摘要

从普通碎石路面到沥青路面再到混凝土路面，路面的结构性能不断地得到改善。通常天然地基不能承受车辆和其它交通荷载，所以一般需要在地基上面建筑路面。由于采用混凝土路面所需费用很高，故用稳定粒料路面代替。稳定路面的作用旨在改善土和路面的工程性能。稳定的形式有三种，即土工合成形式（土工布或土工格栅）、力学稳定（压实）和化学稳定（加入某些化学物质或者添加剂），本文主要研究化学稳定，特别是水泥和粉煤灰稳定的道路路面。基层和底基层的水泥稳定是最普通的化学稳定形式。这是因为与其他添加剂相比，水泥的掺入会使混合料的强度有很大的提高，并且具有优越的工程性能。但是过去用水泥处理的基层性能不好，使得基层和底基层出现过大的断层和收缩裂缝，当水泥含量提高时，这些现象更加明显。多年来，有很多研究致力于解决这些问题。将附加胶凝材料（SCM'S）如石灰、粒状高炉矿碴（BFS）、粉煤灰（FA）和非晶体硅石（AS）加入到土与水泥混合料中，可以减少或消除上述不利影响。在减少和消除这些不利影响的附加剂中，SCM' S 附加剂可以改善混凝土的力学和结构性能，还可减少材料费用（因为 SCM'S 附加剂比水泥便宜）。但是这些附加胶凝材料随土或石的不同以及养护条件和养护时间的不同，作用效果也不相同，所以附加胶凝材料的类型与用量、土石类型、道路（现场条件）或试件养护条件与养护时间对道路或试件的强度、结构或力学性能有显著影响。

本文研究利用水泥掺粉煤灰稳定或加强路面的好处，以及象配合比设计、温度、湿度、时间这些因素是怎样影响稳定路面的结构和力学性能的。试验采用粘土、普通波特兰水泥和 F 级粉煤灰。对土的分类、密度、密实度及无侧限受压强度进行了试验，因为这些性能指标与其它工程力学特性如刚度和耐久性有关。在试验室制作了试件来模拟现场稳定过程。按不同比例的水泥和粉煤灰制作了试件并压实后在不同的养护条件下养护不同的时间。一共采用了十四个不同的配比，胶凝材料用量在碎石干重的 0 到 20%范围内变化。养护条件分温度 20℃和湿度 100%、室内温度和湿度、温度 60℃和湿度 100%三种。养护时间为 7 天和 28 天两种。对于每一种配比制作了 6 个试件，在三种不同的养护条件下养护，在指定的养护时间结束后，对试件进行了无侧限受压试验，并记录了强度以备分析，从中找出哪一种配比最经济同时又有良好的力学和结构性能。

对得到的强度结果采用统计软件 SPSS 进行了理论与数值分析，在理论分析时，用 excel 绘制了直方图来表示强度随配比、温度、湿度以及龄期的变化规律。在数值分析中用 SPSS 软件进行了线性回归分析。统计结果表明强度与配比、温度、湿度和龄期的相关性以及它们的相关程度。理论分析与试验结果吻合良好。

两种分析表明，水泥掺粉煤灰提高了稳定或加强路面的力学和结构性能。对不同的混合物，掺粉煤灰的水泥试件脆性变小，而且配比设计、温度、湿度、时间对水泥-粉煤灰-碎石稳定路面的结构和力学性能有很大的影响。混合料的强度随水泥和粉煤灰用量的增加而增加，但是超过一定比例后，强度反而降低。在一定的养护条件和养护时间内，试件的强度随温度、湿度和时间的增加而增加，不掺粉煤灰和水泥掺量大于粉煤灰掺量的试件在前 7 天的强度增长较快，但是随后增长速放慢。相反，对于只掺粉煤灰和粉煤灰掺量大于水泥掺量的试件，前 7 天的强度增长慢，但随后强度增长加快。

关键词：路面层、水泥—粉煤灰加固、无侧限抗压强度、线性回归分析

Abstract

Roads have developed from ordinary gravel roads to asphalt roads to concrete roads, each with increasing improvement in structural properties. Most of the time the natural subgrade is not strong enough to carry or support loads from vehicles and other traffic, so it is normally required to build a pavement on top of the subgrade (the in-situ soil). Instead of building a road exclusively made of concrete, which can be very expensive, pavement layers can be reinforced or stabilized. Reinforcement or stabilization is aimed at improving the engineering properties of the soil and subsequently that of the pavement. Reinforcement or stabilization can be in the form of geosynthetics (geotextiles or geogrids), mechanical (compaction) or chemical (addition of certain chemicals or additives). This research concentrates mainly on chemical stabilization, specifically cement and fly ash stabilization of pavement layers of a road. Cement stabilization of bases and subbases is the most common form of chemical stabilization; this is because cement when compared to other additives provides considerable strength to the mixture and has excellent engineering properties. However cement treated bases have shown poor performances in the past. Cement treated bases and subbases exhibit excessive pumping, faulting, and shrinkage cracking. These are thought to be more pronounced as the cement content is increased. A lot of research has been done over the years to help combat these problems. Supplementary cementitious materials (SCM's) like lime, granulated blast furnace slag (BFS), flyash (FA), and amorphous silica (AS) have been added to soil-cement mixtures to help reduce or eliminate the above mentioned undesirable effects on soil - cement mixes. In addition to reducing and eliminating such undesirable effects, addition of SCM's improves the mechanical and structural properties of the concrete and subsequently cut material costs (as some cement is replaced by SCM's, which are cheaper than cement). These supplementary cementitious materials however perform differently with different soils or rocks and also under different curing conditions and durations, so the type and amount of supplementary cementitious material used, type of soil or rock used, conditions under which the road (insitu) or the sample (laboratory) is cured and duration of curing are thought to grossly affect strength, structural and mechanical properties of the road or laboratory sample.

This thesis presents research on the benefits of adding flyash to cement mixes for stabilizing or reinforcing pavement layers and how factors like mix design, temperature, humidity and time affect the structural and mechanical properties of stabilized pavement layers. A cohesionless-frictional soil, ordinary Portland cement and Class F flyash was used. Soil classification, density and compaction and unconfined compressive strength tests were performed as these properties identify or relate to other engineering properties such as stiffness, durability etc. Samples were fabricated in the laboratory to simulate insitu stabilization process. Samples made of different proportions of cement and flyash where made, compacted and cured at different curing conditions and durations. Fourteen different mixes were used and cementitious material content was between 0% and 20% of dry weight of gravel. Curing conditions were 20°c and 100% humidity, room temperature and humidity and 60°c and 100% humidity. Curing durations were 7 days and 28 days. For each mix, six samples were made and cured at the three different curing conditions and the two different curing durations. After the specified curing durations, unconfined compressive tests (UCS) were done on the cured samples and strength results in Psi (pounds per square inch) were recorded for subsequent analysis, to see which one is the most economic (in terms of least cement or flyash content) but with good mechanical and structural properties.

The strength results got were analyzed theoretically and numerically (using Statistical Package for Social Scientists, SPSS). In the theoretical analysis, simple excel plots were drawn in the form of histograms to show how strength varies with respect to mix, temperature, humidity and number of days. In the numerical analyses, linear regression analyses were done using SPSS software. The statistical outputs showed how strength, mix, temperature, humidity and number of days are correlated and the extent of their correlation. The theoretical and numerical analyses agree with each other in every way.

From the two analyses, it was concluded that flyash enhances the mechanical and structural properties of cement mixes used in stabilizing or reinforcing pavement layers. For the different mixes, cement samples with flyash incorporated in them were less brittle and showed an increase in strength than their cement only counterparts. Also it can be concluded that factors like, mix design, temperature, humidity and time affect the structural and mechanical properties of cement-flyash-gravel (CFG) stabilized pavement layers greatly. For both cement and flyash, as cement and flyash content is increased, strength increases, but starts to decrease after a certain percentage is exceeded. Within the specified curing conditions and durations, as temperature, humidity and number of days increases, strength of samples increased. Cement only and more cement than flyash samples gain strength at a faster rate within the first 7 days but continue to gain strength at a slower rate afterwards. It is the opposite for flyash only and more flyash than cement samples, their rate of strength gain is slow within the first 7 days but increases afterwards.

Keywords: Pavement Layers, Cement-Flyash Stabilization, Unconfined Compressive Strength, Linear Regression Analysis.

List of Abbreviations

1-0-19:	5% by weight of cement, 0% by weight of flyash and 95% by weight of gravel, this holds for all the others. The ratios are got by dividing each part of the mix design by 5.
100%H:	100% Humidity.
RT & H:	Room Temperature and Humidity.
C-F-G:	Cement-Flyash-Gravel.
deg:	means °c or degrees centigrade

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Dedication

Dedicated to my Dad and Mum
Kwame Leslie Albert Harleston
And
Khadijatu Kubura Harleston

Thank you very much for letting me come this far. You guys gave your all for Sariffou and I . I don't have words to describe how I feel about you guys, how grateful I'm to have you guys as parents and how I love you guys. I pray the good LORD continue to bless and keep you guys and that we will all make it to heaven one day.

To the world's greatest parents, I say Thank You!!!

Chapter 1 Introduction

1.1 Background/Problem statement

Roads have developed from ordinary gravel roads to asphalt roads to concrete roads, each with increasing improvement in structural properties. With the growth of traffic volume and axial load, the requirements for pavement performances are higher each day.

Most of the time the natural subgrade is not strong enough to carry or support loads from vehicles and other traffic, so it is normally required to build a pavement on top of the subgrade (the in-situ soil), this should be strong enough to support vehicular and any other traffic using the road as well as adequately distribute these loads to the underlying subgrade, so as to not to cause any permanent distress or deformation of the subgrade[1, 2]. A typical urban road pavement is made up of the natural subgrade, subbase, base course and then the wearing course (which is in direct contact with vehicles and other traffic)[3, 4]. Depending on the type of wearing course, roads can be classified as rigid (normally made of Portland cement concrete) pavement or flexible (normally made of asphaltic concrete) pavement[5, 6]. Both types of pavements distribute loads and stresses differently to the underlying subgrade[7, 8]. Whether a pavement is rigid or flexible it is often necessary to reinforce or stabilize the underlying soil, be it subgrade, subbase or base course. Loose sand, soft clays, and organic deposits are often unsuitable for use in construction due to their less-than-desirable engineering properties[9, 10]. Construction of any infrastructure over a weak or a soft soil is highly typical on geo-technical grounds as the soil undergoes differential settlements, poor shear strength and high compressibility[11, 12]. Normally, the type of design varies depending upon the availability of soil strata as well as cost involvement. When faced with such soil conditions, improvement of load bearing capacity of soil is very much essential[11]. In these aspects, improvement of load bearing capacity of soil has been improved by adopting various techniques like soil stabilization, adoption of reinforcement etc. Traditional methods of stabilizing these soils through in-situ ground improvement or replacement techniques are costly. Instead of building a road exclusively made of concrete, which can be very expensive, pavement layers can be reinforced or stabilized. Reinforcing or stabilizing is aimed at improving the engineering properties of the soil and subsequently that of the pavement. This directly translates to a better, long lasting and relatively low cost road pavement. Reinforcement or stabilization can be in the form of geosynthetics (geotextiles or geogrids), mechanical (compaction) or chemical (addition of certain chemicals or additives)[13, 14]. This research will concentrate mainly on chemical stabilization, specifically cement and fly ash stabilization of subbases and bases of road pavements. Nevertheless some literature will also be reviewed on the other forms and types of reinforcement or stabilization. Cement stabilization of bases and subbases is the most common form of chemical stabilization; this is because cement when compared to other additives provides considerable strength to the mixture and has excellent engineering properties. Cement stabilization of subbases and bases started around 1945[15, 16]. However cement treated bases have shown poor performance under both flexible and rigid pavements in the past. Cement treated bases and subbases exhibit excessive pumping, faulting, and shrinkage cracking[17]. This is most likely due to the impervious nature of the base, which traps moisture and yet can break down and contribute to the movement of fines beneath the slab. These are thought to be more pronounced as cement content is increased[18, 19]. Erosion and stripping (water washing away cement paste, binders, and fines) can also be an issue for cement treated bases and subbases[17]. A lot of research has been done over the years to help combat these problems. Supplementary cementitious materials (SCM's) like lime, granulated blast furnace slag (BFS), flyash (FA), and amorphous silica (AS) have been added to soil-cement mixtures to help reduce or eliminate the above mentioned undesirable effects on soil - cement mixes[20,21]. In addition to reducing and eliminating such undesirable effects, addition of SCM's improves the mechanical and structural properties of the concrete and subsequently cut material costs (as some cement is replaced by SCM's, which are cheaper than cement)[20]. These supplementary cementitious materials however perform differently with different soils or rocks and also under different curing conditions and durations, so the type and amount of supplementary cementitious material used, type of soil or rock used, conditions under which the road (insitu) or the sample (laboratory) is cured and duration of curing are thought to grossly affect strength, structural and mechanical properties of the road or laboratory sample. Of the most popular SCM's flyash is one of the most recently used (around 1975)[15] and research on it is relatively small as compared to the others (lime and BFS). This research will look into various mix designs of a particular gravel mixed with cement and a Class F flyash(cured under different conditions and durations) and see which one is the most economic (in terms of least cement or flyash content) but with relatively high unconfined compressive strength. Also, careful attention would be given to the cured samples to see which one had fewer cracks and shrank less. This will help highway engineers to select optimum mix designs that will be economical and meet strength criteria at the same time.

1.2 Objectives

1.2.1 General

To evaluate the usefulness of flyash in concrete mixtures used for reinforcing pavement sections.

1.2.2 Specific

The objectives of this investigation were to conduct series of comprehensive laboratory tests on soil samples

1) To assess the usefulness of flyash as an admixture in concrete mixtures for pavement construction and focus on how it affects the mechanical properties of the pavement.
2) To determine to what extent (greater or lesser) does CFG affect the mechanical properties of pavement sections when compared to ordinary cement reinforced pavement sections.

The study was aimed at evaluating the mechanical and engineering properties of cement reinforced and CFG reinforced soil samples, thereby determining how and to what extent these two different reinforcement techniques affect and improve soil engineering properties.

1.3 Research Scope

The geotechnical characteristics of ordinary cement samples and cement-flyash samples were investigated. The investigation described the behavioral aspect of samples reinforced with cement only and cement-flyash to improve the load bearing capacity of the pavement. A cohesionless-frictional soil was used for the laboratory tests.

1.3.1 Literature Review

Literature from previous publications and books on pavements, soil reinforcement or stabilization, cement stabilization, flyash stabilization, cement-flyash stabilization and factors influencing the strength, mechanical and structural properties of cement-flyash mixes is reviewed inorder to understand the effects each of the above mentioned have had on pavement engineering.

1.3.2 Testing

Laboratory sieve analysis, density and compaction and unconfined compressive strength (UCS) tests were conducted to establish the feasibility of reinforcing inadequate soils with a mixture of cement and flyash as to the conventional cement only method to support traditional pavement systems.

For the UCS tests, soil samples were prepared with different proportions of cement and flyash and cured under different conditions and durations. These soil samples were then tested after different durations. Also plain soil samples were fabricated, cured and tested the same way as for the cement only and cement-flyash samples, for comparison purposes.

Brief but well detailed explanations of how the tests were carried out in the laboratory are given.

1.3.3 Data Collection

Data was collected from the laboratory tests performed. They were recorded in an orderly manner in charts for analysis.

1.3.4 Data Analysis

Based on the test results, strength properties of the two kinds of reinforced soil samples were studied to get the relation between the strength index of the cement reinforced samples and that of the corresponding cement-flyash reinforced samples. The influences of the mixture variables viz. proportions of cement and flyash in the mixtures and the different curing conditions and durations of soil samples on the bulk mechanical characteristics of the samples were analyzed theoretically and also numerically(using the statistical package for social scientists software, SPSS).

1.3.5 Conclusions and Recommendations

After analyzing the data collected, theoretically as well as numerically, a small comparison of the two analyses was done and subsequent conclusions and recommendations are made.

Chapter 2 Literature Review

2.1 Background

Construction of any infrastructure over a weak or a soft soil is highly typical on geo-technical grounds as the soil undergoes differential settlements, poor shear strength and high compressibility. Normally, the type of foundations varies depending upon the availability of soil strata as well as cost involvement. Sometimes, it is essential to have a high rise building over a weak soil or a road on impossible soils, in such conditions, improvement of load bearing capacity of soil is very much essential. In these aspects, improvement of the load bearing capacity of soil has been done by adopting various techniques like soil stabilization, adoption of reinforcement etc. Generally, admixing technique in soil is an effective ground improvement because of its easy adaptability[11].

Soil reinforcement is a special and recent field of soil improvement. It covers a range of techniques which consist of placing resisting inclusions in the soil. Depending on the type of the inclusion two extreme cases can be considered: a 'uniform inclusion' where the soil-reinforcement interaction can develop in any point along the inclusion; a 'composite inclusion' which consists of an inclusion reinforced at some particular points where the soil-reinforcement interaction is concentrated. In the case of a 'uniform inclusion' a relatively high and uniform density of the reinforcements will result in a new composite material called the 'Reinforced Soil'. The behavior of the 'reinforced soil' mass can be investigated considering a representative sample of the new composite material. Reinforced soil is a soil strengthened by a material capable of resisting tensile stresses and interacting with the soil through friction and/or adhesion. The effect of the reinforcement can be interpreted as a restraint against expansion in the form of induced normal or shear stresses[22].

In the constant search for low-cost solutions to road construction and maintenance problems, one area of new technology which has already shown major cost savings is the use of geosynthetics or geotextiles especially in the reinforcement of roads, embankments and reinforced soil retaining walls[23].

About 35 years ago, the first generation of geosynthetics took its place in geotechnical engineering. Initial refusal to accept geosynthetics as a building material has ceased. Today, geosynthetics are classified as an independent building material because of their diversity and specific attributes. Existing as geotextiles, geogrids, geomembranes and related products, they enable technically simple, low-priced and alternative solutions. Many geotechnical applications nowadays cannot be imagined without geosynthetics[24].

Applications of geotextiles in civil engineering have been successfully developed and also offer other benefits in terms of durability and performance. Geotextiles also play an important role in geotechnical engineering works, like railroads, reinforced soil, and stabilization of soil or rock slopes, drainage control, dams, tunnel constructions, reservoirs, coastal engineering and canals[25].

Geosynthetic materials have found useful applications when unbound aggregates have been placed on cohesive soil with very weak subgrade. They have also been successfully used in retarding reflective cracking in both flexible and rigid pavements. There are many applications of geosynthetics in pavement engineering yet there is considerable lack of understanding in the behavior of the material. Geosynthetic materials exhibit very peculiar properties in the area of tensile strength and reinforcement[26, 27].

In road construction, substitution of conventional steel reinforcing bars with geosynthetics or geotextiles in Continuously Reinforced Concrete Pavement (CRCP) also gives solutions to the problems caused by corrosion of reinforcement. Concrete volume change is known to cause crack development in CRCP in the early age, afterwards, wheel load will be the governing factor for the development and the propagation of further cracks. Fabrics have been successfully used for roads on very soft subgrade for some time, usually fulfilling one or more of the basic functions of separation, filtration, drainage and reinforcement. By providing reinforcement, geotextiles improve the performance of unpaved or paved roads, and for a given traffic, the thickness of the aggregate layer can also be reduced[28, 29].

Also, recycled materials such as scrap tires, plastics, ash, slag, and construction debris provide a viable alternative both for their relatively lower cost and desirable engineering properties. Furthermore, use of recycled materials prevents their disposal into landfills, which are approaching capacity in many parts of the world. Generally, admixing technique in soil is an effective ground improvement because of its easy adaptability[30, 29].

In recent years, with the extensive application of deep mixing method in reinforcing soft clay, studies on the basic properties of cement-soil had been conducted deeply. In-place cement-stabilized soils have served as the primary base material for the majority of pavements worldwide for many years. These materials are economical and can be easily constructed and provide outstanding structural characteristics for pavements. However, these cement-treated materials crack due to shrinkage, with the cracks reflecting from the base to the surface. In order to improve the economic and social benefits of the deep mixing method, fly-ash is normally incorporated in cement-soil mixes[31].

Fly ash is a waste produced from burning of coal in thermal power stations. The staggering increase in the production of fly ash and its disposal in an environmentally friendly manner is increasingly becoming a matter of global concern. Efforts are underway to improve the use of fly ash in several ways, with the geotechnical utilization also forming an important aspect of these efforts. It is currently used in various areas of Civil Engineering namely: load bearing fills, soil stabilization, concrete and in a variety of grouting applications. A better understanding of flyash can help in providing geotechnical engineers a lot of information on how and to what extent it can be incorporated in engineering practices inorder to maximise its use[32, 33].

2.2 Roads and Pavements

Roads and highways are broadly classified as permanent and temporary. Permanent Roads — paved and unpaved systems usually remaining in service for ten years or more. Temporary Roads — unpaved or paved (e.g., construction bypass) systems with a short service life, usually less than one year[34, 1].

Pavements are also classified as flexible or rigid

Flexible pavement---the wearing course is made of asphaltic concrete (most popular).

