

**FIVE COMPONENT CONCRETE MIX OPTIMIZATION OF
ALUMINUM WASTE USING SCHEFFE'S THEORY**

BY

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DEDICATION

This work is dedicated to God Almighty who gave me strength and wisdom to carry out this work.

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ABSTRACT

The research investigated some mechanical properties of aluminum waste concrete to harness its structural properties in the construction industry. Aluminum waste which was obtained from Aluminum Extrusion Industry (ALEX) Inyishi in Ikeduru Local Government Area of Imo State was investigated. The mathematical models for the optimization of the compressive and flexural strengths of a five component concrete mix was obtained. A computer program for the optimization of the compressive and flexural strengths of aluminum waste concrete was developed. Scheffe's experimental design technique was followed to produce concrete containing five components, which were used to cast cube and beam samples. The cubes and beams have dimensions of 150mm x 150mm x 150mm and 100mm x 100mm x 500mm respectively. The cube samples were tested for 7, 14 and 28 days strength. The result showed that the addition of 5% aluminum waste to a standard 1:2:4:0.55 mix caused compressive strength of the concrete to rise from 26.07N/mm² to 28.47N/mm². This result represents an increase of 9.21% in compressive strength. Aluminum waste produced no significant effect on the density, Poisson ratio, young's modulus of the concrete. The computer program gave an optimum mix ratio of 1:1.1:1.75:1.15:0.7 (Cement, fine aggregate, coarse aggregate, aluminum waste, water), which generated a compressive strength of 29.81N/mm², an increase of 14.35% in compressive strength over a standard mix. The result represented a saving of 16% by volume of concrete and a reduction of four thousand naira per cubic meter of concrete when compared with the standard mix. The computer program for the optimum mix ratio for flexural strength gave a value of 11.72N/mm². There was an increase in flexural strength when compared to 9.46N/mm² of the standard mix. The research concludes that aluminum waste concrete is economical and produces high compressive and flexural strength and can be

used in structural members such as beams and columns where high compressive strength concrete is needed.

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LIST OF SYMBOLS

Symbol and meaning	unit
S_t = Tensile strength of concrete	N/mm^2
C, e, a = volume of cement, water and air	m^3
K = constant	
F_{cu} = Compressive strength of concrete	N/mm^2
P = Crushing load	N
A = Cross sectional area of concrete cube	mm^2
F_s = Flexural strength	N/mm^2
A_w = Aluminum waste	dimensionless
E_c = Static modules of elasticity	dimensionless
D = Density of concrete	kg/m^3
G_c = Modulus of rigidity	dimensionless
J = Shear stress in concrete	N/mm^2
γ_c = Shear (Lateral) strain in concrete	dimensionless
μ = Static position ratio	dimensionless
S_c = Compressive stress at cracking	N/mm^2
L = Length of beam	mm
B = width of beam	mm
D = depth of beam	mm

ASTM	American Society for Testing and Materials
MSWI	Municipal Solid Waste Incineration
MK	Metakaolin
HPC	High Performance Concrete
C-S-H	Calcium Silicate Hydrate
A-S-R	Alkaline Silica Reaction
BS	British Standard
ACI	American Concrete Institute
W/C	Water- Cement ratio
AW	Aluminum Waste

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CHAPTER ONE

INTRODUCTION

1.0 GENERAL

Shelter is a serious problem in developing countries like Nigeria. As a result, majority of the people in Nigeria especially those occupying the riverine areas are living in substandard houses (Kashi et al, 2002). The major factor militating against the provision of affordable houses in Nigeria is high cost of building materials – “concrete materials” and “steel materials”. Steel buildings are not cheap and common compared to concrete buildings due to underdeveloped steel industry in Nigeria.

The materials commonly used in concrete construction industry include water, cement, sand and granite (Neville, 1983). Water is always available in its natural states, as rainwater, river water, fresh seawater, and borehole water. Sand is also available in its natural state as river sand, sea sand, erosion sand and desert dunes (sand from the desert). Cement and granite (Coarse aggregate) are not commonly available in their natural states. They are

processed materials. In most case the point of use is different from point of manufacture. As such they are the determinant factors in the cost of concrete products. Concrete can be defined in various ways, each depending on the understanding and the level of discussions. According to Neville and Brooks (2002), concrete is any product or mass made by the use of any cementing medium. Concrete in this study is a composite material made from the combination of aggregates, cement, water and admixtures (if any). Aggregates are defined as, particles of rock which, when brought together in a bound or unbound conditions form part or whole of an engineering or building structure (Majid, 2002).

Concrete has been classified into two broad classes, plain and reinforced (Ghose, 1989). Generally, concrete is good in compression and poor in tension (Orie, 2005). Modern research in concrete seeks to provide greater understanding of its constituent materials and possibilities of improving its desired qualities. For instance, cement has been partially

replaced with fuel ash (David and Galliford, 2000). The cost of cement and coarse aggregate is on the increase and apparently unaffordable to the rural dwellers, especially those living in the riverine areas of Nigeria. This trend of cost of concrete products has led many researchers to go into the search for alternative and affordable materials for use in concrete. It is in the same spirit of the search for alternative and affordable materials for concrete that this research work tried to see the applicability of aluminum waste in concrete production.

1.1 STATEMENT OF PROBLEM

Production of cement causes replacement of spare parts and high cost of energy production. The high cost of cement in Nigeria makes it impossible for most people to own a house. Because of these, literature has therefore revealed the need for the exploration of possible ways of using local materials in the construction industry. It identifies that additives in concrete makes the resultant concrete to have the desired properties. Therefore, there is a need to develop optimized

mix proportions of the natural constituents of concrete and the chosen admixture. This research work therefore, seeks to find a process for the optimization of aluminum waste concrete.

1.2 AIMS AND OBJECTIVES

The work aims amongst others to:

- i. Examine the effect of using aluminum waste as additive on some mechanical properties of concrete.
- ii. Investigate the use of aluminum waste as a fifth component in concrete.
- iii. Determine the optimal combination of materials in concrete containing aluminum waste in terms of compressive and flexural strength characteristics.
- iv. Investigate the use of Scheffe's second degree optimization theory in a five component concrete mix.
- v. Develop models for the optimization of the mechanical properties of five-component concrete mix.

1.3 JUSTIFICATION OF THE STUDY

The work finds its usefulness in the present economy of developing countries such as Nigeria and the need to provide adequate structural elements using the optimum combination of locally available, accessible and affordable materials. Optimized quantities provide relatively cheaper and better result in any field of human endeavour. The results derived from the work will also serve as a spring board for the optimization of concrete mixes that have five components. This will be of immense benefit to the general construction industry.

1.4 SCOPE OF STUDY

The scope of the study is as follows:

- (i) Effect of variation of percentage of aluminum waste.
- (ii) Effect of variation of water-cement ratio.
- (iii) Optimal combination.
- (iv) Compressive strength.
- (v) Flexural strength.
- (vi) Static modulus of elasticity and.
- (vii) Modulus of rigidity.

CHAPTER TWO

LITERATURE REVIEW

2.0 INTRODUCTION

Concrete is a mixture of several component materials: water, cement, fine and coarse aggregates. According to Oyenuga (1999), concrete is known to be a composite inert material comprising of a binder course (cement) and mineral filler (body) or aggregates and water. Concrete, is a building and structural material, in which the properties may be predetermined by careful design and control of the constituent materials. The cement forms the binder for the mix, while water is added for hydration of cement, but when added in excess it will affect the strength of concrete produced.

According to Shetty (2000), the strength that may be developed by workable, properly placed mixture of cement, aggregates and water (under the same mixture) depends on the ratio of cement to aggregate grading, surface texture, shape, strength and stiffness of aggregate particles, and maximum size of aggregates.

According to Jackson (1981) concrete is composite materials, of which the major constituent is natural aggregates such as gravel (river stone) and sand. Alternative artificial aggregates include blast furnace slags, expanded clay and broken bricks.

Concrete is classified based on its uses or method of application and constituents. Considering the classification based on its constituents, we have heavy-weight concrete and light-weight concrete (Abuguo, 1984). For the purpose of this research, heavy-weight concrete will be considered.

Generally, concrete is used in virtually all civil engineering works. In buildings, it finds application from the foundation to the roof. Concrete is good in compression but poor in tension. Hence, in reinforced concrete design, it is assumed that the concrete in the tension zone of the member has failed (BS 8110, part 5, 1985).

2.1 HEAVY WEIGHT CONCRETE

This is the most common structural concrete available in construction. It usually has a high density ranging from 2200kg/m^3 to 2600kg/m^3 . The aggregates used in the production of heavy weight concrete include sand, gravel, and crushed stone. For this research, sand and gravel were used as fine and coarse aggregates respectively.

2.1.1 PROPERTIES OF FRESH CONCRETE

Fresh concrete or plastic concrete is a freshly mixed material which can be moulded into any shape. The relative quantities of cement, aggregates and water mixed together affects the states, both fresh and hardened state (Shetty, 2004).

2.1.1.1 WORKABILITY

According to Jackson and Dhir (1996), workability is the ease with which a concrete mix can be handled from the mixer to its finally compacted shape. The three main characteristics are consistency, mobility and compactibility. Consistency is the measure of wetness or fluidity. Mobility

defines the ease with which a mix can flow into and completely fill the formwork or mould. Compactibility is the ease with which a given mix can be fully compacted to remove all trapped air. Four tests widely used in measuring workability includes: slump, compacting factor, vebe consistometer and flow tests.

2.1.1.2 SLUMP

This test primarily measure the consistency of plastic concrete. An increase in the water content or deficiency in the proportion of fine aggregate results in an increase in slump. The three types of slump usually observed are true slump, shear slump and collapse Slump (Neville, 1999). A true slump is observed with cohesive and rich mixes. A collapse slump is usually association with very wet mixes and is generally an indication of poor quality concrete and most frequently result in segregation of the constituent materials. Shear slump is obtain more often in leaner mixes and indicates a lack of cohesion which is generally associated with harsh mixes.

2.1.1.3 COMPACTING FACTOR TEST

This test measures the degree of compaction imparted to concrete for a standard amount of work and thus offers a direct and reasonably reliable assessment of workability of concrete.

2.1.1.4 VEBE CONSISTOMETER TEST

Although generally regarded as a test primarily used in measuring workability, it is not widely used. In this test (BS 1881: part 04), the time taken to transform, by means of vibration, a standard cone of concrete to a compacted flat cylinder is recorded in seconds.

2.2 FACTORS AFFECTING WORKABILITY OF CONCRETE

Workable concrete is the one which exhibits very little internal friction between particles or which overcomes the frictional resistance offered by the framework surface or reinforcements contained in the concrete with just little amount of compactive effort. The factors that affect

workability includes: water content, mix proportion, size of aggregate, grading of aggregates and surface texture.

2.2.1 WATER CONTENT

Shetty(2004) pointed out that water content in a given volume of concrete, will have significant influence on its workability. The higher the water content per cubic meter of concrete, the higher will be the fluidity of concrete, which is one of the important factors affecting workability.

2.2.2 MIX PROPORTIONS

Aggregate/cement ratio is an important factor influencing workability. The higher the aggregate/cement ratio, the leaner is the concrete. In lean concrete, less quantity of paste is available for providing lubrication per unit surface area of aggregate and hence the mobility of aggregate is restrained. On the other hand, in case of concrete with lower aggregate/cement ratio, more paste is available to make the mix cohesive which will give better workability.

2.2.3 SIZE OF AGGREGATE

The larger the size of aggregates, the less is the surface area and hence much water is required for wetting the surface and much paste is required for lubricating the surface to reduce internal friction. For a given quantity of water and paste, larger sizes of aggregates will give higher workability.

The shape of aggregates influence workability of concrete according to Shetty (1982).

2.2.4 GRADING OF AGGREGATE

This is one of the factors which influences workability. A well graded aggregate is the one which has least amount of voids in a given volume. Other factors being constant, when the total voids are less, excess paste is available to give better lubricating effect. With excess amount of paste, the mixture becomes cohesive which prevents segregation of particles. The better the grading, the less the void content and higher the workability.

2.2.5 SURFACE TEXTURE

The influence of surface texture on workability is due to the fact that the total surface area of rough textured aggregates is more than the surface area of smooth rounded aggregates of the same volume. From the earlier discussions, it can be inferred that rough textured aggregates will result to poor workability while smooth or glassy textured aggregates will give better workability.

2.3 PROPERTIES OF HARDENED CONCRETE

The properties of hardened concrete are very important. Some important properties of hardened concrete are strength, deformation under load, durability, permeability, strength and shrinkage. According to Jackson and Dhir (1996), the most important properties of concrete is strength. However, in water retaining structures, permeability and shrinkage should be considered as important properties.

2.3.1 STRENGTH

The strength of concrete is defined as the maximum load (stress) it can carry. The strength of concrete is usually affected by the water/cement ratio. According to Walker and Bloem (1979), it has been shown that for a given concrete and acceptable aggregate, the strength that may be developed by a workable concrete is influenced by the following factors.

- Ratio of cement to aggregate
- Grading, surface texture, shape, strength and stiffness of the aggregate particle.
- Maximum size of aggregate
- Strength of the mortar
- The bond between the mortar and the coarse aggregate
- The strength of the coarse aggregate i.e. it's ability to resist stresses applied to it.

2.3.1.1 COMPRESSIVE STRENGTH

Compressive strength of concrete is affected by the unit weight of the concrete. Ding and Zongjin (2004) showed

that the type of aggregate as well as the aggregate/binder ratio affects the compressive strength of concrete. The aggregates they used were river sand, dead burnt magnesia and sintered alumina. From their results, it was discovered that the higher the aggregate/binder ratio, the lesser the compressive strength. It was also discovered that at the same aggregate/binder ratio the mix made with either magnesium sand or aluminum sand had higher compressive strength than that made with river sand. They also, in the same study showed that the higher the water/cement ratio the lesser the compressive strength. Their experimental result showed that at all aggregate/cement ratio the compressive strength is smaller with increase in water/cement ratio and vice-versa.

2.3.1.2 TENSILE STRENGTH

The tensile strength of concrete is of importance in the design of concrete roads and runways. According to Jackson and Dhir (1996), concrete members are also required to withstand tensile stresses resulting from any restraint to

contraction due to drying or temperature variation. The tensile strength of concrete is usually taken to be about one tenth of its compressive strength. This may vary, however, depending on the method used for measuring tensile strength and the type of concrete.

2.3.1.3 SOME FACTORS AFFECTING STRENGTH OF CONCRETE

2.3.1.3.1 WATER/CEMENT RATIO

Strength of cement primarily depends upon the strength of cement paste (Shetty,1982). It has been shown from experiment according to Shetty (1982) that the strength of cement paste depends upon the strength of paste. In other words, the strength of paste increases with cement content and decreases with air and water content.

Abram water/cement ratio law states that the strength of concrete is only dependent upon water/cement ratio provided the mix is workable.

Ferraris et al (1987) formulated a general rule defining the strength of concrete paste and concrete in-terms of volume fraction of its constituents by the equation.

$$S_t = K(c/(c + e + a))^2 \text{ ————— 2.0}$$

Where S_t = tensile strength of concrete

C,e and a = volume of cement, water and air respectively

K = constant.

2.3.1.3.2 AGGREGATE

When concrete is stressed, failure may originate within the aggregate, the matrix or at the aggregate matrix interface, or any combination of these may occur. "In general the aggregates are stronger than the concrete itself and in such cases the aggregate strength has little effect on the strength of concrete" (Arthur and Peter, 1981).

The bond (aggregate matrix interface) is an important factor in determining concrete strength. Bond strength is influenced by the shape of the aggregate, its surface texture

and cleanliness. A smooth rounded aggregate will result in a weaker bond between the aggregate and the matrix than an angular or irregular aggregate or an aggregate with a rough surface texture. The associated loss in strength however may be offset by the smaller water-cement ratio required for the same workability. "Aggregate shape and surface texture affect the tensile strength more than the compressive strength "Jackson and Dhir (1996). A fine coating of impurities such as silt and clay, on the aggregate surface hinders the development of a strong bond.

2.3.1.3.3 INFLUENCE OF CURING

According to Jackson and Dhir (1996), curing of concrete is a prerequisite for the hydration of the cement content. For a given concrete, the amount and rate of hydration and furthermore the physical make-up of rate of hydration products depends on temperature.

Generally the longer the period during which concrete is kept in water the greater its final strength. It is normally accepted that concrete made with Ordinary Portland Cement

and kept in normal conditions will develop about 75 percent of its strength in the first 28 days.

2.3.2 DEFORMATION

Concrete in its hardened state also has the property to resist deformation up to a certain applied load. When concrete is loaded, it deforms. The deformation increases with increase in load. The deformation due to increase in load is known as elastic deformation.

2.3.3 DURABILITY

In general, the major durability problems concrete faces are harsh weather condition and chemical environment. Air entrained concrete seem to be more durable than others. They resist freeze - thaw better than concrete without air entrainment. The hydraulic pressure caused by expulsion of water from the aggregates can be accommodated by the entrained air present in the cement mortar, thus preventing damage to the concrete. The ability of concrete to resist chemical attacks is a welcomed development. Ferraris et al (1997) studied the effect of stress relaxation, self

desiccation and water absorption on the alkali silica reaction in low water/cement ratio mortar. The aggregates experimented on were sprat (with more than 0.1% expansion at 14 days, ASTM C1260 (12), silica dolomitic limestone and non reactive limestone (with 0.01% expansion at 14days ASTM C1260 (12)). Their result showed that the mix with silica dolomitic limestone expanded up to a maximum of 0.43% at 30days with that of later expanded up to a maximum of 0.02% at 30 days. The mix of the former gained more mass than the mix of the latter. Laukaitis et al (2003) studied the effect of polystyrene granules on thermal property of cement composites. Their results showed that the thermal conductivity coefficients for coarse granule composites corresponding to 108kg/m^3 , 220kg/m^3 and 260kg/m^3 are respectively $0.0754\text{Wm}^{-1}\text{k}^{-1}$, $0.0868\text{Wm}^{-1}\text{k}^{-1}$ and $0.0981\text{Wm}^{-1}\text{k}^{-1}$. The coefficients for fine granules of the density are respectively $0.0723\text{Wm}^{-1}\text{k}^{-1}$, $0.0803\text{Wm}^{-1}\text{k}^{-1}$ and $0.0883\text{Wm}^{-1}\text{k}^{-1}$. Their result showed that the more the composite density the more the thermal conductivity and the less the density the more the thermal

conductivity. In a study to determine the bond strength of concrete made with different aggregates, Yassar (1996) showed that normal weight aggregate concrete has lesser bond strength than lightweight aggregate concrete. Three types of concrete were studied. They were foamed concrete, lightweight aggregate concrete and normal weight aggregate concrete. The result revealed that normal weight aggregate concrete had highest compressive strength compared with others.

2.3.4 SHRINKAGE

Hardened concrete has the ability to shrink. Shrinkage of concrete is caused by the settlement of solids and the loss of free water from the plastic concrete (plastic shrinkage), by the chemical combination of concrete with water (autogenous shrinkage) and by the drying of concrete (drying shrinkage). Shrinkage also can be referred to as the volume contraction as the concrete hardens and dries. According to Asuquo (1997) shrinkage occurs due to the capillary tension which develops in the water remaining in

the concrete. Conversely, if dry concrete is immersed in water, it expands thereby regaining much of the volume loss prior shrinkage. The value of final shrinkage for ordinary concrete is generally in the order of 0.0001 to 0.0007 depending on initial water content, ambient temperature, humidity and nature of aggregates.

2.4 ALUMINUM WASTE

Generally, aluminum is extracted from its ores (alumina, Al_2O_3) by electrolysis. The use of aluminum as a raw material in the manufacturing industries normally produces some waste materials such as aluminum fibres, dross and sludge. However, aluminum waste (particularly dross) have been found to be useful in concrete production. The use of aluminum waste (pozzolan) for partial replacement of cement in various proportions have resulted to the decrease in the strength of concrete (Elinwa and Mbadike, 2011).

Other uses of aluminum waste includes:

- i. Production of alloys
- ii. manufacturing of cooking utensils

- iii. manufacturing of aluminum paints
- iv. thermit processes.

2.5 POZZOLANIC MATERIALS

2.5.1 NATURAL POZZOLANAS

2.5.1.1 PRODUCTION AND USE OF CALCINED NATURAL POZZOLANAS IN CONCRETE

The goal of producing concrete that provides long term durability with regard to properties such as improved sulphate resistance and reduced susceptibility to alkali-silica reactions, has led to the development of several high performance materials (Gregory et al, 2001). The use of fly ash and ground granulated blast furnace slag in concrete, is gaining acceptance in various applications. The mineralogical composition of such by-product materials cannot be as easily controlled as a manufactured pozzolana. Processing of these performances enhancing pozzolana is accomplished by thermally treating and converting crystalline clay materials to amorphous alumino-silicates (Barger et al, 1997). These pozzolans can be inter-ground

with Portland Cement clinker and gypsum to produce a type IP blended cement or they can ground separately as mineral admixtures for concrete. These two products are produced under the specification requirements of ASTM C1157 or ASTM C595 for hydraulic cements and ASTM C618 for admixtures respectively. In ASTM C618, the classification for raw or calcined natural pozzolanas is class N.

As the need for more durable Portland cement concrete continues to grow, so does the search for components of concrete that will significantly change its physical properties. Reduced permeability, improved sulphate resistance and improved resistance in deleterious expansion that most researchers and concrete practitioners have found will contribute to better long term durability(Ramachandran, 1995). To this end, Ash Grove Cement Company has tested various clay and shale material for potential use as pozzolanas in concrete, and has manufactured blended cements and pozzolanas from these calcined clays since 1993, with blended cement production rates making up a significant portion of the total annual production for a

manufacturing site. Ash Grove's performance goals regarding placement, workability and finishing were to match physical characteristics of concrete containing type 1 cement so that finishers would not notice a significant differences. The blended cements contain less than optimum pozzolana content for full calcium hydroxide consumption in order to allow for the use of economical ternary systems containing fly ash. Three different materials, depending upon the geographic region are being quarried, calcined and inter-ground into type IP cements or ground into finely divided powers for use as mineral admixtures for concrete. Generally speaking these materials are kaolin, clays, montmorillonitic shales and kaolin/Opal deposits (Ambroise, 1994).

From the work carried out in calcined clay, it was observed that the use of calcined clay pozzolanas can dramatically improve the durability of concrete. Since calcined clay pozzolanas are manufactured, they can be "engineered" to

perform in a reliable and reproducible manner to achieve the desired results (Taylor, 1997).

2.5.1.2 THE OMANI POZZOLANAS

2.5.1.2.1 CHEMICAL EFFECT

The Indian Standard states that for good pozzolanas, the calcium oxide (CaO) content should not be greater than 10%, and in addition, the sum of the SiO₂ plus AL₂O₃ should be greater than 50%(Varshney, 1982).

AL-Rawas et al(1998) indicated that a total percentage of SiO₂, AL₂O₃ and Fe₂O₃ greater than 50% is sufficient to produce good pozzolanic material. For high reactivity, the SiO₂ should be greater than 40%, AL₂O₃ greater than 30%, Fe₂O₃ 20%, magnesium oxide (MgO) plus sulphur dioxide (SO₂) less than 4%, moisture content less than 3% and loss on ignition less than 10%. The chemical composition, however, can not be used as a single factor for determining the pozzolanic activity of the clays, and therefore, should be used together with the temperature and duration of calcination (Price, 1975).

2.5.1.2.2 MINERALOGICAL EFFECT

Natural clays usually contain a mixture of clay minerals associated with some non-clay minerals. Most of natural pozzolanas develop their activity from clay mineral such as kaolinite, montmorillonite, illite, etc. Each clay has an optimum calcinations temperature range that causes breakdown of the crystalline structure of the clay and formation of amorphous silica and alumina. This temperature range depends on the type of clay minerals making up the clay. Therefore, it is useful to know the types of clay minerals of the raw clay (Hi, 2001).

2.5.1.2.3 CALCINATION EFFECT

Each clay has an optimum temperature range at which it will become a potential pozzolanic material. Price (1975) reported that the optimum activity of kaolin and montmorillonite type of clays are developed at temperatures between 538 and 932⁰C. Forrester (1975) stated that the clay must be heated to a temperature between that

required to remove lattice water and collapse the structure and that required when recrystallization in order to form a potentially pozzolanic material.

