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Analyzing the Tested Result of a Moulded Bricks to ascertain the Compressive, Wet, Flexural Tensile, Water Absorption, Dry Bulk Density, Abrasion Resistance, and the Dry Weight Strength of Bricks

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Abstract

The mechanical properties of the bricks evaluated were compressive strength, flexural strength, abrasion resistance, water absorption and dry density. The mean values of all the mechanical properties of the bricks produced were directly proportional to the percentage content of the granite powder added but inversely proportional to the percentage content of the polyethylene powder. It was observed that maximum of 10% incorporation of only granite powder in the soil produced specimen bricks with the best mechanical properties, while the same percentage content of 10% of only polyethylene powder produced specimen bricks with the least mechanical properties. However, a combined inclusion of the two wastes in the soil, indicated that 7.5% of the granite powder and 2.5% of the polyethylene all by weight of the soil produced specimens' bricks with good satisfactory results.

Keywords: Strength and Durability Properties, Fired Bricks, Polythene Powder and Granite Powder, Clayey Soil

1.0 INTRODUCTION

Ghana as a developing country is faced with great housing problem for the citizens and efficient waste management challenges. This is largely attributed to the progressive escalating cost of building materials, most of which are imported into the country at high imported charged rates. There are a whole lot of local waste material which are left unharnessed and thereby posing serious environmental challenges. The two serious wastes among the many others which this study attempts tackling are pure water sachet (PWS) plastics and granite powder (GP). It has been estimated that about 90% of the total solid wastes generated on our streets are discarded pure water sachets (http: www.modernghana.com/thread/179007/27322).

Uncontrolled burning of the PWS plastics lowers the quality of the air that we breathe in, gives off stench and causes harm through the release of toxic gases and smoke. The oxides of carbon, sulphur and nitrogen, methane and many others, produced from burning disposed PWS causes various health problems such as cancer, carboxyhaemoglobin, brain damage, dizziness, headache, fatigue, lethargy, respiratory related problems and eye irritation. It also causes environmental problems such as acidification, eutrophication, the greenhouse effect (or global warming), smog and ozone loss. In addition, drainage system choked with discarded pure water sachet (DPWS) could lead to flooding which of course may bring about loss of lives and property, stagnant water in the choked gutters breeds mosquitoes for fast malaria spread and other epidemics. Also, PWS seriously affects the general fertility of the soil for agriculture use (Onemano&Otun, 2003)

Granite powder (GP) is yet another huge volume of solid wastes generated daily by many quarries in Ghana. According to Menezes et al. (2005) and Saboya et al.(2007) the quarry activities produce a great volume of granite powder which causes serious damage to the environment such as soil and underground water contamination and it has been blamed as the reason for severe lung diseases among local people, if not efficiently treated before disposal. In dry season, the granite powder floats in the air, flies and deposits on crops and vegetation and seriously affect the environment and micro ecosystems (Pappu et al., 2007)

It is in this direction that the current study aims at investigation the possibilities of applying modern technological and scientific approaches to effectively put to good economic use these wastes and thereby promote efficient waste management system for Ghana. According to Cengizler et al. (2008) large utilization of local wastes as partial replacement materials to produce building units (bricks, blocks, tiles, concrete, etc) will be a very beneficial solution to handling such hugely polluting materials raising serious environmental concerns and also solving the high housing deficit problems in Ghana. In effect, this discarded pure water sachet (DPWS) and the granite powder (GP) are proportionally mixed with raw clayey soil as a partial replacement of the soil in varying percentages to develop new burnt bricks christened GPC (Granite, Polythene, Clay) bricks for the construction industries in Ghana.

2.0 LITERATURE REVIEW

2.1.1 Clayey Soil

Over many centuries now, the main conventional raw material used in the manufacturing of burnt brick is clay. It forms part of the soil, the term “clay” according to Velde (1995) is applied both to materials having a particle size of less than 2 micrometers (25,400 micrometers = 1inch) and to the family of minerals that have similar chemical compositions and common crystal structural characteristic. Clay is a natural fine sized material with very cohesive properties and very fine mineral fragment or microscopic properties smaller than 0.002mm. Ghose (2002) noted that a good brick clay contains 20% - 30% of alumina, 50% - 60% of silica, the remaining constituents being lime, magnesia, sodium, potassium, manganese and oxide of iron.

Thus, a clay is a hydrated silicate of alumina derived from the decomposition of Feld spathic and filicious rocks. According to Spence and Kultermann (2011) clay is found in three forms: surface clay, shale and fireclay. Surface clay resides near the surface of the earth and is striped mined. Most bricks are made from surface mined clays. Shale is a clay that has been subjected to high pressure, causing it to be relatively hard. Fire clay is found at deeper levels and has more uniform physical and chemical properties. Fireclays can withstand higher temperatures and are used for the inner lining of the fire – place.

2.1.2 Physical and Chemical Properties of Clays

From the view of soil texture, soil scientists have proved that clayey soil has the smallest sized particles and sticky when held. Clayey soil also shows a character of being hard to squeeze. The smallest sized particles of clayey soil influence the porosity, permeability, water holding capacity and soil particle surface, clayey soils show that for porosity properties, it dominantly has small pores and slow permeability. Clay is also capable of holding water in a very large capacity, same goes with the soil particles surface (Mitchell, 1994).

The characteristic common to all clay minerals derived from their chemical compositions, layered structure and size. Clay minerals all have a great affinity for water. Some swell easily and may double in thickness when wet. Most have the ability to soak up ions (electrically charged atoms and molecules) from a solution and release the ions later when conditions change.Water molecules are strongly attracted to clay mineral surfaces. When a little clay is added to water, slurry forms because the clay distributes itself evenly throughout the water. This property of clay is used by the paint industry to disperse pigment (color)

2.1.3 Granite

The word “granite” comes from the Latin “granum”, grain, in reference to the coarse – grained structure of such a crystalline rock. Granite is possibly the most common igneous rock type known to the general public. By definition, granite is an igneous rock formed from magma with at least 20% of quartz (www.galleries.com/rock/granite.htm). According to Clemens (1998) granite is a common type of intrusive, felsic, igneous rock which is granular and phaneritic in texture, has crystal that tend to be easily seen, although they are generally small. This rock consists mainly of quartz, mica and feldspar. It can be pink, gray, brown, blue, green, black, red and white in colour, depending on their chemistry and mineralogy. It is one of the most popular building materials. It is a prestigious material that has been used for centuries for many different purposes in construction to produce impression of elegance and quality. It is used for the decoration of counter tops, tiles, tombstones, roads, jewelry and curting stones. Granite was used with limestone as a building material for the pyramids of Egypt. Its durability, beauty, excellent engineering properties and abundance make it a preferred choice of stone over most other stones (htt://geology.com/articles/granite.shtml).

2.1.4 Physical and Chemical Properties of Granite

Granite rock is nearly always massive (lacking internal structures), hard and tough, and therefore it has gained widespread use as a construction stone. The average density of granite is between 2.65 g/cm^3 and 2.75 g/cm^3, its compressive strength usually lies above 200MPa. Melting temperature is 1215^{0}C – 1260^0 C (Velde, 1995). These rocks are non-porous for water. They are not subject to strong erosion. That is, they resist erosion but their weathering goes up at a slow rate. The silica content ranges from 40% to 80%. Many different types of granite have been identified based on their varied chemical and mineralogical composition. Generally, the term granite is used as a suffix to indicate its textural and general compositions.

In some granite, the feldspars had time to form rectangular crystals before quartz and other mineral crystallised. The resulting rock appears to be a collection of unintelligible letters, numbers or figures and the rock is called "Graphic Granite". Quartz is always a must in the identification of granite rock. Basically, if there are randomly scattered crystals of nearly equal amount of quartz and plagioclase feldspar with some K – feldspar and hornblende or mica crystal that are melted into each other (an intrusive igneous rock), then it is granite.

Table 2.1 Chemical Composition of Granite

Name	Chemical formula	Mineral composition (%)
Silica oxide	SiO_2	72.04
Aluminium oxide	Al_2O_3	14.42
Potassium oxide	K_2O	4.12
Sodium oxide	Na_2O	3.69
Calcium oxide	CaO	1.842
	FeO	1.68
Ferric oxide	Fe_2O_3	1.22
Magnesium oxide	MgO	0.71
	TiO_2	0.30
Phosphorus oxide	P_2O_3	0.12
	MnO	0.05

A worldwide average of the chemical composition of granite by weight % based on 2485 analysis.Source: hht://en.wikipedia.org/wiki/granite//chemical-composition.

2.1.5 Polyethylene

According to Hugh and Ducan (2011) polyethylene is a type of thermoplastic material manufactured chemically by adding together (polymerisation) of its sub units (monomers) to form long chain; the monomers for polyethylene is "ethylene" or "ethane" represented as $CH_2 = CH_2$ or C_2H_4 or

```
    H   H
    l   l
 –  C = C  –
    l   l
    H   H
```

When the monomer, ethylene molecule, C_2H_4 is pressurized (200 N/mm^2) at temperature of about 220°C in the presence of a catalyst, the double bond between the two carbon atoms of ethylene is opened up or activated. When in activated state, the ethylene monomer forms a polymer through a covalent bond between adjacent carbon atoms, the resulting polymer is called polyethylene (polyethene, PE). The diagrams in Figures 2.2 and 2.3 explain the polymerization processes.

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(a)

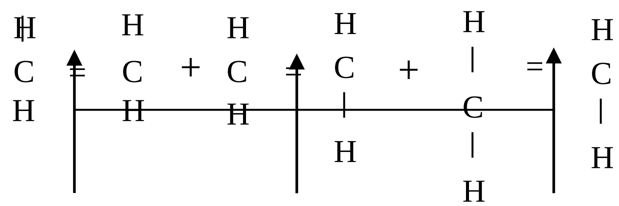

Figure 2.2 Commencement of Ethylene (Ethane) molecules polymerisation by the aid of a catalyst. Ethylene (ethane) molecules repeatedly being added one to another during the polymerisation process with the help of a catalyst.

(b)

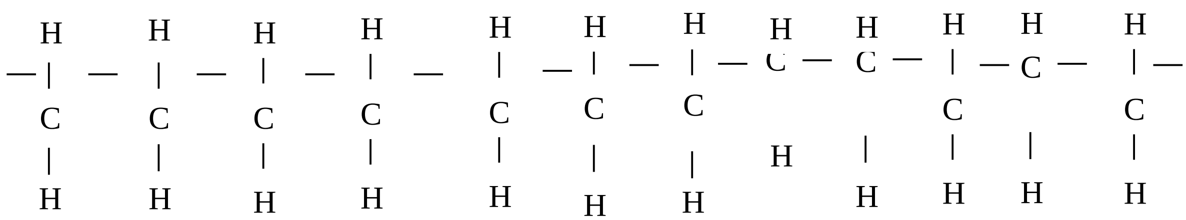

Figure 2.3 Completion of polymerisation process to produce polyethylene

Polymerisation completed resulting into polyethylene (polythene). Activated ethylene molecules joined up with other separate ethylene molecules to form a polymer called polyethylene through a covalent bond between adjacent carbon atoms.

2.1.6 Types of Polyethylene

The four main types of polyethylene according to Hinsley (2009) are Low Density Polyethylene (LDPE), Linear Low Density Polyethylene (LLDPE), Medium Density Polyethylene (MDPE) and High Density Polyethylene (HDPE). Bamidele et al. (2013) in their research on pure water sachet (PWS) confirmed that the infrared spectroscopy indicated that the PWS sample possibly contains polyolefin, secondary polyamine and polyamide. Also, the PWS sample can be classified as a Linear Low Density Polyethylene (LLDPE). Since PWS falls under the Linear Low Density Polyethylene (LLDPE), it will be considered comprehensively.

Linear Low – Density Polyethylene is a substantially linear polymer (polyethylene) with significant number of short branches, commonly made of copolymerisation of ethylene with longer-chain olefins. LLDPE is produced at lower temperature and pressures by copolymerisation of ethylene and such high alpha-olefins as hexane, butane or octane. The copolymerisation process produces an LLDPE polymer that has a narrow molecular weight distribution and in combination with the linear structure, significantly different rheological properties. Ashby and Jones (2006) describe LLDPE as linear, because, they are not cross-linked (though they may branch occasionally). This is the more reason why they soften if the polymer is heated to a higher temperature. It has been noted by Domone and Illston (2010) that the intermolecular forces are weakened and the polymer becomes soft and flexible; at high temperature it becomes viscous. When it is allowed to cool again it solidifies. The cycle of softening by heating and hardening by cooling can be repeated almost indefinitely but with each cycle, the material tends to become more brittle. This unique property of brittleness gives it the added advantage and possibility to be ground into fine aggregates.

2.1.7 Properties of LLDPE

Mitchell (1994) points out that the range of properties in polymeric materials is so great that generalization is difficult to make. However, Domone and Illston (2010) say that thermoplastic polymers which are not cross-linked like LLDPE derive their strength and stiffness from the properties of the monomers unit and their high molecular weight. LLDPE melts when heated and remains molten until cooled. The solidified LLDPE undergoes only a physical change on cooling. This is one of the main

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advantages of LLDPE in that they can be recycled many times, often with minimal loss of some its properties. LLDPE is solid, stable, impermeable to water, unaffected by salt water and resistant to bacteria and acid. It is an electrical insulator (in solid and molten state) because electrons are fixed by the strong covalent bond into the molecules. It burns like a "super paraffin wax". If the oxygen supply is restricted, it burns with a smoky flame, because of the hydrogen.

Table 2.2 Other physical properties of LLDPE

Properties	Value
Density	0.92g/cm3
Surface hardness	SD48
Tensive strength	20MPa
Flexural strength	0.35GPa
Notched izod	1.06+ KJ/M
Linear expansion	20 x 10-5/oC
Elongation at break	500%
Strain at yield	20%
Max. operating temp	50oC
Water absorption	0.01%
Oxygen index	17%
Flammability UL94	H

Source: Shell Bitumen Handbook (1990)

2.2 Categories of Admixtures

Admixtures are substances which are added in varying percentage proportions to the raw mixes of material so as to produce different effects in the finished product. They are either agricultural or industrial wastes, for instance, wood ash, sawdust, coal, fly ash, charcoal, sewage sludge. All these admixtures have been categorized into three major groups as first category admixtures, second category admixtures and third category admixtures. The first category of admixtures according to Okunade (2008) are fine sand, ground furnace slag, ground shells, coarse – grained laterite soil, grog (fired and pulverized clay product) and other non-plastic materials. The presence and the addition of these categories of admixtures is basically to produce strength and increase resistance to crushing and abrasion. The granite powder (GP) chosen for this study rightly falls into this category of admixtures, since granite rock is naturally tough, has high compressive strength, high resistance to crushing and abrasion and also non plastic. So the choice of granite powder to be incorporated into the body of the clayey soil material for this study is purposely to serve as an enhancer to boost up the engineering properties of the fired bricks. The second category of admixtures according to Ashish and Rinku (2012) include organic matter, such as rice husk; sawdust, coal, paper processing residues (PPR), etc. which are combustible in nature and usually burn out when the bricks undergo intensive firing at about 800^{0}C to 1300^{0}C. According to them, this category of admixtures serves three major purposes;

1. As they burn out they leave pores in the body of the finished brick products and help in producing lighter and more porous bricks.

2. Secondly, they result in more uniformly burnt bricks especially when the firing is being done outside of factory condition, in which case inability to reach the minimum desired temperature of 1000^{0}C result in un-burnt cores especially in solid bricks.
3. The pores produced as the additivees are burnt out permit the heat to reach into the innermost part of the core, thereby avoiding un-burnt core as, while the additives on their own part serve as extra fuel which provides more heat for the firing. Therefore, there is a reduction in fuel and power expenditures.

