INVESTIGATION OF MECHANICAL PROPERTIES OF STRUCTURAL LIGHTWEIGHT HIGH STRENGTH CONCRETE USING LOCAL LIGHTWEIGHT AGGREGATES

Final Year Project UG 2013

By

2013-NUST-SCEE-BE-CE-5106 Taha Fawad Azim
2013-NUST-SCEE-BE-CE-5922 Muhammad Shahzad
2013-NUST-SCEE-BE-CE-6835 Zeeshan Zulfiqar
2013-NUST-SCEE-BE-CE-6831 Qasim Naveed

NUST Institute of Civil Engineering

School of Civil and Environmental Engineering

National University of Sciences and Technology, Islamabad, Pakistan

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This is to certify that the

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2013-NUST-SCEE-BE-CE-6831 Qasim Naveed

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Abdul Basir Awan

Designation (Assistant Professor)

NUST Institute of Civil Engineering

School of Civil & Environmental Engineering

National University of Sciences & Technology Islamabad, Pakistan

ABSTRACT

This paper determines mix proportions and properties of Structural Lightweight High Strength Concrete (SLWHSC) made using lightweight aggregates and silica fumes. In the mixtures, three different materials were used as lightweight aggregates which are Expanded Slate, Expanded Shale and Over Burnt Bricks. These aggregates were used to replace normal weight coarse aggregate in concrete. These aggregates had specific gravities in range of 1.5 to 1.9. The concrete mix design was adjusted by replacing 10% of the cement with silica fume to gain high strength. SLWHSC samples were made with and without silica fume to compare the results with normal weight concrete. A number of cylinder specimens were casted to measure compressive and splitting tensile strength. The behavior of stress-strain of concrete mixtures was also studied. Results were astonishing as SLWHSC had 20% less weight and 75% more compressive strength than a normal weight concrete of 150 pcf weight and 4000 psi strength. Over burnt bricks and Expanded Shale proved to be suitable for SLWHSC. The SLWHSC produced had unit weight 115-120 pcf and compressive strength 6000-7000 psi. SLWHSC with reduced dead load and increased strength can be used for high rise structures and bridges.

Dedicated to our beloved parents……

Acknowledgement

Our respects and unpretentious thanks to Almighty Allah, who bestowed upon us enough vigor and urge to work and finish the task undertaken by us. We would like to pay our gratitude to the academic members of NUST Institute of Civil Engineering, who provided a lot of knowledge during undergraduate program.

In the end, we pay our solemn appreciation with sincerest sense of reverence to our parents for their inspiration, prayers and their good wishes for successful completion of the project.

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INTRODUCTION

1.1 General

Structural lightweight concrete is defined by American Concrete Institute 213 as "*Concrete with an air-dry density in the range of 85 to 115 pounds per cubic foot (pcf), with some job specifications allowing air-dry densities up to 120 pcf, and a 28-day compressive strength greater than 2500 psi*". In comparison to normal weight concrete having weight 150 pcf, lightweight concrete is at least 20% lighter in weight. But Structural Lightweight High Strength goes further than that. It also pursues an increase in strength while maintaining the decrease in weight.

1.1.2 Structural Lightweight High Strength Concrete

Structural lightweight high strength is an exciting new development in the field of construction. Therefore limited studies have been carried out on this topic. This type of concrete involves two very contradictory properties which are lightweight and high strength. Structural lightweight high strength concrete (SLWHSC) can be defined as a concrete with air-dry density less than 115 pounds per cubic feet and 28 days compressive strength more than 6000 psi. SLWHSC is usually prepared by using lightweight aggregates for low weight of concrete and silica fumes & fly ash for high strength.

SLWHSC has the unique benefit of decreasing the self-weight of the buildings and areas of sectional components. Use of SLWHSC in high rise buildings and long span bridges can reduce costs. However, a specific mixture has to be designed for SLWHSC which differs a lot from the conventional concrete. This is due to the reason that normal mix design method would affect the material segregation, along with a reduction in strength due the lower density of the aggregate. Since the earthquake forces are relative to the weight of the structures, it is essential that the mass of buildings is decreased for cost efficiency and earthquake sustainability.

Structural Lightweight High Strength Concrete (SLWHSC) is an effective way to lessen the dead weight of the structure. Escalating environmental problems, combined with the fact that the production of conventional aggregates is unable to keep up with the demand, have together led to the rise in usage of the aggregates attained by solid waste materials of various industries. Structural Lightweight Concrete can easily be produced by using both natural and artificial light weight aggregates i.e. Leca, scoria, pumice, expanded shale, expanded clay and expanded slate.

The advantages of Lightweight High Strength Concrete (LWHSC) include higher strength with low weight along with reduction in thermal expansion. The air voids in the aggregate result in better sound and heat insulation. Furthermore, reducing the dead weight of structure results in the designing of cross sections of columns, beams, plates and foundations with the smaller cross sections. This also means that the requirement for steel reinforcement is reduced as well.

1.2 Background

For several years, Lightweight High Strength Concrete (LWHSC) has been used productively for structural objectives. The research of Norokshchenov and WhitComb have presented that it can be possible to make lightweight concrete by using Leca with 10 % silica fume which achieved 70.5 MPa compressive strength having 1,860 kg/m^3 density. Some studies have shown that lightweight concrete with 43.8 MPa 90 days' compressive strength and dry density 1,860 kg/m^3 can be produced by using basalt-pumice as coarse aggregate.

For structural functions of lightweight concrete, the density often plays an important role because it directly relates with the weight of the concrete. A reduction in density results in a decrease in the foundation size and building costs. In recent years, higher-performance concrete can be produced more easily due to the rapid development of concrete. Lightweight High Strength Concrete is a construction material suitable to be used in many countries such as Pakistan because of its cost effectiveness. However information on the mechanical properties of lightweight high strength is unavailable due to lack of research in this area.

1.2.1 Problem Statement

Main problem confronted by construction industry is dense concrete production resulting in increased dead load, transportation/ handling cost and slow building rates. There is a need of cost-effective and lightweight concrete mix that resolves these problems. Our research provides solution to these problems alongside with significant compressive strength using naturally available lightweight aggregates e.g. expanded slate, shale and over burned bricks. The primary aim of this project is to provide an efficient strength to weight ratio by production of Structural lightweight high strength concrete (SLWHSC) that reduces the dead load and design size of the concrete.

In concrete construction, self-weight of concrete represents major proportion of load on structure. Therefore, Use of normal weight aggregate in Pakistan results in additional dead load causing increase in structural member sizes which reduces available space. To support such structure footing size is also increased resulting in cost multiplication. Transportation and handling of these pre-cast dense concrete is also problematic and cost increasing factor.

SLWHSC is not widely used in Pakistan due to the high cost of lightweight aggregates being imported for structural purposes. There is a lack of research on this subject and very few professionals have the required expertise on the topic. Also the labor is not skilled enough to deal with the manufacturing of lightweight high strength concrete.

1.2.2 Solution

Under these circumstances, there is a need to make improvements in construction industry to deal with these problems. Therefore, by introduction of SLWHSC in market will offer design flexibility to the designers allowing reduction in member size especially in column and more useable space, especially on the floors of buildings (usually required by the client).Thus there are clearly considerable advantages in reducing weight which results in low density of concrete for high rise buildings, long span bridges and for various types of structures.

1.3 Objectives

This investigation pursues two objectives.

1. To produce a Structural Light Weight High Strength Concrete with target compressive strength and density by using local aggregates such as expanded slate, expanded shale and over burnt bricks.
2. To study the comparison of lightweight high strength concrete produced by using the selected lightweight aggregates focusing on compressive strength, splitting tensile strength and stress strain behavior

1.4 Project Scope

Our project aimed to cover following:

- Selection and Evaluation of properties of lightweight aggregates
- Determining the admixtures to be utilized in constructing Structural Lightweight High Strength Concrete
- Formulation of Mix Design to produce SLWHSC and acquire properties of mix using selected LWA.
- Evaluate Compressive strength, Density, Workability, Splitting Tensile strength and the Stress -Strain Curve of the mix using different lightweight aggregates

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

There are a number of techniques to produce lightweight concrete. In one way stable air bubbles are introduced in concrete by using chemical admixtures and mechanical foaming. This type of concrete is known as “aerated or cellular concrete”. Another approach of creating Light Weight Concrete is to remove the fine aggregates from the concrete mix. This is called “no-fines concrete”. The prevalent way to produce Lightweight Concrete is by replacing normal aggregate with lightweight aggregate. These aggregates are present in both natural and artificial form around the world and can be utilized to make concrete according to the suitable strength and unit weight requirements.

Lightweight concrete is fabricated by using different LWA that includes:

- Using artificial treatment (expanding/bloating) of natural mineral aggregates like clay/slate/shale that has been heated in a rotary kiln to develop a porous structure. Blast furnace slag which is cooled by air can also be used.
- Natural aggregate consisting of volcanic rocks e.g traventine, scoria and pumice which can be used in concrete as lightweight aggregates.
- Non-structural lightweight aggregates with lower density e.g. plastic granules as aggregates with high amount of air voids in the cement paste matrix. This type is mostly used for insulation purposes.

Utilization of lightweight aggregates goes back to Pre-Roman time. Areas prone to volcanic activities used permeable volcanic rocks. Start of the 20th century brought revolution when USA discovered that clay and shale expands upon heating. Tailing it, in 1917 a rotary kiln was set in Kansas for delivering expanded clay and expanded shale aggregates.

The consistent expansive scale extraction of naturally available aggregates is yielding natural issues, resulting in decay of rural zones topography and bringing about other potential issues like erosion. Therefore, artificial aggregate from industry offer an additional source of aggregates as well as relieve the danger of environmental depreciation e.g. Expanded Shale/Slate.

2.2 Previous Studies on SLWHSC Concrete

Previous researches done on this type of concrete were studied. The main research was done on how both polar opposites of high strength and low unit weight was achieved. Most researches had utilized admixtures such as silica fumes, fly ash and superplasticizer. Furthermore different types of lightweight aggregates were used.

2.2.1 Use of Silica Fumes & Fly Ash

Nastratullah[13] showed that the strength of the concrete is affected by the addition of silica fumes. Four mixes of different were prepared by varying the concentration of silica fumes. Among these four mixes, 0%, 5%, 10% and 15% silica fumes replacement with cement were done. It was observed that there was an increase in compressive strength with an increase in % replacement of silica fumes. Compressive strength increased at a significant rate till the silica fumes reached 10%, but at 15% of silica fume compressive strength of concrete doesn't increases significantly. At 10% silica fumes replacement the mix gave the highest compressive strength.

A minor number of investigations have been conducted on SLWHSC with silica fumes and fly ash. The effect of these admixtures is analyzed by making use of outcome of the following research. A research study was carried out on the compressive and tensile strength of scoria aggregate high strength concrete with silica and fly ash separately. This research by Alaettin Kılıc[2] showed a clear comparison of silica fumes and fly ash mixes. Scoria aggregate concrete with fly ash produced 28 days compressive strength of 29.2 MPa in comparison to lightweight silica fume mixture concrete 28 days compressive strength of 38.9 MPa. Therefore, as per this research the use of silica fume guarantees the production of lightweight concrete with a 40 MPa cylinder compressive strength

Furthermore, isolated researches S. Marikunte and S. Nacer[3] dictates effect of silica fumes on water-cement ratio and compressive strength. This report states that highest compressive strength is achieved by an amalgamation of low water-cementitious material ratio along with the addition of silica fumes. However, at a very low water-to-cement ratio of 0.2, concrete becomes sensitive to increased silica fume content. Based on the data generated and results analyzed report states a maximum amount of silica fume is 15%.

The literature of Hon. FICT, Dip M [12] suggests that silica fumes reduces bleeding significantly. The reason behind this is that large surface area of the silica fume consumes the free water and hence the free water left in the mix for bleeding also decreases.

2.2.2 Use of Superplasticizer

Report of CI-PREMIER PTE LTD studied the effect of superplasticizers on workability, splitting tensile and compressive strength of the concrete. Therefore, results of the report conclude an increase in 28 days tensile strength from 810 to 875 Psi. Furthermore, it is also concluded that use of superplasticizer also increases the workability of the concrete. However, high dosages of superplasticizers tend to weaken the cohesiveness of concrete. As a whole, superplasticizers are prominent in terms of increase in the workability and water reduction of concrete.

2.3 Research on Lightweight Aggregates

The first challenge faced by us was the selection of lightweight coarse aggregate. Investigation of lightweight aggregate in Pakistan was difficult because lightweight concrete using lightweight aggregate is not wildly being used in Pakistan so very few people have knowledge about it. On extensive research and analysis of geologically available data, it was found that Pakistan contains both natural artificial lightweight aggregates. Mostly lightweight aggregates are characterized as aggregates having specific gravity less than 2.