This temperature is just above the completion of the dehydroxylation peak and below the onset of the crystallization peak. Differential Thermal Analysis (DTA) is very useful in this respect since it can give the dehydroxylation and crystallization temperatures and saves time and effort. Otherwise, a time consuming procedure of burning at a series of temperature is needed. Active amorphous silica and alumina materials react with lime in the presence of water and form new cementing compounds such as calcium silicate hydrates and calcium aluminate hydrates of the type found in hydrated Portland cement and hydrate high alumina cement respectively (Ikpong and Okpala, 1992). Generally, amorphous silica react with calcium hydroxide more rapidly than does silica in the crystalline form. Therefore natural clays are not pozzolanic since clay minerals do not react with lime by heat (Werner et al, 1994).

2.5.1.2.4 POZZOLANIC ACTIVITY

Various chemical and physical tests have been reported for the measurement of pozzolanic activity. Chemical tests include the measurement of alkali-soluble silica (Surana and Joshi, 1990), measurement of acid soluble silica and alumina (He and Osbaeck, 1994), and measurement of the uptake of lime from a solution of calcium hydroxide (Chatterji et al, 1960, Forrester, 1975) and measurement of heat solution of burnt clay in a mixture of nitric and hydrofluoric acids (Ruiz, 1958).

Physical tests refer to compressive strength tests of lime pozzolana sand mortars and related properties. Compressive strength tests were reported to give direct and reliable measurement of the pozzolanic activity and considered to be the best and safest method (Sayanam et al 1991, AL-Rawas et al 1998). However, from the work carried out in Omani puzzles, the following findings and recommendation were made:

- i. The chemical analysis indicated that the total silica, alumina and iron oxide present in Omani pozzolan is 60.8%, 32.5% and 77.7% respectively. According to the lime reactivity test, the total silica, alumina and iron oxide content was found to be reliable indication of pozzolanic activity. Further more, a total silica, alumina and iron oxide greater than 50% is sufficient to produce good pozzolanic material.
- ii. Montmorillonite, illite and kaolinite clay mineral were present in the clay tested.
- iii. Good lime reactivity can be obtained with clays having composition higher than 50% of the three major chemical compounds (silica, alumina and iron oxide).

2.5.2 ARTIFICIAL POZZOLANAS

2.5.2.1 EFFECTS OF INCORPORATION OF MUNICIPAL SOLID WASTE INCINERATION FLY ASH IN CEMENT PASTES AND MORTARS

The incorporation of waste in concrete manufacture may provide a satisfactory solution to the problems posed by waste management (Remond et al, 2002). The building sector uses large quantities of natural materials: hence, its capacity to recycle and upgrade waste is considerable. Certain industrial bi-products have been used for a number of years as cement or concrete components (fly ash, silica fume, etc). Other waste products may also be recycled and upgraded in concrete. However, the new material thus formed must be usable as a building material and in particular, have the necessary performance characteristics (workability, mechanical strength etc) to satisfy the specifications determined by its applications. In addition, it should, be inoffensive with regards to health and the environment (Pinto et al, 1993). Finally, the incorporation of the waste should not impair concrete durability.

Traditional assessment methods must therefore be adopted to evaluate these new materials, (Remond et al, 1997). This study contributes to the development of a methodology for assessing concrete manufactured from waste. The methodology is based on the study of mortar containing experimental municipal solid waste incineration fly ash (MSWI fly ash). The ash is considered as experimental waste because of, in particular, its high content of soluble salts and heavy metals (Remond et al, 1999). The durability and the environmental impact of concrete are closely connected to its transport properties, which control the kinetics of the penetration of water and aggression agents into concrete. The movement of chemical species within the material and the leaching of certain chemicals are also closely linked to concrete diffusivity. However, the transport properties of concrete are likely to evolve considerably as the material ages (carbonation, leaching etc). The study of the development of the microstructure of concrete containing waste is therefore very important in

predicting the long term behaviour of these materials. (Spense and Allen, 1990).

From the work carried out on the effect of the incorporation of municipal solid waste incinerating fly ash in cement paste and mortars, it was observed that the main oxide component of the fly ash are SiO_2 , CaO and Al_2O_3 . The loss on ignition at 975°C is also very high. (13%). In addition, the ash has high chlorine, sodium and potassium contents. The most abundant heavy initials are zinc and lead. The total quantity of heavy zinc metal represents approximately 2% of the mass of the ash (Remond et al, 2002).

2.5.2.2. PROPERTY IMPROVEMENT OF PORTLAND CEMENT BY INCORPORATING WITH METAKAOLIN AND SLAG.

Metakaolin (MK) is a thermally activated aluminosilicate material with high pozzolanic activity comparable to or exceeded the activity of fume silica (Caldaron et al, 1994). According to Ding et al (1997), metakaolin is quite useful in improving cement quality such as enhancing strength,

shortening setting time (whether this characteristics is advantageous or disadvantageous depends on the application of cement), decreasing autogenous shrinkage, (Tazawa, and Miyazawa, 1995), controlling alkali aggregate reaction (Liu and Wen, 1995), reducing risk of chloride induced corrosion of embedded steel (Colemen and Page ,1997), controlling hydrate transformation of high-alumina cement (Majundar and Singh, 1992) and improving the durability of concrete (Zhang and Malhora, 1999). Therefore, metakaolin is a promising supplementary material for manufacturing high performance concrete (HPC).

In order to increase the fluidity of fresh concrete for pumping, increase strength and prolong durability of hardened concrete, a small quantity of superplasticizers are often added into concrete mixture (Ben, 1999). As it is well known, there is often a compatibility problem between superplasticizers and cement. The compatibility may be characterized by the fluidity of cement paste and its loss

with time. Generally, the fluidity of cement pastes increase with the increase in the dosage of superplasticizer. When the dosage of superplasticizer reaches a certain amount, the fluidity of the paste does not increase significantly. The threshold dosage of the superplasticizer is called the saturation point. The better the compatibility, the lower the dosage of superplasticizer needed, the higher the fluidity of cement paste, and the lower the loss of fluidity with time. It is therefore desirable to minimize the amount of superplasticizer used while enhancing the fluidity of slurry and strength of hardened concrete (Pat Gibbons, 1997).

From the work carried out on the property improvement of Portland cement by incorporating with metakaolin and slag, it was observed that it has a good effect on the mechanical properties of concrete (Zongjin, 2003). Metakaolin blended cement has a poorer fluidity compared to Portland cement under the condition which used the same amount of superplasticizer. By incorporating 10% MK and 20% or 30% ultrafine slag jointly into Portland cement not only the

fluidity of blended cement was improved but also the 28 days compressive strength of the concrete was enhanced. Metakaolin can increase the hydration of Portland cement, shorten the setting time of cement, increase the water requirement and increase the fluidity loss of the fresh paste. Slag can differ the reaction of cement hydration and prolong the setting time of cement paste, (Zongjin, 2003). Both Metakaolin and slag can react with C.H released by the cement clinker hydration to produce secondary C-S-H gel inside the cement paste. The secondary formed C-S-H gel improves the macrostructure of cement paste matrix and therefore, the macroscopic property of cement was also improved. X-ray diffracting analysis indicates that more $\text{Ca}(\text{OH})_2$ was consumed after adding both mineral admixtures.

2.6 AGGREGATES

The inclusion of coarse aggregates in concrete production improves the properties of the hardened concrete by reducing the drying shrinkage. Also, the coefficient of

thermal expansion of the aggregate has a major effect on the strength of the concrete as a whole. On the other hand, the use of excess fine aggregates will result in producing concrete of a very low strength.

2.6.1 CHEMICAL COMPOSITION OF AGGREGATES

The chemical composition or content of an aggregate for concrete determines how the aggregates will behave in the concrete. To a large extent the durability of concrete depends on the type of aggregates used. The work of Ferraris et al (1997) showed that reactive aggregates expand geometrically when compared with non reactive aggregates in concrete of the same mix and condition. The result also showed that the reactive aggregate concrete gained more mass when compared to non reactive aggregate concrete. The reactive aggregate used in the experiment is siliceous dolomite limestone. According to them most deterioration of concrete is due to the reaction between reactive silica and hydroxide ion (a by-product of cement hydration) in the pore of concrete known as Alkali-

Silica Reaction (A-S-R). The implication is that if an aggregate is reactive to alkaline medium especially calcium hydroxide then the concrete that will be made from it will not be durable. Thus, the aggregate may not be good to be used in producing concrete. Hence if the reverse is the case, then the aggregate will be good for use in concrete production.

2.6.2 PHYSICAL PROPERTIES OF AGGREGATES

Aggregates are classified in terms of their shape. Some are rounded aggregates. Others are angular, elongated, irregular etc in shape. The size of aggregate makes it coarse or fine. BS 3797 (1964) and BS 877 (1967) have it that aggregates 2mm and below are considered fine aggregates while the ones above 3mm are coarse aggregates. Some aggregates are smooth in texture while others are rough.

2.7 SOME OTHER PROPERTIES OF CONCRETE

Generally, concrete properties can be classified into:

Optical- This is the property of concrete which is a measure of its response to light.

Physical- This property defines the appearance of the concrete to the eyes. The aesthetics of a finished concrete work to a large extent depends on the property. The physical property of concrete is a function of design and workmanship.

Thermal- This is the ability of the concrete to resist a specified heat over a specified period. It is a function of the constituent materials and the design of the concrete. Various fire resistances for concrete are specified in concrete design codes.

Mechanical- This is a measure of resistance of the concrete material to stresses. These properties includes:

a. Compressive strength

Most of the determinants of the quality of concrete depends on its compressive strength and it is the most convenient to measure (Neville, 1983). Compressive strength (Crushing strength) is given by

$$f_c = \frac{P}{A} \quad \text{Where } P = \text{Crushing load} \quad (2.7.1)$$

A = Cross section area of concrete cube

b. Flexural strength

This is one of the mechanical properties of concrete. Concrete is not normally designed to resist direct flexure. However, the knowledge of it is of value in estimating the load under which cracking will develop (Neville , 1993). It is also of interest in un-reinforced concrete structures such as air field pavement and highways. Flexural test procedures are specified in BS 1881, part 118 code of practice.

$$FS = \frac{\text{failure load}}{\text{Loaded area of beam}} \dots\dots\dots (2.7.2)$$

It has been shown that at the point of initial cracking of the beam in flexure and the lateral tensile strain in a cylinder in a uniaxial compression are of similar magnitude (Berugo , 1950). There is also a linear relationship between the modulus of rupture and splitting tensile strength at a given age (Melis , 1985).

c. Static Modulus of Elasticity

Modulus of elasticity of concrete (E_c) is the ratio of stress to strain in concrete. The strain in concrete is not only due to

stress, but also shrinkage. Strain in concrete increases with time (Creep), under sustained loading. Modulus of elasticity in concrete depends on the strength of the concrete. The higher the strength, the higher the modulus of elasticity (Neville, 1996). Static modulus of elasticity, E_c is given by Neville and Brooks (2002).

$$E_c = 1.7 \ell^2 f_{cu}^{0.33} \times 10^{-6} \dots\dots\dots (2.7.3)$$

Where ℓ = density of concrete

f_{cu} = compressive strength of concrete

d. Modulus of rigidity

The modulus of rigidity or shear modulus, G_c of concrete is given by

$$G_c = \frac{j}{\gamma_c} \dots\dots\dots (2.7.4)$$

Where j = shear stress in concrete

γ_c = shear (lateral) strain in concrete.

The modulus of rigidity is not usually determined by direct measurement (Neville, 1983). Lateral strain r_c is given by

$$r_c = \frac{\mu \sigma}{E_c} \dots\dots\dots (2.7.5)$$

Where μ is the static Poisson ratio, σ is the compressive stress at cracking and E_c is the modulus of elasticity of

concrete over the linear range of deformation. The modulus of rigidity can be determined as given by (Neville, 1996)

$$G_c = \frac{E_c}{2(\mu + 1)} \dots\dots\dots (2.7.6)$$

Poisson ratio, μ is the ratio of the lateral strain accompanying an axial strain to the applied axial load with the signs of the strains ignored. Poisson's ratio for normal weight and lightweight concrete ranges between 0.15 and 0.20 when determined from strain measurements taken in the static modulus of elasticity test (code of practice, BS 1881, part 121, 1983).

2.8 CONCRETE MIX DESIGN

Mix design of concrete is a means of producing the most economic and durable concrete that meet certain properties as consistency, strength and durability by properly and systematically combining the ingredients at relative proportion (Neville, 1983). Two categories of mix design method exist. They are empirical method and statistical method (Simon et al, 1997).

2.8.1 EMPIRICAL METHOD

Here one will rely on information from historic data or laid down rules (codes) for mixture proportioning. Historic data is just about the rule of thumb. It will only work for the materials that were used for it in the past. The method will not incorporate new material other than the ones used in the past. The use of trial mixes and repeated mixes (further trials) to enable all specified criteria to be met is inevitable. Here, it will be difficult if not impossible to achieve an optimal mixture for desired criterion with historic information method of concrete mixture design. The use of laid down rules or codes in concrete mix design is an improvement over the historic information method. This is so because there is stepwise (though rigorous) approach and it can accommodate a wider range of materials. Some common laid down rules in concrete mix design are Road Note No 4, ACI standard and 1975 British method (Simon et al, 1997), Road Research (1950), ACI committee 211 (1974) and Teychenne et al (1975). In general, empirical methods are prone to trial and error which leads to material wastage whenever they are used.

2.8.2 STATISTICAL EXPERIMENTAL METHOD

This method makes use of theory of statistics and some specified laboratory results from practical experiments to formulate a mathematical model (equation), which will later be used to predict concrete mix ratio when a desired target strength is known. The long run advantage will always pay off or compensate the initial input and justifies it. Unlike the empirical method, there won't be any further trial mixes once the model has been formulated. The limitation to this method is that the model is always particularized and cannot be used as a generalized model. For example, if a model is formulated for aluminum waste concrete, it cannot be used to predict the concrete mixture ratio involving any other waste other than the aluminum waste. Some statistical experimental methods are simplex design (Obam 1998), Axial design, mixture experiments involving process variables, mixture model with inverse terms (Draper and St. John, 1997) and K-model (Draper and Pukelsheim, 1999)

2.8.2.1 SIMPLEX DESIGN

Scheffe (1958) was the first person to introduce simplex mixture design. Later in 1963 he also introduced simplex centroidal design. Simplex is a factor space. The simplest factor space is a straight line comprising of two component at both ends. The points within a simplex lattice (space factor) are symmetrically arranged and equidistant from the centroid. In the design a suitable polynomial will be chosen to represent the response surface of the entire space. The number of points on the space correspond to the number of parameters in the chosen polynomial equation. The difference between the simplex mixture and simplex centroidal design is in simplex mixture design the points considered either fall at the vertices of the factor space or at the edges while in the centroidal design one of the points must fall at the centre of the factor space.

2.8.2.2 AXIAL DESIGN

The points in simplex designs fall on the surface (vertices and edges) and only one point falls at the centre. However, the axial design is an improvement over the simplex design

because most of the points fall inside the factor space (Aggarwal, 2002).

2.8.2.3 MIXTURE EXPERIMENTS INVOLVING PROCESS VARIABLES

This method is an addition to simplex design. In simplex design the response only depends on the mixture components present in the mixture. But this method in addition to the proportion of mixture considers the process variable. The process variables are factors involved in the experiment that do not form part of the mixture, however they influence interaction of the mixture ingredients (John, 1984).

The process here involves two small designs. One of the design is meant for mixture components and the other is for process variables.

2.8.2.4 MIXTURE MODELS WITH INVERSE TERMS

Draper and St. John, (1977) introduced the method of mixture model with inverse terms to statistical experiment

method. The only difference between this model and simplex design is the addition of inverse terms. The inverse terms take care of the extreme change in response as components move towards zero.

2.8.2.5 K-MODEL

Draper and Pukelsheim, (1999) developed K-model of mixture design. The model is quite different from the simplex design and all the above mentioned designs. It makes use of kronecker algebra of vector and matrices. The use of any factor is not involved at all.

2.9 SCHEFFE'S THEORY

Simplex mixture design is an experimental statistical approach in mixture design. In carrying out the design, three stages are involved. The first stage is concerned with formulation of polynomial with unknown coefficients. This polynomial is an equation relating the dependent variable (otherwise called response) and the independent variable (otherwise called

predictors). In the equation each predicting variable is accompanied with a constant coefficient.

The polynomial, as far as this design is concerned, is useless if the values of the coefficients remain unknown. It is at this point that the second stage comes in, at this stage a number of experimental tests will be carried out. Before carrying out the experiments one should know the number of coefficients required. The total number of experimental tests to be carried out should be at least two times the number of the coefficients. The first set of tests (this is exactly equal to the number of coefficients) will be used to determine values of the coefficients. It is the results of these tests that are normally used. The second set of tests (this will be at least the number of coefficients) will be used to validate the model. Having gotten the values of the unknown coefficients of the equation, the resulting equation becomes the final model equation.

It will not be wise to start using this model equation until it proves beyond doubt that its results will not vary from the results gotten from experimental tests. Here is where the third

stage comes in. in this stage one will make use of some statistical tools. Some of these tools include chi-square, fisher f-test, ANOVA, student t-test etc. At this point one will run the model and compare its results with those from experimental tests. If the difference between these two sets of results is significant then the model is inadequate for use. If on the contrary, the difference is not significant then the model is adequate for use.

2.9.1 INTRODUCTION TO FACTOR SPACE IN SIMPLEX DESIGN

A factor space is a one dimension (a line), a two dimension (a plane), a three dimension (a tetrahedron) or any other imaginary spaces where mixture components interact. The boundary within which these mixture components interact is defined by the space. Many factor spaces exist but Scheffe's factor space will be used in this work.

2.9.2 SCHEFFE FACTOR SPACE

Scheffe (1958) stated that a $q-1$ space would be used to define the boundary where q components are interacting in a mixture. In other words, a mixture comprising of q

components can be analysed using a $q-1$ space. For a mixture comprising of 2 components, a line (which is a one-dimensional space) will be used to analyse the interaction of the components. In the same manner, mixture comprising three and four components will be respectively analysed using a plane and a tetrahedron, which are respectively a two-dimensional and a three dimensional spaces. See figure 3.1 and figure 3.2

2.9.2.1 INTERACTION OF COMPONENTS IN SCHEFFE FACTOR SPACE

The components of a mixture are always interacting with each other within the factor space. Three regions exist in a factor space. These regions are the vertices, borderlines and inside body of the space. Pure components of a mixture exist at the vertices of the factor space. The borderline can be a line for one-dimensional factor space and a two dimensional factor space. It can also be both lines and planes for a three dimensional, four-dimensional etc. factor space. Two components of a mixture exist at any point along a line border. Three or more components exist at any point on a plane border, which depends on how many vertices that defined the plane border. All the components of a mixture exist right inside the body of the space. At any point within the factor space, the total quantity of the pseudo components must be equal to one.

A two-dimensional factor space will be used here to clarify the interaction of components. Figure 3.3 shows seven points on

the two-dimensional factor space. Three of the points, A_1 , A_2 and A_3 , are on the vertices.

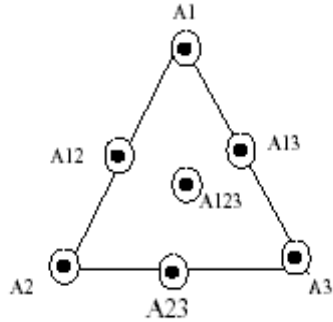


Fig. 3.3. A two-dimensional factor space

Three other points A_{12} , A_{13} and A_{23} are on the line border of the space.

One remaining point A_{123} is right inside the body of the space.

A_1 , A_2 and A_3 are called the principal co-ordinates. Only one pure component exists at any of these principal coordinates. The total quantity of the pseudo component at each of these coordinates is equal to one. The other components outside these co-ordinates are all zero .

For instance at co-ordinate A_1 , only A_1 exists and the quantity of its pseudo component is equal to one. The other components are equal to zero.

A12, A13 and A23 are points/co-ordinates where binary mixtures occur. At these points only two components exist and the rest don't. For instance, at point A12, components of A1 and A2 exist. The total quantity of pseudo components of A1 and A2 at the point is equal to one.

Component A3 is equal to zero at that point. If A12 is midway (halfway), then pseudo component of A1 is equal to half and that of A2 is also equal to half while A3 is equal to zero at the point. At any point inside the space all the three components A1, A2 and A3 exist. The total quantity of their pseudo components is equal to one. Consequently if the point A123 is exactly at the centroid of the space, the pseudo component of A1 is equal to those of A2 and A3 and is equal to one-third ($1/3$).

It is worthy of note that the components referred to here are pseudo components and not actual (real) components. Furthermore, it should be noted that the total quantity of the pseudo components at any point on the factor space is equal to one. This implies that no individual pseudo component in the mixture should be greater than one.

$$X_i \leq 1 \text{ ----- (2.9.1)}$$

Where X_i is the i th pseudo component in the Scheffe factor space interacting with other pseudo components to form a mixture, Scheffe also assumed that negative pseudo components never exist. Hence,

$$X_i \geq 0 \text{ ----- (2.9.2)}$$

Combining equations 2.9.1 and 2.9.2, one can see that

$$0 \leq X_i \leq 1 \text{ ----- (2.9.3)}$$

Since the total amount of the pseudo components of a mixture in a factor space is one then,

$$X_1 + X_2 + X_3 + \cdots + X_{q-1} + X_q = 1 \text{ (2.9.4)}$$

That is

$$\sum_{i=1}^q X_i = 1 \text{ (2.9.5)}$$

2.9.2.2. NUMBER OF COEFFICIENT

Henry Scheffe (1963) stipulated a formula for determining the number of coefficient (k) at a given number of components (q) at the presumed degree of polynomial (m). This formula according to Scheffe is given as:

$$K = \frac{(q + m - 1)!}{(q - 1)! m!} \dots \dots \dots (2.9.5a)$$

Therefore, for Scheffe's (5,2) lattice polynomial equation,

Number of components, q = 5

Degree of polynomial, m = 2

Number of coefficient, k = 15

This implies that 15 coefficients are expected in the polynomial. Recall the Henry Scheffe's stipulation on the relationship between Pseudo and actual component. He stipulated that in simplex design, only the pseudo components will be used. These pseudo components should not be negative or greater than unity (1). This means that at any point in the simplex, the summation of the pseudo components should always be equal to one(1).

2.9.2.3 RELATIONSHIP BETWEEN PSEUDO AND ACTUAL COMPONENTS

In the Scheffe mixture design, the pseudo components have relationship with the actual components. This means that the actual components can be derived from the pseudo components in that relationship and vice versa. The pseudo

components are designated as X and the actual components are designated as Z. Hence, according to Scheffe,

$$Z = A * X \text{ ----- (2.9.6)}$$

Where A is the coefficient of the relationship

Rearranging equation 2.9.6 will give

$$X = 1 / A * Z \text{ ----- (2.9.7)}$$

Assume $B = 1 / A$, then equation 2.9.7 becomes

$$X = B * Z \text{ ----- (2.9.8)}$$

Equation 2.9.6 will be used to determine the actual components of the mixture when the pseudo components are known. Also equations 2.9.7 and 2.9.8 will be used to determine the pseudo components of the mixture when the actual components are known.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Materials

3.1.1 Cement

The dangote cement which is ordinary portland cement was used in this work. The chemical analysis of the dangote cement is shown in table 3.1

Table 3.0: Result of chemical analysis of dangote cement

Oxide Composition	Percentage by Weight (%)
Magnesium oxide (MgO)	0.093
Iron Oxide (Fe ₂ O ₃)	6.405
Lime (CaO)	11.30
Aluminum Oxide (AL ₂ O ₃)	20.60
Silicate (SIO ₂)	52.40
Titanium Oxide (TIO ₂)	0.52
Sodium Oxide (Na ₂ O)	2.10
Potash (K ₂ O)	2.60
Loss on ignition (LO1)	3.90
TOTAL	99.918

The Portland Cement used in this research work conforms to BS 12 (1978) code of practice.

3.1.2 Aggregates

3.1.2.1 Fine Aggregates

The fine aggregate used in this work is clean river sand which is free from deleterious materials. The fine aggregates used passes through 2.36mm sieve size.

3.1.2.2 Coarse Aggregate

The coarse aggregates used is also very clean and free from dirt. The coarse aggregates passed through 19mm sieve size.

3.1.2.3 Water

The water used is potable water.

3.1.2.4 Aluminum Waste

The aluminum waste which was obtained from Aluminum Extrusion Industry (ALEX) Inyishi in Ikeduru Local Government Area of Imo State is irregular in shape and black in colour. The waste was sieved with 150µm sieve

size to obtain a finely divided (powdered) material which was used in this research work.

3.2 METHODS

3.2.1 Setting time of cement

This test was carried out in accordance with BS 12 (1978) using the Vicat apparatus. The Vicat apparatus uses initial and final setting pins for the determination of initial and final setting time respectively.