Polyethylene powder (PEP) which is also one of the materials chosen for the study perfectly falls into the second category of additives because, it is combustible in nature and when burnt out leaves pores in the body of the finished product just like the other organic materials. The third category of admixture is the consolidating substances or fusing agents. These admixtures are added to increase the bond between the particles and thus the strength of the bricks. Such admixtures are either cementations or pozzolanic materials. Pozzolanic materials include the traditional lime. The recent non-traditional pozzolanic admixtures used for brick production include rice husk ash, sawdust ash, wood ash, fly ash and corn husk ash.

2.3 Types of Fired Brick

Clay brick is most commonly used in today's construction. The main material used in making this type of brick is clayey soil. The use of clay brick in construction is with reference to BS 3921: 1985 (specification for clay bricks). By referring to BS 3921: 1985, the size of clay brick had been set to 215mm x 102.5mm x 65mm while the coordinating size of clay brick had been set to 225mm x 112.5mm x 75mm. Work size means the actual size of the brick that should conform with specified permissible deviation while coordination size means the size of a coordinating space allocated to a brick including allowance for joints and tolerances. Table 2.1 which is extracted from BS 3921: 1985 shows the size of the clay brick. Clay brick can further be classified into three categories as common brick, facing brick and engineering brick.

Table 2.3 Sizes of bricks, BS 3921: 1985

Coordinating size			Work size		
Length (mm)	Width (mm)	Height (mm)	Length (m)	Width (mm)	Height (m)
225	112.5	75	215	102.5	65

Note: the work sizes are derived from the corresponding coordinating sizes by the subtraction of a nominal thickness of 10mm for the mortar joint.

2.3.1 Common Bricks

This category of bricks is not designed to have either aesthetic value or very high compressive strength. These bricks are suitable for general building work which does not involve extreme loading. These bricks are commonly used to construct partitions separating spaces within a building. Plastering is done onto the bricks to cover the unpleasant surfaces and to enforce the partition.

2.3.2 Facing Bricks

This category of bricks is specially made or selected to give an attractive appearance when used without rendering or plaster or other surface treatment of the wall. These bricks are available in a wide range of colours and textures. The various colours to the facing bricks depend on the mineral content of the raw clay used for the bricks production. The surfaces of the bricks have high durability as they can resist the extreme weather conditions. However, facing bricks have lower compressive strength compared to common bricks and engineering bricks.

2.3.3 Engineering bricks

Engineering bricks are densed and strong compared to the previous two categories. Engineering brick is further sub-divided into two classes. Engineering A and Engineering B, based on their compressive strength and water absorption as stated BS 3921: 1985. Table 2.4 shows the classification of bricks by compressive strength an water absorption. These bricks are used in construction of bridges, sewers and retaining walls.

Table 2.4Classification of Bricks by Compressive Strength and Water Absorption, BS 3921: 1985

Class	Compressive strength(N/mm^2)	Water absorption(%)
Engineering A	≥ 70	≤ 4.5
Engineering B	≥ 50	≤ 7.4
Damp – proof course 1	≥ 5	≤ 4.5
Damp – proof course 2	≥ 5	≤ 7.0
All others	≥ 5	No limit

NOTE 1: There is no direct relationship between compressive strength and water absorption as given in this table and durability.

NOTE 2: Damp proof coursed bricks are recommended for use in buildings while damp – proof course 2 bricks are recommended for use in external works. (See Table 13 of BS 5628: 3: 1985)

2.3.4 Sand – Lime Bricks

Sand – lime bricks or blocks also known as calcium silicate bricks are made using mixtures of lime and sand with the proportion of 1: 8 added with water. Pressure and heat are applied for the sand and lime to mix together and react chemically to form the bricks. After that, the bricks are remoulded and cooled. They are then put into the autoclave machine and applied with heat and pressure for further hardening. The compressive strength of the bricks is between 7 $N/mm^2$to 50 N/mm^2 . The colour of the sand – lime bricks are commonly light gray. BS 187 included the details of the minimum specification for the production of the sand – lime bricks.

Table 2.5Classes of Calcium Silicate Bricks

Class	Minimum mean compressive strength (wet) of ten bricks N/mm^2	Minimum predicted lower limit of compressive strength N/mm^2
7	48.5	40.5
6	41.5	34.5
5	34.5	28.0
4	27.5	21.5
3	20.5	15.5

2.4 Engineering Properties of Fired Bricks

The properties of burnt bricks to a larger extent depend on the materials and the methods used to produce the bricks. Applicable properties that are majorly used to distinct the quality of bricks are compressive strength, flexural strength, water absorption, porosity, density and abrasion. However, there are other properties like fire resistance, chemical resistance, thermal resistance, sound absorption and transmission, moisture movement, efflorescence, soluble – salt content, colour, texture and frost resistance.

2.4.1 Compressive Strength

The compressive strength is a mechanical property used in brick specifications, which has assumed great importance for two reasons. Firstly, with a higher compressive strength, other properties like flexure, resistance to abrasion, porosity, density, thermal conductivity, durability, etc, also improve. Secondly, while other properties are relatively difficult to evaluate, the compressive strength is easy to determine (Adeola, 1977). From quality control point of view, the compressive strength of bricks is the accepted measure of the quality of most brick works. Generally, compressive strength decreases with increasing porosity but strength is also influenced by clay composition, methods of manufacturing and firing. The compressive strength of compositions could be determined by dividing the maximum load with the applied load area of the brick specimens. The Compressive Testing Machine (CTM) is a modern developed testing machine which determines the compressive strength of specimens more easily, efficiently and accurately.

2.4.2 Flexural Tensile Strength

Apart from determining the quality of bricks by means of their compressive strength index, flexural strength is yet another important engineering property which can be employed to measure the quality of bricks. Flexural strength depends on the material compositions, dimension and morphology of the flows. The mechanical behaviour of the specimens can be explained taking into account the different microstructures developed during firing (Luz &Ribeiro, 2007). The flexural strength is determined by the three-point bending test of a constant cross-head speed of 0.5mm/min. It has been clearly reported that BS 6073 requires 0.65MPa as a aminimum flexural strength for the building materials to be used in structural applications (Turgut&Vesilata, 2008).

2.4.3 Water Absorption (Porosity)

Water absorption is the property of a material to be saturated with water. It is closely associated with the porosity of the material. Water absorption (WA) may be converted to porosity through n = $\frac{WA.P}{(100.PW)}$where P and PW are the densities of the material and water, respectively. However, not always may all pores of a material be filled with water when its water absorption is being determined. This fact is attributed to the size, volume, configuration and mutual arrangement of pores in the material. The average 24-hour cold water absorption and 5-hour boil absorption of bricks determines the saturation co-efficient. That is, the ratio of the 24-hour cold water absorption to the 5-hour boil absorption.

2.4.4 Durability

The durability of a material is its ability to withstand a particular recurrent weathering effect without failure. It is often measured by the softening co-efficient, Ks, which is the ratio of the wet compressive strength to the dry compressive strength. The durability of a masonry structure under severe weather conditions (wind, rain, heat, etc) is dependent upon the quality of the unit materials.

2.4.5 Abrasion Resistance

The abrasion of a brick is the ease with which it undergoes wearing out when an external force is exerted on its surface. The abrasion resistance therefore is the ability of the masonry unit to withstand or resist wearing out when an external force acts on its surface, the resistance is often measured by the abrasion index. This is obtained by dividing the 24-hour cold water absorption by the dry compressive strength (expressed in psi) and then multiplying by 100.

2.4.6 Density

The density of a material will normally influence other properties such as compressive strength, durability, thermal conductivity, porosity, flexural strength and mineral composition. Basically, the density of a material is its mass per unit volume. Shestoperov (1983) specifies the density of special masonry as ranging between 1200 and 2400Kgm^{-3}.

2.4.7 Fire resistance

Clay bricks are subjected to much higher temperature during firing than they are likely to be exposed to in a building fire. As a result, they possess excellent fire resistance properties (Henry, 1981). BS 1758: 1966 (Specification for fire clay refractory) explained clearly on the clay bricks resistance duration depended on the resistance of the brick against fire.

2.4.8 Chemical resistance

Most of the bricks are with protection layer such as paints or coating if plastering is not desired. This is to increase the durability of the bricks against weather exposure and chemical reaction. Chemical reaction occurred to the brick mostly due to the industrial activities, atmospheric pollution, soil content or surface water. Without coating, clay bricks themselves have high durability against chemical substance especially acid and alkaline. In BS 3679: 1963, bricks durability against acid is categorized into four conditions according to the size, composition and the texture of the bricks.

2.4.9 Thermal Resistance

In tropical zone such as West Africa, the ideal constructional materials are the materials that exhibit the ability to release the heat within the building and to resist heat from outside sources such as the sun. This is due to the factor that the temperature in Ghana is between 30^{0}C to 37^{0}C during day time. Bricks with higher density cannot fulfill that requirement, so with the hollow bricks. However, there is a solution to this problem which is not to fill up the hollow of the bricks during brick laying work.

2.4.10 Sound Absorption and Transmission

Brick may not be ideal for sound insulation as they contain pores that enable sound transmission, unless one of the faces is plastered or painted to cover the pores of the brick. Sound transmission problem can be worsened if the brick is drilled for the purpose of electrical socket installation or outlets for wires or pipes. The bricks production quality is important to produce brick with low sound transmission rate and high sound absorption rate. This also means proper production method is required to produce bricks with higher density and lesser prores. In sound transmission rate problem, clay brick is found to have more ideal absorption rate than other kind of brick. This is due to it high density, 2800kg/m^3 (Jackson, 1983)

2.4.11 Colour

The colour of burnt brick depends on its chemical composition, the heat of the kiln and the method used to control the burning. All clays containing iron will burn red if exposed to an oxidizing fire. If it is burned in a reducing atmosphere, the same clay will take on a purple tint, due to the ferrous silicate content. If the same clay is under burnt, salmon colour is produced. Over burning produces dark red brick. Buff clays produce the buff and brown bricks, depending on the temperature of burning. Colour of the bricks can sometimes be used to identify the quality of the bricks at first sight.

2.4.12 Texture

Texture is produced by the treatment that the bricks are given as it copies the extruding die or mould. A smooth texture is produced by the pressure of the clay against the sides of the steel die. But in the stiff – mud process rough textures may be added to the brick as it leaves the die and these include scored finishes, in which the brick surface is grooved; combed finished, produced by placing parallel scratches on the brick; and rough – textured finishes, produced by wire – cutting or wire – brushing the brick as it emerges from the die.

2.4.13 Frost Resistance

The frost resistance of calcium silicate brick is generally higher than ordinary bricks and should not be used where they may be subject to sale spray.

2.4.14 Efflorescence

Efflorescence is a crystalline (white) deposit left on the surface of clay brickwork after the evaporation of water carrying dissolved soluble salts. Efflorescence is harmless and usually temporary. It can be minimized by protecting the bricks from rain at the early stage of construction. To test for efflorescence, a brick is immersed 25mm deep in water and left in a well – ventilated room at a temperature of 20 – 30^{0}C until all the water evaporates. This process is then repeated. After the second evaporation has taken place, the brick is examined for white patches.

3.0 RESEARCH METHODOLOGY

This chapter discusses the methods employed by the researcher to prepare all the materials (polyethylene, granite powder, clay) used for moulding the specimens, the procedures used in moulding the specimens, the standard guides based on the code of practice used for carrying out all the soil analysis test to determine the index properties of the soil and finally how the moulded specimens were carefully tested with reference to their engineering properties. Basically, this research work aimed at investigating the engineering properties of fired bricks made from polyethylene (pure water sachets), granite powder and clayey soil. In order to achieve the stated objectives and also to arrive at empirical results, some systematic laboratory works were carried out on the materials chosen for the study.

Testing methods and procedures prescribed by the standard guides of the code of practice for a study of this nature were also employed to test the specimens prepared. Some of the engineering properties considered were compressive strength, flexural strength, water absorption, abrasion resistance and dry bulk density. Detailed soil analysis tests such as Atterberg tests (liquid limit, plastic limit and plastic index), shrinkage limit and compaction(protor) were conducted on the soil so to obtain all the relevant index properties of the soil under consideration. Analysis on the soil is very important because it provided background information with respect to all the behavior of the soil used. All the laboratory and other essential works concerning this study were meticulously undertaken in the University of Education, Winneba, Kumasi Campus (UEW-K), Kwame Nkrumah University of Science and Technology (KNUST), Sunyani Polytechnic, Building and Road Research Institute (BRRI) Kumasi, and Vicalex Brick Factory, Efensi, in the Ashanti Region.

3.1 Classification of Soil

A basic element in the classification of soil is the determination of the amount and distribution of the particle size of the soil. The distribution of particle size larger than 0.075mm (No. 200 sieved is determined by sieving while the distribution of particle sizes smaller them 0.075mm is determined by a sedimentation process or the hydrometer.

Table 3.1 Classification of Soil

Soil Type	Particle Size
Coarse gravel	Particle from 60mm to 20mm
Medium gravel	Particle from 20mm to 6mm
Fine gravel	Particle from 6mm to 2mm
Coarse sand	Particle from 2mm to 0.6mm
Medium sand	Particle from 0.6mm to 0.2mm
Fine sand	Particle from 0.2mm to 0.06mm
Silt	Particle from 0.06mm to 0.002
Clay	Particle smaller than 0.002mm
Fine	Particle which passes a 63um sieve

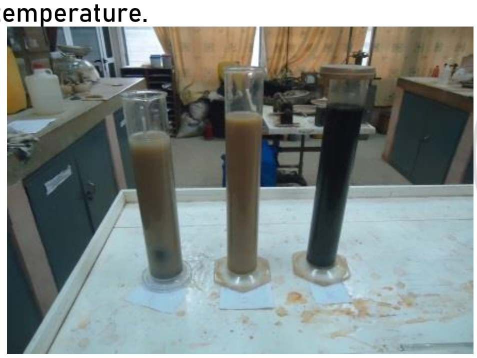
Source: (Head, 1992; Kezdi, 1980 and BS 1377 – 1: 1990 Clause 2.2.22)

Typical soil at a depth of one meter from Vicalex Bride factory located at Efensi in the Ashanti Region was used. The soil was first air dried in the laboratory for a week and was thoroughly visually inspected for the removal of all unwanted materials before characterized. Sieve analysis test was used to determine the proportion of various particle sizes and hence the soil type. The sedimentation method was used as a confirmation test of the soil type. All the laboratory tests on the soil were conducted at the Geological Department of Building and Road Research Institute (BRRI), Fumesua, Kumasi.

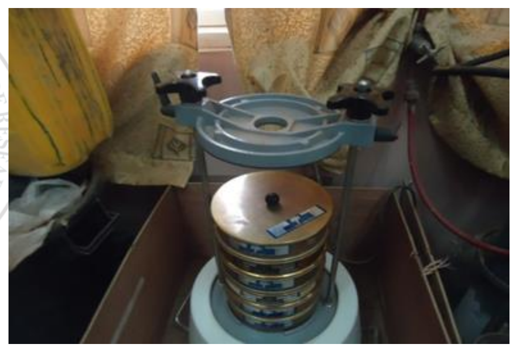
3.1.1 Sedimentation (Hydrometer) Analysis

This method was used to determine the particle distribution for fines (silt and clay size particles finer than the (no.200 sieve). The hydrometer test is based on stroke's law, which relates the diameter of a single sphere to the time required for the spheres to fall a certain distance in a liquid of known viscosity. The idea is that larger and hence heavier soil particles will fall faster through distilled water than smaller, and hence lighter, soil particle.

