

**Utilization of Ladle Refined Furnace Slag and Sand  
Dust as Partial Replacement of Cement**

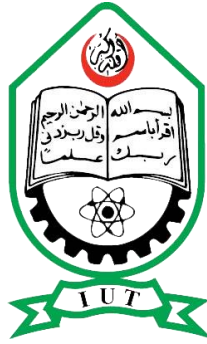
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**ISLAMIC UNIVERSITY OF TECHNOLOGY**

**2016**



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**A THESIS SUBMITTED  
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# PROJECT REPORT APPROVAL

The thesis titled “Utilization of Ladle Refined Furnace Slag and Sand Dust as Partial Replacement of Cement” submitted by Md. Aminul Haque Nipu , S.M.Raihanul Islam and Mahadi Hasan, St. No. 125412,125425 and 115439 has been found as satisfactory and accepted as partial fulfillment of the requirement for the Degree Bachelor of Science in Civil Engineering.

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# DECLARATION OF CANDIDATE

We hereby declare that the undergraduate research work reported in this thesis has been performed by us under the supervision of Professor Dr. Tarek Uddin and this work has not been submitted elsewhere for any purpose (except for publication).

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Academic Year :2015-2016

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# **DEDICATION**

We dedicate our thesis work to our family. A special feeling of gratitude to our loving parents.

We also dedicate this thesis to our many friends who have supported us throughout the process. We will always appreciate all they have done.

# ACKNOWLEDGEMENTS

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*"In the name of Allah, Most Gracious, Most Merciful"*

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# Chapter 1 Introduction

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## 1.1 General

Concrete is one of most extensively used construction materials in the world. It is attractive in many applications because it offers considerable strength at a relatively low cost. Concrete can generally be produced of locally available constituents, can be cast into a wide variety of structural configurations and requires minimal maintenance during service. However, environmental concerns, stemming from the high energy expense and CO<sub>2</sub> emission associated with cement manufacture, have brought about pressures to reduce cement consumption through the use of supplementary materials.

Supplementary cementitious materials (SCMs) are finely ground solid materials those are used to replace part of the cement in a concrete mixture. These materials react chemically with hydrating cement to form a modified paste microstructure. In addition to their positive environmental impact, SCMs may improve concrete workability, mechanical properties and durability. SCMs may possess pozzolanic or latent hydraulic reactivity or a combination of these. The term pozzolan refers to a silicious material, which, in finely divided form and in the presence of water, will react chemically with calcium hydroxide (CH1) to form cementitious compounds. Pozzolans can be of natural or industrial origin. Natural pozzolans include volcanic ash and diatomaceous earth, although pozzolans from industrial by-products are more commonly used today.

Latent hydraulic SCMs, like slag, react directly with water to form cementitious compounds. Slags used in concrete come from the blast furnace production of iron from ore. Steel slag, a byproduct of steel making, is produced during the separation of the molten steel from impurities in steel-making furnaces. The annual yield of steel in China has ranked first among the world. After removal of the entrained steel, the slag is equivalent to about 10% to 15% of the original steel output. The large unused portion was

deposited in areas adjacent to the steel manufacturing plants, occupied a large amount of farms, and polluted environment. In recent years, the excellent physical and mechanical properties generated by steel slag have been reported and give a promise for a potential new use for the material in civil engineering as aggregates .

Metakaolin (MK) is an SCM that conforms to ASTM C 618, Class N pozzolan specifications. MK is unique in that it is not the by-product of an industrial process nor is it entirely natural; it is derived from a naturally occurring mineral and is manufactured specifically for cementing applications. Unlike by-product pozzolans, which can have variable composition, MK is produced under carefully controlled conditions to refine its color, remove inert impurities, and tailor particle size [Brooks, 2001; Ding, 2002]. As such, a much higher degree of purity and pozzolanic reactivity can be obtained. MK has great promise as an SCM, as it can improve many properties of concrete while also reducing cement consumption. This research evaluates the potential of locally produced metakaolins for use as supplementary cementitious materials.

Measurements of early age properties of fresh concrete including slump, unit weight, and setting time, are examined. Mechanical performance (compressive strength) also evaluated.

## **1.2 Scope**

### **Economic**

- In most markets SCM less expensive than cement (except Silica Fume)

### **Environmental**

- Use of recycled materials (industrial by-products)
- Reduced landfill
- Reduced cement usage (CO<sub>2</sub> emissions)

## **Technical**

- Improved performance – especially durability (with appropriate use)

### **1.3 Objectives of the study**

1. To study the fresh and hardened properties of mortar made with Ladle Refined Slag and sand dust as replacement of cement.
2. To compare mechanical properties of conventional mortar and mortar made with Ladle Refined Furnace (LRF) slag and sand dust.

### **1.4 Scope of the study**

The scope of the study involves-

- 1 Experimenting the effect of variation in compressive strength of mortar .This test method covers determination of the compressive strength of hydraulic cement mortars, using 2-in cube.
- 2 Analyzing and comparing the compressive strength prediction with conventional mortar.

Chapter II consists of a literature review of LRF slag and sand dust replacement and its effect on concrete properties. Mixture designs, testing program and other experimental procedures are discussed in Chapter III. Chapter IV contains the results and discussion of all data from testing. Finally, Chapter V presents conclusions, recommendations for use of these, and suggestions for future testing.

## **Chapter 2 Literature Review**

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### **2.1 General**

Many researchers try to use different supplementary cementitious material as replacement of cement and thus minimizing the use of cement in concrete. In the attempt, many parameters were chosen to study to see whether Ladle Refined Slag and Sand Dust can be a partial replacement of cement or not. Some of these parameters and their studies are discussed in this literature review.

#### **2.1.1 Slag**

The utilisation of ground granulated blast-furnace slag (GGBS) in concrete as a partial replacement of Portland cement (PC) is well established. Generally and provided that a proper curing is adopted and depending upon the GGBS content, the long-term strength and durability of concrete containing GGBS exceeds that of normal Portland Cement (PC) concrete. In addition, the presence of GGBS increases the workability of concrete and therefore an equal 28-strength to the control can be achieved by lowering the water to cementitious materials ratio in the mix.

Hogan and Meusel [Hogan FJ, 1981] found that the strength development was slow during the first three days of hydration for concrete containing 40–65% GGBS as PC replacement. However, after three days of hydration, the strength of GGBS concrete was higher than that of normal concrete especially at 40% replacement. This is also in agreement with results reported elsewhere [Roy DM, 1982]. However, it was reported that the benefit in strength of concrete containing 20–60% GGBS does not occur until after 28 days of curing, where similar or higher long term strength was obtained as compared with that of normal PC concrete. The slightly varying results reported were mainly due to the chemical composition and the fineness of GGBS used in each study. Concrete containing

GGBS is more sensitive to poor curing than normal PC concrete, and this sensitivity increases with increasing amount of GGBS [Ramezaniapour AA, 1995]. The rapid removal of water during the early stages of GGBS hydration can lead to surface cracking known as crazing. This would have an impact on concrete strength and durability.

On the other hand, GGBS concrete minimises the heat of hydration and thereby, the early thermal contraction is reduced [ Concrete Society Report TR34. Concrete industrial ground floors. 3rd ed. Crowthorne; 2003.].

Generally, partial replacement of PC with GGBS improves the sulphate resistance of concrete but the effectiveness depends on the properties (e.g. chemical composition, fineness) and content of GGBS. Replacing more than 65% of PC with GGBS tends to improve the sulphate resistance of concrete regardless of the Al<sub>2</sub>O<sub>3</sub> content of GGBS or the C<sub>3</sub>A content of PC. However concrete made with lower content of GGBS tends to resist sulphate only if PC is low in C<sub>3</sub>A [Taylor HFW, 1990].

Mehta [Mehta PK, 1983] suggested that the improved sulphate resistance is not only due to the reduction in free lime and reactive alumina content in concrete, but also as a result of reduction in permeability associated with pore refinement which would hinder the ingress of sulphate ions. Concretes with 50% GGBS replacement achieved similar resistance to carbonation to that of normal PC concrete. However, carbonation was greater at high (70%) GGBS content. In addition, initially dry cured concrete exhibited greater degree of carbonation, especially those containing high GGBS content.

The greater sulphate resistance was attributed to the high degree of carbonation. The low expansion in concrete containing GGBS due to alkali silica reaction is attributed to the reduction in alkali [Taylor HFW, 1990]. The presence of GGBS in concrete increases the chloride penetration resistance, which is mainly due to the refinement in pore structure rather than any change in the hydration products. Pastes containing GGBS have a higher chloride binding capacity compared to the control paste and the difference increases with increasing GGBS content. It was also emphasized that a balance must be struck between

strength and durability. For example a high GGBS content (>65%) is desirable to improve durability, whereas strength is substantially reduced.

### **2.1.2 Metakaolin i.e. burnt sand dust**

In recent years, there has been an increasing interest in the utilisation of metakaolin (MK) as a supplementary cementitious material in concrete [De Silva PS, 1990]. MK is an ultra fine pozzolana, produced by calcining kaolin at temperatures between 700 and 900 °C and consists predominantly of silica and alumina. The use of MK is reported to increase the concrete strength especially during the early ages of hydration. After 14 days of curing the contribution that MK provides to concrete strength is reduced. The increase in compressive strength of MK concrete is thought to be due to the filling effect where MK particles fill the space between cement particles, acceleration of cement hydration and pozzolanic reaction of MK. This effect is similar to that of silica fume. Although the pore volume slightly increases in pastes containing MK, the pore structure of paste, however, is found to be refined [Khatib JM, 1996]. The improvement in pore structure of the paste is increased when the amount of MK increases up to at least 20% as partial substitution of PC [Khatib JM, 1996]. The incorporation of up to at least 30% MK increases the sulphate resistance of mortar. The portlandite content in MK paste and mortar is reduced due to the reaction between PC hydration product and MK [Frias M, 2000]. Therefore, the increased sulphate resistance in mortars containing MK was attributed to the reduction in portlandite in the system, which in turn would reduce the gypsum and ettringite formation.

The other possible reason for the improved sulphate resistance is the refinement in pore structure, which would hinder the ingress of sulphate ions. The incorporation of MK in concrete increases the penetration resistance of chloride ions. Pastes containing MK showed higher capacity to bind chloride ions compared with PC pastes. Concrete containing 10% MK showed excellent performance under freezing and thawing.

## **2.2 Binding Material Properties**

### **2.2.1 Pozzolanic Reaction and CH Consumption**

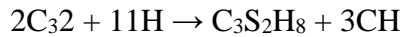
Regardless of the reactivity of an SCM, if it is extremely fine, it will generally impart some benefit to mortars and concrete. Small particles, which can fit between cement grains, allow for more efficient paste packing, which in turn reduces bleeding, lowers the mean size of capillary pores, and may reduce water requirements due to a ball bearing effect (if the particles are round) [Mindess, 2003]. Improved particle packing at the aggregate/paste interface results in a thinner transition zone with a denser, more homogeneous microstructure [Wild, 1996]. In addition, acting together, many small particles have a large total surface area, leading to an increase in reactivity.

