COMPACTION AND STRENGTH CHARACTERISTICS OF LIME ACTIVATED FLYASH WITH GGBS AS AN ADMIXTURE

A Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of

Master of Technology

In

Civil Engineering

(Geotechnical Engineering)

Devansh Nema

DEPARTMENT OF CIVIL ENGINEERING

NATIONAL INSTITUTE OF TECHNOLOGY, ROURKELA

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Under the guidance and supervision of

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Submitted by

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CERTIFICATE

This is to certify that the project entitled "***Compaction and Strength Characteristics of Lime activated Flyash with GGBS as an Admixture***" submitted by Mr. Devansh Nema (Roll No. 215CE1265) in partial fulfillment of the requirements for the award of Master of Technology Degree in Civil Engineering at NIT Rourkela is an authentic work carried out by him under my supervision and guidance.

To the best of my knowledge, the matter embodied in this report has not been submitted to any other university/institute for the award of any degree or diploma.

Place: Rourkela

Date:

Prof. Suresh Prasad Singh

Department of Civil Engineering

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Devansh Nema

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LIST OF SYMBOLS

Notation	*Description*
E	*Compaction Energy, kJ/m3*
OMC	*Optimum Moisture Content, %*
MDD	*Maximum Dry Density, kN/m3;*
UCS	*Unconfined Compressive Strength, kN/m3*
FS	*Failure Strain, %*
MC	*Moisture Content, %*
CBR	*California Bearing Ratio, %*
Cu	*Coefficient of uniformity*
Cc	*Coefficient of uniformity*
G	*Specific Gravity*
k	*Coefficient of permeability, cm/sec*

Abstract

A very fine by-product generated through coal combustion process at thermal power plants is known as flyash and a part of ash falls down at the bottom of the boiler is known as bottom ash. Out of the total production of waste material flyash generated is approximately 80% whereas bottom ash generated is 20% (by weight of total generated waste).

In India, the total production of flyash was 184.14MT in the year of 2014-2015. Out of which total utilization of flyash was 102.59MT or 60.94% and in the year of 2015-16, the production of flyash was 176.74MT. Out of which total utilization of flyash was 107.77MT or 60.97%. Here it can be seen that the production and utilization both are increasing but there is still 40% of flyash that producing as a waste.

The flyash that remained unused will deposited as landfills and brings environmental problems. From these landfills, some of the heavy metals like mercury, cadmium and boron and the very fine particles of flyash leach to groundwater and cause the ground water contamination. And also unused flyash is the major cause of air pollution.

In the present study, a try has been made for effective utilization of flyash as a geoengineering material. Material that has been used in the study was class-F flyash and brought up from Adhunik Metaliks Limited, Sundergarh. The geotechnical properties like specific gravity, OMC, MDD, and UCS strength has been evaluated, of this virgin flyash.

To enhance the properties of the flyash, it was mixed with lime and slag at different proportion. Lime was mixed with flyash at 0%, 2%, 4%, 8% and 12% whereas slag

was mixed at 0%, 5%, 10%, 15%, and 20%. A number of combinations of flyash, lime, and slag have been made for testing. The light compaction test has been done to determine the OMC and MDD of different mixes of flyash-GGBS-lime. In total 25 numbers of compaction test has been conducted to find out the OMC and MDD of the above mixes. Further UCS test has been done with different combinations of flyash-GGBS-lime compacted to their respective MDD at OMC. These samples were cured under an average temperature of 28ºC with samples sealed in wax for curing periods of 0, 7, 14 and 28 days and the UCS values were determined.

In the hydrometer analysis, it was found that the flyash particles are uniformly graded and the size of the particles lies between fine sand to silt size. The MDD determined was low at higher OMC. After treatment of flyash with lime and slag, the OMC reduced and MDD increased. The UCS determined for virgin flyash was very less and when treated with lime, it increased immediately marginally. UCS for the lime treated flyash samples were increased with increase in curing period. UCS for the slag-treated flyash samples was very low when tested immediately and with increasing curing periods the UCS values increased up to some extent. The strength of flyash treated with lime and slag was found to be highest when cured for 28 days of curing period.

At a given curing period flyash samples mixed with slag and lime shows a higher UCS value then flyash treated with the same percentage of lime without slag. This indicates a defiant advantage in adding slag to flyash. Slag which is rich in pozzolanic material like silica and alumina and it also contains a substantial amount of lime. However GGBS possess latent hydraulic properties which have to be activated by an alkali environment, here lime has used to provide an alkali environment to initiate the pozzolanic reaction of slag.

1 Introduction

1.1 General

Flyash is generated from coal combustion process as a by-product and it is a material having properties nearly same as in volcanic ash. When coal is burning at thermal power plants the temperature reaches to 2800F. In this temperature, the non-combustible minerals that are formed due to combustion of coal are bottom ash and flyash. The flyash is carried out with flue gasses and collected whereas the bottom ash is light in weight and falls bottom at the boiler.

In India, the production of flyash was around 176.74MT in the year of 2015-16. And the utilization was 107.77MT or 60.97%. The rest of waste is dumped into the ground which will cause the environmental issues either in the form of polluting the air or contaminating the ground water.

1.2 Properties of Flyash

Fly is a fine product produced from coal combustion at power plants. It is also known as pulverized fuel ash. Its particle size generally ranges from fine sand to silt size. Silica is the main constituent followed by alumina and ferrous oxide.

The pozzolanic activity of flyash is described as the reaction of $Ca(OH)_2$ with the main components of flyash. When SiO_2 and Al_2O_3 present in flyash, coming contact with the $Ca(OH)_2$ then it forms CSH and CAH. The main pozzolanic reaction will take place between $Ca(OH)_2$ and SiO_2, but reaction between Al_2O_3 and $Ca(OH)_2$ will also be considerable.

1.3 Classification of Fly Ash

In the thermal power plant when the coal is burnt, the non-combustible mineral from the coal is collected from the combustion air stream, which is called flyash.

Pozzolan is defined as the material which contains minerals like siliceous or siliceous and aluminous material, which shows little or no cementing properties. But when it comes in contact with calcium hydroxide at normal temperature then they form the compounds that possess cementing properties.

Generally, the flyash is classified into two types: lass-C flyash and class-F flyash.

The most of the flyash formed from the combustion of coal process is class-F flyash. It mostly contains silica, alumina, and iron greater than 70% and a very less amount of lime mostly under 15%. As class-F flyash contains a lesser amount of lime, so to possess the pozzolanic activity additional amount of lime is required.

class-C flyash naturally contains a higher amount of lime usually more than 30%. So it naturally shows pozzolanic activity without any requirement of an additional amount of lime.

1.4 Strength Characteristics of Flyash

In the present study, class-F flyash was used. The flyash has been brought from Adhunik Metaliks Limited, Sundergarh. To check the suitability of flyash as a construction material, its properties like consistency, strength and settlement parameters should be tested. In the project, an attempt was made to compare such properties of flyash, stabilized with lime and slag in proper proportion to the virgin flyash.

The project work was divided into two phases, in the first phase, the physical and chemical properties of flyash were determined by hydrometer analysis, standard Proctor test, and UCS test. In the second phase, the flyash was mixed with lime and slag at different proportion and a number of combinations were made. These combinations were gone through light compaction test and OMC and MDD were determined. UCS has been done with 0, 7, 14 and 28 days of delay to study the effect of curing.

1.5 Lime an Overview

Lime is an alkaline material which formed by heating of limestone. It is an inorganic material which contains carbonates, hydroxides, and oxides as major constituents. When limestone is heated at a very high temperature than quicklime is formed and when water is added to the quicklime than slaked lime is formed and when this slaked lime reacts with carbonates than again limestone is formed. Cycle for the formation of lime is as shown-

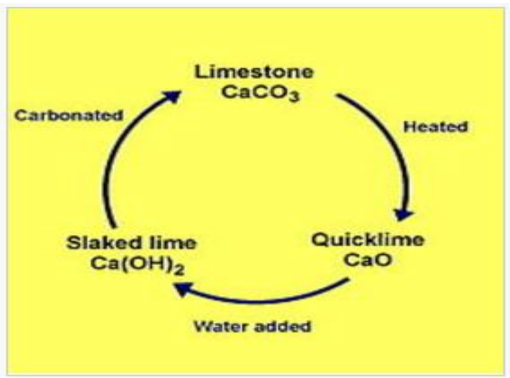

Fig.1.Lime cycle

Lime is one of the most important construction materials which has been using since very old time. In many of the Indian ancient infrastructures lime was used as a building material. Lime has also been using in geotechnical engineering work. It is mainly used as a stabilizer for soil. Its necessity as a stabilizer is because it is having pozzolanic properties. When lime is used as a stabilizer than a pozzolanic reaction will take place. And as the time passes the soil gained strength. In the present study, lime was used as the main stabilizer for flyash but as the lime is an expensive material, so in the study different proportion of lime and slag was used as a stabilizer.

1.6 Slag an Overview

GGBS is a by-product produced from the manufacturing process of iron. It is obtained by quenching the molten iron blast furnace slag in water or stream immediately. A glassy granular product formed which then dried and ground into a fine powder. There are mainly three types of slag present on the basis of different production techniques.

1. Slag produced from traditional ball mill.
2. Slag produced from high-pressure roller press.
3. Vertical roller press.

GGBS produced from the modern vertical mill will be having high fineness, nicely distributed particle size, high activity index, very less variation in the quantity as compare to the traditional ball mill slag.

The mineralogical composition of slag varies on the basis of the composition of raw material in the production of iron. Slag is a very less viscous material which contains aluminates and silicate impurities from ore and coke. The main components of GGBS are CaO, SiO_2, Al_2O_3, and MgO. In which on increasing the composition of CaO the compressive strength of slag increases. The MgO and Al_2O_3, also give the strength to some extent.

Similar to Cement, Slag is having lime and silica as the main components so it can effectively use in place of cement in making of concrete. Production of cement causes environmental issues and also lime is one of the main constituents in the production of cement which is going to be vanishes one day. So slag is the best option to replace it, but the ultimate strength of slag concrete is not as much as of cement concrete so slag can be used as a partial replacement of cement which can lower the amount of cement production.

In geotechnical project works lime stabilization is a very well known technique. Slag is also rich in lime, so slag can be used as the replacement of lime but GGBS cannot use directly as a stabilizer because of its latent heat property so to activate it any alkaline material is required. In the present study, class-F flyash stabilized by lime and GGBS with different proportion. Lime has been used as an activator and a different combination of lime and GGBS has been made and tested to determine required physical and chemical properties of mixtures.

2 Literature Review

2.1 Introduction

The literature review is presented in this sections included an overview of treatment procedures that are available for stabilizing flyash along with a detailed review on stabilization with lime also it include stabilization of expansive soil using lime and some study made on slag as a construction material.

2.2 Literature on Flyash

Al-Rawas *et al.* (2003) stated that Industrial products such as cement, lime, furnace slag and cement by-pass dust (CBPD) can be effectively used for stabilization of Flyash. Among the following, the stabilization with furnace slag requires any activator such as lime.

Hardjito *et al.* (2004) investigate the compressive strength of geopolymer concrete using flyash. The tests conducted are based on curing time, curing temperature, the quantity of superplasticizer. In the test, it is stated that at a higher temperature and longer curing period the compressive strength found to be higher and also it is stated that the workability of fresh geopolymer concrete can be increased by adding naphthalene based superplasticizers. And also it is stated that there is a very little difference in the specimen which is tested immediately and tested after 60 minutes of curing period.

Kim *et al.* (2005) used the industrial waste like class-F flyash and bottom ash as a construction material. It will be an economic alternative to the use of traditional material. The materials are collected from Indiana and tested for compaction, permeability, strength, stiffness, and compressibility. The mixtures of flyash and bottom ash are used in the ratio of 50, 75, and 100 (flyash to bottom ash by weight). After the test, it is found that specific gravity of flyash and bottom ash are varied to plant to plant and the maximum dry density was found to be lower than conventional geoengineering material.

Phanikumar *et al.* (2007) investigate the swelling behavior of expansive soil can be reduced by using flyash. It will also increase maximum dry density (MDD) and reduce optimum moisture content (OMC).

Reddy and Gaurav (2011) investigate that the compressive strength of flyash can be increased by using additives such as lime and gypsum And also stated that the compressive strength can be increased under steam curing condition than normal wet curing condition.

Chithiraputhiran (2012) use flyash, in place of Ordinary Portland Cement and an attempt has been made to geopolymerise it with alkali activated aluminosilicates. In the paper, alkali activated flyash blended system has discussed. In this paper optimal binder and n-values are selected on the basis of setting times. It was stated that at early as well as later ages a very high compressive strength can be obtained and the compressive strength decreased when there is an increase in flyash content.

Rajesh *et al.* (2013) stated that alkali-activated slag (AAS) can be used as a cement and as sole binder in producing concrete. To activate slag, alkali activator was used at 4% Na_2O (by weight of slag) and 4% hydrated lime by total weight of the solid binder was used as retarded. In this paper, four mixes are compared- normal OPC and 3-alkali activated slag with same binder content. The delay properties were checked.

The compressive strength was measured in 1, 7 and 28 days. The split tensile strength was measured in 7 and 28 days and flexure, shear and punching were tested in 12 days. The alkali activated slag is found to be achieving good workability as compare with that of conventional OPC.

Pani (2014) used flyash as a geoengineering material for its effective utilization. for the investigation, class-F flyash has been used. Lime was used as the main stabilizer, and it was added to flyash at 2%, 4%, 8% and 12% by weight. The different mixtures have been tested for standard proctor test, modified proctor test, permeability test, UCS test, and CBR test. The effect of curing temperature has also been recorded and the UCS test has been done for 10º, 25º, 45º and 90º with different curing periods of 7, 15, 30 and 60 days. The UCS samples were coated with wax and for higher temperature, it was sealed with heat resistant polyethylene cover to retain water, and a comparative study has been done in between sealed and unsealed samples. The OMC and MDD used corresponding to 593 and 2483 kJ/m3 compaction energy. With this capacitive energy and 7 and 30 days of curing period and 4 days of the soaking period, the CBR test has been done. The lime-treated flyash has found to be having more UCS strength than a virgin flyash.