Apparatus: The apparatus for the test were a hydrometer, two 1 litre graduated glass measuring cylinder, thermometer, stirring rod, mechanical shaker, test sieves with receivers, a balance, drying oven, stopwatch, hydrogen peroxide, sodium hexametaphosphate, sodium carbonate and distilled water. A 50g of the soil sample was weighed and prepared with a dispersing agent (sodium hexameta- phosphate) the dispensing agent prevent the clay size particle from forming floes during the hydrometer test. The soil specimen, dispensing agent and distilled water were thoroughly mixed using electric stirrer and then transferred to a 1000ml glass cylinder for 24 hours. Hydrometer readings versus time (0.5, 1, 2, 4, 8, 15, 30, 60, 120, 240 and 1440) min. from the beginning of sedimentation were then recorded including temperature.



Samples in 1000ml cylinder for hydrometer analysis



Mechanical sieve analysis

Figure 3.1 Sedimentation and Dry Mechanical Sieving of Soil and Granite Powder.

The portion of the soil sample soaked for 24 hours was washed, oven dried and then sieve analysis test performed using a stacked standard sieved with a receiver. The result from the sieve analysis and the hydrometer tests were plotted on a graph so as to develop the grain size curve for the soil classification and the determination of the particle size of the soil in the next chapter. Refer to appendix A2 for more comprehensive experimental works on hydrometer and sieve analysis on the soil and granite powder.

3.2 Organic content (Loss on Ignition) – LoI (BS: 1377 Part 3: 1990).

The organic content of the soil greatly influences the strength characteristics of bricks. The amount of organic material can be determined by ignition. Organic materials are carbon based. In the ignition process, a dry soil sample was heated to a high temperature (of about 120C°) until the organic materials in the soil sample had been given off as gases. This resulted in a weight change which allowed for calculation of the organic content of the sample. For this study, a sample of the soil was oven - dried to remove any existing moisture content. An evaporating dish and cover was weighed. A sample of the oven dried soil of approximately 10 grammes was placed in the container and covered. Prior to this, mass of container and lid was weighed (m_1), mass of containers plus lid plus sample of soil (m_2) was determined.

The container with the sample was heated on a gas stove which resulted in fume generation. The heating continued until there was no visible fume. The container with lid and soil sample was weighed again and the percentage of organic content was thus calculated as follow;

Mass of container + lid (m_1)
Mass of container + lid + soil sample (m_2)
Mass of soil sample before ignition $m_3 = m_2 - m_1$
Mass of container + soil sample after ignition (m_4)
Mass of organic materials $m_5 = m_4 - m_1$
Therefore percentage of organic content = $\frac{m_5}{m_3} x\ 100$

3.3.1 Determination of Liquid Limit (LL)

The liquid limit is the moisture content at which a soil changes from the liquid state to the plastic state. Also, the liquid limited is arbitrarily defined as the water content at which part of the soil, cut by a grove of standard dimension, will flow together for distance of 12.7mm under the impact of 25 blows in a standard liquid limit device. The determination of the liquid limit of soil was used as a means of classifying the soil. The Casagrande method was used. Even though the cone penetrometer method is preferred to this one, it has been reported that it could be used to give satisfactory results if the Casagrande apparatus is correctly maintained and the test procedure is strictly adhered to.

The test was carried out on the soil according to procedures in BS 1377:2:1990 section 4.5. Approximately 300g of soil in the natural state was taken from soil sample that had passed through 425µm test sieve. The soil was placed on a flat glass plate and was mixed thoroughly at least for 10 minutes with distilled water using two spatulas until the sample became a thick and homogeneous paste. A portion of the soil paste about 10 grammes was forced into a cup with a spatula making sure air was not trapped. The soil paste in the cup was leveled off parallel to the base. A grooving tool was used to divide the soil into two equal parts by drawing the tool from the hinge towards the front in continuous circular movement. The grooving tool was held normal to the surface of the cup with the chamfered edge facing that direction of the movement.

Preparing samples for all Atterberg tests

Oven- dried samples for all Atterberg tests

Figure 3.1 Determination of Liquid and Plastic Limits of the Soil.

The switch was turned on so that the cup was lifted and dropped, counting the number of bumps until the two parts of the soil came into contact at the bottom of the groove along a distance of approximately 13mm. The number of bumps was noted and recorded when the soil closed. In the course of the test, care was taken to make sure the soil did not dry out between repeated tests by covering it. Upon completing a run for the test, a bulk of the soil from the cup was removed with the spatula and placed in a suitable container and its moisture content determined as specified in BS 1377:2:1990, section3.2.

3.3.2 Determination of plastic limit and plastic index (PL, PI)

The plastic limit is the empirically established moisture content at which a soil becomes too dry to be plastic. In other words, it is the water content at which a soil or clay just begin to crumble when rolled into thread approximately 3mm in diameter. It is used together with the liquid limit to determine the plastic index which when plotted against the liquid limit, the plastic chart provides a means of classifying cohesive soil. The test was conducted according to BS 1377: 2: 1990 clause 4.2. A sample of 300 grammes of the soil was passed through 425um of the test sieve. A sample of about 20gram from the soil paste was taken from the sieved one and prepared on the glass mixing plate. The soil was allowed to dry partially on the plate until it became plastic enough to be shaped into a ball. The ball of the soil was moulded between the fingers and rolled between the palms of the hands until the heat of the hands dried 'the soil sufficiently for slight cracks to appear on the surface. The sample was divided into two subsamples of about 10g.

The soil was moulded in the fingers to equalize the distribution of moisture and then the soil was formed into a thread of about 6mm in diameter between the first finger and the thumb of each hand. The threads were rolled between the fingers from finger - tip to the second joint of one hand and the surface of the glass rolling plate. Enough pressure was used to reduce the diameter of the thread to about 3mm in five to ten complete forward and back, movement of the hand. Uniform rolling pressure was maintained till the thread got to 3mm in diameter. It was realized that gradual drying of the soil was affected by alternately rolling and moulding, not by continued rolling, either as bill or as thread which only produced a dried crust. Moulding and rolling of the soil was repeatedly done until the threads sheared both longitudinally and transversely, when it was rolled to about 3 diameters. The sheared sample was put into containers and its moisture content determined as specified in B5 1377:21990 Clause 3.2. The average of the two moisture content values became the plastic limit of the soil.

3.3.3 Linear Shrinkage

Shrinkage due to drying is significant in clays but less in silt and sand. This test enables the shrinkage limit, of clay to be determined. Thus, the moisture content below which clay ceases to shrink. The determination of linear shrinkage was carried out on 300gram of soil that passed through the 435µm test sieve in accordance with BS 1377: 2: 1990 clause 6.5. The soil was mixed thoroughly with distilled water using spatula on flat glass plate till the mass became a smooth homogenous paste with moisture content about the liquid limit (LL) of the soil. Thus, about 25 bumps of the Casagrande apparatus. Two brass mould were carefully, smeared with silicon grease and soil paste was added gently to each, ensuring that there weere no air bubbles present. This was achieved by gently hitting the loaded brass mounld on a hard surface.

The surfaces were smoothened using a straight edge. The mould were then placed on a table where the wet soil could air dry slowly until it had shrunk away from the walls of the mould. The drying was completed by placing the sample in an oven, initially, at 60°c to prevent rapid evaporation of the water from the body of the sample which could cause the sample to develop cracks until shrinkage had largely ceased. The sample in the mould was then put in an oven at a temperature of 105°c for 24 hours to finally complete the drying. The mould with soil bar was allowed to cool and the measurement of the mean length of the soil bar was taken. Refer to appendix A3 for the full experimental procedures on the linear shrinkage. The linear shrinkage of the soil was then calculated as a percentage of the original length of the specimen, 10mm from the equation.

Percentage of linear shrinkage = $(1-\frac{L_D}{L_0})$ 100

Where;

L_D is the length of the oven -dried specimen (in mm)

Lo is the initial length of the specimen (in mm)

3.4 Compaction Test

The rationale behind this test was to obtain the empirical relationship between compacted dry density and soil moisture content. Compaction of soil is the process by which the soil particles are packed more closely together, usually by mechanical means, thereby increasing the dry density of the soil. This test covered the determination of dry density of soil passing through 20mm test sieve when compacted over a range of moisture contents. The range includes the optimum moisture content at which the maximum dry density for this degree of compaction is obtained. In this test, a 2.5 kg rammer falling through a height of 300mm was used to compact the soil in three layers into one litre compaction mould in accordance with BS 1377:4: 1990 clause 3.3.1.

a. Main Apparatus: The apparatus for the compaction test consists of a small cylindrical mould made up of corrosion-resistant metal with internal volume of one litre. The mould was fitted with detachable base plate and a removal extension. A metal rammer of approximately 50mm diameter and weight of 2.5kg, balance, spatula, test sieve, a corrosion resistant metal tray.

b. Procedures: The mould was weighed with the base plate attached (m1). The extension was attached to the mould and assembled on the concrete floor. The solid leveled concrete floor provided a good stabilised surface for the base of the mould for easy and efficient compaction to be done on the soil. A quantity of the moist soil was placed in the mould such that when compacted it occupied a little over one- third of the height of the mould body.

In accordance with BS 1377:4:1990 section 3.3.4.1.4, 27 blows were applied manually with the 2.5kg rammer that was dropped from height of 300mm above the soil as controlled by the guide tube. The blows were uniformly distributed over the surface and it was ensured that the rammer always fell freely and not obstructed by soil in the guide tube. The process of filling and ramming the mould was repeated to bring about a total of three layers so that the amount of soil used was sufficient to fill the mould body, with the surface not more than 6mm above the upper edge of the mould body. The total volume of the soil compacted was as a matter of fact controlled, since experience had shown that if the amount of soil struck off after removing the extension was too great, the accuracy of the final result was not guaranteed.

Compacting soil with rammer

Striking off excess soil

leveled soil according to mould

Figure 3.3 Determination of the Optimum Moisture Content of the Soil through Compaction.

The extension of the mould was carefully removed and the excess compacted soil struck off with a palette knife and leveled off the surface of the compacted soil carefully to the top of the mould using a straight edge. In the process of leveling the compacted soil, any soil particle removed was replaced from the prepared sample and well pressed in. The compacted soil, the mould with the base plate was weighed (m_2). The compacted soil was removed from the mould and placed on a metal tray. A representative sample of the soil was taken for moisture content determination as specified in BS 1377: 2: 1990 section 3.2. The remainder of the soil was broken up, rubbed through the 20mm test sieve and mixed with the remainder of the prepared test sample. Systematic percentage increment of water by weight of the soil was added and mixed thoroughly for each stage of the test such that a range of moisture content were obtained which included the optimum moisture content. Since the soil sample was a cohesive type, a range of 2% to 4% was specified by BS 1377: 4 : 1990. In order to increase the accuracy of the test, the increment of the water was reduced within the region of the optimum moisture content. The process of filling the mould and compacting it with the 27 blows from the rammer by manual means was repeated using the specified percentage range of water until a total of five determinations were arrived at the moisture content was such that the optimum moisture content at which the maximum dry density occured was near the middle of the range.

3.5 Materials for Specimen Moulding

3.5.1 Soil

The original raw material solely used in the manufacture of fired bricks is clayey soil. However, in this particular study, two other new materials namely granite and polyethylene (PWS) powered forms were incorporated into the clayey soil for investigation. The presence and addition of the clayey soil to the GP and PEP provided for fusing during firing (Okunade, 2008). Basically, the clayey soil as a major material component is serving as the binding material, binding the granite power (GP) and the polyethylene (PWS). The clayey soil was dug and collected from vicalex Brick factory at Efensi located along Kumasi - Sunyani high way in the Ashanti Region at a depth of about 1m below the ground level. It was mechanically dug by tractor shovel. The colour of this clay is dark yellow.

3.5.2 Granite

The granite powder was collected by means of shovel from a quarry site at Ntesere located along Kumasi-Sunyani high way in the Ashanti Region. This material is a by-product (waste materials) being produced in the quarry during their normal quarry operations. It should be noted that the granite powder (GP) used for this particular study should not be mistaken for quarry dust. It is completely different from the normal "quarry dust" used for concrete and pavement blocks production. The major difference between these two materials is by virtue of their characteristics grain sizes. The granite powder is extremely finer than the quarry dust. The granite powder could be classified as fine sand. While 98.6% of the granite powder particle sizes passed through 0.2mm standard sieve, only 50.4% of the quarry dust particles sizes passed through it.

In other words, the GP comes out during the operation in the form of air floated dust, which finally settles on the ground, on the machines and on the vegetation around the site. Since no economic value has been attached to it from the time of the commencement of the quarry activities, it is so much abundant on the site. The choice of the granite powder for partial replacement of the soil is basically to enhance the engineering properties of the bricks. The granite powder naturally is tough and possess high compressive strength, high flexure strength, high resistance to crushing and abrasion. It therefore suggests that incorporating it into the soil body for bricks production will obviously increase the mechanical properties of the finished products.

3.5.3 Polyethylene

The polyethylene (pure water sachet, PWS) was collected from the University of Education, Kumasi Campus from the students' halls, hostels and restaurants. Empty sacks were distributed to some of the pure water sellers on the campus and outside to pack the discarded ones. The collection of the pure water sachets did not pose any problem at all, since a great quantity is being discarded off every day. It was a great relief to the sellers during the periods of collection. The polyethylene (pure water sachet) was chosen primarily to serve as a pore – forming material in the body of the brick. It is combustible so when subjected to intensive firing temperature, the PWS burns out leaving pores or voids inside the brick. The PWS was thoroughly processed from its original raw form into powdered form before it was added to the clayey soil for the specimen bricks production. Subsequent pages discussed in detail the systematic procedures followed in processing the PWS.

3.6 Materials Preparation and Processing

3.6.1 Soil

There was a heavy down pour of rain some few days before the clay was dug from the site so it made the material very wet. According to Ashby and Jones (1986) clays have plate-like molecules with charges on their surface and therefore little exposure of the clayey soil to moisture makes the charges draw water into the clay rendering it plastic. It was really difficult to work on this wet clayey soil so it was air-dried for some days in the factory under open shed to get some of the water evaporated. During these drying periods, the clayey soil was manually turned over and over with shovel for the purpose of exposing the total surface of the soil to natural air for faster evaporation to take place. When the clayey soil was partially dried, it was visually inspected thoroughly for any unwanted materials like leaves, roots of trees, rubber and sticks to be excluded before the milling was done. The clay was milled with the milling machine, thereby reducing the size of the clay in bigger lump form into smaller manageable particle sizes for easy mixing with the other two materials.

3.6.2 Granite Powder

The granite power was partially wet when it was collected from the quarry site. It was therefore speeded in the laboratory for seven days so as to reduce its moisture content for easy sieving. Only natural air was used for the drying purpose. Thorough visual inspection was done for the removal of any unwanted materials that would otherwise affect the authenticity of the results. The granite powder was finally sieved through standard sieve opening of 0.2m.