Rigid pavement----the wearing course is normally made of ordinary Portland cement concrete[35].

For permanent roads, a roadway *section* consists of a complete pavement system, including its associated base course, subbase course, subgrade, and required drainage system components. A *pavement system* consists of one or more layers of flexible asphalts together with their associated seal, tack and prime coats[15, 36].

Referring to figure 2.1, the following general terminology is typically used in the pavement and stabilization industries. The *subgrade* refers to the insitu soils on which the stresses from the overlying roadway will be distributed. The *subbase* or *subbase course* and the *base* or *base course* materials are stress distributing layer components of a pavement structure. The subbase and base materials must be able to provide drainage in the pavement structure[15, 37].

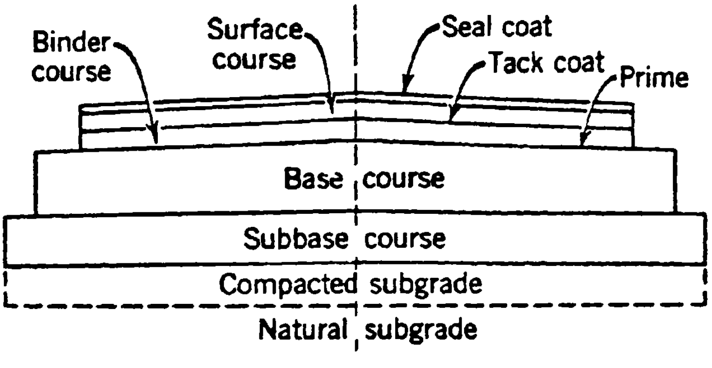


Figure 2. 1 Pavement Structure Terminology[38]

2.3 Soil stabilization

Construction of long lasting, economical flexible pavement structures requires subgrade materials with good engineering properties. Desirable properties that the subgrade should possess to maximize the service life of the roadway section and to minimize the required thickness of the flexible pavement structure include strength, drainage, ease and permanency of compaction, and permanency of strength[38, 39]. In many locations, the insitu soils are high plasticity clays or other types of fine-grained soils, which are not satisfactory materials for use as subgrade in a pavement structure. These subgrade soils exhibit poor strength, shrink/swell, freeze/thaw, and load deformation properties and must be replaced or stabilized in some manner. Bases and subbases needs to be stabilized at times, especially when they do not meet the desired physical, mechanical and structural specification for an intended pavement design[15, 40]. Soil stabilization techniques include physical, mechanical and chemical (physicochemical).

2.3.1 Physical

Compaction-compaction has the following effect on the soil, increases density, increases strength and reduces permeability. Compaction is aided by the addition of water.

Altering size distribution- as in concrete, having particles of varying sizes will improve packing density and reduce the risk of segregation.

Drying-performance of soil can be greatly improved by drying in the sun or oven.

2.3.2 Mechanical

Mechanical stabilization normally refers to the use of geosynthetics and addition of inert materials such as surge stone to increase the effective bearing capacity of soft subgrade soils while reinforcing the overlying subbase or base course. Geosynthetics used in pavement systems include woven and nonwoven geotextiles, geogrids, and Geogrid-Geotextile composites. Work performed to examine the use of geosynthetics as reinforcement in unpaved roads began in the mid-1970s. Geotextiles were examined first, since geogrids were not readily available until the mid-1980s[34].

Mechanical stabilization does not affect the other engineering properties of the subgrade soils. Base course reinforcement is applicable to subgrades with a CBR (California Bearing Ratio) greater than or equal to 3. Potential benefits of base course reinforcement include: reduced surface rutting due to lateral movement of the base course aggregate; increased performance periods; decreased life-cycle costs; reduced maintenance; and a reduced base course thickness[15].

2.3.3 Chemical (physicochemical)

Combinations of chemical and/or physical reactions. Materials known as stabilizers or additives are normally added to the soil. *Additives* refer to manufactured commercial products that, when added to the soil in proper quantities and thoroughly mixed, will improve the quality of the soil layer. Examples of admixtures include Portland cement, lime, fly ash, bitumen, and any combination of the cement, lime, and fly ash materials. The two most commonly used chemical stabilization methods are cement and lime stabilization. Chemical stabilization of soils can increase their strength and bearing capacity, and improve their shrink/swell and freeze/thaw characteristics[41].

Because of the significant improvement in soil properties, cementitious stabilized soil has been used as base underlying asphalt or concrete pavement surfaces on an even-increasing scale during the last fifty years. Other benefits of cementitious stabilization include possibly using borderline base materials and avoiding the generally more expensive process of transporting large quantities of granular fill[42].

2.3.4 Materials

1) Soil materials

Almost all types of soils can be stabilized. Some exceptions include organic soils, highly plastic clays, and poorly reacting sandy soils. Typically, soils containing between 5% and 35% passing a No. 200 sieve produce the most economical stabilized soil. Types of soil used include silty sand, processed crushed or uncrushed sand and gravel, and crushed stone.

Soils containing more than two percent organic material are usually considered unacceptable for cement treatment. Fine-grained soils generally require more cement or supplementary cementing materials (SCM) for satisfactory hardening and, in the case of clays, are usually more difficult to pulverize for proper mixing[20].

2) Cementitious materials

For most applications, Type I or Type II Portland cement is normally used. Cement requirements vary depending on desired properties and type of soils. Cement contents may range from as low as 4% to a high of 16% by dry weight of soil. Generally, as the clayey portion of the soil increases, the quantity of cement required also increases. The strength of concrete is directly influenced by the quantity of cement and the water cement ratio[20]. Increasing the quantity of cement and lowering the water cement ratio generally helps produce a denser and more durable mixture with higher early strength, but it may also contribute to a higher potential for uncontrolled cracking. Mixtures with higher quantities of portland cement require more mixing water and consequently shrink more. Even if the water to cementitious materials ratio is minimized, the actual volume of water increases with higher cementitious material content[43].

Conversely, mixtures containing certain fly ashes or ground-granulated blast furnace slag (GGBFS) may experience a retarded early-age strength development, particularly in cooler weather. Depending upon the ambient air, subbase, and concrete temperature, this could delay the concrete set time. This could result in severe strength differences when there is a sudden temperature drop and the subbase remains warm. This may not only delay the time until sawing begins but it increases the risk of uncontrolled cracking in cooler weather because of strength and shrinkage gradients in the pavement[43]. Fly ash with high calcium oxide content or that is mixed with lime has also been used for soil stabilization[44].

3) Water

Water is necessary in a stabilized soil to help obtain maximum compaction and for the hydration of Portland cement or SCM's. Moisture contents of soil with cement or SCM's treated are usually in the range of 10% to 20% by weight of dry soil/stabilizer mixture[20].

2.4 Cement stabilization

2.4.1 Cement- soil stabilization

The use of cement for soil stabilization is over 65 years old. The methods and materials are proven and well established. Portland cement stabilization is commonly referred to as soil cement. Soil cement is a mixture of Portland cement, water and soil compacted to a high density. When cured, the soil cement mixture becomes a hard, rigid base material. A flexible or rigid pavement surface is placed on top of the soil cement to complete the pavement structure[15, 45, 46].

Portland cement is one of the oldest materials used for stabilization. Soil cement is used as a base course, a subbase course and a subgrade treatment for flexible and rigid pavements. Other uses include slope protection for dams and embankments, liners for channels and reservoirs, and mass soil cement placements for dikes and foundation stabilization. Almost all types of soils can be used for cement stabilization except highly organic soils and heavy clay soils. Granular soils with high sand or silt content can be stabilized very well. Stabilized soils must be compacted, cured and protected (as with concrete) after compaction[15].

The four fundamental control factors for the design and construction of soil cement are moisture content, curing procedure and duration, compaction, and cement content. These factors are determined before construction by laboratory testing of representative soil samples using ASTM, AASHTO or any appropriate standard testing procedure. Other test methods developed for local climatic and soil conditions have proven satisfactory in some cases[47].

Soil cement construction follows a prescribed procedure. The objective of the construction procedure is to mix pulverized soil with the correct amount of Portland cement and enough water to permit maximum compaction. The construction procedure entails spreading the prescribed amount of Portland cement, mixing of the soil and cement with sufficient water to bring the soil cement mixture to the optimum moisture content, compacting of the soil cement, finishing the soil cement mixture to grade and curing[15,48].

The objectives of cement stabilization is firstly to improve the engineering characteristics of the subgrade soils, including reduction of the PI of the soil, strength increase, reducing volume change characteristics (shrink/swell), and reducing permeabilities. This is attained primarily through hydration of the cement added to the soil. In addition to the cementing reaction, the surface chemistry of any clay particles is improved by the cation exchange phenomenon. Cement stabilization is generally considered to be too expensive for workability improvement alone. The second objective is to increase the strength of the soil cement mixture over the long term. This objective is attained through continued hydration of the cement with time. A minor strength increase may be attributed to any pozzolanic materials used in the soil cement mixture[15, 49].

2.4.2 Mechanism of Cement Stabilization

The improvement of the engineering properties of soil cement is often attributed solely to the hydration of the Portland cement added to the soil material to be stabilized. This concept assumes that the soil is inert, similar to an aggregate in Portland cement concrete. In reality, the soil is not inert and certain physico-chemical reactions take place between the cement, water, and soil [15, 50, 51, 52, 53]. The four mechanisms contributing to the cement stabilization of soil materials are summarized in Table 2.1[15].

Table 2. 1 Mechanisms Contributing To Cement Stabilization of Soil Materials

Cement Stabilization Mechanism	**Description**	**Importance**
Hydration of Cement	Strong linkages develop between the soil particles. Continuous skeleton of hard, strong material forms and encloses a matrix of unaltered soil, strengthening the treated material and filling some of the voids. Permeability and shrink/swell tendencies reduced, Resistance to changes in moisture content increased.	Highest
Cation Exchange	Cation exchange alters electric charge, reducing plasticity and resulting in flocculation and aggregation of soil particles.	High
Carbonation	Lime generated during hydration of cement reacts with carbon dioxide in air to form cementing agents.	Minor
Pozzolanic Reactions	Free lime liberated during hydration and from silica or alumina from clay particles react in the presence of moisture to form cementing agents.	Minor

2.5 Flyash stabilization

Fly ash is a pozzolan, which in the presence of lime [CaO or $Ca(OH)_2$]; fly ash hardens when in contact with water.

Fly ash has been successfully used with granular and fine-grained materials to improve soil characteristics, providing adequate support for pavements and improving working conditions where undesirable soils are encountered[15, 54]. Stabilization of soils with fly ash alone has been limited in the U.S, China and other industrialized nations in the world. Fly ash and other ash, such as bottom ash and boiler slag, have been widely used in applications with cement, lime, and/or bituminous materials. Fly ash bound mixtures (FABM) are mixtures of fly ash and other constituents that have a water content compatible with compaction by rolling and a performance that relies on the pozzolanic properties of the fly ash.

The quality and reactivity of fly ashes varies with source. In the U.S fly ashes from bituminous coals found in the Appalachian region do not behave as true pozzolans, with little or no cementing property except when a source of lime is added. Fly ashes produced from burning coal from the mid-continent have natural setting properties because of the lime naturally available in these ashes. Fly ashes produced from the subbituminous and lignite coals from the northern and western plains states have high natural lime content and may be highly cementitious, even without any addition of lime[15, 55].

The factors that most readily influence the quality and reactivity of fly ashes are the source of coal, the degree of pulverization of the coal, the efficiency of the burning operation, and the collection and storage methods of the ash. ASTM classifies fly ashes as either Class C or Class F (ASTM Designation C 618). The basic difference is the percent lime in the ash[15].

A successful lime or lime-cement-fly ash (LCF) base or subbase is reflected in the magnitude of deflections in the final product, the unconfined compressive strength, shear strength, and bearing strength. Durability is often measured in terms of weight loss, strength reduction, absorption, or softening. Construction procedures are similar to those discussed for cement stabilization. Cement-fly ash uses are the same as those discussed for cement stabilization[15, 56, 57, 58].

2.6 Factors influencing the strength, mechanical and structural properties of cement-flyash mixes

The properties of stabilized soil are influenced by several factors, including the type and proportion of soil, the type and proportion of cementitious materials, water content, compaction, uniformity of mixing, curing conditions, and age of the compacted mixture. Because of these factors, a wide range of values for specific properties may exist. Important properties include density, compressive strength, stiffness, durability, permeability, and volume stability[20].

2.7 Effect of Soil Parameters on the Performance of the Pavement Structure

Several aspects of basic soil mechanics influence the performance of the subgrade and therefore the entire pavement structure. These are summarized in Table 2.2 for a conventional flexible pavement structure. These parameters impact soil stabilization of pavement layers[15, 59].

Table 2. 2 Soil Parameters Affecting the Performance of a Flexible Pavement Structure

Parameter	**Discussion**
Compaction	Compaction increases density with a consequent lower in-service moisture content, even in the event of subsequent saturation.
Strength, Moisture–Density, and CBR	Soaked CBR vs. moisture content curve will have a shape similar to moisture-density curve. A higher density results in a higher CBR, which is a measure of strength.
Shrink/Swell	Subgrade soils with a high PI have a high potential for volume change. An increase in moisture results in swelling and consequent heaving of the pavement structure. A loss of moisture can result in shrinkage. Shrinkage cracking of the subgrade can result in reflection cracking in flexible pavements and can create a pathway for moisture to enter into the subgrade.
Drainage	Improper drainage can allow an increase in moisture content. Results are loss of subgrade strength, heaving of subgrade soils, and more severe frost action.
Frost Action	Includes frost heave and loss of subgrade support during frost melt.
Seasonal Wetting and Softening	Seasonal wetting leads to softening of the subgrade and loss of subgrade support and consequent rutting and other pavement distress. Freezing temperatures can worsen this problem.
Contamination of Aggregate	Improper gradation differences between base course and subgrade can result in migration of fines and contamination of base course material with subgrade material. This impedes drainage, reduces the strength of the base course and the subgrade, and results in rutting and other pavement distress.

2.8 Engineering Properties and Characteristics of Soil-Cement Mixtures: Laboratory Results

During construction, soil cement is compacted to a high density. As the cement hydrates, the soil cement mixture hardens in this dense state and becomes a slab-like structural material. Soil cement can bridge over small, local weak subgrade areas and does not consolidate under traffic. If the appropriate freeze-thaw and wet-dry soil cement design criteria have been satisfied, the soil cement will not rut or shove during spring thaws and will be minimally affected by water or, freezing and thawing[15].

Since soil cement is a structural material, it possess engineering properties and characteristics such as maximum dry density, optimum moisture content, shrink/swell, unconfined compressive strength, CBR, and freeze-thaw resistance. The magnitude of these properties and characteristics is dependent on several primary factors like the ones mentioned earlier. Because of these factors, a wide range of values for specific engineering properties and characteristics may exist.

2.8.1 Density and compaction

Density of treated soil is usually measured in terms of dry density. Adding cementitious materials to a soil generally causes some change in both optimum moisture content and maximum dry density for a given compaction effort. However, the direction of this change is not usually predictable[20]. The flocculating action of the cementitious materials tends to produce an increase in optimum moisture content and decrease in maximum density. However, for cement, its high specific gravity relative to the soil tends to produce a higher density. In general, for given cementitious material content the higher the density, the higher the compressive strength of the stabilized soil mixtures[20].

2.8.2 Compressive strength and stiffness

Unconfined compressive strength is the most widely referenced engineering property of soil cement. Unconfined compressive strength is typically measured using ASTM D 1633[15, 60]. The unconfined compressive strength is an indicator of the degree of reaction of the soil-cement (cementitious materials) - water mixture and of the rate of hardening. The unconfined compressive strength serves as a criterion for determining the minimum cement content requirements for proportioning soil cement (cementitious) mixtures. Factors which can affect the unconfined compressive strength of soil-cement mixtures include moisture density, cement content, soil type and gradation, curing conditions and duration, compaction and compactive effort, length of mixing, degree of pulverization, cement(cementitious) type, repeated loads, and shrinkage[15].

Typical ranges of 7 day and 28 day unconfined compressive strengths for soaked soil-cement mixture specimens are presented in Table 2.3. Soaking specimens prior to testing is recommended since most soil cement mixtures may become permanently or intermittently saturated during the service life of the soil cement, and since soil cement mixtures exhibit a lower unconfined compressive strengths under saturated conditions. The data in Table 2.3 are grouped under broad textural soil groups; these textural groups include the range of soil types normally used in soil cement construction. The ranges of values presented in Table 2.3 are representative of the majority of soils normally used in soil-cement construction[15].

Table 2. 3 Ranges of Unconfined Compressive Strengths of Soil-Cement

(After ACI 230.1R-90)

Soil Type	7-Day Soaked Compressive Strength, psi	28-Day Soaked Compressive Strength, psi
Sandy and gravelly soils	300 – 600	400-1000
Silty soils	250-500	300-900
Clayey soils	200-400	250-600

The strength development of soil stabilized with most SCM's also follows a similar pattern as that with cement. The strength increases rapidly at first, generally during the first 7 days of curing. Depending on the type of soil, the 28 day unconfined compressive strength can reach up to 700 psi.

2.9 Mix Proportioning and Construction

The principal structural requirements of a hardened soil-stabilizer mixture are based on adequate strength and durability[20].

2.9.1 Proportioning

Various criteria are used by different organizations to determine acceptable mix proportions. The durability and strength requirements developed by USACE for Portland cement stabilization are given in Tables 2.4 and 2.5, respectively[20].

In many cement stabilized soil applications, both strength and durability requirements must be met to achieve satisfactory service life. It is common practice, however, to use compressive strength to determine the minimum cement content[20].

Table 2. 4 USACE durability requirements

Type of soil stabilized	**Maximum allowable weight loss after 12 wet-dry of freeze-thaw cycles, percent of initial specimen weight**
Granular PI <10	11
Granular PI >10	8
Silt	8
Clays	6

Table 2. 5 USACE minimum unconfined compressive strength criteria

Stabilized soil layer	**Minimum unconfined compressive strength at 7 days, psi**	
	Flexible pavement	Rigid pavement
Base course	750	500
Subbase course, select material or subgrade	250	200

2.10 Remarks

Pavement layers of roads (especially subgrades) often need to be reinforced or stabilized, inorder to improve their engineering properties and to meet the required design criteria and specifications.

Pavement layers can be stabilized physically (compaction), mechanically (geosynthetics and other related products) and chemically (addition of stabilizers or additives like cement to the soil).

Almost all types of soils can be stabilized, except organic soils, high plastic clays and poorly reacting sandy soils.

Cement stabilization is the most common form of pavement stabilization, because when compared to other forms of chemical stabilization, it has considerable strength. However cement stabilization has its shortcomings, so it is often necessary to add other kinds of cementitious materials (supplementary cementitious materials, SCM's) to make up for these shortcomings. Many SCM's have being discovered and used, with flyash being the most recent. Cement-flyash stabilization of soils occurs mainly through four processes, hydration of cement, cation exchange, carbonation and pozzolanic reactions (mainly due to the added flyash). The properties of stabilized soil are influenced by several factors, including the type and proportion of soil, the type and proportion of cementitious materials, water content, compaction, uniformity of mixing, curing conditions, and age of the compacted mixture. Because of these factors, a wide range of values for specific properties may exist. Important properties include density, compressive strength, stiffness, durability, permeability, and volume stability.

Cement and flyash added in right proportions to pavement layers and cured properly give excellent results.

Chapter 3 Experimental Program and Laboratory Testing

3.1 Experimental program

Based on the research objectives and scope as well as information from the literature review, an experimental program was organized into the following components: experimental studies of a cohesionless-frictionless soil stabilized using different kinds and proportions of cementitious materials in order to develop cost effective methods to reinforce or stabilize the soil; and a general experimental investigation of factors influencing the mechanical properties of the soil reinforced with these cementitious materials.

3.2 Laboratory Soil Testing

Lots of tests are available concerning the materials characterization of stabilized soils. Among them soil classification, density and compaction and compressive strength are the basic and most important. These identify or relate to other engineering properties such as stiffness, durability etc., and lead to routine laboratory soil testing procedures for stabilized soils[20, 59]. The present research work was focused on these three basic tests.

Experiments comprising soil classification, compaction as well as unconfined compressive strength testing were conducted according to TB 10102-2004, GB/T 50123-1999, GB 10102-2004 (specifications of railway and road construction in china), respectively.

3.2.1 Soil Classification

Soil classification categorizes soils according to their probable engineering behavior. By knowing the soil classification, a fairly good idea is obtained of the way the soil will behave during construction and service. According to TB 10102-2004 or GB/T 50123-1999 (specifications of railway and road construction in china), laboratory tests for soil classification comprise grain size analysis and Atterberg limit tests. The particle-size distribution involves two tests, which determine the percentages of individual particle sizes present in a soil. These two methods are sieve analysis for particle sizes larger than 0.075 mm in diameter, and hydrometer analysis for particle sizes smaller than 0.075 mm in diameter. If significant (quantities of both coarse- and fine- grained particles are present in the given soil, the results of both tests may have to be combined to give the particle-size distribution. The results of a particle-size analysis are presented to make a plot of the sieve or particle size versus the percentage passing the given sieve. The results of this test are of most value when used for soil classification purposes. It is often found that the larger the particle size, the better will be the engineering properties of the soil for pavement construction[20].