To carry out this experiment, 94g of water was added to 200g of cement to form cement paste. The paste was then placed on the Vicat apparatus using Vicat mould. Before the placement of the paste on the apparatus, the initial setting pin was fixed on the apparatus for initial setting time. The apparatus is calibrated in millimeters. For the initial setting time the initial setting pin was dropped on the paste to 5 ± 1 mm calibration mark on the apparatus. The initial setting time was then recorded starting from the time the water was added to the paste

to the time the dropping of the pin on the paste was 5 ± 1 mm mark on the apparatus.

Similarly, the final setting time was recorded using the final setting pin. The final setting pin has an inner and outer edge. The final setting time was taken when only the inner edge makes a mark on the paste when allowed to drop freely. The final setting time was then recorded starting from the time the water was added to the paste to the time the inner edge of the final setting pin makes a mark on the paste.

3.2.2 Compressive Strength and Water Cement Ratio

Preliminary investigations were carried out to ascertain the behaviour of aluminum waste concrete. A standard mix ratio of 1:2:4 and 1:3:6 were used to cast cubes of 150mm x 150mm x 150mm. These ratios were kept constant but first at varying water cement ratio and then at varying aluminum waste content. Batching was carried

out by weight. For each mix ratio with varying water cement ratio and aluminum waste content, three cubes were cast and cured at room temperature. The concrete cubes were filled and compacted in three layers i.e 1/3, 2/3 and 3/3 respectively. Each layer was compacted 200 times using a tamping rod. At the end of each hydration period, the three cubes cast for each mix ratio with varying water cement ratio and aluminum waste content were crushed and the average compressive strength recorded. The compressive strength is calculated by dividing the crushing load with the area of the concrete cube.

$$\text{i.e Compressive strength} = \frac{\text{Maximum Load (N)}}{\text{Area of concrete cube (mm}^2\text{)}}$$

3.2.3 Flexural Strength

Concrete beams measuring 100mm x 100mm x 500mm were used. The concrete beams were filled and compacted in three layers ie 1/3, 2/3 and 3/3 respectively. Each layer was compacted 200 times using

a tamping rod. The beams were cast and cured at room temperature. At the end of the hydration period, the three beams cast for each mix ratio were crushed to determine the flexural strength. The flexural strength was calculated by

$$F_s = \frac{PL}{bd^2}$$

Where P = failure load (N)

L = length of beam (mm)

b = width of beam (mm)

d = depth of beam (mm)

3.2.4 Modulus of Elasticity and Modulus of Rigidity

Cube samples were produced from concrete prepared from selected mixes and were used to determine young's modulus, Poisson's ratio and the modulus of rigidity of the aluminum waste concrete. These were obtained using the relationships:

Modulus of Elasticity (E_c)

$$E_c = 1.7f^2_{cu} \times 10^{-6} \dots\dots\dots (2.7.3)$$

Modulus of rigidity (G_c)

$$G_c = \frac{E_c}{2(\mu + 1)} \dots\dots\dots(2.7.6)$$

Where μ is the ratio of lateral strain to longitudinal strain.

3.3 FIVE COMPONENT FACTOR SPACE

This research work is dealing with a five component concrete mixture. The components that form the concrete mixture are water/cement (w/c) ratio, cement, sand, coarse aggregates and aluminium waste. The number of components, q is equal to five. The space to be used in the analysis will be $q - 1$, which is equal to four-dimensional factor space. A four-dimensional factor space is an imaginary dimensional space. The imaginary

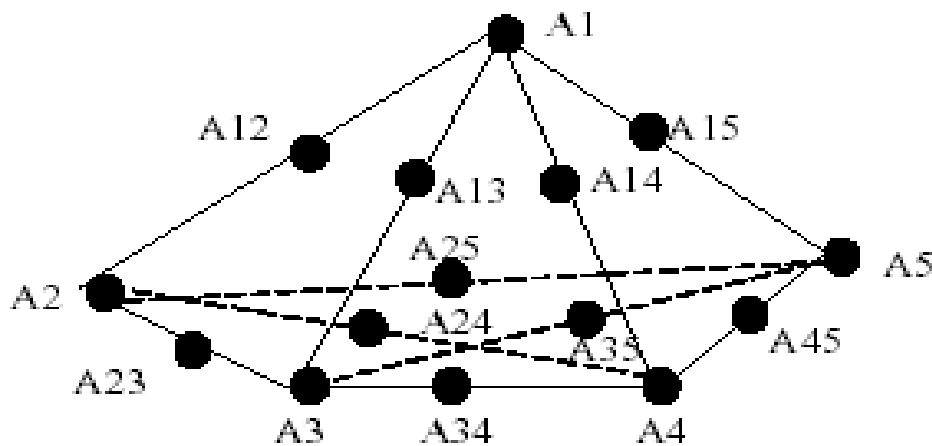


Fig3.4 A four-dimensional factor space

Figure 3.4 shows fifteen points on the four-dimensional factor space. The various quantities of the pseudo components of the mixture at these fifteen points are not shown for clarity of the figure. Let the arbitrary quantities of the five-pseudo components of the mixture at an arbitrary point on the factor space be designated as A_{jk} (X_{ijk}). Where A_{jk} is an arbitrary point on the factor space and X_{ijk} is the arbitrary quantities of all the pseudo components, X_i at an arbitrary point, A_{jk} .

X_{ijk} can otherwise be written as

$$X_{ijk} = X_{1jk}, X_{2jk}, X_{3jk}, X_{4jk}, X_{5jk}.$$

The quantities of the five-pseudo components at the fifteen points are follows:

$$A_1 (1,0,0,0,0)$$

$$A_2 (0,1,0,0,0)$$

$$A_3 (0,0,1,0,0)$$

$$A_4 (0,0,0,1,0)$$

$$A_5 (0,0,0,0,1)$$

$$A_{12} (, \frac{1}{2}, \frac{1}{2} ,0,0,0)$$

$$A_{13} (\frac{1}{2},0,\frac{1}{2},0,0,)$$

$$A_{14} (\frac{1}{2},0,0,\frac{1}{2},0)$$

$$A_{15} (\frac{1}{2},0,0,0,\frac{1}{2})$$

A23 (0, 1/2, 1/2, 0, 0)

A24 (0, 1/2, 0, 1/2, 0)

A25 (0, 1/2, 0, 0, 1/2)

A34 (0, 0, 1/2, 1/2, 0)

A35 (0, 0, 1/2, 0, 1/2)

A45 (0, 0, 0, 1/2, 1/2)

3.4 RESPONSES

Responses, according to Simon et al (1997), are the properties of fresh and hardened concrete. These properties can be compressive strength, flexural strength, elastic modulus, shear modulus, modulus of rupture, slump, density etc. This response is a polynomial function of pseudo component of the mixture. The equation for response according to Scheffe (1958) and Simon et al (1997) is

$$Y = \sum b_0 + \sum b_i X_i + \sum b_{ij} X_i X_j + b_{ijk} X_i X_j X_k + \dots + \sum b_{i_1 i_2 \dots i_n} X_{i_1} X_{i_2} \dots X_{i_n} + e \text{ -----(3.9)}$$

Where $1 \leq i \leq q$, $1 \leq i \leq j \leq q$, $1 \leq i \leq j \leq k \leq q$ and

$1 \leq i_1 \leq i_2 \leq \dots \leq i_n \leq q$ respectively, and b_0 = arbitrary constant, e = random error and Y = the response.

Response equation for a two-pseudo component mixture is

$$Y = b_0 + b_1X_1 + b_2 X_2 + b_{11}X_1^2 + b_{12}X_1X_2 + b_{22}X_2^2 + e - (3.10)$$

That for a three-pseudo component mixture is

$$Y = b_0 + b_1X_1 + b_2X_2 + b_3X_3 + b_{11}X_1^2 + b_{12}X_1X_2 + b_{13}X_1X_3 + b_{22}X_2^2 + b_{23}X_2X_3 + b_{33}X_3^2 + e \text{ ----- (3.11)}$$

For a four-pseudo component mixture the equation is

$$Y = b_0 + b_1X_1 + b_2X_2 + b_3X_3 + b_4X_4 + b_{11}X_1^2 + b_{12}X_1X_2 + b_{13}X_1X_3 + b_{14}X_1X_4 + b_{22}X_2^2 + b_{23}X_2X_3 + b_{24}X_2X_4 + b_{33}X_3^2 + b_{34}X_3X_4 + b_{44}X_4^2 + e \text{ ----- (3.12)}$$

Now for a five-pseudo component mixture, which is what the research is dealing with the response equation, is

$$Y = b_0 + b_1X_1 + b_2X_2 + b_3X_3 + b_4X_4 + b_5X_5 + b_{11}X_1^2 + b_{12}X_1X_2 + b_{13}X_1X_3 + b_{14}X_1X_4 + b_{15}X_1X_5 + b_{22}X_2^2 + b_{23}X_2X_3 + b_{24}X_2X_4 + b_{25}X_2X_5 + b_{33}X_3^2 + b_{34}X_3X_4 + b_{35}X_3X_5 + b_{44}X_4^2 + b_{45}X_4X_5 + b_{55}X_5^2 + e \text{ ----- (3.13)}$$

The "e" term is the random error that represents the combined effects of variables not included in the model.

Equation 3.5 states that $\sum_{i=1}^q X_i = 1$

Hence,

$$\sum_{i=1}^5 X_i = 1$$

That is, $X_1 + X_2 + X_3 + X_4 + X_5 = 1$ ----- (3.14)

Multiplying equation 3.14 by b_0 will give

$$b_0 X_1 + b_0 X_2 + b_0 X_3 + b_0 X_4 + b_0 X_5 = b_0$$
 ----- (3.15)

Multiplying equation 3.14 also by X_1 will give

$$X_1^2 + X_1 X_2 + X_1 X_3 + X_1 X_4 + X_1 X_5 = X_1$$
 ----- (3.16)

In similar manner multiplying equation 3.14 by

X_2, X_3, X_4 and X_5 will respectively give

$$X_1 X_2 + X_2^2 + X_2 X_3 + X_2 X_4 + X_2 X_5 = X_2$$
 ----- (3.17)

$$X_1 X_3 + X_2 X_3 + X_3^2 + X_3 X_4 + X_3 X_5 = X_3$$
 ----- (3.18)

$$X_1 X_4 + X_2 X_4 + X_3 X_4 + X_4^2 + X_4 X_5 = X_4$$
 ----- (3.19)

$$X_1 X_5 + X_2 X_5 + X_3 X_5 + X_4 X_5 + X_5^2 = X_5$$
 ----- (3.20)

Rearranging equations 3.16 -- 3.20 in terms of X_i^2 will give respectively

$$X_1^2 = X_1 - X_1 X_2 - X_1 X_3 - X_1 X_4 - X_1 X_5$$
 ----- (3.21)

$$X_2^2 = X_2 - X_1 X_2 - X_2 X_3 - X_2 X_4 - X_2 X_5$$
 ----- (3.22)

$$X_3^2 = X_3 - X_1 X_3 - X_2 X_3 - X_3 X_4 - X_3 X_5$$
 ----- (3.23)

$$X_4^2 = X_4 - X_1 X_4 - X_2 X_4 - X_3 X_4 - X_4 X_5$$
 ----- (3.24)

$$X_5^2 = X_5 - X_1 X_5 - X_2 X_5 - X_3 X_5 - X_4 X_5$$
 ----- (3.25)

Substituting equation 3.15 and equations 3.21-3.25 into equation 3.13 will give

$$\begin{aligned}
 Y = & b_0X_1 + b_0X_2 + b_0X_3 + b_0X_4 + b_0X_5 + b_1X_1 + b_1X_2 + b_1X_3 + \\
 & b_1X_4 + b_1X_5 + b_{11}X_1 - b_{11}X_1X_2 - b_{11}X_1X_3 - b_{11}X_1X_4 - b_{11}X_1X_5 + \\
 & b_{22}X_2 - b_{22}X_1X_2 - b_{22}X_2X_3 - b_{22}X_2X_4 - b_{22}X_2X_5 + b_{33}X_3 - b_{33}X_1X_3 \\
 & - b_{33}X_2X_3 - b_{33}X_3X_4 - b_{33}X_3X_5 + b_{44}X_4 - b_{44}X_1X_4 - b_{44}X_2X_4 - \\
 & b_{44}X_3X_4 - b_{44}X_4X_5 + b_{55}X_5 - b_{55}X_1X_5 - b_{55}X_2X_5 - b_{55}X_3X_5 - \\
 & b_{55}X_4X_5 + b_{12}X_1X_2 + b_{13}X_1X_3 + b_{14}X_1X_4 + b_{15}X_1X_5 + b_{23}X_2X_3 + \\
 & b_{24}X_2X_4 + b_{25}X_2X_5 + b_{34}X_3X_4 + b_{35}X_3X_5 + b_{45}X_4X_5 + e \text{----} (3.26)
 \end{aligned}$$

Rearranging equation 3.26 and bringing like terms together will give

$$\begin{aligned}
 Y = & (b_0 + b_1 + b_{11}) X_1 + (b_0 + b_1 + b_{22}) X_2 + (b_0 + b_1 + b_{33}) X_3 \\
 & + (b_0 + b_1 + b_{44}) X_4 + (b_0 + b_1 + b_{55}) X_5 + (b_{12} - b_{11} - b_{22}) \\
 & X_1X_2 + (b_{13} - b_{11} - b_{33}) X_1X_3 + (b_{14} - b_{11} - b_{44}) X_1X_4 + (b_{15} - \\
 & b_{11} - b_{55}) X_1X_5 + (b_{23} - b_{22} - b_{33}) X_2X_3 + (b_{24} - b_{22} - b_{44}) X_2X_4 \\
 & + (b_{25} - b_{22} - b_{55}) X_2X_5 + (b_{34} - b_{35} - b_{44}) X_3X_4 + (b_{35} - b_{33} - \\
 & b_{55}) X_3X_5 + (b_{45} - b_{44} - b_{55}) X_4X_5 + e \text{---} (3.27)
 \end{aligned}$$

It is worthy of note here that when constants are added together, another constant will result. Hence, the summation

terms in parenthesis in equation 3.27 will be replaced with α as:

$$\begin{aligned}
 \alpha_1 &= b_0 + b_1 + b_{11} \\
 \alpha_2 &= b_0 + b_2 + b_{22} \\
 \alpha_3 &= b_0 + b_3 + b_{33} \\
 \alpha_4 &= b_0 + b_4 + b_{44} \\
 \alpha_5 &= b_0 + b_5 + b_{55} \\
 \alpha_{12} &= b_{12} - b_{11} - b_{22} \\
 \alpha_{13} &= b_{13} - b_{11} - b_{33} \\
 \alpha_{14} &= b_{14} - b_{11} - b_{44} \\
 \alpha_{15} &= b_{15} - b_{11} - b_{55} \\
 \alpha_{23} &= b_{23} - b_{22} - b_{33} \\
 \alpha_{24} &= b_{24} - b_{22} - b_{44} \\
 \alpha_{25} &= b_{25} - b_{22} - b_{55} \\
 \alpha_{34} &= b_{34} - b_{33} - b_{44} \\
 \alpha_{35} &= b_{35} - b_{33} - b_{55} \\
 \alpha_{45} &= b_{45} - b_{44} - b_{55}
 \end{aligned}
 \tag{3.28}$$

Substituting equation 3.28 into equation 3.27 will give

$$Y = \alpha_1 X_1 + \alpha_2 X_2 + \alpha_3 X_3 + \alpha_4 X_4 + \alpha_5 X_5 + \alpha_{12} X_1 X_2 + \alpha_{13} X_1 X_3 + \alpha_{14} X_1 X_4 + \alpha_{15} X_1 X_5 + \alpha_{23} X_2 X_3 + \alpha_{24} X_2 X_4 + \alpha_{25} X_2 X_5 + \alpha_{34} X_3 X_4 + \alpha_{35} X_3 X_5 + \alpha_{45} X_4 X_5 + e \text{ ----- (3.29)}$$

$$\text{Equation 3.29 can be rewritten as } Y = \ddot{Y} + e \text{ ----- (3.30)}$$

Where e = standard error or standard deviation and

$$\ddot{Y} = \alpha_1 X_1 + \alpha_2 X_2 + \alpha_3 X_3 + \alpha_4 X_4 + \alpha_5 X_5 + \alpha_{12} X_1 X_2 + \alpha_{13} X_1 X_3 + \alpha_{14} X_1 X_4 + \alpha_{15} X_1 X_5 + \alpha_{23} X_2 X_3 + \alpha_{24} X_2 X_4 + \alpha_{25} X_2 X_5 + \alpha_{34} X_3 X_4 + \alpha_{35} X_3 X_5 + \alpha_{45} X_4 X_5 \text{ ----- (3.31)}$$

Equation 3.31 is the sheffe's (5,2) lattice polynomial equation.

These responses are constant and are determined by carrying out laboratory practicals. A total of fifteen (15) such practical test will be carried out to correspond to the fifteen coefficients of equation 3.31

Equation 3.31 can be rewritten in the form

$$\hat{Y} = \sum_{i=1}^5 \alpha_i X_i + \sum_{1 \leq i < j \leq 5} \alpha_{ij} X_i X_j \text{(3.32)}$$

Equation 3.32 can be seen as response to the pure components "i" and the binary mixture components "ij".

At each vertex of the factor space, the component $X_i = 1$ while other components are all equal to zero. At the mid point of all

the border lines of the factor space, the two components X_i and X_j are equal to $\frac{1}{2}$ each, while the rest of the components are equal to zero. Assuming that the response function is represented by y , the response function for the pure component and that for the binary mixture components will be y_i and y_{ij} respectively. Using this to rewrite equation 3.32 will give

$$\left. \begin{aligned} n_i &= \sum_{i=1}^5 \alpha_i X_i \\ n_i &= \sum_{i=1}^5 \alpha_i X_i + \sum_{1 \leq i < j \leq 5} \alpha_{ij} X_i X_j \end{aligned} \right\} \dots \dots \dots (3.33)$$

The response at a point on the factor space is n_1 . At point 1, component $X_1 = 1$ while components X_2, X_3, X_4 and X_5 are all equal to zero. Substituting this into

equation 3.33 will give $y_1 = \alpha_1$ ----- (3.34)

Similarly, $y_2 = \alpha_2$ ----- (3.35)

$y_3 = \alpha_3$ ----- (3.36)

$y_4 = \alpha_4$ ----- (3.37)

$y_5 = \alpha_5$ ----- (3.38)

Equation 3.34 – 3.38 can be summarised as $y_i = \alpha_i -$ (3.39)

At mid point of the borderline connecting points 1 and 2 of the factor space, component $X_1 = 1/2$ and that of $X_2 = 1/2$ and the rest (x_3, x_4 and x_5) are equal to zero. The response at this point is y_{12} . Substituting for the values of the components x_1, x_2, x_3, x_4 and x_5 into equation 3.33 will give

$$\begin{aligned} y_{12} &= 1/2 \alpha_1 + 1/2 \alpha_2 + \alpha_{12} * 1/2 * 1/2 \\ &= 1/2 \alpha_1 + 1/2 \alpha_2 + 1/4 \alpha_{12} \\ \alpha_{12} &= 4y_{12} - 2y_1 - 2y_2 \text{-----} (3.40) \end{aligned}$$

Similarly,

$$\begin{aligned} y_{13} &= 1/2 \alpha_1 + 1/2 \alpha_3 + 1/4 \alpha_{13} \\ \alpha_{13} &= 4y_{13} - 2y_1 - 2y_3 \text{-----} (3.41) \end{aligned}$$

$$\begin{aligned} y_{14} &= 1/2 \alpha_1 + 1/2 \alpha_3 + 1/4 \alpha_{14} \\ \alpha_{14} &= 4y_{14} - 2y_1 - 2y_4 \text{-----} (3.42a) \end{aligned}$$

$$\left. \begin{aligned} \alpha_{15} &= 4y_{15} - 2y_1 - 2y_5 \\ \alpha_{23} &= 4y_{23} - 2y_2 - 2y_3 \\ \alpha_{24} &= 4y_{24} - 2y_2 - 2y_4 \\ \alpha_{25} &= 4y_{25} - 2y_2 - 2y_5 \\ \alpha_{34} &= 4y_{34} - 2y_3 - 2y_4 \\ \alpha_{35} &= 4y_{35} - 2y_3 - 2y_5 \end{aligned} \right\} (3.42b)$$

$$y_{45} = 1/2 \alpha_4 + 1/2 \alpha_5 + 1/4 \alpha_{45} \dots\dots\dots(3.43)$$

$$\alpha_{45} = 4y_{45} - 2y_4 - 2y_5 \quad \text{-----} \quad (3.44)$$

Summarising equations 3.40 – 3.43 will give

$$y_{ij} = 1/2 \alpha_i + 1/2 \alpha_j + 1/4 \alpha_{ij} \text{-----} \quad (3.45)$$

Rearranging equations 3.39 and 3.44 will give

$$\alpha_i = y_i \text{-----} \quad (3.46)$$

$$\alpha_{ij} = 4y_{ij} - 2\alpha_i - 2\alpha_j \text{-----} \quad (3.47)$$

Substituting equation 3.45 into equation 4.46 gives

$$\alpha_{ij} = 4y_{ij} - 2y_i - 2y_j \text{-----} \quad (3.48)$$

3.5 OPTIMUM POINT

Optimum mixture is that mixture proportion that has the highest or most desired property. In a factor space different points exist. Each point in a factor space yields mixture proportion of a particular property. The point in the factor space that produces the mixture proportion that yields the most desired property is the optimum point. Different optimum points exist in the imaginary space. Many factors and considerations bring about a particular optimum point. For a

particular optimum point desired to meet the considerations in mind, it is pertinent to use a defined factor space to enclose (trap) it. Failure to trap the desired optimum point means that the optimum point will fall outside the defined factor space. The consequence of this is that the model will not produce the optimum point. To define a factor space that will enclose the desired optimum point, previous experiments and past experience will come into play. Where there is no past experience or previous experimental data, trial mixes can be made, which can serve as fair guide of where the optimum point will be. The actual mixture proportions required at this point are the five mixture proportions that are located at the five vertices of the factor space. These five proportions will define the required factor space that will entrap or enclose the desired optimum point. Listed below are the actual mixture proportion at the five vertices:

A1(0.67:1:1.7:2:0.5)

A2(0.58:1:1.5:1.9:0.8)

A3(0.6:1:1.2:1.7:1)

A4(0.8:1:1:1.8:1.3)

A5(0.74:1:1.2:1.3:1.5)

The proportions correspond to water/cement ratio, cement, sand, coarse aggregates and aluminum waste.

3.6 ACTUAL COMPONENTS AND PSEUDO COMPONENTS

It was mentioned earlier that the actual components of a mixture are related with the pseudo components of the same mixture. The two are related with coefficient of relation, A. The relationship is defined according to equation 3.6 as $Z = A X$.