Another important factor to consider when using SCMs is dilution. When used as a replacement for cement, concrete mixtures will experience some effect of the removal of cement from the reacting system. As such, unless the SCM begins reacting immediately, there will generally be a reduction in the rate of heat evolution and strength gain in proportion to the amount of cement being replaced. Fly ash, especially, and even silica fume to a lesser extent, do not show beneficial effects until later in the hydration process [Curcio, 1998; Poon, 2001]. MK, however, because it is very small and possesses some latent hydraulic reactivity, may overcome the dilution effect, contributing to both heat and strength evolution at very early ages.

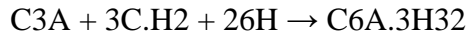
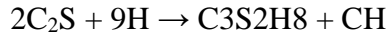
The presence of MK has an immense effect on the hydration of portland cement (PC). When portland cement alone hydrates, typically 20-30% of the resulting paste mass is CH. However, when MK is introduced, it reacts rapidly with these newly forming CH compounds to produce supplementary calcium silicate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

Recalling cement chemistry notation, the basic hydration reactions are as follows:

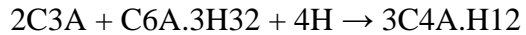




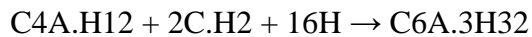
(C-S-H) (CH)



(gypsum) (ettringite)



(monosulfate)



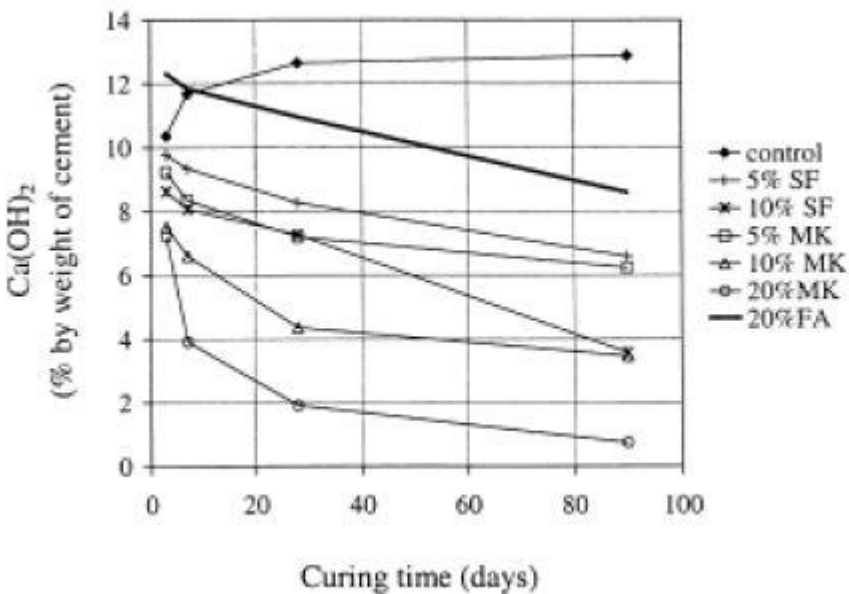
In general, SCMs with higher alumina contents, such as MK, tend to have higher pozzolanic capacities because formation of C-A-H has a high CH demand. This is critical, as CH does not make a significant contribution to concrete strength and can be detrimental to durability. Its elimination or reduction by secondary reaction with MK can greatly enhance concrete performance [Mindess, 2003; Poon, 2002].

Determination of the degree of pozzolanic reaction completed can be accomplished via a selective dissolution procedure, like that developed by Oshawa *et al.* [Oshawa, 1985] and Li *et al.* [Li, 1985]. The procedure is based on the assumption that the majority of the unreacted pozzolan is acid insoluble. In a blended cement paste, the pozzolan reacts with CH to form acid soluble hydration products. Thus, it is possible to dissolve the unreacted cement and the hydration products of both the cement and the pozzolan, leaving behind the insoluble residue of the unreacted pozzolan. The degree of pozzolanic reaction completed is defined as the percentage of unreacted pozzolan remaining relative to the initial amount of pozzolan present in the cement paste.

Results from such selective dissolution evaluations, carried out by Poon *et al.* [Poon, 2001], showed that the degree of pozzolanic reaction was higher at a replacement level of 5% MK than at replacement levels of 10% and 20% for all ages. Similar results were observed with silica fume, though the 5% silica fume values were never as high as the 5%

MK values. This higher rate of pozzolanic reaction in pastes with a lower replacement level could likely be attributed to the greater amount of cement, and thus higher concentration of CH, available for reaction with the pozzolan.

Because MK reacts with and consumes free CH, another method for determining the extent of pozzolanic reaction completed is to measure the remaining CH content in a paste, mortar, or concrete sample. As part of the same study, Poon *et al.* [Poon, 2001] also determined total CH content of paste samples, both based on the ignited weight and the weight of cement, using differential scanning calorimetry. This was performed in air atmosphere at a heating rate of 10 °C/min. The CH content was calculated from the weight loss between 425 °C and 550 °C. In either case, cements blended with 20% MK showed the least total CH at all ages. MK mixtures showed steadily decreasing CH contents up to 90 days, as illustrated in Figure 2.1.



**Figure 2.1. CH content calculated based on cement weight [Poon, 2001].**

Wild and Khatib [Wild, 1997] performed a similar experiment, measuring CH consumption in MK-PC pastes and mortars, which were cured in water at 20 °C. Results from these thermogravimetric analyses (TGA) are shown in Figure 2.2. The CH, expressed as a percentage of cement weight, showed a minimum at about 14 days of

curing. This was attributed to a peak in pozzolanic activity for which more CH was being removed from the paste by reaction with MK than was being generated by the cement hydration. Interestingly, the peak in relative compressive strength (the ratio of strength at a given age to the strength of the control at the same age) coincided with the maximum in pozzolanic activity -- at 14 days of age. Increases in CH content and a lag in strength gain beyond 14 days were attributed to the formation of an inhibiting layer of reaction product on the surface of the MK particles.

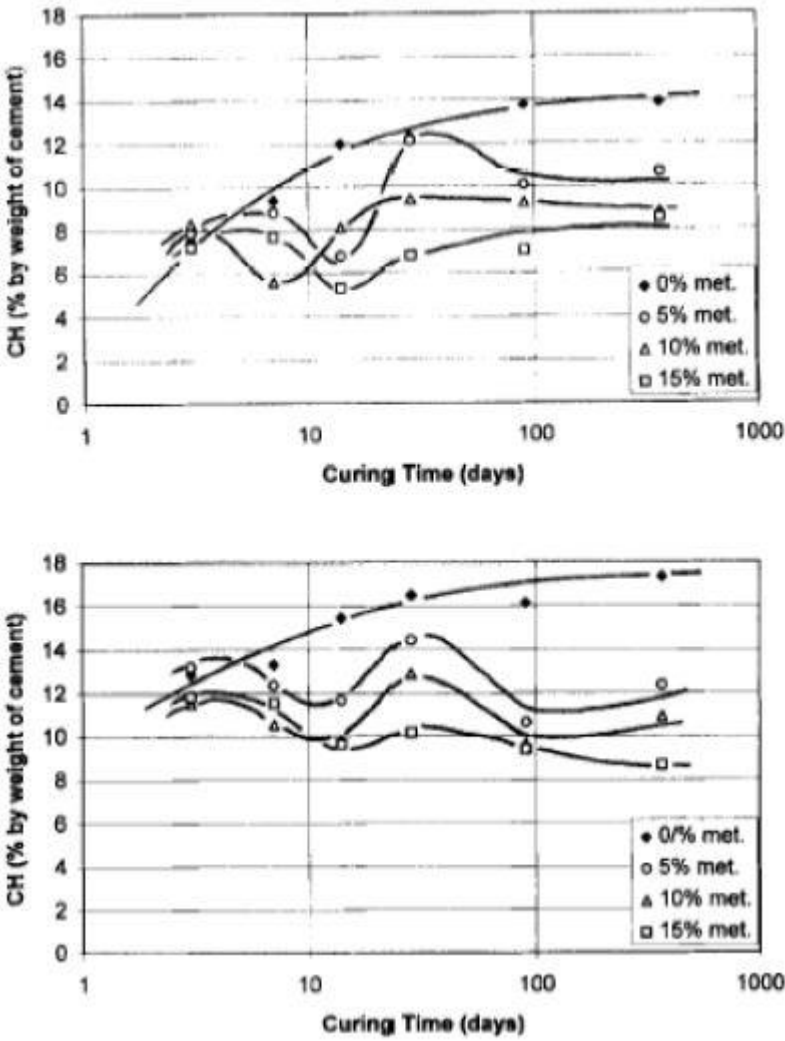
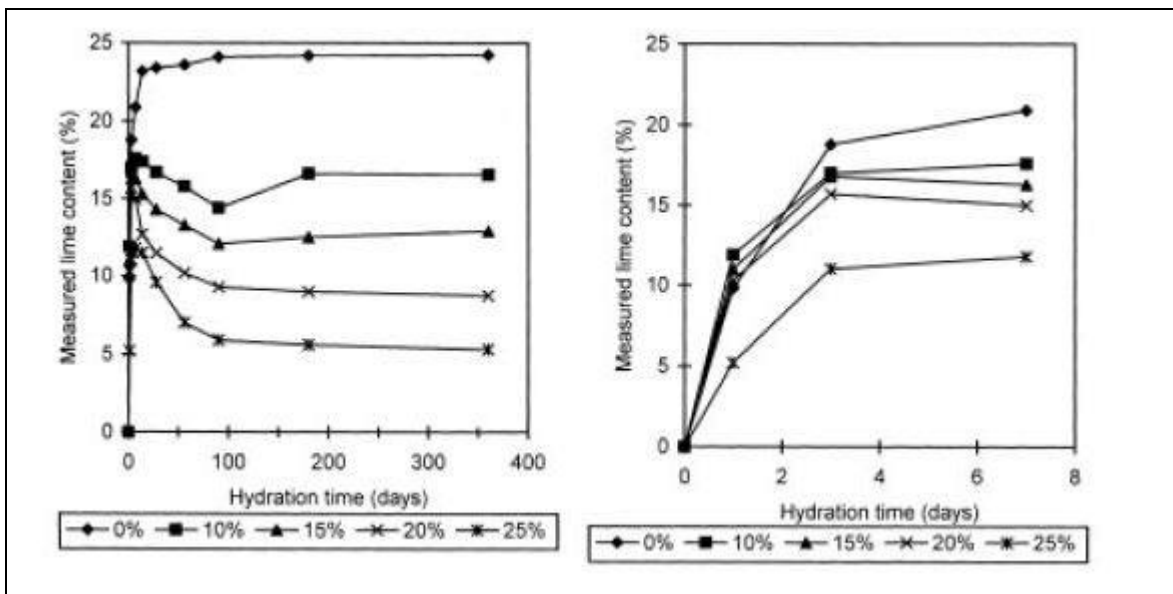


Figure 2.2. Change in CH content versus curing time, as measured by TGA, for metakaolin (a) mortar and (b) paste [Wild, 1997].

Frías and Cabrera [Frías, 2000] evaluated CH content of MK pastes via DTA and TGA. These analyses were conducted in nitrogen atmosphere and at a heating rate of 20°C/min. CH contents of MK-PC specimens were found to increase with age until 3-7 days. Subsequently, as with the Wild and Khatib [Wild, 1997] study, CH contents began decreasing in proportion to the percentage of MK added. Interestingly, the 10% and 15% MK curves showed an inflection point around 90 days of age, after which CH content again began to rise, however slightly (Figure 2.3). This point could represent the end of the pozzolanic reaction due to the total consumption of MK.