2.3.1 Natural Lightweight Aggregates

Lightweight aggregates that are found naturally in the earth crust are mostly part of the igneous rocks. But due to being in the vicinity of volcanoes, these rocks become lightweight but also retain their high strength which is usually found in the igneous rocks. Scoria and pumice are examples of rocks belonging to this category. So these rocks are most suitable to be used as lightweight aggregates in concrete as their properties will give both low weight and high strength to the concrete.

Natural occurring lightweight aggregates are of volcanic rocks. In Pakistan there are 8 dead volcanos from Qila Saif-u-llah to Chagi in Balochistan. These dead volcanos have volcanic rocks which are lighter in weight and have high strength. There are many types of rocks like traventine, scoria and pumice which can be used in concrete as lightweight aggregates.

Unfortunately it is very difficult to harvest material from these sites in Balochistan because this area is not developed, there are no transportation routes and there are no crushers there to crush these rocks. Only geological survey has been done and no extraction has been done in the area so the natural lightweight aggregates are currently inaccessible. Hence the stance was shifted to artificial lightweight aggregates. Examples of natural light weight rocks along with their specific gravities:

Table 1: Properties of natural lightweight rocks

Rocks	Specific Gravity	Compressive Strength N/mm^2	Hardness	Porosity
Traventine	1.68	35-80	3-4	High
Scoria	2.3	>30	5-6	High
Comendite	2.38	92.4	6-7	High
Girtstone	2.25	70	6-7	High
Itacolumite	2.2-2.8	95	6-7	High
Ganister	2.2-2.8	95	6-7	High
Tuff	<2.4	200	4-6	High
Ignimbrite	<2.4	200	4-6	High
Pumice	<2	50	6	High
Rhyodacite	2.34-2.4	200.5	5.5-6	Low

2.3.2 Artificial Lightweight Aggregates

Depending upon the requirements and the situation aggregates are sometimes artificially converted to lightweight aggregates. This is done by expanding the volume of the aggregate so that it becomes light in weight. This can be achieved either by heating in a rotary kiln or sintering the aggregate. Some common aggregates which are converted to lightweight aggregates are shale, slate or clay.

The manufacturing of lightweight aggregate starts with excavating or quarrying the material from the site. This material usually in form of big rocks is then crushed using crushers and then screened according to the size of the aggregate. The material is shifted to hoppers from where it is delivered to the rotary kiln. The material is heated at temperatures of around 1110-1200°C which turns it to a molten state. The expanded aggregate is removed from the bottom of the kiln.

According to the pie chart below, the aggregates suitable to achieve required high strength are expanded slate, expanded shale, cinders and expanded clay. The availability of the aggregates was checked and most suitable aggregates were selected.

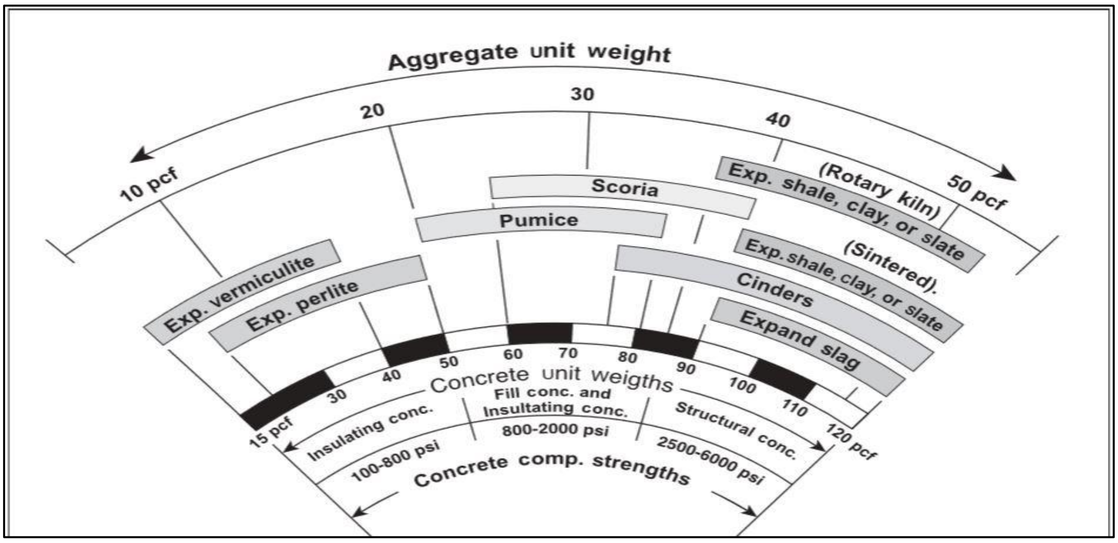


Figure 1 Lightweight aggregates with respective unit weight and compressive strength .Concrete Microstructure, Properties, and Materials by P. Kumar Mehta &Paulo J. M. Monteiro, Third Edition

CHAPTER 3

MATERIALS

3.1 Cement

A cement is substance which is widely used in the construction industry. It serves its purpose as a binder which sticks to other different materials and then binds them together. Its usage is prominent in mortar and concrete where it is added in the mix to bind both fine aggregate (sand) and coarse aggregate (gravel) together. It is used for masonry work with fines only as a mortar.

BESTWAY Cement was acquired from local market in Islamabad with properties shown below in table

Table 2: Properties of Cement

Properties of Cement	
Manufacturer	BESTWAY
Factory	Hattar, Pakistan
Type	OPC Type 1 (ASTM C)-150
Density	$1440 kg/m^3$
Color	Greenish Grey
Blaine fineness	360-370

Figure 2: BESTWAY Cement

3.1.1 Chemical Constituents

X-Ray Fluorescence (XRF) test was conducted on cement out at Institute of Environmental Sciences and Engineering (IESE), NUST. Results are shown below in table.

Table 3: XRF Results for BESTWAY Cement

XRF Results for BESTWAY Cement	
Constituents	Percentage
CaO	61.7
SiO_2	21
Al_2O_3	5.04
Fe_2O_3	3.24
MgO	2.56
LOI	1.83
SO_3	1.51
Free lime	0.98
IR	0.54

Figure 3: XRF Machine at IESE, NUST, Islamabad

Particle Size Distribution (PSD) test on cement was conducted at School of Chemical and Material Engineering (SCME), NUST Islamabad. The results are shown below in figure

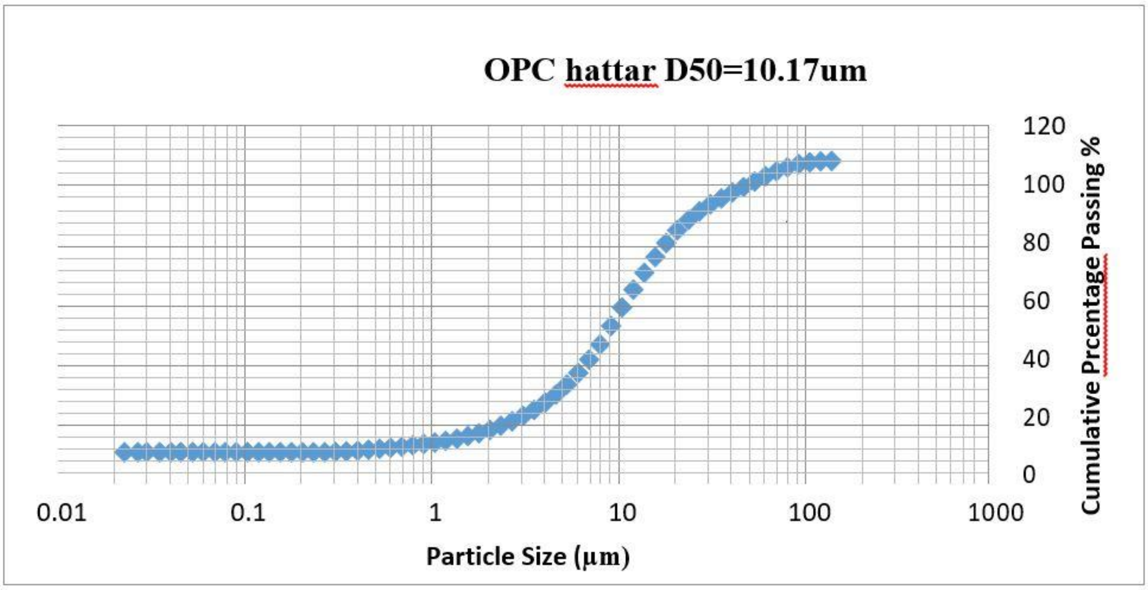


Figure 4: Particle Size Distribution for Bestway Cement

3.2 Sand

Normal weight sand was utilized as fine aggregate. The source of the sand was Lawrencepur, Pakistan. Sand is a vital component in the concrete. It acts to fill the voids in the concrete mix. The properties of sand were investigated and are presented in the following table:

Table 4: Properties of Sand

Fineness Modulus	2.5
Specific Gravity	2.67
Moisture Content (%)	1.0
Absorption (%)	1.2

Figure 5: Lawrencepur Samd

3.3 Silica Fumes

Silica fumes is a very reactive pozzolanic material which has very beneficial use in concrete. It increases the durability and strength of the concrete. The particles of silica fumes are extremely small. Also it has high SiO_2 content due to which it results in an increase in both compressive and tensile strength.

Silica is a byproduct of producing silicon metal. The silica fume was procured by us from the suppliers of concrete admixtures. The quality of silica fumes is specified by ASTM C1240. When silica fumes are added into the concrete mix, they react with Calcium Hydroxide (CH) to produce additional Calcium Silicate Hydrate (CSH) which in turn results in a much denser mix providing high strength and resistivity.

Also fineness modulus of concrete is complemented by the small particle size of the silica fumes which modifies the concrete viscosity. Hence segregation and bleeding of concrete is extremely diminished.

The silica fumes MS-85 was procured from PAGEL Construction in Pakistan. Following are the properties of silica fumes as provided by the company:

Table 5: Properties of Silica Fumes

TYPE	MS-85
Color	Dark grey / blue powder
Loss of ignition, LOI	< 6.0%
Moisture	< 3.0%
Bulk density	600-750 kg/m^3
Retained on 45 micron sieve	< 10%
Flash point	None
Consumption with 100kg Cement	5-15kg
SiO_2	> 85%

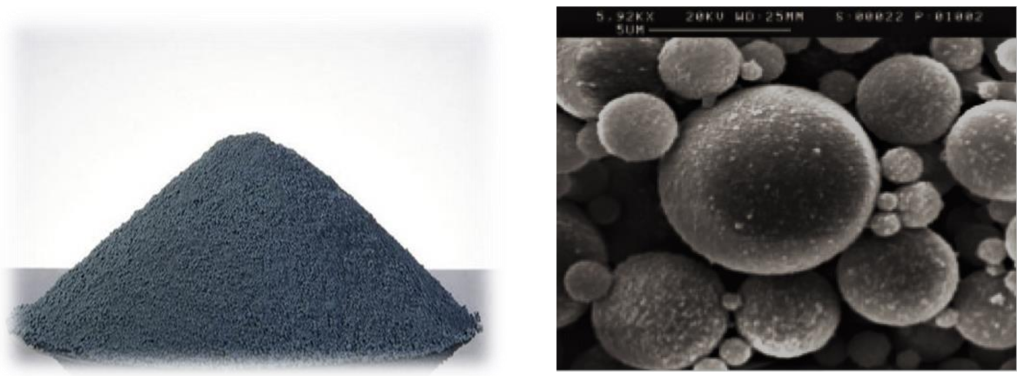


Figure 6: Silica Fumes; Physical appearance (left), Microscopic appearance (right)

X-Ray Fluorescence (XRF) test on silica fumes was carried out at Institute of Environmental Sciences and Engineering (IESE), NUST Islamabad. The results are given in the following table:

Table 6: XRF Results of Silica Fumes

XRF Chemical Composition of Silica Fumes	
Constituents	Percentage
SiO_2	89.20
K_2O	0.98
CaO	1.44
MnO	1.08
Fe_2O_3	3.41
ZnO	3.35
PbO	0.51

3.4 Super Plasticizer

It is a chemical admixture used to enhance the flow properties of suspensions such as in concrete applications. The water to cement ratio of concrete or mortar can be reduced with the addition of superplasticizer. The strength of concrete increases when the water to cement ratio decreases. As our aim also included high strength so it necessitated the use of superplasticizer to provide workability at low water cement ratio. Production of high performance concrete and self-consolidating concrete can also be achieved by using this admixture.