Singh and Sharan (2014) studied that the strength characteristic of compacted flyash/pond ash depends on Compaction energy and degree of saturation. A study has been made on UCS and CBR values on the basis of energies varying from 357 kJ/m3 to 3488 kJ/m3.

Chowdhury *et al.*(2015) used flyash as a substitute geomaterial, in this paper an attempt has been made to stabilize it with alkali (i.e. NaOH, KOH, $Ca(OH)_2$). In the study, flyash was mixed with 2%, 4%, 8%, 12% 16% and 20% of alkali and the mixed material have gone through the modified proctor test and OMC and MDD were determined. With this mixed material and corresponding OMC, MDD the UCS samples are made and kept for 0, 3, 7, and 28 days. As a result, they found the increase in OMC and MDD when stabilized with NaOH and KOH whereas addition of $Ca(OH)_2$ does not show that much increment in OMC and MDD And also an increase in UCS value when stabilized with NaOH, KOH and $Ca(OH)_2$ with an increase in curing period and with an increase in alkali content a decrease in alkali content is also observed.

Hussain (2015) stated that an effective utilization of waste material as a construction material can control the greenhouse gases. In the study bottom ash and GGBS based geopolymer was used as the source material to produce geopolymer concrete for paver blocks. For polymerization sodium hydroxide (NaOH) and sodium silicate (Na_2SiO_3) were used. With these materials, they tried to make M30 & M35 grade paver blocks. They used 75% bottom ash and 25% GGBS with the ratio of 2.5 between Na_2SiO_3 and NaOH. After testing the M30 grade achieved at 6M NaOH in 3-days and at 8M in 1-day. Whereas M35 grade achieved at 6M NaOH at 28-days and at 8M in 7-days.

Sharma and Sivapullaiah (2015) investigated that the industrial waste such as flyash and ground granulated blast furnace slag (GGBS) can be effectively used as a stabilizer when a small amount of activator is added.

Neupane (2016) stated that geopolymer can be used as a binding material. The geopolymer that is used is generally made from activated alumina-silicate powder which is highly concentrated sodium hydroxide or sodium silicate solution which are generally called as liquid activated geopolymer. In this study, two types of powder activated geopolymer binders are used. Which are having different properties of flyash and slag. As investigation purpose, four different types of strength 40, 50, 65, and 80MP were used for different curing conditions and it was compared with OPC concrete of the same grade. If comparing to OPC, the geopolymer concrete required less amount of water for 28 days compressive strength than OPC concrete. Geopolymer concrete exhibited 15 to 20% of higher indirect tensile and flexural strength than OPC concrete of the same grade.

Rios *et al.* (2016) studied that, the binders like geopolymer, lime and flyash can be used to stabilize silty sand. A number of samples have been made using these three binders and the samples were gone through unconfined compressive strength and indirect tensile strength after 63 days curing period. It has been found that the stiffness and the strength of samples made with geopolymer as a binder are very high then the samples made with lime and flyash as a binder. It is also stated that the strength of mixtures using lime and flyash as a binder is higher than the mixtures using only lime as binder.

2.3 Objective of the Present Study

As stated above in the literature review, the biggest issue with the disposal of flyash is that it requires a large amount of area for dumping and it causes very serious environmental hazards. Use of flyash as a construction material is the best option to utilize the highest amount of flyash. The objective of the current project work is to utilize industrial solid waste as a substitute for conventional earth material by adapting and appropriate stabilizing technique. The Class-F fly ash produced from Adhunik Metaliks Limited, Sundergarh. has been stabilized with lime which is the main stabilizing material used. In addition to this, the ground granulated blast furnace slag GGBS has been used to reduce the consumption of lime which is an expensive material as compared to GGBS. As GGBS poses latent hydraulic properties it can’t be used as a stabilizing agent unless and otherwise activated by an alkali. So in the present investigation lime is used as an activator to initiate the pozzolanic reaction.

The main aspects of the current project work are-

- ❖ Effect of addition of lime and curing period on the unconfined compressive strength of flyash.
- ❖ Effect of addition of slag and curing period on the unconfined compressive strength of flyash.
- ❖ Effect of addition of lime and slag in proper proportion and curing period on the unconfined compressive strength of flyash.

3 Experimental Program

3.1 Introduction

When flyash gone through the compaction than it gain some strength but when it became saturated than it will lose its strength immediately. So a proper stabilization technique is must to use for using flyash as a construction material. In the current project, flyash is stabilizing with lime as the main constituent. But as the lime is an expensive material GGBS is using as a stabilizer. But to activate GGBS, the addition of lime was required. So in the study, an attempt has been made to stabilize the flyash and enhance its physical and chemical properties to use it as a geoengineering material by adding lime and GGBS in proper proportion. The different mixes of flyash, lime, and slag were gone through light compaction test to check the OMC and MDD and UCS has been done to check the strength of different mixes at different curing period. In this chapter, a detail on the material used, sample preparation and testing procedure has been given.

3.2 Experimental Arrangments

3.2.1 Materials Used

3.2.1.1 Flyash

In the study, class-F flyash was used. The flyash has been brought from Adhunik Metaliks Limited, Sundergarh. Before using, the sample was passed through 2mm sieve for the separation of foreign and vegetative matters. The sample was collected and mixed thoroughly and kept it in the oven for 24hr at a temperature of 105º-110ºC. Then the sample was kept in an airtight container for further use.

Fig 3.1 Flyash

3.2.1.2 Lime

The lime used in the present study was commercial lime, which has been brought from Rourkela market and passed through 150µ sieve and kept in an airtight container for further use.

Fig 3.2 Lime

3.2.1.3 Slag

The ground granulated blast furnace slag was brought from Shiva Cement Rourkela. And it was crushed, oven dried, passed through 300µ sieve and kept in an airtight container for further use.

Fig 3.3 Powdered slag

3.2.2 Physical Properties of Flyash

Physical properties of class-F flyash, passing through 2mm sieve are determined and shown in the table:

Table 3.1 Physical properties of flyash.

Physical Parameters	**Values**	**Physical Parameters**	**Values**
Colour	Grey	Shape	Rounded/sub-rounded
Fine sand (%)	14	Coefficient of curvature, Cc	1.26
Silt and clay (%)	86	Coefficient of uniformity, Cu	5.66
Coarse sand (%)	0	Specific Gravity, G	2.40
Medium sand (%)	0	Plasticity Index	Non-plastic

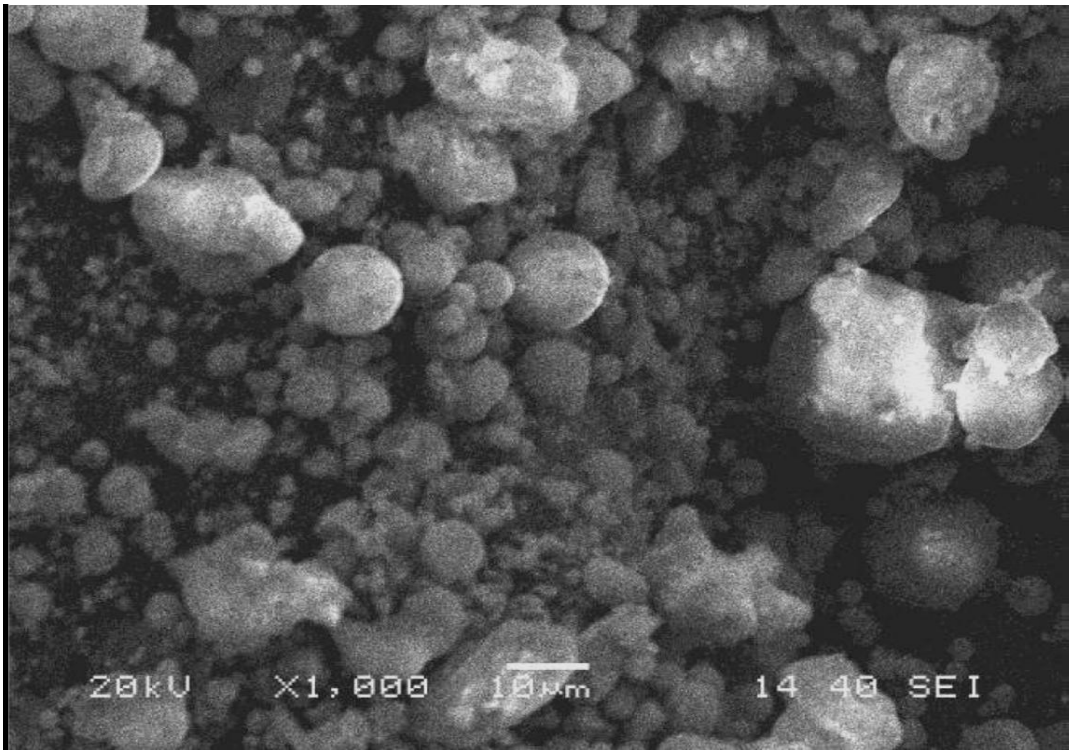

Fig 3.4 Scanning Electron Micrograph (SEM) of flyash

The fig shows the surface morphology of flyash taken by using scanning electron micrograph (SEM). The picture shows the particles are mainly angular size particles and having a uniform gradation. For the best possible resolution morphology were done at an accelerating voltage of 20kV.

3.2.3 Chemical composition of Flyash

The chemical composition of class-F flyash was determined and is shown in Table 3.2.The main chemical component was found to be SiO_2 and Al_2O_3. Apart from these minerals, it also contains (MgO), potassium (K_2O), calcium oxide (CaO).

Table 3.2 Chemical composition of flyash.

Elements	MgO	Al_2O_3	SiO_3	K_2O	P_2O_3	CaO	Fe_2O_3	Na_2O_3	MnO	TiO_2	Loss on ignition
Composition (%)	1.6	28.2	53.11	1.98	1.71	2.66	1.79	0.6	0.4	0.75	6.4

3.3 Determination of Index Properties

3.3.1 Determination of Specific Gravity

The specific gravity of class-F flyash was determined according to IS:2720 (part III, section-1) 1980. By density bottle test using kerosene as the solvent and it was found to be 2.40.

3.3.2 Determination of Grain Size Distribution

For the determination of grain size distribution, flyash were passed through a 75μ sieve. For the distribution of coarser particles sieve analysis was conducted as per IS:2720 part (IV), 1975 and similarly for finer particles hydrometer analysis was conducted as per IS:2720 part (IV). The flyash passing through the 75μ sieve was found to be 87%. So the flyash can be classified as fine sand to silt size. The coefficient of uniformity (Cu) was found to be 5.66 whereas the coefficient of curvature (Cc) was found to be 1.26. That indicates the uniform gradation of flyash.

3.4 Determination of Engineering Properties

3.4.1 Moisture Content Dry Density Relationship

The moisture content dry density relationship was found by using standard Proctor test as per IS:2720 (part VII) 1980. Flyash was mixed with lime at 0%, 2%, 4%, 8% and 12% and with slag at 0%, 5% 10% 15% and 20% by its dry weight and different combinations have been made. For this test, an adequate amount of water was added to the mixtures and thoroughly mixed and compacted in Proctor mould in three layers using standard Proctor hammer weighing 2.6 kg as per IS: 2720 (part 2) 1973 and the optimum moisture content (OMC) and dry density (MDD) were determined. Similarly, the different combinations were tested to the same procedure and corresponding OMC and MDD was determined. The compactive energy used in the test program was 595 kJ/m^3.

Table 3.3.Details of Flyash-GGBS-Lime mixes used in the test program.

% LIME	FLYASH-SLAG MIXING PROPORTION				
0	(100-0)	(95-5)	(90-10)	(85-15)	(80-20)
2	(100-0)	(95-5)	(90-10)	(85-15)	(80-20)
4	(100-0)	(95-5)	(90-10)	(85-15)	(80-20)
8	(100-0)	(95-5)	(90-10)	(85-15)	(80-20)
12	(100-0)	(95-5)	(90-10)	(85-15)	(80-20)

The test results are as shown in the table:

Table 3.4.Variation of MDD with different combinations of lime and slag.

% LIME	MAXIMUM DRY DENSITY (kN/m^3)				
	0% SLAG	5% SLAG	10% SLAG	15% SLAG	20% SLAG
0	10.93	11.13	11.33	11.42	11.66
2	11.18	11.25	11.41	11.55	11.72
4	11.24	11.34	11.47	11.63	11.76
8	11.41	11.52	11.63	11.79	11.87
12	11.68	11.75	11.83	12.01	12.12

Table 3.5.Variation of MDD with different combinations of lime and slag.

% SLAG	MAXIMUM DRY DENSITY(kN/m^3)				
	0% LIME	2% LIME	4% LIME	8% LIME	12% LIME
0	10.93	11.18	11.24	11.41	11.68
5	11.13	11.25	11.34	11.52	11.75
10	11.33	11.41	11.47	11.63	11.83
15	11.42	11.55	11.63	11.79	12.01
20	11.66	11.72	11.76	11.87	12.12

Table 3.6.Variation of OMC with different combinations of lime and slag.

% LIME	OPTIMUM MOISTURE CONTENT (%)				
	0% SLAG	5% SLAG	10% SLAG	15% SLAG	20% SLAG
0	42.12	38.58	38.28	38.12	37.96
2	40.32	38.28	38.17	37.93	37.83
4	38.32	37.86	37.52	36.83	36.11
8	36.85	36.21	35.83	35.24	34.95
12	34.16	33.86	33.24	32.97	32.23

Table 3.7.Variation of OMC with different combinations of lime and slag.