By consistency is meant the property of a soil which is manifested by its resistance to flow. As such it is a reflection of the cohesive resistance properties of the soil rather than of the intergranular ones. These properties are considerably affected by the moisture content of the soil. The behavior of soil can be divided into four basic states: solid, semisolid, plastic, and liquid. The moisture contents defining the transition from one state to another are defined by three limit values. Among them, two of these limits, the liquid limit (LL) and the plastic limit (PL) are used in the engineering classification systems[20].

The liquid limit of a soil is the moisture content, expressed as a percentage by mass of the oven-dry soil, at the boundary between the liquid and solid states. This boundary was arbitrarily defined by Atterberg (1911) as being the moisture content which caused the soil to begin to flow when lightly jarred against the heel of the hand. The plastic limit of a soil may be defined as the moisture content of the soil at the boundary between the plastic and semi-solid states. This boundary was also defined by Atterberg (1911) as the moisture content at which a sample soil begins to crumble when rolled into a thread under the palm of the hand. A value usually used in conjunction with the liquid and plastic limits is the plasticity index. The plasticity index (PI) of a soil is the arithmetic difference between the liquid and plastic limits[20]. The most common application of the Atterberg limits test results is for the purpose of soil classification. Both the liquid limit and the plasticity index can be used to a certain extent as a quality-measuring device for pavement materials, in order to exclude soil materials with too many fine-grained particles that have cohesive plastic qualities[20].

3.2.2 Density and Compaction

Density is an elementary soil property which characterizes the state of a soil. Soil density can be altered by compaction to control and improve other engineering properties such as compressibility and strength[20]. The denser the soil, the higher it's strength. Wherever soil is used for pavement construction purposes, it is placed in a loose state and then compacted by rolling or vibrating until the desired degree of compaction is achieved.

Field moisture-density tests provide a means by which compaction of the soil is controlled on site. The moisture-density test is designed specifically to aid in the field compaction of soil. The assumption is that the stability of a given soil increases with increasing dry density. It is therefore common practice to specify the compaction required for a soil or soil-aggregate mixture as a percentage of that achieved in the laboratory when compacted at the moisture content which produced the maximum density for the applied effort. The most important factor to be noted about this test is that the presence of a certain amount of water is needed in order to achieve the desired dry densities. Water facilitates the compaction process. However, as the moisture content is increased, a point is reached at which only a small amount of air remains trapped in the soil; this is the point at which maximum density is achieved. Any increase in moisture content above this level simply results in soil being replaced by water, with a consequent reduction in dry density. Thus the laboratory test not only defines the maximum dry density but also suggests how much water should be used during the compaction if this density is to be achieved. However, the laboratory compaction method does not generally duplicate field compaction processes[20].

The compaction test was used to determine proper moisture content and density to which the soil mixture is compacted. The soil is mixed with varying amounts of water and then compacted in molds with volume of 2650.7 cm^3. For each test, the moisture content is determined and the dry density calculated. The relationship between dry density and moisture content reveals the maximum dry density and optimum moisture content.

3.2.3 Strength

Unconfined compressive strength is one of the most widely referenced properties of stabilized soils. Because strength is directly related to density, this property is affected in the same manner as density by degree of compaction and water content[20]. For strength testing, specimens are generally tested at their maximum dry density and optimum moisture content.

The unconfined compressive strength test may be classed as a shear strength test, since it is essentially a triaxial test with zero lateral pressure. For soil stabilization work, the test serves much the same purpose as for concrete work. Particular uses of the test are to determine the suitability of the soil for stabilization with a given stabilizer, to compare different mixes, to specify the stabilizer content to be used in construction, and to provide a standard by which the quality of the field processing can be assessed[20]. The procedure used for preparation of unconfined compressive strength test was similar to that used for the compaction tests. However, the specimens for strength testing were compacted at their corresponding maximum dry density and optimum moisture content values.

3.3 Specimen Preparation and Laboratory testing

A cohesionless-frictional soil obtained from an empty plot of land adjacent to the east gate of the railway campus of Central South University, 32.5MPa ordinary Portland cement and Class F flyash (obtained from Hunan Electric Power Development Co. Ltd) was used for the cement-flyash-gravel (CFG) mixes.

3.3.1 Specimen preparation

All gravel particles with sizes greater than 20mm where removed before soil classification tests and specimen preparation. Specimens where thoroughly mixed by hand and compacted at their respective maximum dry densities and optimum moisture contents before curing. 2650.7cm^3 molds were used for compaction and to prepare specimens. The gravel was mixed with different proportions of cement and flyash. Cementitious materials were between 5% and 20%. Compositions of the test specimens are as listed in Table 3.1.

Table 3. 1 Specimen preparation matrix

	COMPOSITION (WEIGHT %)		
	Cement	**Flyash**	**Gravel**
Mix 1	5	0	95
Mix 2	0	5	95
Mix 3	10	0	90
Mix 4	0	10	90
Mix 5	5	5	90
Mix 6	15	0	85
Mix 7	0	15	85
Mix 8	10	5	85
Mix 9	5	10	85
Mix 10	20	0	80
Mix 11	0	20	80
Mix 12	10	10	80
Mix 13	15	5	80
Mix 14	5	15	80

About 6kg of CFG mix was needed to fill the compaction mold, so the weight of cement, flyash and gravel needed for each mix was obtained by using their respective percentages in the different mixes and multiplying by 6kg to get their respective weights. Example, for mix 1, 5% cement by weight of total mix means 5% of 6kg that is 0.3kg of cement.

The Zhejiang Luda JZ-2D Heavy Electronic compactor was used for compaction.

3.3.2 Curing

Specimens where cured at 20°c and 100% humidity, room temperature and humidity, 60°c and 100% humidity for 7days and 28days respectively. That is each design mix was cured at 20°c and 100%H for 7days and 28days, also at room temperature and humidity for 7days and 28days, and also at 60°c and 100%H for 7days and 28days. This translates to six different curing conditions.

3.3.3 Unconfined Compressive Strength (UCS) Test

After curing under the different curing conditions and durations, each specimen was tested for its UCS using the Lu Da TYA-2000 Hydraulic Pressure Machine. Specimens were not soaked prior to testing as has been done in previous researches.

3.4 Remarks

Three tests, soil classification, density and compaction and unconfined compressive strength tests where done. All three tests where done according to TB 10102-2004, GB/T 50123-1999, GB 10102-2004 (specifications of railway and road construction in china), respectively.

A cohesionless-frictional soil, 32.5MPa ordinary Portland cement and Class F flyash (got from Hunan Electric Power Development Co. Ltd) was used for the cement-flyash-gravel (CFG) mixes. The gravel was mixed with different proportions of cement and flyash. Cementitious materials were between 5% and 20%, fourteen different mixes were used. Specimens where compacted and cured under different curing conditions and durations. UCS tests were then performed after the specified curing conditions and durations and the results recorded for subsequent analysis.

Chapter 4 Results and Discussions

4.1 Results

The colour of the soil was in between light and dark brown (not light, not dark). It was dense and homogeneous and a well graded sandy gravel. The fines were mostly silt size (non-cohesive and non-plastic). 88.6% of the soil was made up of coarse material. 65.1% gravel, 23.5% sand, 10.8% silt and 0.6% clay. According to AASHTO specifications, the soil can be classified as A-1-a. The maximum dry density and optimum moisture content of the natural gravel is 2.4g/cm^3 and 7.4% respectively. Unconfined compressive strength of the natural specimen was 55psi.

Table 4. 1 Unconfined compressive strength in psi (same curing conditions together)

	7dys,20c&100%H	28dys,20c&100%H	7dys,RT&H	28dys,RT&H	7dys,60c &100%H	28dys,60c &100%H
1-0-19	184	393	231	449	257	482
0-1-19	95	101	98	130	188	222
2-0-18	347	425	412	628	517	758
0-2-18	78	93	83	111	165	215
1-1-18	170	191	187	297	404	553
3-0-17	435	698	553	849	676	1006
0-3-17	71	75	73	80	97	152
2-1-17	181	479	282	499	478	614
1-2-17	102	167	116	212	144	296
4-0-16	473	936	675	963	984	1097
0-4-16	74	84	79	88	155	158
2-2-16	179	327	318	460	505	582
3-1-16	326	517	496	678	633	788
1-3-16	108	178	128	250	206	381

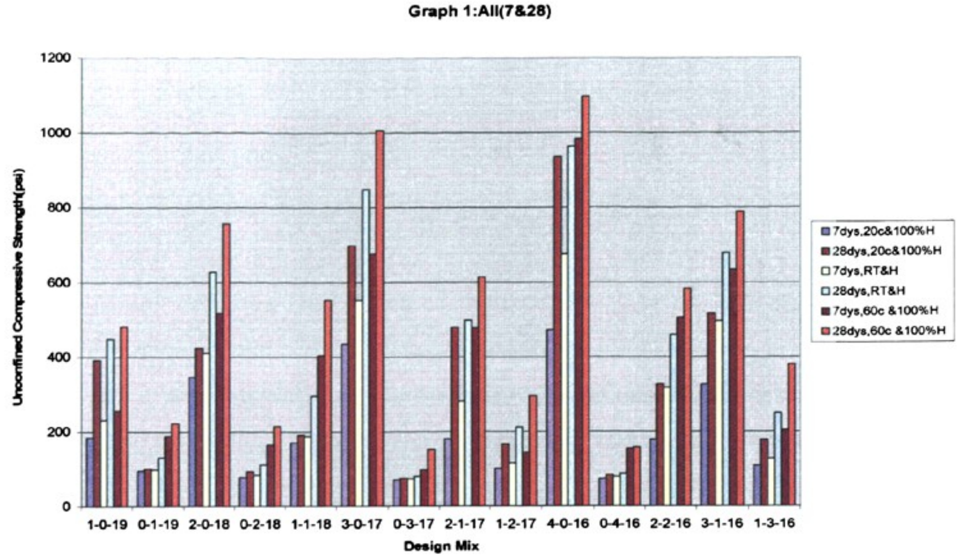


Figure 4. 1 Unconfined compressive strength in psi (same curing conditions together)

Table 4. 2 Unconfined compressive strength in psi (same curing durations together)

	7dys,20c&100%H	7dys,RT&H	7dys,60c &100%H	28dys,20c&100%H	28dys,RT&H	28dys,60c &100%H
1-0-19	184	231	257	393	449	482
0-1-19	95	98	188	101	130	222
2-0-18	347	412	517	425	628	758
0-2-18	78	83	165	93	111	215
1-1-18	170	187	404	191	297	553
3-0-17	435	553	676	698	849	1006
0-3-17	71	73	97	75	80	152
2-1-17	181	282	478	479	499	614
1-2-17	102	116	144	167	212	296
4-0-16	473	675	984	936	963	1097
0-4-16	74	79	155	84	88	158
2-2-16	179	318	505	327	460	582
3-1-16	326	496	633	517	678	788
1-3-16	108	128	206	178	250	381

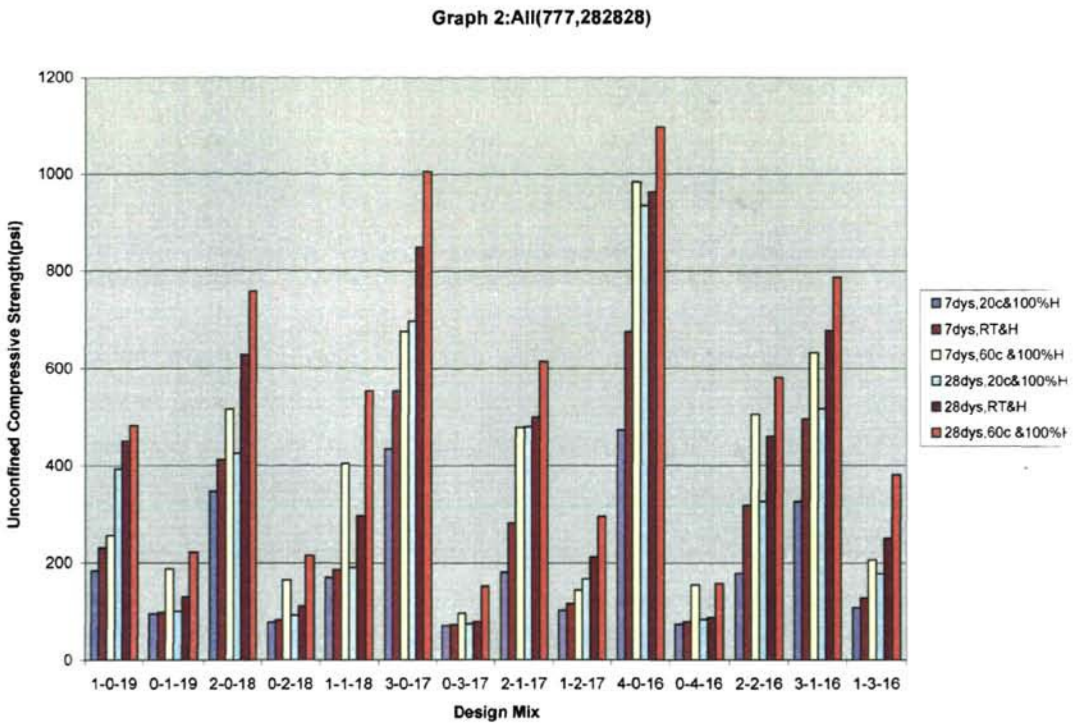


Figure 4. 2 Unconfined compressive strength in psi (same curing durations together)

Room temperature was between 30°c and 40°c, therefore greater than 20°c, so the strengths where greater than those cured at 20°c. Also the humidity was between 50% and 80%.

4.2 Discussion of Results

4.2.1 Theoretical analysis of Data- Cross classification technique

In cross classification, two variables that are thought to be strongly associated with unconfined compressive strength are selected, for example, design mix or curing conditions or durations. That is design mix/curing conditions, design mix/ curing durations, curing conditions/curing durations etc.

On the basis of the selected variables, groups are defined such that the samples belonging to a particular group would have relatively similar strength characteristics.

Same curing conditions but different curing durations

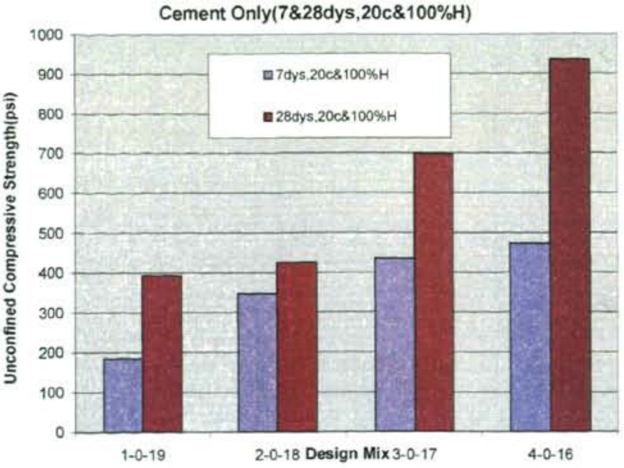
Horizontal differences in strength

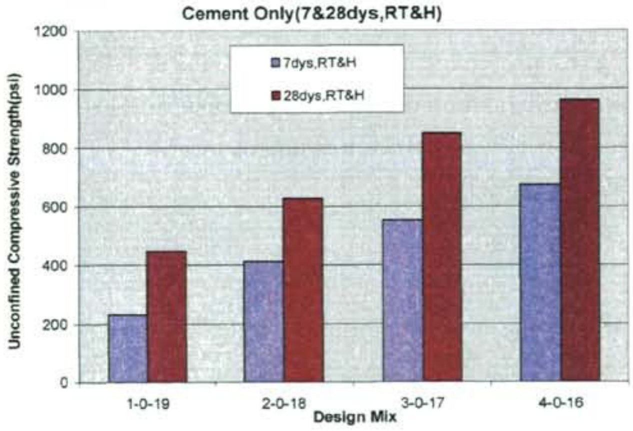
(7dys & 28dys) 20°c &100% H, (7dys &28dys) RT & H, (7dys & 28dys) 60°c &100% H

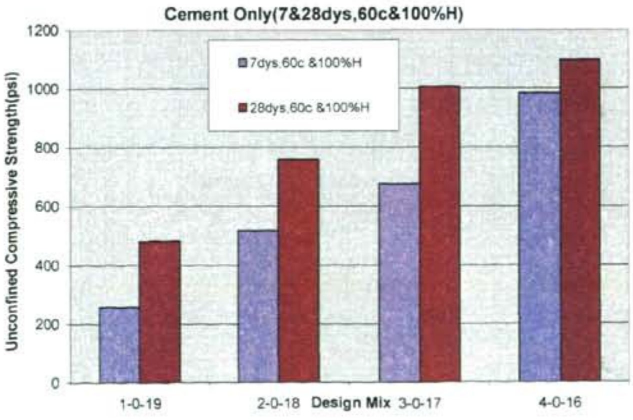
- For 20°c & 100% H, specimen strengths increases as number of days increases
- For the same room temperature and humidity, specimen strengths increases as number of days increases
- For 60°c & 100% H, specimen strengths increase as number of days increases.

Output 4. 1 Cement only

	7dys,20c&100%H	28dys,20c&100%H	7dys,RT&H	28dys,RT&H	7dys,60c &100%H	28dys,60c &100%H
1-0-19	184	393	231	449	257	482
2-0-18	347	425	412	628	517	758
3-0-17	435	698	553	849	676	1006
4-0-16	473	936	675	963	984	1097


Cement Only(7&28dys,20c&100%H)
Unconfined Compressive Strength(psi)
1000
900
800
700
600
500
400
300
200
100
0
7dys,20c&100%H
28dys,20c&100%H
1-0-19
2-0-18
Design Mix
3-0-17
4-0-16


Cement Only(7&28dys,RT&H)
Unconfined Compressive Strength(psi)
1200
1000
800
600
400
200
0
7dys,RT&H
28dys,RT&H
1-0-19
2-0-18
3-0-17
4-0-16
Design Mix


Cement Only(7&28dys,60c&100%H)
Unconfined Compressive Strength(psi)
1200
1000
800
600
400
200
0
7dys,60c &100%H
28dys,60c &100%H
1-0-19
2-0-18
Design Mix
3-0-17
4-0-16

When comparing the strengths of the samples at the three different curing conditions at 7days and 28days, we see that for 1-0-19, 2-0-18, 3-0-17, 60°c & 100% H has the highest strengths followed by RT & H, followed by 20°c & 100% H, that is 60°c &100% H> RT & H> 20°c &100% H. Also the differences in strength for same mixes under the same curing conditions but different number of days,1-0-19, 2-0-18, 3-0-17, 60°c & 100% H has the highest difference in strength followed by RT & H, followed by 20°c & 100% H, that is 60°c &100% H> RT & H> 20°c &100% H. This means that strength increased as temperature and humidity increases, increase is very rapid at high temperatures and humidities. Also as the number of days increases for cement only specimens, strength increases. Cement needs a lot of water and high temperature to harden and gain strength; it needs this for the complete chemical process of hydration and cation exchange. Therefore, the higher the temperature and humidity together with an increase in number of days, the strength increases rapidly. Thus, the strength growth and high differences in strength growth from 20°c &100% H to RT & H to 60°c &100% H at the two different time periods.