3.6.3 Polyethylene (Pure Water Sachet, PWS)

After collecting the pure water sachets, they were shredded (cut into smaller manageable sizes) by a pair of scissors and then thoroughly washed with clean warm water two times for the removal of all dirt in the form of dust, mud, grease that might have got attached to the PWS. Soapy water was not used during the washing, because it could affect the outcome of the results if not well rinsed. Refer to appendix A4 for the step by step procedures in processing the pure water sachets. The washed shredded PWS were dried under the sun for all surplus water to dry up and were heated in a metal pot intensively by means of a gas stove to a temperature far above 120°C for the PWS to completely melt. The PWS was considered suitably melted, when it became as light as water. It was seriously observed that when the PWS was not heated sufficiently for it to melt completely, processing it further into the needed powdered form proved highly impossible. In other words, incomplete melted PWS produced a "chewing gum-like" substance upon solidifying. This implies that the heating and the melting was incomplete and therefore all the molecular bonds holding the molecules one to another were partially still existing. A very simple test through experience employed by the researcher to determine whether the PWS had suitably melted was a kind of sound it produced which resembles the sound produced by a dried piece of stick when broken by the hand.

In the course of heating, the pot with the PWS was properly covered due to the heavy smoke it was producing. The melted PWS was carefully poured into prepared moulds which solidified within a few minutes after being exposed to the atmospheric air. Better results in terms of solidifying and easy removal from the mould were achieved when water was used for the cooling process instead of atmospheric air. After removing the solidified PWS from the mould, they were reduced by pounding them in deep mortar into smaller manageable particles for drying under a shed for natural fresh air to blow over them for at least 30 days. During this period of drying, it was turned manually with the hands over and over for three times within 24 hours. After 30 days of drying, the reduced solidified PWS granules were milled into powder and then sieved through a standard sieve aperture of 0.2mm. When sieving the milled PWS powder, some appreciable quantity with particle sizes bigger than the aperture of the sieve were retained on the sieve while those smaller easily went through. The bigger particles retained on the sieve were either milled and sieved again if the quantity was great or carefully pounded in a deep mortar using pestle if the quantity was relatively smaller. The sieved pure water sachet powder (PWSP) was carefully bagged in an air and water tight polythene for preservation.

3.7 Preparation of Specimens

Three major materials namely clayey soil, granite powder and powdered pure water sachet in varying percentages were used for the preparation of the specimens. In all, six different batches in terms of material percentages were prepared for the study. For easy identification, they were labeled alphabetically as follows: A, B, C, D, E and F. The letter A, represented the control specimen with 100% composition of only clayey soil, no granite powder and no PWS. Specimen B composed of 90% of clayey soil, no granite powder and 10% of PWS. C composed of 90% of clayey soil, 2.5% of granite powder and 7.5% of PWS. D composed of 90% of clayey soil, 5% of granite powder and 5% of polyethylene. E-composed of 90% of clayey soil, 7.5% of granite powder and 2.5% of PWS. The last composition was F with 90% of clayey soil, 10% of granite powder and no PWS (See Table 3.2). The selection of precentages for the specimen's preparation is based on literature.

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3.7.1 Batching and Mixing of Materials.

The three materials used for the study were all batched by weight using a sensitive scale at the laboratory of Building and Road Research Institute (BRRI), Kumasi. Batching by weight according to Seeley (1995) gives more accurate results compared to batching by volume. Veiseh and Yousefi (2003) who conducted similar study by incorporating polystyrene into clay also batched by weight. The batching of granite powder and polyethylene powder were done per percentage weight of the clayey soil. Granite powder and polyethylene powder were used to partially replace 10% weight of the clayey soil in varying proportions, while the clayey soil, the main traditional material for manufacturing bricks which is serving as the binder of the other two materials was kept constant at 90% as shown in Table 3.2. .

Table 3.2 Batching of Materials for Specimen Moulding

Specimen	Clayey Soil (%)	Granite powder (%)	Polyethylene powder (%)	Total
A	100	0.0	0.0	100
B	90	0.0	10.0	100
C	90	2.5	7.5	100
D	90	5.0	5.0	100
E	90	7.5	2.5	100
F	90	10.0	0.0	100

Nine standard perforated burnt bricks of dimensions (225 x 110x 65) were sampled from Vicalex brick factory at Efensi and grouped into three groups of three. Each group was ground into powder and averaged for the actual quantity by mass of clayey soil used in moulding one brick. It was found out that an average of 2.7 kg (2700g) of clayey soil was used to mould one perforated brick. Based on this result the estimated quantity of clayey soil by mass used for one solid brick was 3.0kg (3000g). So in effect, all calculations regarding the batching of the three materials used for the study were based on the 3.0kg (3000g) as illustrated below.
If 100% = 3000g = 1 solid brick
Then 90% = 90/100 x 3000= 2700g (2.7kg), (mass of clayey soil equivalent to 90%)

So the rest of the 10% of clayey soil replaced by varying percentage proportions were just calculated through the same arithmetic procedures. Thus;
If 100% = 3000g
Then, 10% = 10/l00x 3000= 300g (0.3kg) (mass of clayey soil equivalent to 10%)
100% =3000g

Then, 2.5% = 2.5/1 00 x3000 =75g (0.75kg) (mass of clayey soil equivalent to 2.5%)
And, 7.5% = 7.5/100 x 3000 = 225g (0.225kg) (mass of clayey soil equivalent to 7.5%)
5% =5/1 00 x3000 =150g (0.15kg) (mass of clayey soil equivalent to 5%)

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Table 3.3 Batched materials by weight of clayey soil.

Specimen	Clayey Soil (g)	Granite powder (g)	Polyethylene powder (g) (PWS)	Total (g)
A	3000 x 30 = 90000	0.00	0.00	90000
B	2700 x 30 = 81000	0.00	300 x 30 = 9000	90000
C	2700 x 30 = 81000	75 x 30 = 2250	225 x 30 = 6750	90000
D	2700 x 30 = 81000	150 x 30 = 4500	150 x 30 = 4500	90000
E	2700 x 30 = 81000	225 x 30 =6750	75 x 30 = 2250	90000
F	2700 x 30 = 81000	300 x 30 = 9000	0.00	90000

Each determined weight for moulding a brick was therefore multiplied by 30 so as to get the total estimated quantity by weight of each material needed to mould the total bricks required for A, B, C, D, E and F groups respectively.

The number 30 was simply arrived at by multiplying the number of bricks needed for each batch (A B C D E F) by the total batches under consideration shown in Table 3.3. In this study, an average of five bricks were needed for every composition and there were six batches, therefore, (5 x 6) = 30. This implies that an average of 30 bricks (5 from each of the 6 batches were assigned to testing an engineering property of the brick. For instance, to test the compressive strength alone, we need a total of 30 bricks to be able to successfully carry out the test for all the six (A, B, C, D, E and F) batches. The choice of replacing only 10% of clayey soil by the other two materials in varying proportions was informed by literature. Veiseh and Yousefi (2003) in their work on incorporating polystyrene foam into clayey soil to produce fired bricks used 0.5%, 1%, 1.5% and 2% by mass of the added polystyrene form. The current study used polyethylene waste which belongs to the same family as the polystyrene but with different monomers (styrene) and (ethylene).

Many other researchers who incorporated combustible waste materials into clayey soil to mould fired bricks restricted their mix proportions of the combustible waste to a range of (1 to 15%) to the clayey soil which always takes the greater percentage. Demir et al. (2005) used Kraft pulp production residues in the range of (0%,2.5%,5% and 10%), Demir (2006) used processed waste tea (PWT)in the range of (0%, 2.5% and 5%), Okunade (2008) used sawdust in the range of (0%, 2.5%, 5%, 7.5%, 10%), Abali et al. (2007) used phosphogypsume of (1 %, 3%, 5% and 20%) and Abdul and Mohajeram"(2011) used cigarette butts in the range of (0%, 2.5%, 5% and 10%). According to the findings of these earlier researchers, any combustible waste materials incorporated into the clay burn out when subjected to intensive firing and thereby leave pores in the product. This helps in producing lighter and more porous bricks and therefore implies that the greater the percentage of combustible waste in the clay body the more porous the finished product. Since there is a relationship between compressive strength, flexural strength and porosity, there is therefore justification for reasonably regulating the proportion of combustible waste into clay for fired bricks production, so that the engineering properties of the bricks are not compromised.

The materials (clay soil, granite powder and polyethylene powder) were thoroughly mixed dried and uniform colour obtained before adding 12.5% water by weight of soil. The mixing was carefully done manually on an impermeable thick polyethylene rubber spread on a working bench. Each batch was mixed at a time starting with the control A then, B, C, D, E and F. Each batch was mixed and kneaded to the right consistency and workability and then tied in an air and water tight polythene rubber for the preservation of the attained plasticity. The kneaded mixture for all the batches were left in the brick factory for three days for the particles to get soaked, softened and well integrated into each other for satisfactory plasticity.

3.7.2 Moulding of Specimen

The specimens were moulded using the Pyrex press machine dimensioned 225 x 115 x 65. The various batches (A, B, C, D, E, F) were again kneaded after keeping them for 3 days thoroughly by hand to finally ensure absolute uniform mixture of all the materials used. The kneaded mixtures were moulded by hand into sizeable cylindrical shape to fill the whole volume of the mould once it was forced into it. In order to produce well compacted bricks, the kneaded clay was hand lifted above the head and forcefully released with a considerable speed to slap the mould.

Figure 3.4 Pyrex Press Brick Moulding Machine

A heavy metal cover of the mould was used to give more compaction by lifting it and slapping hard on the surface of the mixture ten times. All the excess clay was carefully trimmed off with a well-designed wire cut. The green brick was forcefully ejected from the mould by means of a foot paddle connected to a based plate just under the mould box. Two wooden small board measuring 230 x 100 mm were used to lift off the green brick gently from the mould into a smooth wooden palate for drying. Before moulding the brick, a small quantity of sand sieved through 0.2mm aperture was sprinkled evenly into the mould box for easy removal of the green bricks.

In all, 150 bricks were moulded for the study. After moulding, the green bricks were air- dried for fourteen days under a shade in the factory. During those days, they were turned intermittently on their edges. After fourteen days of air drying which made a significant amount of water to evaporate from the green bricks, they were further sun dried in the open for seven days. According to Okunade (2008) this is to permit development in the brick body some appreciable strength before the firing is done and to avoid the development of cracks which might result from a fast and high rate of dehydration. He noted that the drying should be relatively slow. That is, the rate at which moisture evaporates from the surface should not be faster than the rate at which it diffuses through the fine pores of the green brick. Green bricks, not sufficiently dried, are likely to be crushed in the kiln under the weight of those piled on top. They may also shrink and crack under firing.

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Procedures for Manufacturing Fired Bricks

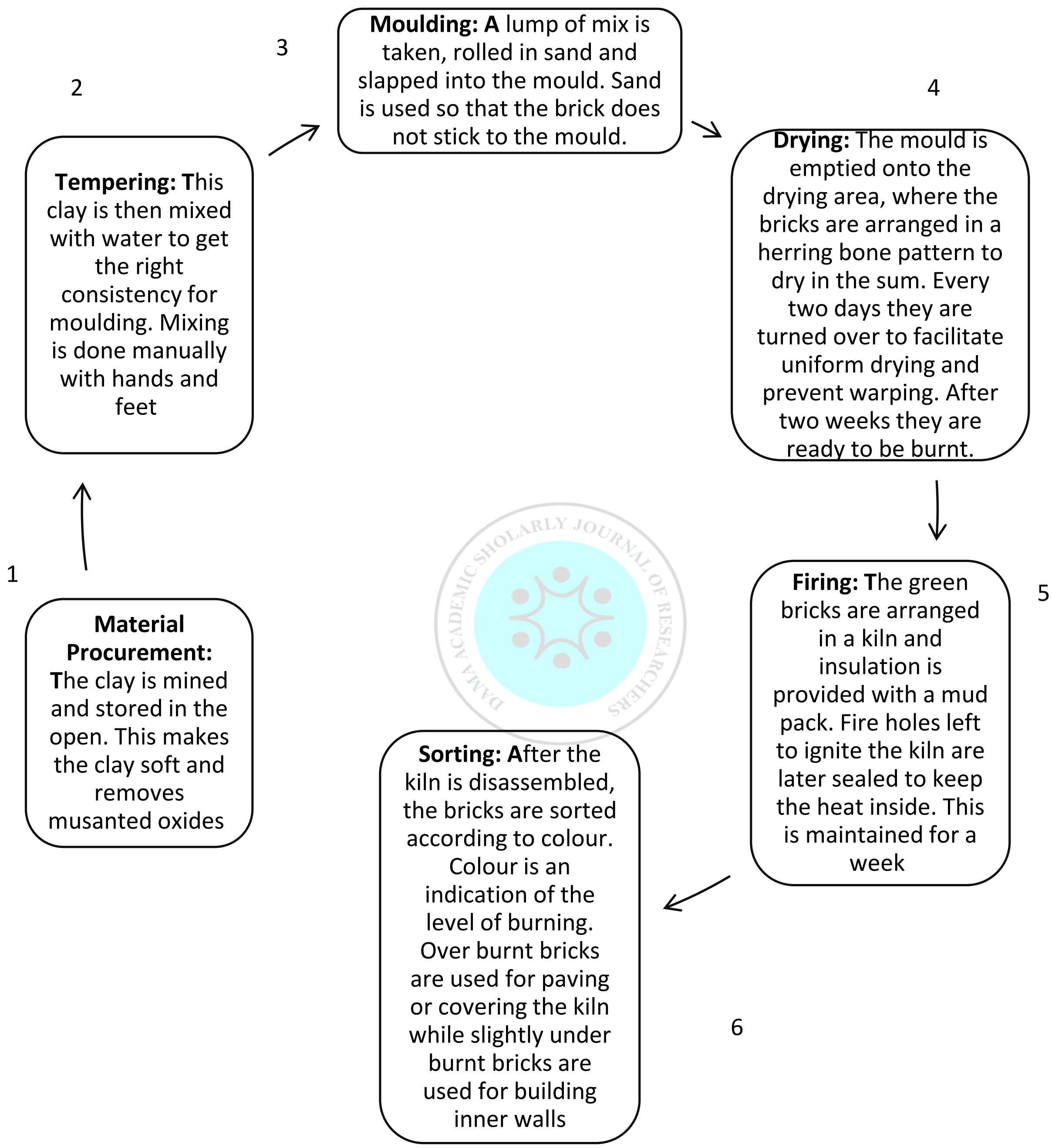

Figure 3.5 Procedures for Manufacturing Fired Bricks.

3.7.3 Firing of Specimens

All the bricks were fired in an electric kiln at the Ceramic Department in KNUST, Kumasi. After the bricks had adequately dried and gained appreciable strength to be handled, they were carefully inspected one after the other to check for any possible cracks and any other defects that might have occurred during the drying periods. The bricks were orderly arranged edge-on- edge in the kiln in honey comb manner to allow free circulation of heat to every brick. According to Clews (1969) as cited in Okunade (2008) the green bricks even after preliminary drying contain as much as 10% by weight of water which is lost rapidly as the kiln temperature rises above 100°C. He further noted that the application of heat from the beginning of the firing must be gradual to avoid formation of cracks.

Dried bricks arranged in electric oven

Fired bricks arranged according to batches

Figure 3.6 Arrangement of Dried Bricks in Electric Oven and the final Fired Bricks.

The firing of the bricks was done at a temperature of 1100°C. It started gradually from the beginning before finally attaining this desired temperature of 1100^0C the second day of continuous firing and was maintained the third day. In effect, the whole firing was successfully carried out for three continuous days. The bricks were left to cool down for another 24 hours before removing them from the kiln. Since the firing was done using an eclectic kiln, temperature regulation was strictly programmed by means of a temperature monitoring device attached to the kiln which made it possible for the desired result to be achieved.

