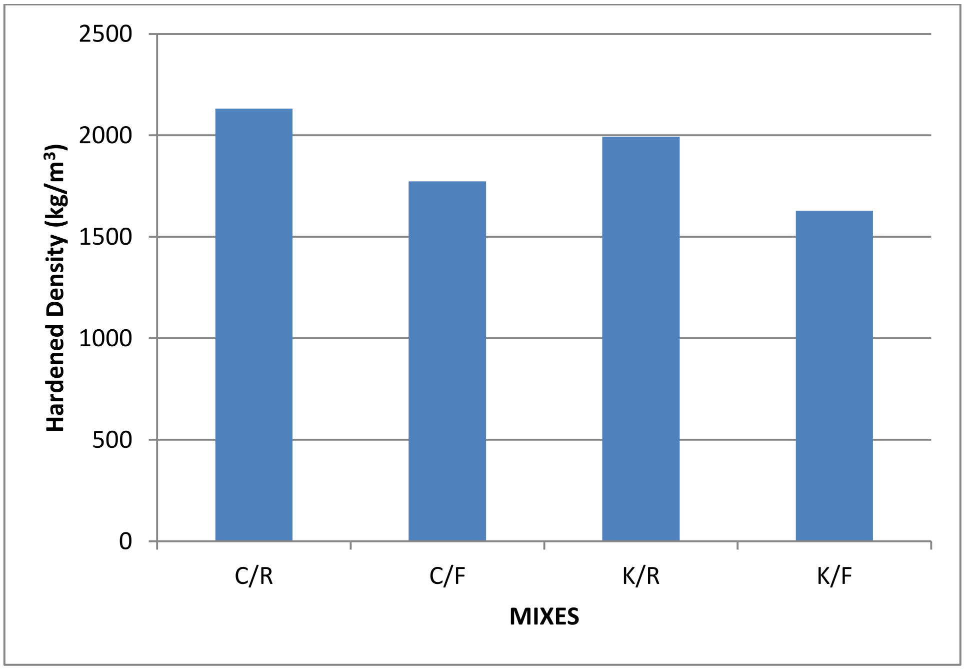


Figure 4.6: Hardened density for mix C/R, C/F, K/R and K/F

g) 28-day Compressive Strength

The 28-day Compressive strength for the mix containing RS and SFS with the binder as cement (i.e. mix C/R and C/F) was observed as 8.32 and 4.39 N/mm^2, respectively, whereas, for the mix containing river sand and spent foundry sand with CKD as binder (i.e. mix K/R and K/F) was observed as 2.05 and 1.43N/mm^2, respectively. Lower value of compressive strength has been observed for the mix containing CKD as compared to the mix containing cement, even if the amount of CKD was more (300 kg/m^3) w.r.t. the amount of cement (140 kg/m^3) used in the mix for same type of sand. This reduction in the compressive strength can be stated due to the fact that CKD is the unreacted raw material of cement and the CSH gel formed in case of cement is much superior as compared to the mix containing CKD. Moreover, the amount of water used in the mix containing CKD was more, leading to formation of higher number of voids in the mix containing CKD. The variation in the compressive strength with respective standard deviation has been shown in Figure 4.7.

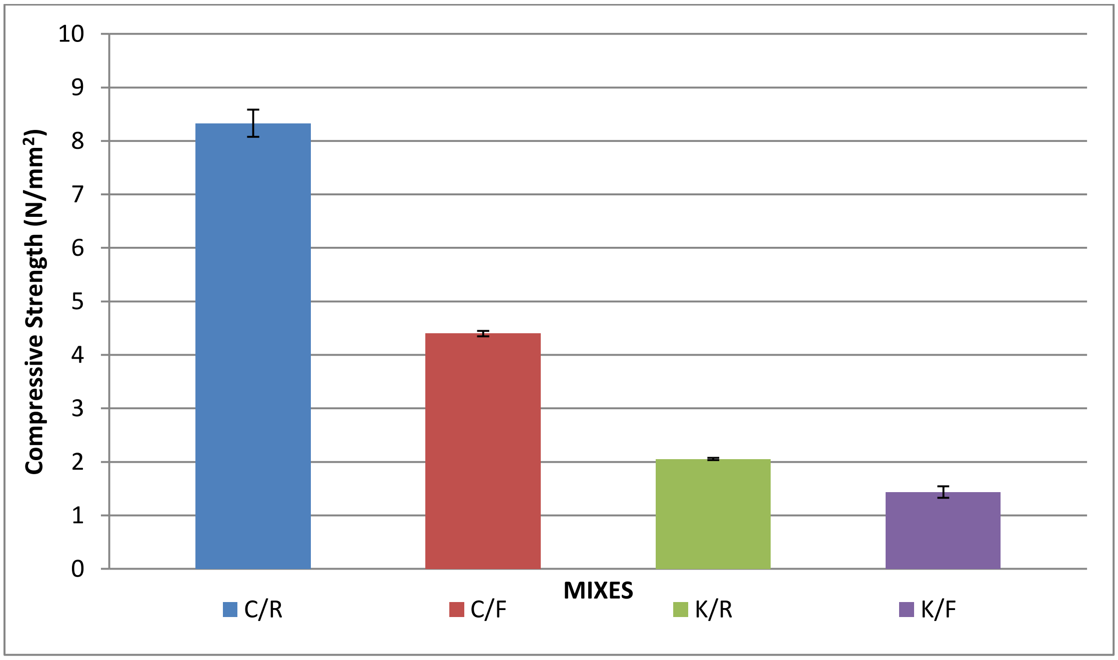


Figure 4.7: 28-day Compressive strength results for mix C/R, C/F, K/R and K/F

Observation: From the basic mixes discussed in this chapter, it has been as found that the flow properties of mix containing foundry sand were better as compared to the mix containing natural river sand and the mix containing CKD were better as compared to the mix containing cement. Although K/F mix had strength less than 2.0MPa, all the basic mixes did not satisfy the fresh state properties as they all show segregation, were inconsistent and a lot of bleeding had been observed and unmixed water was present in the mix. To rectify this problem, binary or ternary mix incorporating other fines such as fly ash or GGBS were derived, as the fines present in the mix were not enough to absorb the water present in the mix.

CHAPTER 5

PROPERTIES OF BINARY AND TERNARY MIXES

5.1 GENERAL

As observed in previous chapter, the CLSM mixes made by using only cement or CKD as binder did not comply with the required properties of CLSM. To rectify the base mixes further, binary and ternary CLSM mixes were derived using GGBS and Fly ash to improve the consistency, workability and to achieve 28-days compressive strength below 2 MPa. The study was focused on optimizing the CLSM mixture ratios using trial mixes with various combinations of cementitious and filler materials to achieve desired performance.

5.2 BINARY AND TERNARY MIXES

The binary and ternary mixes were made using cement or CKD as binder, Ground Granulated Blast-furnace Slag (GGBS) and Fly Ash (FA) as filler and Natural River Sand (NS) and Spent Foundry Sand (SFS) as fine aggregates.

5.2.1 GGBS

GGBS, as earlier defined, is a by-product of iron and steel manufacturing industry. The molten slag lying on the top of the molten iron in the blast furnace comprises mainly of silicates (glass) which is the main component of GGBS. The molten slag is cooled and then finely ground so that it can be used as a partial replacement of cement. GGBS is a recycled product having same, but not identical composition as compared to Ordinary Portland cement (OPC). GGBS is frequently used as a pozzolana in the mix designs for normal concretes. The researchers have compared the strength versus time graph for GGBS/cement mix with only cement mixes and observed that the GGBS/Portland cement mix will gain its strength much more slowly when compared with that of Portland cement mix. This lower strength is desirable for CLSM mixes also (Achtemichuk et al., 2009). Hence, it was chosen as one of the filler materials.

5.2.2 Fly Ash

Fly Ash (FA) is a by-product of the combustion of pulverized coal in thermal power plants. When the pulverized coal is ignited in the combustion chamber, the carbon and volatile materials are burned off. However, some of the mineral impurities of clay, shale, feldspars, etc., are fused in suspension and carried out of the combustion chamber as exhaust gases. As the exhaust gases cool, the fused materials solidify into spherical glassy particles called fly ash. Due to its pozzolana properties Fly ash chosen as a filler material in CLSM mixes.

5.2.3 Purpose of Using Pozzolans

The use of these pozzolanic materials in CLSM leads to economic and environmental benefits. These benefits include recycling of a waste product, which would otherwise be dumped in the environment, reducing the cement content and to improve the flowability of the material as well as reduction in bleeding (Achtemichuk et al. 2009). As the cement reacts with water in the mix, the hydration products which are most abundant are Calcium Silicate Hydrate (CSH) and calcium hydroxide. The pozzolanic materials react with the calcium hydroxide to form additional CSH gel over time; this is known as secondary CSH which is formed from the pozzolanic reaction. CSH is the product that binds the aggregate together and provides material with its strength. On hydration of the cement, the CSH gel comprises of approximately 65% of the total volume of cement phase whereas calcium hydroxide accounts for approx. 15% of the volume. The presence of this pozzolana in the mix acts as a retarder and reduces the rate of heat of hydration, resulting in the reduction of early age strength of the material. However, as the pozzolana consumes calcium hydroxide over time it is expected to increase the long term strength of the mix.

However, in CLSM mixes the quantity of cement used is generally kept very low and only 15% calcium hydroxide is produced as the hydration product for the cement paste. The amount of calcium hydroxide available for supplementary cementing reaction with pozzolan will not be sufficient. The pozzolans, which does not react with the calcium hydroxide remains inert in the matrix, and this is an advantage for the CLSM mixes as the fine particles provide a consistent and flow-able mix as well as fulfilling the requirement of low compressive strength.

5.2.4 Binary Mixes

Binary mixes consisted of the mixes containing two binders/fillers at a time. In one set, cement was used as binder with either GGBS or Fly Ash as filler. While, in another set CKD was used as binder with either GGBS or Fly Ash as filler.

5.2.5 Ternary Mixes

Ternary mixes consisted of using cement as binder with various proportions of both GGBS and Fly Ash as filler. Similarly, in another set of ternary mixes. CKD was used as binder with various proportions of both GGBS and Fly Ash as filler.

5.3 PROPERTIES OF MIXES WITH CEMENT AS BINDER AND RIVER SAND AS FINE AGGREGATE

In this set of mixes cement was used as binder and river sand was used as fine aggregate. An estimate from the literature survey was done to evaluate the quantity of various materials to be used in the present study. In previous research works, the quantity of cement used was between 25 to 200 kg/m^3 (Taha et al. 2007, Wang et al. 2013 and Alizedh et al 2014) and the quantity of GGBS used varied from 40 to 300 kg/m^3 (Lachemi et al. 2010).

5.3.1 Mixes with 200 kg/m^3 of GGBS

For the trial mixes, a cement content of 50 kg/m^3 was used with initial quantity of GGBS at 200 kg/m^3. Binary mix was prepared using an initial quantity of GGBS and for the generation of ternary mixes, GGBS was replaced by FA on one to one bases by volume. The ratios of GGBS and FA used for mix C/R/G$_{100A}$ and C/R/G$_{80A}$ were 100/0 and 80/20, respectively. The amount of water to be added in each mix was decided using cylinder slump test with a desired spread of 200 mm (ACI 229R, 1999). To achieve this for all mixes, a trial was started at 300 kg/m^3 of water initially and then an increment of 15 kg/m^3 was given till a slump of 200 mm was achieved. Mix proportions which were used for mixes C/R/G$_{100A}$ and C/R/G$_{80A}$ are shown in Table 5.1. The above mix showed high segregation and bleeding during cylinder slump flow test but it was necessary to evaluate the response of the material during other tests, hence further testing for CLSM for slump cone diameter, J-ring total flow, bleeding, fresh state density, hardened density and 28-day compressive strength were also done. The results of mix C/R/G$_{100A}$ and C/R/G$_{80A}$ are shown in Table 5.2 and are discussed as below.

Table 5.1: Quantities of material for mix $C/R/G_{100A}$ and $C/R/G_{80A}$

MIX	Mix proportions (kg/m^3)				
	Cement	**GGBS**	**Fly Ash**	**RS**	**Water**
$C/R/G_{100A}$	50	200	0	1740	386
$C/R/G_{80A}$	50	160	34.2	1740	390

Table 5.2: Test results for mix $C/R/G_{100A}$ and $C/R/G_{80A}$

MIX	Slump Flow(mm)	J Ring (mm)	Fresh Density (kg/m^3)	Bleeding (%)	Hardened Density (kg/m^3)	Compressive Strength (N/mm^2)
$C/R/G_{100A}$	560	510	2043	3.55	2070	3.27±0.07
$C/R/G_{80A}$	540	500	2029	4	2046	1.90±0.09

a) Water content

The water content which was used for mix $C/R/G_{100A}$ and $C/R/G_{80A}$ to obtain a spread of 200mm for cylinder slump flow test was observed to be 386 and 390 kg/m^3, respectively. The results show that mix containing higher quantity of GGBS has lower water requirement. As particle size of GGBS is very small as compared to Fly ash (Figure 3.14 and 3.18), the particles of GGBS would be able to fill the inter-particle voids of the matrix causing reduction in the number of voids to be filled by water. It provides dense matrix pore structure resulting in reduction in the water required for workability (Soni et al. 2013).

b) Flow table and J-ring test

Mix $C/R/G_{100A}$ showed a moderate flowability of 560 mm and for Mix $C/R/G_{80A}$ a flowability of 540 mm was achieved. The lower workability of the later mix with the increase in the water content in the mix further explains the void filling tendency of GGBS in order to achieve a dense pore matrix. For mix $C/R/G_{100A}$, a total flow in J-ring has been observed as 510 mm and for $C/R/G_{80A}$ as 500 mm. Higher passing ability has been observed in case of mix $C/R/G_{100A}$ containing GGBS when compared with mix $C/R/G_{80A}$ containing fly ash.

c) Bleeding

The percentage bleeding observed for Mix $C/R/G_{100A}$ is 3.55% and for Mix $C/R/G_{80A}$ is 4%. The excessive bleeding was also observed during casting of cubes in which water started accumulating at the top surface of the cube. It indicated that the cohesive fines in the mix are not sufficient so as to hold water. The bleeding in the mix containing fly ash increased further due to presence of more water in the mix.

d) *Density*

Mix $C/R/G_{100A}$ has observed a fresh state density of 2043 kg/$m^3$and Mix $C/R/G_{80A}$ has shown a lower fresh state density of 2029 kg/m^3. The reduction in density of the mix containing fly ash may be due to the lower specific gravity of Fly ash and higher amount of water used in the Mix $C/R/G_{80A}$.