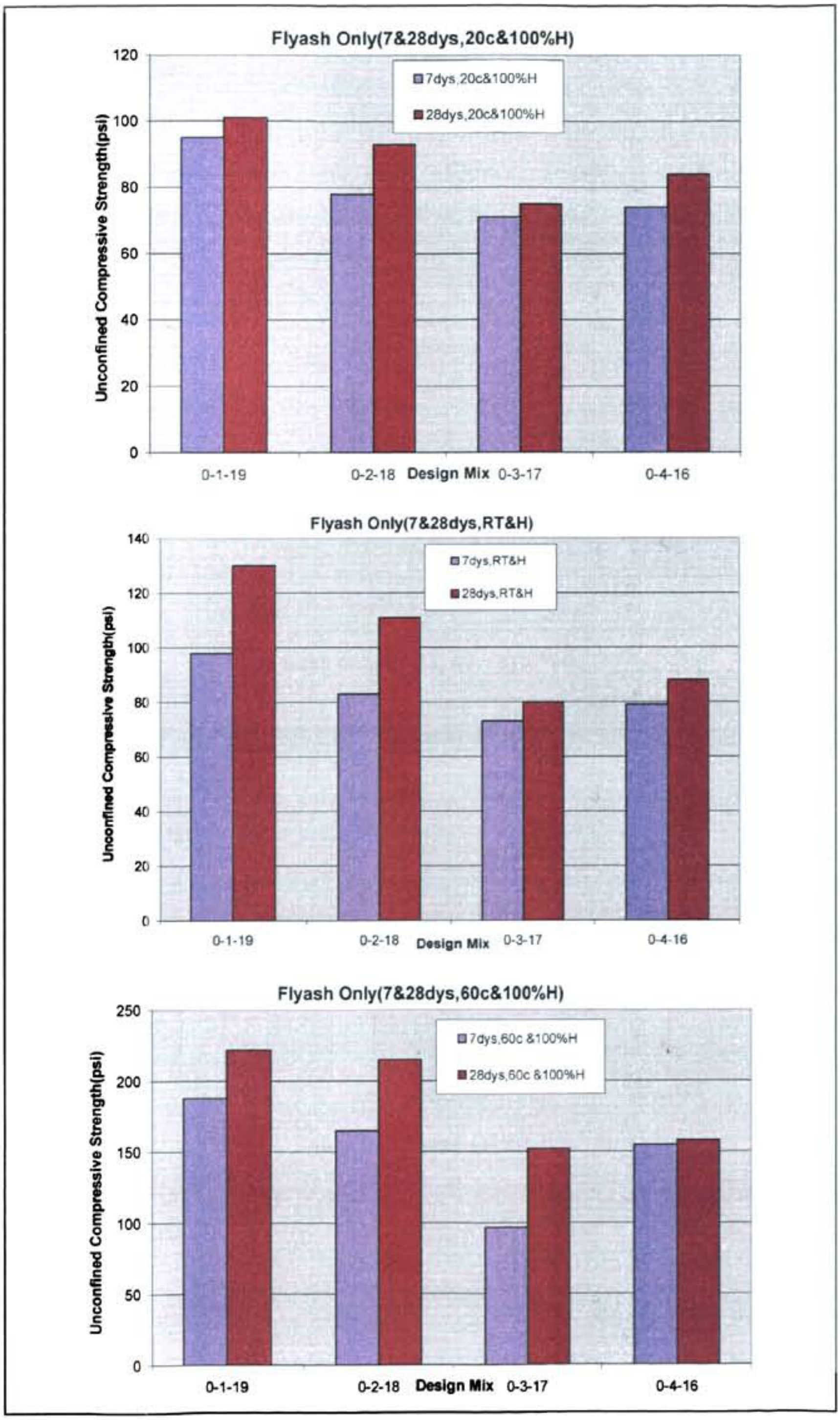
For 1-0-19, 2-0-18, 3-0-17, 20°c & 100% H has the lowest strengths and differences in strengths between 7days & 28days because temperatures where relatively low and strength gain was slow for the first 7days and continues at that rate up to 28dys. Because of the low temperature, strength gain was gradual and slow, it only increased as number of days increases, so the differences in strength is not as much as the ones at higher temperatures.

For 4-0-16, 60°c & 100% H we see that strengths at the two time periods where very high (highest) but differences in strengths is the lowest and 20°c & 100% H has the lowest strengths but the highest differences in strength. That is for differences in strength 60°c & 100% H< RT & H < 20°c & 100% H. Strength increased from 7days to 28days for 60°c & 100% H but not as much as for the previous mixes (differences in strength for 7days and 28days increased as mix proportion increases). This is because after awhile, adding more cement to the mix would not cause any significant strength gain. This is due mainly to shrinkage cracking, as the amount of cement in the specimen is increased, it starts to shrink and then crack. Shrinkage cracking increases as the amount of cement increases and is more pronounced at high temperatures, as temperature increases the reaction process. So, more cement at high temperature implies more shrinkage cracking which implies less strength (as these cracks are planes of weakness in the samples). Thus, even though for 60°c & 100% H strength of specimen 4-0-16 increased as number of days increased, it did not increase as it should because of shrinkage cracking which is due to the high cement content and high temperature. Also for cement, strength gain at such high temperatures is rapid for the first 7days and then continues at a slower rate up to 28days and beyond, so there is no significant strength increase between 7days and 28days.

For 4-0-16, 20°c & 100% H has lowest strength but highest differences in strength. This is because at this low temperature, strength gain is gradual (not rapid). Also even though the cement content is high (implying more shrinkage) shrinkage was not pronounced because of the relatively low temperature, the reaction process is slow and not too pronounced. So specimens were able to develop more strength as number of days increased, even at such high cement contents. More cement content implies more shrinkage cracking which means less strength, but because temperature is relatively low, less cracking occurred meaning more strength development as number of days increases. Strength increase for the first 7days is slow but as number of days increases the rate of strength gain increased, even at such low temperatures.

Output 4. 2 Flyash Only

	7dys,20c&100%H	28dys,20c&100%H	7dys,RT&H	28dys,RT&H	7dys,60c &100%H	28dys,60c &100%H
0-1-19	95	101	98	130	188	222
0-2-18	78	93	83	111	165	215
0-3-17	71	75	73	80	97	152
0-4-16	74	84	79	88	155	158


Flyash Only(7&28dys,20c&100%H)
7dys,20c&100%H
28dys,20c&100%H
Unconfined Compressive Strength(psi)
120
100
80
60
40
20
0
0-1-19
0-2-18
Design Mix
0-3-17
0-4-16
Flyash Only(7&28dys,RT&H)
7dys,RT&H
28dys,RT&H
Unconfined Compressive Strength(psi)
140
120
100
80
60
40
20
0
0-1-19
0-2-18
Design Mix
0-3-17
0-4-16
Flyash Only(7&28dys,60c&100%H)
7dys,60c &100%H
28dys,60c &100%H
Unconfined Compressive Strength(psi)
250
200
150
100
50
0
0-1-19
0-2-18
Design Mix
0-3-17
0-4-16

We see that for 0-1-19, 0-2-18, 0-3-17, 60°c & 100% H has the highest strengths followed by RT & H, followed by 20c & 100% H, that is 60°c &100% H> RT & H> 20°c &100% H. Also the differences in strength for same mixes under the same curing conditions but different number of days, 0-1-19, 0-2-18, 0-3-17, 60°c & 100% H has the highest difference in strength followed by RT & H, followed by 20°c & 100% H, that is 60°c &100% H> RT & H> 20°c &100% H. This means that strength increased as temperature and humidity increases, increase is very rapid at high temperatures and humidities. Also as the number of days increases for flyash only specimens, strength increases. Flyash also needs a lot of water and high temperature to harden and gain strength; it needs this for the complete chemical process of hydration and cation exchange to occur. So the higher the temperature and humidity and as number of days increases, strength increases rapidly. Thus, the strength growth and high differences in strength growth from 20°c &100% H to RT & H to 60°c &100% H at the two different time periods.

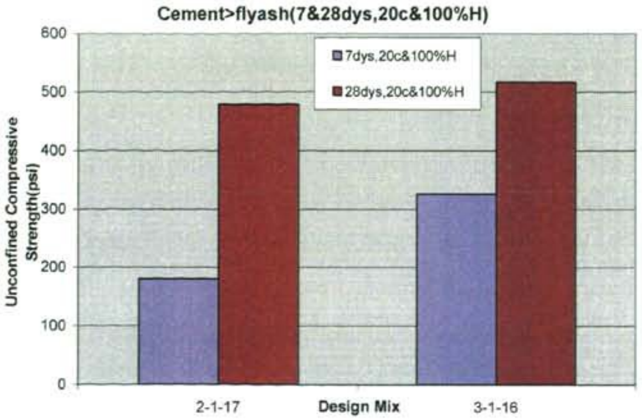
For 0-1-19, 0-2-18, 0-3-17, 20°c & 100% H has the lowest differences in strength between 7days & 28days because temperature is low, strength gain was a little fast within the first 7days and continues at a slower rate up to 28days and beyond. Normally strength growth for flyash within the first 7days is normally low; it starts to gain strength after 7days. But because of the low temperature the process was reversed.

For 0-4-16, 60°c & 100% H we see that strengths at two time periods where high (highest) but differences in strengths is the lowest and 20°c & 100% H has the lowest strengths but the highest differences in strength. That is for differences in strength 60°c & 100% H< RT & H < 20°c & 100% H. Strength increased from 7days to 28days for 60°c & 100% H but not as much as for the previous mixes (differences in strength for 7days and 28days increased as mix proportion increases). This is because after a while, adding more flyash to the mix would not cause any significant strength gain. Flyash is not a good stabilizer on its own as cement is. So even at 60°c & 100% H strength of specimen 0-4-16 increased as number of days increased but not as much as compared to cement, so as more flyash is added, it does not impact the strength properties of the specimens positively. Also it did not increase as it should because for flyash strength gain at such high temperatures is rapid for the first 7days and then continues at a slower rate up to 28days and beyond, so there is no significant strength increase between 7days and 28days.

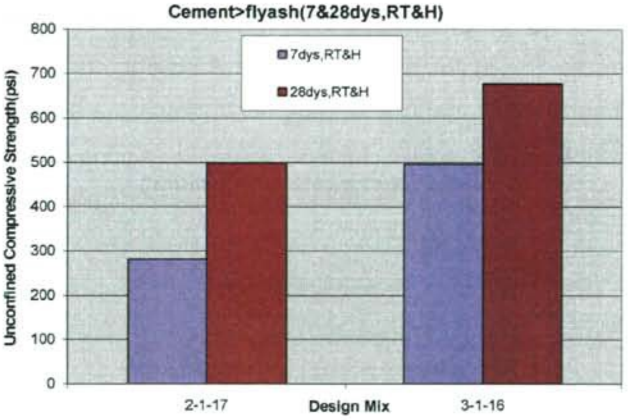
For 0-4-16, 20°c & 100% H has the lowest strengths but highest differences in strength. This is because at this low temperature, strength gain is gradual (not rapid). Also even though the flyash content is high (implying more strength difference between 7days and 28days) strength gain was gradual as the temperature was relatively low. The reaction process is slow but steady. So, specimens were able to develop more strength as number of days increases even at such flyash contents. Strength increase for the first 7days is fast even at such low temperatures, but as number of days increases the rate of strength growth was much slower because of the relatively low temperature. Normally flyash's strength gain is a bit slow during the first 7days but gains tremendous strength as the number of days increase after 7days (opposite of cement). It did not increase much after the first 7days because of the low temperature.

Output 4. 3 Cement > flyash

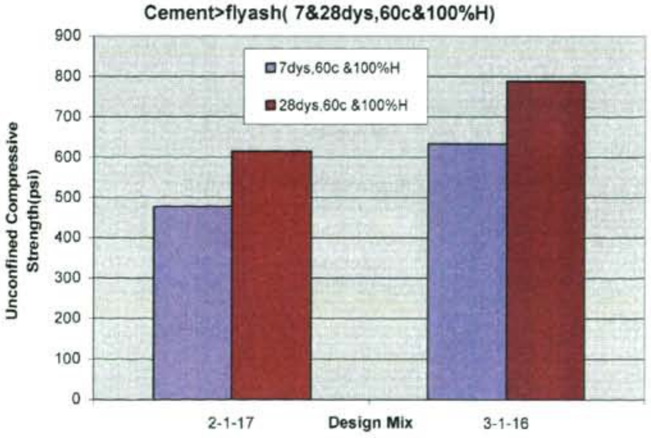
	7dys,20c&100%H	28dys,20c&100%H	7dys,RT&H	28dys,RT&H	7dys,60c &100%H	28dys,60c &100%H
2-1-17	181	479	282	499	478	614
3-1-16	326	517	496	678	633	788



Cement>flyash(7&28dys,20c&100%H)



Cement>flyash(7&28dys,RT&H)



Cement>flyash(7&28dys,60c&100%H)

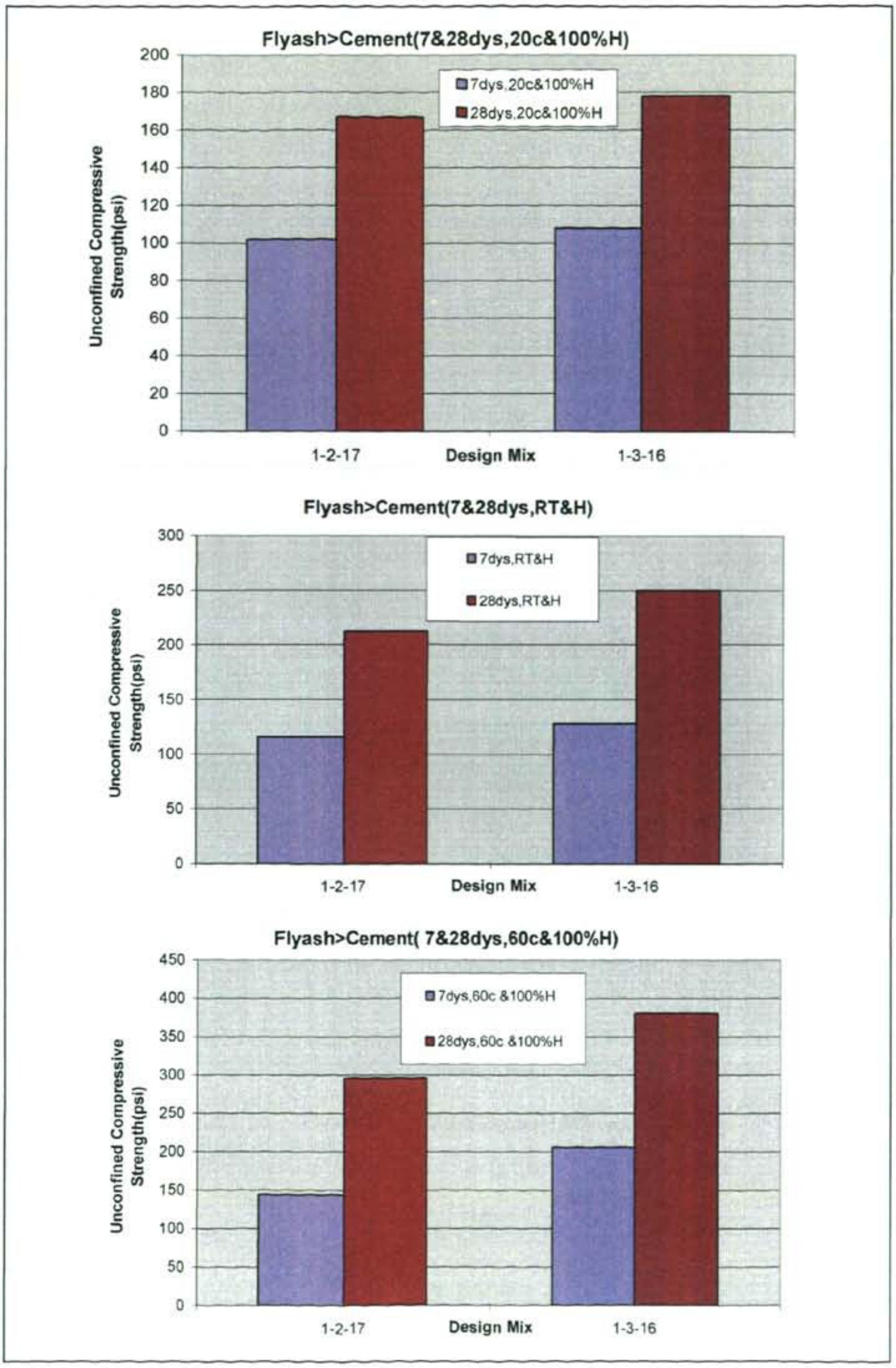
For 2-1-17 and 3-1-16, 60°c & 100% H has the highest strengths followed by RT & H, followed by 20°c & 100% H, that is 60°c &100% H> RT & H> 20°c &100% H. Also the differences in strength for same mixes under the same curing conditions but different number of days, 2-1-17 and 3-1-16 , 20°c & 100% H has the highest difference in strength followed by RT & H, followed by 60°c & 100% H, that is 60°c &100% H< RT & H< 20°c &100% H. This means that strength increase as temperature and humidity increases, increase is very rapid at high temperatures and humidities. Also as the number of days increases for more cement than flyash specimens, strength increases. Also for more cement than flyash, specimen strength gain at such high temperatures is rapid for the first 7days and then continues at a slower rate up to 28days and beyond, so there is no significant strength increase between 7days and 28days, thus the low difference in strength between the 7days and 28days strengths.

The 20°c & 100% H has lowest strength but highest differences in strength. This is because at this low temperature, strength gain is gradual (not rapid). Specimens were able to develop more strength as number of days increased. Strength increase for the first 7days is a bit slow but as number of days increases the rate of strength gain increased, even at such low temperatures, hence the high difference in strength.

For 60°c & 100% H, strength gain was rapid for the first 7days (cement characteristics) and then continued to increase gradually up to 28days, so the difference was small. Whereas at low temperatures strength gain is small at first and continues to increase as number of days increases, hence the high differences in strength.

Output 4. 4 Flyash > cement

	7dys,20c&100%H	28dys,20c&100%H	7dys,RT&H	28dys,RT&H	7dys,60c &100%H	28dys,60c &100%H
1-2-17	102	167	116	212	144	296
1-3-16	108	178	128	250	206	381

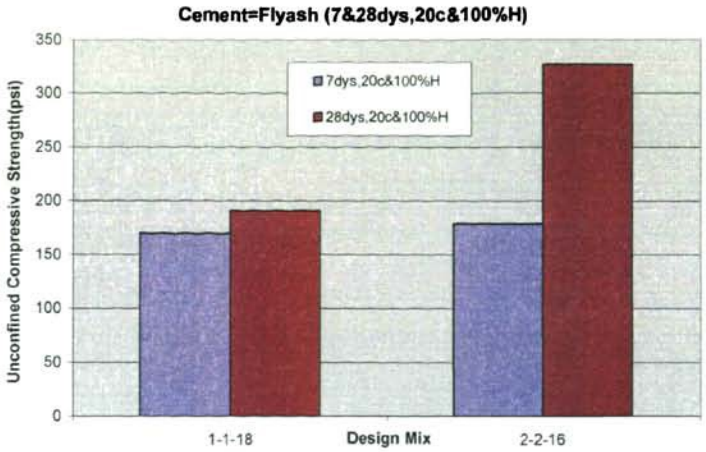

Flyash>Cement(7&28dys,20c&100%H)
Unconfined Compressive Strength(psi)
0
20
40
60
80
100
120
140
160
180
200
7dys,20c&100%H
28dys,20c&100%H
1-2-17
Design Mix
1-3-16
Flyash>Cement(7&28dys,RT&H)
Unconfined Compressive Strength(psi)
0
50
100
150
200
250
300
7dys,RT&H
28dys,RT&H
1-2-17
Design Mix
1-3-16
Flyash>Cement(7&28dys,60c&100%H)
Unconfined Compressive Strength(psi)
0
50
100
150
200
250
300
350
400
450
7dys,60c &100%H
28dys,60c &100%H
1-2-17
Design Mix
1-3-16

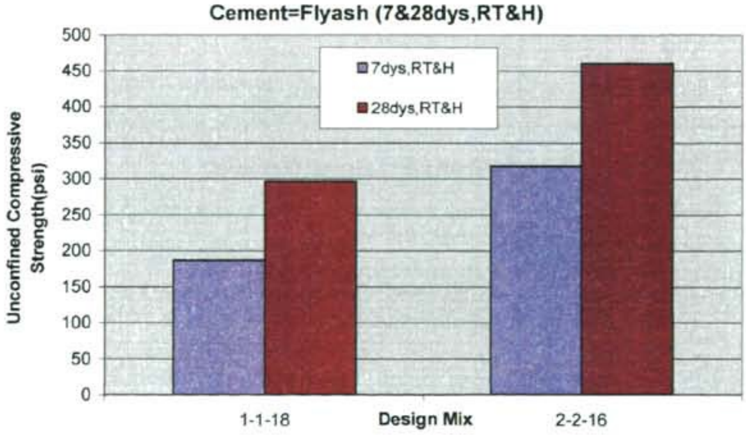
For 1-2-17, 1-3-16, 60°c & 100% H has the highest strengths followed by RT & H, followed by 20°c & 100% H, that is 60°c &100% H> RT & H> 20°c &100% H. Also the differences in strength for same mixes under the same curing conditions but different number of days, 1-2-17 and 1-3-16 , 60°c & 100% H has the highest difference in strength followed by RT & H, followed by 20°c & 100% H. That is 60°c &100% H> RT & H> 20°c &100% H. This means that strength increase as temperature and humidity increases. Strength is high and rate of increase fast at high temperatures and humidities. Also as the number of days increases for more flyash than cement specimens, strength increases. As temperature and humidity is increased, difference in strength between 7days and 28days increases rapidly (high differences). Strength gain for flyash is a bit slower than that for cement. For specimens with more flyash, differences in strength at high temperatures are high.