**Figure 2.3. Evolution of CH with hydration time [Frías, 2000].**

Oriol and Pera [Oriol, 1995] utilized DTA and Fourier transform infrared spectrometry to follow lime consumption in MK blended cements under microwave treatment. This treatment was intended to accelerate hydration like traditional thermal curing methods. These authors reported that total elimination of CH was achievable in binders containing 15% MK given sufficient hydration time. To fully eliminate CH in binders with a w/cm of 0.5 in just 28 days, between 30% and 40% MK was required.

### 2.2.2 Composition and properties of cementitious materials (CM)

From a study of Khatib [J M Khatib, J J Hibbert, 2004] Composition of PC, GGBS and MK is given in Table 2.1.

	PC a	GGBS b	MK c
SiO <sub>2</sub> (%)	20.4	36.0	52.1
Al <sub>2</sub> O <sub>3</sub> (%)	4.89	9.0	41.0
Fe <sub>2</sub> O <sub>3</sub> (%)	3.18	1.0	4.32
CaO (%)	64.02	43.0	0.07
MgO (%)	2.56	7.0	0.19
SO <sub>3</sub> (%)	2.85	–	–
Na <sub>2</sub> O (%)	0.07	1.0	0.26
K <sub>2</sub> O (%)	0.53	–	0.63
Insoluble residue (%)	0.37	–	–
Loss on ignition (%)	0.98	0.42	0.6
Free lime (%)	2.37	–	-

a Portland cement.      b Ground granulated blast furnace slag.      c Metakaolin.

**Table 2.1: Composition and properties of cementitious materials (CM)**

### 2.3 Burning temperature

A study from R. San Nicolas[1] shows that Metakaolinite is obtained by heating sand dust at temperatures between 700 and 850 °C. This heating induces the dehydroxylation of

sand dust, leading to the production of an amorphous material that is usually very reactive in basic environments such as cement-based materials. On an industrial scale, most metakaolins (MK) are obtained from a three-stage method that comprises a selection/grinding process, then calcination of the raw Kaolinite for several hours in a rotary kiln, followed by grinding of the burned material.

From the study of B. Fabbri[2], The kaolin powder underwent thermal treatment at temperatures in the range comprised between the de-hydroxylation of kaolinite(500–550 °C) and the formation of  $\gamma$ -alumina (900–1000 °C). The following temperatures were selected: 550 °C, 650 °C, 750 °C and 850 °C. The thermal treatment was carried out in an electric kiln with a heating gradient of 200 °C/h, a soaking time of 2 h, and natural cooling inside the kiln. Several previous studies showed that 2 h soaking is sufficient to attain the maximum de-hydroxylation of the material at temperatures higher than 600 °C.

## **2.4 Setting Time**

Setting time can be defined as the time it takes for concrete to go from a viscous fluid to a solid material and is typically measured by applying a known force and measuring penetration (Vicat

ASTM C 191) or measure the resistance for a give penetration depth (ASTM C 403). It should be noted that testing of concrete setting is usually done by wet sieving out the large coarse aggregate, so in reality all time of set testing is done on mortar.

The setting of concrete is generally understood as the onset of solidification and hardening (strength gain) of a fresh concrete mixture. Initial setting time (initial set) is defined as the time elapsed between the addition of water and the point when paste ceases to be fluid and plastic. This is the limit for handling concrete -- it should be placed before initial set. Final set indicates the onset of the development of mechanical strength. Many factors

influence setting time, including the w/cm, casting and curing temperature, admixture type, source, and dosage, and cement content, fineness, and composition [Brooks, 2000].

Setting time is mainly dependent on: the w/cm ratio, cement content of the mix, the cement chemistry, cement fineness, temperature and admixtures. As with compressive strength the setting time of concrete is influenced by the hydration of  $C_3S$  and  $C_2S$  but the other major constituents  $C_3A$  and  $C_4AF$  also play a significant role. A low w/cm ratio or low temperature will cause a delay in setting, but a higher temperature or finer cement will cause a reduction in setting time. Admixtures can do both, depending on the desired purpose, there exist accelerators, retarders, suspenders, etc. which all alter the setting time.

Knowledge of setting behavior is extremely important in the field of concrete construction. This information is helpful in scheduling the various stages of construction operations, such as transporting, placing, compacting, finishing, and demoulding of concrete, and is a necessity when deciding whether set-accelerating or set-retarding admixtures will be necessary. Further, measurements of autogenous shrinkage, an important property of high-strength (HSC) and high-performance concrete (HPC), should commence at the time of initial set. Previous researchers have found MK incorporation to have varying effects on the setting behavior of mortars and pastes.

Brooks *et al.* [Brooks, 2000] examined the effect of silica fume, MK, FA, and Slag on setting time of high strength concrete via ASTM C 403. This method involves passing freshly mixed concrete through a 5 mm sieve, and measuring the force required for a needle to penetrate 25 mm into the collected mortar. An optimum w/cm of 0.28 was obtained for the control mixture using the Cabrera Vibrating Slump test, developed by Cabrera and Lee [Cabrera, 1985], and was used for all concrete mixtures. A sulfonated vinyl copolymer superplasticizer was added as necessary to achieve similar workability between mixtures.

Initial and final setting times are defined as the times at which the penetration resistance in mortar reaches values of 3.5 MPa (500 psi) and 27.6 MPa (4000 psi), respectively (ASTM C 403). Brooks *et al.* found that all SCMs tended to retard setting time, and that increasing the levels of silica fume, FA, and slag resulted in greater retardation of the set. For HSC containing MK, there was a progressive increase in the retarding effect up to 10% replacement, but a reduction at higher replacement levels.

Similar results were reported by Batis *et al.* [Batis, 2004], who examined both a local Greek kaolin heat-treated in their own lab and a commercially available MK product. These authors found all MK mixtures to have significantly longer setting times than control pastes. The mixture slowest to set was incorporated with 20% MK, requiring 205 minutes for initial set versus 105 minutes for the control. This could be due, in part, to the high water demand of MK pastes. While controls required a w/c of 0.275 to achieve "normal consistency," 20% MK mixtures required a w/cm of 0.41.

Vu *et al.* [Vu, 2001] reported that higher blending percentages resulted in a higher water demand to reach normal consistency. For the particular Vietnamese kaolin used in this study, setting times of pastes in the lower replacement range (10-20% MK) were not significantly affected by blending. Beyond this range, the initial and final setting times increased by 15% and 10%, respectively, likely due to the lower cement and higher water contents involved.

Conversely, in a 2001 study, Moulin *et al.* [Moulin, 2001] found pastes made from MK blended cements to have a much shorter setting time compared to control pastes. These results were obtained using a Vicat needle apparatus according to ASTM C191 and were conducted at a w/cm on 0.40. Moulin also examined the rheology of the same pastes using a shear vane rheometer to characterize yield stress. He found that the presence of MK significantly increased both the five and 90 minute yield stress when compared to reference pastes. This confirmed that MK blending results in a higher water demand and



leads to thixotropic behavior, and Moulin *et al.* explained these to be the result of the accelerating effect of MK on PC hydration.

Caldarone *et al.* [Caldarone, 1994] also found MK to shorten setting time, as compared to control samples. In this study, initial set of MK mixtures was reported as 4.1 h, while SF and control mixtures did not achieve initial set until 4.2 h and 4.8 h, respectively. However, these authors, who were careful to note when ASTM standards were followed, do not indicate how initial set was determined. Since the remainder of the evaluations were performed on concrete, we are left to assume that initial set was determined by visual inspection of concrete specimens, which is arbitrary.

## **2.5 Mechanical Properties**

### **2.5.1 Compressive and Tensile Strength of slag**

*Bilim et al. (2008)* studied artificial neural networks and predicted the compressive strength of ground granulated furnace slag concrete. A data set of a laboratory work, in which a total of 45 concretes were produced, was utilized in the ANNs study. The concrete mixture parameters were three different water–cement ratios (0.3, 0.4, and 0.5), three different cement dosages (350, 400, and 450 kg/m<sup>3</sup>) and four partial slag replacement ratios (20%, 40%, 60%, and 80%). Compressive strengths of moist cured specimens were measured at 3, 7, 28, 90, and 360 days and are tabulated in Table 2.2.

w/c ratio	GGBFS(%)	Age (days)				
		3	7	28	90	360
0.30	0	63.8	75.7	80.3	85.7	92.8
	20	58.0	72.1	81.8	90.1	95.9
	40	49.8	66.4	83.8	91.4	96.8
	60	36.8	63.2	80.6	92.5	101.3
	80	26.3	50.2	66.3	77.4	78.4
0.40	0	53.0	59.2	64.3	71.0	79.4
	20	45.8	60.3	73.5	82.3	86.6
	40	35.9	56.3	66.4	81.0	84.6
	60	26.9	38.6	61.8	73.4	80.6
	80	22.6	36.7	46.8	54.6	58.9
0.50	0	25.8	36.6	48.7	50.5	60.2
	20	21.3	33.2	50.4	56.2	66.7
	40	16.7	28.3	49.3	53.4	65.1
	60	13.0	20.8	39.5	49.1	57.4
	80	9.0	17.5	27.7	35.0	39.6

**Table 2.2: Compressive strength of GGFS concrete for 450 kg/m<sup>3</sup> (MPa)**

For all slag replacement ratio, strength contribution of slag to concrete is low up to 7 days of age. However, compressive strength of concrete containing slag concrete is higher than that of control normal Portland cement concrete for 20% and 40% replacement ratios at 28 days, three months and one year. Compressive strength of slag concrete is found to be equivalent to that of control normal Portland concrete for 60% replacement ratio at 28 days and beyond. The data used in the ANN model are arranged in a format of six input parameters that cover the cement, ground granulated blast furnace slag, water, hyper plasticizer, aggregate and age of samples and, an output parameter which is compressive strength of concrete. The results showed that ANN can be an alternative approach for the predicting the compressive strength of ground granulated blast furnace slag concrete using concrete ingredients as input parameters.

## 2.5.2 Compressive and Tensile Strength of metakaolin

A study by Khatib tested the effect of metakaolin replacement on strength with replacement levels of 5, 7.5, 10, 12.5, 15, and 20% with a w/cm ratio of 0.3. Regardless of the replacement level an increase of strength occurred. Most studies show that approximately 15% replacement is optimum and any further additions tend to be detrimental to the concrete mix.