3.8 Testing the Moulded Specimens

All the specimens moulded at the brick factory of the Building and Road Research Institute (BRRI) in Kumasi were sent to the Sunyani Polytechnic for testing. In all, 150 specimens were tested. The tests were carried out so as to determine the engineering properties of the bricks. The engineering properties of interest for this study were compressive strength, flexural strength, water absorption, abrasion resistance and dry bulk density.

3.8.1 Compressive Strength

The compressive strength of the bricks was done according to BS 3921:1985. The required apparatus was compression machine. The test started by preparing the test specimens which were chosen from the stack of bricks. The overall dimensions of each brick were measured and the area of the bed face of the specimen was calculated. For the compression machine, the bearing surface of all the platens were wiped clean. Any loose grit or other materials were removed from the surface of the specimens which were to be in contact with the platens. To ensure a uniform bearing for the brick specimen, the specimen was placed between 3mm thick plywood sheet to take up irregularities, then, load was applied onto the specimen without shock until failure.

Failure occurred at a point where there was a fall on the graph monitoring the test and immediately the compression machine was stopped for the result to be recorded. At this point the specimen experience explosive collapse. The maximum load (N/mm^2) carried by the specimen during the test was recorded. To obtain the strength of each specimen, the maximum load obtained from the compression strength test was divided by the area of the bed face determined earlier. The strength was recorded in N/mm^2 to the nearest $0.1N/mm^2$. Finally, the compressive strength was calculated by taking the mean of the strength of the five (5) specimens. Figure 3.7 shows the machine used for the compression.

$$\text{Compressive strength (N/mm}^2\text{)} = \frac{\text{Applied load (N)}}{\text{Area of bed face (mm}^2\text{)}}$$

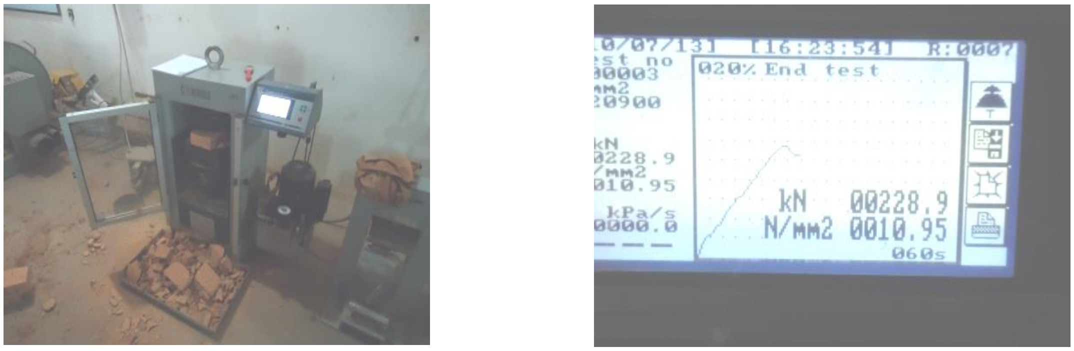

Figure 3.7 Testing Compressive Strength of Bricks and automatic gragh plotted during the test

3.8.3 Water Absorption

The purpose of this test was to determine the percentage of water absorption of the bricks. Apparatus for the test were water bath, electric oven and a sensitive balance. The test was carried out based on BS 3921:1985 guidelines. The specimens were taken from the brick stack and carefully inspected so as to guarantee their suitability for this test. They were all weighed and recorded as (m_1) after they were oven dried at a temperature of 105°C till they attain substantially constant mass. They were then cooled to room temperature. The oven dried specimens were then completely immersed in a big water trough for 24 hours as shown in Figure 3.8. The specimens were all removed after 24 hours and thoroughly wiped cleaned out of any traces of water with a neat damp cloth. They were immediately reweighed and the new weight recorded as (m_2).

Figure 3.8 Bricks Completely Immersed in water trough for 24 hours for Water Absorption

Water absorption, percentage by mass, after 24 hours emersion in cold water is given by the formula.

$$W = \frac{m_2 - m_1}{m_1} \times 100$$

Where;

W = water absorption

M_1 = weight of the specimen when completely oven dried at 105°c for 24 hours

M_2 = weight of the specimen when completely immersed in cold water for 24 hours.

So, the average of the above computation on the specimens was finally recorded for the respective compositions.

3.8.4 Abrasion Resistance

Basically, this test aimed at finding out the effect weathering will have on the bricks. Wind, rain storm and other factors generally have wearing effect on walls. Apparatus for the test were metal wire brush, straight edge, soft sweeping brush, weighing machine. In this test, the bricks were subjected to mechanical erosion applied by brushing with a metal wire brush at a constant pressure over a number of cycles on the face of the bricks, which would serve as the facing when walling. The bricks were picked from the stack of bricks of each composition and visually inspected for defects such as cracks and irregular edges.

Five bricks from each batch were weighed (m_1) and each was placed on a table and the surface of the brick was carefully brushed in turn with wire brush at one forward and backward motion per about a second for 60 cycles. Care was taken so that the brushed width of the brick did not exceed the width of the brush by more than 2mm and the brushing took place along the whole length of the brick. When brushing was completed all loose matter was then thoroughly removed from the bricks by using soft sweeping brush and weighed after the test as (m_2). The mass of the eroded matter (m_1- m_2) was calculated using the formula;

Abrasion coefficient: Ca = $\left(\frac{A}{M1-M2}\right)$cm^2/g

Where;
A= area of brushed surface
M_1 = mass of brick before brushing
M_2 = mass of brick after brushing.

3.8.5 Flexure Tensile Strength of Bricks.

The flexure tensile strength was measured with a Universal Testing Machine in a three – point bending test of a constant cross – head speed of 0.5 mm/min. The primary aim of this test was to determine the bricks ability to resist deformation under load. Apparatus for the test were Universal testing machine, weighing machine, straight edge and three 12 mm diameter iron rods, measuring 150 mm in length. A center line was marked at the top of the specimen, using marker. This line was perpendicular to its length. Specimens for the tests were all weighed and recorded by means of a sensitive electric weighing machine. The specimens were then tested under the center line load while simply supported over supporting span of 150mm as shown in figure 3.6.

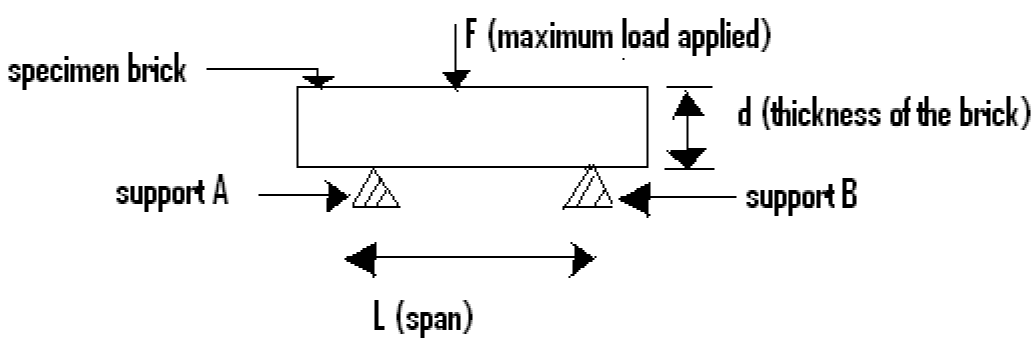

Figure 3.9 Bricks under three – point Bending test

The test was considered completed when the graph which was simultaneously being plotted by the universal testing machine during the test indicated a fall. The machine was immediately switched off and the maximum load applied, F (KN) recorded. Since the specimens are rectangular and under a load in a three – point bending setup, the flexure strength was then calculated from the formula below;

Flexural strength, $f_t = \frac{3FL}{2bd^2}$

Where,
F = the maximum load (force) at the fracture point (N)
L = the length of the support span (mm)
b = the width of the specimen brick (mm)
d = the thickness of the specimen brick (mm)

Figure 3.10 Testing the Flexural Strength of Bricks by means of three – point Bending Moment.

4.0 DATA ANALYSIS

4.1 Result of the Moulded Bricks Tested

4.1.1 Dry Compressive Strength of Bricks

This is a very important mechanical property used in brick specifications. In all, 30 specimens (5 from each of the 6 batches) were selected and compression test performed on them. The average results of the test are summarized in Table 4.13 and graphically represented in Figure 4.6. Refer to table B6 in the appendix for the detailed result.

Table 4.13 Dry and Wet Compressive Strength of Bricks

Specimen	Dry Mean Compressive Strength (N/mm^2)	Wet Mean Compressive Strength (N/mm^2)
A100 (control)	10.63	9.51
B 90/0/10	5.24	4.82
B 90/5/5	5.95	5.35
B 90/7.5/2.5	7.34	6.26
B 90/2.5/7.5	8.03	7.71
B 90/10/0	13.23	12.21

Note: B i/j / k represents the specimens with the various materials percentages. Thus,
i = Percentage of soil in the specimen moulded. The soil is 90% and it is constant in all the specimens.
j = Percentage of granite powder in the specimen moulded.

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k = Percentage of polyethylene powder in the specimen moulded.

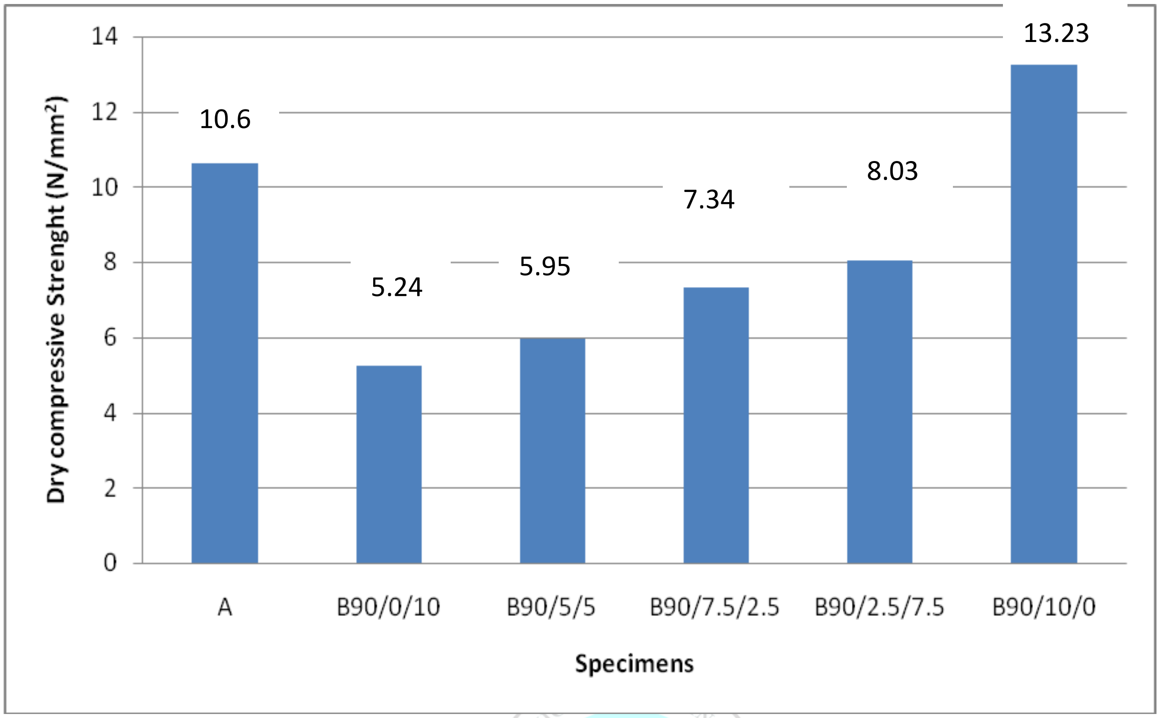

Figure 4.6 Dry Compressive strength of bricks

According to the result shown in Table 4.13 and Figure 4.6, it could be observed that specimen B90/10/0 which has 10% of granite power as a replacement of the soil recorded the highest compressive strength of 13.23 N/mm^2 against the control specimen A, 10.63N/mm. The strength is 2.4% higher than the control specimen. Specimen B90/0/10 which contains 10% of polythene powder recorded the lowest compressive strength of 5.24 N/mm^2 This implies that there is a reduction in the strength of the control specimen A, by 50.7% as a result of 10% replacement of the clayey soil by the polyethylene powder. The brick B90/2.5/7.5 with 2.5% of granite powder and 7.5% of polyethylene was higher than the brick, B90/5/5, with 5% granite powder and 5% polythene powder by 25.9% but lower than the control specimen A, by 24.4%. In conclusion, it could be seen from the Table 4.13 that when the content of the granite powder increased, there was a corresponding increase in the compressive strength. On the contrary, an increase in the content of the polythene powder resulted in a decrease in the compressive strength of the bricks as well.

4.1.2 Wet compressive strength of the Bricks

The main purpose of this test was to find the strength of the bricks they absorb water and also to improve on the strength of the wet bricks if they are found to be structurally unsatisfactory. The experimental results of the test are shown in Table 4.13 and Figure 4.6 respectively. Refer to Table B7 in the appendix for the detailed result.

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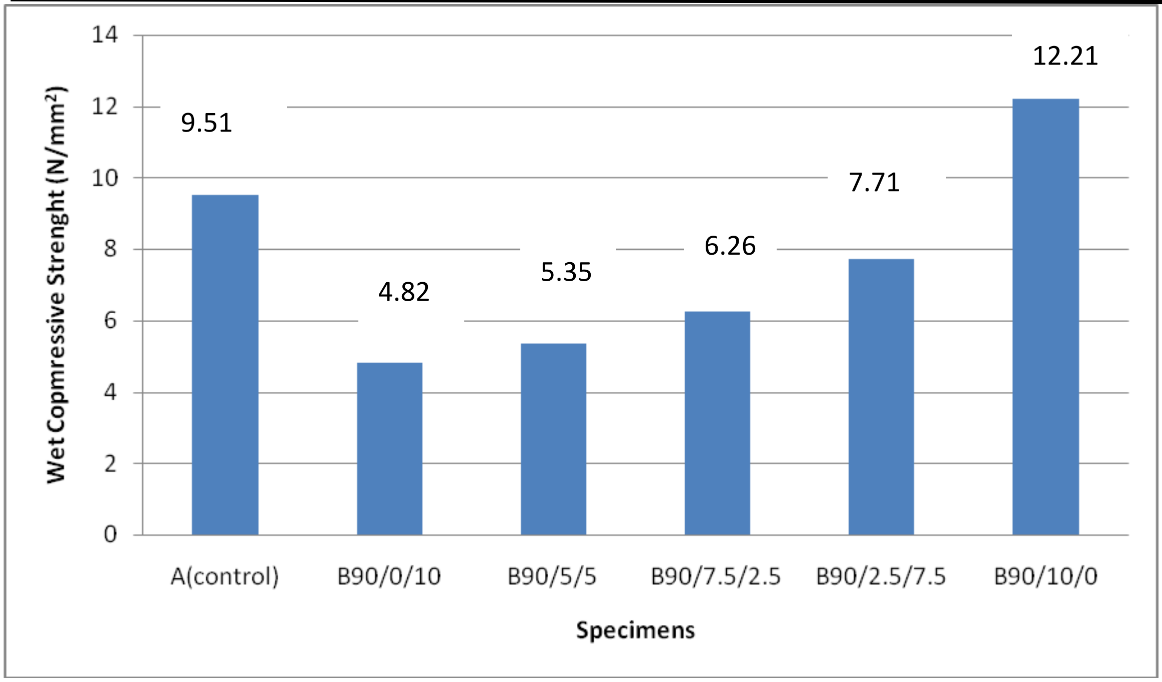

Figure 4.7 Wet Compressive Strength of the Bricks.