% SLAG	OPTIMUM MOISTURE CONTENT (%)				
	0% LIME	2% LIME	4% LIME	8% LIME	12% LIME
0	42.12	40.32	38.32	36.85	34.12
5	38.58	38.28	37.86	36.21	33.86
10	38.28	38.17	37.52	35.83	33.24
15	38.12	37.93	36.83	35.24	32.97
20	37.96	37.83	36.11	34.95	32.23

3.4.2 Determination of Unconfined Compressive Strength

The unconfined compression strength test was used to determine the compressive strength of flyash and flyash stabilized with lime and slag. For the preparation of specimen MDD at OMC determined by the standard Proctor test at an energy of 595 kJ/m^3 was used as per IS:2720 Part (X). The size of the cylindrical specimen was 76 mm in height and 38 mm in diameter and the specimen were gone through an axial strain of 1.25mm/min till the failure occurs. The samples prepared were wax coated to retain the moisture so that proper reaction can take place between flyash, lime and GGBS. To measure the effect of curing the samples were kept for 0, 7, 14 and 28 days of curing period. For each different combinations of flyash, lime and GGBS with different curing period three identical test specimen were tested and the average value has been reported.

Fig 3.5.UCS arrangement.

Fig 3.6.UCS samples coated with wax.

The test results are as shown in the table:

Table 3.8.UCS (MPa) at 0% slag.

% lime	Unconfined compressive strength in MPa			
	Immediate	7-Days	14-days	28-days
0	0.24	0.24	0.24	0.24
2	0.61	0.62	0.68	0.78
4	1.02	2.02	2.87	3.05
8	1.03	3.01	3.05	4.52
12	1.22	3.16	3.55	5.75

Table 3.9.UCS (MPa) at 5% slag.

% Lime	Unconfined compressive strength in MPa			
	Immediate	7-Days	14-days	28-days
0	0.13	0.19	0.26	0.30
2	0.72	1.39	1.60	1.65
4	0.90	1.8	2.33	2.88
8	0.94	3.02	3.06	4.85
12	1.00	3.58	5.29	5.39

Table 3.10.UCS (MPa) at 10% slag.

% Lime	Unconfined compressive strength in MPa			
	Immediate	7-Days	14-days	28-days
0	0.19	0.40	0.46	0.62
2	0.34	0.88	1.79	2.92
4	0.47	1.43	3.00	3.33
8	0.56	1.96	3.17	3.77
12	0.58	3.15	3.23	4.91

Table 3.11.UCS (MPa) at 15% slag.

% Lime	Unconfined compressive strength in MPa			
	Immediate	7-Days	14-days	28-days
0	0.20	0.45	0.60	0.92
2	0.79	1.28	1.92	3.13
4	0.82	2.07	3.55	3.62
8	0.87	2.18	3.71	4.00
12	0.99	3.77	4.30	5.07

Table 3.12.UCS (MPa) at 20% slag.

% Lime	Unconfined compressive strength in MPa			
	Immediate	7-Days	14-days	28-days
0	0.25	0.60	1.22	1.39
2	0.88	2.92	3.62	3.77
4	0.90	3.23	4.57	5.23
8	0.91	5.40	6.85	7.31
12	1.15	5.75	8.04	8.44

4 Results and Discussion

4.1 General

Coal ashes are fine products which generated through combustion of coal process. These waste generated through the combustion process are dumped into the ground which causes environmental and health issues. So it is very necessary to utilize this waste in the quantity as high as possible. So its utilization as a construction material will be the best option. In the study class-F, flyash has been used and tried to stabilize it with lime and GGBS. The mixtures made have gone through some standard tests like standard Proctor test, UCS test. In this chapter, the results are presented and discussed.

4.2 Index Properties

4.2.1 Specific Gravity

As per IS: 2720 (Part-III, section-1) 1980, the specific gravity was determined by using density bottle method and it was found to be 2.40. The specific gravity is one of the most important basic properties of any kind of geotechnical work. The specific gravity of flyash was found is not that much as other geotechnical materials. It poses a large number of cenospheres which not let the microbubbles of air to remove it, or it may because of variation in chemical composition of present iron content. In general, the specific gravity of ash varies in the range of 1.6 to 3.1 (pani 2014) and it depends on its parent material.

4.2.2 Grain Size Distribution

In the test, it was found that the particles present in the class-F flyash were uniformly graded. And the particle size varies mostly from fine sand to silt size. In the test 86% of flyash passed through the 75µ sieve, and the coefficient of curvature (Cc) was found to be 1.26, whereas the coefficient of uniformity (Cu) was 5.66. The grain size distribution mainly depends on the degree of pulverization, temperature present in boiler unit and also on the presence of foreign particles in the flyash.

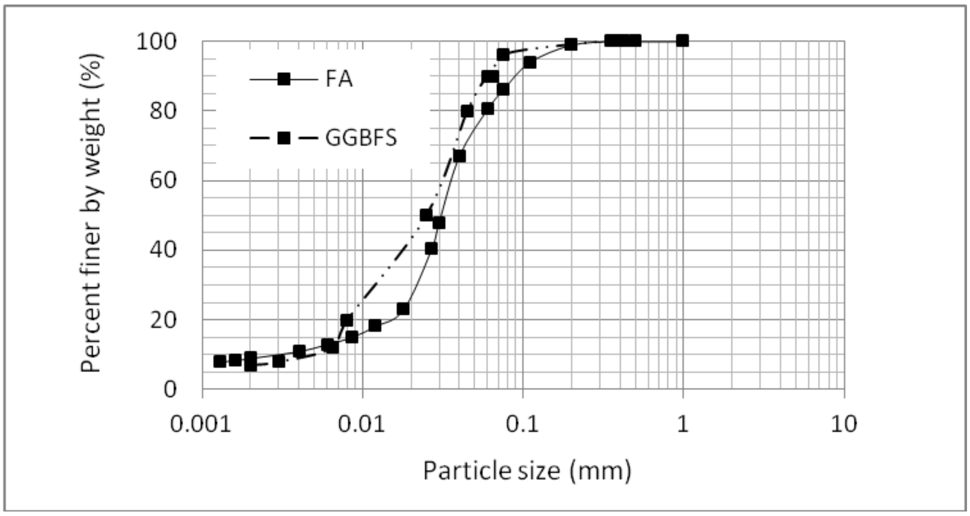

Fig 4.1.Grain size distribution curve of class-F flyash.

4.3 Engineering Properties

4.3.1 Compaction Characteristics.

In the current project work, the light compaction has been used. Each combination has been compacted to three layers and 25 number of blows with a hammer of weight 2.6 kg. The energy applied in each compaction was 595 KJ/m^3. OMC and MDD have been determined for each combination. The graph obtained for different combinations were compared and presented. Variation of MDD and OMC with varying percentage of lime and variation of MDD and OMC with varying percentage of slag also presented.

Compaction characteristic of flyash at different percentage of slag and 0%, 2%, 4%, 8% and 12% lime content-

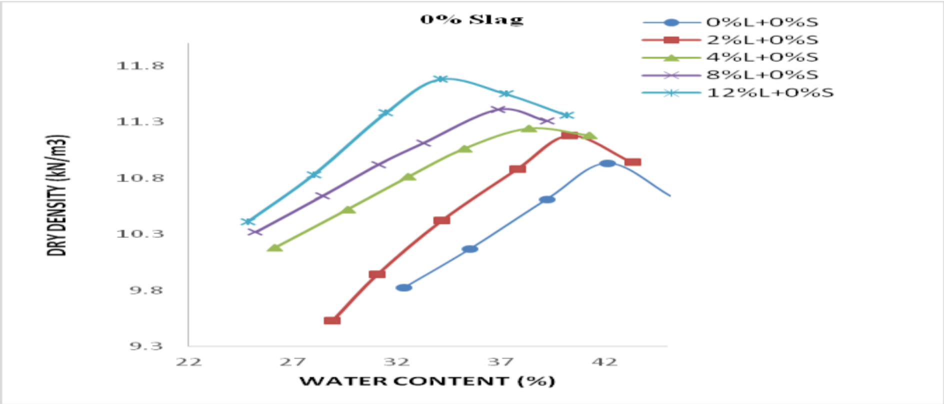

Fig 4.2.Compaction characteristic of flyash at 0% slag and 0%, 2%, 4%, 8% and 12% lime content.

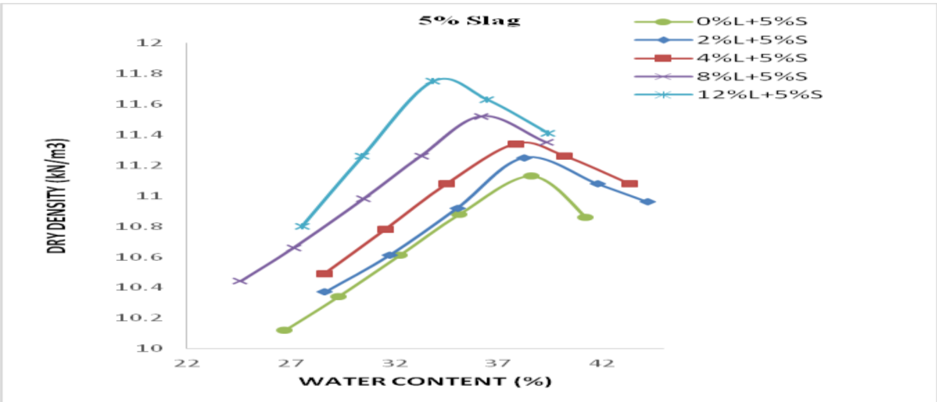

Fig 4.3.Compaction characteristic of flyash at 5% slag and 0%, 2%, 4%, 8% and 12% lime content.

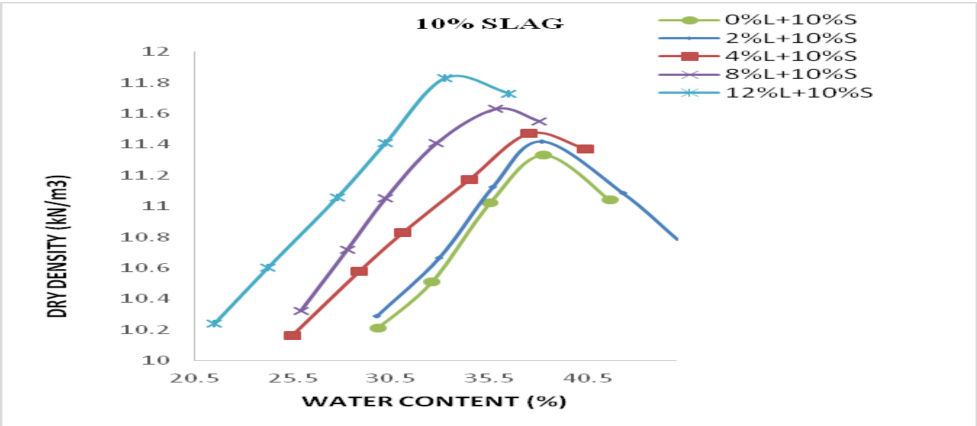

Fig 4.4.Compaction characteristic of flyash at 10% slag and 0%, 2%, 4%, 8% and 12% lime content.

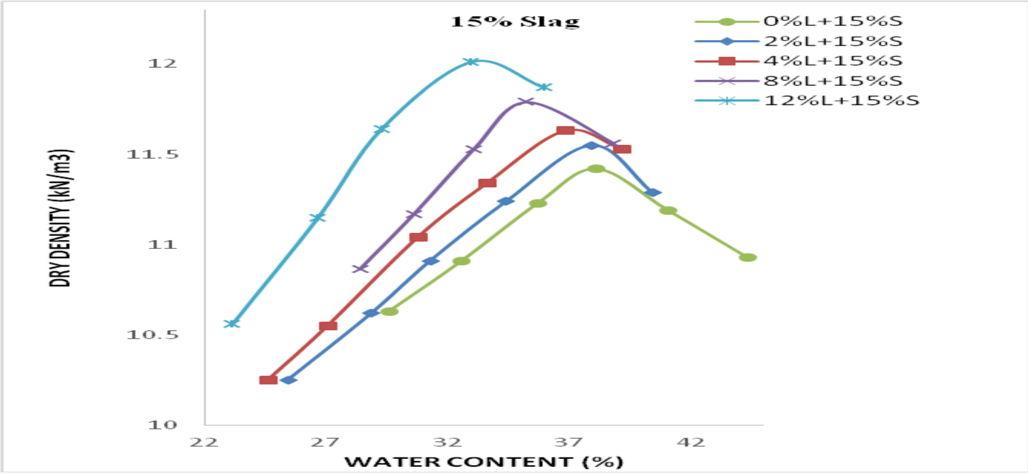

Fig 4.5.Compaction characteristic of flyash at 15% slag and 0%, 2%, 4%, 8% and content.12% lime

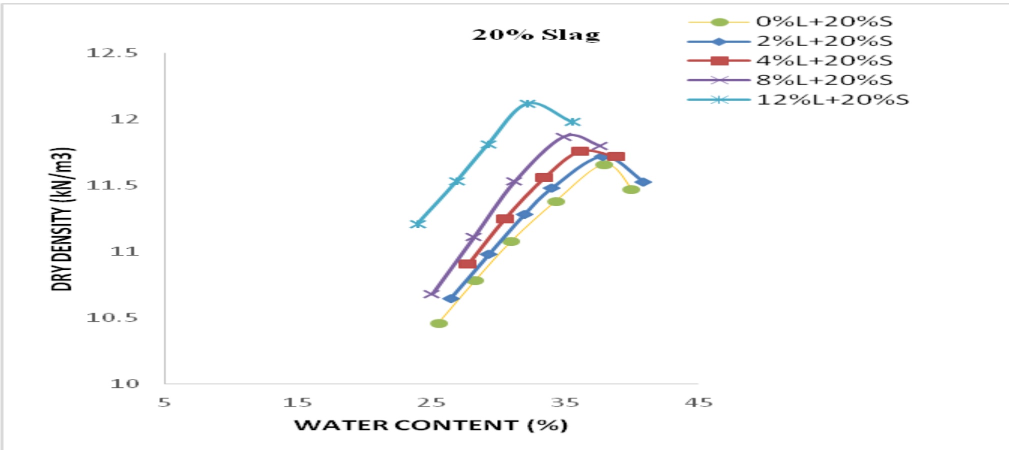

Fig 4.6.Compaction characteristic of slag and flyash at 20% 0%, 2%, 4%, 8% and 12% lime content.