Table 2.3, from Khatib shows the benefits of metakaolin: adding 5% increases the 28 day strength by 10% while 15% replacement increases the strength by 36%. Another positive trait of metakaolin as opposed to fly ash or slag is that most of the strength gain occurs within the first

Mix	MK (%)	Density (kg/m <sup>3</sup> )	Age (days)				
			1	7	14	28	56
1	0	2293	28.9	55.3	60.7	66.1	71.3
2	5	2261	30.6	59.2	67.7	72.5	79.0
3	7.5	2316	25.1	62.2	74.4	81.4	85.7
4	12.5	2329	28.5	68.6	81.6	85.3	90.4
5	15	2337	28.6	70.2	83.6	89.7	91.0
6	20	2329	22.8	62.8	78.9	83.2	86.1

**Table 2.3: Metakaolin compressive strength development**

Series	w/b	Mix	Compressive strength (MPa)			
			3 days	7 days	28 days	90 days
1	0.3	Control	68.5	81.1	96.5	102.5
		5% MK	73.0	88.2	103.6	112.9
		10% MK	85.9	99.8	116.8	120.3
		20% MK	70.8	87.6	99.6	113.8
		5% SF	67.0	79.3	106.5	110.2
		10% SF	63.2	76.9	107.9	115.6
2	0.5	Control	28.6	41.2	52.1	60.4
		5% MK	32.6	45.9	57.1	66.5
		10% MK	40.4	55.2	66.2	71.6
		20% MK	30.0	43.2	58.4	69.1
		5% SF	27.4	47.0	54.3	67.5
		10% SF	25.8	47.4	58.4	69.1

**Table 2.4: Strength with metakaolin and w/cm**

week of mixing. In Table 1 it can be seen that with a 5% replacement the concrete has attained the control mixes 28 day strength at 14 days and in 7 days with a 15% replacement. Another study conducted by Poon, used the same replacement percentages but a different w/cm (0.3 and 0.5) but the results were the same as shown in Table 2.4.

The conclusions which can be drawn are that regardless of w/cm ratio, metakaolin will increase the strength significantly and that a large portion of that strength increase will occur in the first 7 days.

Partial replacement with MK can improve concrete strength. However, it is not clear whether MK or silica fume produces greater increases in strength. If it is determined that MK increases strength as much or more than silica fume, MK might find greater application in HSC and HPC in the future. The vast majority of papers about MK incorporation make some mention of strength. Caldarone *et al.* [Caldarone, 1994] produced concretes with 5% and 10% MK by weight of Type I cement, with w/cm of 0.40, which showed enhanced strengths at ages up to 365 days. These specimens showed strengths an average of 10% greater than concrete incorporated with the same amount of

silica fume. At 365 days, the specimens prepared with 5% MK showed the highest strength of the group, 11.35 ksi, followed by 10% MK, 10% silica fume, and 5% silica fume (9.21 ksi). Control specimens had the lowest strengths at all ages.

Similar results were reported by Wild *et al.* [Wild, 1996], who tested concretes ranging from one to 90 days in age, produced at a w/cm of 0.45 with cement complying with BS12:1989. He found that 20% replacement with MK was optimal for achieving maximum long-term strength enhancement. A summary of Wild *et al.*'s results is shown in Table 2.5.

MK (%)	Density (kg/m <sup>3</sup> )	Compressive strength (N/mm <sup>2</sup> )				
		1 day	7 days	14 days	28 days	90 days
0	2490	19.07	50.23	57.10	62.60	72.43
5	2440	21.50	53.80	58.97	63.50	71.63
10	2460	22.43	62.30	69.23	71.00	80.07
15	2470	20.23	64.80	74.67	76.00	83.70
20	2480	19.33	66.47	75.73	82.47	85.13
25	2470	15.73	62.50	69.77	73.93	82.23
30	2480	14.53	60.53	72.33	76.73	81.80

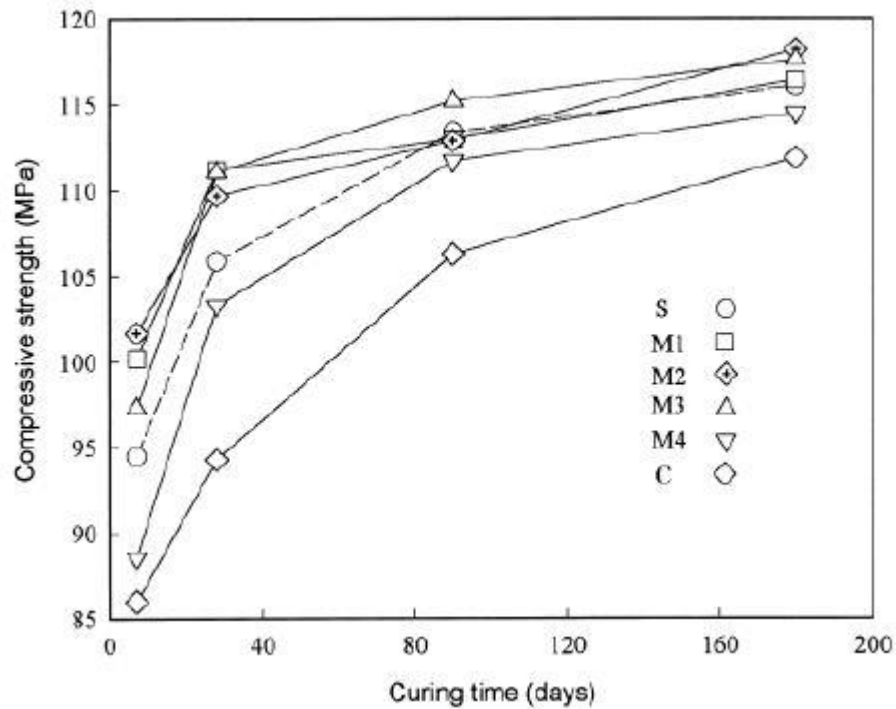
**Table 2.5. Compressive strengths of metakaolin-concretes [Wild, 1996].**

These authors concluded that there are three elementary factors influencing the contribution that MK makes to strength when it partially replaces cement in concrete. These are the filler effect, the acceleration of PC hydration, and the pozzolanic reaction of MK with CH. According to Wild *et al.*, the filler effect is immediate, the acceleration of PC hydration has maximum impact within the first 24 hours, and the pozzolanic reaction makes the greatest contribution to strength somewhere between 7 and 14 days of age. Wild *et al.* also concluded that the positive contribution made by MK does not continue beyond 14 days, irrespective of the replacement level. This result was not confirmed by other researchers [Ding, 2002] and the table above indicates otherwise.

Wild *et al.* [Sabir, 2001] later showed that increasing the specific surface of MK from 12 to 15 m<sup>2</sup>/g reduces the age at which maximum strength enhancement occurs in MK mortars, illustrating the effect of particle size on reaction rate. Because of the increased surface area, MK was able to react more rapidly, leading to a faster rate of strength evolution. This increase in fineness also resulted in an increase in the optimum level of replacement of cement by MK, meaning that more of the cement could be replaced by this MK without the system suffering a lag due to dilution. Interestingly, this change in fineness did not influence the long-term (90 day) strength. Ding and Li [Ding, 2002], who examined 5, 10, and 15% replacement with either MK or silica fume, found that both were effective in increasing strength beyond 14 days.

At all ages, MK and silica fume performed similarly, increasing concrete strength to almost the same extent over controls. MK increased strength nearly linearly during the first 28 days of curing and then slowed down -- 65-day strength was only 6-8% greater than 28-day strength. Li and Ding [Li, 2003] further investigated 10% replacement with MK, combining it with PC alone or with both PC and ultra-fine slag. The compressive strength of the mortar mixture containing only MK was always greater than the control mixture, and was approximately 8 MPa greater by 28 days. Further, although initially lower, the MK-slag mixtures showed the highest 28-day strength.

Curcio *et al.* [Curcio, 1998] examined compressive strength development in mortars containing 15% MK. Specimens cast with three of the four MK materials tested showed higher rates of strength evolution than controls at ages up to 28 days. Samples cast with silica fume (S) and the fourth MK (M4), which was coarser but of approximately the same chemical composition, did not accelerate strength gain. Beyond 28 days, as shown in Figure 2.4, differences between controls and specimens containing admixtures were smaller.



**Figure 2.4. Compressive strength v. curing time for control mortars (C) and mortars containing 15% MK (M1-M4) or silica fume (S) [Curcio, 1998].**

Vu *et al.* [Vu, 2001] studied a specific kaolin indigenous to northern Vietnam in order to determine the degree to which kaolin could replace PC in local mortar and concrete production. He found that the optimum PC replacement level increased with mortar maturity for all water-to-cement ratios. For early age mortars (up to seven days), 10% replacement with MK was optimal, while 15-20% was best in the 7-28 day range and 20-25% replacement resulted in the highest strength mortars 28 days and older. This implies that the pozzolanic reaction of MK may not make its peak contribution to strength until later in the hydration process. Vu also examined the effects of varying water content, and found that less MK was necessary to achieve maximum strength increases at lower w/cms. For mortars with a w/cm of 0.32, 10% replacement was optimum; for w/cm=0.44, 20% was optimum.

Qian *et al.* [Qian, 2001] measured both compressive and tensile strength of concretes incorporating MK. Compressive strength was found to increase substantially with increasing MK content. In samples with 15% replacement, compressive strength had increased 51% over controls by three days of age. In fact, the compressive strengths of samples containing 10% and 15% MK were higher at three days than the 28-day control strength, confirming that MK has a pronounced effect on early strength. Courard *et al.* [Courard, 2003] came to a similar conclusion, reporting that mortars had achieved 79% of their 28-day compressive strength by just three days of age. Qian [Qian, 2001] found that tensile strength also increased systematically with increasing MK content. The average tensile strength increases over controls were as follows: 7% (5% MK), 16% (10% MK), and 28% (15% MK). This was the only study reporting MK's effects on tensile strength.

## **2.6 Durability**

In addition to strength, MK incorporation is widely regarded as an effective means to increase concrete durability. This is achieved primarily in the ITZ, which is characterized by a higher porosity, a higher local w/cm, and differing mineralogical and chemical composition than the bulk paste. It has been suggested that these properties of the ITZ can be detrimental to some composite properties, including resistance to chloride and sulfate transport. MK, which has been shown to affect the chemistry and microstructure of the ITZ, may thus play a role in reducing ion transport and improving concrete durability.

## **2.7 Summary**

There is good agreement in the existing literature that Slag and Metakaolin improves the properties of concrete. In general, Slag and Metakaolin have been shown to impart the following benefits:



- o increased compressive strength,
- o increased tensile strength,
- o increased flexural strength, and
- o decreased porosity and permeability (and thus increased resistance to chemical attack).

However, MK has also been shown to increase shrinkage and heat evolved during hydration, which can be detrimental. Since it is possible to tailor composition and particle size, each MK produced must be evaluated for efficacy in cementitious systems.

Overall, Slag and MK have great promise as SCMs, and the utilization of Slag and MK will likely increase in the future.

## **Chapter 3 Methodology**

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### **3.1 General**

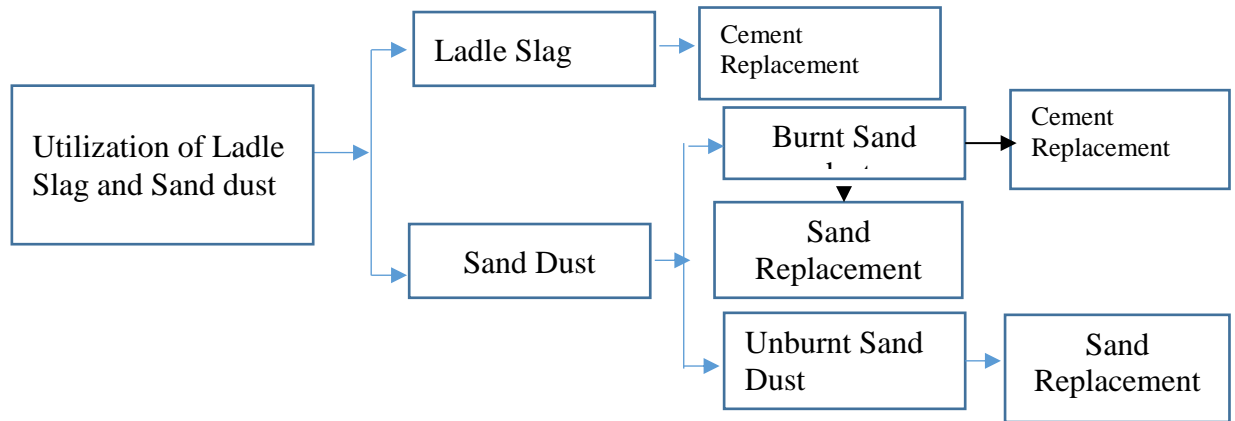
As the study has a wide insight on a variety of aspects, different methods were adopted in order to achieve the objective of this study properly. And by implementing these methods, a direct approach has been set out to fulfill the scope of the study. In this chapter, the methods adopted and implemented are discussed thoroughly. This involves the selection of key parameters for mixture proportions, the mix design, the testing parameters etc.