Now the actual components at the five vertices are known and that of the pseudo components are also known. With these the coefficients of relation, A will be determined. Making "A" the subject of the equation from equation 3.6 gives form as

$$A = X^{-1} Z \quad \text{-----} \quad (3.49)$$

Equation 3.6 is a vector equation and will better put in matrix form as

$$\begin{pmatrix} Z_1 \\ Z_2 \\ Z_3 \\ Z_4 \end{pmatrix} = \begin{pmatrix} a_{11} & a_{12} & a_{13} & a_{14} & a_{15} \\ a_{21} & a_{22} & a_{23} & a_{24} & a_{25} \\ a_{31} & a_{32} & a_{33} & a_{34} & a_{35} \\ a_{41} & a_{42} & a_{43} & a_{44} & a_{45} \end{pmatrix} \begin{pmatrix} X_1 \\ X_2 \\ X_3 \\ X_4 \end{pmatrix} \quad \text{-----} \quad (3.50)$$

Let Y stand for any point on the factor space. This means that

$$1 < Y < 15.$$

When $Y = 1$

$$Z_1 = 0.67, Z_2 = 1, Z_3 = 1.7, Z_4 = 2 \text{ and } Z_5 = 0.5.$$

$$X_1 = 1, X_2 = X_3 = X_4 = X_5 = 0$$

Substituting these values into equation 3.50 will give

$$\begin{pmatrix} 0.67 \\ 1 \\ 1.7 \\ 2 \\ 0.5 \end{pmatrix} = \begin{pmatrix} a_{11} & a_{12} & a_{13} & a_{14} & a_{15} \\ a_{21} & a_{22} & a_{23} & a_{24} & a_{25} \\ a_{31} & a_{32} & a_{33} & a_{34} & a_{35} \\ a_{41} & a_{42} & a_{43} & a_{44} & a_{45} \\ a_{51} & a_{52} & a_{53} & a_{54} & a_{55} \end{pmatrix} \begin{pmatrix} 1 \\ 0 \\ 0 \\ 0 \\ 0 \end{pmatrix} \quad -(3.51)$$

This gives: $a_{11} = 0.67, a_{21} = 1, a_{31} = 1.7,$

$$a_{41} = 2, a_{51} = 0.5$$

Similarly for $Y = 2$

$$a_{12} = 0.58, a_{22} = 1, a_{32} = 1.5,$$

$$a_{42} = 1.9, a_{52} = 0.8$$

For $Y = 3$

$$a_{13} = 0.6, a_{23} = 1, a_{33} = 1.2$$

$$a_{43} = 1.7, a_{53} = 1$$

For $Y = 4$

$$a_{14} = 0.8, a_{24} = 1, a_{34} = 1,$$

$$a_{44} = 1.8, a_{54} = 1.3$$

For $Y = 5$

$$a_{15} = 0.74, a_{25} = 1, a_{35} = 1.2, a_{45} = 1.3, a_{55} = 1.5$$

Combining all the a_{ij} in matrix form gives

$$A = \begin{pmatrix} 0.67 & 0.58 & 0.6 & 0.8 & 0.74 \\ 1 & 1 & 1 & 1 & 1 \\ 1.70 & 1.50 & 1.20 & 1 & 1.20 \\ 2 & 1.90 & 1.70 & 1.80 & 1.30 \\ 0.50 & 0.80 & 1 & 1.30 & 1.50 \end{pmatrix} \text{-----}(3.52)$$

$$\begin{pmatrix} Z_1 \\ Z_2 \\ Z_3 \\ Z_4 \\ Z_5 \end{pmatrix} = \begin{pmatrix} 0.67 & 0.58 & 0.6 & 0.8 & 0.74 \\ 1 & 1 & 1 & 1 & 1 \\ 1.70 & 1.50 & 1.20 & 1 & 1.20 \\ 2 & 1.90 & 1.70 & 1.80 & 1.30 \\ 0.50 & 0.80 & 1 & 1.30 & 1.50 \end{pmatrix} \begin{pmatrix} X_1 \\ X_2 \\ X_3 \\ X_4 \\ X_5 \end{pmatrix} \text{-----(3.53)}$$

With coefficient of relation A known and pseudo components

X_1 from $Y = 12$ to $Y = 15$ also known, the actual components

Z_1 from $Y = 12$ to $Y = 45$ will be determined.

Substituting the pseudo components $Y = 12$ into eqn 3.53 will

give

$$\begin{pmatrix} Z_1 \\ Z_2 \\ Z_3 \\ Z_4 \\ Z_5 \end{pmatrix} = \begin{pmatrix} 0.67 & 0.58 & 0.6 & 0.8 & 0.74 \\ 1 & 1 & 1 & 1 & 1 \\ 1.70 & 1.50 & 1.20 & 1 & 1.20 \\ 2 & 1.90 & 1.70 & 1.80 & 1.30 \\ 0.50 & 0.80 & 1 & 1.30 & 1.50 \end{pmatrix} \begin{pmatrix} 0.5 \\ 0.5 \\ 0 \\ 0 \\ 0 \end{pmatrix} \quad 97$$

$$Z_1 = 0.625, Z_2 = 1.00, Z_3 = 1.60, Z_4 = 1.95, Z_5 = 0.65$$

Similarly, at $Y = 13$

$$Z_1 = 0.635, Z_2 = 1, Z_3 = 1.45, Z_4 = 1.85, Z_5 = 0.75$$

At $Y = 14$

$$Z_1 = 0.735, Z_2 = 1, Z_3 = 1.35, Z_4 = 1.90, Z_5 = 0.90$$

At $Y = 15$

$$Z_1 = 0.705, Z_2 = 1, Z_3 = 1.45, Z_4 = 1.65, Z_5 = 1$$

At $Y = 23$

$$Z_1 = 0.59, Z_2 = 1, Z_3 = 1.35, Z_4 = 1.80, Z_5 = 0.90$$

At $Y = 24$

$$Z_1 = 0.69, Z_2 = 1, Z_3 = 1.25, Z_4 = 1.85, Z_5 = 1.05$$

At $Y = 25$

$$Z_1 = 0.66, Z_2 = 1, Z_3 = 1.35, Z_4 = 1.60, Z_5 = 1.15$$

At $Y = 34$

$$Z_1 = 0.70, Z_2 = 1, Z_3 = 1.10, Z_4 = 1.75, Z_5 = 1.15$$

At $Y = 35$

$$Z_1 = 0.67, Z_2 = 1, Z_3 = 1.20, Z_4 = 1.50, Z_5 = 1.25$$

At $Y = 45$

$$Z_1 = 0.77, Z_2 = 1, Z_3 = 1.10, Z_4 = 1.55, Z_5 = 1.40$$

Arranging all the pseudo components and the corresponding actual components at the different points on the factor space will give Table 3.1.

Table 3.1: Design matrix for Scheffe's (5,2) lattice (actual and pseudo components)

S/No	Z ₁	Z ₂	Z ₃	Z ₄	Z ₅	RESPONSE	X ₁	X ₂	X ₃	X ₄	X ₅
1	0.67	1	1.7	2	0.5	Y ₁	1	0	0	0	0
2	0.58	1	1.5	1.9	0.8	Y ₂	0	1	0	0	0
3	0.60	1	1.2	1.7	1	Y ₃	0	0	1	0	0
4	0.80	1	1	1.8	1.3	Y ₄	0	0	0	1	0
5	0.74	1	1.2	1.3	1.5	Y ₅	0	0	0	0	1
12	0.625	1	1.6	1.95	0.65	Y ₁₂	0.5	0.5	0	0	0
13	0.635	1	1.45	1.85	0.75	Y ₁₃	0.5	0	0.5	0	0
14	0.735	1	1.35	1.90	0.90	Y ₁₄	0.5	0	0	0.5	0
15	0.705	1	1.45	1.65	1	Y ₁₅	0.5	0	0	0	0.5
23	0.59	1	1.35	1.80	0.90	Y ₂₃	0	0.5	0.5	0	0
24	0.69	1	1.25	1.85	1.05	Y ₂₄	0	0.5	0	0.5	0
25	0.66	1	1.35	1.60	1.15	Y ₂₅	0	0.5	0	0	0.5
34	0.70	1	1.10	1.75	1.15	Y ₃₄	0	0	0.5	0.5	0
35	0.67	1	1.20	1.50	1.25	Y ₃₅	0	0	0.5	0	0.5
45	0.77	1	1.10	1.55	1.40	Y ₄₅	0	0	0	0.5	0.5

Legend: X₁ = Water cement ratio
X₂ = Fraction of Ordinary Portland cement
X₃ = Fraction of fine aggregate
X₄ = Fraction of coarse aggregates
X₅ = Fraction of aluminum waste.

3.6.1 CONTROL POINTS FOR TEST OF ADEQUACY

Table 3.1 will be used to determine the fifteen coefficients of the model. Mix proportions other than the fifteen in table 3.1 are required to confirm the adequacy of the model. Fifteen control points will be used. They are $C_1, C_2, C_3, C_4, C_5, C_6, C_7, C_8, C_9, C_{10}, C_{11}, C_{12}, C_{13}, C_{14}, C_{15}$. The pseudo components and the corresponding actual components of the control points are shown in table 3.2

Table 3.2: Mixture proportions of the control points showing actual and pseudo components

Legend: X_1 = Water Cement ratio

S/No	Z_1	Z_2	Z_3	Z_4	Z_5	RESPONSE	X_1	X_2	X_3	X_4	X_5
1	0.6625	1	1.35	1.85	0.90	C_1	0.25	0.25	0.25	0.25	0
2	0.6475	1	1.40	1.725	0.95	C_2	0.25	0.25	0.25	0	0.25
3	0.6975	1	1.35	1.75	1.025	C_3	0.25	0.25	0	0.25	0.25
4	0.7025	1	1.275	1.70	1.075	C_4	0.25	0	0.25	0.25	0.25
5	0.68	1	1.225	1.675	1.15	C_5	0	0.25	0.25	0.25	0.25
6	0.678	1	1.32	1.74	1.02	C_6	0.2	0.2	0.2	0.2	0.2
7	0.635	1	1.42	1.86	0.82	C_7	0.3	0.3	0.3	0.1	0
8	0.629	1	1.44	1.81	0.84	C_8	0.3	0.3	0.3	0	0.1
9	0.689	1	1.38	1.84	0.93	C_9	0.3	0.3	0	0.3	0.1
10	0.695	1	1.29	1.78	0.99	C_{10}	0.3	0	0.3	0.3	0.1
11	0.668	1	1.23	1.75	1.08	C_{11}	0	0.3	0.3	0.3	0.1
12	0.661	1	1.28	1.82	0.98	C_{12}	0.1	0.3	0.3	0.3	0
13	0.679	1	1.32	1.84	0.92	C_{13}	0.3	0.1	0.3	0.3	0
14	0.675	1	1.38	1.88	0.88	C_{14}	0.3	0.3	0.1	0.3	0
15	0.683	1	1.23	1.81	1.03	C_{15}	0.1	0.2	0.3	0.4	0

X_2 = Fraction of Ordinary Portland Cement

X_3 = Fraction of fine aggregates

X_4 = Fraction of coarse aggregates

X_5 = Fraction of aluminum waste

Table 3.3: Selected mixes used for the poisson ratio test

S/NO	Z₁	Z₂	Z₃	Z₄	Z₅	RESPONSE
1	0.55	1.00	0.00	1.50	3.00	Y ₁
2	0.55	0.95	0.10	2.00	4.00	Y ₂
3	0.55	0.88	0.16	2.50	4.00	Y ₃
4	0.55	0.83	0.20	2.00	5.00	Y ₄
5	0.55	0.92	0.80	2.50	4.50	Y ₅
6	0.55	0.96	0.70	2.25	4.00	Y ₁₂
7	0.55	0.85	0.75	1.85	3.70	Y ₁₃
8	0.55	0.80	0.50	2.25	3.75	Y ₁₄
9	0.55	0.78	0.13	2.25	4.75	Y ₁₅
10	0.55	0.80	0.25	2.20	4.40	Y ₂₃
11	0.55	0.78	0.23	2.25	5.00	Y ₂₄
12	0.55	0.88	0.15	1.75	3.50	Y ₂₅
13	0.55	0.76	0.60	2.25	4.75	Y ₃₄
14	0.55	0.78	0.78	2.00	3.50	Y ₃₅
15	0.55	0.79	0.65	2.00	4.25	Y ₄₅

Legend: Z₁ = Water cement ratio
 Z₂ = Fraction of Ordinary Portland cement
 Z₃ = Fraction of aluminum waste
 Z₄ = Fraction of fine aggregates
 Z₅ = Fraction of coarse aggregates.

Table 3.4: Selected control mixes used for the poisson ratio

S/NO	Z ₁	Z ₂	Z ₃	Z ₄	Z ₅	RESPONSE
1	0.55	0.97	0.09	2.15	4.30	C ₁
2	0.55	0.90	0.08	2.13	4,10	C ₂
3	0.55	0.89	0.08	2.19	4.44	C ₃
4	0.55	0.83	0.10	2.00	4.13	C ₄
5	0.55	0.81	0.13	2.04	3.88	C ₅
6	0.55	1.00	0.09	2.10	3.83	C ₆
7	0.55	0.96	0.07	2.25	4.38	C ₇

3.6.2 FINALIZING THE SIMPLEX MODEL

The final model equation will be written in chapter four. The reason why it will not be written in this chapter is because the values of y_i and y_{ij} will be determined in chapter four after carrying the experiment in chapter four.

3.7 TESTS FOR GOODNESS OF FIT OF THE MODELS

It is expected that the results of the Models will be accepted with about 95% risk of being correct or 5% risk of being incorrect. The results being correct means that there is no difference between model results and experimental test

results. At this point it will be wise to state the statistical hypothesis for accepting or otherwise the adequacy of the Models' results as follows:

- i. Null Hypothesis (H_0): There is no significant difference between the models' results and experimental test results.
- ii. Alternative Hypothesis (H_1): There is a significant difference between the models' results and the experimental test results
- iii. The risk involved is that 5% or below of the Models' results will be incorrect.

Several methods of testing the adequacy of Models' results exist. Some of the known methods are Least Square method, Chi-Square method, Z – test method,

Student t-test method, Fisher test method and the like. For the purpose of this work the use of Student t-test method and the Fisher method and ANOVA method will be employed.

Before treating the tests for adequacy of the Models, the error inherent in the experimental test results will be discussed. This error is called the Replication error.

3.8 ERROR OF THE REPLICATES

During the experimental test several errors were introduced. Some occurred due to human inconsistency, variation in test tools and equipment. Other occurred due to conditional variation like humidity, temperature, pressure and the like. This error was described as random error in paragraph 3.4 above. At any arbitrary point of observation, replicate values are obtained and used to get the mean value of response at that point. The mean value is used because the replicate values vary from each other due to the inconsistencies mentioned above. The variance of the replicates at the arbitrary point of observation is designated as S_i^2 . Cramer (1946) gave the equation of variance as: $S_y^2 = 1/(n-1) * [\sum (y_i - \bar{y})^2]$ ----- (3.54)

$$1 \leq i \leq n$$

Where n is the number of observation, y_i is the value at any arbitrary point of observation and $\bar{y}$ is the mean value of the y_i values. That is $\bar{y} = \sum y_i / n$ ----- (3.56)

$$1 \leq i \leq n$$

When equation 3.84 is expanded it becomes approximately equal to $S_y^2 = 1/(n-1) * [\sum y_i^2 - 1/n * (\sum y_i)^2]$ ----- (3.57)

$$1 \leq i \leq n$$

Thus, the equation of variance of the replicates at any arbitrary point of observation will be given as: $S_i^2 = 1/(n_i-1) * [\sum y_i^2 - 1/n_i * (\sum y_i)^2]$ ----- (3.58)

$$1 \leq i \leq n_i$$

Hence, the variance of the replicates at all the points of observation will be the summation of the individual variances divided by number of points of observation. That is to say

$$S_y^2 = 1/V * \sum S_i^2$$
 ----- (3.59)

$$1 \leq i \leq N$$

Where V is the degree of freedom, which is equal to N – 1.

Therefore, the random error or standard deviation becomes

$$S_y = \sqrt{(S_y^2)}$$
 ----- (3.60)

3.9 FISHER TEST

In the formulation of a model for predicting mix ratios where desired response is known and vice versa, two things are involved. One of them is the generation of a mathematical equation with unknown coefficients. The second is the carrying out experimental test to generate the unknown coefficients.

This means that response can be got by the experimental test that uses replicates and as well be got from the model when the coefficients are known. It is very vital that the variance ST^2 from the model should be compared with the variance SE^2 from the experimental test to see if they are similar or different. Akhnazorova (1958) and Brookes (1979) devised means of establishing the fact to prove whether or not SE^2 and ST^2 are similar through the use Fisher test. S_1^2 and S_2^2 were used in this test.

S_1^2 is the greater of SE^2 and ST^2 . The equation for the Fisher-test is given as

$$F = S_1^2 / S_2^2 \text{ ----- (3.61)}$$

The range of S_1^2 / S_2^2 to accept the fact that SE^2 and S_T^2 are similar is shown as

$$1 / f_{\alpha} (v_1, v_2) < S_1^2 / S_2^2 < f_{\alpha} (v_1, v_2) \text{ ----- (3.62)}$$

α is significant level, v is the degree of freedom = $N-1$.

3.10 STUDENT T-TEST METHOD

Nwaogazie (1999) observed that a situation may arise in which field tests or experiments are carried out in pairs for sake of comparing two different methods or techniques. In

such cases we seem to be more interested in the difference between each pair of measurements rather than the variations between different samples assigned to a particular technique.

Consider a case of determining the strength of concrete cubes/ beam using two different methods, M_1 and M_2 , and of which n different concrete cubes/ beams were tested by the two methods and the results are as given in Table 3.5. If the two methods offer similar results, the differences, d_1 (Table 3.5) should be seen as observations from a population with mean zero (that is, $\mu=0$).

For n pairs of measurement which are independent observations from populations with mean μ_{1i} , μ_{2i} , the null and alternative hypotheses can be stated as follows:

H_0 : $\mu_{1i} = \mu_{2i}$ (for all i), and that each pair of means are equal, any difference may have arisen by chance (for there is no significant difference in the two methods).

H_1 : $\mu_{1i} \neq \mu_{2i}$ (for all i), and there is significant difference in the two methods adopted.

Table 3.5: A case of Paired Comparison

Concrete cube/beam number, i	Methods of Testing Strength		Difference* $d_i = M_{2i} - M_{1i}$
	M_{1i}	M_{2i}	
1	M_{11}	M_{21}	$d_1 = M_{21} - M_{11}$
2	M_{12}	M_{22}	$d_2 = M_{22} - M_{12}$
3	M_{13}	M_{23}	$d_3 = M_{23} - M_{13}$
.	.	.	.
.	.	.	.
.	.	.	.
N	M_{1n}	M_{2n}	$d_N = M_{2n} - M_{1n}$

Difference, d as per the two methods for each set of concrete cubes/beams.

From Table 3.5, an average difference, d, can be computed, then the variance and the t-statistic are equally calculated as:

$$S_d^2 = \frac{\sum_{i=1}^N (d_i - d)^2}{N - 1} \dots\dots\dots (3.63)$$

$$t = \frac{d}{s_d/\sqrt{N}} \dots\dots\dots (3.64)$$

At a specified level of significance (1%, 5%, etc), we can accept or reject the null hypothesis based on the computed t-value (Equation 3.64), and the percentage point, $t_{\alpha, v}$ read from the Students-t distribution table.

3.11 ANOVA TEST

The aim of this test was to ascertain whether the difference between the results of compressive strength/flexural strength from experiment and model was significant or not.

$$S_E^2 = (YE - YAE)^2 / (N - 1)$$

$$S_T^2 = (YT - YAT)^2 / (N - 1)$$

The value of F can be read from the table as $F_{\alpha}(v_1, v_2)$

Where

YE = experimental strength; YAE = average of the experimental strength

YT = the model strength; YAT = the average of the model strength, N is the number of points of observation; v is the degree of freedom; α is the significance level

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1 RESULTS

The results of the experimental work are presented below.

Four properties of concrete were studied: Compressive strength, flexural strength, modulus of elasticity and modulus of rigidity.

Table 4.1: Setting Time of Cement

Type of Cement	Dangote Portland Cement
Initial Setting Time (mins)	53
Final Setting Time (mins)	587

Table 4.2: Chemical Analysis of Aluminum Waste

Property	Aluminum Waste
CaO (%)	18.2
MgO (%)	0.5
Fe ₂ O ₃ (%)	0.26
Na ₂ O(%)	0.36
AL ₂ O ₃ (%)	15.89
S1O ₂ (%)	56.58
ZnO (%)	0.79
MnO (%)	0.56
Loss in ignition (%)	6.4
SO ₄ (%)	Nil
CUO (%)	Trace
T1O ₂ (%)	Trace
C _d O (%)	Trace

Table 4.3: Compressive Strength of Concrete with Aluminum waste AW = 0%, and W/C = 0.55 for 1:2:4 Mix

Slump:15mm	7 days			14 days			28 days		
Samples	A	B	C	A	B	C	A	B	C
Mass (kg)	8.280	9.170	9.414	9.050	9.040	8.889	8.900	8.960	9.050
Failure Load (KN)	350	470	400	460	430	460	600	570	590
Compressive Strength (N/mm ²)	15.60	20.90	17.80	20.40	19.10	20.40	26.70	25.30	26.20
Average Comp. Strength N/mm ²)	18.10			19.97			26.07		

Table 4.4: Compressive Strength of Concrete with Aluminum waste AW = 2.5% and W/C = 0.55 for 1:2:4 Mix

Slump:12mm	7 days			14 days			28 days		
Samples	A	B	C	A	B	C	A	B	C
Mass (kg)	9.50	8.60	9.20	9.61	8.13	9.32	9.68	8.79	9.38
Failure Load (KN)	400	370	390	440	420	430	480	445	470
Compressive Strength (N/mm ²)	17.80	16.40	17.30	19.60	18.70	19.10	21.30	19.78	20.80
Average Comp. Strength N/mm ²)	17.17			19.13			20.63		

**Table 4.5: Compressive Strength of Concrete with
Aluminum waste AW = 5% and W/C = 0.68 for
1:2:4 Mix.**

Slump:10m m	7 days			14 days			28 days		
Samples	A	B	C	A	B	C	A	B	C
Mass (kg)	9.15	9.50	9.60	8.89	8.86	9.05	8.90	8.96	9.05
Failure Load (KN)	280	300	350	310	330	340	352	370	430
Compressiv e Strength (N/mm ²)	12.44	13.33	15.56	13.78	14.67	15.11	15.64	16.44	19.11
Average Comp. Strength N/mm ²)	13.78			14.52			17.06		

Table 4.6: Compressive Strength of Concrete with Aluminum waste AW = 7.5% and W/C = 0.55 for 1:2:4 Mix

Slump:7m m	7 days			14 days			28 days		
Samples	A	B	C	A	B	C	A	B	C
Mass (kg)	8.89	8.87	9.05	9.15	8.50	8.50	8.69	8.92	8.65
Failure Load (KN)	300	360	400	330	400	450	360	458	493
Compressi ve Strength (N/mm ²)	13.33	16.00	17.78	14.67	17.78	20.00	16.00	20.36	21.91
Average Comp. Strength N/mm ²)	15.70			17.48			19.42		

Table 4.7: Compressive Strength of Concrete with Aluminum waste AW = 10% and W/C = 0.55 for 1:2:4 Mix

Slump:6m m	7 days			14 days			28 days		
Samples	A	B	C	A	B	C	A	B	C
Mass (kg)	9.41	8.30	8.90	9.04	9.05	8.88	8.91	8.32	8.45
Failure Load (KN)	560	320	350	430	400	410	650	420	450
Compressi ve Strength (N/mm ²)	24.89	14.22	15.56	19.11	17.78	18.22	28.89	18.67	20.00
Average Comp. Strength N/mm ²)	18.22			18.37			22.52		

**Table 4.8: Compressive Strength of Concrete with
Aluminum waste AW = 12.5% and W/C = 0.55 for
1:2:4 Mix**

Slump:6m m	7 days			14 days			28 days		
Samples	A	B	C	A	B	C	A	B	C
Mass (kg)	9.13	8.57	7.79	8.25	8.59	8.35	8.72	9.61	7.99
Failure Load (KN)	460	300	320	380	400	390	460	580	470
Compressi ve Strength (N/mm ²)	20.44	13.33	14.22	16.89	17.78	17.33	20.44	25.78	20.89
Average Comp. Strength N/mm ²)	16.00			17.33			22.37		

**Table 4.9: Compressive Strength of Concrete with
Aluminum waste AW = 15% and W/C = 0.55 for
1:2:4 Mix**

Slump:5 mm	7 days			14 days			28 days		
Samples	A	B	C	A	B	C	A	B	C
Mass (kg)	8.57	7.80	8.70	8.24	8.54	8.26	8.98	8.31	8.56
Failure Load (KN)	320	270	330	310	340	370	430	410	390
Compressive Strength (N/mm ²)	14.22	12.00	14.67	13.78	15.11	16.44	19.11	18.22	17.33
Average Comp. Strength N/mm ²)	13.63			15.11			18.22		

Table 4.10: Compressive Strength of Concrete with Aluminum waste AW = 20% and W/C = 0.55 for 1:2:4 Mix

Slump:5m m	7 days			14 days			28 days		
Samples	A	B	C	A	B	C	A	B	C
Mass (kg)	7.76	8.14	8.55	8.41	8.14	8.76	8.01	8.30	8.97
Failure Load (KN)	220	300	340	320	350	310	370	380	415
Compressi ve Strength (N/mm ²)	9.78	13.33	15.11	14.22	15.56	13.78	16.44	16.89	18.44
Average Comp. Strength N/mm ²)	12.74			14.52			17.26		

Table 4.11: Compressive Strength of Concrete with Aluminum waste AW = 25% and W/C = 0.55 for 1:2:4 Mix.