Figures representing variation of OMC and MDD with different lime and slag content-

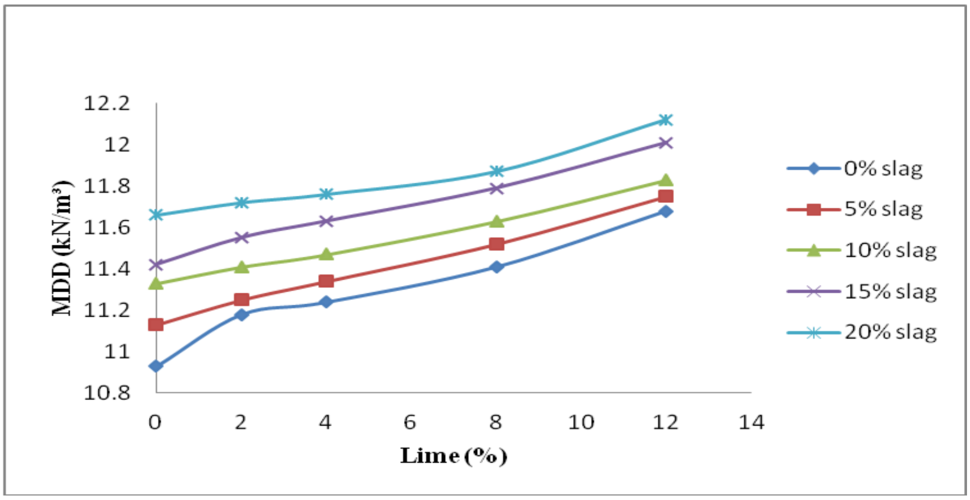

Fig 4.7.Variation of MDD with varying percentage of lime.

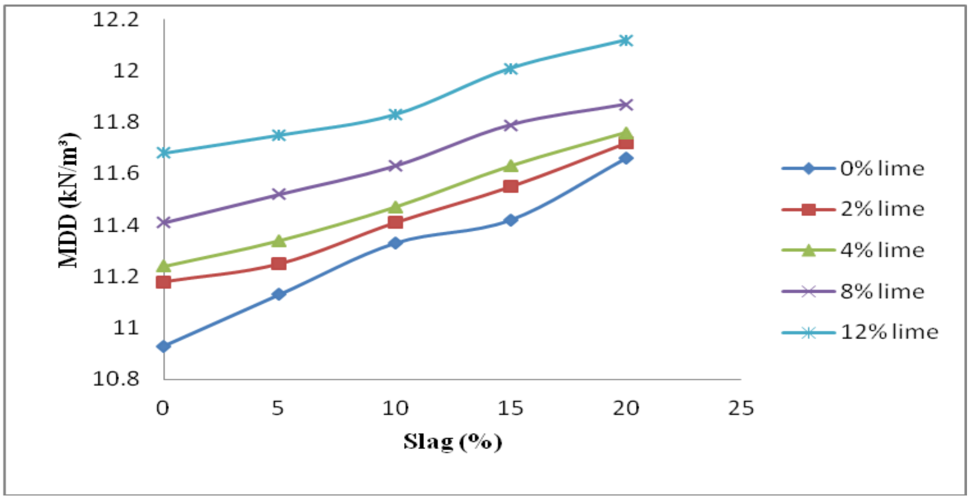

Fig 4.8.Variation of MDD with varying percentage of slag.

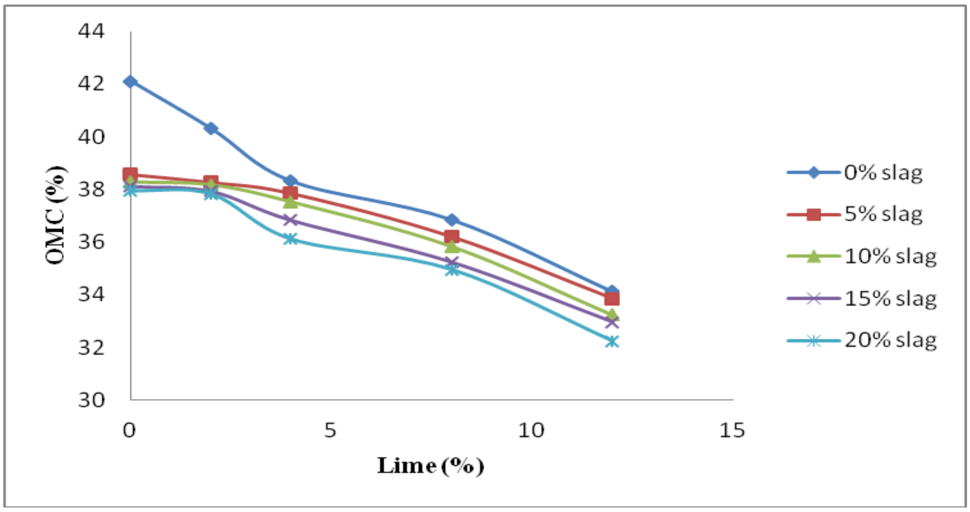

Fig 4.9.Variation of OMC with varying percentage of lime.

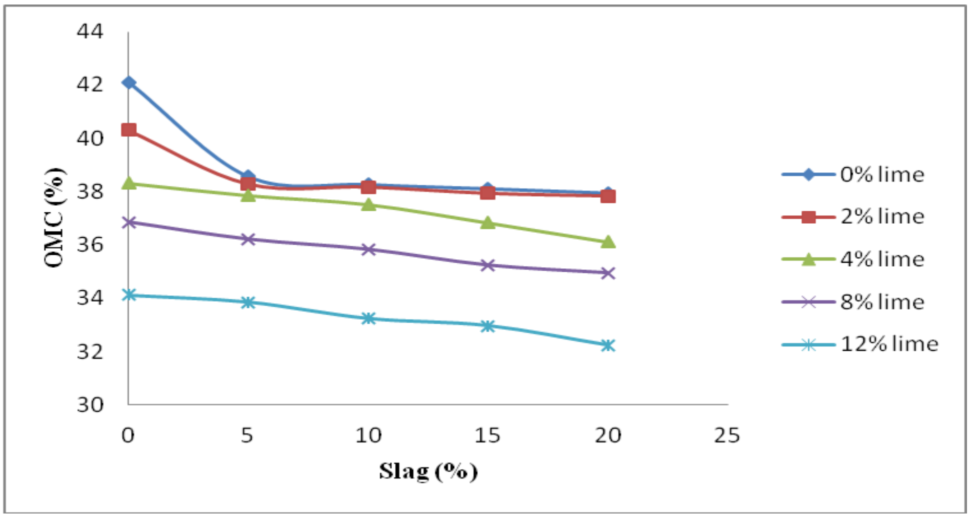

Fig 4.10.Variation of OMC with varying percentage of slag.

4.3.2 Determination of Unconfined Compressive Strength

The unconfined compressive strength or UCS values were determined by UCS test. The sample size taken was 76mm in height and 38mm in diameter. Three samples have been made for each different combination of flyash, lime and GGBS using OMC and MDD determined by SPT test, and an average of the three has been taken. the stress-strain relationship for the treated flyash has been compared with 0, 7, 14 and 28 days of curing period. Variation of UCS values with varying curing period i.e. 0, 7, 14, and 28 and variation of UCS values with varying percentage of lime was presented through bar charts. Variation of UCS values with different lime content at different slag with varying curing period has also been presented.

Figures representing stress-strain characteristic of flyash amended with different lime and slag percentage-

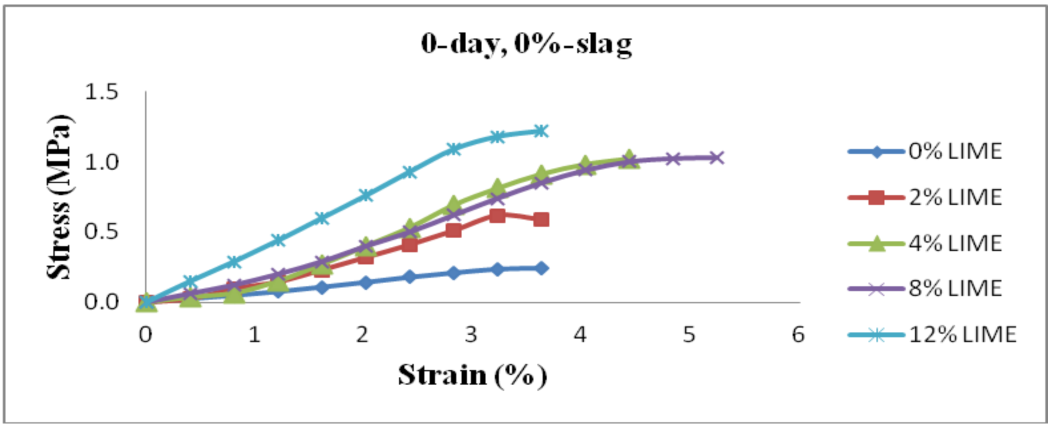

Fig 4.11.Stress-strain relationship of flyash only at 0-day of curing period.

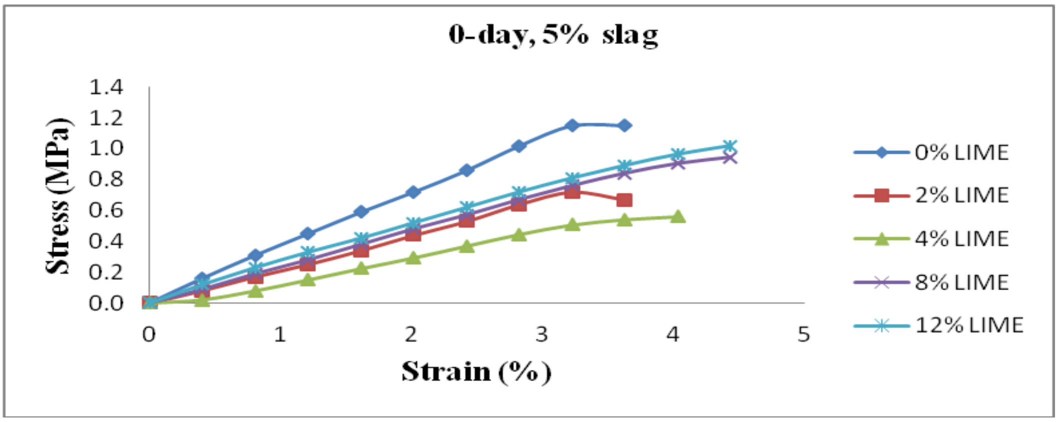

Fig 4.12.Stress-strain relationship of flyash with 5% slag at 0-day of curing period.

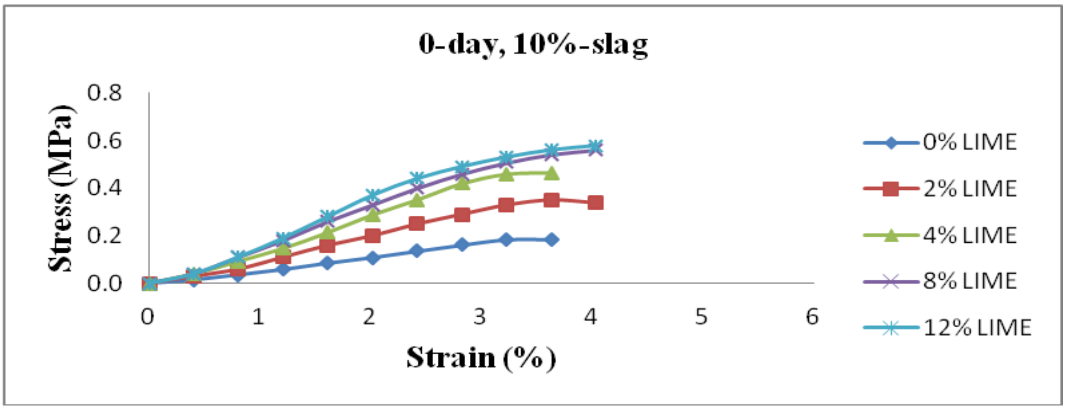

Fig 4.13. Stress-strain relationship of flyash with 10% slag at 0-day of curing period.

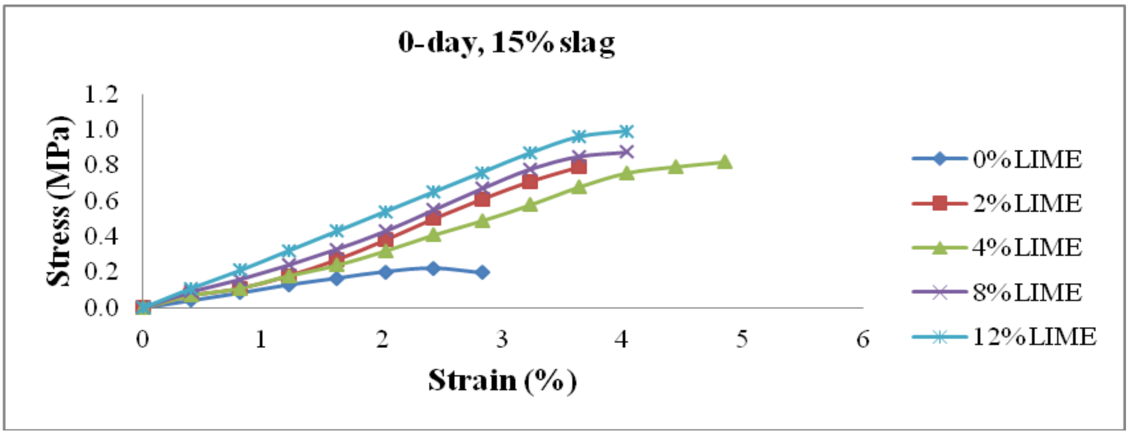

Fig 4.14. Stress-strain relationship of flyash with 15% slag at 0-day of curing period.