From Table 4.13 and Figure 4.6, it has been observed that specimen B90/ 0/10 containing 10% polythene powder as a pore forming material in the body the bricks recorded the lowest compressive strength of 4.8 N/mm^2 as compared to the control specimen A, of 9.5 N/mm^2 This implies that by replacing 10% of the soil by a corresponding 10% of the polyethylene powder, the wet compressive strength of the control brick has significantly suffered a reduction by 49.3%. On the other hand, specimen B90/10/0 which had 10% content of granite powder as an enhancer recorded 12.21 N/mm^2 Compressive strength which is higher than the control specimen A, of 9.51 N/mm^2 by 28.4%. Specimen B90/2.5/7.5 with 2.5% granite powder and 7.5% polythene powder registered a wet compressive strength of 7.71 N/mm^2 which is higher than specimen B90/5/5 with 5% granite powder and 5% polythene powder by 30.6% but lower than the control specimen A, by 18.9%. It is interesting to note that specimen B90/2.5/7.5 with 7.5% polythene powder content higher than the polythene content of specimens B90/7.5/2.5 rather recorded higher wet compressive strength than these two specimens having lesser polythene powder content. However, from the analysis, it has been generally realized that the more the percentage content of the polythene powder, the lesser the compressive strength. On the contrary, the higher the percentage contents of the granite powder the higher the compressive strength.

4.1.3 Flexural Tensile Strength of fired bricks

This is one of the important engineering properties of bricks. Apart from compressive strength, the qualities of bricks moulded were further measured by examining the flexural tensile strength of bricks. According to Luz and Ribeiro (2007) the mechanical behaviour of the specimens can be explained taking into account the difference microstructure developed during firing. The average results of the tests are summarized in Table 4.14 and graphically represented in Figure 4.7. Refer to Table B8 in the appendix column for the detailed result.

Table 4.14 Flexural Strength of Fired Bricks

Specimen	Mean load (KN)	Mean flexural tensile strength (N/m^2)
A 100 (control)	4.2	2.4
B90/0/10	1.4	0.8
B90/2.5/7.5	1.7	1.0

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B90/5/5	2.1	1.2
B90/7.5/2.5	5.1	2.9
B90/10/0	5.4	3.1

Note: Bi/j/k represents the specimen with the various materials percentages. Thus,
i= Percentage of clayey soil in the specimen moulded. The soil is 90% and it is constant in all the specimens.
j = Percentage of granite powder in the specimen moulded.
k = Percentage of polyethylene powder in the specimen moulded.

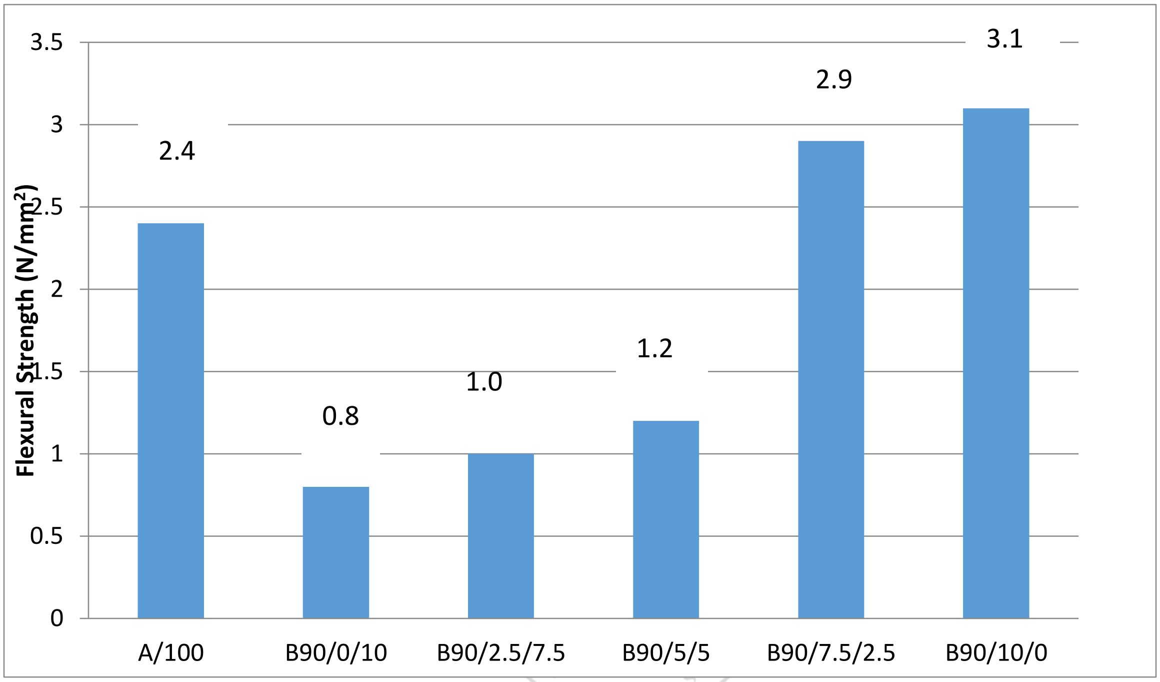

Figure 4.7 Flexural Tensile Strength of Bricks

With reference to the analysis shown in Table 4.19 and Figure 4.12, it could be observed that specimen B90/10/0 made up of the highest granite powder content of 10% with no polyethylene powder content had the highest flexural strength of 3.1 N/mm^2 compared to the control specimen A, which recorded 2.4 N/mm^2. There is a clear indication that the 10% granite powder as an enhancer has increased the flexural strength of the control specimen by 26.9%. On the contrary, specimen B90/0/10 which is a direct opposite of the specimen B90/10/0 containing the highest polyethylene powder content of 10% with no granite powder, registered the least flexural strength of 0.8N/mm^2 which is 66.7% lower than the control specimen A.

The next specimen with a better flexural strength of 2.9N/mm^2 than the control A, is B90/7.5/2.5 with 7.5% granite powder content and 2.5% polyethylene powder. It is higher than the control specimen by 20.8%. From the analysis, there is a clear indication that the flexural strength of the specimen increased with a corresponding increase of the granite powder content, while the polyethylene powder also lowered the flexural strength of the bricks tremendously.

4.1.4 Water Absorption of the Bricks

The water absorption rate, which refers to the weight moisture in the pores compared to the sintered specimen weight, is an effective index for evaluating the brick quality. The less water that infiltrates the brick makes to expect greater durability and resistance to the natural environment (Lin, 2006). So the water absorption of the bricks is measured to investigate the extents of densification in the fired body and also used as an expression to open pores (El – Mahllawy, 2008). Table 4.15 and Figure 4.8

clearly show the water absorption rate of the various specimens. Refer to Table B9 in the appendix column for the detailed result.

Table 4.15 Water Absorption after 24 hours Immersion in Water

Specimen	Mean Weight before, m_1 (g)	Mean weight after, m_2 (g)	Absorption Difference $(m_2-m_1) = m_3$ (g)	Absorption coefficient $\frac{m3 \times 100}{m1}$
A/ 100 (control)	2347.2	2596.6	249.4	10.63
B 90/10/0	2324.2	2487.8	163.6	7.04
B 90/7.5/2.5	2185.4	2563.6	378.8	17.31
B 90/2.5/7.5	1966.8	2332.4	365.6	18.59
B 90/5/5	2127.0	2534.2	407.2	19.14
B 90/0/10	1866.0	2243.4	377.4	20.23

Note: B i/ j/ k represents the specimens with the various materials percentages. Thus,
i = Percentage of soil in the specimen moulded. The soil is 90% and it is constant in all the specimens.
j = Percentage of granite powder in the specimen moulded.
k = Percentage of polyethylene powder in the specimen moulded.

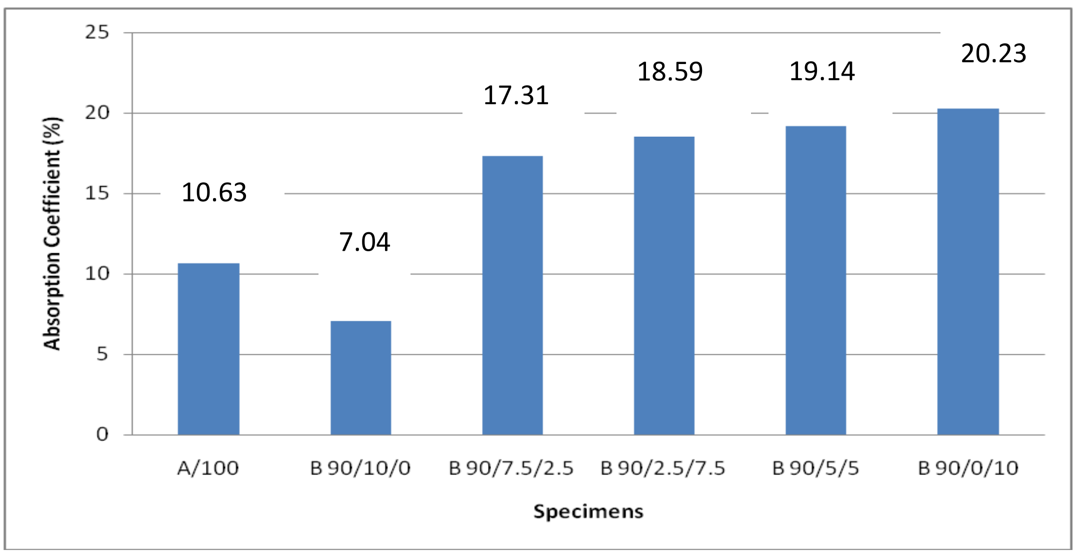

Figure 4.8 Water Absorption of the Bricks

From the analysis shown in Table 4.15 and Figure 4.8, respectively, specimen B90/10/0 with the highest granite powder content of 10% and no polythene powder content registered the lowest or the best water absorption rate of 7.04% compared to the control specimen A, of 10.63%. By replacing 10% of the soil with a corresponding 10% of the granite powder, an enhancer, it has reduced the water absorption rate of the control specimen A, by 30%. On the contrary, specimen B90/0/10 with the highest polyethylene powder of 10% and no granite powder content recorded the poorest water absorption rate of 20.23% as against 10.63% for the control specimen A. This is an indication that a 10% replacement of the soil with 10% of the polythene powder, a pore – former, it has tremendously increased the water absorption rate of the brick by 90.3%. Specimen B90/7.5/2.5 which is the second best in terms of water absorption with 7.5% content of granite powder and 2.5% content of polythene recorded 17.31%. Comparatively, it is higher than the control specimen A, by 62.8% but 10.6% lower than specimen B90/5/5 containing 5% of granite powder and 5% polythene powder.

In conclusion, it could be generalized that higher percentage content of granite powder significantly reduced the water absorption rate of the brick whereas higher percentage content of polyethylene

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increased the water absorption of the brick. In other words, the water absorption is inversely proportional to the percentage content of the granite powder but directly proportional to the polythene powder content.

4.1.5 Abrasion Resistance of the Bricks

Abrasion is the ease with which a material undergoes wearing out when an external force is exerted on its surface. It is one of the mechanical properties usually used to determine the durability of bricks. The abrasion resistance therefore is the ability of the masonry unit to resist wearing out when an external force acts on its surface. It is measured by the abrasion index. Table 4.16 and Figure 4.9 show the mean abrasion coefficient of each of the specimen. The higher the numerical value, the better the resistance to abrasion. Refer to table B10 in the appendix column for the detailed result.

Table 4.16 Abrasion resistance of the Bricks

Specimen	Abrasion difference (g)	Coefficient of abrasion, Ca (cm^2 /g)
A/ 100 (control)	14.2	2.68
B 90/0/10	24.4	0.16
B 90/5/5	12.6	3.02
B 90/2.5/7.5	10.6	3.58
B 90/7.5/2.5	9.0	4.22
B 90/10/0	6.4	5.59

Note: Bi / j/k represents the specimens with the various materials percentages. Thus,
i = Percentage of soil in the specimen moulded. The soil is 90% and it is constant in all the specimens.
j = Percentage of granite powder in the specimen moulded.
k = Percentage of polyethylene powder in the specimen moulded.

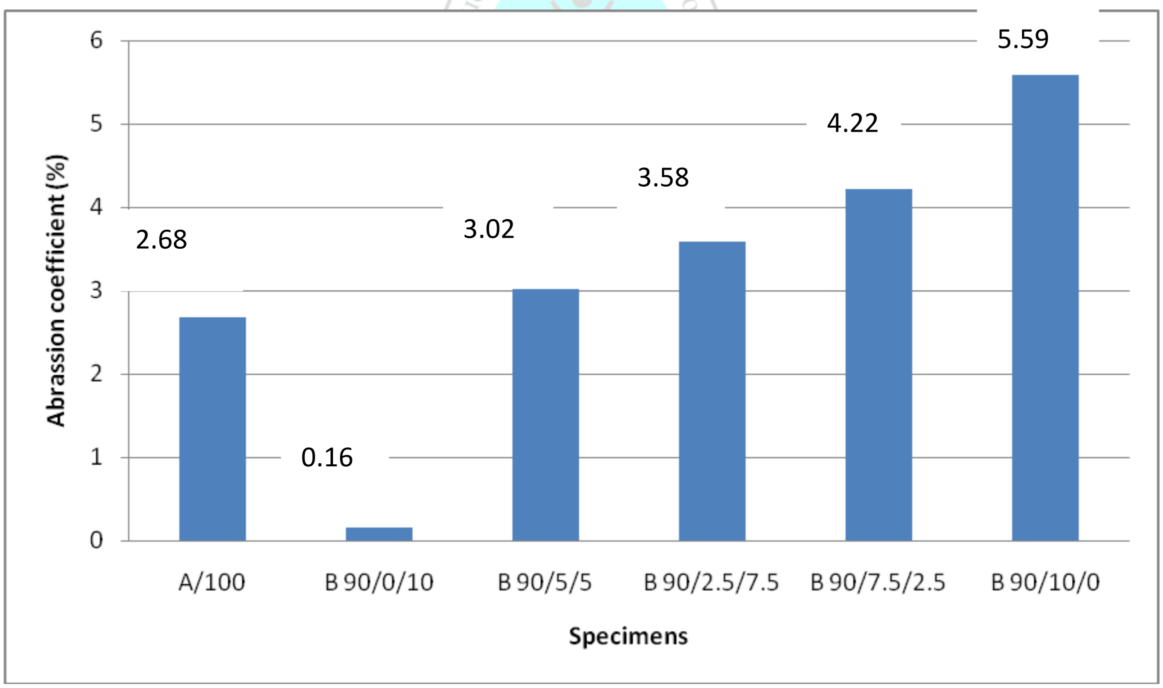

Figure 4.9 Abrasion of the Bricks

Closely studying the result shown in Table 4.16 and Figure 4.9, it is observed that specimen B90/10/0 made up of the highest granite powder content of 10% with no polythene powder content had the highest abrasion resistance coefficient of 5.93 cm^2/g compared to the control specimen A, which recorded 2.68 cm^2/g. it could be seen that the 10% granite powder as an enhancer has tremendously increased the abrasion resistance of the control specimen by 121.35%.