Slump:4m m	7 days			14 days			28 days		
Samples	A	B	C	A	B	C	A	B	C
Mass (kg)	8.86	8.90	8.61	8.14	8.24	8.68	8.86	8.71	8.17
Failure Load (KN)	310	270	290	340	360	312	370	390	410
Compressi ve Strength (N/mm ²)	13.78	12.00	12.89	15.11	16.00	13.87	16.44	17.33	18.22
Average Comp. Strength N/mm ²)	12.89			15.00			17.33		

**Table 4.12: Compressive Strength of Concrete with
Aluminum waste AW = 30% and W/C = 0.55 for
1:2:4 Mix**

Slump:4m m	7 days			14 days			28 days		
Samples	A	B	C	A	B	C	A	B	C
Mass (kg)	8.90	9.00	8.62	9.21	8.10	9.18	8.87	8.71	8.97
Failure Load (KN)	400	420	390	450	440	458	490	520	540
Compressi ve Strength (N/mm ²)	17.78	18.67	17.33	20.00	19.56	20.36	21.78	23.11	24.00
Average Comp. Strength N/mm ²)	17.93			19.97			22.96		

Table 4.13: Compressive Strength of Concrete with Aluminum waste AW = 5% and W/C = 0.55 for 1:2:4 Mix

Slump:5m m	7 days			14 days			28 days		
Samples	A	B	C	A	B	C	A	B	C
Mass (kg)	8.61	9.20	8.51	8.82	8.34	8.25	9.00	8.28	8.16
Failure Load (KN)	410	419	380	540	530	508	610	630	682
Compressi ve Strength (N/mm ²)	18.22	18.62	16.89	24.00	23.56	22.58	27.11	28.00	30.31
Average Comp. Strength N/mm ²)	17.91			23.38			28.47		

**Table 4.14: Compressive Strength of Concrete with
Aluminum waste AW = 5% and W/C = 0.50 for
1:2:4 Mix**

Slump:5m m	7 days			14 days			28 days		
Samples	A	B	C	A	B	C	A	B	C
Mass (kg)	8.25	9.20	8.68	8.68	8.73	8.37	8.86	8.52	8.73
Failure Load (KN)	390	440	410	530	450	493	650	600	510
Compressi ve Strength (N/mm ²)	17.33	19.56	18.22	23.56	20.00	29.91	28.89	26.67	22.67
Average Comp. Strength N/mm ²)	18.37			24.49			26.08		

**Table 4.15: Compressive Strength of Concrete with
Aluminum waste AW = 5% and W/C = 0.65 for
1:2:4 Mix.**

Slump:12 mm	7 days			14 days			28 days		
Samples	A	B	C	A	B	C	A	B	C
Mass (kg)	8.25	8.60	8.69	9.20	9.30	8.62	9.11	8.92	8.32
Failure Load (KN)	320	430	380	365	530	438	600	300	550
Compressive Strength (N/mm ²)	14.22	19.11	16.89	16.22	23.56	19.47	26.67	13.33	24.44
Average Comp. Strength N/mm ²)	16.74			19.75			21.48		

Table 4.16: Compressive Strength of Concrete with Aluminum waste AW = 5% and W/C = 0.70 for 1:2:4 Mix.

Slump:20 mm	7 days			14 days			28 days		
Samples	A	B	C	A	B	C	A	B	C
Mass (kg)	8.67	8.80	8.86	8.50	8.96	8.21	8.05	8.77	8.96
Failure Load (KN)	280	450	320	470	399	306	400	620	384
Compressive Strength (N/mm ²)	12.44	20.00	14.22	20.89	17.73	13.60	17.78	27.56	17.07
Average Comp. Strength N/mm ²)	15.55			17.41			20.80		

**Table 4.17: Compressive Strength of Concrete with
Aluminum waste AW = 0% and W/C = 0.80 for
1:3:6 Mix.**

Slump:14 mm	7 days			14 days			28 days		
Samples	A	B	C	A	B	C	A	B	C
Mass (kg)	8.76	9.12	8.52	8.69	8.96	7.97	8.50	8.89	9.10
Failure Load (KN)	360	340	390	400	411	379	483	559	450
Compressive Strength (N/mm ²)	16.00	15.11	17.33	17.78	18.27	16.84	21.47	24.84	20.00
Average Comp. Strength N/mm ²)	16.15			17.63			22.10		

**Table 4.18: Compressive Strength of Concrete with
Aluminum waste AW = 2.5% and W/C = 0.80 for
1:3:6 Mix**

Slump:14m m	7 days			14 days			28 days		
Samples	A	B	C	A	B	C	A	B	C
Mass (kg)	8.52	8.05	7.76	8.98	8.79	8.17	9.00	8.97	8.86
Failure Load (KN)	340	392	280	360	284	377	400	466	439
Compressiv e Strength (N/mm ²)	15.11	17.42	12.44	16.00	12.62	16.76	17.78	20.71	19.51
Average Comp. Strength N/mm ²)	14.99			15.13			19.33		

**Table 4.19: Compressive Strength of Concrete with
Aluminum waste AW = 5% and W/C = 0.80 for
1:3:6 Mix.**

Slump:13m m	7 days			14 days			28 days		
Samples	A	B	C	A	B	C	A	B	C
Mass (kg)	7.86	7.98	8.78	8.18	8.90	8.87	8.78	8.08	8.61
Failure Load (KN)	310	290	330	320	342	378	510	650	483
Compressiv e Strength (N/mm ²)	13.78	12.89	14.67	14.22	15.20	16.80	22.67	28.89	21.87
Average Comp. Strength N/mm ²)	13.78			15.41			24.34		

Table 4.20: Compressive Strength of Concrete with Aluminum waste AW = 7.5% and W/C = 0.80 for 1:3:6 Mix.

Slump:10 mm	7 days			14 days			28 days		
Samples	A	B	C	A	B	C	A	B	C
Mass (kg)	8.00	8.77	8.81	8.11	8.52	8.61	9.40	8.71	8.89
Failure Load (KN)	290	260	284	316	300	332	403	320	390
Compressive Strength (N/mm ²)	12.89	11.56	12.62	14.04	13.33	14.76	17.91	14.22	17.33
Average Comp. Strength N/mm ²)	12.36			14.04			16.49		

Table 4.21: Compressive Strength of Concrete with Aluminum waste AW = 10% and W/C = 0.80 for 1:3:6 Mix.

Slump:9m m	7 days			14 days			28 days		
Samples	A	B	C	A	B	C	A	B	C
Mass (kg)	8.72	7.51	7.89	8.11	8.79	8.89	8.01	8.53	8.14
Failure Load (KN)	260	251	273	299	308	250	331	347	380
Compressi ve Strength (N/mm ²)	11.56	11.16	12.13	13.29	13.69	11.11	14.71	15.42	16.89
Average Comp. Strength N/mm ²)	11.62			12.70			15.67		

Table 4.22: Compressive Strength of Concrete with Aluminum waste AW = 12.5% and W/C = 0.80 for 1:3:6 Mix.

Slump:12mm	7 days			14 days			28 days		
Samples	A	B	C	A	B	C	A	B	C
Mass (kg)	8.11	8.31	7.71	8.17	8.05	8.90	8.14	8.76	8.19
Failure Load (KN)	240	270	212	264	294	249	318	272	340
Compressive Strength (N/mm ²)	10.67	12.00	9.42	11.73	13.07	11.07	14.13	12.09	15.11
Average Comp. Strength N/mm ²)	10.70			11.96			13.78		

**Table 4.23: Com Concrete with Aluminum waste
pressive Strength of AW = 15% and W/C = 0.80 for
1:3:6 Mix.**

Slump:8mm	7 days			14 days			28 days		
Samples	A	B	C	A	B	C	A	B	C
Mass (kg)									
Failure Load (KN)	254	228	248	251	284	370	426	292	388
Compressive Strength (N/mm ²)	11.29	10.13	11.02	11.16	12.62	16.44	18.93	12.98	17.24
Average Comp. Strength N/mm ²)	10.81			13.41			16.38		

Table 4.24: Compressive Strength of Concrete with Aluminum waste AW = 20% and W/C = 0.80 for 1:3:6 Mix.

Slump:7m m	7 days			14 days			28 days		
Samples	A	B	C	A	B	C	A	B	C
Mass (kg)	8.12	8.90	8.32	8.71	7.61	8.61	8.20	8.41	8.59
Failure Load (KN)	200	420	231	228	385	270	338	460	373
Compressi ve Strength (N/mm ²)	8.89	18.67	10.27	10.13	17.11	12.00	15.02	20.44	16.58
Average Comp. Strength N/mm ²)	12.61			13.08			17.35		

Table 4.25: Compressive Strength of Concrete with Aluminum waste AW = 25% and W/C = 0.80 for 1:3:6 Mix.

Slump:7mm	7 days			14 days			28 days		
Samples	A	B	C	A	B	C	A	B	C
Mass (kg)	8.00	7.66	7.82	8.30	7.53	8.10	8.15	8.80	8.29
Failure Load (KN)	192	230	190	234	187	283	299	261	319
Compressive Strength (N/mm ²)	8.53	10.22	8.44	10.40	8.09	12.58	13.29	11.60	14.18
Average Comp. Strength N/mm ²)	9.06			10.36			13.02		

Table 4.26: Compressive Strength of Concrete with Aluminum waste AW = 30% and W/C = 0.80 for 1:3:6 Mix.

Slump:7m m	7 days			14 days			28 days		
Samples	A	B	C	A	B	C	A	B	C
Mass (kg)8.96	8.96	8.72	8.17	8.00	7.79	8.40	8.71	8.11	8.80
Failure Load (KN)	166	214	273	280	255	260	268	438	416
Compressi ve Strength (N/mm ²)	7.78	951	12.13	12.44	11.33	11.56	11.91	19.47	18.49
Average Comp. Strength N/mm ²)	9.81			11.78			16.62		

Table 4.27: Results of the Determination of Poisson Ratio

No	Replications	Failure Load (KN)	dy ($\times 10^{-2}$ mm)	dx ($\times 10^{-2}$ mm)	Wet Weight (kg)	Dry Weight (kg)
1	A	800	192	87	8.50	8.41
	B	732	176	30	8.00	7.06
	C	776	210	108	8.66	8.54
2	A	750	130	410	8.41	8.40
	B	510	120	98	8.10	8.01
	C	558	121	76	7.92	7.83
3	A	630	250	110	8.80	8.66
	B	667	200	230	8.15	8.02
	C	791	216	58	8.05	8.00
4	A	660	180	80	8.90	8.88
	B	700	189	66	8.55	8.53
	C	600	183	93	8.67	8.67
5	A	410	114	120	7.90	8.56
	B	720	155	130	7.65	8.20
	C	598	162	99	8.63	7.95
6	A	655	100	90	8.11	7.15
	B	582	105	162	8.70	8.69
	C	707	176	155	8.30	8.26
7	A	490	108	102	8.25	8.14
	B	761	140	116	8.70	8.67
	C	713	115	100	8.65	8.60

8	A	680	263	88	8.48	8.39
	B	796	161	106	7.94	7.08
	C	722	237	94	8.02	8.00
9	A	715	112	46	8.55	8.52
	B	820	171	230	8.61	8.60
	C	631	102	152	8.15	7.95
10	A	861	208	100	7.66	5.13
	B	743	183	75	8.00	7.96
	C	666	126	192	8.80	8.40
11	A	620	180	115	8.14	7.75
	B	688	174	68	8.45	8.36
	C	606	128	91	8.11	8.10
12	A	525	145	290	7.98	6.94
	B	766	107	161	8.44	8.43
	C	748	131	167	8.31	7.91
13	A	600	171	84	8.80	8.70
	B	630	133	105	8.42	8.40
	C	690	130	217	8.25	8.22
14	A	592	158	53	7.75	6.60
	B	618	141	98	8.13	8.10
	C	498	148	130	8.62	8.58
15	A	730	150	295	8.55	8.41
	B	695	157	109	8.66	8.60
	C	610	177	76	7.97	7.88

Table 4.28: Results of the Determination of Poisson Ratio (Control)

No	Replica tions	Failure Load (KN)	dy ($\times 10^{-2}$ mm	dx ($\times 10^{-2}$ mm	Wet Weight (kg)	Dry Weight (kg)
1	A	702	110	60	8.12	8.10
	B	776	202	140	7.62	7.50
	C	615	219	91	8.00	7.80
2	A	535	150	10	8.77	8.20
	B	708	158	30	8.61	8.60
	C	762	140	66	8.30	8.30
3	A	697	176	84	8.33	8.11
	B	620	131	52	8.10	8.08
	C	609	157	112	8.46	8.21
4	A	598	196	280	8.22	8.11
	B	701	182	38	8.18	8.12
	C	646	128	74	8.00	6.08
5	A	750	163	100	7.60	7.30
	B	800	177	600	8.82	8.70
	C	708	93	190	8.70	8.55
6	A	724	149	58	8.65	8.52
	B	521	137	121	8.35	8.27
	C	689	132	97	8.41	8.32
7	A	664	98	200	8.20	8.00
	B	840	116	133	8.00	6.50
	C	780	103	109	8.70	8.45

Table 4.29: Results of the Determination of Poisson Ratio, Young's Modulus and Modulus of Rigidity.

No	Replication	Fc	Average Fc	ℓ	μ	E ($\times 10^{-5}$)	G ($\times 10^{-5}$)
1	A	35.56	34.19	2.50	0.38	3.41	1.24
	B	32.53					
	C	34.49					
2	A	33.33	26.93	2.45	1.53	3.03	0.60
	B	22.67					
	C	24.80					
3	A	28.00	30.93	2.47	0.62	3.22	0.99
	B	29.64					
	C	35.16					
4	A	29.33	29.04	2.55	0.43	3.15	1.10
	B	31.11					
	C	26.67					
5	A	18.22	25.60	2.44	0.83	2.95	0.81
	B	32.00					
	C	26.58					

Table 4.29 continued

6	A	29.11					
	B	25.87	28.80	2.39	1.11	2.94	0.70
7	A	21.78					
	B	33.82	29.09	2.54	0.88	2.95	0.78
	C	31.69					
8	A	30.22					
	B	35.38	32.56	2.42	0.46	3.14	1.08
	C	32.09					
9	A	31.78					
	B	36.44	32.09	2.48	1.08	3.28	0.79
	C	28.04					
10	A	38.27					
	B	33.02	33.63	2.48	0.47	3.34	1.14
	C	29.60					
11	A	27.56					
	B	30.58	28.36	2.42	0.58	3.00	0.95
	C	26.93					
12	A	23.33					
	B	34.04	30.19	2.35	1.59	2.89	0.56
	C	33.24					
13	A	26.67					
	B	28.00	28.45	2.52	0.98	3.26	0.82
	C	30.67					
14	A	26.31					
	B	27.47	25.30	2.45	0.64	2.96	0.90
	C	22.13					
15	A	32.44					
	B	30.89	30.15	2.55	1.04	3.40	0.83
	C	27.11					

Table 4.30: Results of the Determination of Poisson Ratio, Young's Modulus and Modulus of Rigidity (Control)

No	Replication	Fc	Average Fc	ℓ	μ	E ($\times 10^{-5}$)	G ($\times 10^{-5}$)
1	A	31.20	31.01	2.41	0.55	3.07	0.99
	B	34.49					
	C	27.33					
2	A	23.76	29.70	2.56	0.24	3.41	1.38
	B	31.47					
	C	33.87					
3	A	30.97	28.53	2.48	0.53	3.16	1.03
	B	27.56					
	C	27.06					
4	A	26.58	28.82	2.43	0.74	3.04	0.87
	B	31.16					
	C	28.71					
5	A	33.33	33.45	2.49	2.01	3.36	0.56
	B	35.56					
	C	31.47					
6	A	32.18	28.65	2.52	0.67	3.27	0.98
	B	23.16					
	C	30.62					
7	A	29.51	33.84	2.47	1.42	3.32	0.69
	B	37.33					
	C	34.67					

Table 4.31: Results of Compressive Strength Test

S/No	Points of Observation	Replications	Failure Load (KN)
1	1	A	612
		B	680
		C	696
2	2	A	400
		B	440
		C	487
3	3	A	416
		B	479
		C	585
4	4	A	487
		B	418
		C	512
5	5	A	586
		B	474
		C	305

Table 4.31 continued

6	12	A	299
		B	214
		C	458
7	13	A	414
		B	496
		C	431
8	14	A	520
		B	608
		C	591
9	15	A	554
		B	518
		C	500
10	23	A	492
		B	501
		C	580
11	24	A	330
		B	451
		C	602

Table 4.31 continued

12	25	A	345
		B	618
		C	503
13	34	A	701
		B	520
		C	791
14	35	A	489
		B	638
		C	614
15	45	A	417
		B	342
		C	281
16	AC1	A	706
		B	405.45
		C	526.05
17	AC2	A	366
		B	401
		C	623

Table 4.31 continued

18	AC3	A	386.55
		B	468
		C	536
19	AC4	A	530
		B	438
		C	494
20	AC5	A	535
		B	500.63
		C	420.75
21	AC6	A	322
		B	394
		C	510
22	AC7	A	513
		B	538
		C	469
23	AC8	A	657
		B	402
		C	455

Table 4.31 continued

24	AC9	A	566
		B	291
		C	308
25	AC10	A	546
		B	590
		C	633
26	AC11	A	403
		B	414
		C	399
27	AC12	A	516
		B	421
		C	445
28	AC13	A	473
		B	451
		C	680
29	AC14	A	490
		B	202
		C	456
30	AC15	A	411
		B	551
		C	286

Table 4.32: Compressive Strength Test Results and Replications Variance

S/No	Replication	Replicate values Y_1 (N/mm ²)	$\bar{Y}$	Y_1^2	ΣY_1	ΣY_1^2	$(\Sigma Y_1)^2$	S_1^2
	1A	27.20		739.84				
1	1B	30.22	29.41	913.25	88.22	2601.73	7782.77	3.737
	1C	30.80		948.64				
	2A	17.78		316.13				
2	2B	19.56	19.66	382.60	58.98	1167.02	3478.64	3.737
	2C	21.64		468.29				
	3A	18.49		341.88				
3	3B	21.29	21.93	453.26	65.78	1471.14	4327.01	14.40
	3C	26.00		676.00				
	4A	21.64		468.29				
4	4B	18.58	20.99	345.22	62.98	1331.53	3966.48	4.69
	4C	22.76		518.02				
	5A	26.04		678.08				
5	5B	21.07	20.22	443.94	60.67	1305.89	3680.85	9.47
	5C	13.56		183.87				
	6A	13.29		176.62				

Table 4.32 continued

6	6B	9.51	14.38	90.44	43.15	681.18	1861.92	30.27
	6C	20.35		414.12				
	7A	18.40		338.56				
7	7B	22.04	19.87	485.76	59.60	1191.43	3552.16	3.69
	7C	19.16		367.11				
	8A	23.20		538.24				
8	8B	27.02	25.50	730.08	76.49	1958.43	5850.72	4.10
	8C	26.27		690.11				
	9A	24.62		606.14				
9	9B	23.02	23.29	529.92	69.86	1629.78	4880.42	1.49
	9C	22.22		493.72				
	10A	21.87		478.30				
10	10B	22.27	23.31	495.95	69.92	1638.86	4888.81	4.63
	10C	25.78		664.61				
	11A	14.67		215.21				
11	11B	20.04	20.49	401.60	61.47	1332.91	3778.56	6.70
	11C	26.76		716.10				
	12A	15.33		235.01				
12	12B	27.47	21.72	754.60	65.16	1489.58	4245.83	7.15
	12C	22.36		499.97				
	13A	31.16		970.95				
13	13A	23.11	29.81	534.07	89.43	2741.25	7997.72	3.10

Table 4.32 continued

	13C	35.16		1236.23				
	14A	21.73		472.19				
14	14B	28.36	25.79	804.29	77.38	2021.22	5987.66	12.67
	14C	27.29		744.74				
	15A	18.53		343.36				
15	15B	15.20	15.41	231.04	46.22	730.40	2136.29	9.15
	15C	12.49		156.00				
	16A	31.38		984.70				
16	16B	18.02	24.26	324.72	72.78	1856.04	5296.93	5.20
	16C	23.38		546.62				
	17A	16.27		264.71				
17	17B	17.82	20.59	317.55	61.78	1349.00	3816.77	11.02
	17C	27.69		766.74				
	18A	17.18		295.15				
18	18B	20.80	20.60	432.64	61.80	1295.18	3819.24	11.05
	18C	23.82		567.39				
	19A	23.56		555.07				
19	19B	19.47	21.66	379.08	64.99	1416.39	4223.70	4.25
	19C	21.96		482.24				
	20A	23.78		565.49				
20	20B	22.25	21.58	495.06	64.73	1410.24	4189.97	6.79
	20C	18.70		349.69				

Table 4.32 continued

	21A	14.31		204.78				
21	21B	17.51	18.16	306.60	54.49	1025.31	2969.16	10.80
	21C	22.67		513.93				
	22A	22.80		519.84				
22	22B	23.91	22.52	571.69	67.55	1471.84	4563.00	-24.58
	22C	20.84		434.31				
	23A	29.20		852.64				
23	23B	17.87	22.43	319.34	67.29	1580.83	4527.94	21.89
	23C	20.22		408.85				
	24A	25.16		633.03				
24	24B	12.93	17.26	167.18	51.78	987.63	2681.17	1.68
	24C	13.69		187.42				
	25A	24.27		589.03				
25	25B	26.22	26.21	687.49	78.62	2067.82	6181.10	3.73
	25C	28.13		791.30				
	26A	20.58		423.54				
26	26B	18.40	18.90	338.56	56.71	1076.45	3216.02	2.22
	26C	17.73		314.35				
	27A	22.93		525.78				
27	27B	18.71	20.47	350.06	61.42	1267.09	3772.42	4.81
	27C	19.78		391.25				
	28A	21.02		441.84				

Table 4.32 continued

28	28B	20.04	23.76	401.60	71.28	1756.69	5080.83	21.54
	28C	30.22		913.25				
	29A	21.78		474.37				
29	29B	8.98	17.01	80.64	51.03	965.88	2604.06	18.93
	29C	20.27		410.87				
	30A	18.27		333.79				
30	30B	24.49	18.49	599.76	55.47	1095.09	3076.92	20.73
	30C	12.71		161.54				
							TOTAL	239.0 44

Hence, to obtain the replication variance,

$$s_y^2 = \frac{239.044}{n-1} = \frac{239.044}{29} = 8.24$$

$$s_y = \sqrt{8.24} = 2.871$$

s_y = Standard error of the replicates.

4.2 THE REGRESSION EQUATION FOR COMPRESSIVE STRENGTH

Based on equation 3.34 and 3.48

$$\alpha_1 = 29.41, \quad \alpha_2 = 19.66, \quad \alpha_3 = 21.93$$

$$\alpha_4 = 20.99, \quad \alpha_5 = 20.22$$

$$\alpha_{12} = 4 \times 14.38 - 2 \times 29.41 - 2 \times 19.66$$

$$= -40.62$$

$$\alpha_{13} = 4 \times 19.87 - 2 \times 29.41 - 2 \times 21.93$$

$$= -23.2$$

Similarly,

$$\alpha_{14} = 1.20, \alpha_{15} = -6.1, \alpha_{23} = 10.06$$

$$\alpha_{24} = 0.66, \alpha_{25} = 7.12, \alpha_{34} = 33.40$$

$$\alpha_{35} = 18.86, \alpha_{45} = -20.78$$

Substituting into equation 3.31, we have

$$\begin{aligned} Y = & 29.41x_1 + 19.66x_2 + 21.93x_3 + 20.99x_4 \\ & + 20.22x_5 - 40.62x_1x_2 - 23.2x_1x_3 + 1.2x_1x_4 - \\ & 6.1x_1x_5 + 10.06x_2x_3 + 0.66x_2x_4 + 7.12x_2x_5 + \\ & 33.4x_3x_4 + 18.86x_3x_5 - 20.78x_4x_5 \end{aligned} \quad (4.1)$$

Equation (4.1) is therefore the mathematical model for optimization of the compressive strength of a five (5) component concrete mix using aluminum waste as the fifth component.