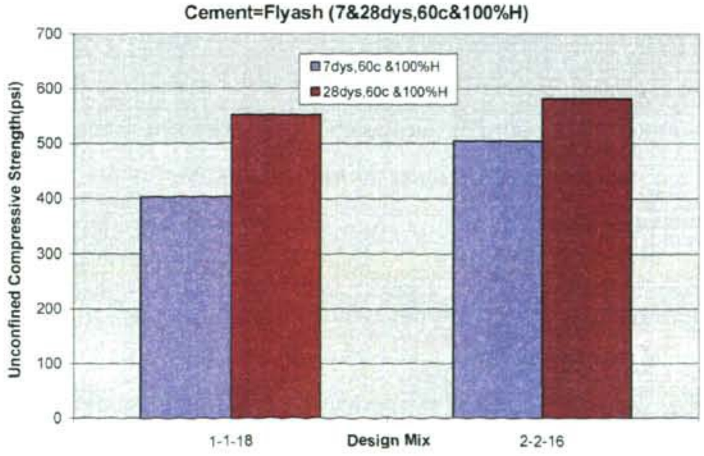
For 20°c &100% H, they have lowest strengths and the lowest differences in strength because of the low temperature. Strength increased from 7days to 28days but not significantly. Meaning, high temperatures are needed for significant strength gain for more flyash than cement specimens. Strength gain is gradual (not rapid) from 0days to 7days to 28days. Specimen strengths increase more rapidly after the first 7days (typical of flyash). Because flyash is more, and flyash gains strength at later time periods, hence such differences in strength.

Output 4. 5 Cement = flyash

	7dys,20c&100%H	28dys,20c&100%H	7dys,RT&H	28dys,RT&H	7dys,60c &100%H	28dys,60c &100%H
1-1-18	170	191	187	297	404	553
2-2-16	179	327	318	460	505	582


Cement=Flyash (7&28dys,20c&100%H)
Unconfined Compressive Strength(psi)
0
50
100
150
200
250
300
350
7dys,20c&100%H
28dys,20c&100%H
1-1-18
Design Mix
2-2-16


Cement=Flyash (7&28dys,RT&H)
Unconfined Compressive Strength(psi)
0
50
100
150
200
250
300
350
400
450
500
7dys,RT&H
28dys,RT&H
1-1-18
Design Mix
2-2-16


Cement=Flyash (7&28dys,60c&100%H)
Unconfined Compressive Strength(psi)
0
100
200
300
400
500
600
700
7dys,60c &100%H
28dys,60c &100%H
1-1-18
Design Mix
2-2-16

For 1-1-18, 60c & 100% H has the highest strengths followed by RT & H, followed by 20°c & 100% H, that is 60°c &100% H> RT & H> 20°c &100% H. Also the differences in strength for same mixes under the same curing conditions but different number of days, 60°c & 100% H has the highest difference in strength followed by RT & H, followed by 20°c & 100% H, that is 60°c &100% H> RT & H> 20°c &100% H. This means that strength increase as temperature and humidity increases, increase is very rapid at high temperatures and humidities. Also as the number of days increases for the specimens, strength increases. As cement and flyash are in equal proportions in this mix, both should determine strength gain and rate of strength gain to the same extent, but because cement has better strength properties than flyash(cement is a better stabilizer than flyash), these specimens will display characteristics of cement only or more cement than flyash specimens at low cement contents.

For 20°c & 100% H, strengths are low and difference in strength is also low because of the low temperature. Strength gain is rapid within the first 7days and continues to increase at a much slower rate afterwards (properties of cement).

For 2-2-16, 60°c & 100% H has the highest strengths followed by RT & H, followed by 20°c & 100% H, that is 60°c &100% H> RT & H> 20°c &100% H. Also the differences in strength for same mixes under the same curing conditions but different number of days , 20°c & 100% H has the highest difference in strength followed by RT & H, followed by 60°c & 100% H, that is 60°c &100% H< RT & H< 20°c &100% H (opposite of 1-1-18). Strength increases as temperature, humidity and number of days increases, but not as much as compared to 1-1-18. The reaction process is rapid and pronounced because of the amount of cement and high temperature, so shrinkage cracking is more. Also at this high temperature strength growth is rapid (not gradual). Strength increased from 7days to 28days but not much because of shrinkage cracking. So the difference in strength for 60°c & 100% H is not too much even though there is an increase from 7days to 28days. Because of the high temperature and mix content, strength increased rapidly within the first 7days even though shrinkage cracking occurred. Therefore strength increase from 7days to 28days was not so pronounced after the 7th day, hence low difference in strength.

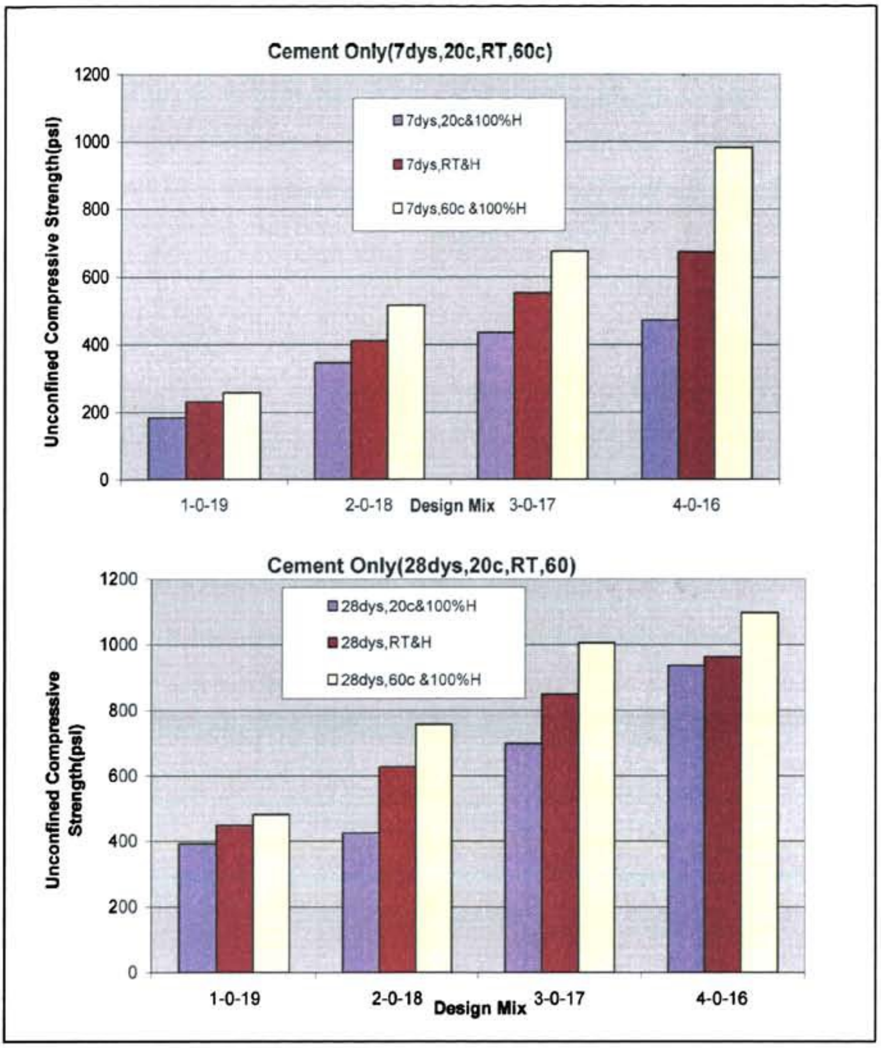
For 2-2-16, 20°c & 100% H strengths are low but difference in strength is high. This is because at this low temperature, strength gain is gradual (not rapid). So, specimens were able to develop more strength as number of days increases even at such cement and flyash contents. Shrinkage cracking hasn't got much effect on specimens as temperature is low (therefore the reaction process is slow and not pronounced). Here shrinkage cracking does not affect strength gain much, even though cement content is high. Strength increase for the first 7days is a bit slow, but as number of days increases the rate of strength growth was much faster (flyash characteristics).

Same mixes, same number of days, but different curing conditions

Horizontal differences in strength
(20°c&100%H, RT&H, 60°c&100%H) 7dys, (20°c&100%H, RT&H, 60°c&100%H) 28dys.

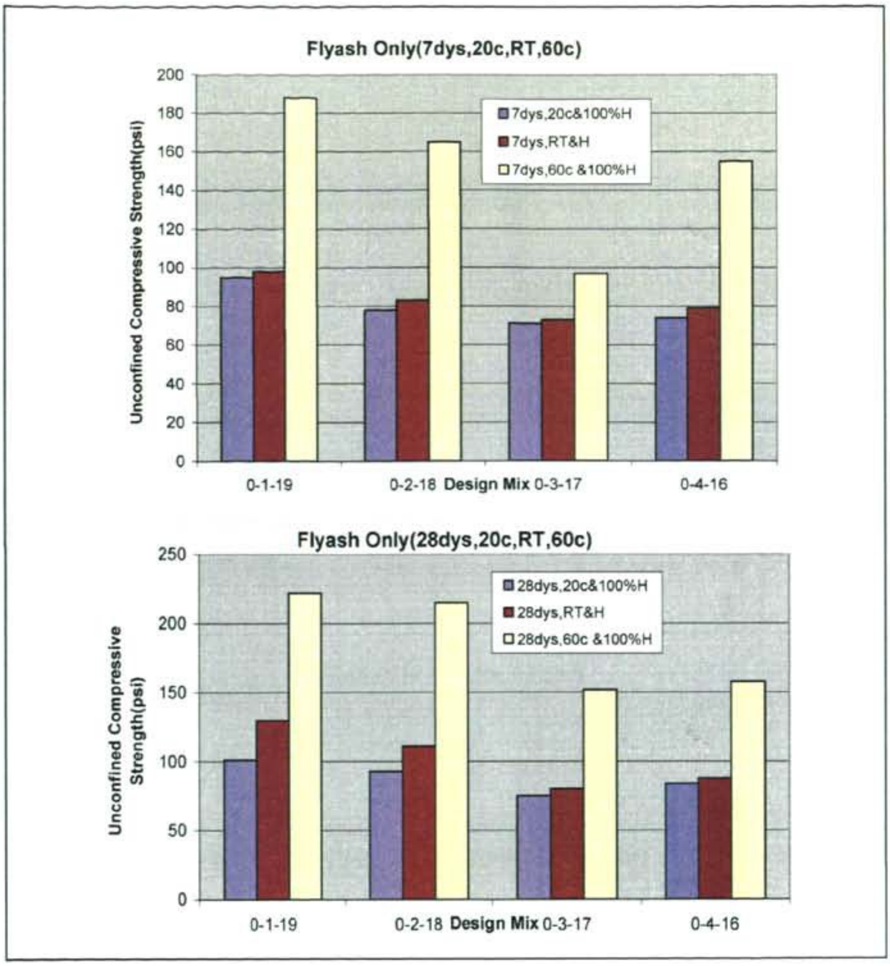
Output 4. 6 Cement only

	7dys,20c&100%H	7dys,RT&H	7dys,60c &100%H	28dys,20c&100%H	28dys,RT&H	28dys,60c &100%H
1-0-19	184	231	257	393	449	482
2-0-18	347	412	517	425	628	758
3-0-17	435	553	676	698	849	1006
4-0-16	473	675	984	936	963	1097



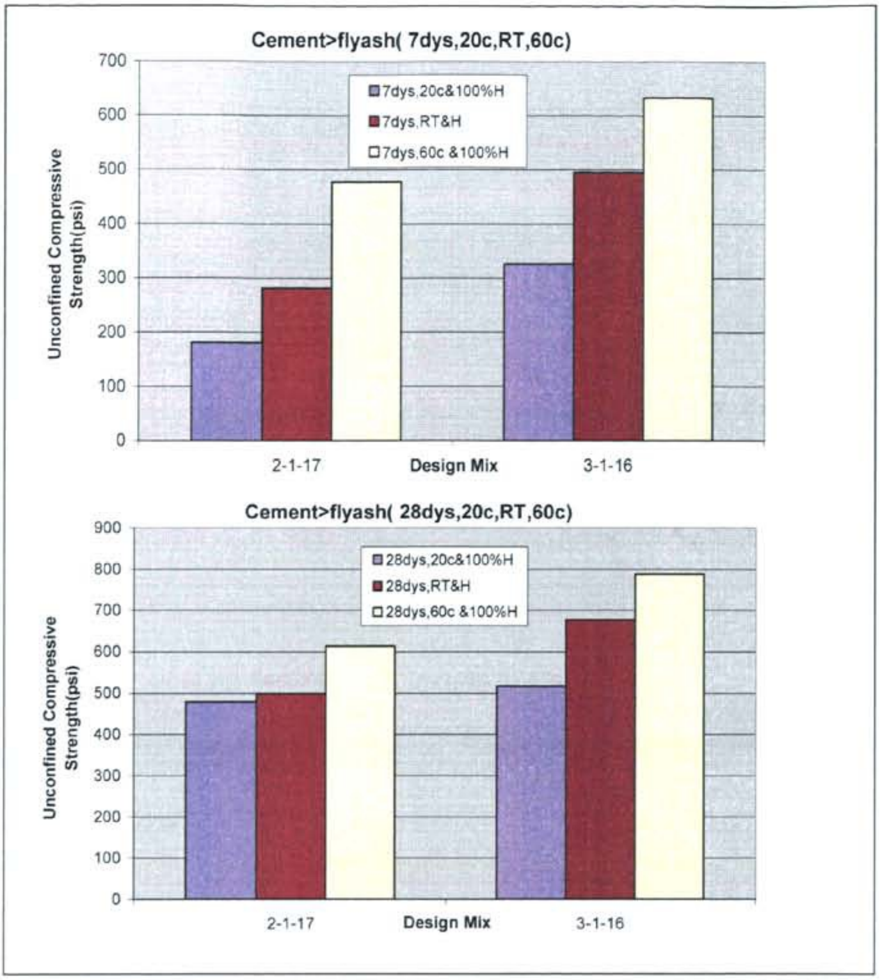
Output 4. 7 Flyash Only

	7dys,20c&100%H	7dys,RT&H	7dys,60c &100%H	28dys,20c&100%H	28dys,RT&H	28dys,60c &100%H
0-1-19	95	98	188	101	130	222
0-2-18	78	83	165	93	111	215
0-3-17	71	73	97	75	80	152
0-4-16	74	79	155	84	88	158



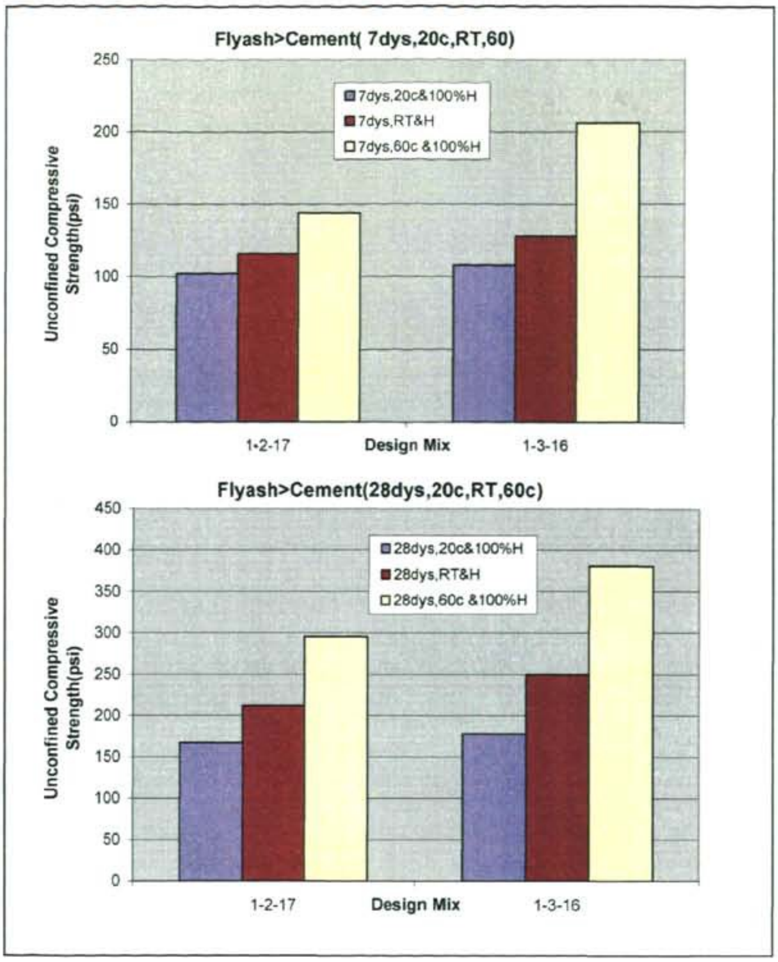
Output 4. 8 Cement > flyash

	7dys,20c&100%H	7dys,RT&H	7dys,60c &100%H	28dys,20c&100%H	28dys,RT&H	28dys,60c &100%H
2-1-17	181	282	478	479	499	614
3-1-16	326	496	633	517	678	788



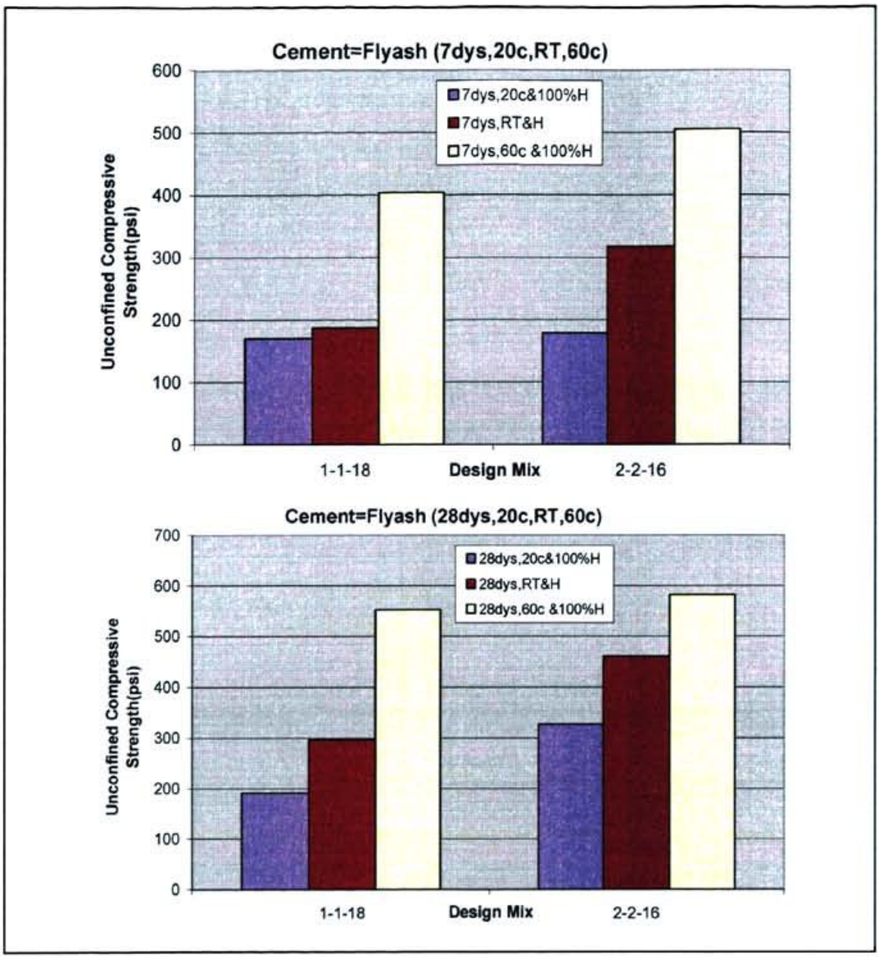
Output 4. 9 Flyash > cement

	7dys,20c&100%H	7dys,RT&H	7dys,60c &100%H	28dys,20c&100%H	28dys,RT&H	28dys,60c &100%H
1-2-17	102	116	144	167	212	296
1-3-16	108	128	206	178	250	381



Output 4. 10 Cement = flyash

	Plain soil	7dys,20c&100%H	7dys,RT&H	7dys,60c &100%H	28dys,20c&100%H	28dys,RT&H	28dys,60c &1
1-1-18		170	187	404	191	297	
2-2-16		179	318	505	327	460	



The subsequent discussions hold for all of the tables and graphs in this section. That is "**Same mixes, same number of days, but different curing conditions**".

- **7days**: as temperature and humidity is increased, strength increases. Specimen strengths increased as the temperature increased from 20°c to 60°c.
- **28days**: as temperature and humidity is increased, strength increases. Specimen strengths increased as the temperature increased from 20°c to 60°c.

That is strengths at 60°c & 100% H> RT & H > 20°c & 100% H.

Vertical Relationships

From the results as a whole, we make the following deductions:

1. Cement specimens are stronger than their corresponding flyash counterparts. Cement has higher strength properties than flyash; cement is a better stabilizer than flyash.
2. As more flyash is added, the lesser the strength of the flyash only specimens. But it increases a little again at 20%. The opposite happens for the cement specimens (strength increases as cement content increases). This means that flyash on its own is not a good stabilizer.
3. The lowest strengths are with 15% flyash only specimen.
4. Specimens with 20% cement had the highest strength for all categories of curing conditions.
5. For specimens with equal amounts of cement and flyash, strength increased as cement and flyash is increased in equal amounts and proportions that is 1-1-18 to 2-2-16.
6. For specimens with more flyash than cement, strength increased as the proportion of flyash is increased. The same happens for those with more cement than flyash.
7. When comparing 1-1-18, 2-2-16, 2-1-17, 3-1-16, 3-1-16 gave the highest strength values for all categories of curing conditions and durations, that is 3-1-16> 2-1-17> 2-2-16> 1-1-18.