On the contrary, specimen B90/0/10 which is a direct opposite of the specimen B90/10/0 containing the highest polythene powder content of 10% with no granite powder, registered the least abrasion coefficient of 0.16 cm^2/g which is 94% lower than the control specimen A. The next specimen with a better coefficient of abrasion of 4.22 cm^2 /g than the control A, is B90/7.5/2.5 with 7.5% granite powder content and 2.5% polythene powder. It is higher than the control specimen by 57.4%. From the analysis, there is a clear indication that the coefficient of abrasion of the specimens increased with a corresponding increase of the granite powder content, while the polythene powder also lowered the abrasion coefficient of the brick tremendously.

4.1.6 Dry Bulk Density of the Brick

The density of a brick is the mass per unit volume. It normally influences other mechanical properties of the brick as compressive strength, flexural strength, thermal connectivity, porosity and durability (Okunade, 2008). Table 4.17 and Figure 4.10 contain the experimental results of the dry density of the specimens. Refer to Table B11 in the appendix column for the detailed result.

Table 4.17 Dry Density of the Bricks

Specimen	Density(g/cm^3)
A 100 (control)	1.729
B 90/10/0	1.775
B 90/7.5/2.5	1.605
B 90/5/5	1.579
B 90/2.5/7.5	1.466
B 90/0/10	1.376

Note: Bi /j /krepresents the specimens with the various materials percentages. Thus,
i = Percentage of soil in the specimen moulded. The soil is 90% and it is constant in all the specimens.
j = Percentage of granite powder in the specimen moulded.
k = Percentage of polyethylene powder in the specimen moulded.

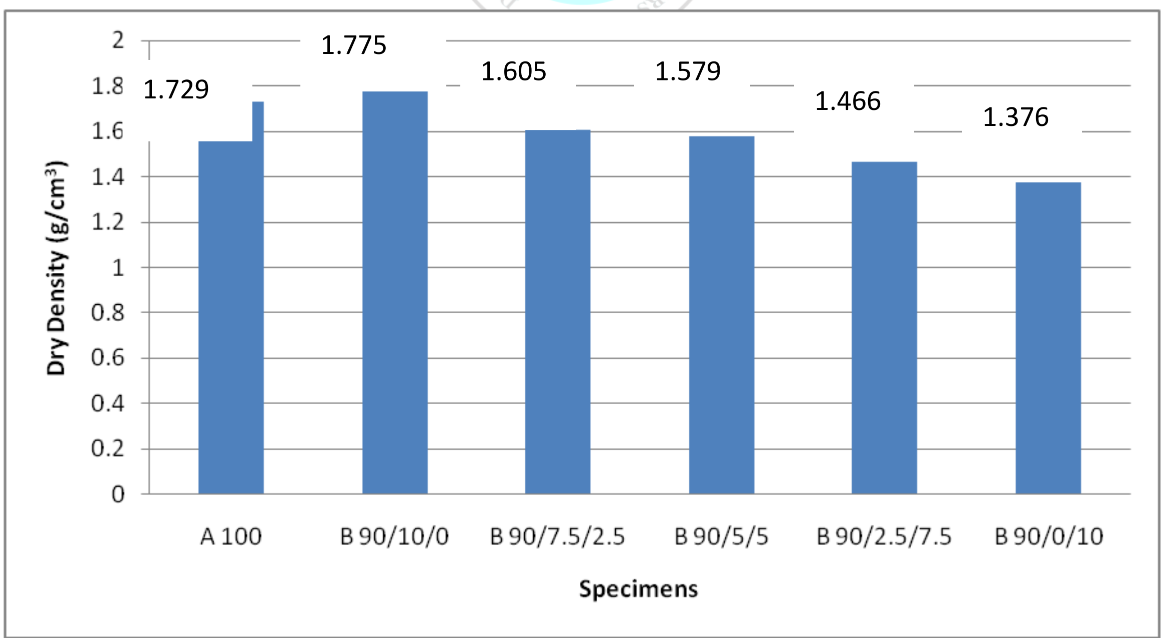

Figure 4.10 Dry Density of the Bricks

Thoroughly studying the analysis done in the table 4.17 and graphically represented in Figure 4.10, it is observed that specimen B90/10/0 made up of the highest granite powder content of 10% as an

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enhancer and no polythene recorded the highest density value of 1.775 g/cm^3 compared to the 1.729 g/cm^3 recorded by the control specimen A. Specimen B90/10/0 has increased the density value of specimen A by 2.7% while specimen B90/0/10 with 10% content of polythene and no granite powder lowered the density value by 20.4%. Specimen B90/0/10 registered the least density value of 1.376g/cm^3. Specimen B90/7.5/2.5 with 75% granite powder and 2.5% polythene powder is lower than the control specimen A, by 7.2% but higher than specimen B90/2.5/7.5 with 2.5% granite powder and 7.5% polythene powder by 8.7%. From the analysis, there is an indication that the density of the brick is directly proportional to the percentage content of the granite powder but inversely proportional to the percentage content of the polyethylene powder. It therefore implies that the two wastes materials significantly played major roles in the densities of the bricks.

4.1.7 Dry Weight of the Bricks

The main reason for most researchers incorporating combustible waste materials into soil for bricks manufacturing is to produce relatively lighter finished products. On the other hand, if the waste is non-combustible, then denser and moderately heavier finished products are expected. The weight of a brick sometimes determines its density and other engineering properties. Table4.18 and Figure 4.11 show the average weight of the various specimens with varying percentages of incorporated waste materials. Refer to table B12 in the appendix column for the detailed result.

Table 4.18. Dry Weight of the Bricks

Specimen	Mean weight (g)
A 100 (control)	2350
B 90/10/0	2413
B 90/7.5/2.5	2181
B 90/5/5	2146
B 90/2.5/7.5	1992
B 90/0/10	1870

Note: Bi/ j/ krepresents the specimens with the various materials percentages. Thus,
i = Percentage of soil in the specimen moulded. The soil is 90% and it is constant in all the specimens.
j = Percentage of granite powder in the specimen moulded.
k = Percentage of polyethylene powder in the specimen moulded.

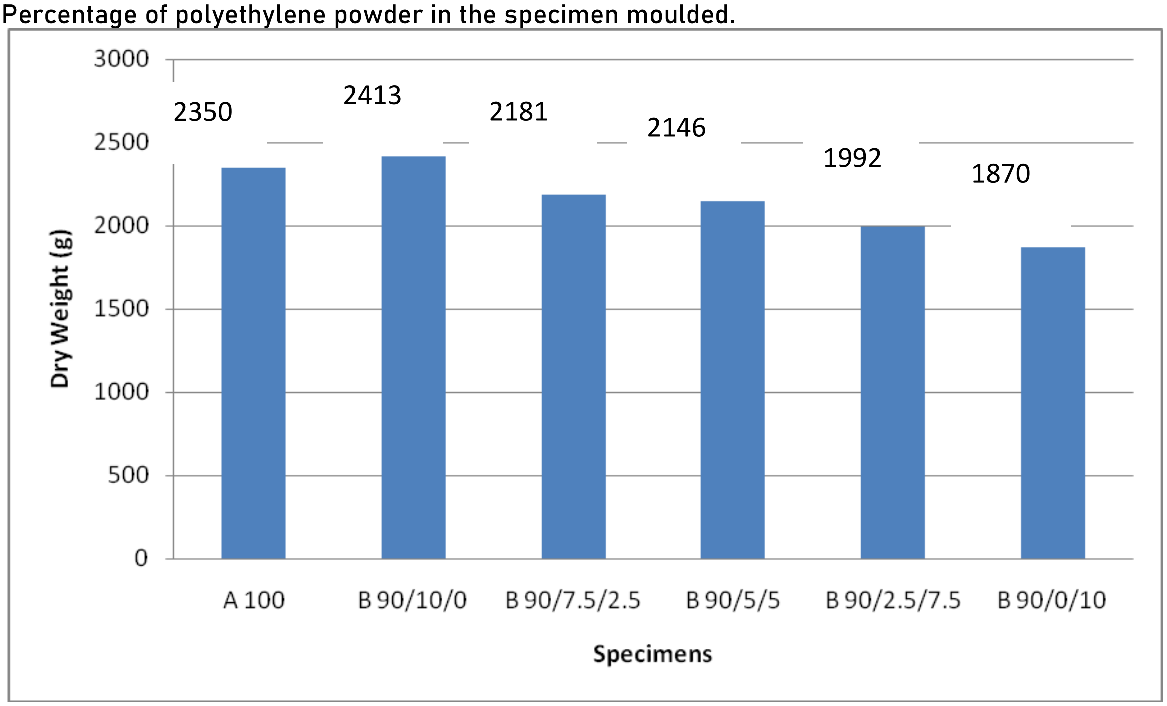

Figure 4.11 Dry Weight of the Bricks

By close observation of the analysis done and shown in Table 4.18 and Figure 4.11, it has been realized that specimen B90/0/10 with 10% of the polythene and no granite powder registered the lowest weight of 1870 g as against 2350 g of the control specimen A, by 20.4%. On the other hand, specimen B90/10/0 containing 10% of granite powder has caused a boost up of 2.7% in the dry weight of the control specimen A. Comparatively, specimen B90/7.5/2.5 with 7.5% granite powder and 2.5% polythene powder content is lower by 7.2% in terms of its weight as against the control specimen A, but higher by 8.7% as against specimen B90/2.5/7.5 containing 2.5% granite powder and 7.5% polyethylene powder.

5.0 DISCUSSION & ANALYSIS

5.1 Engineering Properties of the Bricks

5.1.1 Dry Compressive Strength of the Bricks

Compressive strength is used to assure engineering quality in the application of building materials (Olgun et al., 2005). Carefully considering the results obtained from the dry compressive strength test, it can be observed that the dry compressive strength ranges from 5 N/mm^{2}to 13 N/mm^2 corresponding with the six specimens prepared for the study. According to Table 4.13 and Figure 4.6 specimen B90/10/0 made up of soil 90%, granite powder 10% and no polyethylene recorded the highest compressive strength of 13.23 N/mm^2. Comparing this value with the value of 10.63 N/mm which is for the control specimen A, it is observed that the replacement of 10% of the soil by the granite powder has increased the compressive strength of the brick specimen by 24.5%. The increase in compressive strength experienced by the brick is in perfect agreement with the results obtained by Menezes et al. (2004) and Dhanapandian and Gnanavel (2010). The reason for the increase in the compressive strength of the new specimen may be attributed to the presence of smaller particle size of granite powder (silt fraction) acting as flux agent in the soil materials during the sintering process. In addition, granite rock naturaly possesses high compressive strength value of 200 MPa so, incorporating it into the soil will of course boost up to some extent the mechanical properties of the brick.

On the other hand, specimen B90/0/10 which is made up of soil 90% no granite powder and 10% polyethylene powder indicated the lowest compressive strength result of 5.24 N/mm^2 among the specimens produced. Carefully comparing this result of very low compressive strength of specimen B90/0/10 with the highest combustible waste material of 10% with other related works like Okunade (2008), Demir et al. (2005), Dondi et al., (1997), Sutou and Akurt (2009), Veiseh and Yousefi (2003), Banhidi and Gomez (2008), Saiah et al (2010), Lertwattanaruk and Choksirwanna (2011) and Abdul and Mohajerani (2008a, 2008b, 2010, 2011), it was observed that this particular result is in consonance with these existing literature works. Comparing the compressive strength of the specimen B90/0/10 to the control specimen A, it is observed that by replacing 10% of the soil by 10% of polyethylene powder (PEP), it has accounted for a significant decrease of 50.7% in the compressive strength of the new specimen compared to with the control specimen A This is all the more reason why earlier researchers who incorporated pore -forming (combustible) materials into the body of soil for fired brick production, carefully limited the percentages of their combustible materials from 1% to 15%. This precaution is very necessary so that the engineering properties of the finished products are not compromised.

The reason for this 50.7% decrease in the compressive strength of the new specimen B90/0/10, may be due to the several voids or pores left in the body of the finished product as result of the polyethylene powder burning out completely when the bricks were intensively fired at a temperature of 1100°C. Since there is a direct correlation between compressive strength of a material and its density, it therefore implies that the several pores formed in the body of the brick has drastically reduced the density of the brick, hence, reducing the compressive strength as well. Unlike specimens B90/0/10 and B90/10/0 which were made up of strictly only two raw materials, that is 90% of soil and 10% of polyethylene powder, then 90% of soil and 10% of granite powder respectively, specimens B90/2.5/7.5, B90/5/5 and B90/7.5/2.5 were made up of all the three raw materials (soil, granite powder and polyethylene powder) meant for study. The clayey soil taking a constant percentage of 90% with the rest 10% proportionally assigned to the polyethylene powder and the granite powder in a complementary percentage of (2.5%+7.5%), (5%+ 5%), and (7.5% + 2.5%) with the first and second numbers representing granite powder and polyethylene powder respectively.

Among these three specimens, B90/2.5/7.5, B90/5/5 and B90/7.5/2.5, specimens B90/2.5/7.5 made up of 2.5% granite powder and 7.5% polyethylene powder recorded the highest compressive strength of 8.03N/mm^{2}as against 10.63N/mm for the control specimen A. Comparing the strength of B90/ 2.5/7.5 with B90/0/10 which contained the highest percentage of combustible material (polyethylene powder), it is noticed that the compressive strength of B90/2.5/7.5 is higher by34.7% than specimen B90/0/10. This may be due to the reduction in the pore forming (combustible) material, the polyethylene powder from 10% in B90/0/10 to 7.5% in B90/2.5/7.5 and also increasing the percentage of the granite powder from 0.0% in B90/0/10 to 2.5% in B90/2.5/7.5. In addition, it could also be explained that two phenomena are simultaneously working here. Thus, while reducing the pore-forming material (PEP), the density of the brick is being boosted, hence, an increase the compressive strength of specimen B90/2.5/7.5. Also, increasing the percentage of the granite powder coupled with its small particle sizes with very tough and hard grains (silt fractions) acted as flux agent in the clay material during the sintering process. The specimen with the lowest compressive strength among B90/2.5/7.5, B90/5/5 and B90/7.5/2.5, is B90/5/5. It was made up of soil 90%, granite powder 5% and polyethylene powder 5%. It is the only specimen with equal percentage content of wastes assigned to PEP and GP. Specimen B90/5/5 recording the lowest compressive strength could be likened to the principles of adding together equal but two opposite magnitude forces. The resultant effect becomes either zero or approximately zero. Perhaps more pores or voids were created by the PEP in the body of the bricks than were refilled by smaller particle sizes of the granite powder.

In conclusion, carefully studying the compressive strength results of the new bricks, it could be seen that except for specimen B90/2.5/7.5 with 2.5% granite powder and 7.5% polyethylene, specimen B90/0/10, B90/5/5, B90/7.5/2.5 and B90/10/0 all produced results which are very interesting to note. That is, as the combustible (pore-forming) materials, the PEP systematically reduced from 10% to/ 0% and also the GP increased from 0% to 10%, the compressive strength of the specimens progressively kept on increasing. This is due to the major roles the two wastes materials (the GP and the PEP) played in the body of the brick during the sintering process. While the PEP mainly formed pores or voids in the body of the bricks after firing, hence, reducing the densities of the bricks, the GP by virtue of its smaller but tough and hard particle sizes acted as flux agent in the soil materials during the sintering process and thereby increasing the densities of the finished products, hence, increasing their compressive strength as well.