Table 4.33: Result of Experimental Test and Simplex (Scheffe) Model

S/No	Experimental Compressive Strength Test Result (N/mm ²)	Scheffe's Model Compressive Strength Test Result (N/mm ²)
1	29.41	29.41
2	19.66	19.66
3	21.93	21.93
4	20.99	20.99
5	20.22	20.22
6	14.38	14.38
7	19.87	19.87
8	25.50	25.50
9	23.29	23.29
10	23.31	23.31
11	20.49	20.40
12	21.72	21.72
13	29.81	29.81
14	25.79	25.79

Table 4.33 continued

15	15.41	15.41
16	24.26	21.841
17	20.59	20.688
18	20.60	18.913
19	21.66	23.349
20	21.58	23.783
21	18.16	21.666
22	22.52	19.618
23	22.43	19.08
24	17.26	18.959
25	26.21	24.506
26	18.90	24.923
27	20.47	23.807
28	23.76	23.794
29	17.01	20.33
30	18.49	25.052

Table 4.34: t-statistics for the control points of compressive strength

Points	Methods of Mixing/Test		Difference
	Ye	Ym	$d_1 = Y_e - Y_m$
C ₁	24.26	21.841	+2.419
C ₂	20.59	20.688	-0.098
C ₃	20.60	18.913	+1.687
C ₄	21.66	23.349	-1.689
C ₅	21.58	23.783	-2.203
C ₆	18.16	21.666	-3.506
C ₇	22.52	19.618	+2.902
C ₈	22.43	19.08	+3.35
C ₉	17.26	18.959	-1.699
C ₁₀	26.21	24.506	+1.704
TOTAL			2.867

$$\text{Average difference } d = \frac{\sum d1}{n} = \frac{2.867}{10} = 0.2867$$

$$\text{Variance, } Sd^2 = \frac{(d1 - d)^2}{n - 1} = \frac{53.0318}{9} = 5.892$$

Standard deviation, $Sd = 2.427$

$$t = \text{statistics, } t = \frac{d}{sd / \sqrt{10}} =$$

$$= \frac{0.2867}{2.427 / \sqrt{10}} = 0.37$$

For the case of two tailed test and for 5% level of significance and 9 degrees of freedom, we obtain $t_{0.975, 9} = 2.26$. Because the calculated t- value is less than that obtained from the table (i.e. 2.26), we conclude that there is no significant difference in the two methods. That is to say we accept null hypothesis, H_0 .

Table 4.35: F- statistics for the controlled points of compressive strength

Legend: $Y_{ee} = \Sigma Y_e / N$, $Y_{mm} = \Sigma Y_m / N$, $N=10$

Y_e =experimental laboratory test result

Y_m =model result

Points	Y_e	Y_m	$Y_e - Y_{ee}$	$Y_m - Y_{mm}$	$(Y_e - Y_{ee})^2$	$(Y_m - Y_{mm})^2$
C1	24.26	21.841	2.733	0.6007	7.4693	0.3608
C2	20.59	20.688	-0.937	-0.5523	0.8780	0.3050
C3	20.60	18.913	-0.927	-2.3273	0.8593	5.4163
C4	21.66	23.349	0.133	2.1087	0.0177	4.4466
C5	21.58	23.783	0.053	2.5427	0.0028	6.4653
C6	18.16	21.666	-3.367	0.4257	11.3367	0.1812
C7	22.52	19.618	0.993	-1.6223	0.9860	2.6319
C8	22.43	19.08	0.903	-2.1603	0.8154	4.6669
C9	17.26	18.959	-4.267	-2.2813	18.2073	5.2043
C10	26.21	24.506	4.683	3.2657	21.9305	10.6648
TOTAL	215.27	212.403			62.503	40.3431
MEAN	21.527	21.2403				

$$S_e^2 = \frac{\Sigma(Y_e - Y_{ee})^2}{n - 1} = \frac{62.503}{9} = 6.9448$$

$$S_m^2 = \frac{\Sigma(Y_m - Y_{mm})^2}{n - 1} = \frac{40.3431}{9} = 4.4826$$

S_1^2 is the greater of S_e^2 and S_m^2

$S2^2$ is the least of Se^2 and Sm^2

Therefore, $S1^2 = 6.9448$, $S2^2 = 4.4826$

$$F - calculated = \frac{S1^2}{S2^2} = \frac{6.9448}{4.4826} = 1.549$$

F-table = $F_{\alpha}(V_1, V_2)$

α is the significant level. That is the risk

V is the degree of freedom

$$\alpha = 5\% = 0.05$$

Therefore, $F(0.05)(9,9) = 3.18$ from table

$$(F\text{-table})^{-1} = 0.3145$$

Therefore, $0.3145 < 1.549 < 3.18$

Thus, the null hypothesis is accepted and the model is adequate for use.

Table 4.36: Flexural Strength Test Results

S/No	Points of Observation	Replications	Failure Load (KN)
1	1	A	11.60
		B	12.10
		C	15.20
2	2	A	14.90
		B	19.70
		C	18.60
3	3	A	17.90
		B	19.80
		C	21.20
4	4	A	11.30
		B	13.90
		C	13.20
5	5	A	20.90
		B	25.80
		C	23.60

Table 4.36 continued

6	12	A	13.20
		B	15.20
		C	15.80
7	13	A	14.00
		B	18.00
		C	17.00
8	14	A	11.80
		B	12.40
		C	18.00
9	15	A	15.50
		B	16.20
		C	22.00
10	23	A	17.40
		B	19.20
		C	21.00
11	24	A	14.00
		B	16.00
		C	20.00

Table 4.36 continued

12	25	A	19.00
		B	24.00
		C	20.20
13	34	A	14.90
		B	19.10
		C	17.80
14	35	A	19.90
		B	25.00
		C	21.80
15	45	A	17.48
		B	20.90
		C	17.30
16	AC1	A	16.95
		B	16.00
		C	16.49
17	AC2	A	16.40
		B	21.10
		C	17.50

Table 4.36 continued

18	AC3	A	18.00
		B	15.80
		C	14.00
19	AC4	A	19.00
		B	19.95
		C	15.00
20	AC5	A	18.96
		B	14.00
		C	16.26
21	AC6	A	17.92
		B	26.70
		C	17.80
22	AC7	A	20.00
		B	17.40
		C	18.00
23	AC8	A	19.60
		B	18.40
		C	18.60

Table 4.36 continued

24	AC9	A	22.00
		B	15.80
		C	17.00
25	AC10	A	18.22
		B	28.00
		C	13.90
26	AC11	A	17.90
		B	19.36
		C	13.40
27	AC12	A	16.90
		B	22.08
		C	12.50
28	AC13	A	23.40
		B	16.30
		C	15.20
29	AC14	A	25.90
		B	21.36
		C	19.70
30	AC15	A	28.00
		B	20.00
		C	16.20

Table 4.37: Flexural Strength Test Results and Replication Variance

S/No	Replication	Replicate values $Y_1(\text{N/mm}^2)$	Y	Y_1^2	ΣY_1	ΣY_1^2	$(\Sigma Y_1)^2$	S_1^2
1	1A	5.80	6.48	33.64	19.45	128.00	378.30	0.95
	1B	6.05		36.60				
	1C	7.60		57.76				
2	2A	7.45	8.87	55.50	26.60	239.01	707.56	1.58
	2B	9.85		97.02				
	2C	9.30		86.49				
3	3A	8.95	9.82	80.10	29.45	290.47	867.30	0.69
	3B	9.90		98.01				
	3C	10.60		112.36				
4	4A	5.65	6.40	31.92	19.20	123.78	368.64	0.45
	4B	6.95		48.30				
	4C	6.60		43.56				
5	5A	10.45	11.72	109.20	35.15	414.85	1235.52	1.51
	5B	12.90		166.41				
	5C	11.80		139.24				

Table 4.37 continued

6	6A	6.60		43.56				
	6B	7.60	7.37	57.76	22.10	163.73	488.41	0.46
	6C	7.90		62.41				
7	7A	7.00		49.00				
	7B	9.00	8.17	81.00	24.50	202.25	600.25	1.08
	7C	8.50		72.25				
8	8A	5.90		34.81				
	8B	6.20	7.03	38.44	21.10	154.25	445.21	2.92
	8C	9.00		81.00				
9	9A	7.75		60.06				
	9B	8.10	8.95	65.61	26.85	246.67	720.92	3.18
	9C	11.00		121.00				
10	10A	8.70		75.69				
	10B	9.60	9.60	92.16	28.80	278.15	829.44	0.84
	10C	10.50		110.30				
11	11A	7.00		49.00				
	11B	8.00	8.33	64.00	25.00	213.00	625.00	2.33
	11C	10.00		100.00				
12	12A	9.50		90.25				
	12B	12.00	10.53	144.00	31.60	336.26	998.56	1.70
	12C	10.10		102.01				

Table 4.37 continued

13	13A	7.45		55.50				
	13B	9.55	8.63	91.20	25.90	225.91	670.81	1.15
	13C	8.90		79.21				
14	14A	9.95		99.00				
	14B	12.50	11.12	156.25	33.35	374.06	1112.22	1.66
	14C	10.90		118.81				
15	15A	8.74		76.39				
	15B	10.45	9.28	109.20	27.84	260.41	775.07	1.03
	15C	8.65		74.82				
16	16A	8.48		71.91				
	16B	8.00	8.24	64.00	24.73	203.97	611.57	0.06
	16C	8.25		68.06				
17	17A	8.20		67.24				
	17B	10.55	9.17	111.30	27.50	255.10	756.25	1.51
	17C	8.75		76.56				
18	18A	9.00		81.00				
	18B	7.90	7.97	62.41	23.90	192.41	571.21	1.00
	18C	7.00		49.00				
19.	19A	9.50		90.25				
	19B	9.98	8.99	99.60	26.98	246.10	727.92	1.73
	19C	7.50		56.25				

Table 4.37 continued

20	20A	15.63		244.30				
	20B	14.55	12.76	211.70	38.28	521.61	1465.36	16.58
	20C	8.10		65.61				
21	21A	8.96		80.28				
	21B	13.35	10.40	178.22	31.21	337.71	974.06	6.51
	21C	8.90		79.21				
22	22A	10.00		100.00				
	22B	8.70	9.23	75.69	27.70	256.69	767.29	0.46
	22C	9.00		81.00				
23	23A	9.30		86.49				
	23B	9.20	9.27	84.64	27.80	257.62	772.84	0.00
	23C	9.30		86.49				
24	24A	11.00		121.00				
	24B	7.90	9.13	62.41	27.40	255.66	750.76	2.70
	24C	8.50		72.25				
25	25A	9.11		82.99				
	25B	14.00	10.02	196.00	30.06	327.29	903.60	13.05
	25C	6.95		48.30				
26	26A	8.95		80.10				
	26B	9.68	8.44	93.70	25.33	218.69	641.61	2.41
	26C	6.70		44.89				

Table 4.37 continued

27	27A	8.45		71.40				
	27B	11.04	8.58	121.88	25.74	232.34	662.55	5.75
	27C	6.25		39.06				
28	28A	11.70		136.89				
	28B	8.15	9.15	66.42	27.45	261.07	753.50	4.95
	28C	7.60		57.76				
29	29A	12.95		167.70				
	29B	10.68	11.16	114.06	33.48	378.78	1120.91	2.57
	29C	9.85		97.02				
30	30A	14.00		196.00				
	30B	10.00	10.70	100.00	32.10	361.61	1030.41	9.07
	30C	8.10		65.61				
							TOTAL	89.88

Hence, to obtain the replication variance,

$$S_y^2 = \frac{\sum S_1^2}{n-1} = \frac{89.88}{29} = 3.10$$

S_y = standard error of the replicates.

$$\text{and } S_y = \sqrt{3.10} = 1.76$$

4.3 The Regression Equation for Flexural Strength

Based on equation 3.34 and 3.48

$$\alpha_1 = 6.48, \alpha_2 = 8.87, \alpha_3 = 9.82$$

$$\alpha_4 = 6.40, \alpha_5 = 11.72$$

$$\alpha_{12} = 4 \times 7.37 - 2 \times 6.48 - 2 \times 8.87 = -1.22$$

$$\alpha_{13} = 4 \times 8.17 - 2 \times 6.48 - 2 \times 9.82 = 0.08$$

Similarly,

$$\alpha_{14} = 2.36, \alpha_{15} = -0.60$$

$$\alpha_{23} = 1.02, \alpha_{24} = 2.78, \alpha_{25} = 0.94$$

$$\alpha_{34} = 2.08, \alpha_{35} = 1.40, \alpha_{45} = 0.88$$

Substituting into equation 3.31, we have

$$\begin{aligned} Y &= 6.48x_1 + 8.87x_2 + 9.82x_3 + 6.4x_4 \\ &+ 11.72x_5 - 1.22x_1x_2 + 0.08x_1x_3 \\ &+ 2.36x_1x_4 - 0.6x_1x_5 + 1.02x_2x_3 \\ &+ 2.78x_3x_4 + 1.4x_3x_5 + 0.88x_4x_5 \text{ -----(4.2)} \end{aligned}$$

Equation (4.2) is therefore the mathematical model for the optimization of the flexural strength of a 5 component concrete mix using aluminum waste as the fifth component.

Table 4.38: Result of Experimental Test and Simplex (Scheffe) Model

S/No	Experimental Flexural Strength Test Result (N/mm ²)	Scheffe's Model Flexural Strength Test Result (N/mm ²)
1	6.48	6.48
2	8.87	8.87
3	9.82	9.82
4	6.40	6.40
5	11.72	11.72
6	7.37	7.37
7	8.17	8.17
8	7.03	7.03
9	8.95	8.95
10	9.60	9.60
11	8.33	8.33
12	10.53	10.53
13	8.63	8.63
14	11.12	11.12
15	9.28	9.28
16	11.47	8.336
17	9.17	9.324
18	7.97	8.689
19	8.99	8.993
20	12.76	9.771
21	11.38	9.047
22	9.23	8.397
23	9.27	8.764
24	9.13	8.086
25	11.32	8.439
26	8.44	9.325
27	8.58	8.741
28	9.15	8.181
29	11.16	7.955
30	10.70	8.534

Table 4.39: t-Statistics for the control points of flexural strength

Points	Methods of Mixing/Test		Difference
	Ye	Ym	$d_1 = Y_e - Y_m$
C ₁	8.24	8.336	-0.096
C ₂	9.17	9.324	-0.154
C ₃	7.97	8.689	-0.719
C ₄	8.99	8.993	-0.003
C ₅	8.20	8.771	-0.571
C ₆	10.40	9.047	1.353
C ₇	9.23	8.397	0.833
C ₈	9.27	8.764	0.506
C ₉	9.13	8.086	1.044
C ₁₀	10.02	8.439	1.581
		TOTAL	3.774

$$\text{Average difference, } d = \frac{\sum d_1}{n} = \frac{3.774}{10} = 0.3774$$

$$\text{Variance, } Sd^2 = \frac{\sum (d_1 - d)^2}{n - 1} = \frac{5.8218}{9} = 0.6469$$

Standard deviation, $Sd = 0.8043$

$$t - \text{Statistics}, t = \frac{d}{Sd/\sqrt{n}} = \frac{0.3774}{0.8043/\sqrt{10}} = 1.484$$

For the case of two tailed test and for 5% level significant and the degree of freedom of 9 we obtain $t_{0.975, 9} = 2.26$.

Because the calculated t-value is less than that obtained from the table (i.e. $1.484 < 2.26$), we conclude that the result is not significant at 5% level. Therefore, we accept null hypothesis.

Table 4.40: F-Statistics for the controlled points of flexural strength

LEGEND: $Y_{ee} = \sum Y_e/N$, $Y_{mm} = \sum Y_{mm}/N$, $N=10$

Y_e =laboratory experimental test result

Y_m = model result

Points	Y_e	Y_m	$Y_e - Y_{ee}$	$Y_m - Y_{mm}$	$(Y_e - Y_{ee})^2$	$(Y_m - Y_{mm})^2$
C_1	8.24	8.336	-0.820	-0.449	0.6724	0.2016
C_2	9.17	9.324	0.11	0.539	0.0121	0.2905
C_3	7.97	8.689	-1.09	-0.096	1.1881	0.0092
C_4	8.99	8.993	-0.07	0.208	0.0049	0.0433
C_5	8.20	8.771	-0.86	0.986	0.7396	0.9722

C ₆	10.40	9.047	1.34	0.262	1.7956	0.0686
C ₇	9.23	8.397	0.17	-0.388	0.0289	0.1505
C ₈	9.27	8.764	0.21	-0.021	0.0441	0.0004
C ₉	9.13	8.086	0.07	-0.699	0.0049	0.4886
C ₁₀	10.02	8.439	0.96	-0.346	0.9216	0.1197
TOTAL	90.62	87.846			4.5828	2.3446
L						
MEAN	9.06	8.785				

$$S_e^2 = \frac{\sum(Y_e - Y_{ee})^2}{n - 1} = \frac{4.5828}{9} = 0.5092$$

$$S_m^2 = \frac{\sum(Y_m - Y_{mm})^2}{n - 1} = \frac{2.3446}{9} = 0.2605$$

S₂² is the least of S_e² and S_m²

Therefore, S₁² = 0.5092, S₂² = 0.2605

$$F - \text{calculated} = \frac{S_1^2}{S_2^2} = \frac{0.5092}{0.2605} = 1.95$$

F-table = F_α (V₁, V₂)

α is the significant level, that is the risk

V is the degree of freedom

$$\alpha = 5\% = 0.05$$

Therefore, $F(0.05) (9,9) = 3.18$ from table

$$(F\text{-table})^{-1} = 0.3145$$

Because $F\text{-calculated}$ is less than $F\text{-(table)}$ (i.e. $1.95 < 3.18$), we conclude that the result is not significant at the 5% level. That is to say we accept null hypothesis.

Table 4.41: Comparison of Strength and Mass of Standard and Optimization Mixes

Item	Cement (kg)	Fine Aggregate (kg)	Aluminum Waste (kg)	Coarse Aggregate (kg)	Water (kg)	Compressive Strength (N/mm ²)	Flexural Strength (N/mm ²)
Standard Mix	1	2.00	0.00	4.00	0.55	26.07	9.46
Optimized Mix	1	1.1	1.15	1.75	0.70	29.81	11.72
Saving	0	0.9		2.25	0.15	3.74	

4.4 ECONOMIC BENEFITS OF USING ALUMINUM WASTE IN PRODUCING CONCRETE

From table 4.41, saving in concrete mass per unit design mass

$$= 0.9 + 2.25 + 0.15 = 3.3\text{kg}$$

Mass of concrete in 1m^3 concrete = 2400kg (Victor Oyenuga, 2001)

Hence mass of concrete saved in $1\text{m}^3 = 3.3 \times \text{mass of concrete in } 1\text{m}^3 / \text{Design unit mass}$

$$= 3.3 \times \frac{2400}{20.5} = 386.34 \text{ kg}$$

$$\text{But density of concrete} = \frac{\text{Mass}}{\text{Volume}} = 2400 \text{ kg/m}^3 \text{ --- (5.3)}$$

Hence volume of concrete saved

$$= \frac{\text{Mass}}{\text{Density}} = \frac{386.34}{2400} = 0.16 \text{ m}^3$$

Cost of 1 m^3 of concrete = #25,000 (committee report, 2008)

Therefore, cost of concrete saved per m^3

$$= \#25,000 \times 0.16 = \#4,000$$

Percentage volume of concrete saved per m^3

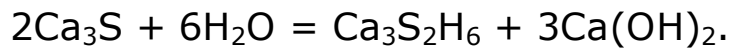
$$= \frac{0.16 \text{ m}^3}{1 \text{ m}^3} \times 100 = 16\%$$

4.5 DISCUSSION OF RESULTS

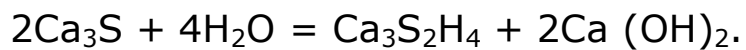
The result of the chemical analysis of the aluminum waste is presented in table 4.2. It showed that aluminum waste contain mainly SiO_2 (56.58%), Al_2O_3 (15.89%) and CaO (18.2%). The presence of calcium oxide constitutes about 11.30% of Ordinary Portland Cement (OPC). The presence of calcium in aluminum waste enhances the complete hydration of OPC and consequently, the development of higher strength concrete. The setting and consequent hardening of paste (water and cement) was

directly responsible for the strength of the concrete. This was enhanced by presence of calcium in aluminum waste. The mechanism is that in the presence of water the silicates and aluminates of OPC form products of hydration or hydrates which in time produce a hard mass. The two calcium silicates (Ca_3S and Ca_2S) are the main cementitious compounds in cement. The approximate hydration reactions are written as follows:

For Ca_3S :



For Ca_2S :



From the result obtained, aluminum waste behaved as a water reducer (Plasticizer) because it helped to achieve a higher strength by decreasing the water/cement ratio at the same workability. Table 4.2 also shows aluminum waste contains 0.5% mgO of which 0.093% is present in OPC. The improved workability of concrete which was

observed during the work may be attributed to the presence of the trace elements.

The maximum compressive strength of 24.34N/mm^2 was attained by the addition of 5% of aluminum waste. This represents an increase of 6.64% in the compressive strength of the mix.

However, the increase in compressive strength of concrete by the use of aluminum waste was not too pronounced in the case of 1:3:6 mix. This behaviour may be attributed to the reduction in the mass of OPC in 1:3:6 mix. It may therefore be concluded that the more the mass of cement in the mix, the better the effect of the aluminum waste.

Table 4.13 to 5.18 show the effect of variation of W/C ratio when certain percentage of Aluminum waste was used. The results showed that the maximum compressive strength was attained at W/C ratio of 0.55 and 5% of aluminum waste (28.47N/mm^2).

Table 4.27 to 5.30 described the effect of aluminum waste on the material properties of concrete. The result showed that there was no significant change in the density, poisson ratio, young's modulus.

The results of the compressive and flexural strengths obtained by the optimization approach applied in the work are presented in tables 4.31 to 4.32 and 4.36 to 4.37 respectively. The results of the experimental test and simplex (Scheffe) model are presented in table 4.33 and 4.38 respectively. The proposed regression models for compressive and flexural strengths were tested for adequacy using the student's t-test and F-test. These are shown in tables 4.34 and 4.35 for compressive strength and tables 4.39 and 4.40 for flexural strength. The tables showed that the regression models are adequate. Table 4.41 presents the results obtained from test carried out to experimentally check the outcome of the regression models. The experimental results agreed favourably with the model results. The compressive strength gave 29.81N/mm^2 and the flexural strength 11.72N/mm^2 . Table 4.41 showed that aluminum waste is not weak in flexure and will therefore be adequate in structural members where the concrete may be required to resist some

measure of flexural stress such as in rigid pavements. The results of table 4.41 also showed that the use of the optimized aluminum waste produced a saving of 16% in mass of concrete. The economic benefit analysis of the work showed that four thousand naira is saved per cubic meter of concrete when aluminum waste is used as admixture instead of a standard component 1:2:4 concrete mix.

CHAPTER FIVE

CONCLUSIONS, RECOMMENDATIONS AND CONTRIBUTIONS TO KNOWLEDGE

5.1 CONCLUSIONS

The research concludes that aluminum waste can be used in construction as an additive in concrete but should not exceed 16% in mass of concrete. Aluminum waste can also be used as a fifth component in concrete production. Aluminum waste has the advantage of high compressive strength material and cost saving over its standard counterpart.

5.2 RECOMENDATIONS

- i. Aluminum waste can be used as an admixture in concrete
- ii. The addition of Aluminum waste in concrete should exceed 16% in mass of concrete
- iii. Other methods of statistically experimental design can also be used in the optimization of Aluminum waste concrete and compared the result with the result of the simplex mixture design in this research work.

5.3 CONTRIBUTION TO KNOWLEDGE

The following contributions to knowledge have been made;

- I. The research verified that aluminum waste can cause an increase in the compressive strength of concrete, hence its use as a construction material.
- II. it has extended Scheffe's optimization theory from the fourth to the fifth concrete component.
- iii. The models for the optimization of the mechanical properties of five component concrete containing Aluminum waste was developed.
- iv. Computer program for the optimization of aluminum waste concrete has been developed.
- v. The work has ensured that admixtures are no longer added to concrete by the method of trial and error, but designed as a component of the composite material.