The superplasticizer NAPHTA-PLAST G909 was procured by PAGEL Construction materials. It was constituted according to the ASTM Standard C494: Type A, B, D, F and G. Following are the properties given by the company:

Figure 7: Superplasticizer G909

Table 7: Properties of Superplasticizer NAPHTA-PLAST G909

TYPE	NAPHTA-PLAST G909
Color	Dark brown liquid
Consumption with 100kg Cement	0.8 - 2.5 %
Air Content	< 1.0%
Nitrate content	Nil
Freezing point	0°C.
Specific Gravity	1.18 - 1.2 @ 25 °C
Flash point	None

The addition of this admixture reduces 20% water content while maintaining durability, workability & impermeability. It also improves cohesive properties of concrete to minimize segregation and bleeding. The finishing of the surface is improved. Only the optimum amount of the superplasticizer should be used and slump tests should be conducted to ensure that over dosage is not taking place.

3.5 Lightweight Coarse Aggregate

After analyzing all the options and checking the availability of the materials, three lightweight aggregates were chosen to make SLWHSC. All three of the aggregates were artificially produced lightweight aggregates. Expanded Slate, Expanded Shale and Over Burnt Bricks were selected to act as replacement to Margalla Crush.

Figure 8: Selected Lightweight Aggregates

3.5.1 Expanded Slate

Slate for our projected was extracted from Manki formation (95 km from Peshawar city). Manki Formation is characterized by metamorphic rocks from Precambrian age e.g. slate, quartzite and phyllite. Raw Slate used in our research was fine grained rock split into thin broad sheets with gray to black color. The slate is a normal weight aggregate but it is converted into a lightweight aggregate by expanding it.

Table 8: Properties of Expanded Slate

Aggregate	Expanded Slate
Oven Dry SG	1.28
SSD SG	1.36
Apparent SG	1.39
Absorption	5.8%
Moisture Content	0.8%
Crushing Value	55.1%
Rodded Density	58.9

3.5.2 Expanded Shale

Shale is finely grained sedimentary rocks that exist in stratified form due to consolidation of mud. This compacted mud consists of silt and clay-sized minerals that are fissile and laminated. Raw Shale sent to PCSIR rotary kiln for expansion was extracted from NUST (National University of Sciences and Technology) foothills. Shale obtained from NUST had variation in color, commonly gray and yellow. Before Rotary kiln method, raw shale was formed into pellets of appropriate band sizes for efficient expansion of rock.

Table 9: Properties of Expanded Shale

Aggregate	Expanded Shale
Oven Dry SG	1.33
SSD SG	1.51
Apparent SG	1.62
Absorption	13.5%
Moisture Content	2%
Crushing Value	31.4%
Rodded Density	66.17

3.5.3 Over Burnt Bricks

Over-burnt bricks used in our study were procured from Chak Shehzad, Islamabad. These bricks are waste products of brick kilns produced by overheating of bricks in kiln. They are rejected bricks easily available with reduced cost. Color of over burnt bricks varies from Blackish Red to Dark Black. Bricks were crushed up to ½" down size by hammer for use as aggregate in concrete.

Table 10: Properties of Over Burnt Bricks

Aggregate	Over Burnt Bricks
Oven Dry SG	1.47
SSD SG	1.59
Apparent SG	1.66
Absorption	7.9%
Moisture Content	0%
Crushing Value	26.9%
Rodded Density	62.45

3.5.4 Expansion Process of Slate and Shale

Artificial LWA, expanded slate and shale were yielded in PCSIR (Pakistan Council of Scientific and Industrial Research) Peshawar through processing of natural aggregate in rotary kiln method. In expansion process, first raw form of the aggregate was conveyed from storage silos into patented pre-heaters that heats the rock at a mild rate. Subsequently, conditioned raw materials from pre-heaters are fed into a lined rotary kiln. The rotary kiln is an extended tube that revolves on sizeable bearings. While in kiln, rocks are heated to approximately 1150-1700 C for ½--1 hour under carefully controlled conditions. The substance is transformed into a molten state as it approaches the given temperature value.

As the shale/slate advances near this temperature it nearly becomes molten, similar to lava. In molten state rock becomes plastic enough to permit evolution of gases. Gases evolved creates small uniform voids all over its mass creating a flux bond within its structure. While in molten state emission of gases expands the aggregate that on cooling modifies into an aggregate acquiring lower unit weight and little absorption capacity. After heating, need for the cooling of hot molten expanded aggregate originates. For cooling purposes a slow and gradual process is preferred to avoid crystallization of aggregates. As a result, air cooling is favored over water-cooling system. Therefore expanded material, known as clinker exits from the base of kiln and enters an air-cooling system. Once expanded material cools, a low unit weight aggregate is yielded.

After cooling, clinker is transferred to a sorting area where final product from kiln is crushed and screened according to the specified size divisions. At the end, expanded aggregates undergo a series of testing that includes moisture content, % absorption, weight and specific gravity. .

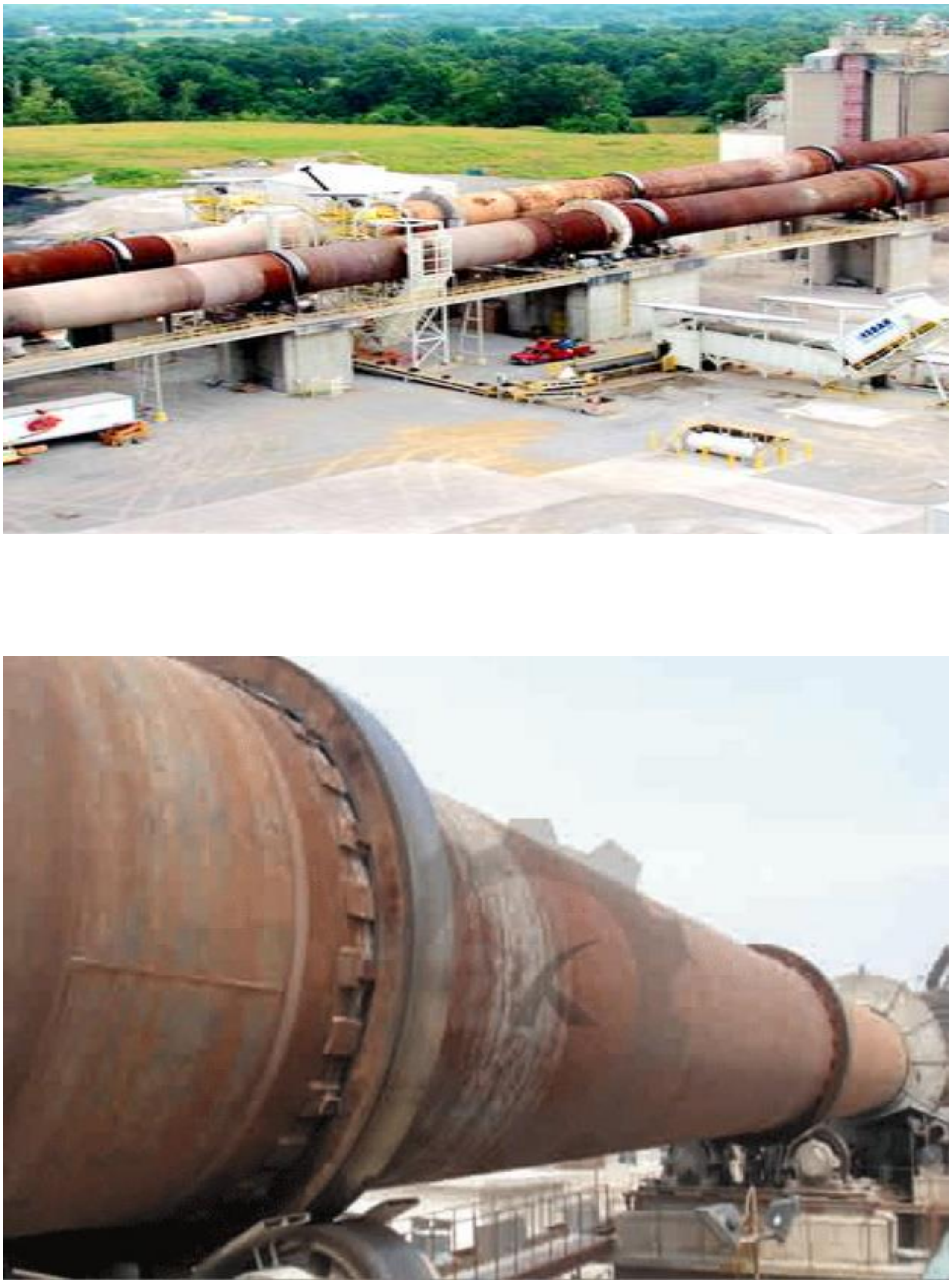


Figure 9: Rotary Kiln for Expansion and Bloating of Aggregates

CHAPTER 4

MIX DESIGN

4.1 Mix Design for Structural Lightweight Concrete

After all the relevant properties of aggregates were investigated by performing the respective experiments, the mix design could be formed using those values. ACI 211.2 code was used to design the respective mixes for the selected aggregates. Following factors affect the mix proportions of Structural Lightweight Concrete:

4.1.1 Aggregate (Absorption and Moisture Content)

The factors which require the modification in the mix design are greatly affected by the higher rates of absorption of lightweight aggregates. The capacity of absorbing water for lightweight aggregate is more due to the increase in the pores as compared to normal weight aggregates. Therefore damp aggregates ae more preferred in the field while casting the concrete as that will cater for the absorption. The usual practice is to immerse the lightweight aggregate in water for a short period of time to cater for the high rates of absorption as during that time the aggregate will absorb the water it needs. Hence proper adjustment of water proportions should not be an issue while designing the mix. The SSD condition can be attained by immersing the lightweight aggregate in water for a period of 24 hours and then drying it.

In retrospect if the aggregate is not immersed in water to achieve the SSD condition, the proportion of water to be added in the mix design will increase which in turn will make the mix much more workable than required. To avoid this problem, it is advised to immerse the lightweight aggregate in half to two-thirds of the mixing water for a period of time then add the rest of the ingredients.

4.1.2 Gradation of Aggregates Used

The total volume of the lightweight coarse aggregate in the mix depends upon the gradation of both fine aggregate and coarse aggregate. The gradation of the fine aggregates dictates its fineness modulus which in turn affects the percentage volume of the coarse aggregate to be added in the mix. A well graded aggregate will have less void content and will provide more strength.

In case of high strength light weight concrete it is desirable that the volume of lightweight coarse aggregate is less as it the aggregate is weak in strength. The volume of the coarse aggregate will be less when:

- The surface texture of coarse aggregate is more porous
- The aggregate is angular in shape
- The aggregate is not well graded

The fractions retained on different sieves have almost the same bulk specific gravity for the normal weight aggregates but the trend does not remain the same for the lightweight aggregates. Workability, paste content and void content is influenced by the volume occupied by each fraction on each sieve. The use of normal weight sand instead of lightweight aggregate results in an increase of strength but it is attained at the behest of increased weight. Hence the mix proportions have to be designed with these factors kept in mind.

4.1.3 Water Cementitious Material Ratio

The water to cement ratio governs the quantity of water and cement to be used. This ratio is affected by the method used to design the mix proportions. According to the weight method, the total weight is obtained by adding all the weights of the materials per unit volume used in the mix. So if the weight of the concrete per unit volume can be obtained the proportion of lightweight aggregate to be used can be attained.

Whereas in volumetric method an accurate measurement of the water proportion utilized in the mix cannot be determined. This is due to the reason that it is difficult to find the total amount of water available for the reaction with cement because the water absorbed by the aggregate in concrete is not known.

4.1.4 Air Entrainment

In Structural Lightweight Concrete sometimes air entrainment is done to decrease the weight of the concrete. Also workability is enhanced and bleeding is reduced. So the percentage of air entrained in the concrete affects the mix proportions due to the volume taken by it. The percentage depends upon the freeze-thaw conditions and the amount of weight to be reduced.

4.2 Parameters of Mix Design

The parameters which are used to calculate the proportions of the mix design are:

4.2.1 Slump

The slump of the concrete is the workability required at the time of casting. It is the measurement of the flowability of concrete. The amount of slump required is dependent on the job conditions. The slump selected should be such that the concrete could be easily placed according to the situation.

4.2.2 Nominal Maximum Size of Aggregate:

Proportions of the mix design depend upon the maximum size of the aggregate. Higher the maximum size of the aggregate, higher will the amount of water to be used. The strength of the concrete is usually dependent upon the maximum size of the aggregate. Lesser the size of the aggregate more will be the strength of the concrete as the concrete produced will be denser.