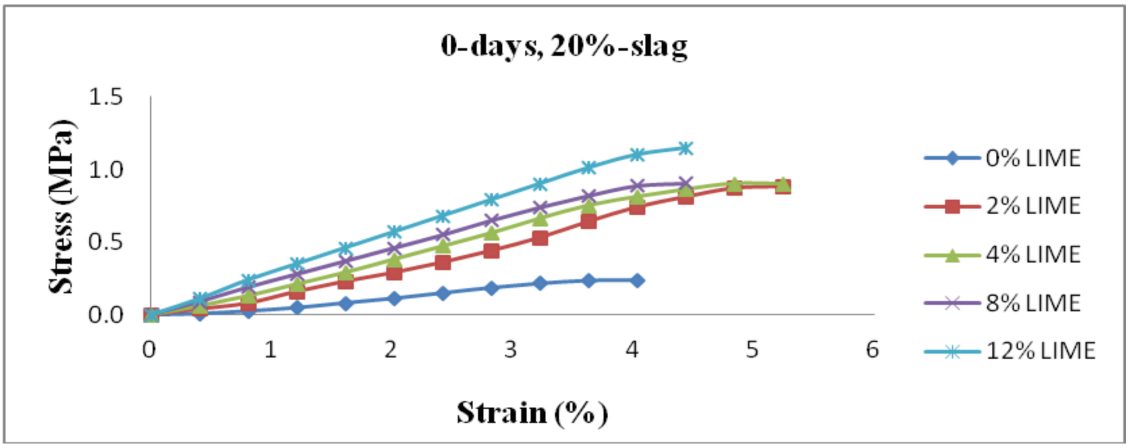

Fig 4.15. Stress-strain relationship of flyash with 20% slag at 0-day of curing period.

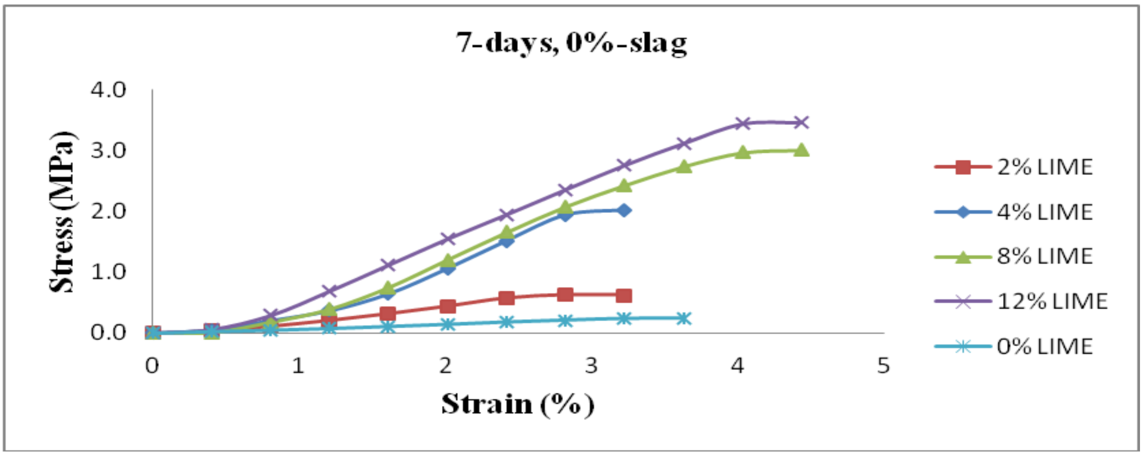

Fig 4.16.Stress-strain relationship of flyash at 7-days of curing period.

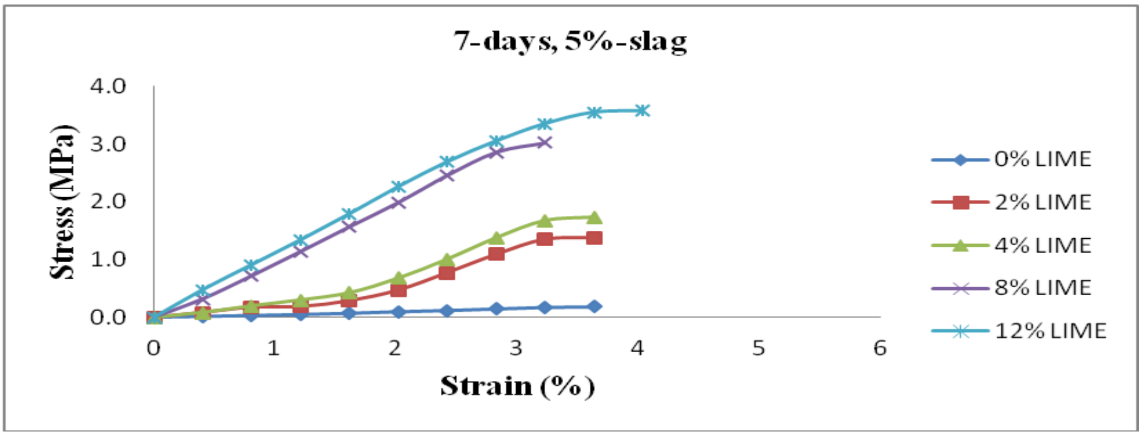

Fig 4.17. Stress-strain relationship of flyash with 5% slag at 7-days of curing period.

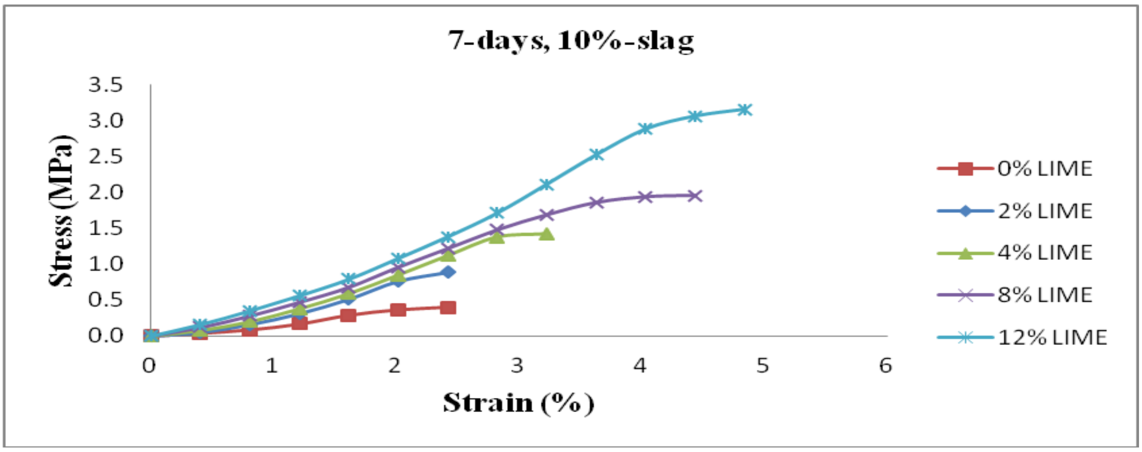

Fig 4.18. Stress-strain relationship of flyash with 10% slag at 7-days of curing period.

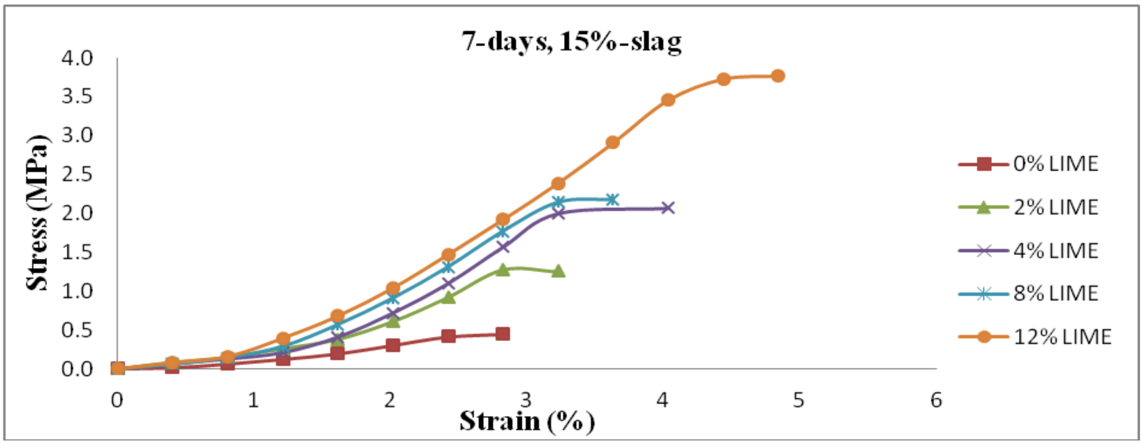

Fig 4.19. Stress-strain relationship of flyash with 15% slag at 7-days of curing period.

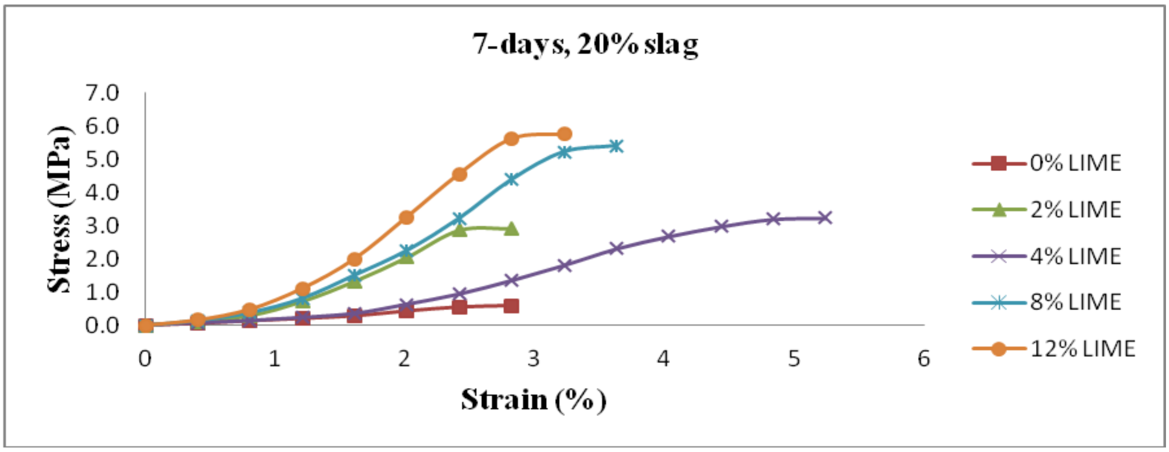

Fig 4.20.Stress-strain relationship of flyash with 20% slag at 7-days of curing period.

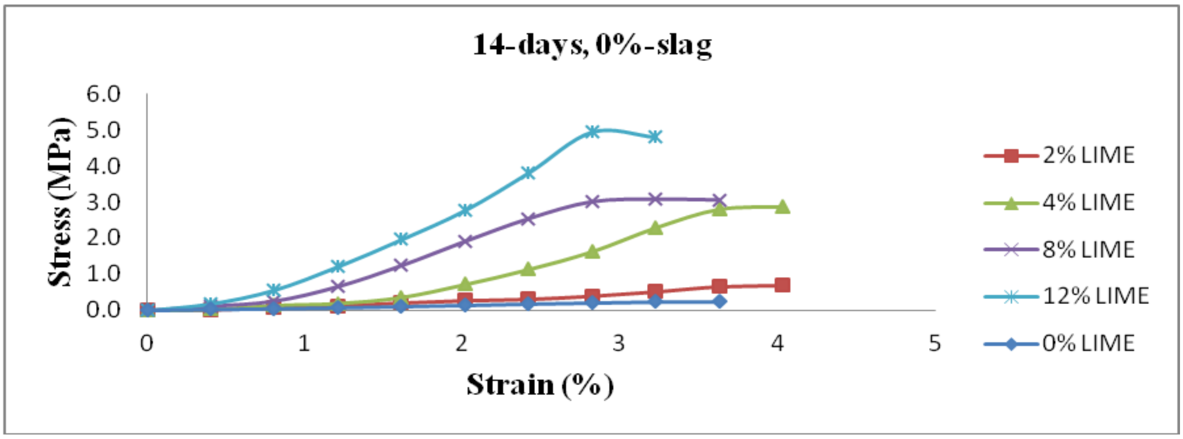

Fig 4.21. Stress-strain relationship of flyash at 14-days of curing period.

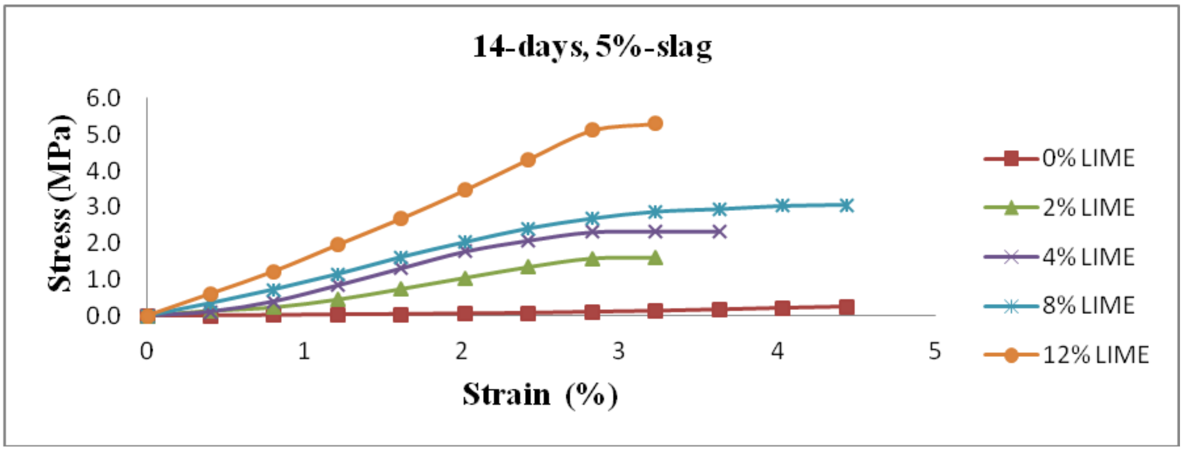

Fig 4.22. Stress-strain relationship of flyash with 5% slag at 14-days of curing period.