The hardened density of mix $C/R/G_{100A}$ and $C/R/G_{80A}$ were observed to be 2070 and 2046 kg/m^3, respectively. Similar to the trend observed in case of fresh state density. An increase in the hardened density of the material is due to the fact that the expulsion of water in bleeding causes shrinkage of the material and reduction in the volume for same amount of material increases the hardened density of the materials.

e) *28-day compressive strength*

Mix $C/R/G_{100A}$ and $C/R/G_{80A}$ were de-molded after 7 days of casting and were tested on Universal Testing Machine (UTM) at a pace rate of 0.1kN/sec. The Unconfined Compressive Strength (UCS) of 150mm cubes at 28th day was observed to be 3.703 and 1.906 N/mm^2, respectively. This reduction in the compressive strength may be due to the fact that mix containing GGBS shows better formation of CSH gel as compared to the mix containing fly ash as seen in the previous research findings (Achtemichuk et al., 2009). Moreover the amount of water used in mix $C/R/G_{100A}$ is more as compared to the mix $C/R/G_{80A}$ causing reduction in the compressive strength.

Observations: For the above trials, mixes were also prepared for GGBS/FA ratio of 40/60, 60/40, 80/20 and 0/100 by volume and cylinder slump flow test was performed. High segregation and bleeding was observed in all these mixes, thereby indicating the replacement to have higher proportions of fines in order to achieve better flow.

5.3.2 Mixes with 400 kg/m^3 of GGBS

To achieve a desirable binary mix with cement as binder, GGBS as filler and natural river sand as fine aggregate, adjustments were made to evaluate the capability of mix to show better flow with low segregation and bleeding. Starting with 200 kg/m^3 of GGBS, the quantity of GGBS was increased by 50 kg/m^3 for next set of trials and cylinder slump test was performed, till a mix proportion was achieved showing no segregation. The quantity of GGBS in the mix showing no segregation was observed as 400 kg/m^3.

Therefore, the finalized binary mix containing 50 kg/m^3 of cement(C), 400 kg/m^3 of GGBS and 1660 kg/m^3 of natural river sand (NS) was prepared. The ternary mixes of C+GGBS+FA were achieved by simply replacing GGBS with FA by volume. The amount of water to be added in each mix was calculated using cylinder slump flow test (ACI 229R, 1999). An initial water content of 300 kg/m^3 was used to find the spread in cylinder slump flow test for river sand and the quantity of water was increased at the rate of 15 kg/m^3 for each step, till a spread of 200mm was achieved. This quantity of water was used to measure various fresh and hardened properties like slump cone flow diameter, J-ring total flow, fresh density, bleeding, hardened density and 28-day compressive strength for all the mixes. The mix proportioning and test results for the mixes C/R/G$_{100B}$, C/R/G$_{80B}$, C/R/G$_{60B}$, C/R/G$_{40B}$, C/R/G$_{20B}$ and C/R/G$_{0B}$ are shown in Table 5.3 and 5.4, respectively.

Table 5.3: Quantity of various materials for mixes C/R/G$_{100B}$, C/R/G$_{80B}$, C/R/G$_{60B}$, C/R/G$_{40B}$, C/R/G$_{20B}$ and C/R/G$_{0B}$

MIX	**Mix Proportions (kg/m^3)**					**GGBS/FA**
	Cement	**GGBS**	**Fly Ash**	**Sand**	**Water**	
C/R/G$_{100B}$	50	400	0	1660	397	100/0
C/R/G$_{80B}$	50	320	68.4	1660	413	80/20
C/R/G$_{60B}$	50	240	136.4	1660	428	60/40
C/R/G$_{40B}$	50	160	205.24	1660	448	40/60
C/R/G$_{20B}$	50	80	273.86	1660	462	20/80
C/R/G$_{0B}$	50	0	342	1660	493	0/100

a) *Water Content*

As shown in Figure 5.1, the water content used for mix C/R/G$_{100B}$, C/R/G$_{80B}$, C/R/G$_{60B}$, C/R/G$_{40B}$, C/R/G$_{20B}$ and C/R/G$_{0B}$ to obtain a spread of 200mm for cylinder slump flow test was observed as 397, 413, 428, 448, 462 and 493 kg/m^3, respectively. The results show that mix containing higher quantity of GGBS has shown better flow at lower water content. Similar observations were made by Soni et al. (2013).

Table 5.4: Test results for mixes C/R/G_{100B}, C/R/G_{80B}, C/R/G_{60B}, C/R/G_{40B}, C/R/G_{20B} and C/R/G_{0B}

MIX	Slump (mm)	J-ring (mm)	Bleeding (%)	Fresh Density (kg/m^3)	Hardened Density (kg/m^3)	Compressive Strength (N/mm^2)
C/R/G_{100B}	600	510	2.88	2090	2146	8.37±0.29
C/R/G_{80B}	625	545	2.5	2050	2102	6.85±0.45
C/R/G_{60B}	600	540	1.9	2039	2050	5.49±0.17
C/R/G_{40B}	625	550	4.24	1985	2010	4.87±0.67
C/R/G_{20B}	555	535	4.268	1957	1970	2.51±0.47
C/R/G_{0B}	555	490	4.34	1938	1955	1.02±0.09

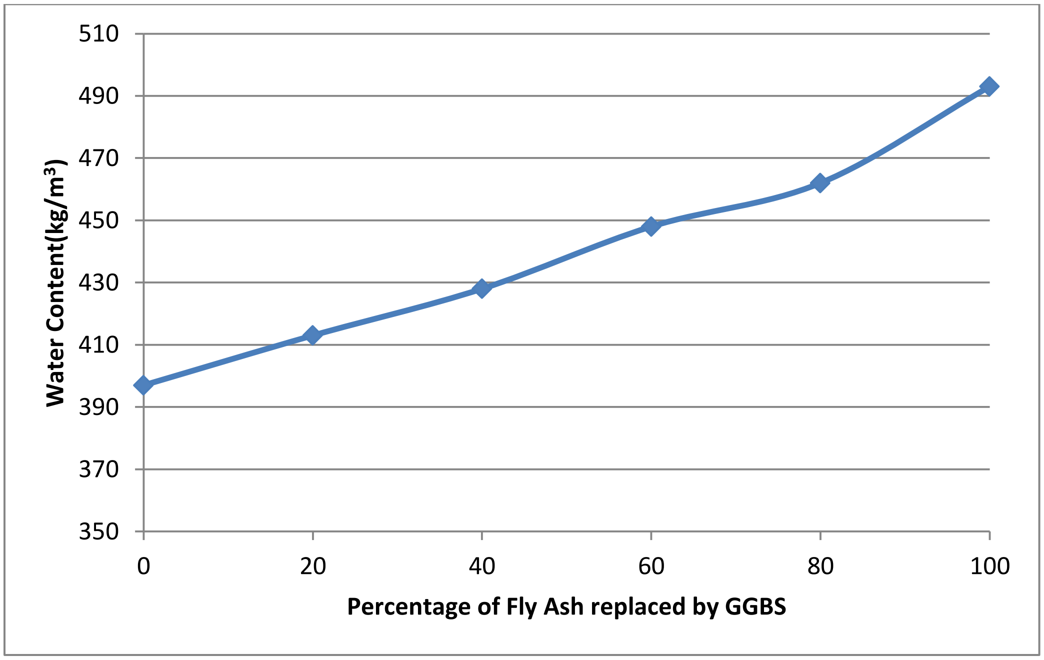


Figure 5.1: Water content obtained from cylinder slump test for mixes C/R/G_{100B}, C/R/G_{80B}, C/R/G_{60B}, C/R/G_{40B}, C/R/G_{20B} and C/R/G_{0B}

b) Flow table and J-ring test

Cone Slump flow diameter for the mixes C/R/G_{100B}, C/R/G_{80B}, C/R/G_{60B}, C/R/G_{40B}, C/R/G_{20B} and C/R/G_{0B} was observed as 600, 625, 600, 625, 555 and 555 mm, respectively (Figure 5.2).

It indicates that the GGBS mixes had similar slump even at lower water content, which may be because of very small particle size of GGBS causing dense matrix pore structure of CLSM. The total flow while conducting J-ring test for mixes $C/R/G_{100B}$, $C/R/G_{80B}$, $C/R/G_{60B}$, $C/R/G_{40B}$, $C/R/G_{20B}$ and $C/R/G_{0B}$ was observed as 510, 545, 540, 550, 535, 490 mm with the water content of 397, 413, 428, 448, 462 and 493 kg/m^3, respectively (Figure 5.3) i.e. an increment in the water content was needed to achieve nearly same amount of passing ability for higher fly ash content.

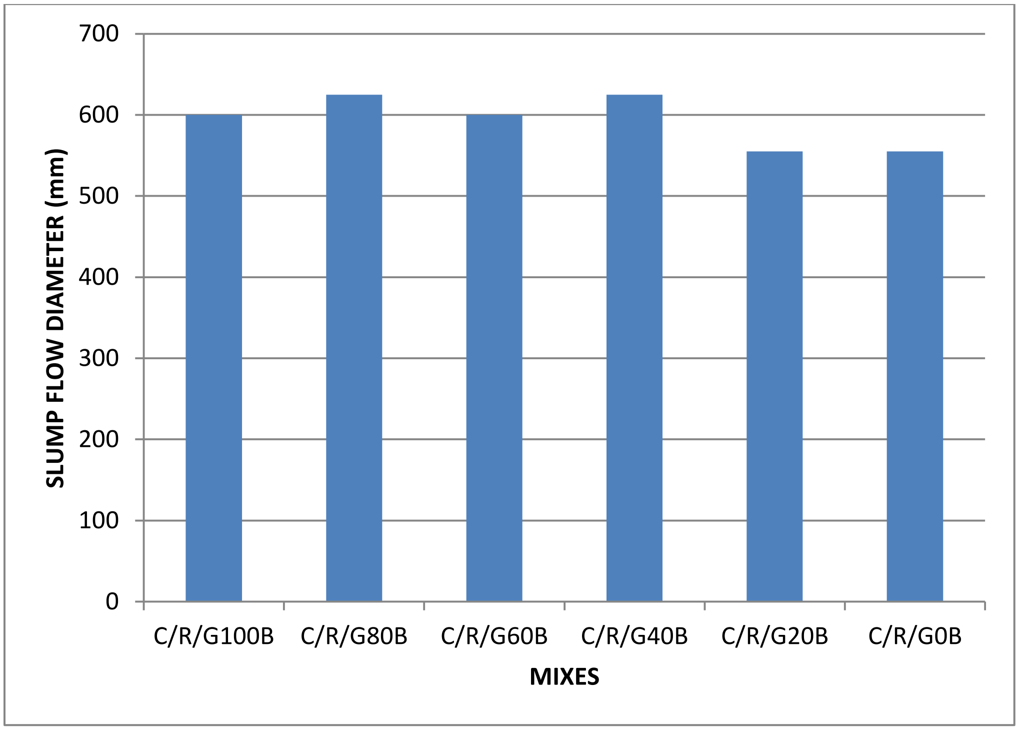


Figure 5.2: Slump flow diameter for mix $C/R/G_{100B}$, $C/R/G_{80B}$, $C/R/G_{60B}$, $C/R/G_{40B}$, $C/R/G_{20B}$ and $C/R/G_{0B}$

c) *Bleeding*

As shown in Figure 5.4, the bleeding for various mix proportions at GGBS/FA ratio of 100/0, 80/20, 60/40, 40/60, 20/80 and 0/100 was 2.88, 2.5, 1.9, 4.24, 4.26 and 4.34%, respectively. The sudden increase in the bleeding is observed for the mix containing 60 or higher percentages of fly ash as replacement of GGBS. It can be due to higher water content used in FA mixes, since at high water content, high sedimentation occurs and causes high bleeding (Katz et al. 2004).

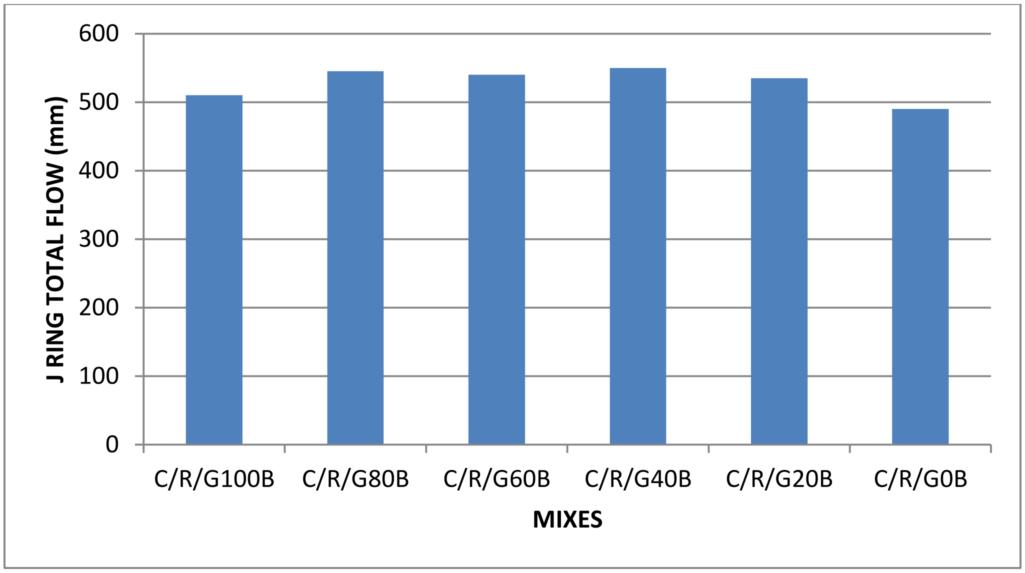


Figure 5.3: J-ring total flow diameter for mix C/R/G_{100B}, C/R/G_{80B}, C/R/G_{60B}, C/R/G_{40B}, C/R/G_{20B} and C/R/G_{0B}

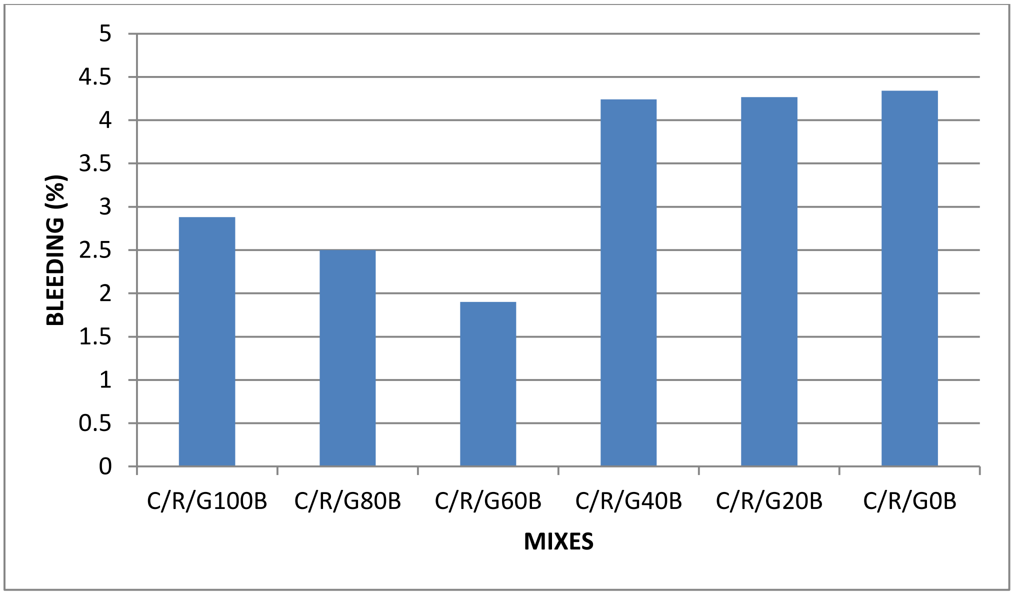


Figure 5.4: Bleeding for mixes C/R/G_{100B}, C/R/G_{80B}, C/R/G_{60B}, C/R/G_{40B}, C/R/G_{20B} and C/R/G_{0B}

d) Density

As shown in Figure 5.5, the fresh state density for mixes C/R/G_{100B}, C/R/G_{80B}, C/R/G_{60B}, C/R/G_{40B}, C/R/G_{20B} and C/R/G_{0B} was observed as 2090, 2050, 2039, 1985, 1957 and 1938 kg/m^3, respectively. As is observed a reduction in the fresh density has been observed with the increase in the ratio of FA in the mix. It can be due to lower specific gravity of FA as compared to GGBS i.e. FA particles are taking same volume with lower weight causing reduction in the density of the material. Also, the quantity of water used for FA mixes was higher as compared to mixes having higher GGBS content which can also result in reduction in density of mix containing higher replacements of FA.