4.2.3 Water Cement Ratio:

Proportions of water and cement are determined by the water cement ratio being used. Lesser will be the water cement ratio more will be the strength as the proportion of cement will increase. In case of Lightweight High strength concrete the water cement ratio should be kept less so that high strength is attainable.

4.2.4 Strength of Concrete:

High strength will naturally either need strong aggregates or strong cement matrix. If high strength is required then the mix will be designed at lower amount of water cement ratio and higher amount of cement. So the mix would have to be modified according to the strength required.

4.2.5 Fineness modulus:

The fineness modulus of sand dictates the percentage of coarse aggregate to be used in the concrete. Higher fineness modulus will result in less percentage of coarse aggregate to be used. More fine soil will result in a denser composition of concrete

4.2.6 Specific Gravity:

The specific gravity of the coarse aggregate played a great part in the mix design. Higher the specific gravity of the aggregate higher will be the unit weight of the concrete produced. Hence to make the concrete lighter, coarse aggregate of low specific gravity should be used.

4.3 Selected Parameters of Mix Design:

Keeping all the conditions and objectives in mind the mx design parameters chosen were the following:

Aggregate Size	:	½ inch
Water/cement	:	0.36
Slump	:	3 – 4 inch
Strength	:	6000 psi
Super Plasticizer	:	0.9 %
Silica Fumes	:	10 %
Coarse Aggregate	:	SSD State
Fine Aggregate	:	Wet State (Absorption & Moisture Content catered)

4.4 Admixtures in mix:

Admixtures were utilized to help us in achieving our objective. There was no need for air entrainment as there is very less probability of the freeze and thaw conditions in Pakistan. Also the aggregate used was lightweight so it was expected that the concrete casted will be lightweight. Hence the was not a need to compromise the strength by further reducing the weight of the concrete by inducing air entrainment as is usually done in lightweight concrete. The two admixtures added in the concrete were silica fumes and superplasticizer.

The silica fumes was replaced with the cement to enhance the strength of the concrete. As our research was pursuing both high strength and lightweight so to achieve high strength it was necessary to choose a strength increasing additive. 10% of the cement content was replaced by silica fumes as past research showed that it as the most optimum amount to attain the highest strength.

Super plasticizer was necessary to achieve the necessary slump for the placement of the concrete. As aforementioned to achieve high strength the water cement ratio of the concrete was kept as low as 0.36. But the side effect was the decrease in the workability of the concrete. So the use of super plasticizer was warranted to make the concrete workable according to the situation. The instructions given by the manufacturer regarding the addition of superplasticizer in concrete were followed and over dosage was avoided. The correct dosage was determined by conducting slump tests to check which percentage was the most optimum to achieve the required workability. The amount of superplasticizer used was 0.9% of the cement content. It was kept the same for all three aggregates so that the results can be compared in the same conditions.

4.5 Quantities of Mix

Six different mixes were designed. Mix was designed for each aggregate separately with both inclusion and exclusion of silica fumes. Following are the quantities for the respective mixes:

Table 11: Quantities for six mixes

	Material	Cement	Silica	Coarse	Sand	Water	Total	Super Plasticizer
W/O Silica	Slate	37.55	0	30.27	32.29	14.87	114.98	0.34
	Bricks	37.55	0	34.43	32.29	16.09	120.36	0.34
	Shale	37.55	0	31.71	32.29	16.94	118.49	0.34
With Silica	Slate	33.80	3.76	29.90	31.88	14.85	114.19	0.34
	Bricks	33.80	3.76	34.00	31.88	16.06	119.49	0.34
	Shale	33.80	3.76	31.31	31.88	16.90	117.65	0.34

All values are in lb/ft3.

4.6 Casting of Concrete

The casting was completed in three steps:

4.6.1 Mixing

In the mixing phase firstly the lightweight coarse aggregates were prepared by immersing them in water for a period of 24 hours, then drying them in the sunlight for a short period of time so that they get in the Saturated Surface Dry state. The sand, cement, silica fumes and coarse aggregate first went through dry mixing in the pan mixer. Then 2/3 of water was added and wet mixing was initiated. Then the super plasticizer was added evenly. The rest of the water was added at the end. Wet mixing was done for a period of 3 to 4 mins.

4.6.2 Sampling

The molds for the casting were prepared beforehand. The bolts of the molds were properly tightened. The mix was transferred to the wheelbarrow from the mixture and then was poured into the molds in three layer. Each layer was tamped 25 times. The top surface of the mold was smoothened for an even surface.

4.6.3 Curing

The samples were taken out of the molds after one day. These sample were then marked and then put into ta water tank for curing purposes. The cylinders were fully submerged in the water so maximum curing can be achieved. For comparison of curing condition effects, for each of the aggregates used, 12 samples were cured and then tested to determine the compressive strength and 6 samples were tested for splitting tensile test for both 7 days strength and 28 days strength.

Total no. of Cylinders Casted: 60

Compressive Strength: 36

Splitting Tensile Strength: 24

Figure 10: Casted Cylinder Samples of Fresh Concrete

CHAPTER 5

EXPERIMENTATION

5.1 Experiments performed on Aggregates

It was necessary to find the properties of the aggregates to get an estimate of the performance of aggregates in the casting of concrete. Also the properties were needed for the production of the mix design. Following tests were performed on the acquired aggregates:

5.1.1 Coarse Aggregates Experimentation

The properties of the selected lightweight aggregates were to be investigated as there was no prior researched data of expanded shale, expanded slate and over burnt bricks in Pakistan. Following tests were performed:

5.1.1.1 Specific Gravity and Absorption

The test was performed according to ASTM standard C127. Different samples were taken from the lightweight aggregates selected. The samples were immersed in water for a period of one day. The sample was then weighted in water in the Specific gravity apparatus set according to the standard. The sample was again weighed in the saturated surface dry (SSD) state after drying the water films on the surface of the aggregate. The mass of the aggregate was also taken after oven drying the sample for 24 hours.

The specific gravity is determined by the following formulas:

$$\text{Bulk Specific Gravity} = \frac{\text{SSD Weight}}{\text{SSD Weight} - \text{Submerged Weight}}$$

$$\text{Oven Dry Specific Gravity} = \frac{\text{Oven Dry Weight}}{\text{SSD Weight} - \text{Submerged Weight}}$$

$$\text{Apparent Specific Gravity} = \frac{\text{Oven Dry Weight}}{\text{Oven Dry Weight} - \text{Submerged Weight}}$$

$$\text{Absorption} = \frac{\text{SSD Weight} - \text{Oven Dry Weight}}{\text{Oven Dry Weight}}$$

Figure 11: Specific Gravity Apparatus

5.1.1.2 Crushing Value

The test was performed according to the standard specification of BS 882:1965. A sample was taken which was then sieved from ½ inch sieve and retained on ¾ inch sieve. The aggregate sample was then placed in a cylindrical mold in three layers after tamping each layer 25 times with the tamping rod. The weight of the prepared sample was weighed. Universal Testing Machine (UTM) was operated to find out the crushing value of the aggregate. The sample was put into the machine and subjected to a load of 40 tons at the rate of 4 tons per 10 minutes.

The aggregate was then removed from the plunger and then sieved through sieve #7. The weight retained on sieve #7 was measured. Crushing value was determined from the following formula:

$$\text{Crushing Value (\%)} = \frac{\text{Total Weight} - \text{\#7 Retained Weight}}{\text{Total Weight}} * 100$$

5.1.1.3 Moisture Content

The test was carried out according to ASTM standard C127. Samples were taken from each of the selected aggregate in the field condition. The weight was then measured on the weight balance. The samples were put in the oven and dried at 110° C for 24 hours.

$$\text{Moisture Content (\%)} = \frac{\text{Field Weight} - \text{Oven Dry Weight}}{\text{Field Weight}} * 100$$

5.1.1.4 Rodded Density

The test was carried out according to the specifications of ASTM Standard C29. Samples of the aggregates were acquired and then dried in the oven for 24 hours. The cylindrical mold was used as a measure. Weight of the mold was measured and its volume was calculated. The sample was then filled in the cylindrical mold in three layers. Each layer was tamped by the tamping rod 25 times. The weight of the cylindrical measure including the sample was measured.

Weight of sample was obtained by subtracting the weight of the cylindrical measure. The rodded density was then measured using the formula:

$$\text{Rodded Density} = \frac{\text{Weight of Sample}}{\text{Volume of Cylindrical Measure}}$$

5.1.2 Fine Aggregates Experimentation

5.1.2.1 Specific Gravity and Absorption:

The test was performed according to the specifications of ASTM standard C128. Sample was taken and was submerged in water for a period of 24 hours. The sample was converted to the saturated surface dry (SSD) state after drying the water films on the surface of the aggregate. Volumetric method was used by filling the flask with water up to 500 ml and submerging around 55g of the SSD sample in the flask. The flask was then weighed. The mass of the aggregate was also taken after oven drying the sample for 24 hours. The values of specific gravity and absorption were calculated by using the given formulas.

$$\text{Oven Dry Specific Gravity} = \frac{\text{Oven Dry Weight}}{\text{SSD Weight} - \text{Submerged SSD Weight}}$$

$$\text{Bulk Specific Gravity} = \frac{\text{SSD Weight}}{\text{SSD Weight} - \text{Submerged SSD Weight}}$$

$$\text{Absorption} = \frac{\text{SSD Weight} - \text{Oven Dry Weight}}{\text{Oven Dry Weight}}$$

5.1.2.2 Fineness Modulus:

The test was performed according to the specification of ASTM Standard C136. Oven dried sample of fine aggregates was taken and sieved through the set arrangement of sieves according to the specification. The material on each sieve was weighed. Fineness Modulus was calculated using the formula:

$$\text{Fineness Modulus} = \frac{\text{Cumulative \% Retained}}{100}$$

5.1.2.3 Moisture Content:

The test was carried out according to ASTM standard C127. Sample was taken from sand in the field condition. The weight was then measured on the weight balance. The sample was put in the oven and dried at 110° C for 24 hours. Oven dried weight was measured. Moisture content was determined using the formula:

$$\text{Moisture Content (\%)} = \frac{\text{Field Weight} - \text{Oven Dry Weight}}{\text{Field Weight}} * 100$$

5.2 Experiments performed on Concrete

5.2.1 Compressive Strength Test: ASTM C39

The compressive strength test was performed according to the specifications of ASTM Standard C39. The Universal Testing Machine was utilized for this purpose. The test was performed for the 4” x 8” cylinder samples for 7 days strength and 28 days strength. The samples were taken out of the curing tank and stored in a cool dry place after capping the top and bottom surfaces. Weight of the samples was taken preceding to the test.

Samples were placed in the machine for the compressive test. Dimensions were added and the loading rate was kept at 0.25 MPa/s. The compressive strength of the sample was recorded at cracking.

Figure 12: Universal Testing Machine (UTM)

5.2.2 Splitting Tensile Strength Test: ASTM C494

The splitting tensile strength test was carried out according to the specifications of

ASTM Standard C494. Specimens of standard concrete cylinder of 6” diameter and 12” length were prepared. The Universal Testing Machine and the splitting tensile apparatus was used. The sample was mounted perpendicular to the direction of loading such that the load was acting along its whole length. No capping was done. The loading rate was kept at 0.02 MPa/s. The strength was noted at the cracking of the specimen.

Figure 13: Splitting Tensile Apparatus

5.2.3 Stress Strain Curves: ASTM C39

The stress strain curves were acquired using the compressive strength test. Standard concrete cylinder of 4” diameter and 8” length were casted. The samples were tested at 7 days and 28 curing days. The sample was mounted in the UTM and a dial was attached to note the longitudinal strain. The loading rate was kept at 0.25MPa/s. The stress and strain were noted with respect to time upto the cracking pf the sample to obtain the stress strain curves.