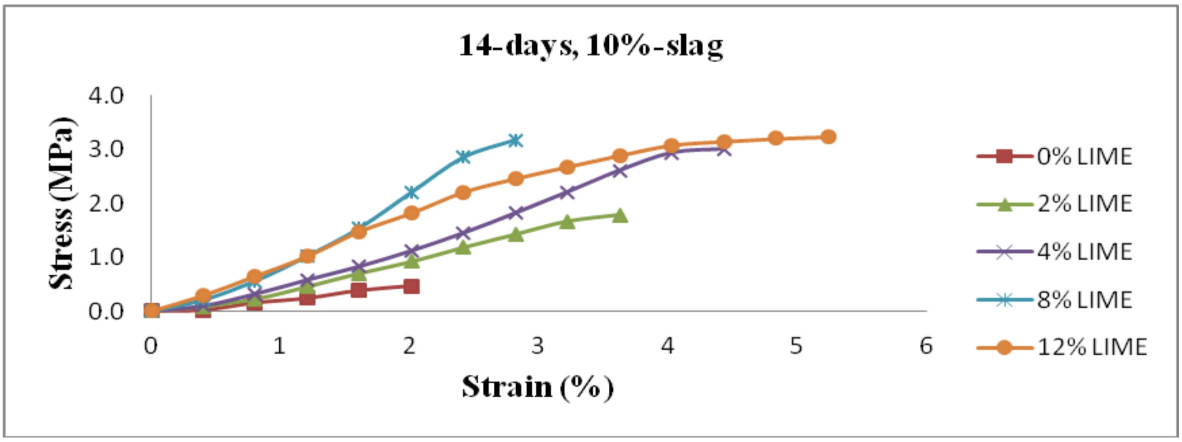

Fig 4.23. Stress-strain relationship of flyash with 10% slag at 14-days of curing period.

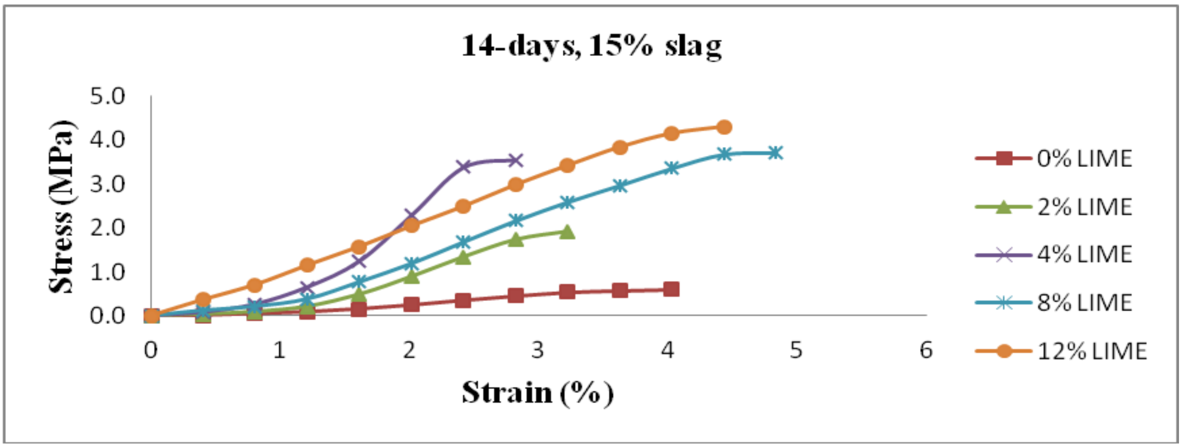

Fig 4.24. Stress-strain relationship of flyash with 15% slag at 14-days of curing period.

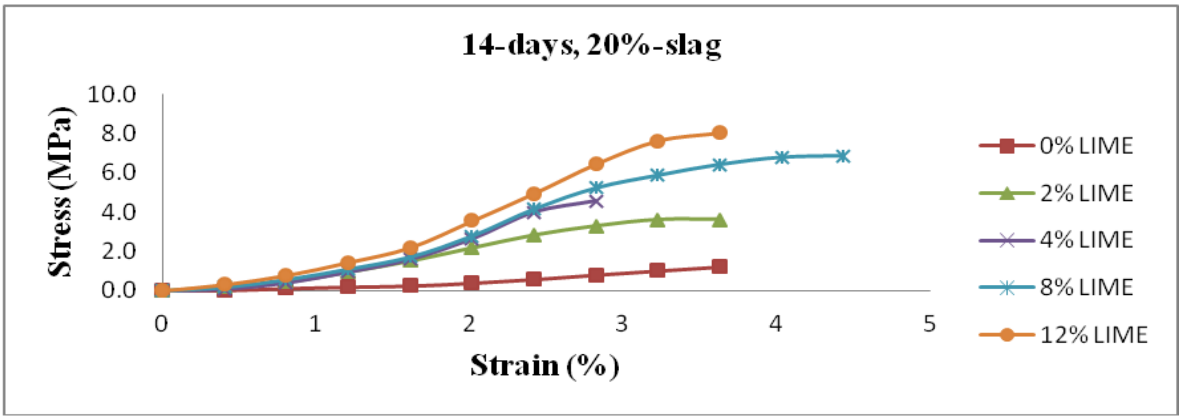

Fig 4.25.Stress-strain relationship of flyash with 20% slag at 14-days of curing period.

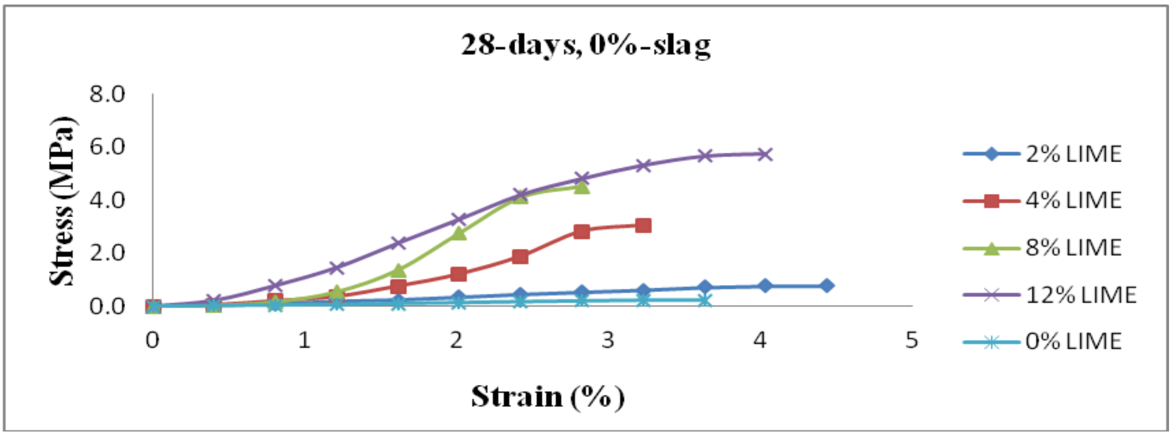

Fig 4.26. Stress-strain relationship of flyash at 14-days of curing period.

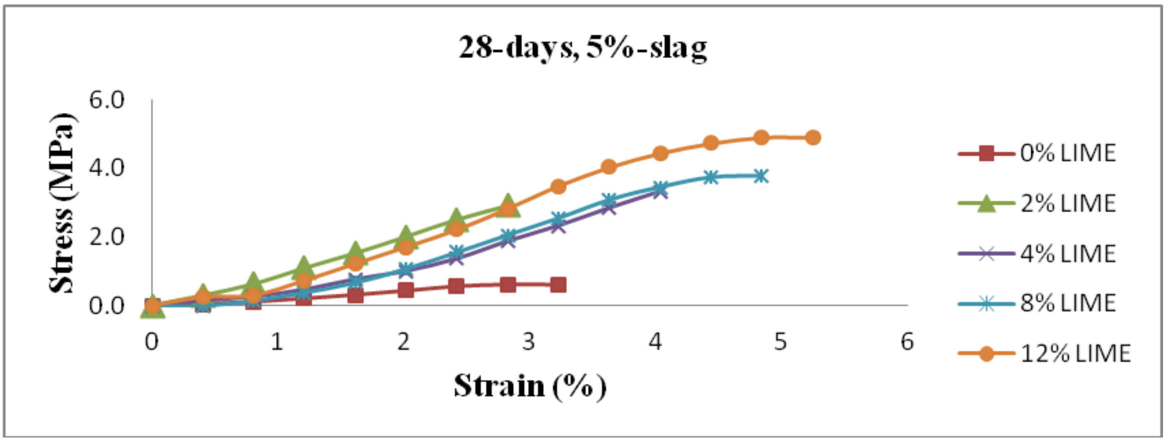

Fig 4.27. Stress-strain relationship of flyash with 5% slag at 28-days of curing period.

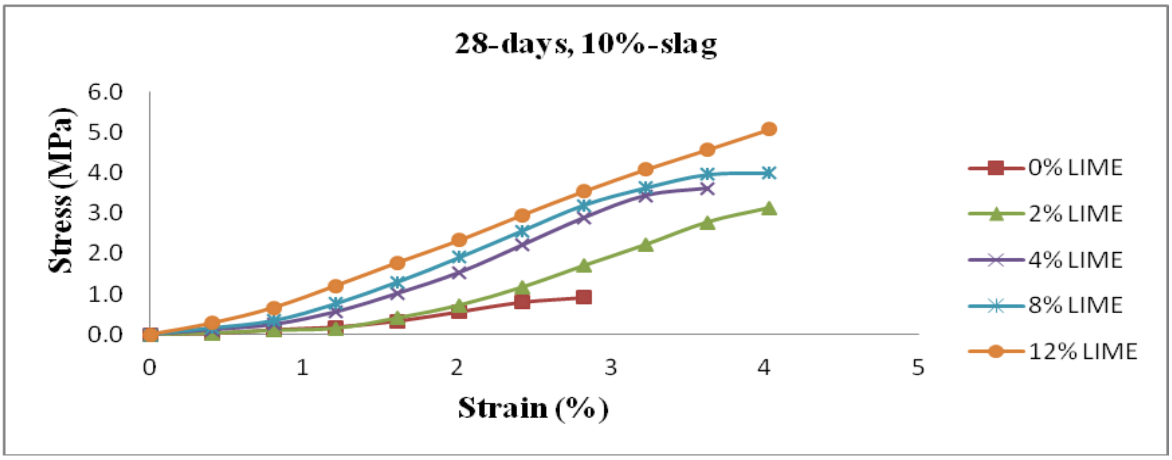

Fig 4.28. Stress-strain relationship of flyash with 10% slag at 28-days of curing period.

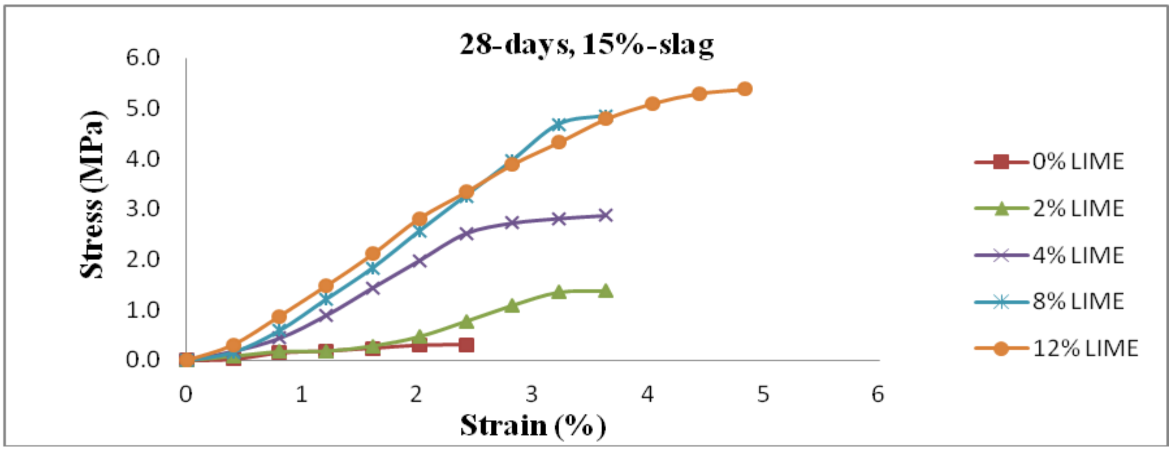

Fig 4.29. Stress-strain relationship of flyash with 15% slag at 28-days of curing period.

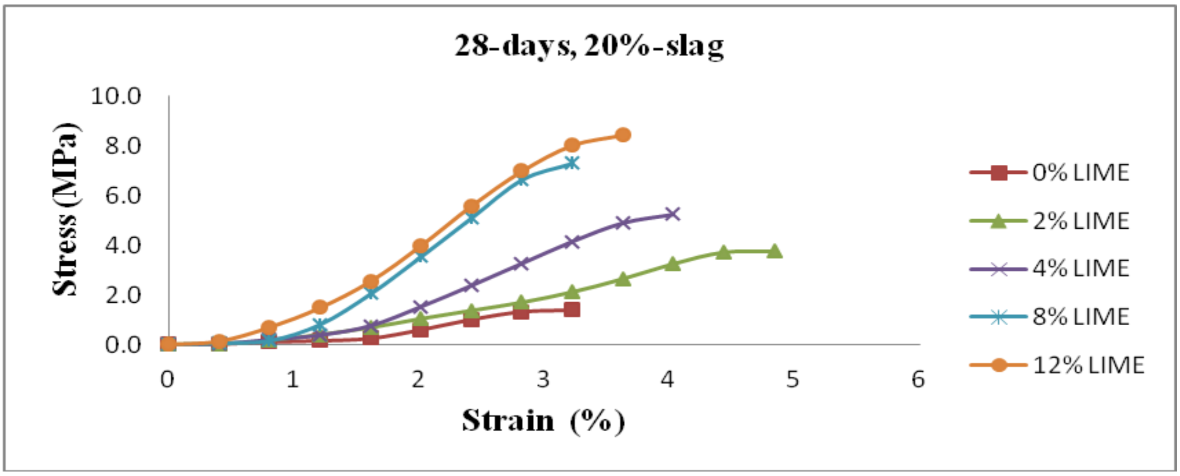

Fig 4.30. Stress-strain relationship of flyash with 20% slag at 28-days of curing period.