Chapter 5 Linear Regression Analysis in SPSS

5.1 Background

Linear regression analysis is a statistical analysis technique that assesses the impact of a predictor variable (the independent variable) on a criterion variable (a dependent variable). Importantly, the independent variable must be continuous (interval-level or ratio-level) or dichotomous. The dependent variable must be either continuous (interval-level or ratio-level). Thesis' often have research questions that are appropriate to this technique[61, 62, 63]. In this research, the research question is "what impact does mix proportion and type, curing conditions and curing durations have on strength (UCS) of CFG samples and to what extent? In this case mix proportion and type, curing conditions and curing durations are the predictor variables (independent variables) and strength (UCS) is the criterion variable (dependent variable).

Reasons why we want a Regression Model:

1) Descriptive - form the strength of the association between outcome and factors of interest, that is dependent variables and independent variables.

2) Adjustment - for covariates/confounders

3) Predictors - to determine important risk factors affecting the outcome

4) Prediction - to quantify new cases[64, 65].

5.1.1 Variables

Linear regression analysis estimates the coefficients of a linear equation, involving one or more independent variables that best predict the value of the dependent variable. The mean is the best predictor of a variable (let's call it "*Y*") in the absence of any other information. With information about a related independent variable, prediction can be improved.

The linear *regression equation* takes the form $Y = b_1x_1 + c + e$, where Y is the true dependent, b is the regression coefficient for the corresponding x (independent) term, where c is the constant or intercept, and e is the error term reflected in the residuals. Sometimes this is expressed more simply as $y = b_1x_1 + c$, where y is the estimated dependent and c is the constant (which includes the error term).

A regression line provides more precise predictions than simply predicting the mean. For each observation "*c*" is the intercept (value of Y when $X = 0$), "*b*" is the slope (change in Y per unit increase in X)[66, 67].

The regression coefficient, *b*, is the average amount the dependent increases when the independent increases one unit and other independents are held constant. Put another way, the b coefficient is the slope of the regression line: the larger the b, the steeper the slope, the more the dependent changes for each unit change in the independent. The b coefficient is the unstandardized simple regression coefficient for the case of one independent[68, 69].

OLS stands for ordinary least squares. This derives its name from the criterion used to draw the best fit regression line: a line such that the sum of the squared deviations of the distances of all the points to the line is minimized[68].

Predicted values, also called *fitted values,* are the values of each case based on using the regression equation for all cases in the analysis[68].

Adjusted predicted values are the values of each case based on using the regression equation for all cases in the analysis except the given case.

5.2 Linear Regression Analysis Assumptions

There are three primary assumptions associated with linear regression: outliers, linearity, and constant variance. Linear regression analysis is very sensitive to outliers. The easiest way to identify outliers is to standardize the scores by requesting SPSS for the *z*-scores. Any score with a *z*-value outside of the absolute value of 3 is probably an outlier and should be considered for deletion. The assumption of linearity and constant variance can be assessed in SPSS by requesting a plot of the residuals ("*z*-resid" on the *y*-axis) by the predicted values (on "*z*-pred" the *x*-axis). If the scatter plot is not u-shaped, indicating non-linearity, or cone-shaped, indicating non-constant variance, the assumptions are considered met[61, 70, 71].

5.3 Regression Analysis Interpretation

The SPSS outputs are very important and need to be interpreted

5.3.1 Correlations (Pearson correlation and sig 1-tailed)

The null hypothesis states that the correlation between dependent and independent variables is equal to zero. The research hypothesis states that the correlation is different from zero[72, 73, 74]. The Pearson's correlation between the dependent variable and the independent variables is given as r. R square shows the % of the dependent variable that can be explained by the independent variables. The correlation coefficient ("*r*") gives two pieces of information: strength of relationship, measured by absolute value and direction of the relationship, indicated by a positive sign or negative sign. For a single independent variable, the Standardized Coefficient (Beta) is the Pearson's correlation value.

5.3.2 Model Summary—shows r and R^2

From this table you can find how well the model fits the data. This table displays *R*, *R* squared, adjusted *R* squared, and the standard error. *R* is the correlation between the observed and predicted values of the dependent variable. The values of *R* range from -1 to 1. The sign of *R* indicates the direction of the relationship (positive or negative). The absolute value of *R* indicates the strength, with larger absolute values indicating stronger relationships. *R* squared is the proportion of variation in the dependent variable explained by the regression model. The values of *R* squared range from 0 to 1. Small values indicate that the model does not fit the data well. The sample *R* squared tends to optimistically estimate how well the models fit the population. Adjusted R squared attempts to correct *R* squared to more closely reflect the goodness of fit of the model in the population[73].

5.3.3 ANOVA (Analysis of Variance)

This table shows significance of r and R2 as an F statistic. The ANOVA table shows the 'usefulness' of the linear regression model – we want the p-value to be <0.05. The *F* statistic is the regression mean square (MSR) divided by the residual mean square (MSE). If the significance value of the F statistic is small (smaller than say 0.05) then the independent variables do a good job explaining the variation in the dependent variable. If the significance value of F is larger than say 0.05 then the independent variables do not explain the variation in the dependent variable, and the null hypothesis that all the population values for the regression coefficients are 0 is accepted[73].

5.3.4 Coefficients

This shows the regression line. Under the B column is intercept and slope. Beta column shows standardized slope (the correlation). The beta's significance can be found by examining the t-value and the associated significance level of the t-value for that particular predictor[61]. The beta coefficient tells you how strongly the independent variable is associated with the dependent variable. It is equal to the correlation coefficient between the 2 variables[73]. Significance of slope is indicated by t. Also the smaller the standard error of estimate, the better the prediction model.

5.4 Significance testing

T-tests are used to assess the significance of individual b coefficients specifically testing the null hypothesis that the regression coefficient is zero. A common rule of thumb is to drop from the equation all variables not significant at the .05 level or better[68].

1) One vs. Two-tailed T tests.

T-tests in SPSS are two-tailed, which means they test the hypothesis that the b coefficient is either significantly higher or lower than zero. If our model is such that we can rule out one directior (example, negative coefficients) and thus should test only if the b coefficient is more than zero, we want a one-tailed test. The one-tailed significance level will be twice the two-tailed probability level: if SPSS reports 0.05, for instance, then, the one-tailed equivalent significance level is 1[68].

2) F test:

The F test is used to test the significance of R, which is the same as testing the significance of R^2, which is the same as testing the significance of the regression model as a whole. If prob (F) < 0.05, then the model is considered significantly better than would be expected by chance and we reject the null hypothesis of no linear relationship of y to the independents. F is a function of R^2, the number of independents, and the number of cases[68].

5.5 Residual Statistics

The *residue* of each observation is given by the difference between the observed value and the fitted value of the regression line[64]. The predicted value is not perfect (unless r = ± 1.0). Notice that it may be that none of the observed data points actually fit exactly on the line. In other words, there is some error. We refer to the error between each point and the predicted points the *residuals*.

$$\text{residual} = \text{observed } y - \text{predicted } y$$

$$= Y - y \tag{5.1}$$

The sum of the residuals should always equal 0 (as should the mean). This is because the least squares regression line splits the data in half, half of the error is above the line and half is below the line.

5.6 Scatter Plots

Scatter plots, show how the dependent variable increase or decrease with respect to the independent variables or vice versa. For linear regression analysis, the relationship between 2 variables is normally linear in nature, the individual points tend to group around a straight line. This line is defined by a *y*-intercept and a slope, which are presented under the column B-coefficients in the coefficients table (produced as an output of the linear regression analysis)[73].

5.7 SPSS Outputs and Analysis

Output 5. 1 Days-ucs-20°c

mix	7 days	28 days
1-0-19	184	393
2-0-18	347	425
3-0-17	435	698
4-0-16	473	936
0-1-19	95	101
0-2-18	78	93
0-3-17	71	75
0-4-16	74	84
2-1-17	181	479
3-1-16	326	517
1-2-17	102	167
1-3-16	108	178
1-1-18	170	191
2-2-16	179	327

Descriptive Statistics

	Mean	Std. Deviation	N
28 days	333.14	259.562	14
7 days	201.64	137.464	14

Correlations

		28 days	7 days
Pearson Correlation	28 days	1.000	.941
	7 days	.941	1.000
Sig. (1-tailed)	28 days	.	.000
	7 days	.000	.
N	28 days	14	14
	7 days	14	14

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.941(a)	.886	.876	91.269

a Predictors: (Constant), 7 days

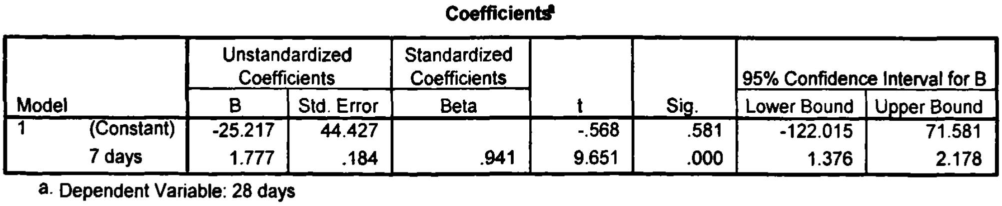
b Dependent Variable: 28 days

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	775880.266	1	775880.266	93.143	.000(a)
	Residual	99959.449	12	8329.954		
	Total	875839.714	13			

a Predictors: (Constant), 7 days

b Dependent Variable: 28 days



Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95% Confidence Interval for B	
		B	Std. Error	Beta			Lower Bound	Upper Bound
1	(Constant)	-25.217	44.427		-.568	.581	-122.015	71.581
	7 days	1.777	.184	.941	9.651	.000	1.376	2.178

a. Dependent Variable: 28 days

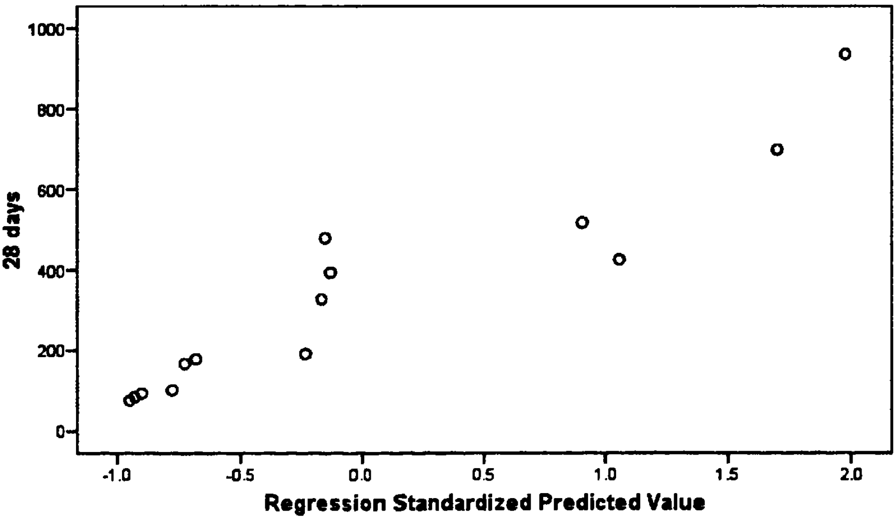
Residuals Statistics[a]

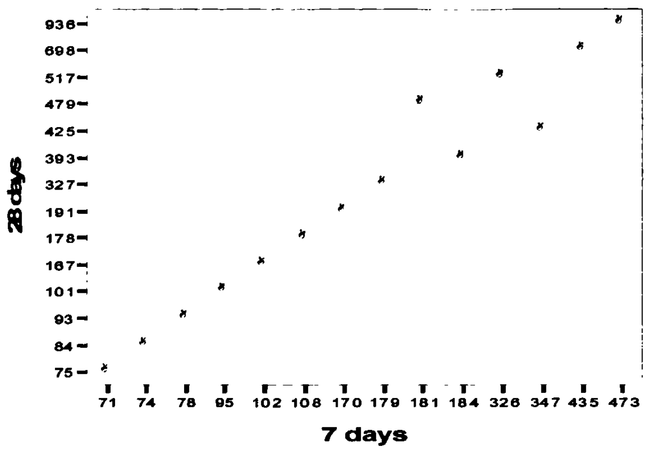
	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	100.96	815.40	333.14	244.301	14
Residual	-166.471	182.544	.000	87.688	14
Std. Predicted Value	-.950	1.974	.000	1.000	14
Std. Residual	-1.824	2.000	.000	.961	14

a Dependent Variable: 28 days

Scatterplot

Dependent Variable: 28 days





Output 5. 2 Days-ucs-RT

mix	7 days	28 days
1-0-19	231	449
2-0-18	412	628
3-0-17	553	849
4-0-16	675	963
0-1-19	98	130
0-2-18	83	111
0-3-17	73	80
0-4-16	79	88
2-1-17	282	499
3-1-16	496	678
1-2-17	116	212
1-3-16	128	250
1-1-18	187	297
2-2-16	318	460

Descriptive Statistics

	Mean	Std. Deviation	N
28 days	406.71	289.247	14
7 days	266.50	198.022	14

Correlations

		28 days	7 days
Pearson Correlation	28 days	1.000	.987
	7 days	.987	1.000
Sig. (1-tailed)	28 days	.	.000
	7 days	.000	.
N	28 days	14	14
	7 days	14	14

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.987(a)	.974	.971	48.964

a Predictors: (Constant), 7 days

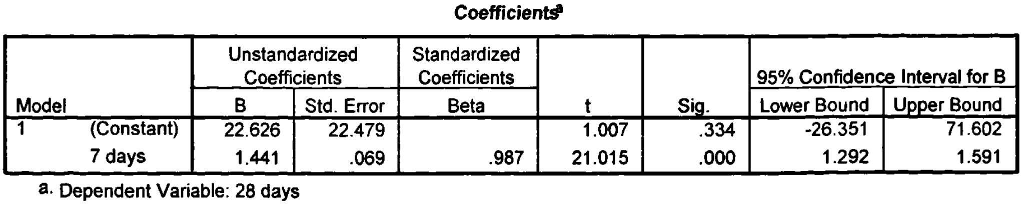
b Dependent Variable: 28 days

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	1058856.621	1	1058856.621	441.647	.000(a)
	Residual	28770.236	12	2397.520		
	Total	1087626.857	13			

a Predictors: (Constant), 7 days

b Dependent Variable: 28 days



Coefficients[a]

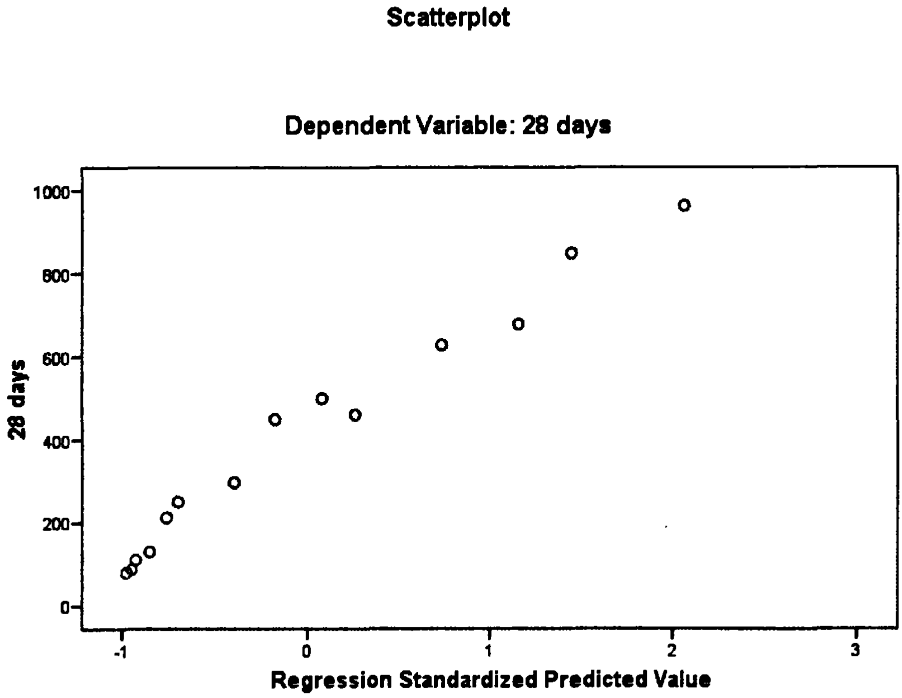
Model		Unstandardized Coefficients		Standardized Coefficients			95% Confidence Interval for B	
		B	Std. Error	Beta	t	Sig.	Lower Bound	Upper Bound
1	(Constant)	22.626	22.479		1.007	.334	-26.351	71.602
	7 days	1.441	.069	.987	21.015	.000	1.292	1.591

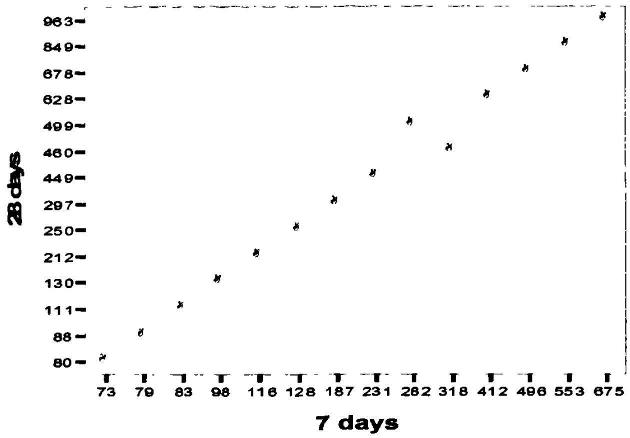
a. Dependent Variable: 28 days

Residuals Statistics[a]

	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	127.84	995.46	406.71	285.395	14
Residual	-59.477	93.449	.000	47.044	14
Std. Predicted Value	-.977	2.063	.000	1.000	14
Std. Residual	-1.215	1.909	.000	.961	14

a Dependent Variable: 28 days





Output 5. 3 Days-ucs-60°c

mix	7 days	28 days
1-0-19	257	482
2-0-18	517	758
3-0-17	676	1006
4-0-16	984	1097
0-1-19	188	222
0-2-18	165	215
0-3-17	97	152
0-4-16	155	158
2-1-17	478	614
3-1-16	633	788
1-2-17	144	296
1-3-16	206	381
1-1-18	404	553
2-2-16	505	582

Descriptive Statistics

	Mean	Std. Deviation	N
28 days	521.71	307.666	14
7 days	386.36	259.490	14

Correlations

		28 days	7 days
Pearson Correlation	28 days	1.000	.964
	7 days	.964	1.000
Sig. (1-tailed)	28 days	.	.000
	7 days	.000	.
N	28 days	14	14
	7 days	14	14

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.964(a)	.929	.923	85.174

a Predictors: (Constant), 7 days

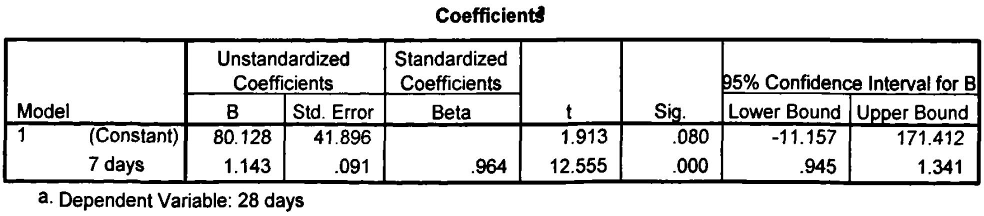
b Dependent Variable: 28 days

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	1143503.075	1	1143503.075	157.623	.000(a)
	Residual	87055.783	12	7254.649		
	Total	1230558.857	13			

a Predictors: (Constant), 7 days

b Dependent Variable: 28 days



Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95% Confidence Interval for B	
		B	Std. Error	Beta			Lower Bound	Upper Bound
1	(Constant)	80.128	41.896		1.913	.080	-11.157	171.412
	7 days	1.143	.091	.964	12.555	.000	.945	1.341

a. Dependent Variable: 28 days

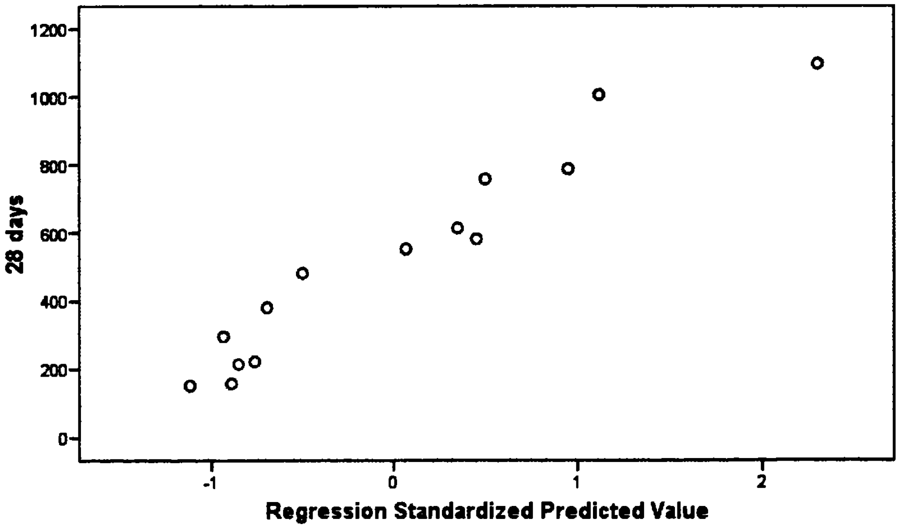
Residuals Statistics[a]

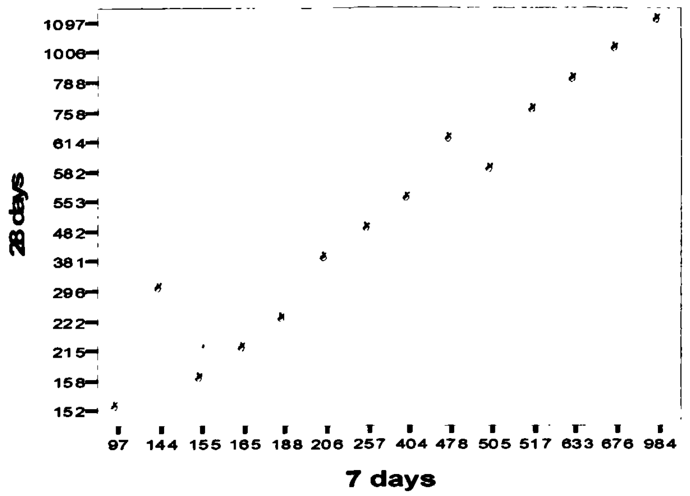
	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	190.99	1204.79	521.71	296.584	14
Residual	-107.790	153.239	.000	81.833	14
Std. Predicted Value	-1.115	2.303	.000	1.000	14
Std. Residual	-1.266	1.799	.000	.961	14

a Dependent Variable: 28 days

Scatterplot

Dependent Variable: 28 days





In analysis 1, 2 and 3

1) Mix trend is constant
2) Temperature is constant
3) Number of days increases from 7days to 28days
4) Number of days is plotted with respect to UCS
5) 7days UCS against 28days UCS, therefore no matter the orientation, results will be the same, as it is UCS against UCS. Just that the plots or outputs will be reversed or inverted.