Figure 14: Stress Strain Dial attached along with compression

CHAPTER 6

RESULTS AND CONCLUSIONS

6.1 Results

6.1.1 Compressive Strength

The compressive strength of the structural lightweight high strength concrete had to exceed the 6000 psi mark. The results of both the concrete made with inclusion of silica fumes and exclusion of silica fumes are shown in Figure

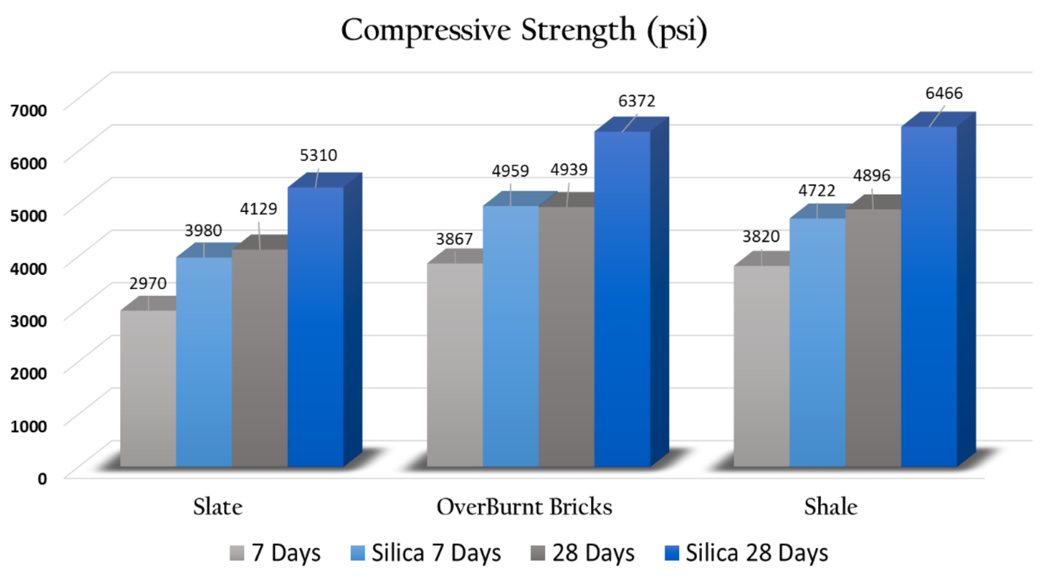


Figure 15: Compressive Strength of different mixes

Shale has endured the highest load whereas slate seemed to be the weakest of the three aggregates. The compressive strength of the concrete mainly depended upon the strength of the aggregate. It can be identified from the results that the stronger aggregates like expanded shale and bricks have given more strength than the weaker aggregate expanded slate.

Concrete made from expanded shale and over burnt bricks managed to exceed 6000 psi and attain high strengths. Without the use of silica fumes all of the aggregates were unable to reach the design strength. It is observed that there is a significant increase in the compressive strength after silica is added in the mix. There is 32.06% increase in strength for expanded shale, a 29.01% increase for over burnt bricks and a 28.69% increase has been shown for expanded slate. Hence it can be inferred that the highest percentage increase has been shown for expanded shale. This further consolidates the notion that the concrete is being cracked through the aggregate. Therefore expanded slate showed little increase in strength than over burnt bricks and expanded shale.

6.1.2 Splitting Tensile Strength

The tensile strength of the concrete was checked to see its behavior in tension. Cylinder specimens of 6” by 12” were used for this test. The results have been displayed in Figure including the strengths for both concrete with silica fumes and concrete without silica fumes.

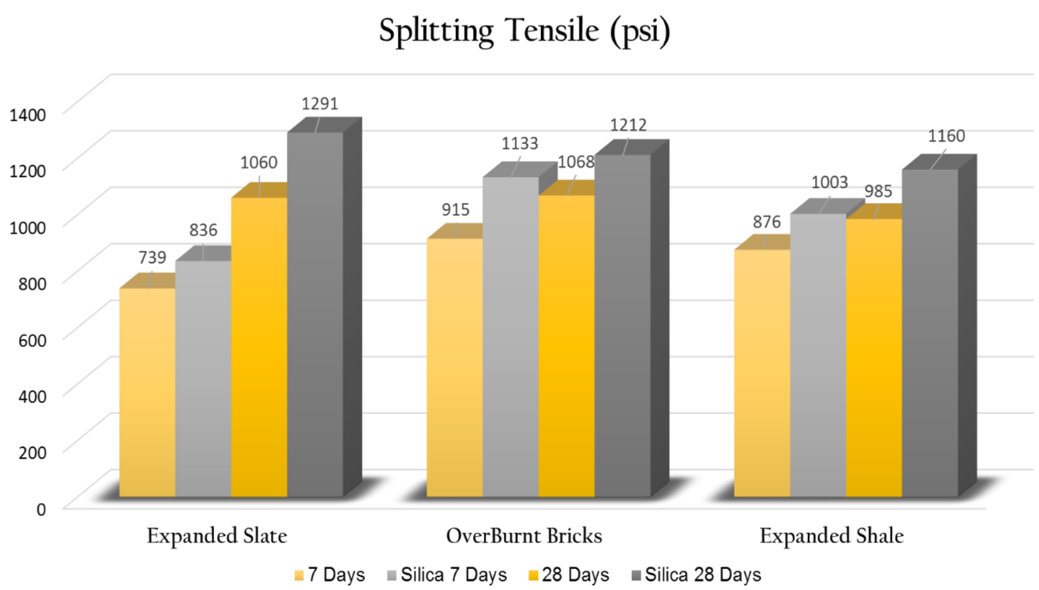


Figure 16: Splitting Tensile Strength of different mixes

An increase in tensile strength is also observed with the addition of silica albeit the difference is little as compared to compressive strength. An increase of only 21.79%

for expanded slate, 13.48% for over burnt bricks and only 17.76% for expanded shale. The tensile behavior was the best for expanded slate. While expanded shale had the least strength in this case. But tensile strength of all the aggregates with silica fumes .was almost same

Whereas there was a difference in the trend in case of lightweight concrete constructed without the addition of silica fumes. Over burnt bricks had got the highest strength whereas expanded slate came in second with expanded shale being the lowest in strength.

6.1.3 Stress Strain Curves

The stress strain behavior of all the mixtures was also studied. After constructing the stress strain graph, the curves were analyzed. Figure displays stress strain curves of the lightweight concrete made without adding silica fumes. Whereas Figure demonstrates the behavior of the lightweight concrete made by the addition of silica.

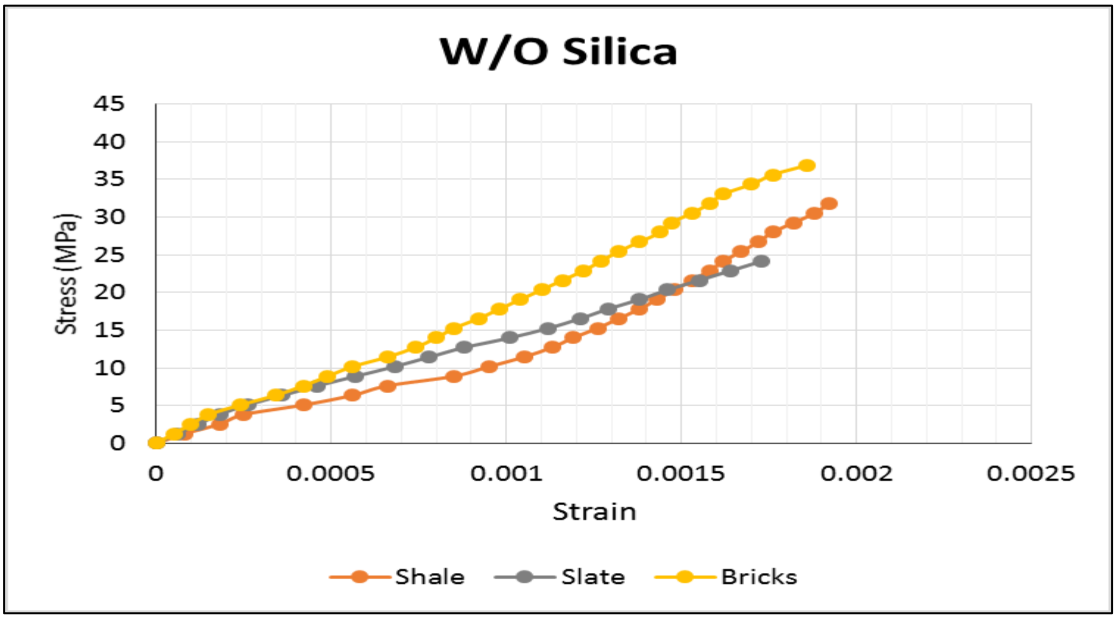


Figure 17: Stress Strain Behavior of mixes without silica

Corresponding to Figure, the curves of all three aggregates show a ductile behavior. Expanded Slate has taken the least strain out of the three because of the low strength of its aggregate. Whereas highest amount of strain has been endured by the expanded shale as its aggregate was more resilient. The most ductility can be observed by the curve of expanded shale. However in this case bricks have resisted the most load.

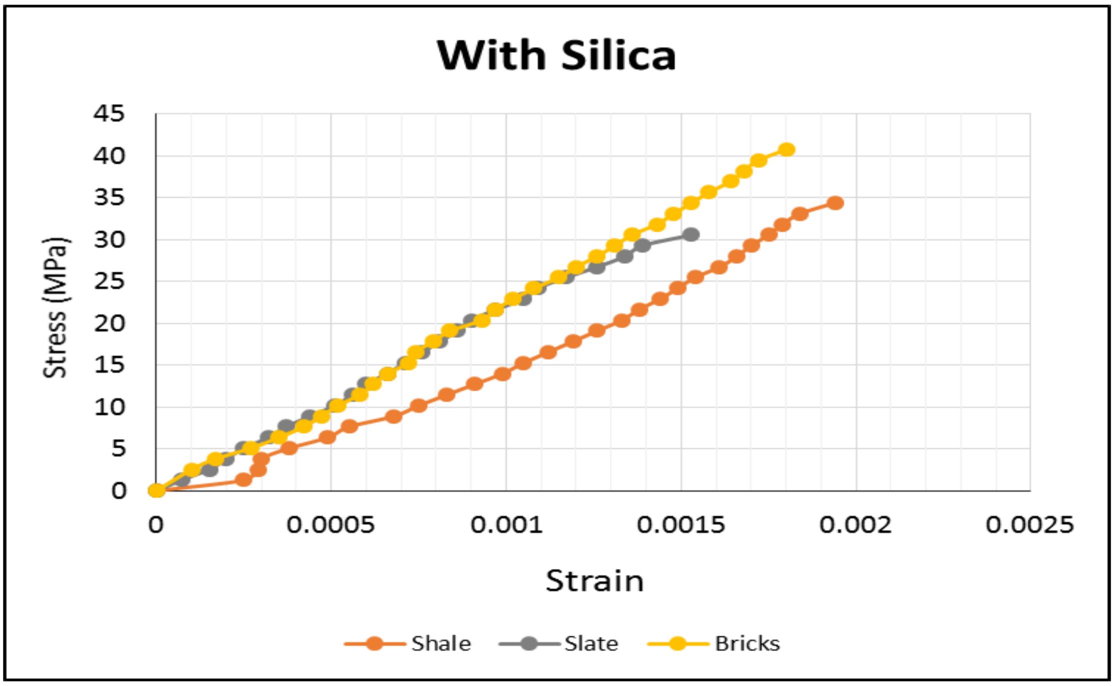


Figure 18: Stress Strain Behavior of mixes with silica

When silica was added in the concrete, its strength has indeed increased but the behavior has tended to be more brittle than that of normal lightweight concrete. The trend of strain has remained the same as expanded shale has still the highest strain and expanded slate experienced the lowest strain. Brick has almost a brittle behavior as a linear curve can be observed in the graph. Expanded slate has relatively more ductility.

6.1.4 Compressive Strength vs Density

The main crux of our research was to maintain the goals set by us for the Structural Lightweight High Strength Concrete. The goal was to achieve a strength exceeding 6000 psi while maintaining the unit weight of the concrete produced less than 120 pounds per cubic feet. The highest individual strength was achieved by over burnt bricks at 7447 psi at 121 pcf. The lowest density was observed by slate in terms of both with and without silica.

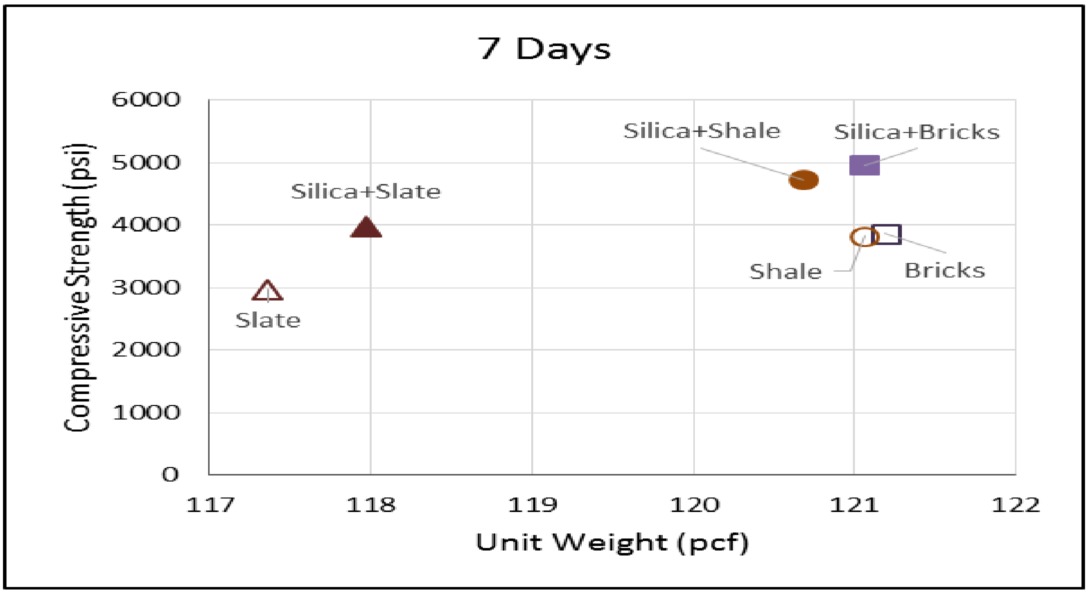


Figure 19: Density vs Compressive Strength 7 days

Expanded slate remained under the limit of 120 pcf whereas shale and bricks n\both crossed it by approximately 1 pounds per cubic feet. This is attributed to the density of the aggregate as it was not light enough but the counterpart was that they gave higher strength and exceeded the 6000 psi mark.