Bar chart representing variation of UCS values with change in curing periods at different lime and slag content-

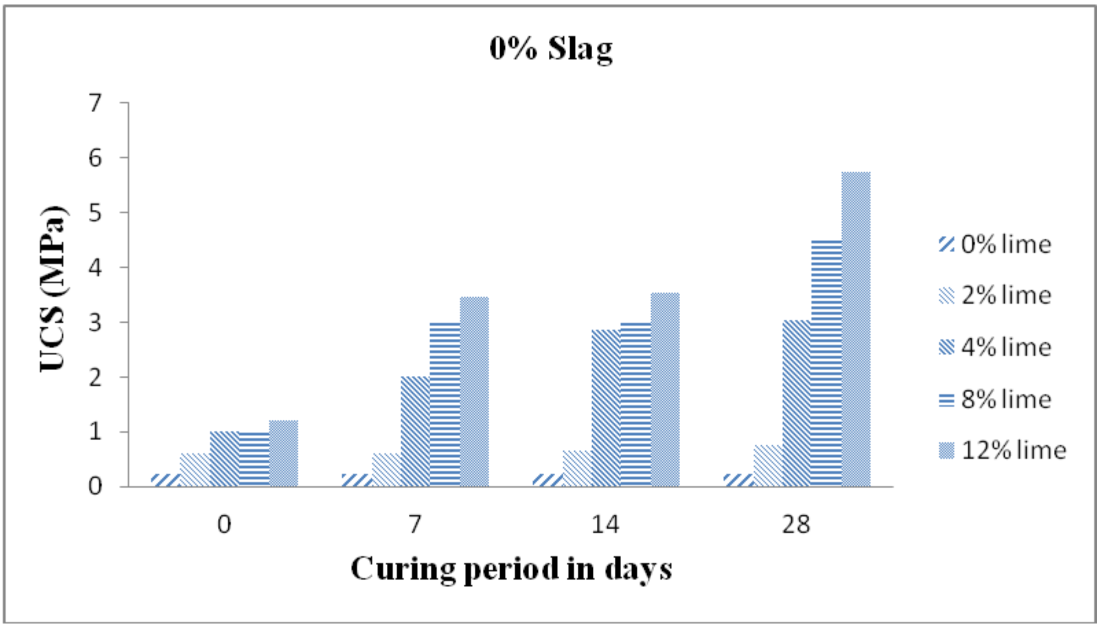

Fig 4.31. Variation of UCS values of flyash at 0, 7, 14 and 28 days of curing period

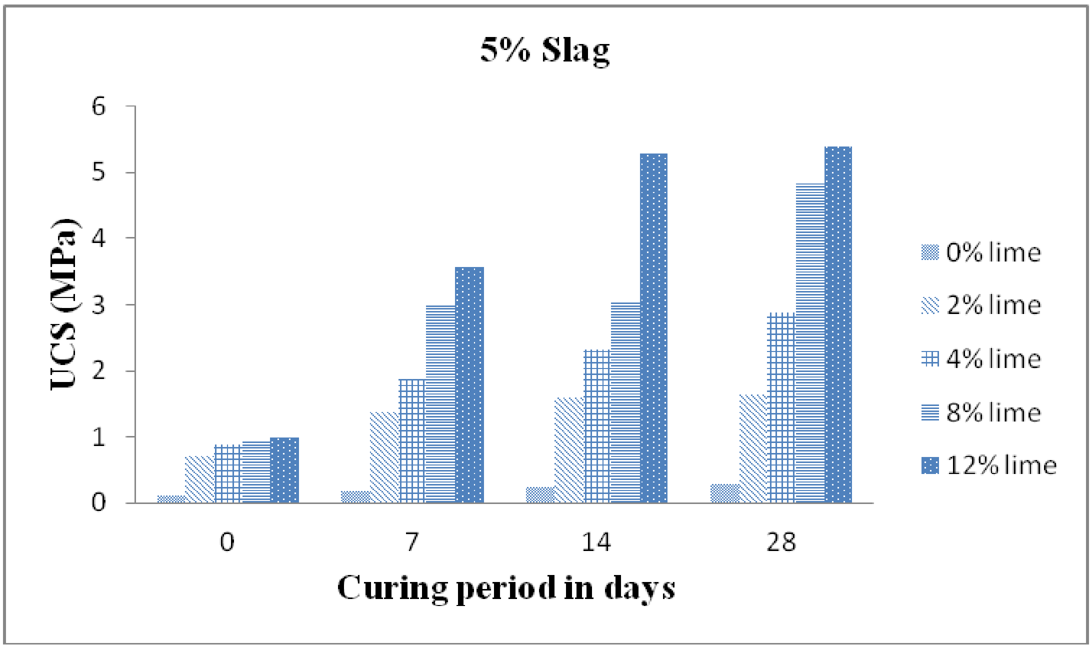

Fig 4.32.Variation of UCS values of flyash at 0, 7, 14 and 28 days of curing period with 5% slag.

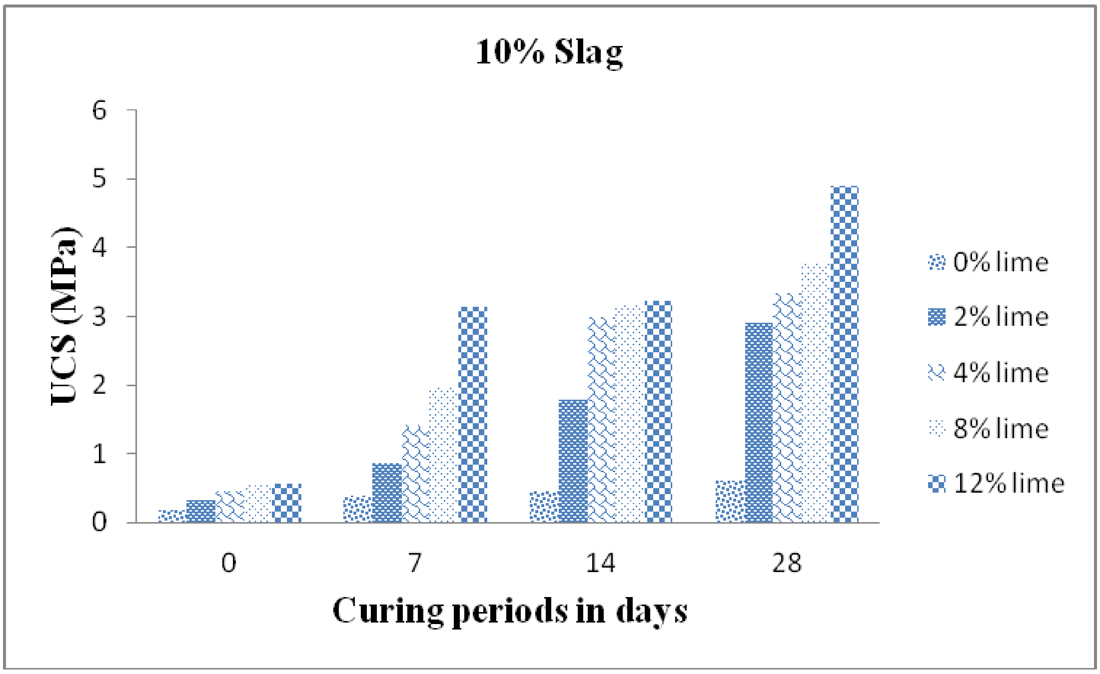

Fig 4.33. Variation of UCS values of flyash at 0, 7, 14 and 28 days of curing period with 10% slag.

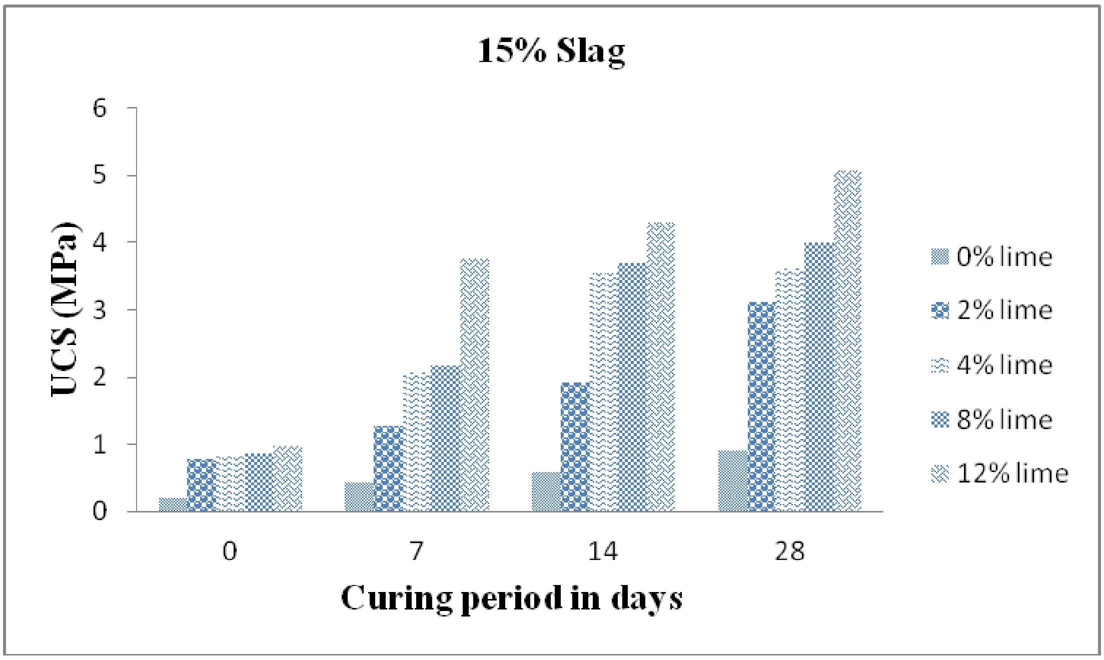

Fig 4.34. Variation of UCS values of flyash at 0, 7, 14 and 28 days of curing period with 15% slag.

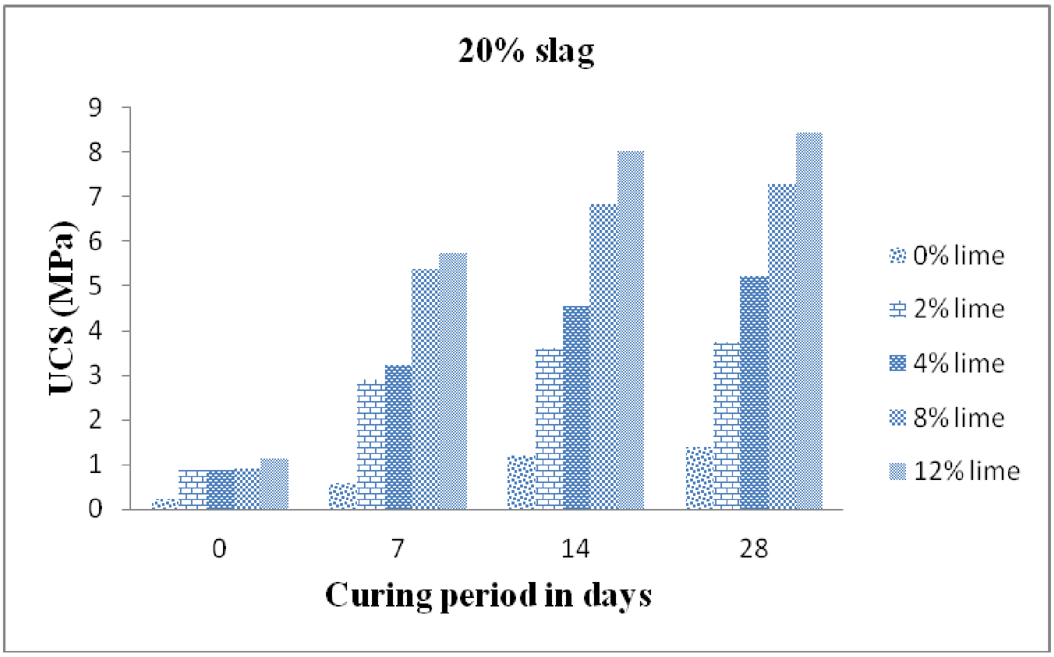

Fig 4.35. Variation of UCS values of flyash at 0, 7, 14 and 28 days of curing period with 20% slag.

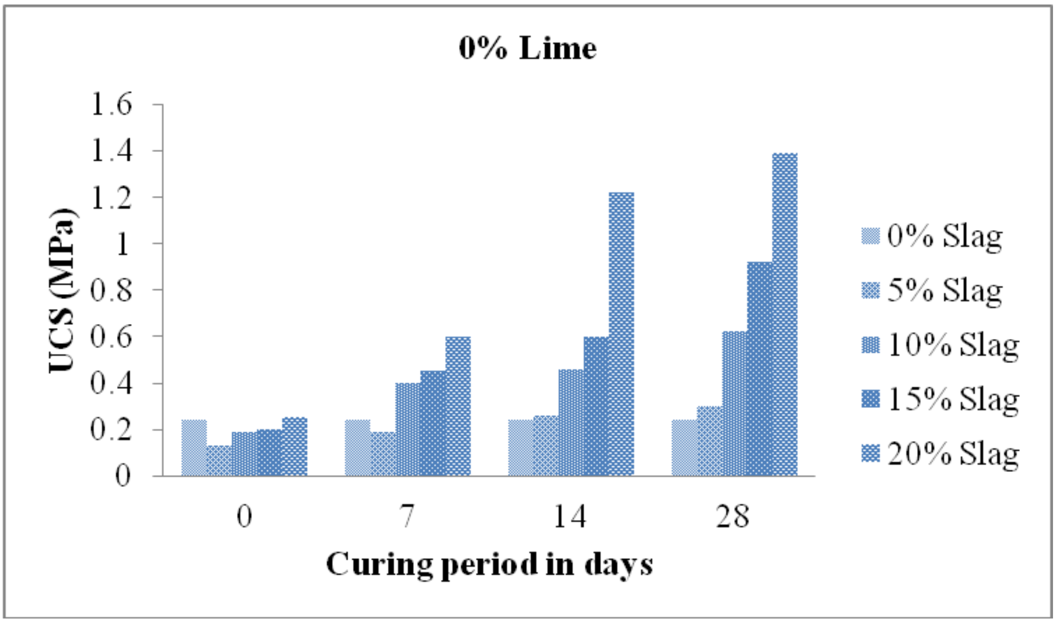

Fig 4.36. Variation of UCS values of flyash at 0, 7, 14 and 28 days of curing period with 0% lime.