The hardened density for mixes $C/R/G_{100B}$, $C/R/G_{80B}$, $C/R/G_{60B}$, $C/R/G_{40B}$, $C/R/G_{20B}$ and $C/R/G_{0B}$ was observed as 2146, 2102, 2050, 2010, 1970 and 1955 kg/m^3, respectively (Figure 5.6). The reduction in the hardened density was similar to the one observed for fresh density. For each mix, an increase in hardened density has been observed while compared to its fresh density. This can be due to expulsion of excess water during bleeding, resulting in shrinkage of the matrix and hence causing increase in its density.

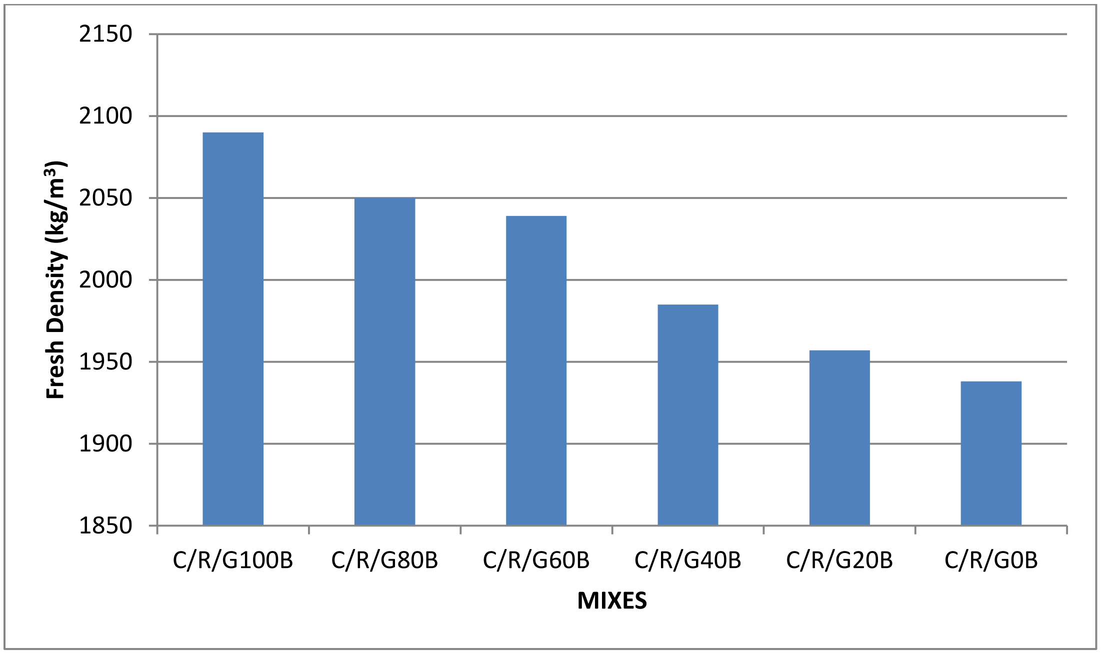


Figure 5.5: Fresh state density for mix $C/R/G_{100B}$, $C/R/G_{80B}$, $C/R/G_{60B}$, $C/R/G_{40B}$, $C/R/G_{20B}$ and $C/R/G_{0B}$

e) *Compressive Strength*

Compressive strength for mixes $C/R/G_{100B}$, $C/R/G_{80B}$, $C/R/G_{60B}$, $C/R/G_{40B}$, $C/R/G_{20B}$ and $C/R/G_{0B}$ was observed as 8.37, 6.85, 5.49, 4.87, 2.57 and 1.024 N/mm^2, respectively (Figure 5.7). The mix containing higher quantity of GGBS has shown greater compressive strength as compared to the mix containing replacements of fly ash. This may be due to the higher number of fines and better production of CSH gel in the mix containing GGBS when compared with the mix with fly ash as replacement of GGBS. The reduction in the compressive strength for mixes containing replacement of GGBS with fly ash may be due to use of higher quantity of water to achieve the required flow. It leads to formation of voids in the resulting mix and hence causing reduction in the strength of the matrix as a whole. A high variation in the results has been achieved from 8.37 to 1.024 N/mm^2, indicating that CLSM with a wide range of strengths can be produced using fly ash and GGBS.

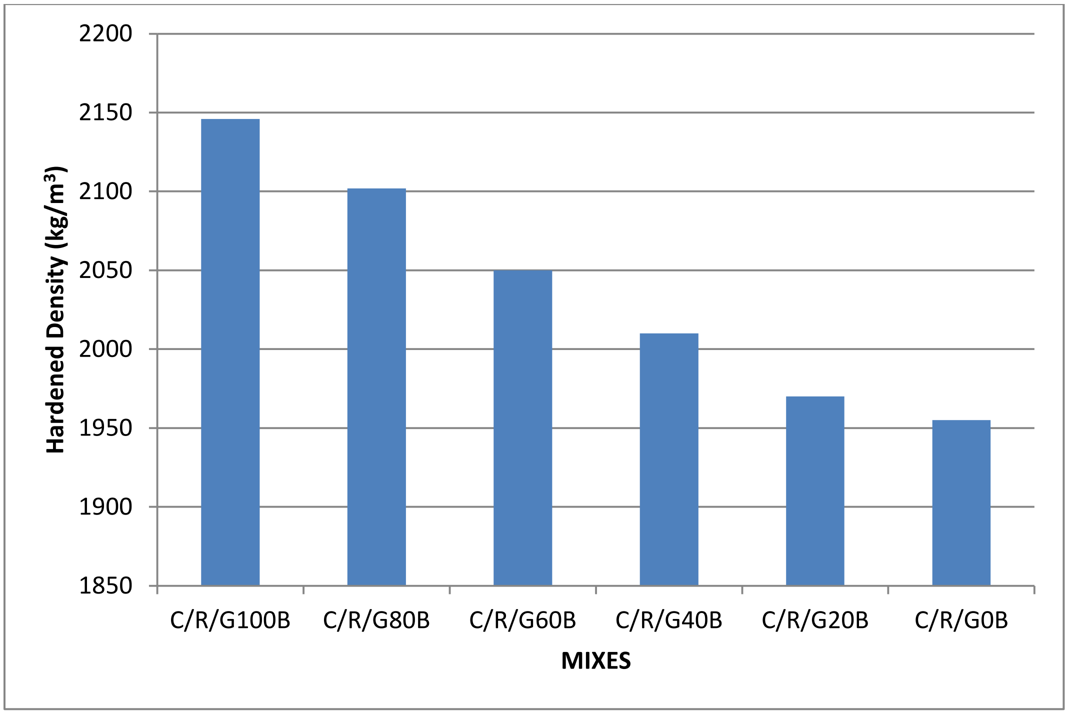


Figure 5.6: Hardened density for mixes C/R/G$_{100B}$, C/R/G$_{80B}$, C/R/G$_{60B}$, C/R/G$_{40B}$, C/R/G$_{20B}$ and C/R/G$_{0B}$

Observations: Except for mix C/R/G$_{0B}$, which has a compressive strength value of 1.024N/mm^2, the compressive strength observed in all mixes was more than 2MPa (desired 28-day compressive strength). Since, it was essential to reduce the compressive strength, two possibilities are explored. The first possibility was to reduce the amount of cement in the mix & the other was by using SFS in place of natural river sand. Reddi et al. (1996) concluded that the mix with SFS has lower compressive strength as compared to the mix with normal fine aggregates., thus SFS replacement option was considered for further experimentation.

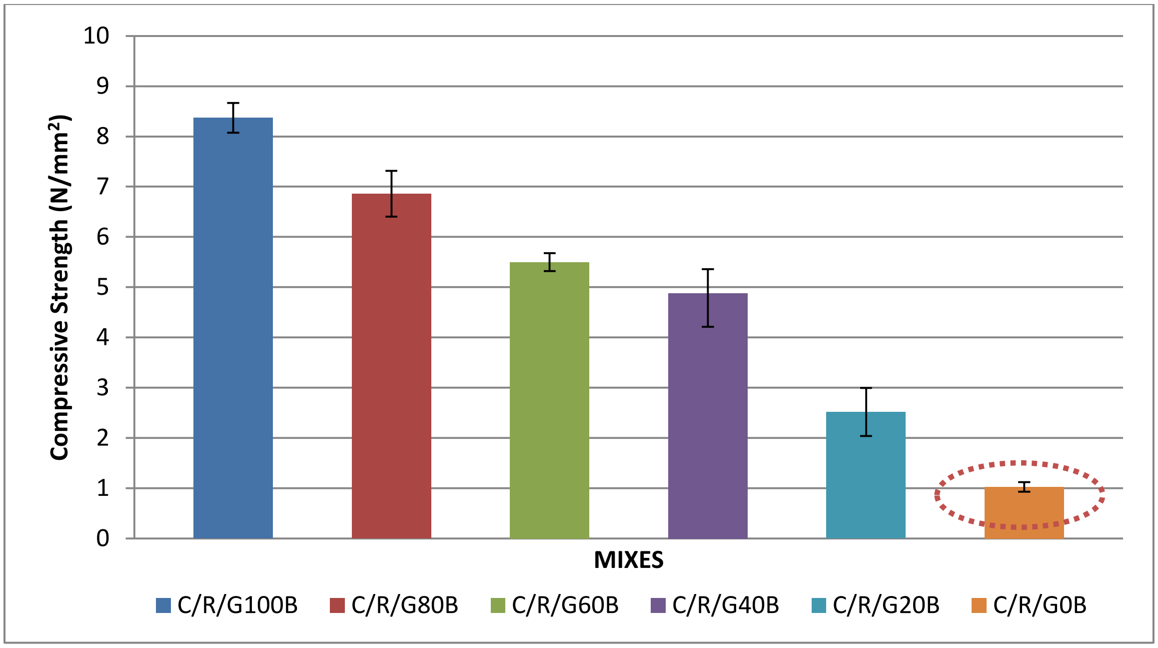


Figure 5.7: Compressive strength for mixes C/R/G_{100B}, C/R/G_{80B}, C/R/G_{60B}, C/R/G_{40B}, C/R/G_{20B} and C/R/G_{0B}

5.4 PROPERTIES OF MIXES WITH CEMENT AS BINDER AND SPENT FOUNDRY SAND AS FINE AGGREGATE

In the second set of trials, natural materials were replaced with industrial by-products i.e. river sand was replaced with spent foundry sand (SFS).

SFS is a by-product from iron or steel casting industries. Foundry sand is recycled again and again in the industry till it could not be further used. The disposal of the spent foundry sand is a very big issue; hence its use in CLSM could help in the reduction of environmental pollution and could lead to the economy of the whole project. The particles of spent foundry sand are much finer as compared to natural river sand (Figure 3.3 and 3.5) hence, it was expected that mix containing foundry sand could show better consistency, flowability and achieve a 28-day compressive strength less than 2MPa.

5.4.1 Mix with 250 kg/m^3 of GGBS

In the mixes containing natural river sand, the quantity of the cement was kept as 50 kg/m^3. Therefore, same amount of cement was used for the mix containing spent foundry sand. Binary mix was generated with the initial quantity of GGBS as 200 kg/m^3 and cylinder slump flow test was performed to evaluate the amount of water needed to achieve a spread of 200 mm. But for this mix, segregation was observed during testing. Hence, the amount of GGBS was increased to 250 kg/m^3 and cylinder slump test was again performed on the mix. The new mix showed true slump with no trace of segregation. The initial quantity of water used for cylinder slump flow test for mix containing spent foundry sand was taken as 450 kg/m^3 and the water content was increased at the rate of 15 kg/m^3 till a spread of 200 mm was observed.

For the purpose of evaluation of ternary mixes, GGBS was replaced with Fly ash on one to one bases by volume. The quantity of various materials for mix C/F/G$_{100C}$, C/F/G$_{80C}$, C/F/G$_{60C}$, C/F/G$_{40C}$, C/F/G$_{20C}$ and C/F/G$_{0C}$ are shown in Table 5.5. This quantity of water was used to measure various fresh and hardened properties like slump cone flow diameter, J-ring total flow, fresh density, bleeding, hardened density and 28-day compressive strength for all the mixes. The results obtained for various tests performed on the mix C/F/G$_{100C}$, C/F/G$_{80C}$, C/F/G$_{60C}$, C/F/G$_{40C}$, C/F/G$_{20C}$ and C/F/G$_{0C}$ are shown in Table 5.6.