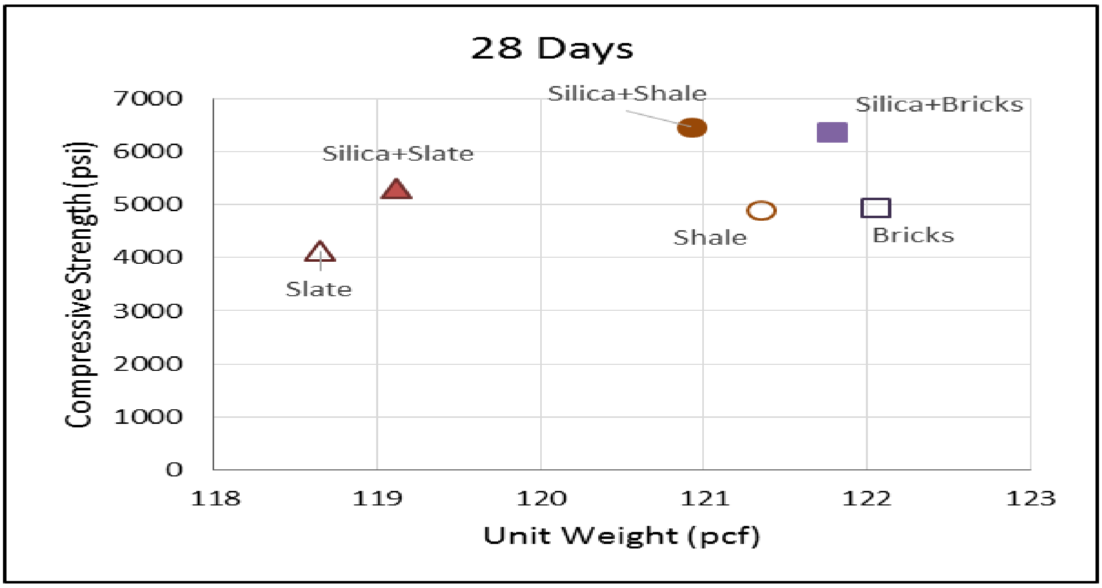


Figure 20: Density vs Compressive Strength 28 days

6.2 Conclusions

- SLWHSC made from:
  - Slate has 20.60 % less dead weight from normal weight concrete.
  - Bricks has 18.81 % less dead weight from normal weight concrete.
  - Shale has 19.39 % less dead weight from normal weight concrete.
- Addition of Silica (supplementary cementitious material) not only increases strength by 20-25% but also reduces the density. So 10% of Silica Fumes
- Structural Light Weight High Strength Concrete made with Expanded Slate proved to be the lightest with a density of 117 pcf and a compressive strength of 5400 psi
- SLWHSC made using Expanded Shale had the highest compressive strength 7266 psi and a density of 120.3 pcf
- But Over Burnt Brick is the most viable solution in term of cost and compressive strength with a maximum value of 7106 psi.

- Conversely Slate has yielded the highest Splitting tensile strength at 1291 psi and Shale has the lowest at 1160 psi.
- Over burnt bricks weighted slightly over threshold of 120lb/ft3, because the aggregate used was too burnt which in turn increased its Specific Gravity.
- SLWHSC is a viable solution to reduce traditional dead loads on a structure and Pakistan has the potential to produce SLWHSC using local materials as aggregates.

6.3 Recommendations

- The reasons behind the increase in tensile strength should be studied.
- Study to further decrease the weight of SLWHSC should be carried out
- Exploration of naturally occurring light weight aggregates available in Balochistan near Qila Saif ullah.
- Detailed cost comparison of structures designed using SLWHSC.

APPENDICES

ANNEXURE A

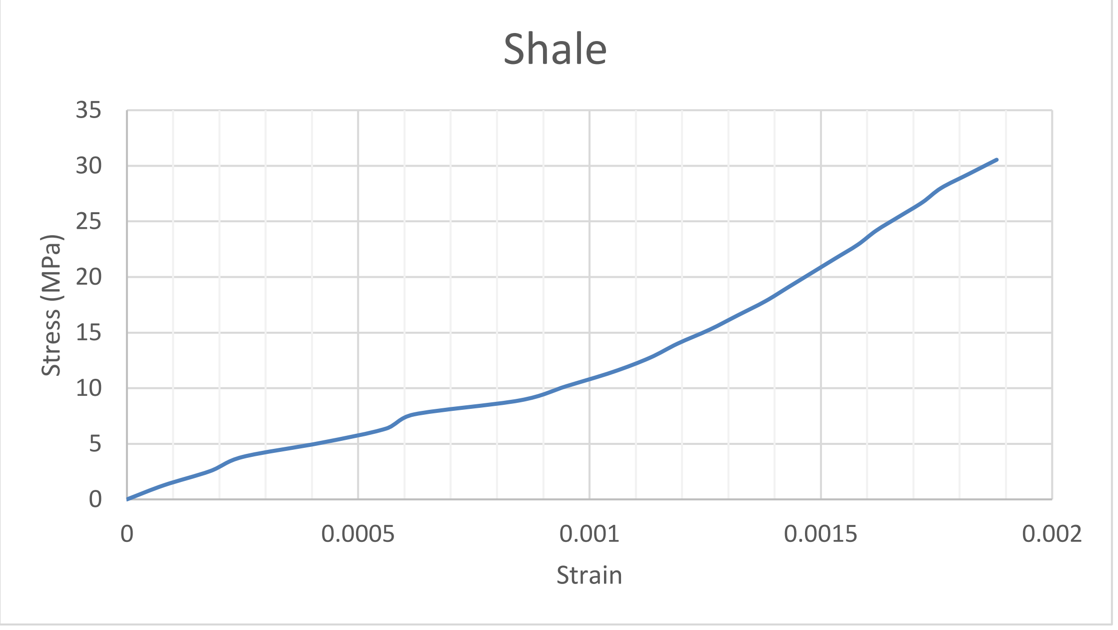
Compressive Strength					
Aggregate Used	Sample	Density (lb./ft^3)	7 days (psi)	Density (lb./ft^3)	28 days (psi)
Slate	1	118.06	3089	118.06	4012
	2	116.97	2937	118.81	4159
	3	117.06	2885	119.07	4216
Slate with Silica	1	117.43	3930	118.81	5453
	2	118.55	3815	119.43	5120
	3	117.93	4195	119.11	5357
Bricks	1	121.36	3872	122.11	5002
	2	120.89	3798	122.32	4954
	3	121.32	3931	121.72	4862
Bricks with Silica	1	121.53	4986	121.9	5912
	2	121.05	5018	121.38	6097
	3	121.6	4873	122.06	7447
Shale	1	121.22	3856	121.93	4756
	2	120.53	3987	121.32	5045
	3	121.42	3617	120.79	4888
Shale with Silica	1	120.18	4702	120.86	6228
	2	121.56	4895	120.32	5903
	3	120.3	4570	121.58	7266

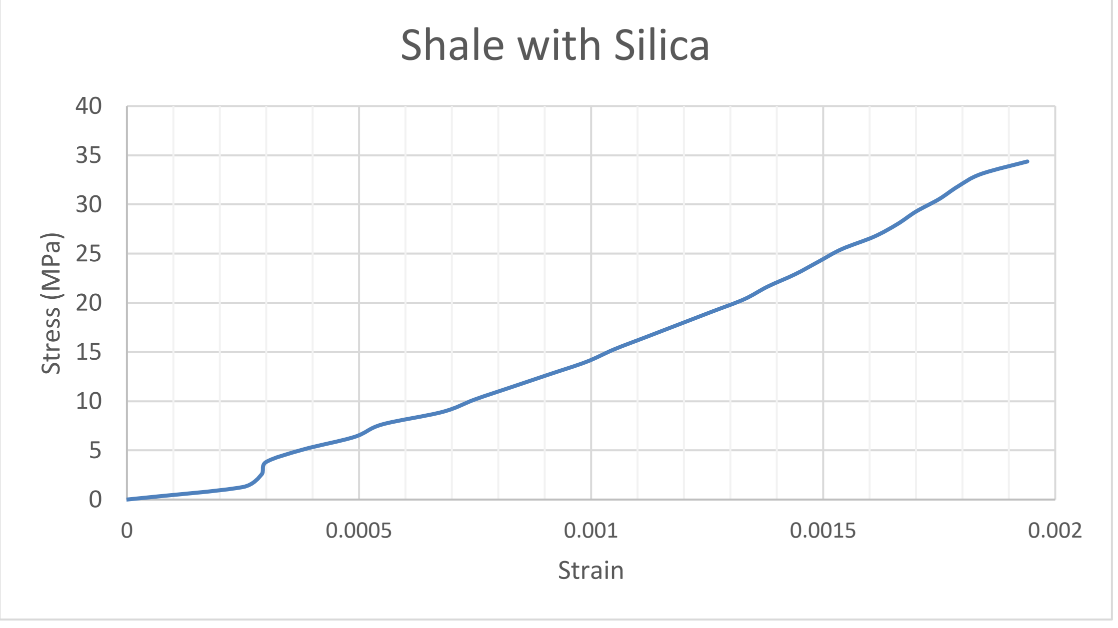
Splitting Tensile					
Aggregate Used	Sample	Density (lb./ft^3)	7 days (psi)	Density (lb./ft^3)	28 days (psi)
Slate	1	119.56	770	119.72	1100
	2	118.81	708	119.42	1021
Slate with Silica	1	116.56	865	116.77	1308
	2	116.56	808	117.01	1274
Bricks	1	121.4	859	121.57	993
	2	122.03	972	121.89	1008
Bricks with Silica	1	120.8	1107	121.28	1242
	2	121.18	1159	121.67	1183
Shale	1	120.56	890	120.83	975
	2	121.8	863	122.11	995
Shale with Silica	1	120.18	949	121.64	1143
	2	121.65	1057	122.13	1178

ANNEXURE B

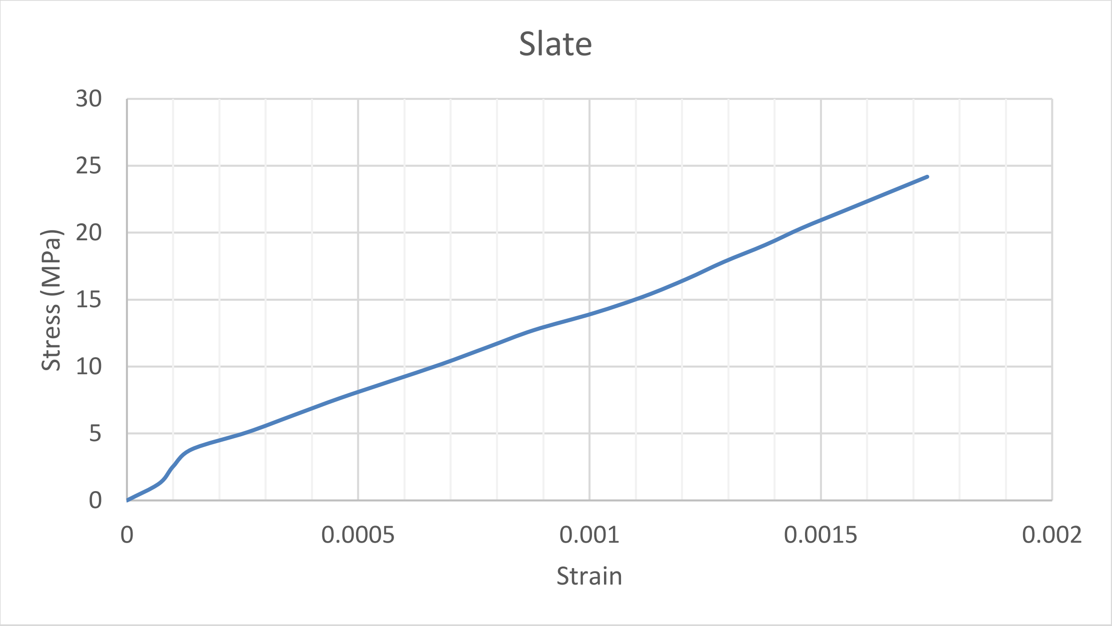
Stress Strain Curves:

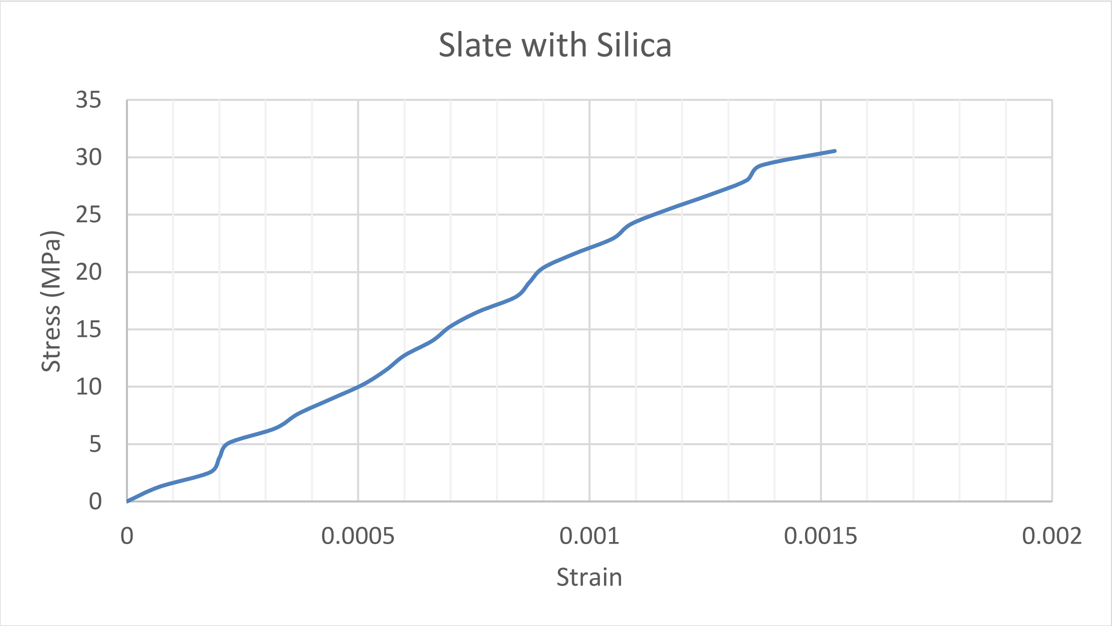
Expanded Shale:



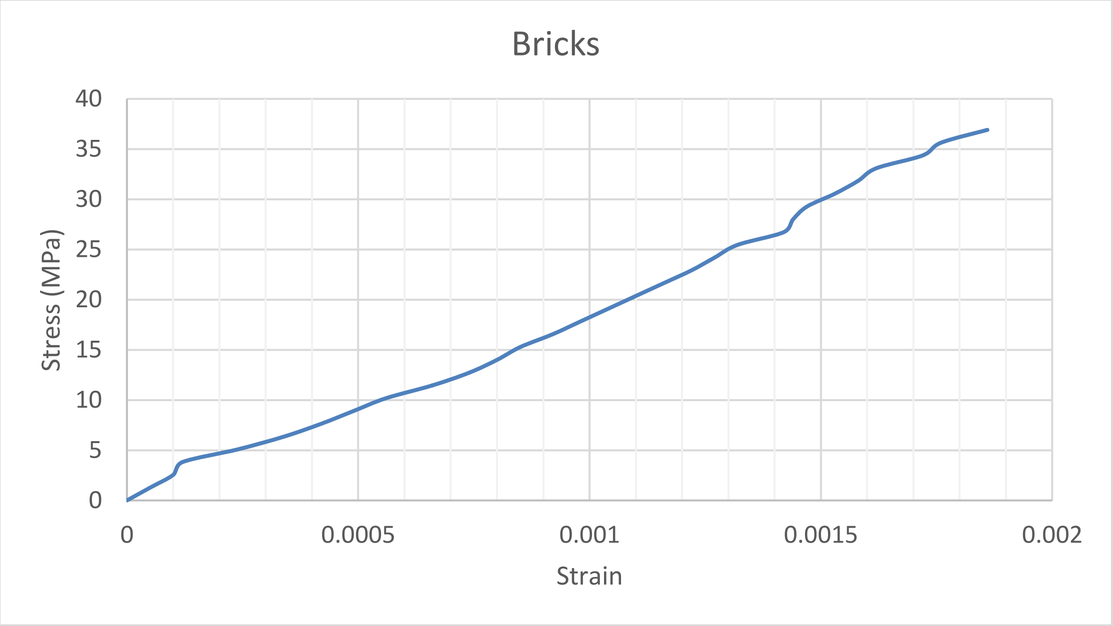


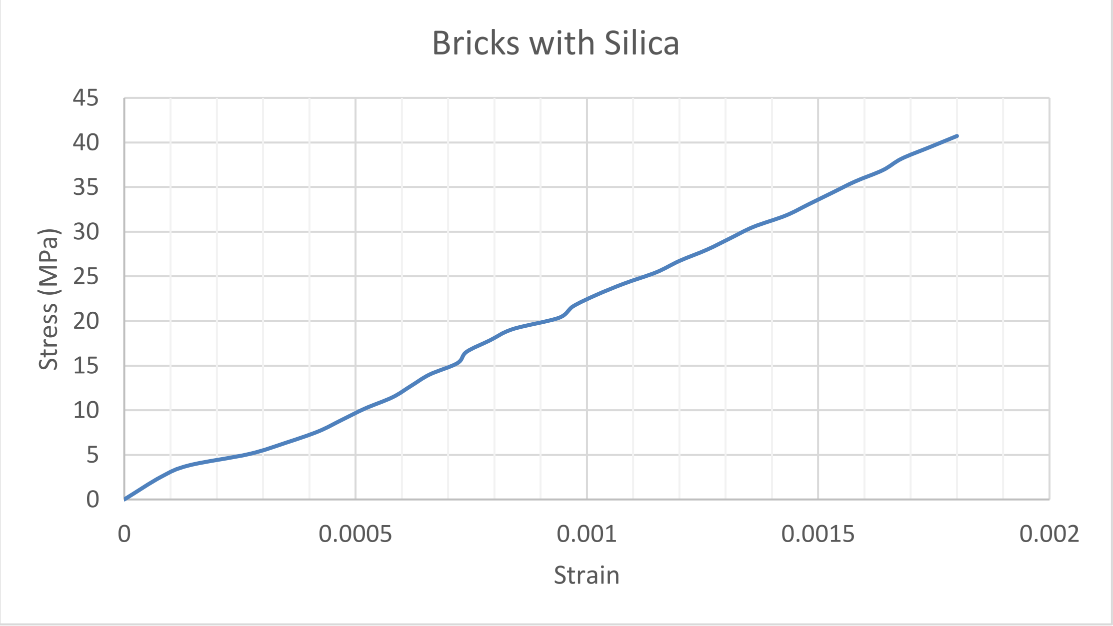
Expanded Slate:





Over Burnt Bricks:





ANNEXTURE C

Internal Matrix of Specimens:

Expanded Slate

Expanded Shale

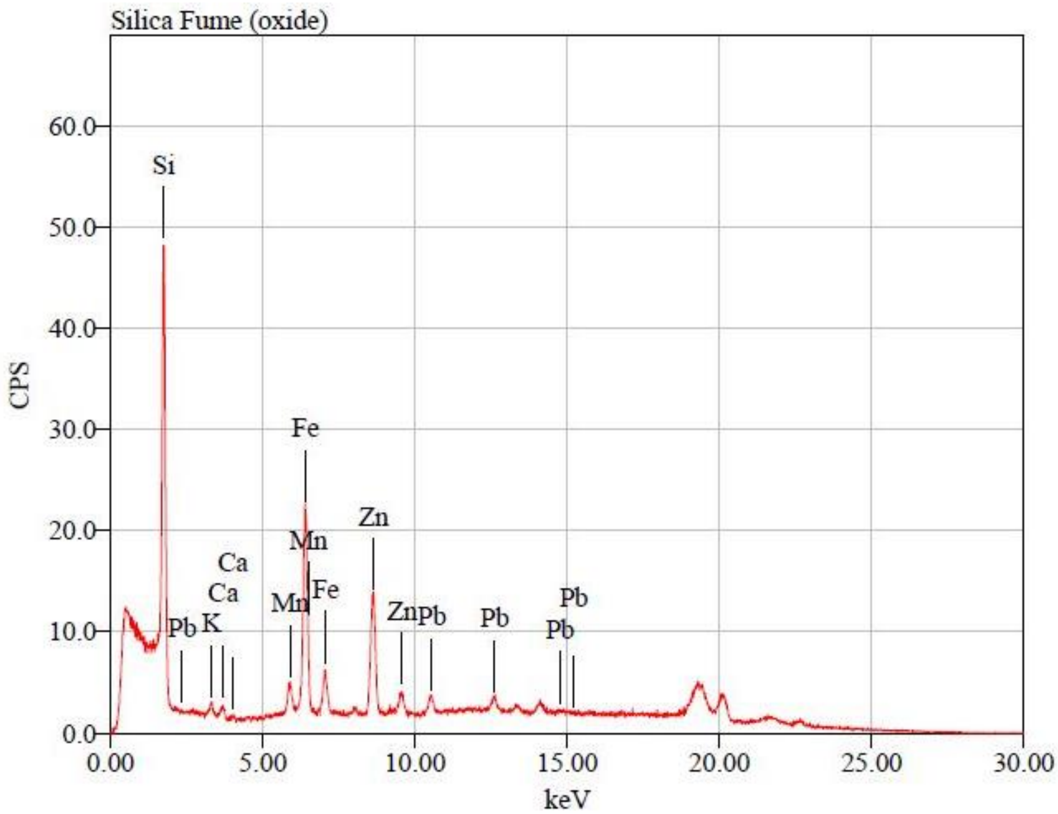
Over Burnt Bricks

Margalla Crush (Gravel)

ANNEXURE D

XRF Results:

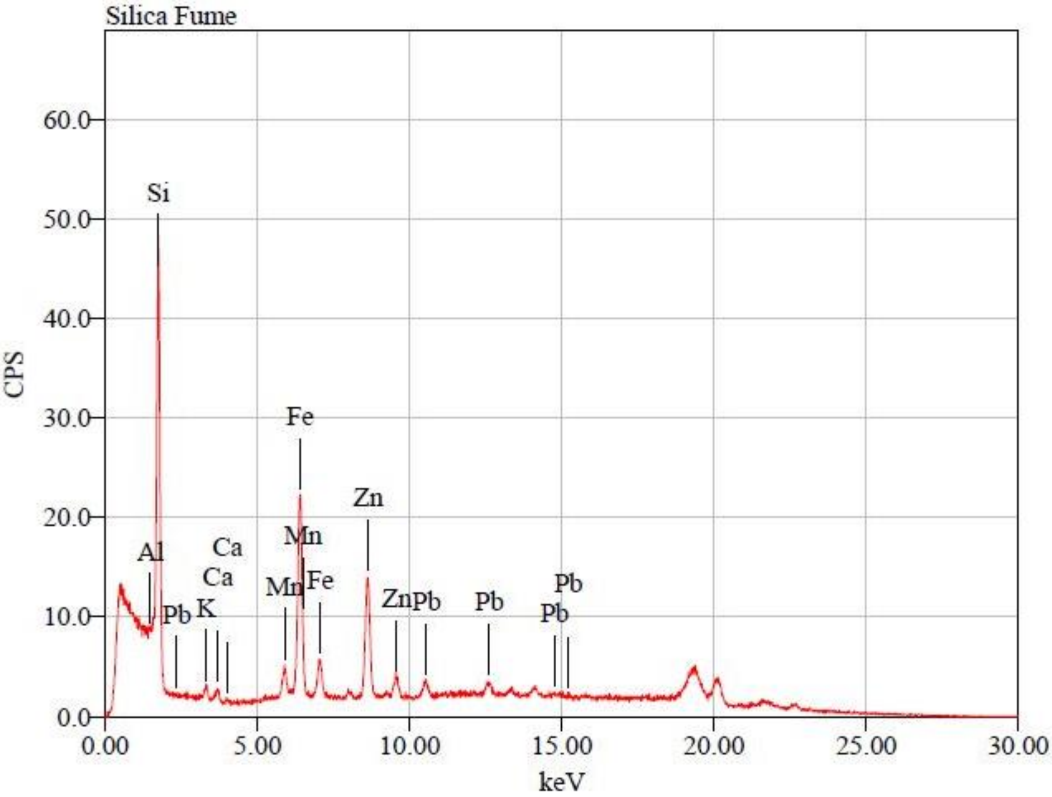
1. **XRF (X-RAY Fluorescence) for Silica Fumes (Oxides)**