### **3.2 Cases Investigated**

For proper insight of the study, different key parameters for mixture proportion are considered in the experiment. All of the cases that selected to carry out are performed with a weight based mix design approach. Although, keeping in mind the general practice in Bangladesh, some volume based mix ratios are also considered to relate to the actual field scenario.

2inch cube (2inch\*2inch\*2inch) mortar specimens were made with fixed s/c ratio 2.75 W/C ratio 0.485 .Ladle slag is used to replace cement and Sand dust for both burnt case and unburnt case is used to replace sand and cement. With these fine aggregates, mortar is to be made and hence the main approach is to find out the possibility of replacing cement, consequently decreasing the consumption of cement and find out the possibility of getting higher compressive strength than conventional mortar. Thus to help toward sustainability of construction materials.

### 3.2.1 Case plan



For Ladle Refined Slag total of 10 independent cases and 180 cube specimens were investigated. The mixture proportions of all 10 cases are summarized in **Table 3.1**.

S/C	W/C	REPLACEMENT CASE	SAND	No.OF CUBE
2.75	0.485	0% Slag+ 100 Cement	100% Natural Sand	18*10=180
		10% Slag+ 90% Cement		
		20% Slag+ 80% Cement		
		30% Slag+ 70% Cement		
		40% Slag+ 60% Cement		
		50% Slag+ 50% Cement		
		60% Slag+ 40% Cement		
		70% Slag+ 30% Cement		
		80% Slag+ 20% Cement		
		90% Slag+ 10% Cement		

**Table 3.1. Mixture proportion of Mortar For Ladle Refined Slag**

For Sand Dust, as there are burnt and unburnt cases, we will start with unburnt case .For sand replacement of unburnt sand total of 3 independent cases and 54 cube specimens were investigated. The mixture proportion of all 3 cases are summarized in **Table 3.2**

S/C	W/C	REPLACEMENT CASE	CEMENT	No. OF CUBE
2.75	0.485	0% Sand dust+100% Sand	OPC	18*3=54
		5% Sand sust+95%Sand		
		10%Sand dust+90 %Sand		

**Table 3.2 Mixture proportion of Mortar for Sand Dust**

For burnt sand dust both sand and cement replacement were done. For sand replacement of burnt sand total of 3 independent cases and 54 cube specimens were investigated. The mixture proportion of all 3 cases are summarized in **Table 3.3**

S/C	W/C	REPLACEMENT CASE	CEMENT	No. OF CUBE
2.75	0.485	0% Sand dust(burnt)+100% Sand	OPC	18*3=54
		5% Sand sust(burnt)+95%Sand		
		10%Sand dust(burnt)+90 %Sand		

**Table 3.3 Mixture proportion for sand replacement of burnt sand dust**

For cement replacement of burnt sand total of 4 independent cases and 72 specimens were investigated . The mixture proportion of all 3 cases are summarized in **Table 3.4**

S/C	W/C	REPLACEMENT CASE	SAND	No. OF CUBE
2.75	0.485	0% Sand dust(burnt)+100% Cement	100% Natural Sand	18*4=72
		5% Sand dust(burnt)+95% Cement		
		10% Sand dust(burnt)+90% Cement		
		15% Sand dust(burnt)+85% Cement		

**Table 3.4 Mixture proportion for cement replacement of burnt sand dust**

### **3.3 Mix Design**

The mix proportion used in this study was done in weight basis and the unit contents of the ingredients of concrete were assumed to sum up to 1 m<sup>3</sup> of concrete and can be correlated by the following equation:

$$\frac{C}{G_c \gamma_w} + \frac{S}{G_s \gamma_w} + \frac{A}{G_A \gamma_w} + \frac{W}{G_w \gamma_w} + \frac{Air (\%)}{100} = 1$$

Where,

$C$  = Unit content of cement ( $\text{kg/m}^3$  of concrete)

$S$  = Unit content of fine aggregate ( $\text{kg/m}^3$  of concrete)

$A$  = Unit content of coarse aggregate ( $\text{kg/m}^3$  of concrete)

$W$  = Unit content of water ( $\text{kg/m}^3$  of concrete)

$\gamma_w$  = Unit weight of water ( $\text{kg/m}^3$ )

$G_c$  = Specific gravity of cement

$G_s$  = Specific gravity of fine aggregate (SSD)

$G_A$  = Specific gravity of coarse aggregate (SSD)

$G_w$  = Specific gravity of water

$Air (\%)$  = Percentage of air in concrete (assumed at 2% without air entraining agent)

And other two equations are  $W/C=0.485$  and  $S/C =2.75$ . By equating these three equations, we found the amount of cement in  $\text{kg/m}^3$ . As the specific gravity of Ladle slag replacing to cement is not same of cement and Sand Dust replacing to cement is not same,

this weight of cement is converted to volume (m<sup>3</sup>).Then replacements have done according to the cases.

### 3.3.1 For Ladle Refined Slag as partial replacement of cement

Specific gravity of cement = 3.1

Specific gravity of sand = 2.56

Specific gravity of ladle slag = 3.1

Unit weight of Ladles lag = 1432kg/m<sup>3</sup>

#### Parameters that are considered for mix design

Water to cement ratio, naturally = 0.485.

Sand to cement ratio = 2.75

S/C	W/C	CASE		CEMENT	VOLUME OF CEMENT(m <sup>3</sup> )	%SLAG	%CEMENT	SAND (kg/m <sup>3</sup> )	CEMENT (kg/m <sup>3</sup> )	SLAG (kg/m <sup>3</sup> )	WATER (kg/m <sup>3</sup> )
		SLAG(%)	Cement(%)								
2.75	0.485	0	100	496.04	0.171	0	0.171	1364.1	496.03	0	240.58
		10	90			0.0171	0.1539		446.43	53.19	
		20	80			0.0342	0.1368		396.83	106.39	
		30	70			0.0513	0.1197		347.22	159.58	
		40	60			0.0684	0.1026		297.62	212.78	
		50	50			0.0855	0.0855		248.018	265.97	
		60	40			0.1026	0.0684		198.41	319.17	
		70	30			0.1197	0.0513		148.81	372.36	
		80	20			0.1368	0.0342		99.2	425.56	
		90	10			0.1539	0.017		49.6	478.76	

**Table 3.5: Mix Design for cement replacement by LRF slag.**

**Mix Design for sand replacement by unburnt sand dust:**

CASE-ID	CEMENT(kg)			SAND					CLAY			WATER		
	kg/m <sup>3</sup>	kg/m <sup>3</sup>	kg(1cube)	kg	m <sup>3</sup>	kg/m <sup>3</sup> (%)	kg/m <sup>3</sup>	kg(1cube)	kg/m <sup>3</sup>	kg/m <sup>3</sup>	kg(1cube)	kg/m <sup>3</sup>	kg/m <sup>3</sup>	kg(1cube)
C100S100	520.778	0.009	0.068	1432.140	0.559	1432.140	0.023	0.188	0.000	0.000	0.000	252.577	0.004	0.033
C100S950	520.778	0.009	0.068	1432.140	0.559	1360.533	0.022	0.178	66.572	0.001	0.009	252.577	0.004	0.033
C100S900	520.778	0.009	0.068	1432.140	0.559	1288.926	0.021	0.169	133.144	0.002	0.017	252.577	0.004	0.033

**Table 3.6 Mix Design for sand replacement by unburnt sand dust**

**Mix Design for burnt sand dust as replacement of sand and cement:**

CASE-ID	CEMENT(kg)			SAND			CLAY			WATER		
	kg/m <sup>3</sup> (%)	kg/in <sup>3</sup>	kg(1cu)	kg/m <sup>3</sup>	kg/in <sup>3</sup>	kg(1cu)	kg/m <sup>3</sup>	kg/in <sup>3</sup>	kg(1cu)	kg	m <sup>3</sup>	kg(1cube)
S100C100CL0	520.78	0.01	0.07	1432.14	0.02	0.19	0.00	0.00	0.00	252.58	0.25	0.03
S100C95CL5	494.74	0.01	0.06	1432.14	0.02	0.19	19.99	0.00	0.00	252.58	0.25	0.03
S100C90CL10	468.70	0.01	0.06	1432.14	0.02	0.19	39.98	0.00	0.01	252.58	0.25	0.03
S100C85CL15	442.66	0.01	0.06	1432.14	0.02	0.19	59.97	0.00	0.01	252.58	0.25	0.03

**Table 3.7 Mix Design for burnt sand dust as replacement of sand and cement**

### 3.4 Material Properties

The properties of materials used were evaluated before casting by testing them in the laboratory according to specifications. The aggregates used in this study were tested



for specific gravity, absorption capacity, abrasion resistance, gradation, and unit weight. The specifications followed are summarized in **Table 3.8**.

<b>Name of the property evaluated</b>	<b>Specification/guideline followed</b>
Specific gravity	ASTM C 128
Absorption capacity	ASTM C 128
Abrasion resistance	ASTM C 131
Unit weight	ASTM C 29
Gradation	ASTM C 33
Fineness Modulus	ASTM C 136

**Table 3.8. Specifications followed to test material properties**

### 3.4.1 Sand

For this study, locally available River sand was used . Prior to casting, the sand was tested for specific gravity, absorption capacity, unit weight, and fineness modulus (FM). The material properties of fine aggregate are summarized in **Table 3.5**.The FM of 2.52 is the natural FM of the sand, and the natural gradation satisfies ASTM C 33 – 03 specifications, as shown in **Figure 3.2**.

<b>Aggregate Type</b>	<b>Specific Gravity</b>	<b>Absorption Capacity (%)</b>	<b>Abrasion (%)</b>	<b>SSD Unit Weight (kg/m3)</b>	<b>Fineness Modulus</b>
Local River Sand	2.6	1.50	-	1520	2.25

**Table 3.9. Properties of Sand**

### 3.4.1.1 Gradation

The sand used for making test specimens was natural silica sand conforming to the requirements for graded standard sand in Specification C 778.