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APPENDX 1: PROGRAM FOR COMPRESSIVE STRENGTH

```
Private Sub ENDMNU_Click()  
End  
End Sub
```

```
Private Sub STARTMNU_Click()  
Rem ONE COMPONENT  
Cls  
' SCHEFFE'S SIMPLEX MODEL  
Print " THE PROGRAM WAS WRITTEN BY"  
Print: Print  
Print " MBADIKE ELVIS"  
Print:  
WWW = InputBox("CLICK OK. TO CONTINUE"): Cls  
Print: Print " THIS PROJECT IS IN PARTIAL FULFILMENT OF THE AWARD"  
Print " OF PH. D IN CIVIL ENGINEERING"  
WWW = InputBox("CLICK OK. TO CONTINUE"): Cls  
Print " I ACKNOWLEDGE MY SUPERVISOR, REV. PROF. NKEMAKOLAM NWAOLISA  
OSADEBE"  
Print " FOR INITIATING AND SUPERVISING THIS PROJECT"  
WWW = InputBox("CLICK OK. TO CONTINUE"): Cls  
  
' CIVIL ENGINEERING DEPARTMENT, FUTU  
  
CT = 0: OPSTRENGTH = 0  
ReDim X(10), A(5, 5), Z(5), N(15), B(5, 5), ZZ(5): QQQ = 1  
  
Cls  
N1 = 29.41: N2 = 19.66: N3 = 21.93: N4 = 20.99: N5 = 20.22  
N6 = 14.38: N7 = 19.87: N8 = 25.5: N9 = 23.29: N10 = 23.31  
N11 = 20.49: N12 = 21.72: N13 = 29.81: N14 = 25.79: N15 = 15.41  
  
5 QQ = InputBox("WHAT DO YOU WANT TO DO? TO CALCULATE MIX RATIOS GIVEN  
DESIRED COMPRESSIVE STRENGTH OR CALCULATING COMPRESSIVE STRENGTH GIVEN MIX  
RATIO?", "IF THE STRENGTH IS KNOWN TYPE 1 ELSE TYPE 0", "TYPE 1 OR 0 and CLICK OK")  
If QQ <> 1 And QQ <> 0 Then EE = InputBox("No Way! You must ENTER 1 or 0", , "CLICK OK  
and do so"): GoTo 5  
If QQ = 0 Then GoTo 900  
Rem *** CONVERSION MATRIX ***  
A(1, 1) = 0.67: A(1, 2) = 0.58: A(1, 3) = 0.6: A(1, 4) = 0.8: A(1, 5) = 0.74  
A(2, 1) = 1: A(2, 2) = 1: A(2, 3) = 1: A(2, 4) = 1: A(2, 5) = 1  
A(3, 1) = 1.7: A(3, 2) = 1.5: A(3, 3) = 1.2: A(3, 4) = 1: A(3, 5) = 1.2  
A(4, 1) = 2: A(4, 2) = 1.9: A(4, 3) = 1.7: A(4, 4) = 1.8: A(4, 5) = 1.3  
A(5, 1) = 0.5: A(5, 2) = 0.8: A(5, 3) = 1: A(5, 4) = 1.3: A(5, 5) = 1.5  
  
YY = InputBox("WHAT IS THE DESIRED STRENGTH?"): YY = YY * 1
```

```

    Rem ONE COMPONENT
    Q = -5: R = 1: E = 1
50 For I = 1 To 5: X(I) = 0: Next I
    X(E) = 1
    If Q = 0 Then GoTo 60
    GoTo 2000
55 E = E + 1: Q = Q + 1: GoTo 50
60 Rem TWO COMPONENTS
    R = R + 1: F = 1: E = 2: T = 1: J = 1: W = 1: K1 = 0.9: K2 = 0.1: V = 6
65 For I = 1 To 5: X(I) = 0: Next I
    X(F) = K1: X(E) = K2
    If T = 6 Then GoTo 70
    If J = V Then GoTo 80
    If W = 5 Then GoTo 90
    GoTo 2000
67 T = T + 1: K1 = K1 - 0.1: K2 = K2 + 0.1: GoTo 65
70 J = J + 1: E = E + 1: K1 = 0.9: K2 = 0.1: T = 1: GoTo 65
80 J = 1: V = V - 1: F = F + 1: E = F + 1: T = 1: W = W + 1: K1 = 0.9: K2 = 0.1: GoTo 65

90 Rem THREE COMPONENTS
    R = R + 1: E = 2: T = 1: J = 1: W = 1
    K1 = 0.89: K2 = 0.01: K3 = 0.1
100 For I = 1 To 5: X(I) = 0: Next I
    If E = 5 Then X(2) = K3: X(1) = K1: X(E) = 0.01: GoTo 110
    X(1) = K1: X(E) = 0.01: X(E + 1) = K3
110 If T = 99 Then GoTo 120
    If J = 5 Then GoTo 130
    If W = 10 Then GoTo 140
    GoTo 2000
115 T = T + 1: X(1) = X(1) - 0.01: X(E) = X(E) + 0.01: GoTo 110
120 T = 1: J = J + 1: E = E + 1: GoTo 100
130 J = 1: T = 1: W = W + 1: E = 2: K1 = K1 - 0.1: K3 = K3 + 0.1: GoTo 100
140 Rem THREE COMPONENTS CONTINUED
    R = R + 1: E = 2: T = 1: J = 1: W = 1
    K1 = 0.69: K2 = 0.11: K3 = 0.2
150 For I = 1 To 5: X(I) = 0: Next I
    If E = 5 Then X(2) = K3: X(1) = K1: X(E) = K2: GoTo 160
    X(1) = K1: X(E) = K2: X(E + 1) = K3
160 If T = 99 Then GoTo 170
    If J = 5 Then GoTo 180
    If W = 8 Then GoTo 190
    GoTo 2000
165 T = T + 1: X(1) = X(1) - 0.01: X(E) = X(E) + 0.01: GoTo 160
170 T = 1: J = J + 1: E = E + 1: GoTo 150
180 J = 1: T = 1: W = W + 1: E = 2: K1 = K1 - 0.1: K3 = K3 + 0.1: GoTo 150

190 Rem FOUR COMPONENTS
    R = R + 1: E = 2: T = 1: J = 1: W = 1

```

$K1 = 0.79$: $K2 = 0.01$: $K3 = 0.1$: $K4 = 0.1$
 200 For $I = 1$ To 5: $X(I) = 0$: Next I
 If $E = 4$ Then $X(1) = K1$: $X(2) = K4$: $X(E) = K2$: $X(E + 1) = K3$: GoTo 210
 If $E = 5$ Then $X(1) = K1$: $X(2) = K3$: $X(3) = K4$: $X(E) = K2$: GoTo 210
 $X(1) = K1$: $X(E) = K2$: $X(E + 1) = K3$: $X(E + 2) = K4$
 210 If $T = 99$ Then GoTo 220
 If $J = 5$ Then GoTo 230
 If $W = 9$ Then GoTo 240
 GoTo 2000
 215 $T = T + 1$: $X(1) = X(1) - 0.01$: $X(E) = X(E) + 0.01$: GoTo 210
 220 $T = 1$: $J = J + 1$: $E = E + 1$: GoTo 200
 230 $J = 1$: $T = 1$: $W = W + 1$: $E = 2$: $K1 = K1 - 0.1$: $K4 = K4 + 0.1$: GoTo 200

 240 Rem FOUR COMPONENTS CONTINUED
 $R = R + 1$: $E = 2$: $T = 1$: $J = 1$: $W = 1$
 $K1 = 0.59$: $K2 = 0.01$: $K3 = 0.2$: $K4 = 0.2$
 250 For $I = 1$ To 5: $X(I) = 0$: Next I
 If $E = 4$ Then $X(1) = K1$: $X(2) = K4$: $X(E) = K2$: $X(E + 1) = K3$: GoTo 260
 If $E = 5$ Then $X(1) = K1$: $X(2) = K3$: $X(3) = K4$: $X(E) = K2$: GoTo 260
 $X(1) = K1$: $X(E) = K2$: $X(E + 1) = K3$: $X(E + 2) = K4$
 260 If $T = 99$ Then GoTo 270
 If $J = 5$ Then GoTo 280
 If $W = 7$ Then GoTo 290
 GoTo 2000
 265 $T = T + 1$: $X(1) = X(1) - 0.01$: $X(E) = X(E) + 0.01$: GoTo 260
 270 $T = 1$: $J = J + 1$: $E = E + 1$: GoTo 250
 280 $J = 1$: $T = 1$: $W = W + 1$: $E = 2$: $K1 = K1 - 0.1$: $K4 = K4 + 0.1$: GoTo 250

 290 Rem FOUR COMPONENTS CONTINUED AGAIN
 $R = R + 1$: $E = 2$: $T = 1$: $J = 1$: $W = 1$
 $K1 = 0.29$: $K2 = 0.01$: $K3 = 0.4$: $K4 = 0.3$
 300 For $I = 1$ To 5: $X(I) = 0$: Next I
 If $E = 4$ Then $X(1) = K1$: $X(2) = K4$: $X(E) = K2$: $X(E + 1) = K3$: GoTo 310
 If $E = 5$ Then $X(1) = K1$: $X(2) = K3$: $X(3) = K4$: $X(E) = K2$: GoTo 310
 $X(1) = K1$: $X(E) = K2$: $X(E + 1) = K3$: $X(E + 2) = K4$
 310 If $T = 99$ Then GoTo 320
 If $J = 5$ Then GoTo 330
 If $W = 4$ Then GoTo 340
 GoTo 2000
 315 $T = T + 1$: $X(1) = X(1) - 0.01$: $X(E) = X(E) + 0.01$: GoTo 310
 320 $T = 1$: $J = J + 1$: $E = E + 1$: GoTo 300
 330 $J = 1$: $T = 1$: $W = W + 1$: $E = 2$: $K1 = K1 - 0.1$: $K4 = K4 + 0.1$: GoTo 300
 340 Rem FOUR COMPONENTS CONTINUED AGAIN AGAIN
 $R = R + 1$: $E = 2$: $T = 1$
 350 For $I = 1$ To 5: $X(I) = 0.25$: Next I
 $X(E) = 0$
 360 If $T = 6$ Then GoTo 370
 GoTo 2000

```

365 T = T + 1: E = E + 1: GoTo 350
370 Rem FIVE COMPONENTS
    R = R + 1: E = 2: T = 1: J = 1: W = 1
    K1 = 0.69: K2 = 0.01: K5 = 0.1
380 For I = 1 To 5: X(I) = 0.1: Next I
    X(1) = K1: X(E) = K2: X(5) = K5
390 If T = 99 Then GoTo 400
    If J = 5 Then GoTo 410
    If W = 8 Then GoTo 420
    GoTo 2000
395 T = T + 1: X(1) = X(1) - 0.01: X(E) = X(E) + 0.01: GoTo 390
400 T = 1: J = J + 1: E = E + 1: GoTo 380
410 J = 1: T = 1: W = W + 1: E = 2: K1 = K1 - 0.1: K5 = K5 + 0.1: GoTo 380

420 Rem FIVE COMPONENTS CONTINUED
    R = R + 1: E = 2: T = 1: J = 1: W = 1
    K1 = 0.49: K2 = 0.01: K3 = 0.1: K4 = 0.2: K5 = 0.2
430 For I = 1 To 5: X(I) = 0.1: Next I
    If E = 2 Then X(E + 1) = K3: X(E + 2) = K4: X(E + 3) = K5: GoTo 440
    If E = 3 Then X(E + 1) = K3: X(E + 2) = K4: X(2) = K5: GoTo 440
    If E = 4 Then X(E + 1) = K3: X(2) = K4: X(3) = K5: GoTo 440
    If E = 5 Then X(2) = K3: X(3) = K4: X(4) = K5
    X(1) = K1: X(E) = K2: X(5) = K5
440 X(1) = K1: X(E) = K2
450 If T = 99 Then GoTo 460
    If J = 5 Then GoTo 470
    If W = 6 Then GoTo 480
    GoTo 2000
455 T = T + 1: X(1) = X(1) - 0.01: X(E) = X(E) + 0.01: GoTo 450
460 T = 1: J = J + 1: E = E + 1: GoTo 430
470 J = 1: T = 1: W = W + 1: E = 2: K1 = K1 - 0.1: K5 = K5 + 0.1: GoTo 430

480 Rem FIVE COMPONENTS CONTINUED AGAIN
    R = R + 1: E = 2: T = 1: J = 1
    K1 = 0.29: K2 = 0.01: K3 = 0.1: K4 = 0.3: K5 = 0.3
490 For I = 1 To 5: X(I) = 0.3: Next I
    If E = 5 Then X(1) = K1: X(2) = K3: X(E) = K2: GoTo 500
    X(1) = K1: X(E) = K2: X(E + 1) = K3
500 If T = 99 Then GoTo 510
    If J = 5 Then GoTo 520
    GoTo 2000
515 T = T + 1: X(1) = X(1) - 0.01: X(E) = X(E) + 0.01: GoTo 500
510 T = 1: J = J + 1: E = E + 1: GoTo 490

520 Rem FIVE COMPONENTS CONTINUED AGAIN AGAIN
    R = R + 1
    X(1) = 0.2: X(2) = 0.2: X(3) = 0.2: X(4) = 0.2: X(5) = 0.2
    GoTo 2000

```

525 Rem END OF THE COMBINATIONS

GoTo 2100

2000 Rem PRINTING OF RESULTS

For I = 1 To 5: Z(I) = 0: Next I

For I = 1 To 5: For JJ = 1 To 5: Z(I) = Z(I) + A(I, JJ) * X(JJ): Next JJ: Next I

If Z(1) < 0 Or Z(2) < 0 Or Z(3) < 0 Or Z(4) < 0 Or Z(5) < 0 Then GoTo 830

If X(1) < 0 Or X(2) < 0 Or X(3) < 0 Or X(4) < 0 Or X(5) < 0 Then GoTo 830

If X(1) > 1 Or X(2) > 1 Or X(3) > 1 Or X(4) > 1 Or X(5) > 1 Then GoTo 830

'If Z(2) + Z(3) < 1 Then GoTo 830

If Z(2) > 1 Then GoTo 830

Y = X(1) * (1 - 2 * X(2) - 2 * X(3) - 2 * X(4) - 2 * X(5)) * N1 + X(2) * (1 - 2 * X(1) - 2 * X(3) - 2 * X(4) - 2 * X(5)) * N2 + X(3) * (1 - 2 * X(1) - 2 * X(2) - 2 * X(4) - 2 * X(5)) * N3

Y = Y + X(4) * (1 - 2 * X(1) - 2 * X(2) - 2 * X(3) - 2 * X(5)) * N4 + X(5) * (1 - 2 * X(1) - 2 * X(2) - 2 * X(3) - 2 * X(4)) * N5 + 4 * N6 * X(1) * X(2) + 4 * N7 * X(1) * X(3)

Y = Y + 4 * N8 * X(1) * X(4) + 4 * N9 * X(1) * X(5) + 4 * N10 * X(2) * X(3) + 4 * N11 * X(2) * X(4) + 4 * N12 * X(2) * X(5) + 4 * N13 * X(3) * X(4) + 4 * N14 * X(3) * X(5) + 4 * N15 * X(4) * X(5)

If Y > OPSTRENGTH Then For I = 1 To 5: ZZ(I) = 0: Next I

If Y > OPSTRENGTH Then OPSTRENGTH = Y: For I = 1 To 5: For JJ = 1 To 5: ZZ(I) = ZZ(I) + A(I, JJ) * X(JJ): Next JJ: Next I

If Y > YY - 0.05 And Y < YY + 0.05 Then GoTo 810 Else GoTo 830

810 CT = CT + 1

For I = 1 To 5: Z(I) = 0: Next I

For I = 1 To 5

For JJ = 1 To 5

Z(I) = Z(I) + A(I, JJ) * X(JJ)

Next JJ

Next I

'If Z(2) > 1.01 Or Z(2) < 0.9998 Then GoTo 830

'If Z(1) < 0 Or Z(2) < 0 Or Z(3) < 0 Or Z(4) < 0 Or Z(5) < 0 Then GoTo 830

If QQQ = 25 Then QQQQ = InputBox("PRESS OK TO CONTINUE", , , 5500, 8500): QQQ =

1: Cls

QQQ = QQQ + 1

820 Print " Y = "; Format(Y, "0.00#"),

Print " WATER "; Format(Z(1), "0.00#"), ;

Print " CEMENT ", Format(Z(2), "0.00#");

Print " FA ", Format(Z(3), "0.00#");

Print " CA "; Format(Z(4), "0.00#");

Print " ALU "; Format(Z(5), "0.00#")

830

If R = 1 Then GoTo 55

If R = 2 Then GoTo 67

```

    If R = 3 Then GoTo 115
    If R = 4 Then GoTo 165
    If R = 5 Then GoTo 215
    If R = 6 Then GoTo 265
    If R = 7 Then GoTo 315
    If R = 8 Then GoTo 365
    If R = 9 Then GoTo 395
    If R = 10 Then GoTo 455
    If R = 11 Then GoTo 515
    If R = 12 Then GoTo 525
2100
    Print: Print
    If CT = 0 Then Print " ***  SORRY THE HARDNESS IS OUTSIDE THE FACTOR SPACE  ***"
    Print: Print
    Print " OPTIMUM STRENGTH PREDICTABLE BY THIS MODEL IS "
    Print OPSTRENGTH: Print
    Print " THE CORRESPONDING MIXTURE RATIO IS AS FOLLOWS:"
    Print "  WATER ="; ZZ(1); "  CEMENT ="; ZZ(2); "  FA ="; ZZ(3);
    Print "  CA ="; ZZ(4); "  ALU ="; ZZ(5)
    GoTo 22222

900
    Cls
    Y = 0
    For I = 1 To 5: X(I) = 0: Next I
    Rem ***  RESPONSE AT THE CHOSEN 15 POINTS ON THE FACTOR SPACE FOR THE MODEL
    ***

    ' N(1) = 29.41: N(2) = 19.66: N(3) = 21.93: N(4) = 20.99: N(5) = 20.22
    ' N(6) = 14.38: N(7) = 19.87: N(8) = 25.5: N(9) = 23.29: N(10) = 23.31
    ' N(11) = 20.49: N(12) = 21.72: N(13) = 29.81: N(14) = 25.79: N(15) = 15.41
    GoTo 3010

3010  Rem ***  CONVERSION MATRIX  ****

    B(1, 1) = 4.680851064: B(1, 2) = 3.358297872: B(1, 3) = -0.323404255: B(1, 4) = -
    1.787234043: B(1, 5) = -2.740425532
    B(2, 1) = -6.382978723: B(2, 2) = -12.83404255: B(2, 3) = 3.531914894: B(2, 4) =
    4.255319149: B(2, 5) = 5.191489362
    B(3, 1) = -1.276595745: B(3, 2) = 16.19319149: B(3, 3) = -4.093617021: B(3, 4) = -
    3.14893617: B(3, 5) = -4.161702128
    B(4, 1) = 2.127659574: B(4, 2) = -4.855319149: B(4, 3) = -0.510638298: B(4, 4) =
    1.914893617: B(4, 5) = 0.936170213
    B(5, 1) = 0.85106383: B(5, 2) = -0.86212766: B(5, 3) = 1.395744681: B(5, 4) = -1.234042553:
    B(5, 5) = 0.774468085

    Rem ***  ACTUAL MIXTURE COMPONENTS  ****
    Z(1) = InputBox("ENTER THE VALUE OF Water")

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Z(2) = InputBox("ENTER THE VALUE OF Cement")
Z(3) = InputBox("ENTER THE VALUE OF FA")
Z(4) = InputBox("ENTER THE VALUE OF CA")
Z(5) = InputBox("ENTER THE VALUE OF ALU")
Rem *** PSEUDO MIXTURE COMPONENTS ***
For I = 1 To 5
For JJ = 1 To 5
X(I) = X(I) + B(I, JJ) * Z(JJ)
Next JJ
Next I

Rem *** CALCULATING THE STRENGTH (RESPONSE) ****
Y = X(1) * (1 - 2 * X(2) - 2 * X(3) - 2 * X(4) - 2 * X(5)) * N1 + X(2) * (1 - 2 * X(1) - 2 * X(3) -
2 * X(4) - 2 * X(5)) * N2 + X(3) * (1 - 2 * X(1) - 2 * X(2) - 2 * X(4) - 2 * X(5)) * N3
Y = Y + X(4) * (1 - 2 * X(1) - 2 * X(2) - 2 * X(3) - 2 * X(5)) * N4 + X(5) * (1 - 2 * X(1) - 2 *
X(2) - 2 * X(3) - 2 * X(4)) * N5 + 4 * N6 * X(1) * X(2) + 4 * N7 * X(1) * X(3)
Y = Y + 4 * N8 * X(1) * X(4) + 4 * N9 * X(1) * X(5) + 4 * N10 * X(2) * X(3) + 4 * N11 * X(2)
* X(4) + 4 * N12 * X(2) * X(5) + 4 * N13 * X(3) * X(4) + 4 * N14 * X(3) * X(5) + 4 * N15 * X(4) *
X(5)

Print " Y = "; Format(Y, "0.00#"),
Print "    WATER    "; Format(Z(1), "0.00#"), ;
Print "    CEMENT   ", Format(Z(2), "0.00#");
Print "    FA      ", Format(Z(3), "0.00#");
Print "    CA      "; Format(Z(4), "0.00#");
Print "    ALU     "; Format(Z(5), "0.00#")
For I = 1 To 5: Print X(I),; Next I

22222

End Sub

```

APPENDIX 1 CONTINUES: PROGRAM FOR FLEXURAL STRENGTH

```

Private Sub ENDMNU_Click()
End
End Sub

Private Sub STARTMNU_Click()
Rem ONE COMPONENT
Cls
' SCHEFFE'S SIMPLEX MODEL
Print "    THE PROGRAM WAS WRITTEN BY"
Print: Print
Print "    MBADIKE ELVIS"

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Print CIVIL; ENGINEERING; DEPARTMENT, UNN:
  WWWWW = InputBox("CLICK OK. TO CONTINUE"): Cls
Print: Print "  THIS PROJECT IS IN PARTIAL FULFILMENT OF THE AWARD"
Print "  OF PH. D IN CIVIL ENGINEERING"
WWWWW = InputBox("CLICK OK. TO CONTINUE"): Cls
Print "  I ACKNOWLEDGE MY SUPERVISOR, REV. PROF. NKEMAKOLAM NWAOLISA
OSADEBE"
Print "  FOR INITIATING AND SUPERVISING THIS PROJECT"
WWWWW = InputBox("CLICK OK. TO CONTINUE"): Cls

CT = 0: OPSTRENGTH = 0
ReDim X(10), A(5, 5), Z(5), N(15), B(5, 5), ZZ(5): QQQ = 1

Cls
N1 = 6.48: N2 = 8.87: N3 = 9.82: N4 = 6.4: N5 = 11.72
N6 = 7.37: N7 = 8.17: N8 = 7.03: N9 = 8.95: N10 = 9.6
N11 = 8.33: N12 = 10.53: N13 = 8.63: N14 = 11.12: N15 = 9.28

5 QQ = InputBox("WHAT DO YOU WANT TO DO? TO CALCULATE MIX RATIOS GIVEN
DESIRED COMPRESSIVE STRENGTH OR CALCULATING COMPRESSIVE STRENGTH GIVEN MIX
RATIO?", "IF THE STRENGTH IS KNOWN TYPE 1 ELSE TYPE 0", "TYPE 1 OR 0 and CLICK OK")
If QQ <> 1 And QQ <> 0 Then EE = InputBox("No Way! You must ENTER 1 or 0", , "CLICK OK
and do so"): GoTo 5
If QQ = 0 Then GoTo 900
Rem *** CONVERSION MATRIX ***

A(1, 1) = 0.67: A(1, 2) = 0.58: A(1, 3) = 0.6: A(1, 4) = 0.8: A(1, 5) = 0.74
A(2, 1) = 1: A(2, 2) = 1: A(2, 3) = 1: A(2, 4) = 1: A(2, 5) = 1
A(3, 1) = 1.7: A(3, 2) = 1.5: A(3, 3) = 1.2: A(3, 4) = 1: A(3, 5) = 1.2
A(4, 1) = 2: A(4, 2) = 1.9: A(4, 3) = 1.7: A(4, 4) = 1.8: A(4, 5) = 1.3
A(5, 1) = 0.5: A(5, 2) = 0.8: A(5, 3) = 1: A(5, 4) = 1.3: A(5, 5) = 1.5

YY = InputBox("WHAT IS THE DESIRED STRENGTH?"): YY = YY * 1

Rem ONE COMPONENT
Q = -5: R = 1: E = 1
50 For I = 1 To 5: X(I) = 0: Next I
X(E) = 1
If Q = 0 Then GoTo 60
GoTo 2000
55 E = E + 1: Q = Q + 1: GoTo 50
60 Rem TWO COMPONENTS
R = R + 1: F = 1: E = 2: T = 1: J = 1: W = 1: K1 = 0.9: K2 = 0.1: V = 6
65 For I = 1 To 5: X(I) = 0: Next I
X(F) = K1: X(E) = K2
If T = 6 Then GoTo 70
If J = V Then GoTo 80
If W = 5 Then GoTo 90

```

GoTo 2000
 67 T = T + 1: K1 = K1 - 0.1: K2 = K2 + 0.1: GoTo 65
 70 J = J + 1: E = E + 1: K1 = 0.9: K2 = 0.1: T = 1: GoTo 65
 80 J = 1: V = V - 1: F = F + 1: E = F + 1: T = 1: W = W + 1: K1 = 0.9: K2 = 0.1: GoTo 65