Table 5.5: Quantity of different materials used for on the mix C/F/G$_{100C}$, C/F/G$_{80C}$, C/F/G$_{60C}$, C/F/G$_{40C}$, C/F/G$_{20C}$ and C/F/G$_{0C}$

MIX	Mix Proportions (kg/m^3)					GGBS/FA
	Cement	GGBS	Fly Ash	Foundry Sand	Water	
C/F/G$_{100C}$	50	250	0	1450	565	100/0
C/F/G$_{80C}$	50	200	42.75	1450	565	80/20
C/F/G$_{60C}$	50	150	85.5	1450	573	40/60
C/F/G$_{40C}$	50	100	128.25	1450	580	60/40
C/F/G$_{20C}$	50	50	171	1450	603	80/20
C/F/G$_{0C}$	50	0	213.75	1450	603	100/0

Table 5.6: Test results for on the mix C/F/G$_{100C}$, C/F/G$_{80C}$, C/F/G$_{60C}$, C/F/G$_{40C}$, C/F/G$_{20C}$ and C/F/G$_{0C}$

MIX	Slump Flow	J-Ring (mm)	Bleeding (%)	Fresh Density (kg/m^3)	Hardened Density (kg/m^3)	Compressive Strength(N/mm^2)
C/F/G$_{100C}$	610	570	4.3	1832	1893	5.62±0.05
C/F/G$_{80C}$	590	530	4.3	1828	1878	3.59±0.12
C/F/G$_{60C}$	645	570	3.5	1817	1864	2.44±0.24
C/F/G$_{40C}$	600	550	3.5	1801	1842	1.59±0.11
C/F/G$_{20C}$	605	580	4.11	1788	1813	0.89±0.06
C/F/G$_{0C}$	575	510	3.1	1782	1796	0.46±0.08

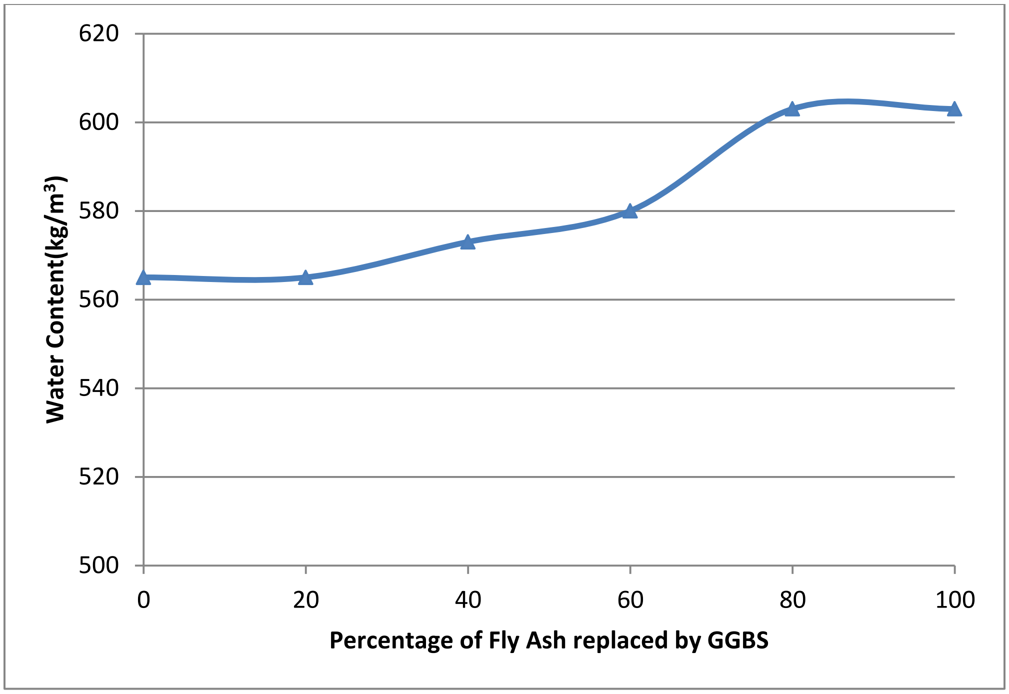


Figure 5.8: Water content for mix $C/F/G_{100C}$, $C/F/G_{80C}$, $C/F/G_{60C}$, $C/F/G_{40C}$, $C/F/G_{20C}$ and $C/F/G_{0C}$

As can be observed form Figure 5.8, minimum water is required for the mix containing only GGBS to achieve the required spread of 200 mm in cylinder slump flow test. As the replacement percentage of GGBS with fly ash is increased, the water requirement increases to achieve similar slump. It again indicates that irrespective of the type of fine aggregates used, the benefit of using very fine GGBS exists. While comparing the amount of water required for the mixes containing spent foundry sand with the mixes containing river sand (Table 5.4 and 5.6), it was observed that the mix containing foundry sand required higher quantity of water to achieve same flow. This increase in the water content can be due to the smaller particle size of foundry sand as compared to river sand resulting in an increase in requirement of water to lubricate the higher surface area of particles in the mix. Moreover, the water absorption of spent foundry sand was observed to be very high (4.43%), thus resulting in increase in the water requirement of the mix containing spent foundry sand.

The slump flow diameter (Figure 5.9) for all mixes lies in the range of 550-650 mm and the J-ring total flow (Figure 5.10) was more than 400 mm as desired. No segregation was observed in any of the mixes. It indicated that natural river sand can be replaced with foundry sand. The finer particle size of spent foundry sand required more water causing it to show better flow and passing ability.

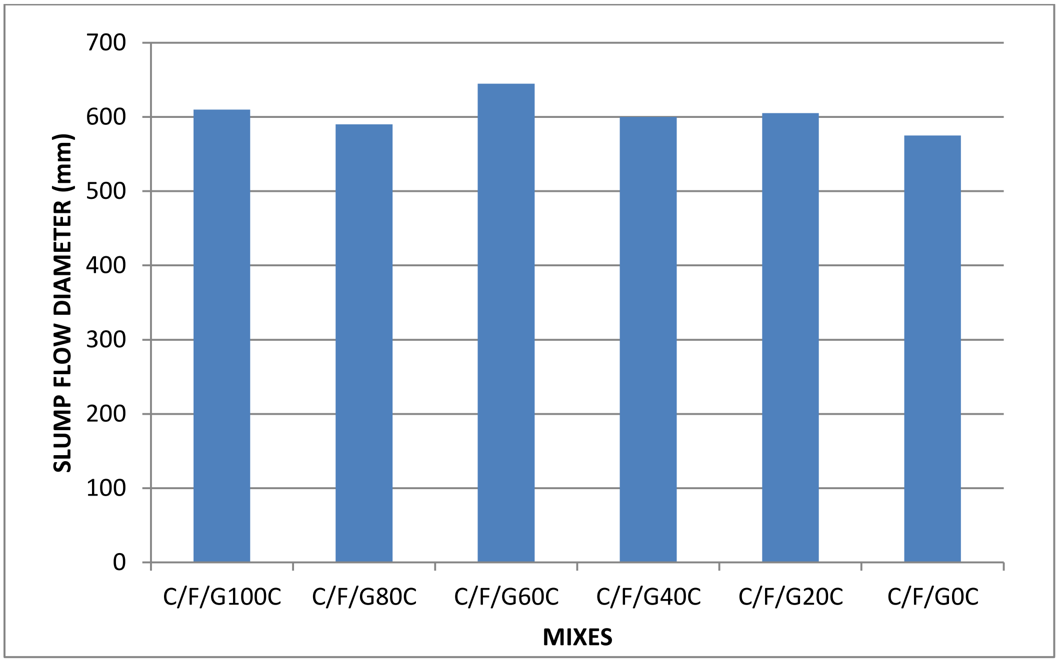


Figure 5.9: Slump Flow diameter for mix C/F/G_{100C}, C/F/G_{80C}, C/F/G_{60C}, C/F/G_{40C}, C/F/G_{20C} and C/F/G_{0C}.

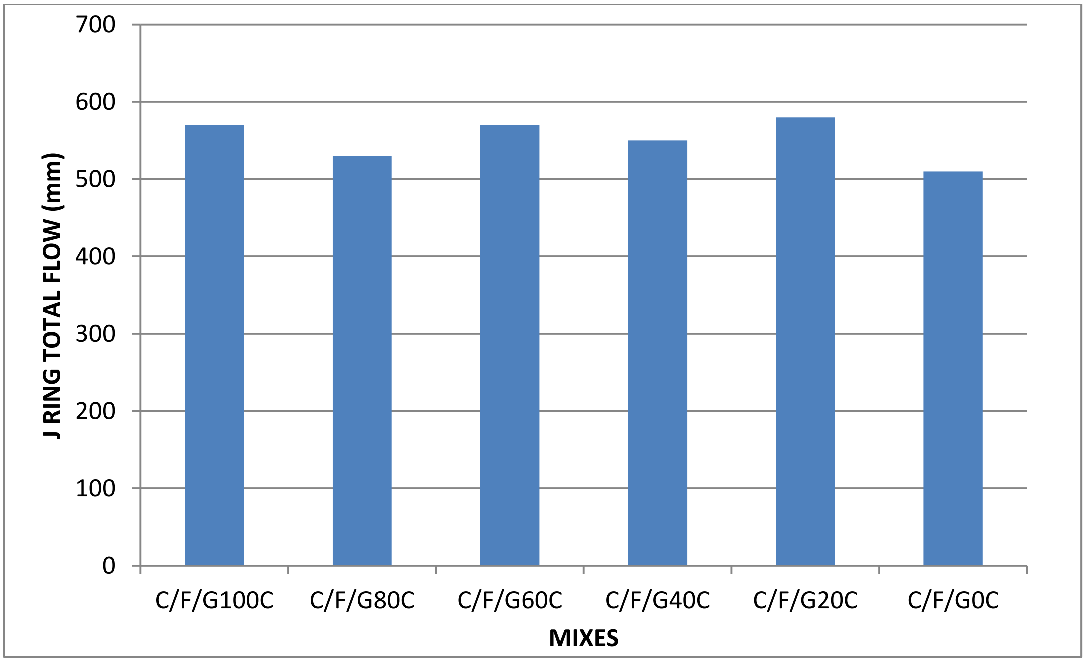


Figure 5.10: J- Ring total flow for mix C/F/G_{100C}, C/F/G_{80C}, C/F/G_{60C}, C/F/G_{40C}, C/F/G_{20C} and C/F/G_{0C}.

However, the bleeding (Figure 5.11) of all the mixes was higher as compared to the corresponding mixes made with natural river sand. It is due to the increased amount of water present in the mix to achieve required slump and the amount of fillers has been reduced from 400 kg/m^3 to 250 kg/m^3, while shifting from natural river sand to foundry sand for same amount of cement as 50 kg/m^3 causing a tendency of water to get separated from the mix.

Similar to previous mixes, the fresh state and hardened density (Figure 5.12 and 5.13) of the mixes is decreasing with increase in the fly ash content as the specific gravity of fly ash is less as compared to GGBS and the mix containing fly ash required higher quantity of water causing reduction in density. Also, the densities of the mix containing spent foundry sand was observed to be less as compared to the mix containing natural river sand for same ratios of GGBS/FA, as spent foundry sand is having lower specific gravity as compared to natural river sand causing reduction in weight per unit volume of the mix. As the quantity of fillers, in case of mixes containing natural river sand, is also more which causes dense packaging of the matrix. Moreover, the high water requirement in mix containing spent foundry sand can also be the factor responsible for reduction in its fresh state and hardened density.

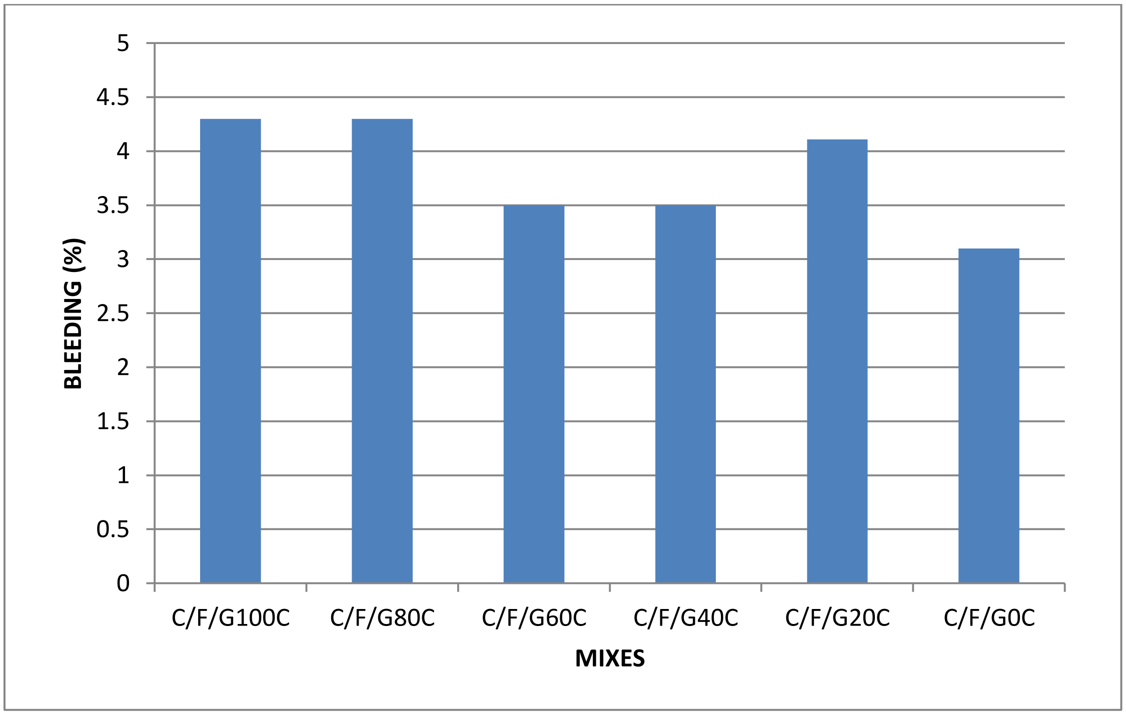


Figure 5.11: Bleeding for mix C/F/G$_{100C}$, C/F/G$_{80C}$, C/F/G$_{60C}$, C/F/G$_{40C}$, C/F/G$_{20C}$ and C/F/G$_{0C}$