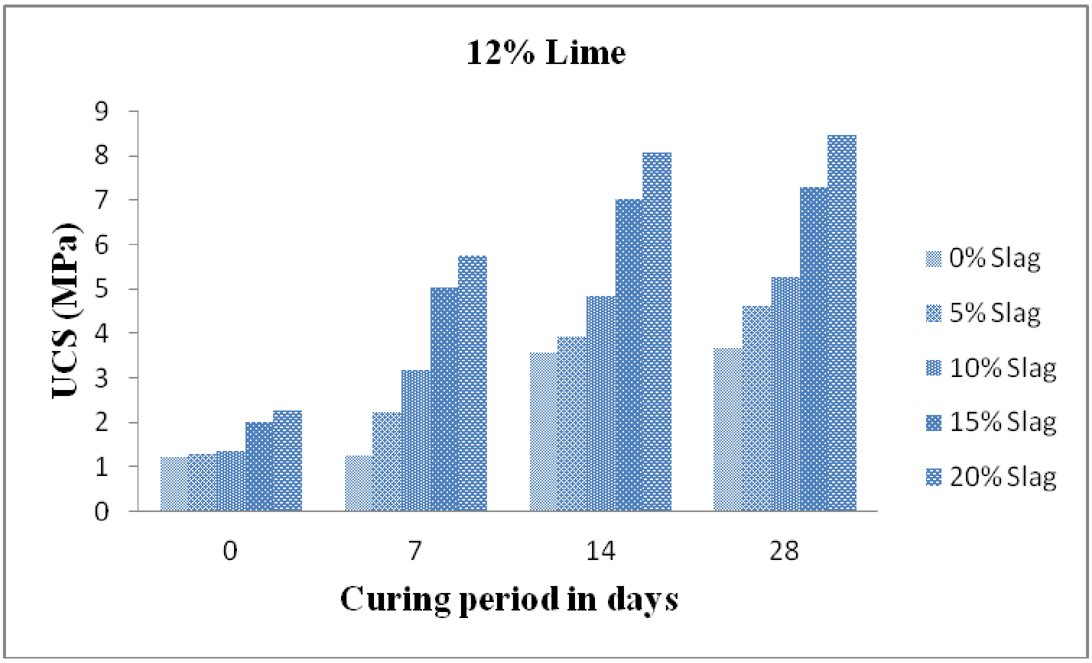

Fig 4.37. Variation of UCS values of flyash at 0, 7, 14 and 28 days of curing period with 12% lime.

Figures representing variation in UCS values of flyash amended with different percentage of lime at different percentage of slag and with different curing periods-

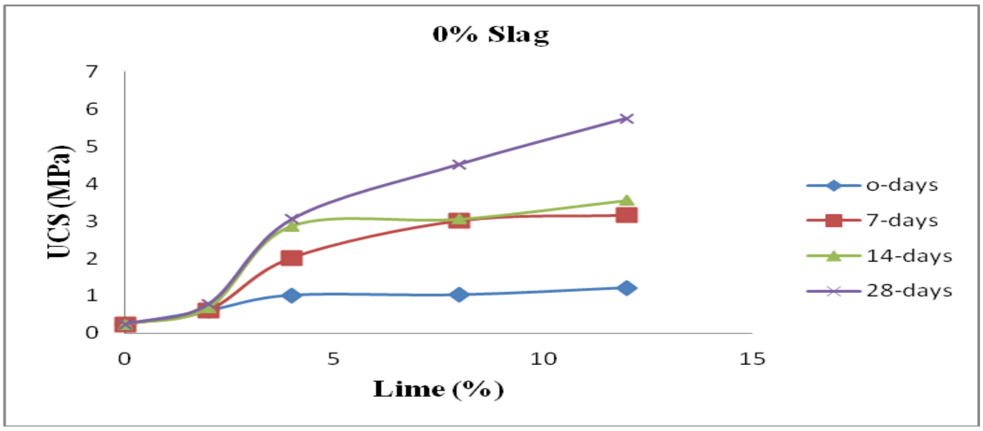

Fig 4.38.Variation of UCS values of flyash at 0%, 2%, 4%, 8%, and 12% lime.

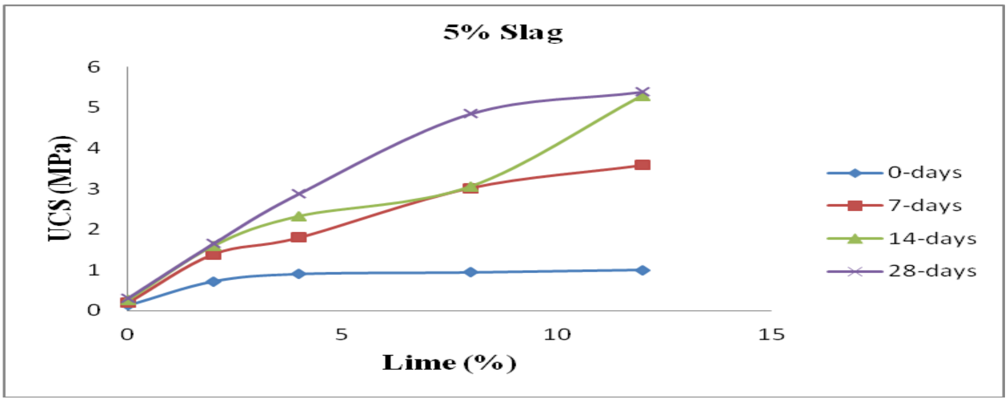

Fig 4.39. Variation of UCS values of flyash at 5% slag and 0%, 2%, 4%, 8%, and 12% lime.

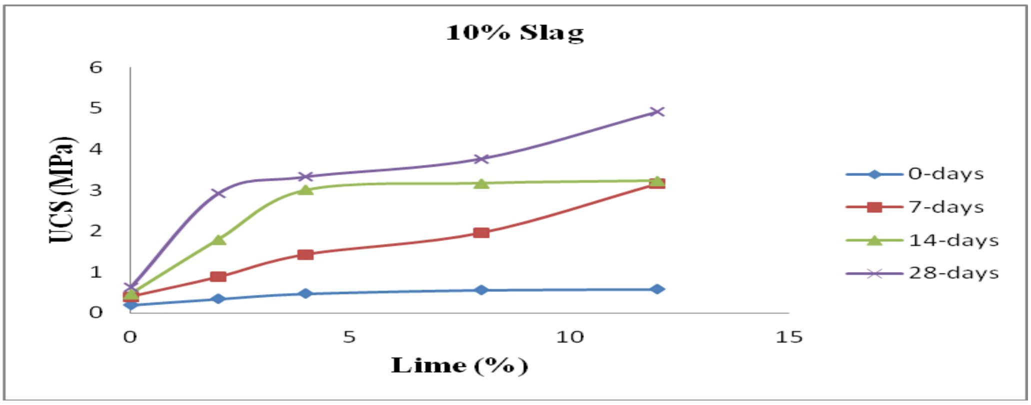

Fig 4.40. Variation of UCS values of flyash at 10% slag and 0%, 2%, 4%, 8%, and 12% lime.

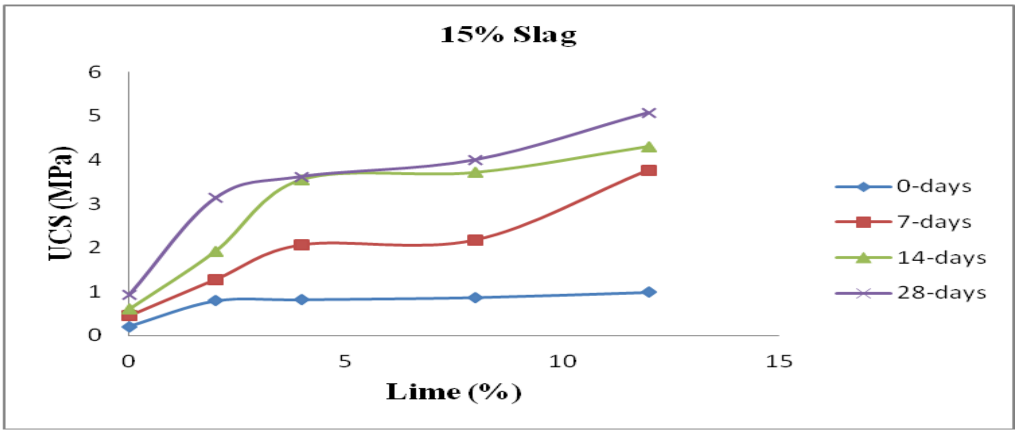

Fig 4.41.Variation of UCS values of flyash at 15% slag and 0%, 2%, 4%, 8%, and 12% lime.

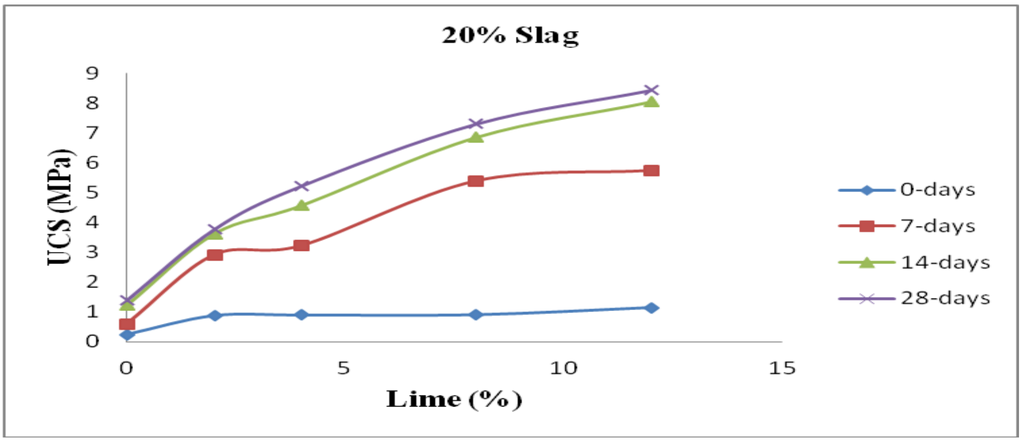

Fig 4.42.Variation of UCS values of flyash at 20% slag and 0%, 2%, 4%, 8%, and 12% lime.

5 Conclusion and Future Work

5.1 Conclusion

In the study, a try has been made to use waste flyash as geoengineering material. The flyash was stabilized with lime and slag and tested for light compaction test. Then the samples are compacted to OMC and MDD determined by standard Proctor test and checked for UCS. The UCS values were compared with the requirements of the base and sub-base course of highway pavement. The conclusions made based on the experimental investigation are-

- In the gradation analysis, it was found that the flyash passing through 75μ was 86%. And the particles were mostly in between fine sand to silt size. The coefficient of curvature and coefficient of uniformity were found to be 1.26 and 5.66 respectively indicating a well-graded material within its size range.

- The standard Proctor test was used to determine OMC and MDD at an energy of 595KJ/m^3. The OMC and MDD for virgin flyash were found to be 10.93kN/m^3 and 42.12% respectively. It can be stated that a virgin flyash possess a low MDD at higher OMC.

- The flyash was mixed with 0%, 2%, 4%, 8% and 12% of lime and the highest MDD was found to be 11.68kN/m^3 with an OMC of 34.12% at 12% lime. From the above results, it can be stated that the addition of lime results in a decrease of OMC value whereas MDD value increased.

- The flyash was mixed with 0%, 5%, 10%, 15% and 20% of slag and the highest MDD was found to be 11.66kN/m^3 with an OMC of 34.16% at 20%

slag. From the above results, it can be stated that with the addition of slag, OMC decreases and MDD increases.

- A combination of slag and lime with flyash has been made and OMC and MDD were determined for each combination. The mixture with 20% slag and 12% lime with flyash possess highest MDD 12.12kN/m^3 at lowest OMC of 32.23%. So it can be stated that with the addition of lime and slag MDD increases whereas OMC decreases.

- UCS has been done with sample size 76mm in height and 38mm in diameter, compacted to corresponding OMC and MDD determined by light Compaction test. The UCS for virgin flyash was found to be 0.24MPa

- UCS value for flyash treated with lime at 0%, 2%, 4%, 8% and 12% was determined and it was found that the maximum UCS value was 1.22MPa at 12% lime. The effect of curing period has also been studied and the samples were cured to 0, 7, 14 and 28 days of curing period. The maximum UCS value was found to be 5.75MPa at 12% lime and 28 days of curing period.

- UCS value for flyash treated with slag at 0%, 5%, 10%, 15% and 20% was determined and it was found that the maximum UCS value was 0.25MPa at 20% slag determined immediately. The samples were cured for 7, 14 and 28 days of curing period. The maximum UCS value was found to be 1.39MPa at 20% slag and 28 days of curing period that indicates a substantial increase in UCS value of virgin flyash with the addition of slag alone.

- The UCS value of the different combination of flyash, lime and slag were determined at different curing periods. And it has been found that the flyash with 12% lime and 20% slag possess maximum strength after 28-days curing period, was 8.44MPa.

- According to "GUIDELINES FOR DESIGN OF FLEXIBLE PAVEMENTS" by IRC: 37-2012, UCS for sub-base should be 1.5 to 3MPa and for base course UCS should be 4.5 to 7MPa. The result obtained by the current project was found to be more than the requirements. So in future, it can be used as a sub-base or base course of pavement.

5.2 Scope for Future Work

Some of the investigation that is necessary for effective utilization of lime activated flyash with GGBS are-

- The performance of the above material under repeated loading condition to be evaluated.
- Variation in curing temperature to investigate the effect of curing temperature on UCS.
- CBR test to check the CBR values of mixtures.
- Permeability test to check the permeability of mixtures.
- Durability test to check the durability aspects.
- oedometer test to the consolidation characteristic of mixtures.
- The effectiveness of lime activated flyash with GGBS against leachate quality coming out.

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