Sieve No	Opening(mm)	% finer
#16	1.18	100
#30	0.6	96
#40	0.425	70
#50	0.3	25
#100	0.15	0

Table 3.10 Sand grading as per Ottawa sand

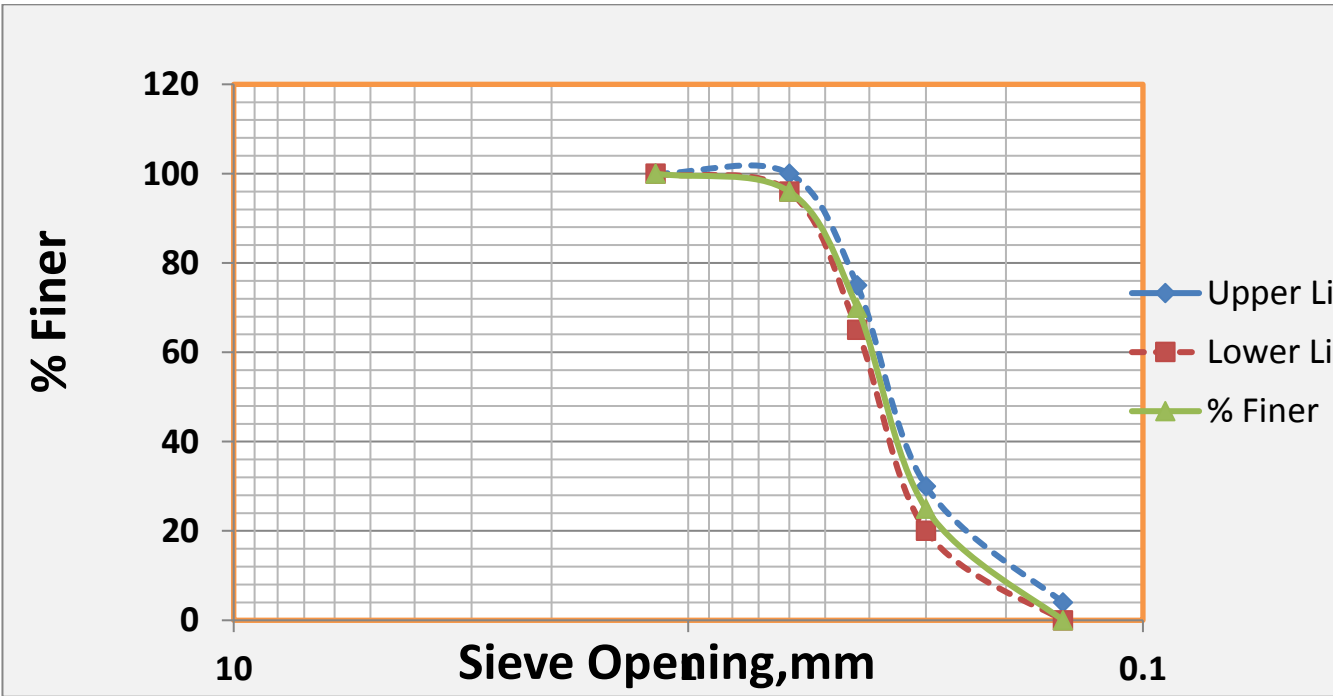


Figure 3.1 Grading as per Ottawa sand.

### 3.4.1.2 Fineness modulus

$$F.M = \frac{\sum \text{Cumulative \% retained on each standard sieve}}{100}$$

### 3.4.2 Cement

CEM Type I (Clinker: 95-100%, Gypsum: 0-5%) cement (as per BDS EN 197-1:2000) was used for mortar specimens casting.

The composition of the mineral components is given in **Table 3.6** (as specified by the manufacturer). It has fairly high C3S content for good early strength development.

Component	Percentage
Clinker	95-100%
Slag, Fly Ash, Limestone etc.	-
Minor additional constituents	0-5%

**Table 3.11. Composition of cement**

### 3.4.3 Water:

Water used in this study for concrete mixing and curing was potable tap water whose unit weight was 1000 kg/m<sup>3</sup>.

### 3.4.4 Ladle Refined Slag

Slag is a waste material considered as a by-product of the steel-making process. Two types of slag are produced in the electric arc furnace steelmaking process: EAF slag and Ladle Refined (LR) slag. . Ladle slag is produced in the secondary metallurgy or refining process, which generates high-grade steels. In this process, liquid steel first undergoes an acid dephosphorization process in the EAF (oxygen blowing). Then, the steel is discharged into a ladle furnace, where it is deoxidized, desulfured and alloyed under the protection of a basic slag desulfured and alloyed under the protection of a basic slag.

<b>Name</b>	<b>Specific Gravity</b>	<b>Absorption Capacity (%)</b>	<b>Abrasion (%)</b>	<b>SSD Unit Weight (kg/m3)</b>
Ladle Refined Slag	3.1	2.63	-	1432

**Table 3.12: Properties of Ladle Refined Slag**

### 3.5 Casting Procedure

### **3.5.1 Preparation of Specimen Molds**

Applied a thin coating of release agent to the interior faces of the mold and non-absorptive base plates. Applied oils and greases using an impregnated cloth or other suitable means. Wiped the mold faces and the base plate with a cloth as necessary to remove any excess release agent and to achieve a thin, even coating on the interior surfaces. At the time of using an aerosol lubricant, released the agent directly onto the mold faces and base plate from a distance of 6 to 8 in. or [150 to 200 mm] to achieve complete coverage. Then wiped the surface with a cloth as necessary to remove any excess aerosol lubricant. The residue coating should be just sufficient to allow a distinct finger print to remain following light finger pressure

Sealed the surfaces where the halves of the mold join by applying a coating of light cup grease such as petrolatum. The amount should be sufficient to extrude slightly when the two halves are tightened together. Remove any excess grease with a cloth.

After placing the mold on its base plate carefully removed with a dry cloth any excess oil or grease from the surface of the mold and the base plate to which watertight sealant is to be applied.

### **3.5.2 Preparation of Mortar**

Mechanically mixed in accordance with the procedure given in Practice C 305.

### **3.5.3 Molding Test Specimens**

.Placed the materials in the mixing bowl of mixer machine .Quickly scraped the bowl sides and transfer into the batch the mortar that may have collected on the side of the bowl

and then remixed the entire batch 15 s at medium speed. Upon completion of mixing, the mixing paddle shall be shaken to remove excess mortar into the mixing bowl.

Started molding the specimens within a total elapsed time of not more than 2 min and 30 s after completion of the original mixing of the mortar batch. Placed a layer of mortar about 1 in. or [25 mm] (approximately one half of the depth of the mold) in all of the cube compartments. Tamped the mortar in each cube compartment 32 times in about 10 s in 4 rounds, each round to be at right angles to the other and consisting of eight adjoining strokes over the surface of the specimen. The tamping pressure was sufficient to ensure uniform filling of the molds. The 4 rounds of tamping (32 strokes) of the mortar was completed in one cube before going to the next. When the tamping of the first layer in all of the cube compartments is completed, filled the compartments with the remaining mortar and then tamped as specified for the first layer. During tamping of the second layer, brought in the mortar forced out onto the tops of the molds after each round of tamping by means of the gloved fingers and the tamper upon completion of each round and before starting the next round of tamping. After completion of the tamping, the tops of all cubes are extended slightly above the tops of the molds. The mortar that has been forced out onto the tops of the molds are brought with a trowel and smooth off the cubes by drawing the flat side of the trowel (with the leading edge slightly raised) once across the top of each cube at right angles to the length of the mold.

#### **3.5.4 Storage of Test Specimens**

Immediately upon completion of molding, the test specimens are placed in the moist closet or moist room. All the test specimens are kept, immediately after molding, in the molds on the base plates in the moist closet or moist room from 24 h with their upper surfaces exposed to the moist air but protected from dripping water.

#### **3.5.5 Curing**

For the curing of specimens, a preliminary curing is done and followed by underwater curing. After casting, unmolding is to be done within  $20 \pm 4$  hours. Within this time range, the cubes can often get dried and it is necessary to wrap its top surface with moist cloth to prevent that. It is done till unmolding and called preliminary curing. After unmolding, specimens are brought underwater and cured till performing the crushing tests.

**3.6 Determination of Compressive Strength:**

The the specimens are tested immediately after their removal from the moist closet in the case of 24-h specimens, and from storage water in the case of all other specimens. All test specimens for a given test age shall be broken within the permissible tolerance prescribed as follows:

**3.7 Test Age Permissible Tolerance**

<b>Test Age</b>	<b>Permissible Tolerance</b>
<b>24 h</b>	$\pm 1/2$ h
<b>3 days</b>	$\pm 1$ h
<b>7 days</b>	$\pm 3$ h
<b>28 days</b>	$\pm 12$ h

**Table 3.13 Test Age Permissible Tolerance**

### **3.8 Casting and testing schedule for sand dust**

**Table**

### **3.14 Casting and testing schedule for sand dust**

### **3.9 Conclusion**

In this chapter, different methods adopted to achieve the objectives of the study are thoroughly discussed. Different parameters of materials are explained in order to relate it to the study result. Experimental method is important in order to set out the scope the study. So, the methodology is followed by result and discussion in the next chapter.



## **Chapter 4 Results and Discussion**

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### **4.1 GENERAL**

This chapter deals with the presentation of results obtained from various tests conducted on concrete specimens cast with and without Ladle Refined Furnace (LRF) slag and Sand Dust. The main objective of the research program was to understand the strength and durability aspects of concrete obtained using LRF slag and Sand Dust as partial replacement for cement. In order to achieve the objectives of present study, an experimental program was planned to investigate the effect of these supplementary cementitious materials on compressive strength of mortar specimens. The experimental program consists of casting, curing and testing of controlled and LRF slag and Sand Dust mortar specimens at different ages.

The experimental program included the following:

- Testing of properties of materials used for making concrete.
- Design mix.
- Casting and curing of specimens.
- Tests to determine the compressive strength of mortar specimens.

### **4.2 COMPRESSIVE STRENGTH**

#### **4.2.1 LRF slag replacement of cement**

Test specimens of size 2”x 2”x 2” were prepared for testing the compressive strength concrete. The concrete mixes with varying percentages (0%,10%,20%,30%,40%,50%,60%,70%,80% and 90%) of LRF slag as partial replacement of cement ; 0%,5% and 10% of unburnt sand dust as partial replacement of

fine aggregate (sand); 0%,5% and 10% of burnt sand dust as partial replacement of fine aggregate (sand) and 0%,5%,10% and 15% of burnt sand dust as partial replacement of cement were casted into cubes for subsequent testing.

In this study, to make mortar, cement and fine aggregate were first mixed dry to uniform color.