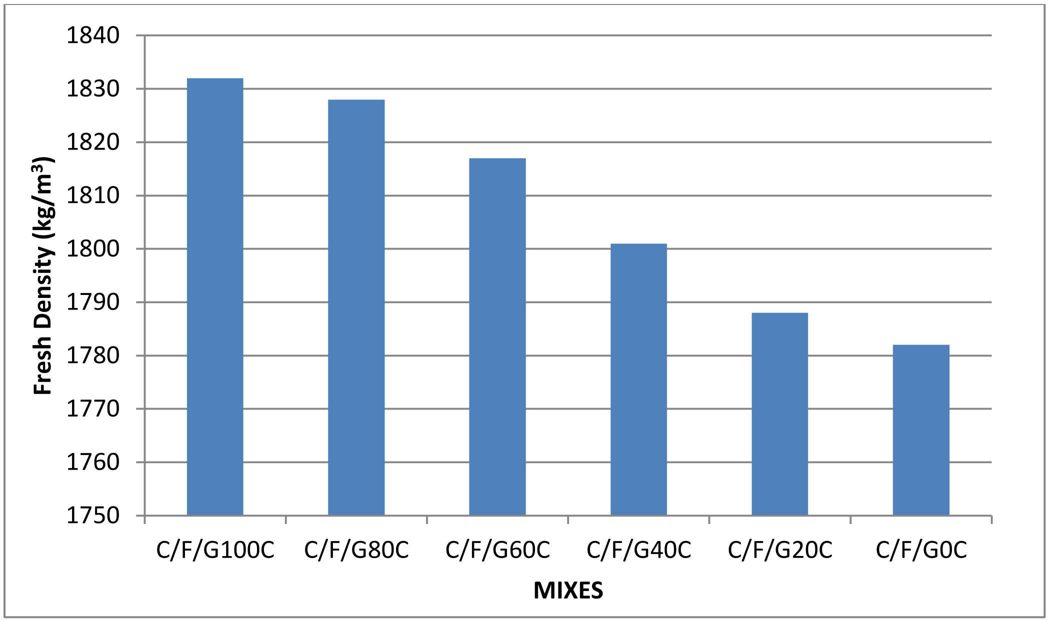


Figure 5.12: Fresh state density for mix C/F/G_{100C}, C/F/G_{80C}, C/F/G_{60C}, C/F/G_{40C}, C/F/G_{20C} and C/F/G_{0C}

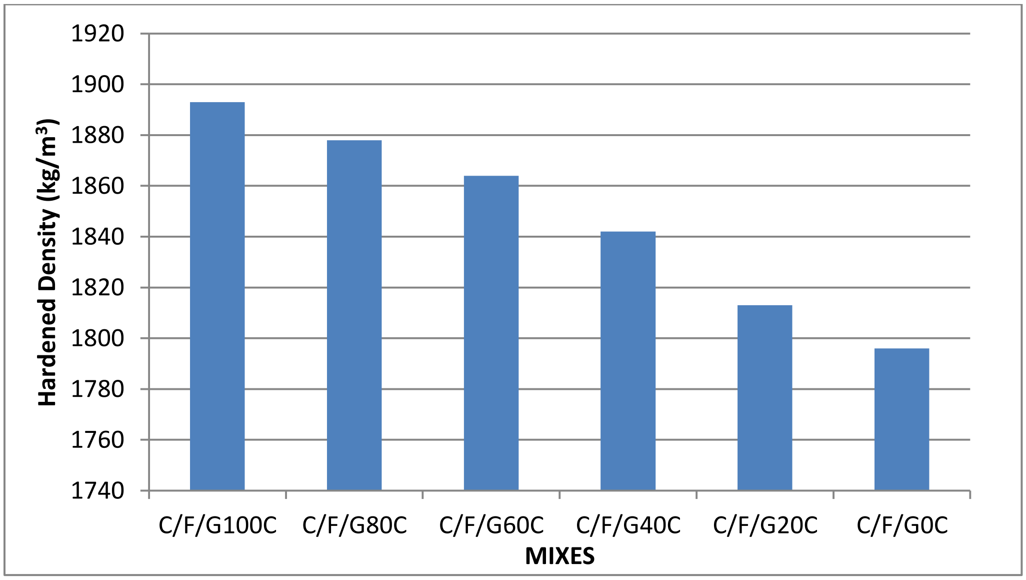


Figure 5.13: Hardened density for mix C/F/G_{100C}, C/F/G_{80C}, C/F/G_{60C}, C/F/G_{40C}, C/F/G_{20C} and C/F/G_{0C}

The compressive strength of CLSM mixes containing spent foundry sand is shown in Figure 5.14 and it is observed to decrease with increase in the percentage replacement of GGBS with FA. This trend is very similar to that observed in case of mix containing natural river sand.

Moreover, reduction in the compressive strength has also been observed for mix containing spent foundry sand, while comparing it with the one containing natural river sand (Table 5.4 and 5.6) for each ratios of GGBS/FA (Reddi et al. 1996, Siddique and Nouwobe 2008). The reduction can be attributed to an increase in the surface area of inert particles to be coated with CSH gel during hydration: the lower quantity of filler used in the mix containing spent foundry sand also causes lesser dense packing behavior. Along with this, for the mixes with spent foundry sand more water was required 565 to 603 kg/m^3 as compared to 397 to 493 kg/m^3 for the mixes containing natural river sand. This large amount of water was not used in hydration and the left out water when evaporated leads to porous structure of concrete. Three mixes C/F/G$_{40C}$, C/F/G$_{20C}$ and C/F/G$_{0C}$ were observed to achieve the desired 28-day compressive strength requirement of less than 2.0 MPa for CLSM, whereas, the other three mixes i.e. C/F/G$_{100C}$, C/F/G$_{80C}$ and C/F/G$_{60C}$ were having value of 28-day compressive strength more than the maximum required value for CLSM.

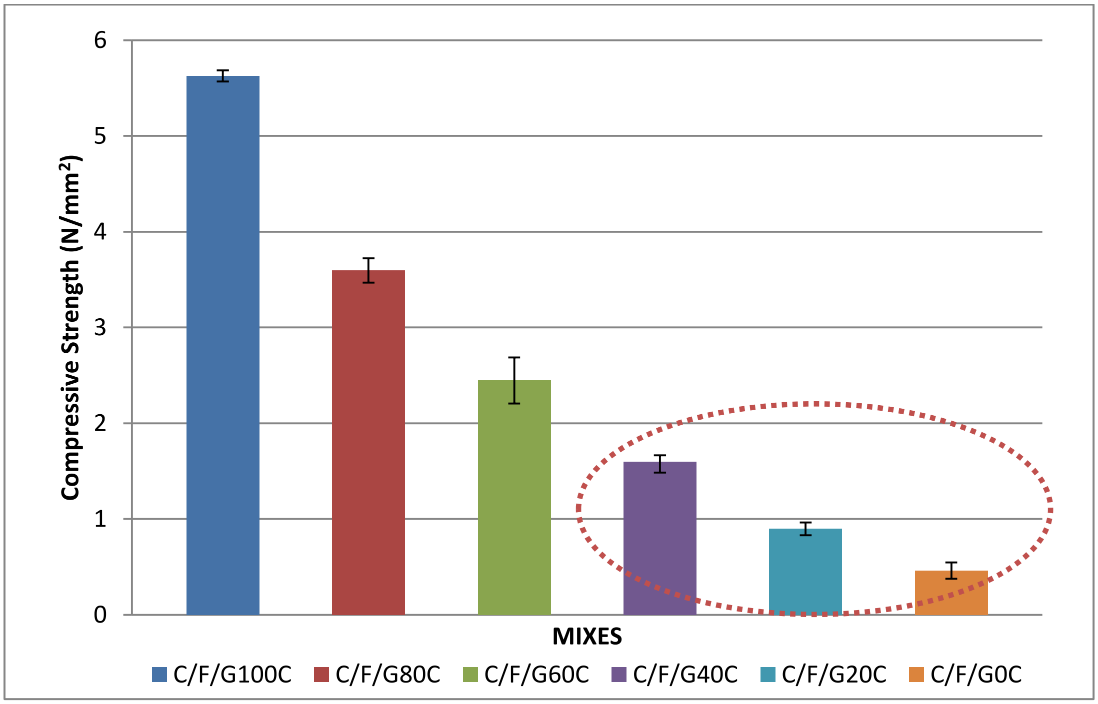


Figure 5.14: 28-day compressive strength for mix C/F/G$_{100C}$, C/F/G$_{80C}$, C/F/G$_{60C}$, C/F/G$_{40C}$, C/F/G$_{20C}$ and C/F/G$_{0C}$

Observations: In the above mixes bleeding is the main concern, to reduce bleeding it was suggested to increase the number of fines but most of the mixes (C/F/G_{100C}, C/F/G_{80C} and C/F/G_{60C}) were already lining outside the criteria of 28-compressive strength to be less than 2.0 MPa. Increase in the compressive strength with increase in the pozzolanic material was expected, as in case of natural sand the compressive strength of mixes C/R/G_{100A} and C/R/G_{100B} containing same amount of cement increased from 3.27 to 8.37 N/mm^2 with the increase in GGBS content from 200 to 400 kg/m^3 (Table 5.2 and 5.4). Hence, if the quantity of fines is increased in the mix, the amount of cementitious material must be reduced to balance the strength requirement.

5.4.2 Mix with 300 kg/m^3 of GGBS

In order to produce mixes having dual benefits of economy and required strength. Cement content was reduced to 25 kg/m^3 and initial GGBS content was increased to 300 kg/m^3 and the binary mix was generated these quantities of cement and GGBS. For the generation of ternary mixes the GGBS content was replaced with FA on one to one bases by volume. The ratios of GGBS/FA used for the mix C/F/G_{100D}, C/F/G_{80D}, C/F/G_{60D}, C/F/G_{40D}, C/F/G_{20D} and C/F/G_{0D} were 100/0, 80/20, 60/40, 40/60, 20/80 and 0/100 by volume. The amount of water to be used in each mix was evaluated in initial test of cylinder slump test in which 200 mm spread was achieved, starting at the water content of 450 kg/m^3 for foundry sand and noting down the spread. The quantity of water was increased at a rate of 15 kg/m^3 till a spread of 200 mm was achieved. The water content observed to achieve required slump was used to find fresh and hardened properties of the CLSM such as slump flow diameter, J-ring total flow, fresh state density, bleeding, hardened density and 28-day compressive strength. The mix proportioning for the mix C/F/G_{100D}, C/F/G_{80D}, C/F/G_{60D}, C/F/G_{40D}, C/F/G_{20D} and C/F/G_{0D} is shown in Table 5.7 and the results from various test conducted are summarized in Table 5.8.

As shown in Figure 5.15, the quantity of water required is increasing for various mixes with increase in the replacement of GGBS by FA to achieve similar spread. This again indicates improvement in the flow due to very finer particle size of GGBS. Moreover, water required for mix containing 25 kg/m^3 of cement was less as compared to the mix containing 50 kg/m^3 of cement for various ratios of GGBS/FA (Table 5.5 and 5.7), which may be attributed to reduction in viscosity of the mix with 25 kg/m^3 of cement resulting in achievement of desired flow at a low water content.

Table 5.7: Mix proportions used for mix C/F/G$_{100D}$, C/F/G$_{80D}$, C/F/G$_{60D}$, C/F/G$_{40D}$, C/F/G$_{20D}$ and C/F/G$_{0D}$

MIX	Mix Proportions (kg/m^3)					GGBS/FA
	Cement	GGBS	Fly Ash	Sand	Water	
C/F/G$_{100D}$	25	300	0	1530	515	100/0
C/F/G$_{80D}$	25	240	51.3	1530	535	80/20
C/F/G$_{60D}$	25	180	102.6	1530	555	60/40
C/F/G$_{40D}$	25	120	153.9	1530	576	40/60
C/F/G$_{20D}$	25	60	205.2	1530	588	20/80
C/F/G$_{0D}$	25	0	256.5	1530	596	0/100

Table 5.8: Test results for mix C/F/G$_{100D}$, C/F/G$_{80D}$, C/F/G$_{60D}$, C/F/G$_{40D}$, C/F/G$_{20D}$ and C/F/G$_{0D}$

MIX	Slump Flow (mm)	J Ring (mm)	Fresh Density (kg/m^3)	Bleeding (%)	Hardened Density (kg/m^3)	Compressive strength (N/mm^2)
C/F/G$_{100D}$	600	540	1947	3.72	1970	3.38±0.08
C/F/G$_{80D}$	580	530	1926	4.1	1963	2.44±0.03
C/F/G$_{60D}$	560	520	1878	3.22	1888	1.17±0.13
C/F/G$_{40D}$	600	555	1843	4.66	1854	0.99±0.11
C/F/G$_{20D}$	590	540	1812	4.7	1836	0.66±0.02
C/F/G$_{0D}$	565	505	1798	4.1	1817	0.34±0.02

All the mixes were in the range of desired slump flow diameter of 550-650 mm and the total flow in J-ring was greater than 400 mm for all the mixes. Slump flow diameter (Figure 5.16) and J-ring total flow (Figure 5.17) has shown a similar trend as was observed in previous set of trials i.e. higher amount of water was required to achieve similar flowability and passing ability of the mix containing higher replacement level of GGBS with FA. While comparing results of pervious mix of foundry sand containing 250 kg/m^3 of GGBS with the present mix containing 300 kg/m^3 of GGBS (Table 5.6 and 5.8) the desired slump flow diameter and J-Ring total flow has been achieved at lower water content for the mix containing 300 kg/m^3 GGBS. This reduction in the water content may be due to decrease in cohesive fines (cement) showing binding during fresh state of CLSM causing reduction in viscosity of the mix hence, resulting in better flow. Moreover, the use of higher quantity of GGBS (300 kg/m^3) leads to dense pore structure matrix resulting in reduction in the water content needed to achieve same flowability and passing ability.