Quantitative result

Element	ms%	mol%	Sigma	Intensity	K ratio	Line	Type
14 SiO2	81.8995	89.2001	0.4773	33183	0.0134265	K	
19 K2O	1.4118	0.9807	0.2261	1006	0.0004731	K	
20 CaO	1.2363	1.4427	0.1854	1126	0.0004127	K	
25 MnO	1.1770	1.0858	0.0510	3237	0.0007419	K	
26 Fe2O3	8.3268	3.4123	0.0524	24477	0.0050975	K	
30 ZnO	4.1764	3.3588	0.0473	16552	0.0033600	K	
82 PbO	1.7722	0.5196	0.1202	5378	0.0034944	L	

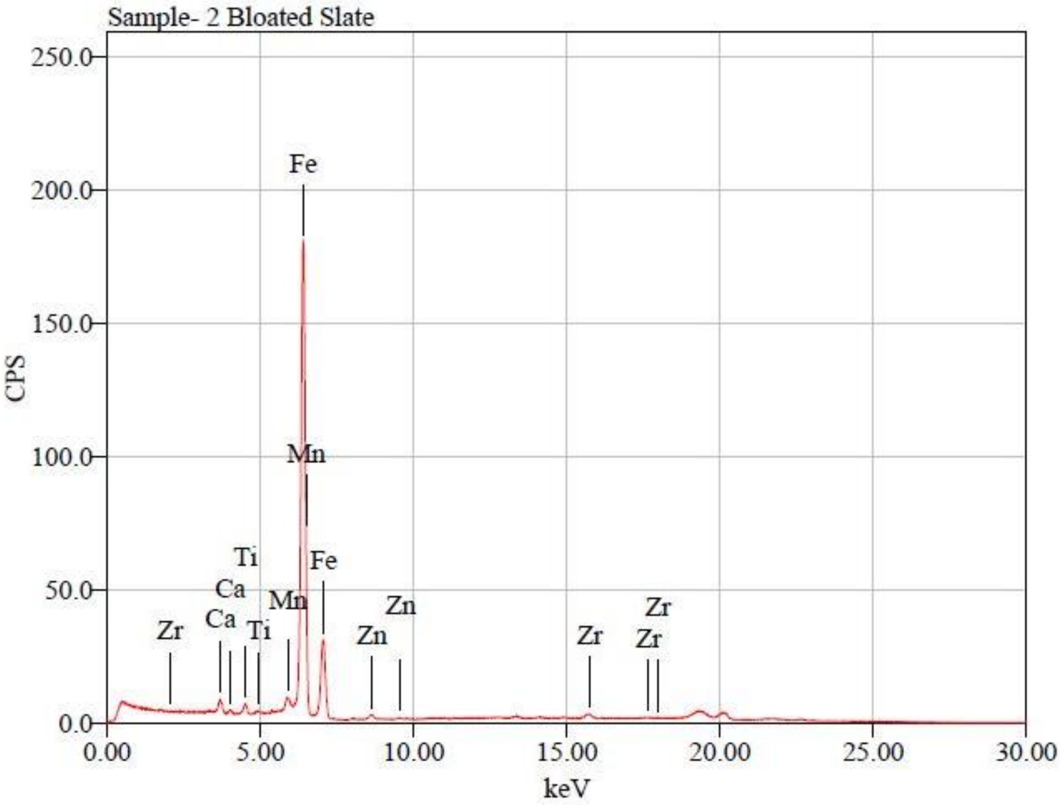
2. XRF for Silica Fumes (Elements)



Quantitative result

Element	ms%	mol%	Sigma	Intensity	K ratio	Line	Type
13 Al	nd					K	
14 Si	64.9582	79.7205	0.3703	31728	0.0128553	K	
19 K	3.1540	2.7803	0.3831	1241	0.0005841	K	
20 Ca	1.9445	1.6723	0.2781	1104	0.0004052	K	
25 Mn	2.0948	1.3143	0.0888	3094	0.0007101	K	
26 Fe	14.4017	8.8887	0.0839	24728	0.0051568	K	
30 Zn	9.3838	4.9479	0.0986	16678	0.0033903	K	
82 Pb	4.0630	0.6759	0.3092	4483	0.0029166	L	

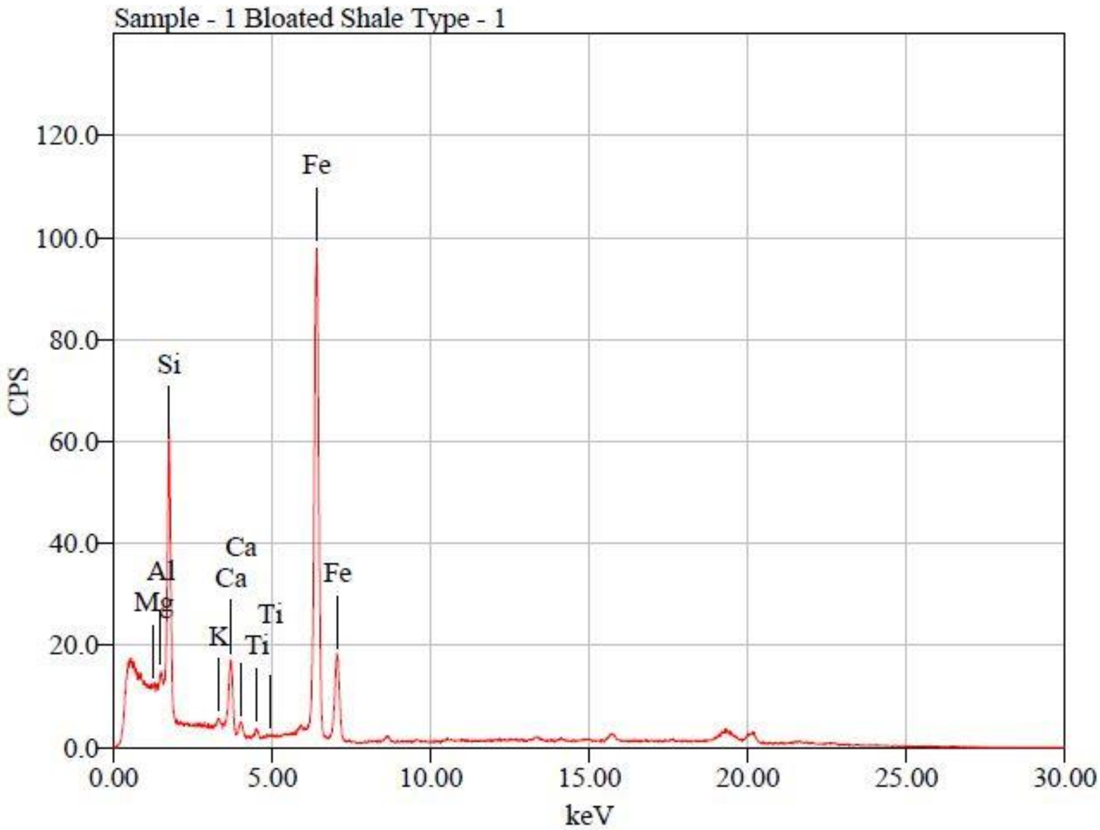
3. XRF for Bloated Slate



Quantitative result

Element	ms%	mol%	Sigma	Intensity	K ratio	Line	Type
20 Ca	4.9524	6.7974	0.1733	4916	0.0035498	K	
22 Ti	2.0276	2.3286	0.0640	3965	0.0017142	K	
25 Mn	2.1751	2.1780	0.0573	5195	0.0015142	K	
26 Fe	87.7859	86.4730	0.0643	205445	0.0521181	K	
30 Zn	1.5858	1.3345	0.1306	2134	0.0005068	K	
40 Zr	1.4732	0.8884	0.1897	2763	0.0011335	K	

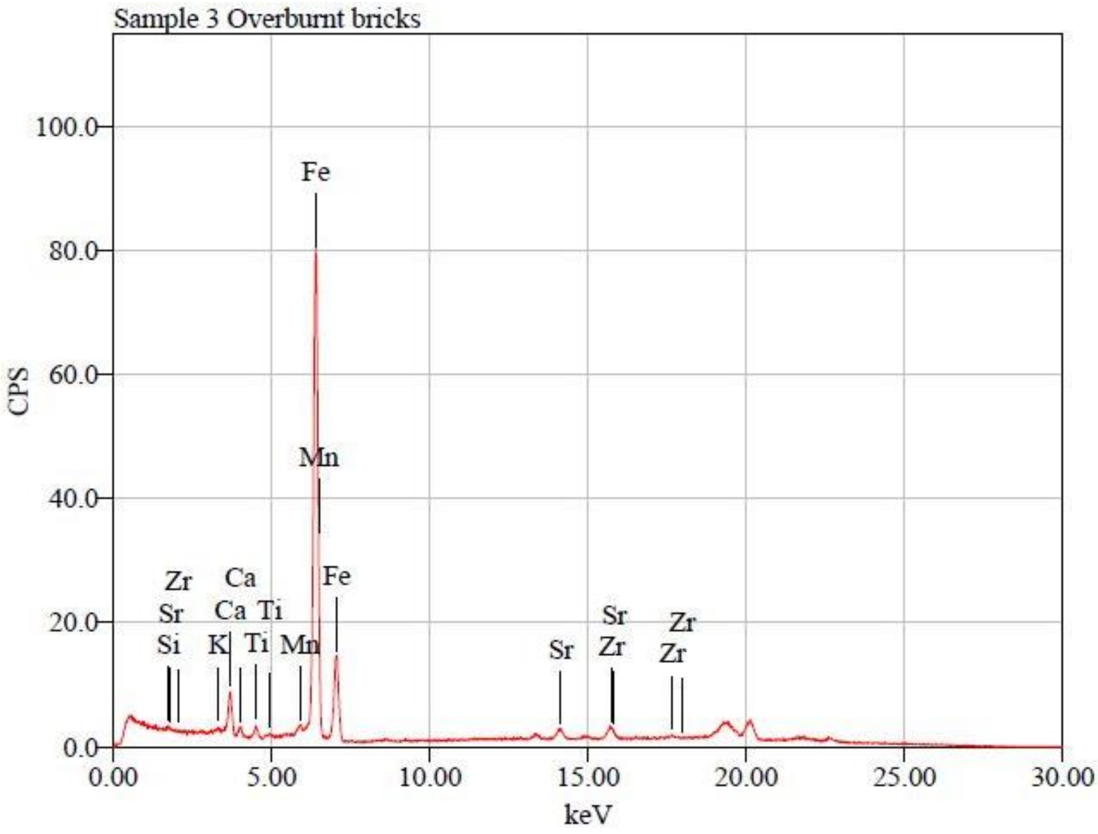
4. XRF for Bloated Shale



Quantitative result

Element	ms%	mol%	Sigma	Intensity	K ratio	Line	Type
12 Mg	3.2994	4.8547	2.1540	421	0.0007315	K	
13 Al	3.7217	4.9341	0.2917	1458	0.0011550	K	
14 Si	43.8611	55.8638	0.2879	39281	0.0165187	K	
19 K	1.3380	1.2241	0.2164	1317	0.0006434	K	
20 Ca	9.6012	8.5692	0.1578	13572	0.0051715	K	
22 Ti	0.9370	0.6998	0.0884	1783	0.0005227	K	
26 Fe	37.2415	23.8544	0.0678	111736	0.0241844	K	

5. XRF for Over Burnt Bricks



Quantitative result

Element	ms%	mol%	Sigma	Intensity	K ratio	Line	Type
14 Si	62.2772	75.0926	31.6426	387	0.0260505	K	
19 K	1.0413	0.9018	0.2607	473	0.0005181	K	
20 Ca	7.9186	6.6908	0.1299	7106	0.0046508	K	
22 Ti	1.0917	0.7718	0.0473	1957	0.0007669	K	
25 Mn	0.5393	0.3324	0.0282	1776	0.0004692	K	
26 Fe	26.0717	15.8099	0.0264	100526	0.0231136	K	
38 Sr	0.4656	0.1799	0.0348	2582	0.0008502	K	
40 Zr	0.5946	0.2208	0.0418	3435	0.0012769	K	

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