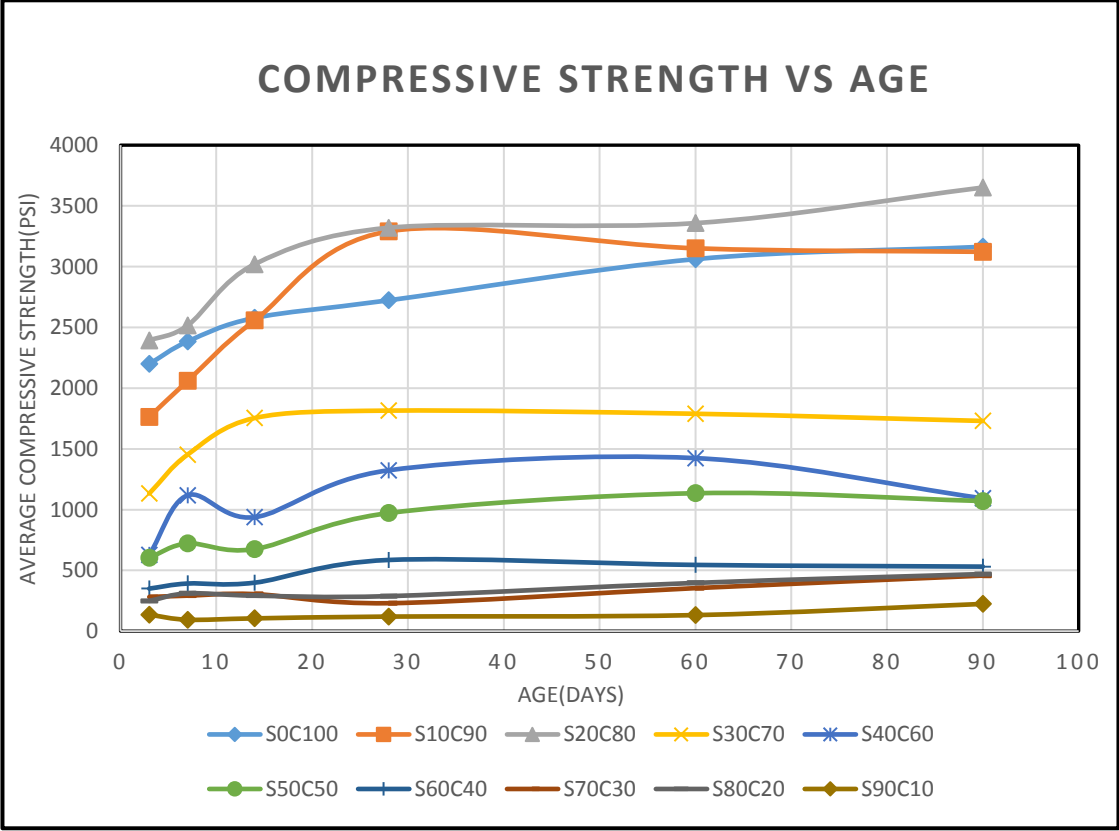
Water was then added and the whole mass mixed. The interior surface of the molds and the base plate were oiled before mortar was placed. After 24 hours, the specimens were removed from the molds and placed in clean fresh water. The specimens so cast were tested after 3, 7, 14, 28, 60, and 90 days of curing. The load was applied axially without shock till the specimen was crushed. Results of the compressive strength test on mortar with varying proportions of LRF slag replacement at different ages are given in the **Table 4.1**.

<b>CASE</b>	<b>Mix</b>	<b>3 Days</b>	<b>7 Days</b>	<b>14 Days</b>	<b>28 Days</b>	<b>60 Days</b>	<b>90 Days</b>
<b>S0 C100</b>	Control	2199	2384	2578	2723	3062	3163
<b>S10 C90</b>	10%	1763	2059	2557	3291	3151	3122
<b>S20 C80</b>	20%	2392	2516	3020	3320	3358	3651
<b>S30 C70</b>	30%	1133	1453	1754	1815	1789	1730
<b>S40 C60</b>	40%	628	1118	938	1324	1424	1093
<b>S50 C50</b>	50%	605	721	675	972	1135	1071
<b>S60 C40</b>	60%	350	392	399	586	545	531
<b>S70 C30</b>	70%	281	292	305	230	354	457
<b>S80 C20</b>	80%	249	311	292	288	397	470
<b>S90 C10</b>	90%	135	94	105	120	132	224

**Table 4.1: Compressive strength of mortar specimens in psi (replacement by LRF slag).**

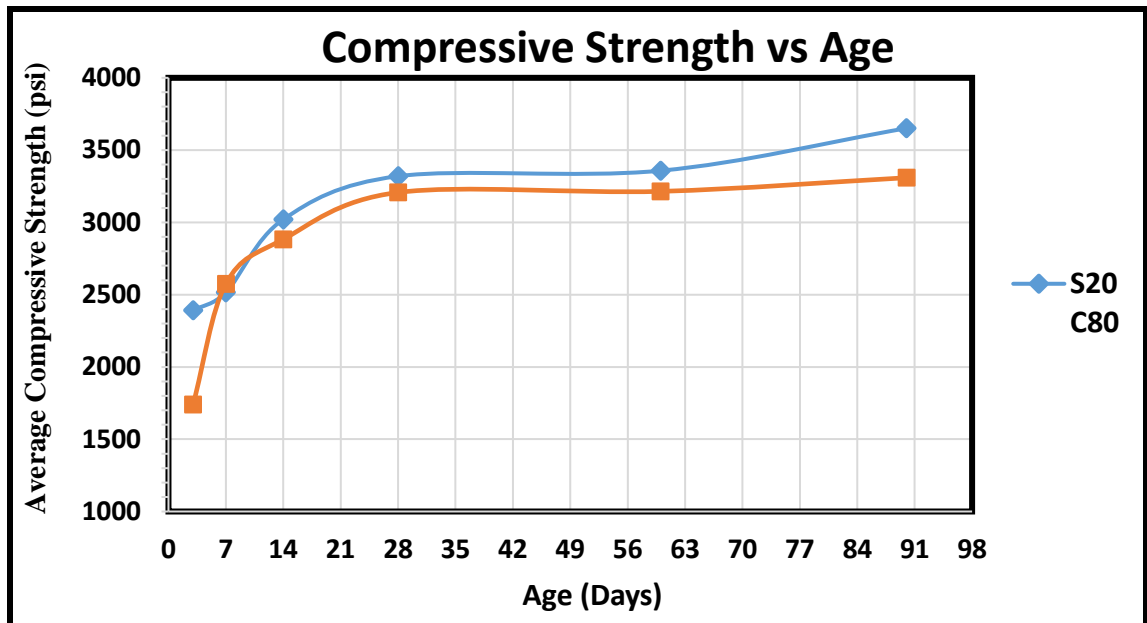
The compressive strength results of mortar specimens are also shown graphically in **Figure 4.1**. The compressive strength increases as compared to control mix as the percentage of

LRF slag is increased up to 20%. We get around 3300 psi strength for 10% and 20% partial replacement of cement by LRF slag at 28 days. For 20% replacement of cement, compressive strength continues to increase up to 90 days. In other cases i.e. for 30% - 90% partial replacement, compressive strengths are found low compared to the control case.



**Figure 4.1: Compressive strength versus age (replacement by LRF slag)**

After adding 10% LRF slag in the mix, there is a decrease of 20% after 7 days, 3% increase after 28 days and 2% decrease after 60 days as compared to the control mix. By adding 20% LRF slag, there is large amount of increase in percentage i.e. 37%, 4%, 4% and 10% after 3, 28, 60 and 90 days respectively. Comparison between control case and 20% replacement of cement by LRF slag is presented graphically in **Figure 4.2**.



**Figure 4.2: Compressive Strength versus Age for control case and 20% replacement of cement.**

It is observed that significant increase in compressive strength is found in 20% partial replacement of Cement by LRF Slag. We get around 3700 psi strength at 90 days where 3000 psi strength is found for no replacement of cement.

**Table 4.2** shows the variation of percentage increase in compressive strength with replacement percentage of LRF slag. The results also indicate that early age strength gain i.e. at 7 and 28 days, is higher when compared to the control mix if 20% of cement is replaced by LRF slag.

Mix	AGE					
	3 Days	7 Days	14 Days	28 Days	60 Days	90 Days
10%	1%	-20%	-11%	3%	-2%	-6%
20%	37%	-2%	5%	4%	4%	10%
30%	-35%	-44%	-39%	-43%	-44%	-48%
40%	-64%	-57%	-67%	-59%	-56%	-67%
50%	-65%	-72%	-77%	-70%	-65%	-68%
60%	-80%	-85%	-86%	-82%	-83%	-84%
70%	-84%	-89%	-89%	-93%	-89%	-86%
80%	-86%	-88%	-90%	-91%	-88%	-86%
90%	-92%	-96%	-96%	-96%	-96%	-93%

**Table 4.2: Variation of percentage increase for different cases compared to control case (replacement of cement by LRF slag).**

#### **4.2.2 Unburnt Sand Dust replacement of sand**

Significant increase in compressive strength was not observed as compared to the ordinary mortar controls for unburnt sand dust samples at 5% and 10% replacement for sand. For 10% unburnt sand dust mixtures, the compressive strength increased at 28 days. The maximum compressive strength observed was 2956 psi, which occurred in the 5% replacement case with w/c=0.485 at 90 days. 5% replacement of sand did not give increase in compressive strength compared to control at 28, 60 and 90 days.

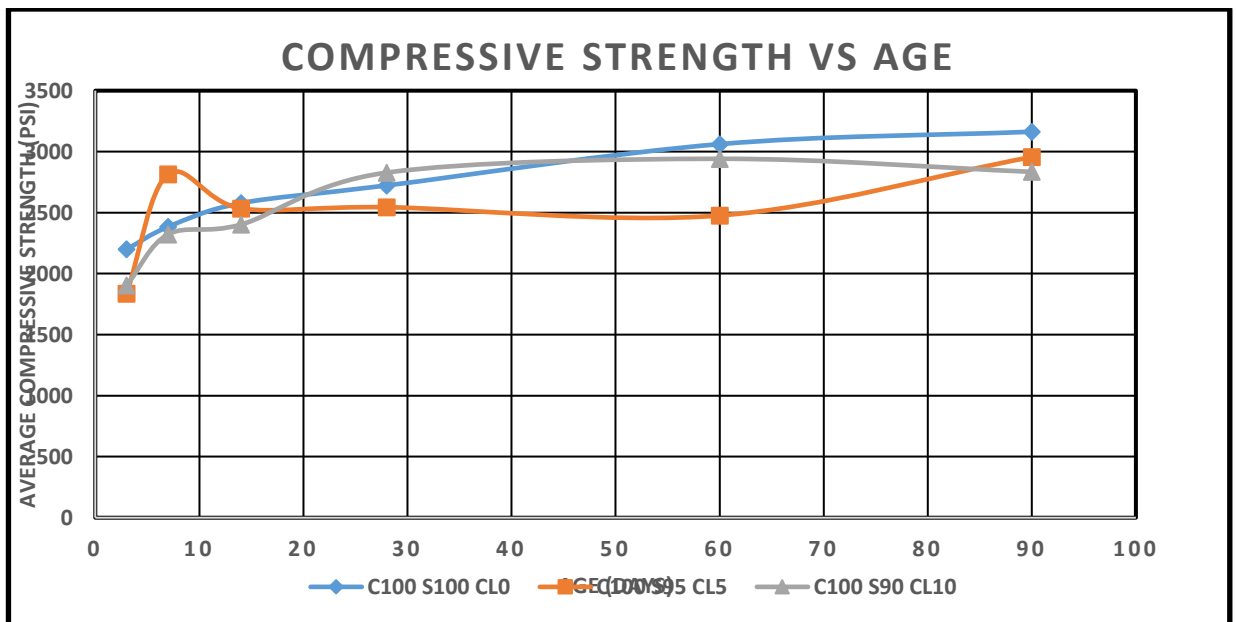
. These results are shown in **Table 4.3** and graphically in **Figure 4.3**. Variation of percentage increase compared to control for 5% and 10% replacement of sand is given in **Table 4.4**.