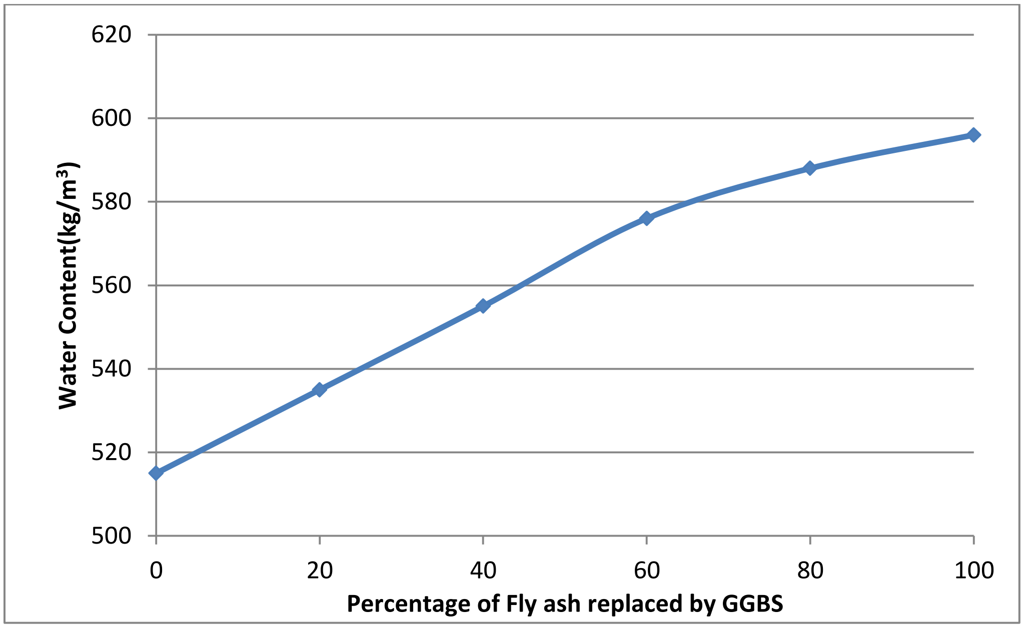


Figure 5.15: Water content used for mix C/F/G_{100D}, C/F/G_{80D}, C/F/G_{60D}, C/F/G_{40D}, C/F/G_{20D} and C/F/G_{0D}

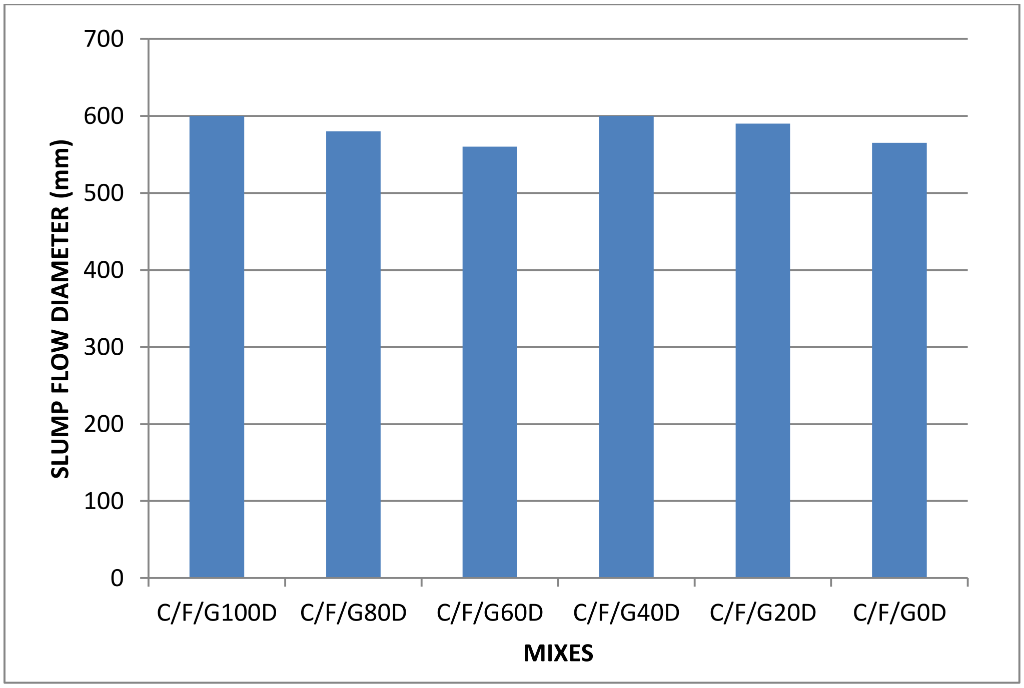


Figure 5.16: Slump flow diameter for mix C/F/G_{100D}, C/F/G_{80D}, C/F/G_{60D}, C/F/G_{40D}, C/F/G_{20D} and C/F/G_{0D}

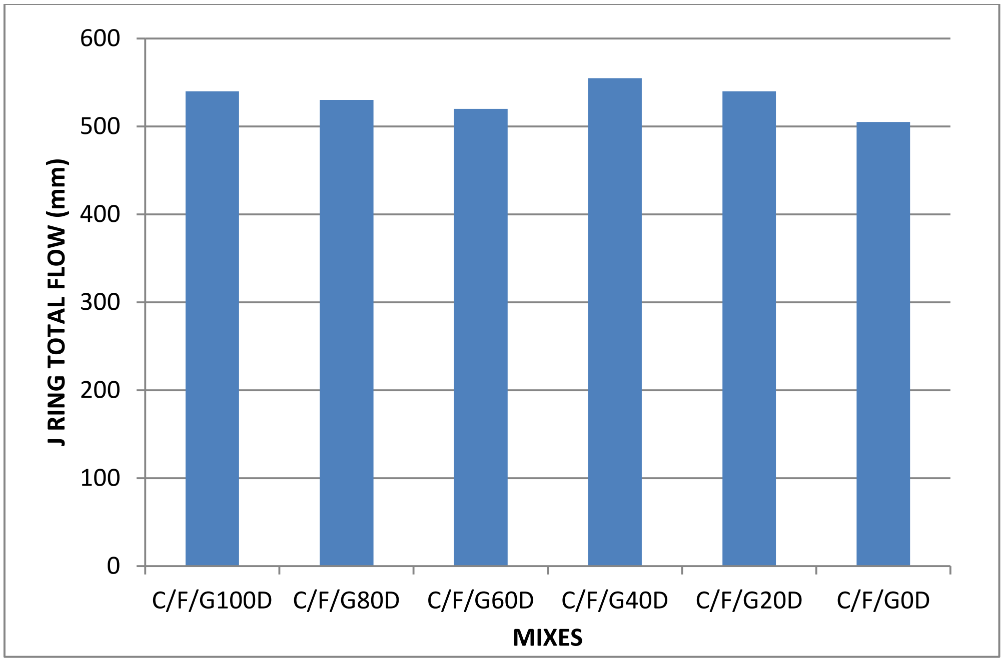


Figure 5.17: J-ring total flow for mix C/F/G_{100D}, C/F/G_{80D}, C/F/G_{60D}, C/F/G_{40D}, C/F/G_{20D} and C/F/G_{0D}

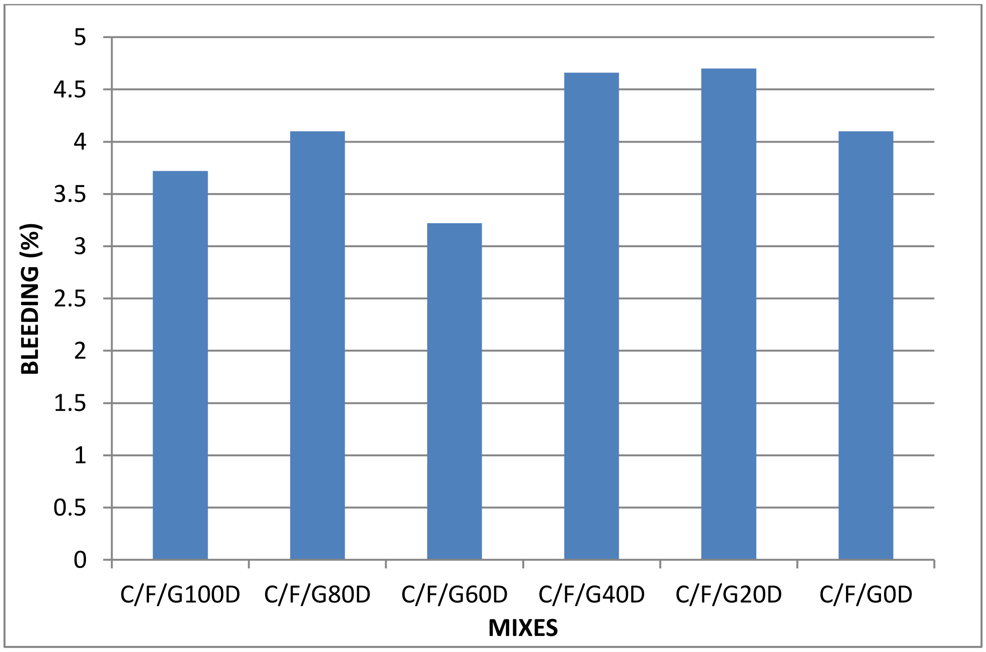


Figure 5.18: Bleeding for mix C/F/G_{100D}, C/F/G_{80D}, C/F/G_{60D}, C/F/G_{40D}, C/F/G_{20D} and C/F/G_{0D}

All the mixes in present trial showed high bleeding even with higher in the GGBS content in the mix (Figure 5.18). The bleeding was not reduced as expected with the increase in the number of fines (GGBS content); it may be due to the reduction of cement content in the mix causing reduction in cohesion of the mix and ability to hold water for longer time when left undisturbed. As GGBS or FA behave as inert fillers during fresh state and reacts mainly with the calcium hydroxide particles formed during the hydration of cement, there increment does not have any significant effect on the bleeding properties of CSLM.

Both the fresh state density (Figure 5.19) and hardened density (Figure 5.20) are observed to decrease with increase in the replacement of GGBS with FA i.e. at higher FA content lower density has been achieved. Thus, a similar trend has been achieved as in the case of previous mixes. While, comparing the set mixes containing 250 kg/m^3 and 300 kg/m^3 of GGBS, containing same ratio of GGBS/FA (Table 5.6 and 5.8), an increase in fresh density has been observed for mixes containing 300 kg/m^3 of GGBS. This increase may be due to the increase in the number of fines causing better particle packaging with lesser number of voids. The reduction in the amount of water used to achieve desired flow properties may also be a cause for the increase in the fresh state and hardened density of present set of mixes.

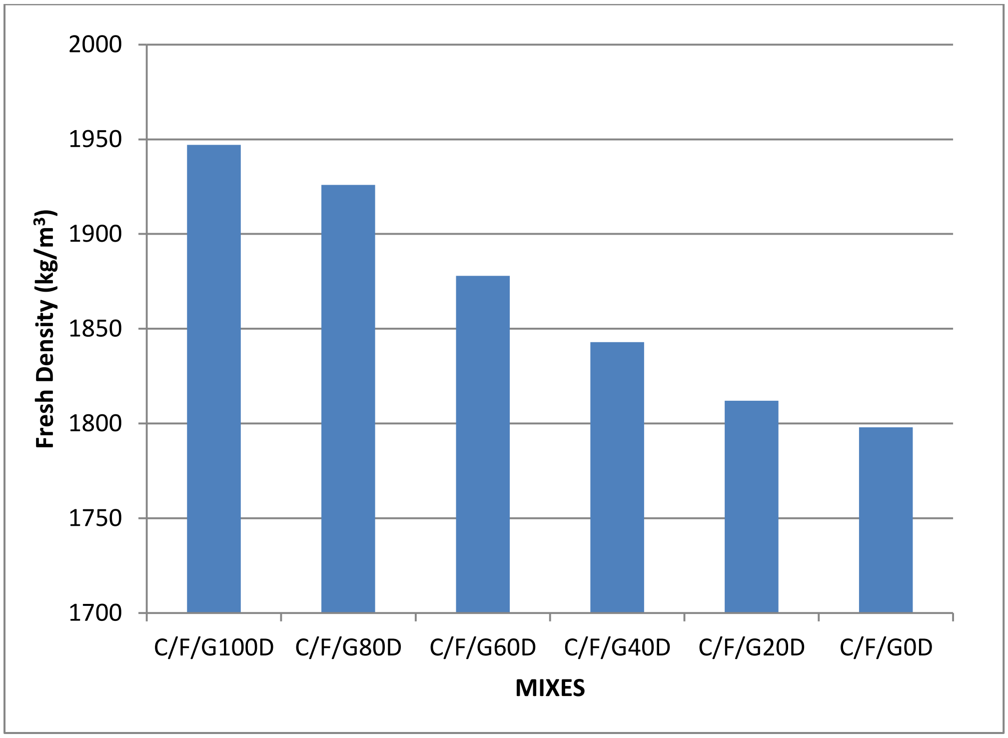


Figure 5.19: Fresh state density for mix C/F/G_{100D}, C/F/G_{80D}, C/F/G_{60D}, C/F/G_{40D}, C/F/G_{20D} and C/F/G_{0D}

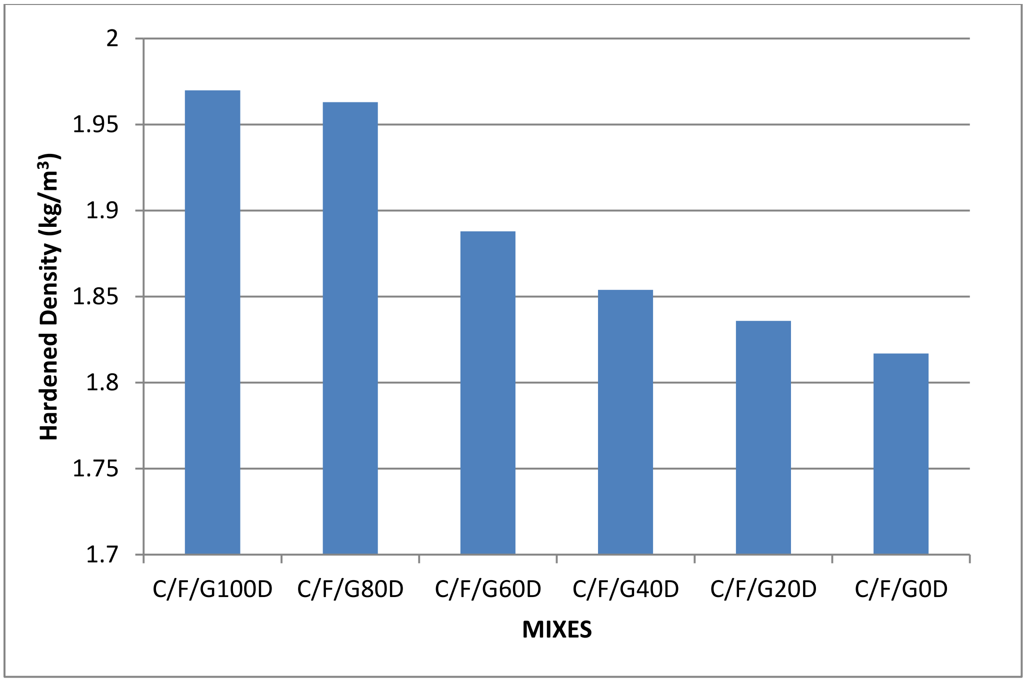


Figure 5.20: Hardened density for C/F/G$_{100D}$, C/F/G$_{80D}$, C/F/G$_{60D}$, C/F/G$_{40D}$, C/F/G$_{20D}$ and C/F/G$_{0D}$

As shown in Figure 2.21, compressive strength for present set of trials also shows a decrease in strength with an increase in fly ash content in the mix, a trend similar to that achieved in case of previous set of trials. For the present set of trials, containing 25 kg/m^3 of cement content three mixes (C/F/G$_{60D}$, C/F/G$_{40D}$ and C/F/G$_{20D}$) were observed to be in the range of desired 28-compressive strength. Only one mix, C/F/G$_{0D}$ was having desired 28-day compressive strength partially below 0.345 MPa indicating that even such a low quantity of cement could be used for the generation of CLSM.