 90 Rem THREE COMPONENTS
 R = R + 1: E = 2: T = 1: J = 1: W = 1
 K1 = 0.89: K2 = 0.01: K3 = 0.1
 100 For I = 1 To 5: X(I) = 0: Next I
 If E = 5 Then X(2) = K3: X(1) = K1: X(E) = 0.01: GoTo 110
 X(1) = K1: X(E) = 0.01: X(E + 1) = K3
 110 If T = 99 Then GoTo 120
 If J = 5 Then GoTo 130
 If W = 10 Then GoTo 140
 GoTo 2000
 115 T = T + 1: X(1) = X(1) - 0.01: X(E) = X(E) + 0.01: GoTo 110
 120 T = 1: J = J + 1: E = E + 1: GoTo 100
 130 J = 1: T = 1: W = W + 1: E = 2: K1 = K1 - 0.1: K3 = K3 + 0.1: GoTo 100
 140 Rem THREE COMPONENTS CONTINUED
 R = R + 1: E = 2: T = 1: J = 1: W = 1
 K1 = 0.69: K2 = 0.11: K3 = 0.2
 150 For I = 1 To 5: X(I) = 0: Next I
 If E = 5 Then X(2) = K3: X(1) = K1: X(E) = K2: GoTo 160
 X(1) = K1: X(E) = K2: X(E + 1) = K3
 160 If T = 99 Then GoTo 170
 If J = 5 Then GoTo 180
 If W = 8 Then GoTo 190
 GoTo 2000
 165 T = T + 1: X(1) = X(1) - 0.01: X(E) = X(E) + 0.01: GoTo 160
 170 T = 1: J = J + 1: E = E + 1: GoTo 150
 180 J = 1: T = 1: W = W + 1: E = 2: K1 = K1 - 0.1: K3 = K3 + 0.1: GoTo 150

 190 Rem FOUR COMPONENTS
 R = R + 1: E = 2: T = 1: J = 1: W = 1
 K1 = 0.79: K2 = 0.01: K3 = 0.1: K4 = 0.1
 200 For I = 1 To 5: X(I) = 0: Next I
 If E = 4 Then X(1) = K1: X(2) = K4: X(E) = K2: X(E + 1) = K3: GoTo 210
 If E = 5 Then X(1) = K1: X(2) = K3: X(3) = K4: X(E) = K2: GoTo 210
 X(1) = K1: X(E) = K2: X(E + 1) = K3: X(E + 2) = K4
 210 If T = 99 Then GoTo 220
 If J = 5 Then GoTo 230
 If W = 9 Then GoTo 240
 GoTo 2000
 215 T = T + 1: X(1) = X(1) - 0.01: X(E) = X(E) + 0.01: GoTo 210
 220 T = 1: J = J + 1: E = E + 1: GoTo 200
 230 J = 1: T = 1: W = W + 1: E = 2: K1 = K1 - 0.1: K4 = K4 + 0.1: GoTo 200

 240 Rem FOUR COMPONENTS CONTINUED

```

R = R + 1: E = 2: T = 1: J = 1: W = 1
K1 = 0.59: K2 = 0.01: K3 = 0.2: K4 = 0.2
250 For I = 1 To 5: X(I) = 0: Next I
    If E = 4 Then X(1) = K1: X(2) = K4: X(E) = K2: X(E + 1) = K3: GoTo 260
    If E = 5 Then X(1) = K1: X(2) = K3: X(3) = K4: X(E) = K2: GoTo 260
    X(1) = K1: X(E) = K2: X(E + 1) = K3: X(E + 2) = K4
260 If T = 99 Then GoTo 270
    If J = 5 Then GoTo 280
    If W = 7 Then GoTo 290
    GoTo 2000
265 T = T + 1: X(1) = X(1) - 0.01: X(E) = X(E) + 0.01: GoTo 260
270 T = 1: J = J + 1: E = E + 1: GoTo 250
280 J = 1: T = 1: W = W + 1: E = 2: K1 = K1 - 0.1: K4 = K4 + 0.1: GoTo 250

290 Rem FOUR COMPONENTS CONTINUED AGAIN
    R = R + 1: E = 2: T = 1: J = 1: W = 1
    K1 = 0.29: K2 = 0.01: K3 = 0.4: K4 = 0.3
300 For I = 1 To 5: X(I) = 0: Next I
    If E = 4 Then X(1) = K1: X(2) = K4: X(E) = K2: X(E + 1) = K3: GoTo 310
    If E = 5 Then X(1) = K1: X(2) = K3: X(3) = K4: X(E) = K2: GoTo 310
    X(1) = K1: X(E) = K2: X(E + 1) = K3: X(E + 2) = K4
310 If T = 99 Then GoTo 320
    If J = 5 Then GoTo 330
    If W = 4 Then GoTo 340
    GoTo 2000
315 T = T + 1: X(1) = X(1) - 0.01: X(E) = X(E) + 0.01: GoTo 310
320 T = 1: J = J + 1: E = E + 1: GoTo 300
330 J = 1: T = 1: W = W + 1: E = 2: K1 = K1 - 0.1: K4 = K4 + 0.1: GoTo 300
340 Rem FOUR COMPONENTS CONTINUED AGAIN AGAIN
    R = R + 1: E = 2: T = 1
350 For I = 1 To 5: X(I) = 0.25: Next I
    X(E) = 0
360 If T = 6 Then GoTo 370
    GoTo 2000
365 T = T + 1: E = E + 1: GoTo 350

370 Rem FIVE COMPONENTS
    R = R + 1: E = 2: T = 1: J = 1: W = 1
    K1 = 0.69: K2 = 0.01: K5 = 0.1
380 For I = 1 To 5: X(I) = 0.1: Next I
    X(1) = K1: X(E) = K2: X(5) = K5
390 If T = 99 Then GoTo 400
    If J = 5 Then GoTo 410
    If W = 8 Then GoTo 420
    GoTo 2000
395 T = T + 1: X(1) = X(1) - 0.01: X(E) = X(E) + 0.01: GoTo 390
400 T = 1: J = J + 1: E = E + 1: GoTo 380
410 J = 1: T = 1: W = W + 1: E = 2: K1 = K1 - 0.1: K5 = K5 + 0.1: GoTo 380

```

420 Rem FIVE COMPONENTS CONTINUED

R = R + 1: E = 2: T = 1: J = 1: W = 1

K1 = 0.49: K2 = 0.01: K3 = 0.1: K4 = 0.2: K5 = 0.2

430 For I = 1 To 5: X(I) = 0.1: Next I

If E = 2 Then X(E + 1) = K3: X(E + 2) = K4: X(E + 3) = K5: GoTo 440

If E = 3 Then X(E + 1) = K3: X(E + 2) = K4: X(2) = K5: GoTo 440

If E = 4 Then X(E + 1) = K3: X(2) = K4: X(3) = K5: GoTo 440

If E = 5 Then X(2) = K3: X(3) = K4: X(4) = K5

X(1) = K1: X(E) = K2: X(5) = K5

440 X(1) = K1: X(E) = K2

450 If T = 99 Then GoTo 460

If J = 5 Then GoTo 470

If W = 6 Then GoTo 480

GoTo 2000

455 T = T + 1: X(1) = X(1) - 0.01: X(E) = X(E) + 0.01: GoTo 450

460 T = 1: J = J + 1: E = E + 1: GoTo 430

470 J = 1: T = 1: W = W + 1: E = 2: K1 = K1 - 0.1: K5 = K5 + 0.1: GoTo 430

480 Rem FIVE COMPONENTS CONTINUED AGAIN

R = R + 1: E = 2: T = 1: J = 1

K1 = 0.29: K2 = 0.01: K3 = 0.1: K4 = 0.3: K5 = 0.3

490 For I = 1 To 5: X(I) = 0.3: Next I

If E = 5 Then X(1) = K1: X(2) = K3: X(E) = K2: GoTo 500

X(1) = K1: X(E) = K2: X(E + 1) = K3

500 If T = 99 Then GoTo 510

If J = 5 Then GoTo 520

GoTo 2000

515 T = T + 1: X(1) = X(1) - 0.01: X(E) = X(E) + 0.01: GoTo 500

510 T = 1: J = J + 1: E = E + 1: GoTo 490

520 Rem FIVE COMPONENTS CONTINUED AGAIN AGAIN

R = R + 1

X(1) = 0.2: X(2) = 0.2: X(3) = 0.2: X(4) = 0.2: X(5) = 0.2

GoTo 2000

525 Rem END OF THE COMBINATIONS

GoTo 2100

2000 Rem PRINTING OF RESULTS

For I = 1 To 5: Z(I) = 0: Next I

For I = 1 To 5: For JJ = 1 To 5: Z(I) = Z(I) + A(I, JJ) * X(JJ): Next JJ: Next I

If Z(1) < 0 Or Z(2) < 0 Or Z(3) < 0 Or Z(4) < 0 Or Z(5) < 0 Then GoTo 830

If X(1) < 0 Or X(2) < 0 Or X(3) < 0 Or X(4) < 0 Or X(5) < 0 Then GoTo 830

If X(1) > 1 Or X(2) > 1 Or X(3) > 1 Or X(4) > 1 Or X(5) > 1 Then GoTo 830

'If Z(2) + Z(3) < 1 Then GoTo 830

If Z(2) > 1 Then GoTo 830

Y = X(1) * (1 - 2 * X(2) - 2 * X(3) - 2 * X(4) - 2 * X(5)) * N1 + X(2) * (1 - 2 * X(1) - 2 * X(3) - 2 * X(4) - 2 * X(5)) * N2 + X(3) * (1 - 2 * X(1) - 2 * X(2) - 2 * X(4) - 2 * X(5)) * N3

```

Y = Y + X(4) * (1 - 2 * X(1) - 2 * X(2) - 2 * X(3) - 2 * X(5)) * N4 + X(5) * (1 - 2 * X(1) - 2 *
X(2) - 2 * X(3) - 2 * X(4)) * N5 + 4 * N6 * X(1) * X(2) + 4 * N7 * X(1) * X(3)
Y = Y + 4 * N8 * X(1) * X(4) + 4 * N9 * X(1) * X(5) + 4 * N10 * X(2) * X(3) + 4 * N11 * X(2)
* X(4) + 4 * N12 * X(2) * X(5) + 4 * N13 * X(3) * X(4) + 4 * N14 * X(3) * X(5) + 4 * N15 * X(4) *
X(5)
If Y > OPSTRENGTH Then For I = 1 To 5: ZZ(I) = 0: Next I
If Y > OPSTRENGTH Then OPSTRENGTH = Y: For I = 1 To 5: For JJ = 1 To 5: ZZ(I) = ZZ(I) +
A(I, JJ) * X(JJ): Next JJ: Next I

```

```

If Y > YY - 0.08 And Y < YY + 0.08 Then GoTo 810 Else GoTo 830

```

```

810 CT = CT + 1
For I = 1 To 5: Z(I) = 0: Next I
For I = 1 To 5
For JJ = 1 To 5
Z(I) = Z(I) + A(I, JJ) * X(JJ)
Next JJ
Next I
If Z(2) > 1.01 Or Z(2) < 0.9998 Then GoTo 830
If Z(1) < 0 Or Z(2) < 0 Or Z(3) < 0 Or Z(4) < 0 Or Z(5) < 0 Then GoTo 830
If QQQ = 25 Then QQQQ = InputBox("PRESS OK TO CONTINUE", , , 5500, 8500): QQQ =
1: Cls
QQQ = QQQ + 1

```

```

820 Print " Y = "; Format(Y, "0.00#"),
Print " WATER "; Format(Z(1), "0.00#"), ;
Print " CEMENT ", Format(Z(2), "0.00#");
Print " FA ", Format(Z(3), "0.00#");
Print " CA "; Format(Z(4), "0.00#");
Print " ALU "; Format(Z(5), "0.00#")

```

```

830
If R = 1 Then GoTo 55
If R = 2 Then GoTo 67
If R = 3 Then GoTo 115
If R = 4 Then GoTo 165
If R = 5 Then GoTo 215
If R = 6 Then GoTo 265
If R = 7 Then GoTo 315
If R = 8 Then GoTo 365
If R = 9 Then GoTo 395
If R = 10 Then GoTo 455
If R = 11 Then GoTo 515
If R = 12 Then GoTo 525

```

```

2100
Print: Print
If CT = 0 Then Print " *** SORRY THE HARDNESS IS OUTSIDE THE FACTOR SPACE ***"

```

```

Print: Print
Print " OPTIMUM STRENGTH PREDICTABLE BY THIS MODEL IS "
Print OPSTRENGTH: Print
Print " THE CORRESPONDING MIXTURE RATIO IS AS FOLLOWS:"
Print "  WATER ="; ZZ(1); "  CEMENT ="; ZZ(2); "  FA ="; ZZ(3);
Print "  CA ="; ZZ(4); "  ALU ="; ZZ(5)
GoTo 22222

900
  Cls
  Y = 0
  For I = 1 To 5: X(I) = 0: Next I
  Rem *** RESPONSE AT THE CHOSEN 15 POINTS ON THE FACTOR SPACE FOR THE MODEL
  ***

' N(1) = 29.41: N(2) = 19.66: N(3) = 21.93: N(4) = 20.99: N(5) = 20.22
' N(6) = 14.38: N(7) = 19.87: N(8) = 25.5: N(9) = 23.29: N(10) = 23.31
' N(11) = 20.49: N(12) = 21.72: N(13) = 29.81: N(14) = 25.79: N(15) = 15.41

GoTo 3010

3010  Rem *** CONVERSION MATRIX ****

B(1, 1) = 4.680851064: B(1, 2) = 3.358297872: B(1, 3) = -0.323404255: B(1, 4) = -
1.787234043: B(1, 5) = -2.740425532
B(2, 1) = -6.382978723: B(2, 2) = -12.83404255: B(2, 3) = 3.531914894: B(2, 4) =
4.255319149: B(2, 5) = 5.191489362
B(3, 1) = -1.276595745: B(3, 2) = 16.19319149: B(3, 3) = -4.093617021: B(3, 4) = -
3.14893617: B(3, 5) = -4.161702128
B(4, 1) = 2.127659574: B(4, 2) = -4.855319149: B(4, 3) = -0.510638298: B(4, 4) =
1.914893617: B(4, 5) = 0.936170213
B(5, 1) = 0.85106383: B(5, 2) = -0.86212766: B(5, 3) = 1.395744681: B(5, 4) = -1.234042553:
B(5, 5) = 0.774468085

Rem *** ACTUAL MIXTURE COMPONENTS ****
Z(1) = InputBox("ENTER THE VALUE OF Water")
Z(2) = InputBox("ENTER THE VALUE OF Cement")
Z(3) = InputBox("ENTER THE VALUE OF FA")
Z(4) = InputBox("ENTER THE VALUE OF CA")
Z(5) = InputBox("ENTER THE VALUE OF ALU")

Rem *** PSEUDO MIXTURE COMPONENTS ***
For I = 1 To 5
  For JJ = 1 To 5
    X(I) = X(I) + B(I, JJ) * Z(JJ)
  Next JJ

```

Next I

```
Rem *** CALCULATING THE STRENGTH (RESPONSE) ****  
Y = X(1) * (1 - 2 * X(2) - 2 * X(3) - 2 * X(4) - 2 * X(5)) * N1 + X(2) * (1 - 2 * X(1) - 2 * X(3) -  
2 * X(4) - 2 * X(5)) * N2 + X(3) * (1 - 2 * X(1) - 2 * X(2) - 2 * X(4) - 2 * X(5)) * N3  
Y = Y + X(4) * (1 - 2 * X(1) - 2 * X(2) - 2 * X(3) - 2 * X(5)) * N4 + X(5) * (1 - 2 * X(1) - 2 *  
X(2) - 2 * X(3) - 2 * X(4)) * N5 + 4 * N6 * X(1) * X(2) + 4 * N7 * X(1) * X(3)  
Y = Y + 4 * N8 * X(1) * X(4) + 4 * N9 * X(1) * X(5) + 4 * N10 * X(2) * X(3) + 4 * N11 * X(2)  
* X(4) + 4 * N12 * X(2) * X(5) + 4 * N13 * X(3) * X(4) + 4 * N14 * X(3) * X(5) + 4 * N15 * X(4) *  
X(5)
```

```
Print " Y = "; Format(Y, "0.00#"),  
Print "      WATER      "; Format(Z(1), "0.00#"), ;  
Print " CEMENT      ", Format(Z(2), "0.00#");  
Print " FA      ", Format(Z(3), "0.00#");  
Print " CA      "; Format(Z(4), "0.00#");  
Print " ALU      "; Format(Z(5), "0.00#")  
For I = 1 To 5: Print X(I),; Next I
```

22222

End

APPENDIX 2

Percentile values, t_p for student's distribution with v degree of freedom..

Y	$t_{.995}$	$t_{.99}$	$t_{.975}$	$t_{.95}$	$t_{.90}$	$T_{.80}$	$t_{.75}$	$t_{.70}$	$T_{.60}$	$t_{.55}$
1	63.66	31.82	12.71	6.31	3.08	1.376	1.000	.727	.325	.158
2	9.92	6.96	4.30	2.92	1.89	1.061	.816	.617	.289	.142
3	5.84	4.54	3.18	2.35	1.64	.978	.765	.584	.277	.137
4	4.60	3.75	2.78	2.13	1.53	.941	.741	.569	.271	.134
5	4.03	3.36	2.57	2.02	1.48	.920	.727	.559	.267	.132
6	3.71	3.14	2.45	1.94	1.44	.906	.718	.553	.265	.131
7	3.50	3.00	2.36	1.90	1.42	.896	.711	.549	.263	.130
8	3.36	2.90	2.31	1.86	1.40	.889	.706	.546	.262	.130
9	3.25	2.82	2.26	1.83	1.38	.883	.703	.543	.261	.129
10	3.17	2.76	2.23	1.81	1.37	.879	.700	.542	.260	.129
11	3.11	2.72	2.20	1.80	1.36	.876	.697	.540	.260	.129
12	3.06	2.68	2.18	1.78	1.36	.873	.695	.539	.259	.128
13	3.01	2.65	2.16	1.77	1.35	.870	.694	.534	.259	.128
14	2.98	2.62	2.14	1.76	1.34	.868	.692	.537	.258	.128
15	2.95	2.60	2.13	1.75	1.34	.866	.691	.536	.258	.128
16	2.92	2.58	2.12	1.75	1.34	.865	.690	.535	.258	.128
17	2.90	2.57	2.11	1.74	1.33	.863	.689	.534	.257	.128
18	2.88	2.55	2.10	1.73	1.33	.862	.688	.534	.257	.127
19	2.86	.254	2.09	.173	1.33	.861	.688	.533	.257	.127
20	2.84	2.53	2.09	1.72	1.32	.860	.687	.533	.257	.127
21	2.83	2.52	2.06	1.72	1.32	.859	.686	.532	.257	.127
22	2.82	2.51	2.07	1.72	1.32	.858	.686	.532	.256	.127
23	2.81	2.50	2.07	1.71	1.32	.858	.685	.532	.256	.127
24	2.80	2.49	2.06	1.71	1.32	.857	.685	.531	.256	.127
25	2.79	2.48	2.06	1.71	1.32	.856	.684	.531	.256	.127
26	2.78	2.48	2.06	1.71	1.32	.856	.684	.531	.256	.127
27	2.77	2.47	2.05	1.70	1.31	.855	.684	.531	.256	.127
28	2.78	2.47	2.05	1.70	1.31	.855	.683	.530	.256	.127
29	2.76	2.46	2.04	1.70	1.31	.854	.683	.530	.256	.127
30	2.75	2.46	2.04	1.70	1.31	.854	.683	.530	.256	.127
40	2.70	2.42	2.02	1.68	1.30	.851	.681	.529	.255	.126
60	2.66	2.39	2.00	1.67	1.30	.848	.679	.527	.254	.126
120	2.62	2.36	1.98	1.66	1.29	.845	.677	.526	.254	.126
∞	2.58	2.33	1.96	1.645	1.28	.842	.674	.524	.253	.126

APPENDIX 3

F -Table

(c) $\alpha = 0.05$

V	1	2	3	4	5	6	7	8	9	10	12	15	20	24	30
1	161.45	199.50	215.71	224.58	230.16	233.99	236.77	238.86	240.54	241.88	243.91	245.95	248.01	249.05	250.10
2	18.51	19.00	19.16	19.25	19.30	19.33	19.35	19.37	19.38	19.40	19.41	19.42	19.43	19.44	19.45
3	10.13	9.55	9.28	9.12	9.01	8.94	8.89	8.86	8.84	8.82	8.79	8.77	8.75	8.74	8.73
4	7.71	6.94	6.59	6.39	6.26	6.15	6.04	6.02	6.02	6.02	5.99	5.96	5.94	5.93	5.92
6	6.61	5.79	5.41	5.19	5.05	4.95	4.88	4.82	4.77	4.74	4.68	4.62	4.56	4.53	4.50
6	5.99	5.14	4.76	4.53	4.39	4.28	4.21	4.15	4.10	4.06	4.00	3.94	3.87	3.84	3.81
7	5.59	4.74	4.35	4.12	3.97	3.87	3.79	3.73	3.68	3.64	3.57	3.51	3.44	3.41	3.38
8	5.32	4.46	4.07	3.84	3.69	3.59	3.51	3.44	3.39	3.35	3.26	3.22	3.15	3.12	3.08
9	5.12	4.26	3.86	3.63	3.48	3.37	3.29	3.23	3.18	3.14	3.07	3.01	2.94	2.90	2.86
10	4.96	4.10	3.71	3.48	3.33	3.22	3.14	3.07	3.02	2.98	2.91	2.84	2.77	2.74	2.70
11	4.84	3.98	3.59	3.36	3.20	3.09	3.01	2.95	2.90	2.85	2.79	2.72	2.65	2.61	2.57
12	4.75	3.89	3.49	3.26	3.11	3.00	2.91	2.85	2.80	2.75	2.69	2.62	2.54	2.51	2.47
13	4.67	3.81	3.41	3.16	3.03	2.92	2.83	2.77	2.71	2.67	2.60	2.53	2.46	2.42	2.38
14	4.60	3.74	3.34	3.11	2.96	2.85	2.76	2.70	2.65	2.60	2.53	2.46	2.39	2.35	2.31
15	4.54	3.68	3.29	3.06	2.90	2.79	2.71	2.64	2.59	2.54	2.48	2.40	2.33	2.29	2.25
16	4.49	3.63	3.24	3.01	2.85	2.74	2.66	2.59	2.54	2.49	2.42	2.35	2.28	2.24	2.19
17	4.45	3.59	3.20	2.96	2.81	2.70	2.61	2.55	2.49	2.45	2.38	2.31	2.23	2.19	2.15
18	4.41	3.55	3.16	2.93	2.77	2.66	2.58	2.51	2.46	2.41	2.34	2.27	2.19	2.15	2.11
19	4.38	3.52	3.13	2.90	2.74	2.63	2.54	2.48	2.42	2.38	2.31	2.23	2.16	2.11	2.07
20	4.35	3.49	3.10	2.87	2.71	2.60	2.51	2.45	2.39	2.35	2.28	2.20	2.12	2.08	2.04
21	4.32	3.47	3.07	2.84	2.68	2.57	2.49	2.42	2.38	2.32	2.25	2.18	2.10	2.05	2.01
22	4.30	3.44	3.05	2.82	2.66	2.55	2.46	2.40	2.34	2.30	2.23	2.15	2.07	2.03	1.98
23	4.28	3.42	3.03	2.80	2.64	2.53	2.44	2.37	2.32	2.27	2.20	2.13	2.05	2.01	1.96
24	4.26	3.40	3.01	2.78	2.62	2.51	2.42	2.36	2.30	2.25	2.16	2.11	2.03	1.98	1.94
25	4.24	3.39	2.99	2.76	2.60	2.49	2.40	2.34	2.28	2.16	2.09	2.09	2.01	1.96	1.92
26	4.23	3.37	2.96	2.74	2.59	2.47	2.39	2.32	2.27	2.22	2.15	2.07	1.99	1.95	1.90
27	4.21	3.35	2.96	2.73	2.57	2.46	2.37	2.31	2.25	2.20	2.13	2.06	1.97	1.93	1.88
28	4.20	3.34	2.95	2.71	2.56	2.45	2.36	2.29	2.24	2.19	2.12	2.04	1.96	1.91	1.87
29	4.18	3.33	2.93	2.70	2.55	2.43	2.35	2.29	2.24	2.18	2.10	2.03	1.94	1.90	1.85
30	4.17	3.32	2.92	2.69	2.53	2.42	2.33	2.27	2.21	2.16	2.09	2.01	1.93	1.89	1.84
40	4.08	3.23	2.84	2.61	2.45	2.34	2.25	2.18	2.12	2.08	2.00	1.92	1.84	1.79	1.74
60	4.00	3.15	2.76	2.53	2.37	2.25	2.17	2.10	2.04	1.99	1.92	1.84	1.75	1.70	1.65
120	3.92	3.07	2.68	2.45	2.29	2.18	2.09	2.02	1.96	1.91	1.83	1.75	1.66	1.61	1.55
∞	3.84	3.00	2.60	2.37	2.21	2.10	2.01	1.94	1.88	1.83	1.75	1.67	1.57	1.52	1.46