Age(Days)	3	7	14	28	60	90
C100 S100 CL0( <i>Control</i> )	2199	2384	2578	2723	3062	3163
C100 S95 CL5	1837	2815	2534	2544	2477	2956
C100 S90 CL10	1903	2322	2403	2828	2941	2835

**Table 4.3: Compressive strength in psi of mortar cubes for Sand replacement by unburnt sand dust.**

MIX	AGE					
	3 DAYS	7 DAYS	14 DAYS	28 DAYS	60 DAYS	90 DAYS
C100 S95 CL5	-16%	18%	14%	-7%	-19%	-7%
C100 S90 CL10	-13%	-3%	-20%	4%	-4%	-10%

**Table 4.4: Variation of percentage increase for 5% and 10% replacement of sand by unburnt sand dust compared to control case.**



**Figure 4.3: Compressive strength versus Age of mortar cubes for Sand replacement by unburnt sand dust.**

### 4.2.3 Burnt sand dust replacement of sand

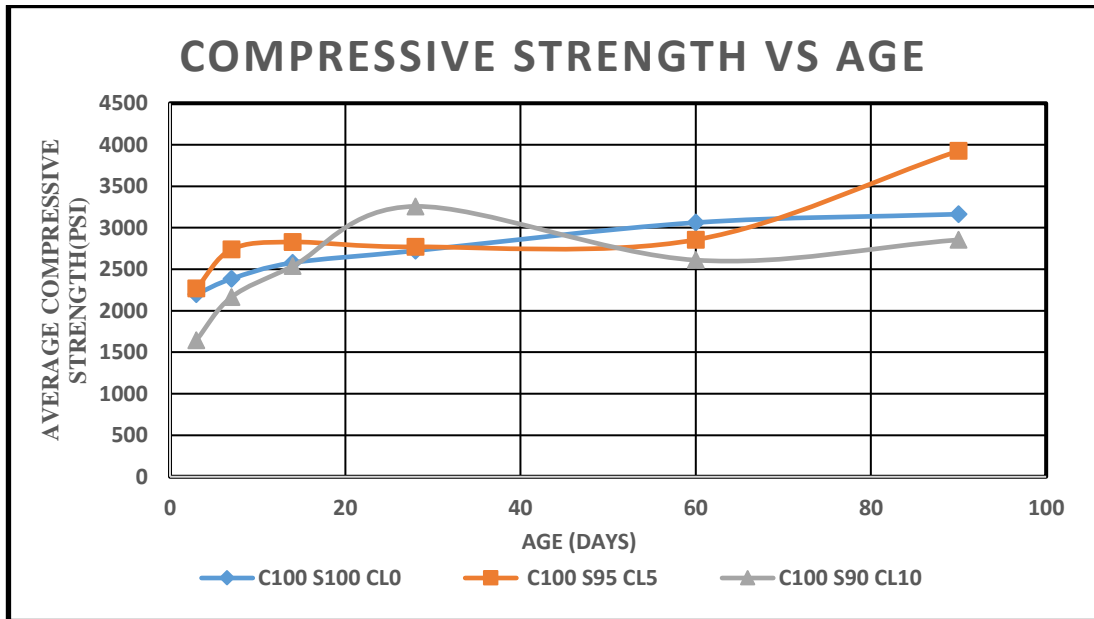
Sand dust was burnt at 200 °C for 24 hours and used after rapid cooling as replacement of sand. After experimenting mortar test, we get increase in compressive strength for 5% replacement of cement at six stages compared to control. 10% replacement of sand gives increase in compressive strength only at 28 days but 60 and 90 days strengths are not satisfactory compared to the control. **Table 4.5** shows the compressive strength results of 5% and 10% replacement of sand by burnt sand dust. The results are presented graphically in **Figure 4.4**. 5% and 10% replacement of sand give 2% and 20% increase in compressive strength respectively after 28 days curing. 60 and 90 days strength show decrease compared to the control. Percentage increases for 5% and 10 % replacement of sand compared to control are shown in **Table 4.6**.

Age(Days)	3	7	14	28	60	90
<b>C100 S100 CL0</b> (Control)	2199	2384	2578	2723	3062	3163
<b>C100 S95 CL5</b>	2268	2737	2829	2770	2855	3926
<b>C100 S90 CL10</b>	1645	2163	2537	3257	2610	2854

**Table 4.5: Compressive strength in psi of mortar cubes for Sand replacement by burnt sand dust.**

Age(Days)	AGE					
	3 days	7 days	14 days	28 days	60 days	90 days
<b>C100S95CL5</b>	3%	15%	27%	2%	-7%	24%
<b>C100S90CL0</b>	-25%	-9%	14%	20%	-15%	-10%

**Table 4.6: Variation of percentage increase for 5% and 10% replacement of sand by burnt sand dust compared to control case.**



**Figure 4.4: Compressive strength versus Age of mortar cubes for Sand replacement by burnt sand dust.**

#### 4.2.4 Burnt sand dust replacement of cement

Sand dust was burnt at 200<sup>0</sup>C for 24 hours and rapid cooled for casting as partial replacement of cement. Mortar specimens for 5%, 10% and 15% replacement of cement by burnt sand dust were casted. Mortar cubes were casted and tested at six stages after curing. Compressive strength results in psi of mortar cubes for 5%, 10% and 15 % cement replacement by burnt sand dust are shown in **Table 4.7**.

5% replacement of cement gives 37%, 12% and 10% increase in compressive strength at 28, 60 and 90 days respectively compared to control. 10% replacement case specimens do not show any increase in strength, where 15% replacement case specimens show increase in compressive strength at 28, 60 and 90 days. Variation of percentage increase compared to control for 5%, 10% and 15% replacement of cement is given in **Table 4.8**. The maximum strength i.e. 3721 psi was found for 5% replacement of cement by burnt sand dust at 28 days. The compressive strength results are presented graphically in **Figure 4.5**.

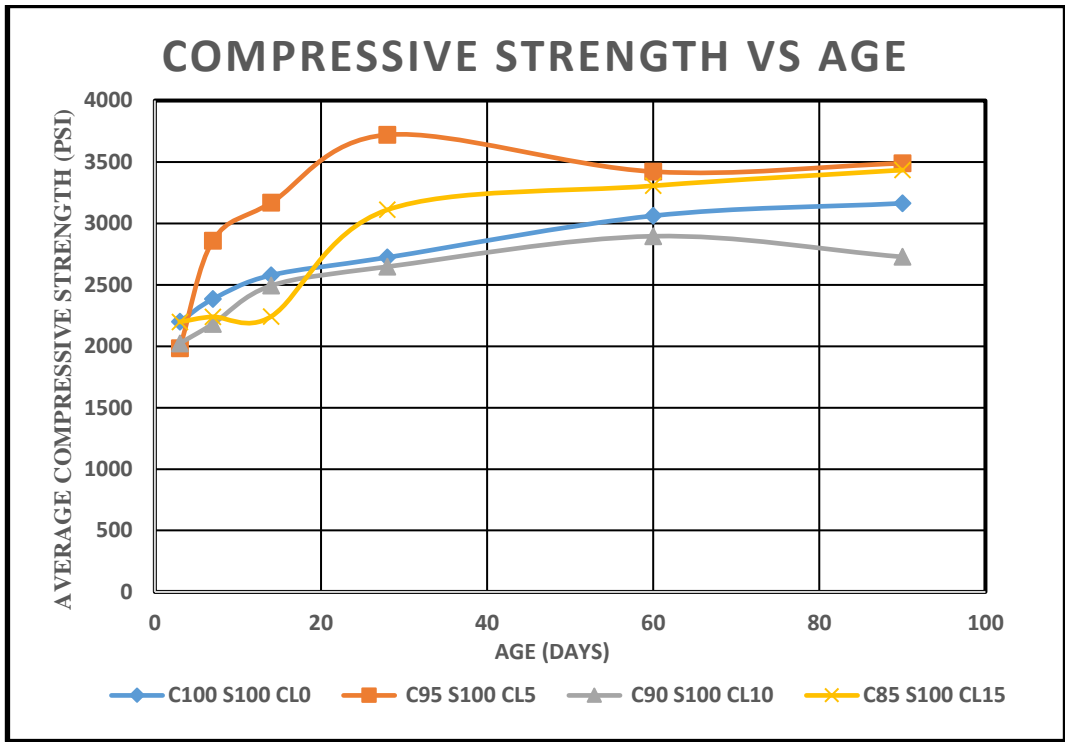


Age(Days)	3	7	14	28	60	90
<b>C100 S100 CL0</b> (Control)	2199	2384	2578	2723	3062	3163
<b>C95 S100 CL5</b>	1985	2859	3168	3721	3421	3489
<b>C90 S100 CL10</b>	2023	2182	2493	2647	2895	2727
<b>C85 S100 CL15</b>	2198	2239	2242	3111	3306	3434

**Table 4.7: Compressive strength in psi of mortar cubes for Cement replacement by burnt sand dust**

Age(Days)	AGE					
	3 days	7 days	14 days	28 days	60 days	90 days
<b>C95S100 CL5</b>	-10%	20%	23%	37%	12%	10%
<b>C90S100CL10</b>	-8%	-8%	-3%	-3%	-5%	-14%
<b>C85S100CL15</b>	0%	-6%	-13%	14%	8%	9%

**Table 4.8: Variation of percentage increase for 5%, 10% and 15% replacement of cement by burnt sand dust compared to control case.**



**Figure 4.5: Compressive strength versus Age of mortar cubes for Cement replacement by burnt sand dust.**

# Chapter 5 Conclusion

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## 5.1 Reviews on Completed Research Work

### 5.1.1 Ladle Refined Furnace (LRF) slag

Based on the results of this experimental investigation the following conclusions are drawn:

1. After adding 10% LRF slag in the mix, there is a decrease of 20% after 7 days, 3% increase after 28 days and 2% decrease after 60 days as compared to the control mix. By adding 20% LRF slag, there is large amount of increase in percentage i.e. 4%, 4% and 10% after 28, 60 and 90 days respectively.

2. The Compressive strength tends to increase with increase percentages up to 20% of LRF slag in the mix.

3. The partial replacement of Cement by LRF slag improves the compressive strength of concrete at different ages and can be declared that LRF Slag can be regarded as cementitious material.

4. 20% of OPC cement can be replaced by LRF slag without reduction of compressive strength.

5. Replacement of cement by LRF slag will reduce the consumption of cement and thereby will help towards sustainability of construction materials.

### 5.1.2 Sand Dust

1. Unburnt sand dust cannot be utilized as replacement of sand or cement as the compressive strength did not increase significantly compared to control case.

2. 5% and 10% replacement of sand by burnt sand dust give 2% and 20% increase in compressive strength respectively at 28 days.
3. Burnt sand dust can be replaced as cement. 5% replacement of cement by burnt sand dust give significant increase in compressive strength at 28, 60 and 90 days.
4. Replacement of cement by 200°C burnt sand dust will reduce the consumption of cement and thereby will help towards sustainability of construction materials.

## **5.2 Future Research**

Future research with use of LRF slag and sand dust should focus on the following areas as this study did not address them:

1. In the present study only 0.485 w/c ratio have been considered. The other ratios i.e. 0.45 and 0.50 and 0.55 need investigation.
2. Sulphate resistance of concrete containing LRF slag needs to be investigated for larger exposure time.
3. Burnt sand dust need further investigation for possibility of containing pozzolanic constituents.
4. There is huge potential of getting Metakaolin in sand dust if sand dust is burnt up to 800°C since it is mentioned in various literature. Presence of metakaolin can be determined by XRD test. Metakaolin can give huge increase in compressive strength of mortar cubes.

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