Observation: As seen in the above set of trials, fresh properties of CLSM can be improved with the increase the number of cohesive fines in the mix but if quantity of cement is increased, the objective of controlled strength below 2.0 MPa may not be satisfied. There is a need for a material showing binding properties as soon as water is added but attain low strength when used as replacement for same quantity of cement in the mix, so that higher quantity of cohesive fines could be used as well as 28-day compressive strength can be controlled to a required value.

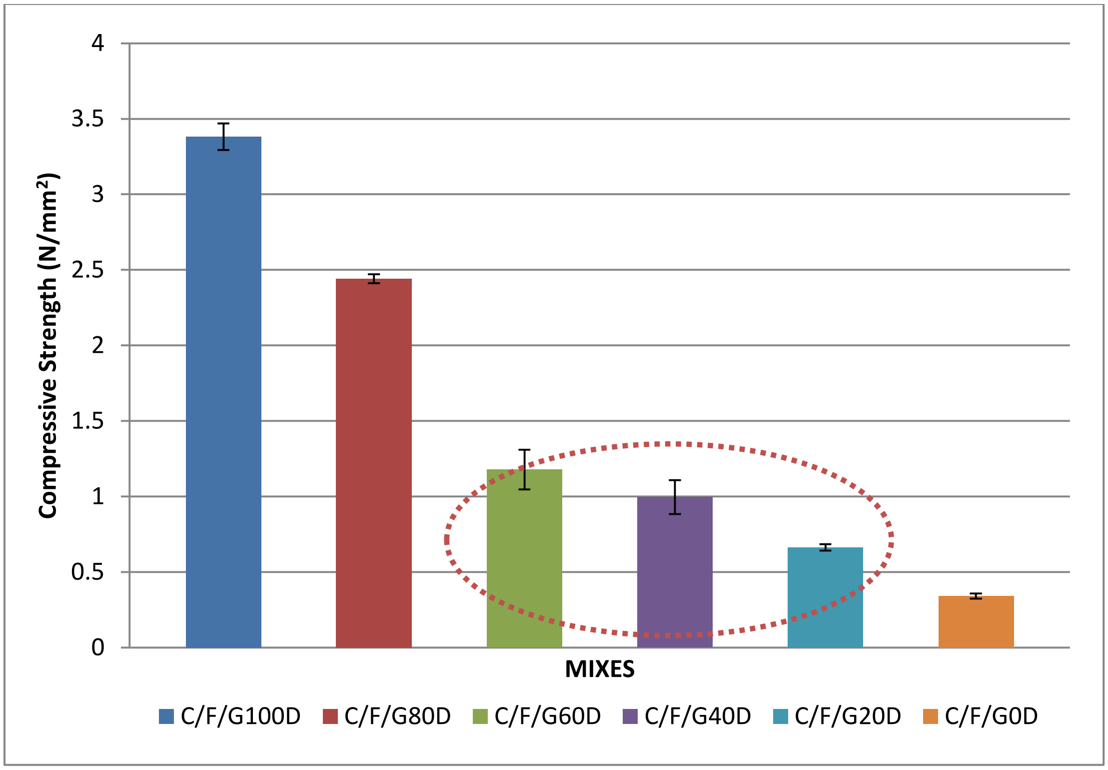


Figure 5.21: 28-day Compressive strength for mix C/F/G_{100D}, C/F/G_{80D}, C/F/G_{60D}, C/F/G_{40D}, C/F/G_{20D} and C/F/G_{0D}

5.5 PROPERTIES OF MIX WITH CKD AS BINDER AND SPENT FOUNDRY SAND AS FINE AGGREGATE

From the previous research findings (Al-Harthy et al. 2005, Taha et al. 2009 and Lachemi et al 2010), it has been found that the behavior of CKD (Cement Kiln Dust) is similar to that of cement but it is not able to impart strength to the mix when compared to the mix containing equal quantity of cement. Thus, it was expected that the incorporation of CKD in the CLSM can improve various fresh and hardened properties of cement. The use of CKD would also lead to reduction in the use of commercial building materials, helping to maintain economic and environmental balance. From literature, it was observed that quantity of CKD varied from 200-300 kg/m^3 to achieve desired strength and consistency in the mix. In the present set of trials, CKD content of 200 kg/m^3 and initial GGBS content of 100 kg/m^3 was used to control the segregation for the generation of binary mix. The ternary mixes were developed by replacement of GGBS with FA in each step by 20% of the volume of GGBS. The ratios of GGBS/FA used in present set of trials were 100/0, 80/20, 60/40, 40/60, 20/80 and 0/100 by volume. The mix proportion used for mixes K/F/G_{100}, K/F/G_{80}, K/F/G_{60}, K/F/G_{40}, K/F/G_{20} and K/F/G_0 is shown in Table 5.9. The quantity of water was calculated using cylinder slump flow test. Starting with an initial water content of 450 kg/m^3, an increment of 15 kg/m^3 was done in each step till a spread of 200 mm was achieved. This water content was used to evaluate various fresh and hardened properties of mixes containing CKD, and the results of various tests such as slump flow, J-Ring total flow, fresh density, bleeding, hardened density, 28-day compressive strength are shown in Table 5.10.

Table 5.9: Quantity of various materials for mixes K/F/G_{100}, K/F/G_{80}, K/F/G_{60}, K/F/G_{40}, K/F/G_{20} and K/F/G_0.

MIX	Mix Proportions (kg/m^3)				
	CKD	GGBS	Fly Ash	SPS	Water
K/F/G_{100}	200	100	0	1400	605
K/F/G_{80}	200	80	16.98	1400	615
K/F/G_{60}	200	60	33.97	1400	626
K/F/G_{40}	200	40	50.96	1400	641
K/F/G_{20}	200	20	67.95	1400	675
K/F/G_0	200	0	85.5	1400	691

Table 5.10: Test results for mixes K/F/G_{100}, K/F/G_{80}, K/F/G_{60}, K/F/G_{40}, K/F/G_{20} and K/F/G_0.

MIX	Slump Flow (mm)	J Ring (mm)	Fresh Density (kg/m^3)	Bleeding (%)	Hardened Density (kg/m^3)	Compressive Strength (N/mm^2)
K/F/G_{100}	620	570	1802	1.3	1821	3.45±0.03
K/F/G_{80}	610	560	1796	1.3	1801	2.79±0.06
K/F/G_{60}	645	580	1783	2.1	1792	2.49±0.10
K/F/G_{40}	610	535	1764	2.5	1778	1.89±0.04
K/F/G_{20}	620	565	1745	2.48	1764	1.64±0.03
K/F/G_0	600	540	1731	2	1752	1.41±0.01

The water required to achieve the spread of 200 mm in cylinder slump test is increasing with increase in the FA content which is similar to the trend found in previous sets of trials. This corroborates the fact that very fine particles of GGBS have filled the inter particle voids cause formation of dense pore structure matrix and reduction of the water requirement (Figure 5.22). The amount of water required in, CKD as binder, was higher as compared to the mixes having cement as binder mixes. This increase in water requirement may be attributed to the fact that higher cementitious material i.e. 200 kg/m^3 of CKD was used as against the 25-50 kg/m^3 of cement (Table 5.5, 5.7 and 5.9), causing increase in thickening of the mix resulting in higher water requirement to achieve desired flow (Katz and Kovler, 2004).

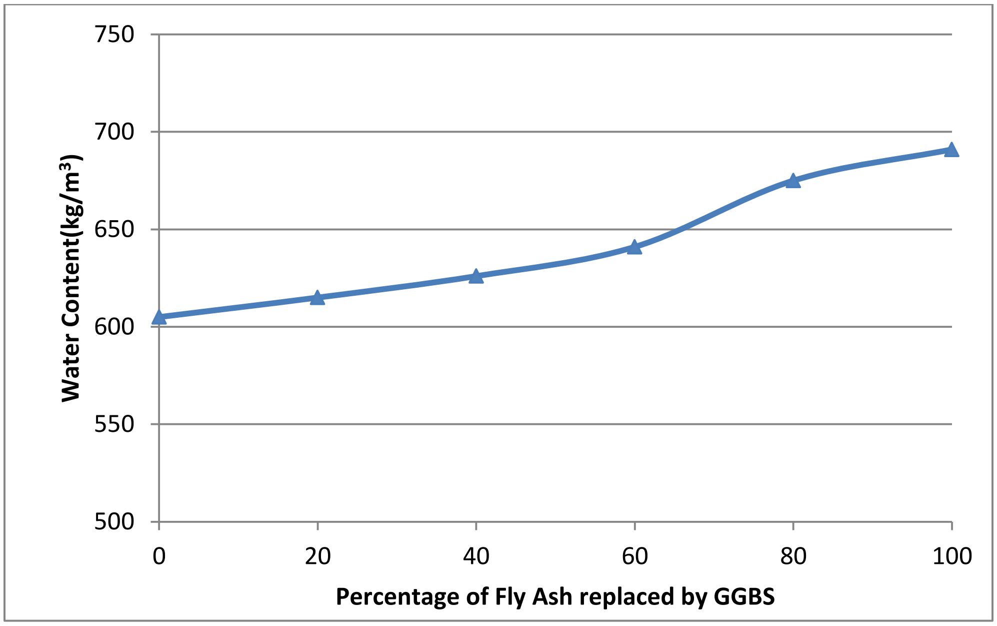


Figure 5.22: Water content required for mixes K/F/G_{100}, K/F/G_{80}, K/F/G_{60}, K/F/G_{40}, K/F/G_{20} and K/F/G_0

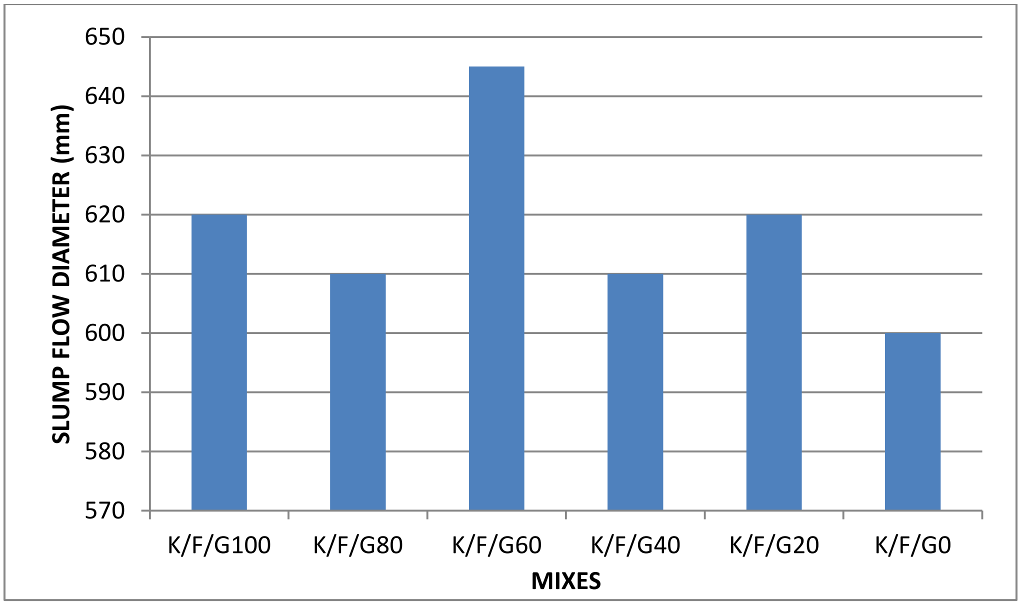


Figure 5.23: Slump flow diameter for mixes K/F/G_{100}, K/F/G_{80}, K/F/G_{60}, K/F/G_{40}, K/F/G_{20} and K/F/G_0

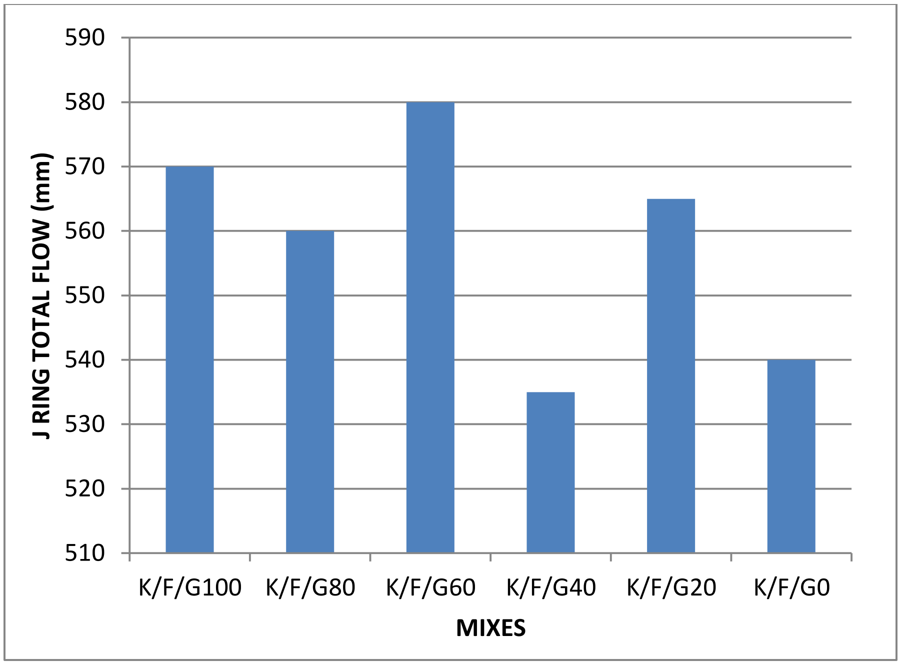


Figure 5.24: J-Ring total flow for mixes K/F/G_{100}, K/F/G_{80}, K/F/G_{60}, K/F/G_{40}, K/F/G_{20} and K/F/G_0

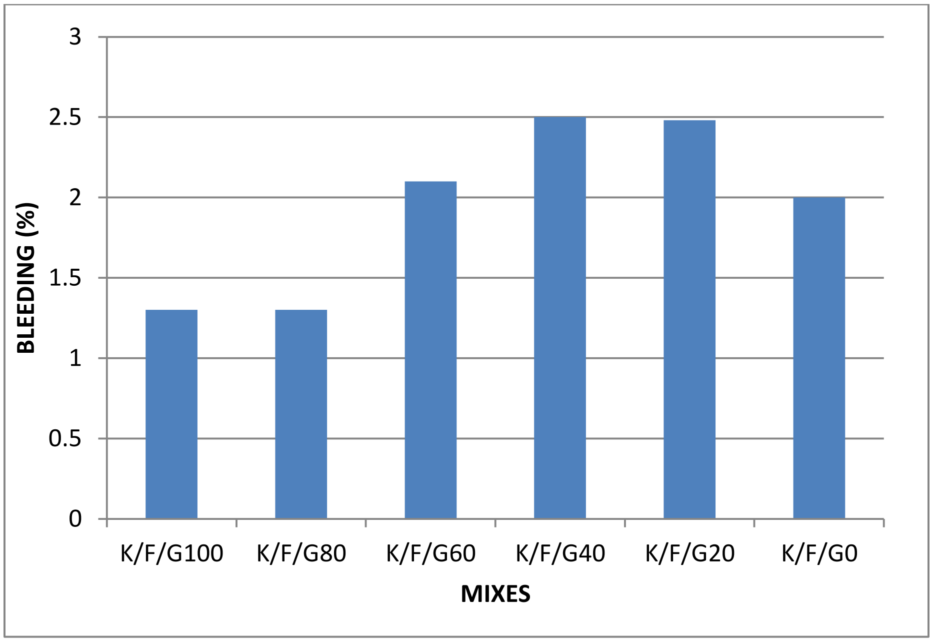


Figure 5.25: Bleeding for mixes K/F/G_{100}, K/F/G_{80}, K/F/G_{60}, K/F/G_{40}, K/F/G_{20} and K/F/G_0

All the mixes were in the range of desired slump flow diameter of 550-650 mm and the total flow in J-ring was greater than 400 mm for all the mixes. Slump flow diameter (Figure 5.23) and

J-ring total flow (Figure 5.24) has shown same trend as observed in previous set of trials i.e. less water was required to achieve similar flowability and passing ability of the mix containing higher quantity of GGBS.