Output 5. 4 temp-ucs-7days (20°c vs. RT)

mix	20°c	RT
1-0-19	184	231
2-0-18	347	412
3-0-17	435	553
4-0-16	473	675
0-1-19	95	98
0-2-18	78	83
0-3-17	71	73
0-4-16	74	79
2-1-17	181	282
3-1-16	326	496
1-2-17	102	116
1-3-16	108	128
1-1-18	170	187
2-2-16	179	318

Descriptive Statistics

	Mean	Std. Deviation	N
RT	266.50	198.022	14
20°c	201.64	137.464	14

Correlations

		RT	20°c
Pearson Correlation	RT	1.000	.980
	20°c	.980	1.000
Sig. (1-tailed)	RT	.	.000
	20°c	.000	.
N	RT	14	14
	20°c	14	14

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.980(a)	.961	.958	40.746

a Predictors: (Constant), 20°c

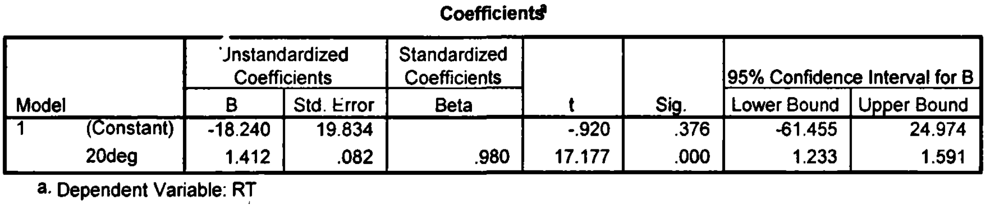
b Dependent Variable: RT

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	489840.681	1	489840.681	295.043	.000(a)
	Residual	19922.819	12	1660.235		
	Total	509763.500	13			

a Predictors: (Constant), 20°c

b Dependent Variable: RT



Coefficients[a]

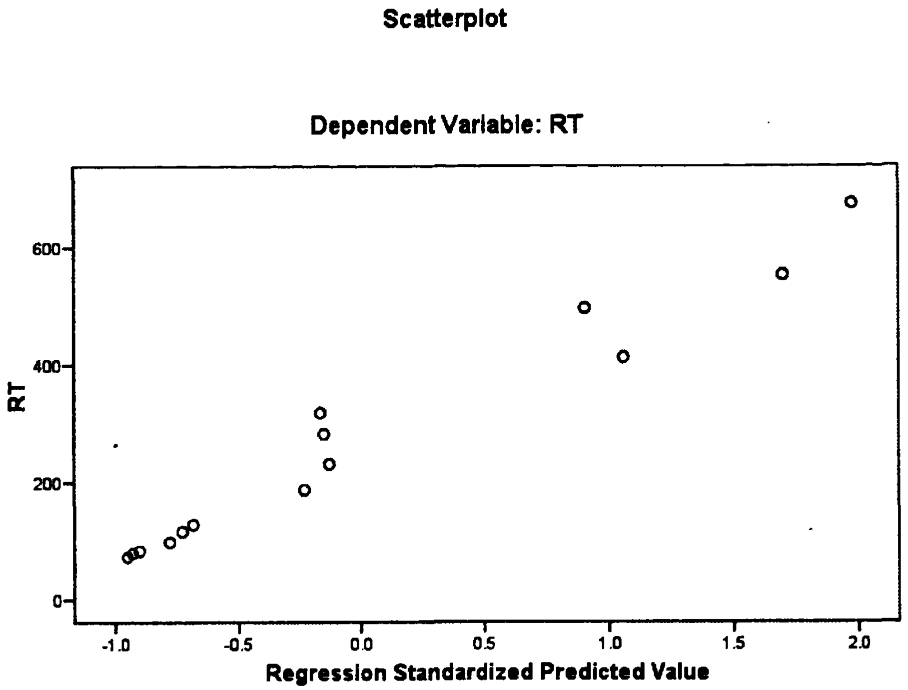
Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95% Confidence Interval for B	
		B	Std. Error	Beta			Lower Bound	Upper Bound
1	(Constant)	-18.240	19.834		-.920	.376	-61.455	24.974
	20deg	1.412	.082	.980	17.177	.000	1.233	1.591

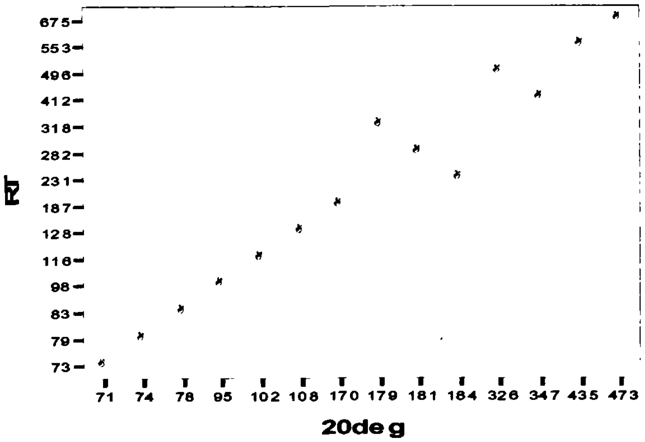
a. Dependent Variable: RT

Residuals Statistics[a]

	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	82.02	649.68	266.50	194.114	14
Residual	-59.759	83.474	.000	39.147	14
Std. Predicted Value	-.950	1.974	.000	1.000	14
Std. Residual	-1.467	2.049	.000	.961	14

a Dependent Variable: RT


Scatterplot
Dependent Variable: RT
RT
600
400
200
0
-1.0
-0.5
0.0
0.5
1.0
1.5
2.0
Regression Standardized Predicted Value


RT
675
553
496
412
318
282
231
187
128
116
98
83
79
73
71
74
78
95
102
108
170
179
181
184
326
347
435
473
20deg

Output 5. 5 temp-ucs-7days (20°c vs. 60°c)

mix	20°c	60°c
1-0-19	184	257
2-0-18	347	517
3-0-17	435	676
4-0-16	473	984
0-1-19	95	188
0-2-18	78	165
0-3-17	71	97
0-4-16	74	155
2-1-17	181	478
3-1-16	326	633
1-2-17	102	144
1-3-16	108	206
1-1-18	170	404
2-2-16	179	505

Descriptive Statistics

	Mean	Std. Deviation	N
60°c	386.36	259.490	14
20°c	201.64	137.464	14

Correlations

		60°c	20°c
Pearson Correlation	60°c	1.000	.935
	20°c	.935	1.000
Sig. (1-tailed)	60°c	.	.000
	20°c	.000	.
N	60°c	14	14
	20°c	14	14

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.935(a)	.874	.863	95.952

a Predictors: (Constant), 20°c

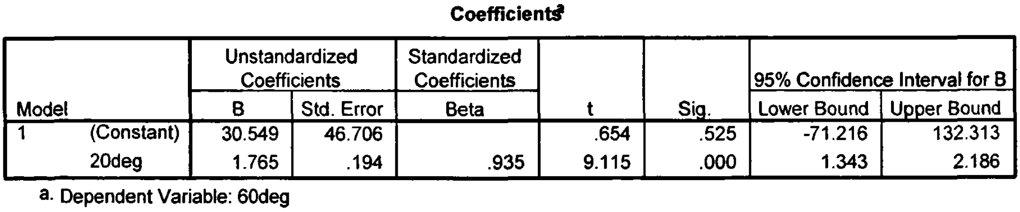
b Dependent Variable: 60°c

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	764872.769	1	764872.769	83.078	.000(a)
	Residual	110480.445	12	9206.704		
	Total	875353.214	13			

a Predictors: (Constant), 20°c

b Dependent Variable: 60°c



Coefficients[a]

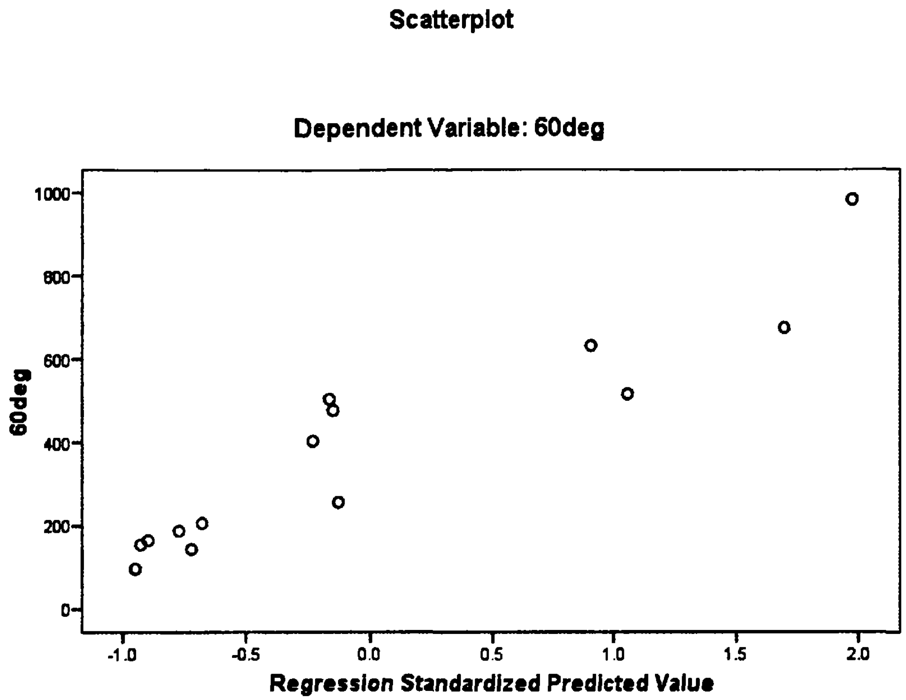
Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95% Confidence Interval for B	
		B	Std. Error	Beta			Lower Bound	Upper Bound
1	(Constant)	30.549	46.706		.654	.525	-71.216	132.313
	20deg	1.765	.194	.935	9.115	.000	1.343	2.186

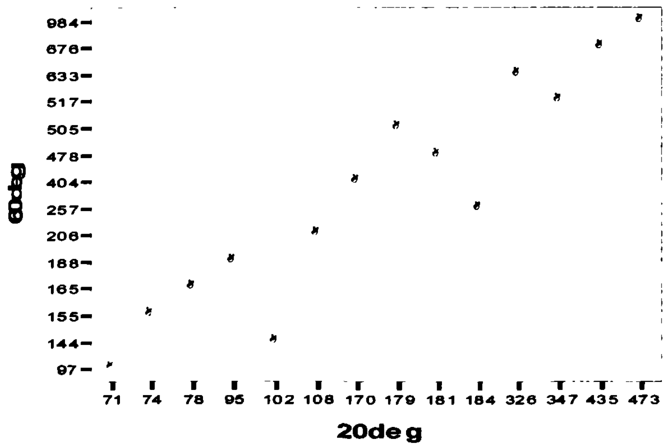
a. Dependent Variable: 60deg

Residuals Statistics[a]

	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	155.83	865.18	386.36	242.562	14
Residual	-125.847	158.597	.000	92.187	14
Std. Predicted Value	-.950	1.974	.000	1.000	14
Std. Residual	-1.312	1.653	.000	.961	14

a Dependent Variable: 60°c


Scatterplot
Dependent Variable: 60deg
1000
800
600
400
200
0
60deg
-1.0
-0.5
0.0
0.5
1.0
1.5
2.0
Regression Standardized Predicted Value


984
676
633
517
505
478
404
257
206
188
165
155
144
97
60deg
71
74
78
95
102
108
170
179
181
184
326
347
435
473
20deg

Output 5. 6 temp-ucs-7days (RT vs. 60°c)

mix	RT	60°c
1-0-19	231	257
2-0-18	412	517
3-0-17	553	676
4-0-16	675	984
0-1-19	98	188
0-2-18	83	165
0-3-17	73	97
0-4-16	79	155
2-1-17	282	478
3-1-16	496	633
1-2-17	116	144
1-3-16	128	206
1-1-18	187	404
2-2-16	318	505

Descriptive Statistics

	Mean	Std. Deviation	N
60°c	386.36	259.490	14
RT	266.50	198.022	14

Correlations

		60°c	RT
Pearson Correlation	60°c	1.000	.971
	RT	.971	1.000
Sig. (1-tailed)	60°c	.	.000
	RT	.000	.
N	60°c	14	14
	RT	14	14

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.971(a)	.942	.937	65.075

a Predictors: (Constant), RT

b Dependent Variable: 60°c

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	824535.641	1	824535.641	194.705	.000(a)
	Residual	50817.574	12	4234.798		
	Total	875353.214	13			

a Predictors: (Constant), RT

b Dependent Variable: 60°c

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95% Confidence Interval for B	
		B	Std. Error	Beta			Lower Bound	Upper Bound
1	(Constant)	47.421	29.875		1.587	.138	-17.670	112.513
	RT	1.272	.091	.971	13.954	.000	1.073	1.470

a. Dependent Variable: 60deg

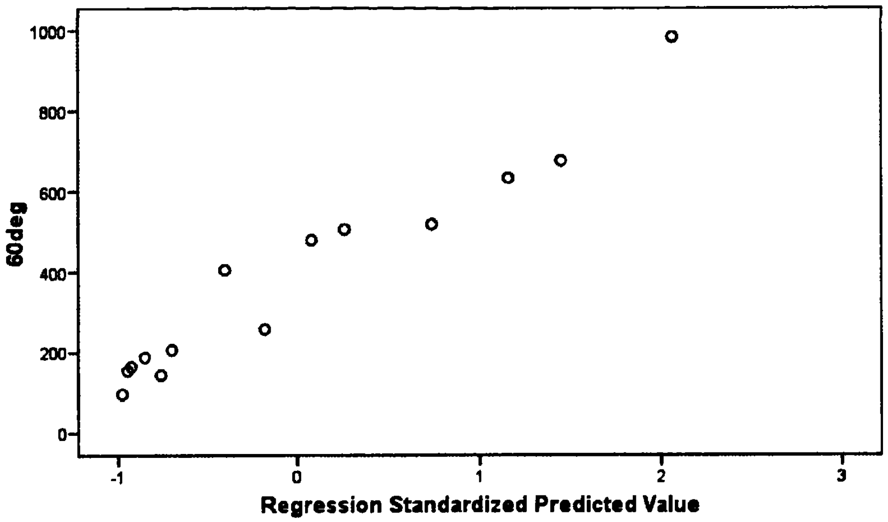
Residuals Statistics[a]

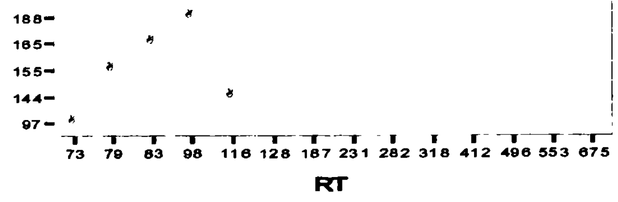
	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	140.26	905.89	386.36	251.845	14
Residual	-84.208	118.751	.000	62.522	14
Std. Predicted Value	-.977	2.063	.000	1.000	14
Std. Residual	-1.294	1.825	.000	.961	14

a Dependent Variable: 60°c

Scatterplot

Dependent Variable: 60deg





In analysis 4, 5, and 6

1. Mix trend is constant
2. Number of days is constant, that is 7days
3. Temperature increases, that is from 20°c to RT, 20°c to 60c and RT to 60°c respectively.

4. Temperature is plotted with respect to UCS.
5. No matter the orientation of temperature, the results will be the same, because it is UCS against UCS. Just that the plots or outputs will be reversed or inverted

Output 5. 7 temp-ucs-28days (20°c vs. RT)

mix	20°c	RT
1-0-19	393	449
2-0-18	425	628
3-0-17	698	849
4-0-16	936	963
0-1-19	101	130
0-2-18	93	111
0-3-17	75	80
0-4-16	84	88
2-1-17	479	499
3-1-16	517	678
1-2-17	167	212
1-3-16	178	250
1-1-18	191	297
2-2-16	327	460

Descriptive Statistics

	Mean	Std. Deviation	N
RT	406.71	289.247	14
20°c	333.14	259.562	14

Correlations

		RT	20°c
Pearson Correlation	RT	1.000	.977
	20°c	.977	1.000
Sig. (1-tailed)	RT	.	.000
	20°c	.000	.
N	RT	14	14
	20°c	14	14

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.977(a)	.955	.951	63.776

a Predictors: (Constant), 20°c

b Dependent Variable: RT

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	1038818.552	1	1038818.552	255.404	.000(a)
	Residual	48808.306	12	4067.359		
	Total	1087626.857	13			

a Predictors: (Constant), 20°c

b Dependent Variable: RT

Coefficients[a]

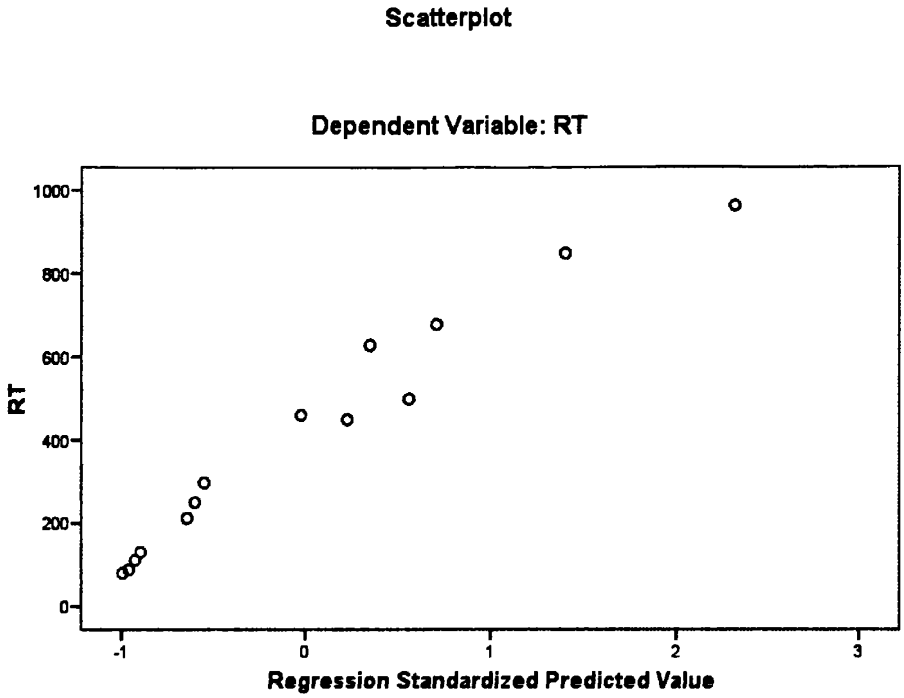
Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95% Confidence Interval for B	
		B	Std. Error	Beta			Lower Bound	Upper Bound
1	(Constant)	43.897	28.389		1.546	.148	-17.957	105.751
	20deg	1.089	.068	.977	15.981	.000	.941	1.238