In the mix containing CKD as binder very less expulsion of water was observed during casting of cubes. Segregation was not observed while carrying out various tests for these set of trials. It can be observed from the Figure 5.25 that the bleeding for all the mixes has been achieved below 2.5% and a lowest bleeding of 1.3% has been achieved in the mix $K/F/G_{100}$ and $K/F/G_{80}$. This low bleeding may be due to increase in the number of cohesive fines in the mix causing thickening of the mix, resulting in reduction in the bleeding.

The fresh state and hardened density of the mix containing CKD are shown in Figure 5.26 and 5.27. A trend similar to the mixes containing cement as binder is observed. It has also been observed that lowest fresh and hardened density has been observed for the mix containing CKD with GGBS and FA replacements when compared with corresponding mix containing cement and same ratio of GGBS/FA. This may be due to the fact that highest quantity of water has been used to achieve the desired slump causing reduction in the density of the mix.

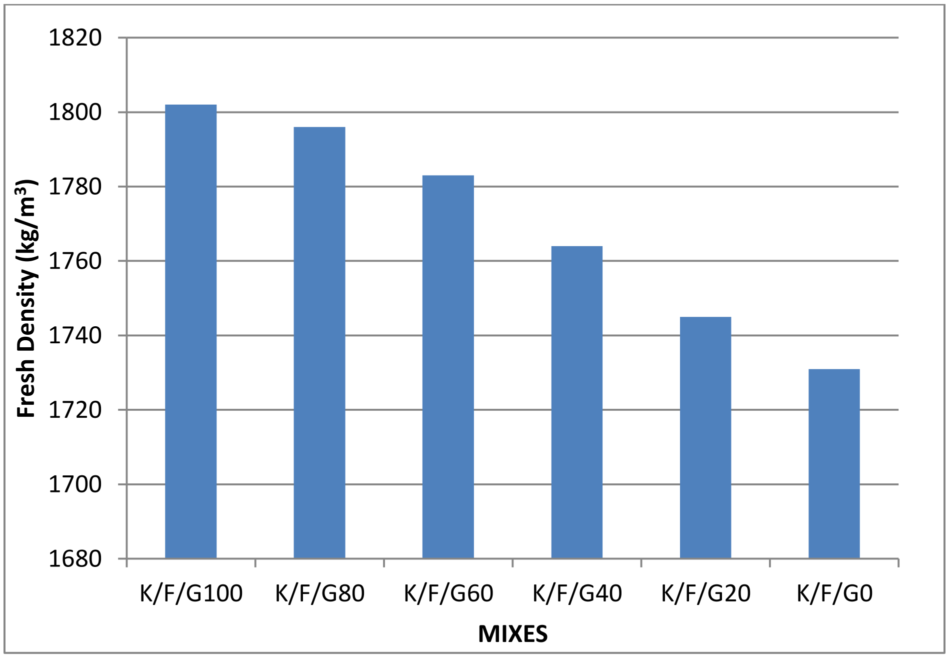


Figure 5.26: Fresh state density for mixes $K/F/G_{100}$, $K/F/G_{80}$, $K/F/G_{60}$, $K/F/G_{40}$, $K/F/G_{20}$ and $K/F/G_0$

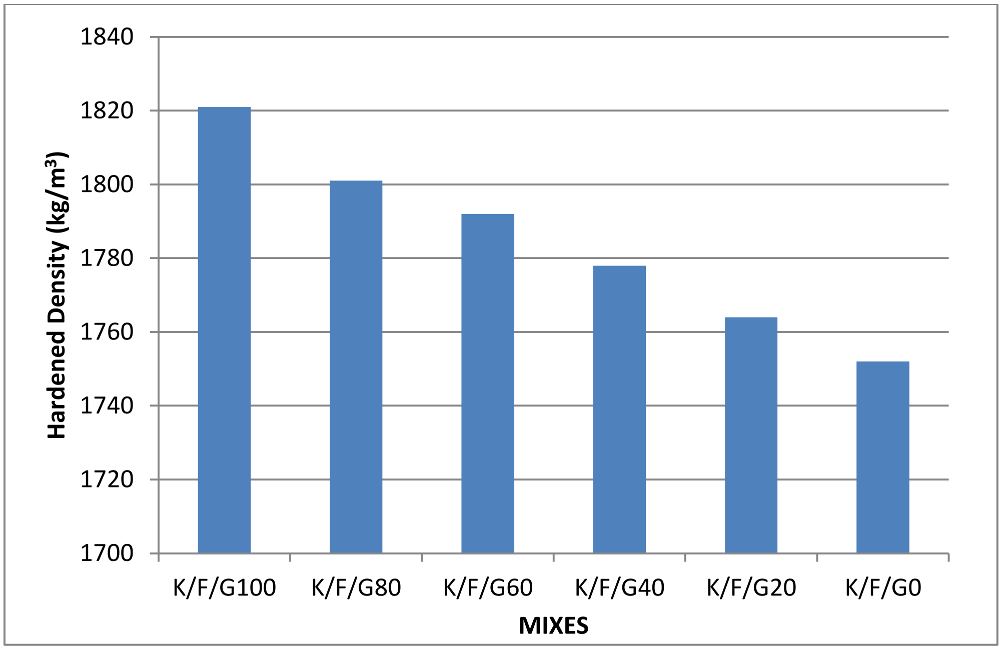


Figure 5.27: Hardened density for mixes K/F/G_{100}, K/F/G_{80}, K/F/G_{60}, K/F/G_{40}, K/F/G_{20} and K/F/G_0

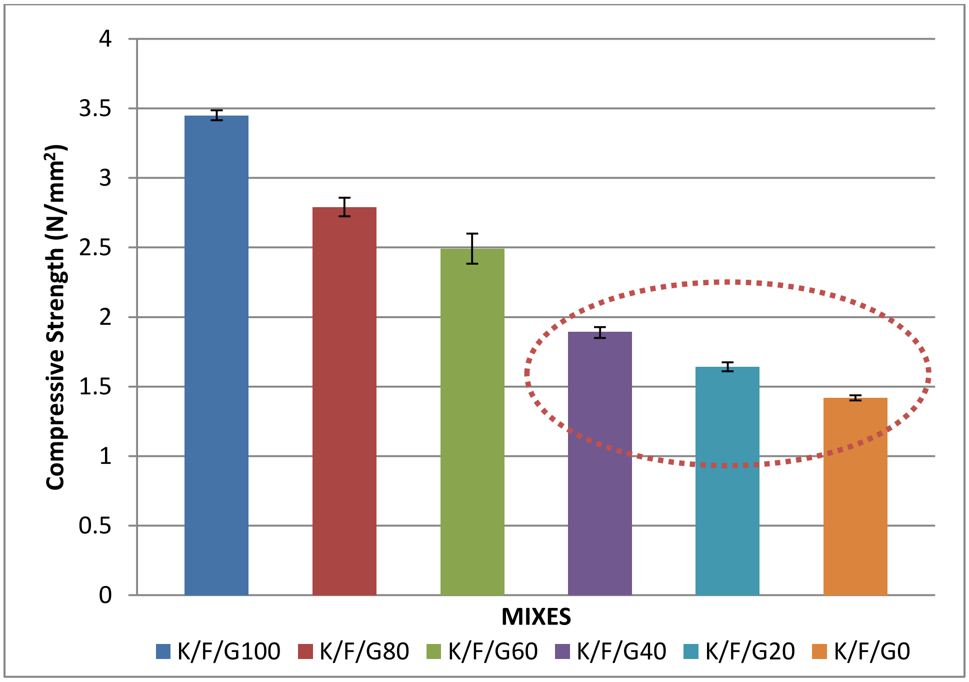


Figure 5.28: 28-day Compressive Strength for mixes K/F/G_{100}, K/F/G_{80}, K/F/G_{60}, K/F/G_{40}, K/F/G_{20} and K/F/G_0

Similar tend i.e. reduction in compressive strength has been observed with increase in replacement percentage of GGBS with FA. Three mixes K/F/G_{40}, K/F/G_{20} and K/F/G_0 were in the range of compressive strength as required for CLSM (Figure 5.28). These mixes also showed much less bleeding as compared to the mixes containing foundry sand as fine aggregate and cement as binder.

Observation: From the above set of trials, it has been found that CKD can be used with spent foundry sand for the generation of CLSM and would achieve better fresh and hardened properties as compared to the conventional cement binder mixes. The 28-day compressive strength of CKD mixes ranges from 1.41 to 3.45 N/mm^2, indicating that the target 28-day compressive strength of less than 2.0 N/mm^2 can easily be achieved for mix containing 100% GGBS with minor adjustments.

CHAPTER 6

CONCLUSIONS

6.1 GENERAL

The aim of this project was to optimize the mix proportions using various filler and cementitious materials for developing Controlled Low Strength Material (CLSM). The conventional building materials were replaced with the industrial by products and the effect on the fresh and hardened properties was studied. From the result of various test performed on a total of 30 mixes following conclusion are drawn:

- Only a few mixes in the present study marginally exceeded or faltered behind the required 28-day compressive strength as stated by ACI 229R (1999). Hence the mixes generated in the present study could also be used for the structural fills where future excavation is not required. The variation in the results of compressive strength from 0.3 to 8.3 MPa can be helpful to generate CLSM to be used for different applications. Objective of the study was to generate the mix having 28-day compressive strength lesser than 2.0 MPa.
- The base mixes containing cement content of 140 kg/m^3 was not able to satisfy both fresh and hardened properties of CLSM, as the mix showed very high bleeding and segregation while performing flow tests. Moreover, 28-day compressive strength for mix containing natural river sand was 8.32 MPa and for mix containing spent foundry sand the 28-day compressive strength was 4.39 MPa i.e. the strength was exceeding the required target strength of less than 2.0 MPa for both the mixes. It indicated that the quantity of cement must be reduced to suppress the compressive strength and some filler must be incorporated for better particle packaging of the mix to avoid segregation and bleeding.
- The base mixes containing CKD as 300 kg/m^3 with different type of fine aggregate were able to achieve the required value of compressive strength between 0.345 to 2.0 MPa i.e. mix containing natural river sand and spent foundry sand showed a 28-day compressive

strength of 2.05 and 1.43 MPa, respectively. There was little segregation in the mix with the bleeding value of 3.5%, which could be seen as expulsion of water on the top surface of cubes while casting. Thus, there was a need to use of fillers in the mix to reduce both bleeding and segregation.

- For the generation of mix containing natural river sand as fine aggregate and cement as binder, very high initial quantity of GGBS (400 kg/m^3) was required. Since, the particle size of river sand was coarser and it required higher number of fines to make the mix homogeneous. The high filler content increased 28-day compressive strength and all the mixes except mix C/R/G$_{0B}$ were having a 28-day compressive strength more than the required limited strength of 2.0 MPa for present study. The 28-day compressive strength of these mixes varied from 8.37 to 1.02 MPa, this variation can be helpful to generate CLSM to be used for different application.
- For the mixes having 25 kg/m^3 of cement with 300 kg/m^3 of initial quantity of GGBS, three mixes (C/F/G$_{60D}$, C/F/G$_{40D}$ and C/F/G$_{20D}$) were lying within the range of target 28-day compressive strength. One of the mixes was having 28-day compressive strength marginally lower than the required strength (0.345 MPa) as stated by ACI 229R (1999). The bleeding observed in these set of trials was not reduced as expected. Since, due to reduction in the quantity of cement, the number of cohesive fines in the mix had reduced it caused the mix to lose its ability to hold high quantity of water.
- Mixes containing 200 kg/m^3 of CKD and initial GGBS content of 100 kg/m^3 showed high flowability with less segregation and bleeding. Three mixes (K/F/G$_{40}$, K/F/G$_{20}$ and K/F/G$_0$) showed compressive strength within the range of CLSM to be developed in present study. The 28-day compressive strength of CKD mixes ranges from 1.41 to 3.45 MPa, indicating that the target 28-day compressive strength of less than 2.0 MPa can easily be achieved.
- From the results of above set of trials, it can be concluded that industrial by-products can be successfully used as a replacement to the conventional building material in CLSM and they also can provide better fresh and hardened properties. The use of these materials will not only help us in developing an economic material but can also provide us environmental benefits, as the industrial by-products, which are utilized, do have various disposal issues.

6.2 SCOPE FOR FUTURE WORK

From the above study, it is suggested that further work could be done on CLSM as stated below:

- The quantity of water used to achieve required flow was very high, causing difficulties in controlling bleeding. Hence, effect of super plasticizers on various properties of CLSM can be studied.
- The viscosity of the CLSM mixes can be evaluated at various water contents, so as to understand the effect of using various materials on the rheological properties.

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