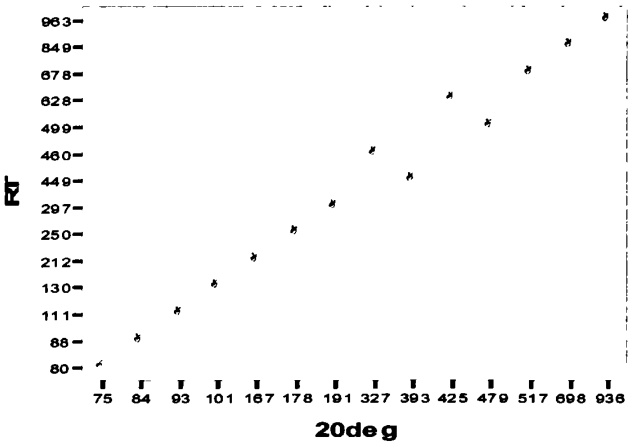
a. Dependent Variable: RT

Residuals Statistics[a]

	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	125.58	1063.27	406.71	282.682	14
Residual	-100.271	121.246	.000	61.274	14
Std. Predicted Value	-.995	2.323	.000	1.000	14
Std. Residual	-1.572	1.901	.000	.961	14

a Dependent Variable: RT


Scatterplot
Dependent Variable: RT
RT
1000
800
600
400
200
0
-1
0
1
2
3
Regression Standardized Predicted Value


RT
963
849
678
628
499
460
449
297
250
212
130
111
88
80
75
84
93
101
167
178
191
327
393
425
479
517
698
936
20deg

Output 5. 8 temp-ucs-28days (20°c vs. 60°c)

mix	20°c	60°c
1-0-19	393	482
2-0-18	425	758
3-0-17	698	1006
4-0-16	936	1097
0-1-19	101	222
0-2-18	93	215
0-3-17	75	152
0-4-16	84	158
2-1-17	479	614
3-1-16	517	788
1-2-17	167	296
1-3-16	178	381
1-1-18	191	553
2-2-16	327	582

Descriptive Statistics

	Mean	Std. Deviation	N
60°c	521.71	307.666	14
20°c	333.14	259.562	14

Correlations

		60°c	20°c
Pearson Correlation	60°c	1.000	.953
	20°c	.953	1.000
Sig. (1-tailed)	60°c	.	.000
	20°c	.000	.
N	60°c	14	14
	20°c	14	14

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.953(a)	.908	.900	97.316

a Predictors: (Constant), 20°c

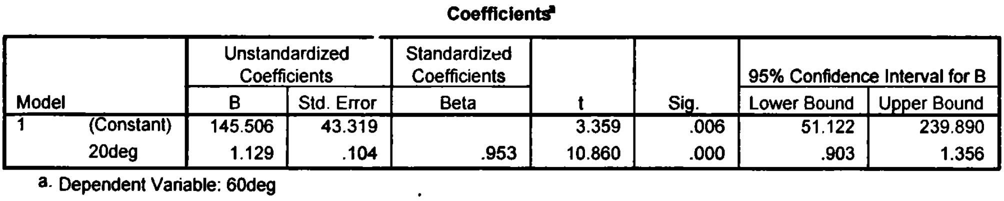
b Dependent Variable: 60°c

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	1116913.108	1	1116913.108	117.936	.000(a)
	Residual	113645.749	12	9470.479		
	Total	1230558.857	13			

a Predictors: (Constant), 20°c

b Dependent Variable: 60°c



Coefficients[a]

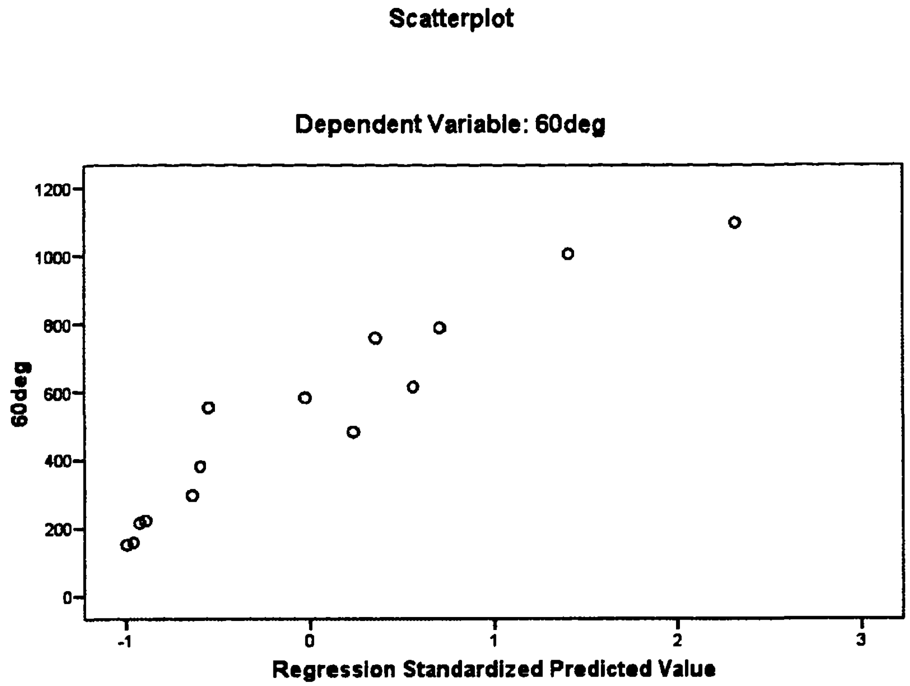
Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95% Confidence Interval for B	
		B	Std. Error	Beta			Lower Bound	Upper Bound
1	(Constant)	145.506	43.319		3.359	.006	51.122	239.890
	20deg	1.129	.104	.953	10.860	.000	.903	1.356

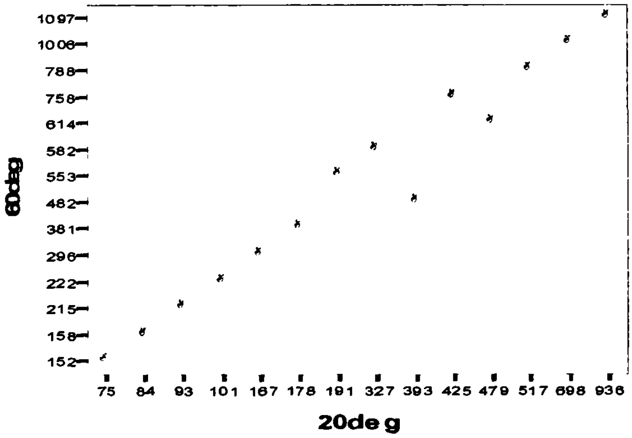
a. Dependent Variable: 60deg

Residuals Statistics[a]

	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	230.20	1202.50	521.71	293.115	14
Residual	-107.309	191.803	.000	93.499	14
Std. Predicted Value	-.995	2.323	.000	1.000	14
Std. Residual	-1.103	1.971	.000	.961	14

a Dependent Variable: 60°c


Scatterplot
Dependent Variable: 60deg
1200
1000
800
600
400
200
0
60deg
-1
0
1
2
3
Regression Standardized Predicted Value


1097
1006
788
758
614
582
553
482
381
296
222
215
158
152
60deg
75
84
93
101
167
178
191
327
393
425
479
517
698
936
20deg

Output 5. 9 temp-ucs-28days (RT vs. 60°c)

mix	RT	60°c
1-0-19	449	482
2-0-18	628	758
3-0-17	849	1006
4-0-16	963	1097
0-1-19	130	222
0-2-18	111	215
0-3-17	80	152
0-4-16	88	158
2-1-17	499	614
3-1-16	678	788
1-2-17	212	296
1-3-16	250	381
1-1-18	297	553
2-2-16	460	582

Descriptive Statistics

	Mean	Std. Deviation	N
60°c	521.71	307.666	14
RT	406.71	289.247	14

Correlations

		60°c	RT
Pearson Correlation	60°c	1.000	.987
	RT	.987	1.000
Sig. (1-tailed)	60°c	.	.000
	RT	.000	.
N	60°c	14	14
	RT	14	14

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.987(a)	.974	.972	51.705

a Predictors: (Constant), RT

b Dependent Variable: 60°c

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	1198477.973	1	1198477.973	448.296	.000(a)
	Residual	32080.884	12	2673.407		
	Total	1230558.857	13			

a Predictors: (Constant), RT

b Dependent Variable: 60°c

Coefficients[a]

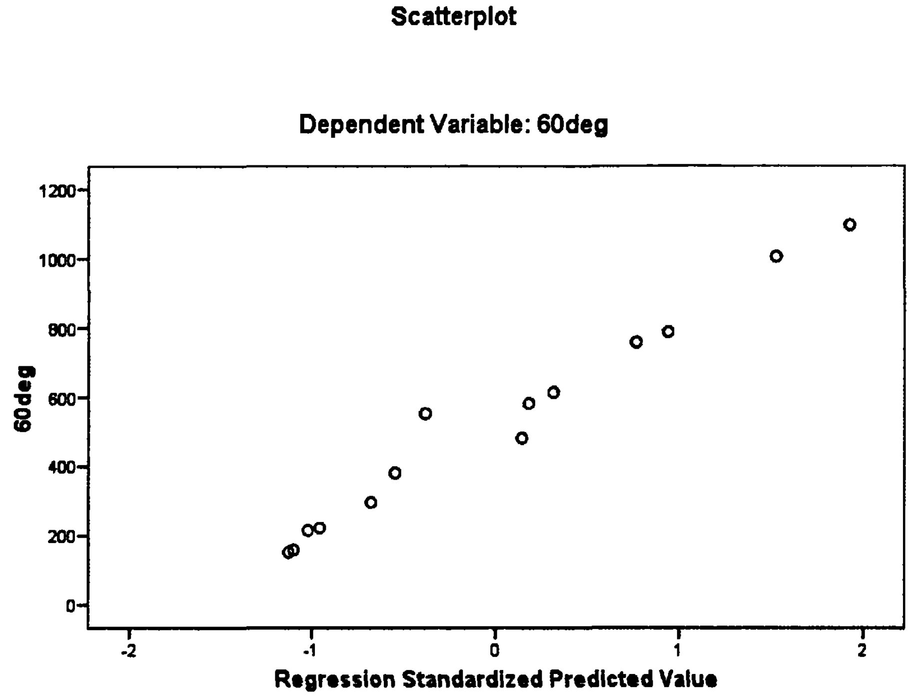
Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95% Confidence Interval for B	
		B	Std. Error	Beta			Lower Bound	Upper Bound
1	(Constant)	94.777	24.445		3.877	.002	41.516	148.038
	RT	1.050	.050	.987	21.173	.000	.942	1.158

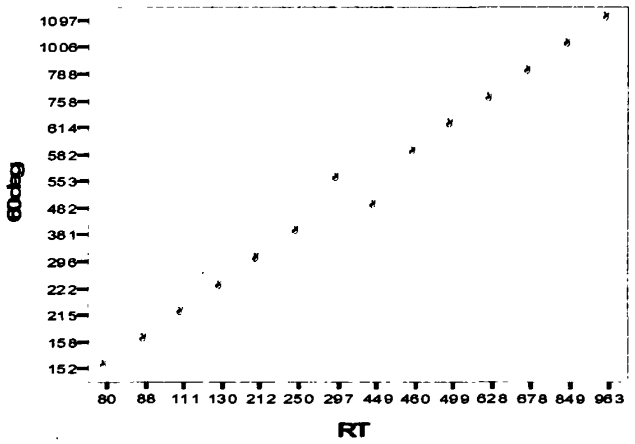
a. Dependent Variable: 60deg

Residuals Statistics[a]

	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	178.75	1105.66	521.71	303.629	14
Residual	-84.103	146.455	.000	49.677	14
Std. Predicted Value	-1.130	1.923	.000	1.000	14
Std. Residual	-1.627	2.833	.000	.961	14

a Dependent Variable: 60°c





In outputs 7, 8, and 9

1) Mix trend is constant
2) Number of days is constant, that is 28days
3) Temperature increases, that is from 20°c to RT, 20°c to 60°c and RT to 60°c respectively.

4) Temperature is plotted with respect to UCS.
5) No matter the orientation of temperature, the results will be the same, as it is UCS against UCS. Just that the plots or outputs will be inverted or reversed.

Output 5. 10 Mix prop-ucs- (Temp and Days) Data Table

mix	7days-20°c	7days-RT	7days-60°c	28days-20°c	28days-RT	28days-60°c
1-0-19	184	231	257	393	449	482
2-0-18	347	412	517	425	628	758
3-0-17	435	553	676	698	849	1006
4-0-16	473	675	984	936	963	1097
0-1-19	95	98	188	101	130	222
0-2-18	78	83	165	93	111	215
0-3-17	71	73	97	75	80	152
0-4-16	74	79	155	84	88	158
2-1-17	181	282	478	479	499	614
3-1-16	326	496	633	517	678	788
1-2-17	102	116	144	167	212	296
1-3-16	108	128	206	178	250	381
1-1-18	170	187	404	191	297	553
2-2-16	179	318	505	327	460	582

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
7days-20°c	14	71	473	201.64	137.464
7days-RT	14	73	675	266.50	198.022
7days-60°c	14	97	984	386.36	259.490
28days-20°c	14	75	936	333.14	259.562
28days-RT	14	80	963	406.71	289.247
28days-60°c	14	152	1097	521.71	307.666
Valid N (listwise)	14				

In output 10

1) Temperature is constant at 20°c, RT or 60°c
2) Number of days is constant at 7days or 28days
3) Mix changes (varies)
4) This shows how UCS varies with mix when temperature and number of days are kept constant at particular temperatures and number of days respectively. Analysis is vertical (column wise).

From all the outputs and plots, it can be seen that all the linear regression analysis assumptions where met. The following interpretations can also be made from the outputs and plots:

1) Correlation

For the research hypothesis to hold, Pearson's correlation r should not be equal to zero (inorder for the null hypothesis to be rejected) and it should be positive and high to show a very strong correlation between the two variables. In all outputs, r was not equal to zero, implying that there is a relationship between the dependent and independent variables. Also the r's were positive and very high (almost 1), implying that there is a very strong relationship between the dependent and independent variables.

2) Model summary

Coefficient r shows the strength of the relationship between the two variables and R^2 is the proportion of variation in the dependent variable explained by the regression model. The sample R^2 tends to optimistically estimate how well the models fit the population. r should be between -1 and +1 and R^2 should be between 0 and 1. For the model to fit the data very well, r and R^2 should be positive and very high. In all the outputs, r's are positive and very high, implying that there is a strong relationship between the two variables. Also the R^2 values are very high, implying that the sample models the population very well.

3) ANOVA

The significance of r and R^2 are shown as an F statistics. If the significance value of the F statistics is small (smaller than 0.05) then the independent variables do a good job explaining the variation in the dependent variable. In all the outputs, the significance value of the *F* statistics is zero (less than 0.05), which is very good, implying that the independent variables explain the variation in the dependent variable very well.

4) Coefficients

The smaller the standard error in the regression equation, the better the prediction model. In all the outputs, the standard errors are very small, implying very good prediction models.

5) Residual statistics

The sum of the residuals should always be equal to zero; also the mean should be zero. In all the outputs, these conditions were satisfied.

6) Scatter plots

For linear regression analysis, the relationship between dependent and independent variables is normally linear in nature; the individual points tend to group around a straight line. In all the plots, almost all the points are in a straight line or tend towards a straight line. This shows a very good linear relationship between the dependent and independent variables. The scatter plots for outputs 5 and 6 are a bit scattered than the others this is because, at low temperatures and low number of days, strengths are relatively low (or ill-defined) and because strength comparison is between low temperatures (20°c, RT) and a high temperature (60°c) at low number of days (7days), hence the scatter.

In summary, it can be seen that there is a very strong correlation between unconfined compressive strength (dependent variable) and design mix, curing conditions and curing durations (independent variables). It is seen that as design mix, curing conditions and curing durations increases, strength increases. The extent of the strength increase is also proportional to the increases in design mix, curing conditions and curing durations.

It can also be seen that the three independent variables (design mix, curing conditions and curing durations) tend to affect strength to the same degree or extent.

The strength properties of flyash is not as good as cement but it can be seen that cement mixes with flyash incorporated in them, showed some increase in strength and had better mechanical properties than their cement only counterparts. So with flyash added to cement mixes, strength can be increased, mechanical properties improved (less brittle) and cost reduced (flyash cheaper than cement).

Chapter 6 Conclusions and Recommendations

6.1 Conclusions

The theoretical and numerical analyses agree with each other in every way, we can therefore, make the following conclusions from our experiments:

1) As temperature, humidity and number of days increases, strength increases.

2) The extent of the strength increase is also proportional to the increases in design mix, curing conditions and curing durations.

3) Design mix, curing conditions and curing durations tend to affect strength to the same degree or extent.

4) At low temperatures, strength gain of specimens is gradual whilst at high temperatures, strength gain is rapid.

5) Cement gains strength rapidly within the first 7days and then continues at a less rapid rate afterwards.

6) Flyash gains strength at a much slower rate within the first 7days and then starts to gain strength at a faster rate afterwards.

7) Cement on its own is way stronger than flyash on its own.

8) The full benefits of flyash are not recognized when it is used in isolation, the pozzolanic reactions are not facilitated, hence the low strength values.

9) Cement and flyash when combined gives a very good product with good structural (relatively high strength) and mechanical(less brittle) properties. They compliment each other, makes up for each others weaknesses. Cement makes up for flyash's low strength qualities and flyash makes up for cement's brittle qualities.

10) Too much cement and flyash is not good in soil stabilization. High cement contents causes shrinkage which lowers strength and affects the serviceability of the road. High flyash contents, instead of increasing strength, lowers it, because more gravel is being replaced by flyash and flyash on its own is not a good stabilizer (pozzolanic reaction not facilitated).

11) After curing and before testing, no cracks were observed in the specimens with flyash, and fewer cracks were observed in the cement specimens mixed with flyash.

12) Flyash can be added to soil-cement mixtures to improve the engineering properties of the soil and also reduce cost.

6.2 Recommendations

1) When comparing 1-1-18, 2-2-16, 2-1-17, 3-1-16, 3-1-16 gave the highest strength values (most of the time) for all categories of curing conditions and durations that is 3-1-16 > 2-1-17 > 2-2-16 > 1-1-18. It is better to use mixes with less cement content to avoid shrinkage cracking and reduce cost but also bearing in mind that you need high strengths too. 3-1-17 gives high strengths but also has high cement contents. In some cases strengths of 2-2-16 is higher than 2-1-17, so it is better to use 2-2-16. But in most case 2-1-17 is higher than 2-2-16, so it is better to use 2-1-17, as this lower cost, as flyash content is less.

2) Depending on the intended use of the highway and specified strength, careful attention should be paid when choosing design mix and specifying curing conditions and durations in order to benefit from the enhancing qualities of flyash in cement mixes.

6 3 Suggestions for Further Research

Due to time limitations, regarding the laboratory tests and subsequent analysis, the following studies could be undertaken:

1) Replicate the same research, but soak samples before testing and compare the results obtained with the unsoaked results in this research.

2) Replicate the same research, but test samples for other engineering properties like stiffness, durability, permeability, volume-stability e.t.c and see how these are affected by mix design, curing conditions and curing durations.

3) Use other curing conditions e.g. 50% humidity.

4) Use other curing durations e.g. 60days and 90days.

5) Using SPSS, do a multivariate analysis of the results obtained in this research.

6) Use different numerical software to analyze the results of this research and compare the results obtained with the ones in this research.

7) Replicate the same research, but instead of conducting tests on laboratory samples, insitu tests should be done.

8) All the above listed recommendations can be done in the field and comparisons can be made between laboratory and insitu results.

Appendix

7dys 20deg


Mix 1


Mix 2


Mix 3


Mix 4


Mix 5


Mix 6


Mix 7


Mix 8


Mix 9


Mix 10


Mix 11


Mix 12


Mix 13


Mix 14

7dys RT & H


Mix 1


Mix 2


Mix 3


Mix 4


Mix 5


Mix 6


Mix 7


Mix 8


Mix 9


Mix 10


Mix 11


Mix 12


Mix 13


Mix 14

7dys 60deg


Mix 1


Mix 2


Mix 3


Mix 4


Mix 5


Mix 6


Mix 7


Mix 8


Mix 9


Mix 10


Mix 11


Mix 12


Mix 13


Mix 14

28dys 20deg


Mix 1


Mix 2


Mix 3


Mix 4


Mix 5


Mix 6


Mix 7


Mix 8


Mix 9


Mix 10


Mix 11


Mix 12


Mix 13


Mix 14

28dys RT & H


Mix 1


Mix 2


Mix 3


Mix 4


Mix 5


Mix 6


Mix 7


Mix 8


Mix 9


Mix 10


Mix 11


Mix 12


Mix 13


Mix 14

28dys 60deg


Mix 1


Mix 2


Mix 3


Mix 4


Mix 5


Mix 6


Mix 7


Mix 8


Mix 9


Mix 10


Mix 11


Mix 12


Mix 13


Mix 14

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Could I make it down here
If YOU didn't
Intercede for me up there"

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