5.1.2 Wet Compressive Strength of the Bricks

Just as the dry compressive strength is very pivotal in determining the engineering qualities of bricks, the wet compressive strength should be equally considered so as to know if the bricks are structurally satisfactory for constructional works. Results shown in Table 4.14 and Figure 4.7 from the wet compressive strength after 24 hours' immersion in water indicated that specimen B90/10/0 with 10% of GP and no PEP to recorded the highest compressive strength value of 12.21 N/mm^2 as against 9.51 N/mm^2 for the control specimen. This implies that there is a percentage drop of 10.5% in the control specimen. In the case of specimen B90/10/0, the percentage drop is 8.3% with reference to its dry compressive strength. The percentage drop difference between specimen B90/10/0 and the control A, is 2.2%. The drop in the wet compressive strength of the specimen is in agreement with the results obtained by Dhanapandian at al. (2010), Manezes et al. (2004) and Okunade (2008).

Carefully considering these percentage drops in the wet compressive strength of the control specimen A, with 100% soil, and specimen B90/10/0, which recorded the highest wet compressive strength with 10% GP replacing 10% soil, it is observed that the percentage drop in the control specimen by 10.5% is more pronounced than in specimen B90/10/0 of 8.3%. The result is in line with the study by Russ et al. (2005). The higher wet compressive strength recorded by specimen B90/10/0 relative to the control specimen could be attributed to the homogeneity of the mixture due to the smaller particles sizes of granite powder filling completely almost all the pores in the soil making it difficult for water infiltration into the brick, hence, increased bulk density value of the specimen which in effect enhanced the compressive strength of the brick.

On the contrary, specimen B90/0/10, which contained the highest percentage content of 10% of the PEP recorded the lowest wet compressive strength value of 4.82 N/mm^2 as against 9.51 N/mm^2 for the control specimen A. This specimen was formed by replacing 10% of the soil by weight with 10% by weight of the PEP. Comparing the wet compressive strength of the specimen, B90/0/10, with the control specimen A, it has been observed that 10% replacement of the soil by 10% PEP has significantly reduced its strength by 54.7%. Since compressive strength is directly proportional to porosity and for that matter water absorption, specimen B90/0/10 which recorded the highest water absorption coefficient of 20.23% should obviously record the lowest wet compressive strength value. Among specimens B90/2.5/7.5, B90/5/5 and B90/7.5/2.5 which contained all the two waste materials (GP and PEP) in varying percentages, specimen B90/2.5/7.5 with GP content of 2.5% and PEP of 7.5% recorded the highest wet compressive strength of 7.71 N/mm^2 compare with the control of 9.51 N/mm^2. This implies that by increasing the percentage content of the GP from 0% to 2.5% and decreasing the percentage content of the PEP from 10% to 7.5% in specimen B90/0/10 to produce B90/2.5/7.5, the wet compressive strength of the specimen jumped from 4.82 N/mm^2 in specimen B90/0/10 to 7.71N/mm^2 in specimen B90/2.5/7.5. This indicates that specimen B90/2.5/7.5 is higher than specimen B90/0/10 by 60%. A close study of the wet compressive strength values recorded by all the specimens B90/0/10, B90/2.5/7.5, B90/5/5, B90/7.5/2.5 and B90/10/0, with the exception of B90/0/10, indicated that the compressive strength values of the specimens progressively kept increasing as the percentage content of the granite powder was increased from 0% to 10% while the percentage content of the polyethylene powder was decreased from 10% to 0% simultaneously. This phenomenon could be attributed to the collective role played by these two waste materials in the body of the soil. Thus, while the PEP acted as the pore-former within the body of the brick when it burnt out during the intensive firing at a temperature of 1100^{0}C the GP on the other hand, actively acted as the pore-filler in the body of the brick during sintering process.

5.1.3 Flexural Strength of the Bricks

The quality of a brick can be further measured by examining the flexural tensile strength of the brick. It depends on the material composition and dimension and morphology of the flows. A close observation of the flexural tensile strength displayed in Table 4.19 and Figure 4.12, it is observed that specimen B90/10/0 with the highest percentage content of 10% of the GP recorded the highest flexural strength of 3.1 N/mm^2 as against 2.4 N/mm^2 for the control specimen A. It implies that by replacing 10% by weight of the clayey soil with 10% by weight of the GP, the flexural strength of the brick has been increased by 26.9%. The reason for this increase may be due to an improvement of the densification process, which is confirmed by the increase in the bulk density value of 1.78 g/cm^3 representing 2.7% higher than the control. The gradual increase in the flexural strength of the specimen can also be attributed to the possible smaller particle sizes of granite powder and the resulting greater homogeneity of the materials. In addition, it could also be inferred that, GP naturally is a very tough and hard material, and therefore incorporating it into the soil body will obviously increase the flexural strength of the finished product.

On the other hand, the poorest or the least flexural strength of 0.8 N/mm^2 as against 2.4 N/mm^2 for the control specimen A, was recorded by specimen B90/0/10/ containing 10% of PEP with no GP content. Comparatively, it therefore indicates that a 10% replacement of the soil by weight with a corresponding 10% by weight of PEP, a pore forming material in the body of the brick, there is a significance reduction in flexural strength 66.7%. The reason accounting for this high decrease in flexural strength of specimen B90/0/10 could be attributed to the several voids or pores left in the body of the bricks after the PEP completely burnt out, hence, significantly reducing the density of the specimen by 20.4%. Density is directly proportional to flexural strength, so low density will expectedly produce low flexural strength. The results perfectly agreed with the ones obtained by Acchar et al. (2006) and Russ et al. (2005). In conclusion, it is observed that flexural strength is directly proportional to the percentage content of the granite powder but inversely proportional to the percentage content of the polyethylene powder.

5.1.4 Water Absorption (Porosity) of the Bricks

Water absorption is one of the important engineering parameters used in evaluating the quality of bricks. According to El-Mahllawy (2008) it measures the extent of densification in the fired body and also used as an expression to open pores. The smaller the numerical value, the better the specimen in preventing water to infiltrate its body. The results of the water absorption rate of the specimen in Table 4.15 and Figure 4.8 revealed that specimen B90/10/0 with the highest percentage content of 10% GP and no PEP recorded the lowest water absorption coefficient of 7.04% as against 10.63% for specimen A, the control specimen. This therefore suggests that by replacing 10% of the soil with 10% by weight of the GP, there is a significant reduction in water absorption of the new specimen. B90/10/0 by 33.5%. The results perfectly agreed with the study by Sanchez et al. (2006), Dhanapandian and Gnanvel (2010) and Manoharan et al. (2010). The reason for the decrease in water absorption and porosity of specimen B90/10/0 might be due to the pores of the soil materials significantly filled up and locked by the incorporation of fine but hard and tough particle sizes of GP at higher content of 10% and at higher sintering temperature of 1100^0C. According to Manoharan et al. (2010) water absorption is based on the amount of open pores in sintered specimen and it is directly proportional to the density of the specimen Since specimen B90/10/0 registered the highest density and compressive strength among all the specimens moulded, it is very obvious that its water absorption rate will be significantly the lowest as against all other specimens.

The specimen with the highest water absorption coefficient is B90/0/10, containing the highest percentage of 10% of the PEP waste and no granite powder. It recorded 20.23% as against 10.63% for specimen A, the control specimen. Comparatively, it could be observed that the value recorded by B90/10/0 is 90.3% higher than the control specimen. This result obtained is in consonance with other related studies conducted by many researchers such as Demir (2008), Demir et al. (2005), Ducman and Kopar (2007), Dondi et al. (1997), Isenhour (1977) and Veiseh and Yousefi (2003). This extremely high water absorption coefficient demonstrated by specimen B90/0/10 is attributed to the several open pores or voids created after the burning out of the PEP in the body of the sintered specimen due to the intensive firing process it went through, hence, significantly lowering the density of the specimen. Since there is a direct correlation between water absorption and the density of a material, it is very obvious that low density specimen like B90/0/10 with the lowest density of 1.37 6g/cm^3 among all the specimens moulded, should indicate the highest water absorption coefficient of 20.23%.

Among specimens B90/2.5/7.5, B90/5/5 and B90/7.5/2.5 containing all the two waste materials in the body of the soil, Specimen B90/7.5/2.5, which contained the percentage of 7.5% of the GP experienced the lowest water absorption coefficient of 17.31% which is 62.8% higher than the control specimen A, but 10.6% lower than B90/5/5 with equal percentage content of 5% of GP and PEP, followed by B90/2.5/7.5 of 18.59% and the highest is B90/5/5 of 19.14%. From the analysis so far, it could therefore be inferred that the specimen with the highest percentage content of GP and lowest percentage content of PEP registered the lowest or the best water absorption coefficient.

5.1.5 Abrasion Resistance of the Bricks

It is one of the mechanical properties usually used in determining the durability of bricks. The abrasion resistance therefore is the ability of the masonry unit to resist or withstand wearing out when an external force acts on its surface. It is measured by the abrasion index. The higher the coefficient of abrasion, the better the specimen in resisting wearing out when its surface is being acted upon by external forces or pressures. A close observation of the abrasion results displayed in Table 4.16 and Figure 4.9, it is observed that specimen B90/10/0 with the highest percentage content of 10% of the GP recorded the highest abrasion coefficient of 5.93 cm^2/g as against 2.68 cm^2/g for the control specimen A. It implies that by replacing 10% by weight of the soil with 10% by weight of the GP, the abrasion resistance of the brick has tremendously increased by 121.2%. The reason for this tremendous increase may be due to its high density of 1.775 g/cm^3 recorded among all the specimens formed and also as a result of the smaller particle sizes of the GP filling completely almost all the pores in the body of the specimen during the manufacturing and the sintering process. It could also be attributed to the fact that, GP naturally possess a very high abrasion resistance index, and therefore incorporating it into the soil material will obviously increase the abrasion coefficient of the finished product.

The poorest or the least coefficient of abrasion of 0.16 cm^2/g as against 2.68 cm^2/g for the control specimen A, was recorded by specimen B90/0/10 containing 10% of PEP with no GP content. This specimen was formed by replacing 10% weight of soil by 10% weight of PEP. Comparatively, it therefore indicates that by replacing 10% of soil with 10% PEP, a pore – former in the brick body, it has greatly reduced the abrasion resistance of the control specimen A, by 94%. This particular result goes a long way to confirm the justification by many researchers to strictly limit their incorporation of combustible waste materials into the body of the soil from 1% to 15%. This precautionary measure is taken so as not to grossly compromise relevant engineering properties of the finished product. The result is in agreement with the study conducted by Okunade (2008). This low resistance could be caused by the high percentage content of the PEP in the soil which affected the density and the compressive strength of the specimen as a result of the many pores or voids created in the body of the brick after the PEP completely burnt out when fired at such intensive temperature of 1100^{0}C.

Among specimens B90/2.5/7.5, B90/5/5 and B90/7.5/2.5 which contained all the two waste materials, specimen B90/7.5/2.5 with 7.5% GP and 2.5% PEP, registered the best abrasion coefficient value of 4.22 cm^2/g compared with 2.68 cm^2/g for the control specimen A. It implies that specimen B90/7.5/2.5 possesses better abrasion resistance ability than the control specimen A, by 57.5%. It has been observed that specimens with an appreciable higher content of GP recorded higher coefficient of abrasion, while those with higher content of PEP also recorded lower coefficient of abrasion. It could therefore be inferred that abrasion coefficient of the bricks is directly proportional to the percentage content of the GP but inversely proportional to the percentage of the PEP.

5.1.6 Dry Bulk Density of the Bricks

Basically, density as one of the mechanical properties of bricks plays a very significant role in influencing other mechanical properties such as compressive strength, flexural strength, thermal conductivity, abrasion resistance, water absorption (porosity) and durability of the bricks. Closely studying the dry bulk density values of the specimens shown in Table 4.17 and Figure 4.10, it is observed that the introduction of the PEP brought about a sharp decline in the value of the dry densities, with specimen B90/0/10 having the highest content of PEP of 10% no GP content producing the least dry density of 1.376 g/cm^3 as against 1.729g/cm^3 for the control specimen, A. It therefore implies that the 10% inclusion of the PEP into the soil material resulted in 20.4% reduction in density of the brick. This sharp decline in the densities of this new specimen formed was as a result of the many pores created within the bodies of the specimen when the combustible material, the PEP completely burnt out after undergoing intensive firing at a temperature of 1100^{0}C. It could be noticed that all the specimens B90/0/10, B90/2.5/7.5, B90/5/5, and B90/7.5/2.5 which contained some percentages of PEP had their densities either grossly or slightly less than the control specimens A, and specimen B90/10/0 without any PEP. Some researchers such as Demir (2006), Sutou and Akurt (2009) and Abdul and Mohajerani (2008a, 2008b) who conducted their studies using combustible waste materials just like the present study reported that all combustible waste materials incorporated into soil significantly reduce the densities of the finished products after intensive firing.

Specimen B90/10/0, with the highest percentage content of 10% of GP recorded the highest density value of 1.775 g/cm^3compared with the control specimen A, of 1.729 $g/cm^{3.}$ A replacement of 10% of soil by 10% of GP increased the density of the new brick by 2.7% compared with the control specimen. This is due to the flux of the GP filling all the pores in the soil material and making the whole unit a well-integrated and denser substance after firing. With regard to specimens B90/2.5/7.5, B90/5/5 and B90/7.5/2.5 containing all the two waste materials in varying percentages, specimen B90/2.5/7.5 with 2.5% GP content and 7.5% PEP content B90/5/5 with equal percentage of 5% content of GP and PEP and B90/7.5/2.5 with 7.5% GP and 2.5% PEP had all their densities lower than the control specimen A, by 15.2%, 8.6%, and 7.2% respectively. In conclusion, it has been observed that reducing the percentage content of the PEP waste from 10% to 0% and equally increasing the percentage content of the GP from 0% to 10% with a common difference of 2.5% in the specimens, there was a gradual progressive increase in the densities of the specimens. The average density of the specimens ranges from 1.200 g/cm^3 to 1.800 g/cm^3. According to Showstopper (1983) the density of special masonry units usually ranges between 1.200 g/cm^3 to 2.400 g/cm^3

5.1.7 Dry weight of the specimen of the Bricks

The fundamental reason for many researchers incorporating waste materials (either combustible or non-combustible) into clay for bricks production is to produce either relatively lighter and more porous bricks in terms of the combustible wastes or denser and more solid finished products in terms of non-combustible wastes. The weight of a brick to some extent influences the engineering properties of the brick. A close observation of the weights recorded for the specimens shown in Table 4.18 and Figure 4.11 point to the fact that there was a significant decrease in weight for specimen B90/0/10 containing the highest percentage content of 10% of the PEP from 2350 g for the control specimen A, to 1870 g for B90/0/10. This indicates that by replacing 10% by weight of soil with a corresponding 10% by weight of PEP, there has been a decline in weight from 100% to 79.6% respectively. On the other hand, specimen B90/10/0 recorded the highest weight value of 2413 g. This specimen contained the highest percentage content of 10% of the non- combustible waste material, the GP. Comparing its weight, 2413 g, with the control specimen, 2350 g, it is noticed that there has been a slight upward adjustment in weight by 3.0%. All these findings are in perfect agreement with the results obtained by other renowed researchers such as Isenhour (1979), Dondi et al. (1997), Veiseh and Yousefi (2003), Okunade (2008), Abali etal. (2007) and Dhanapandian and Gnavavel (2010) who used similar waste materials just as the current study.

For specimen B90/2.5/7.5, B90/5/5 and B90/7.5/2.5, containing both waste materials, B90/7.5/2.5 which contained the highest percentage content of 7.5% of GP and 2.5% of PEP indicated the highest weight of 2181 g, followed by B90/5/5 with 5% GP and 5% PEP with 2146 g and finally the least, B90/2.5/7.5 with 2.5% GP content and 7.5% PEP with 1992 g. Comparing their weights to the control specimen A, they had their weights lower by 15.2%, 8.6% and 7.2% than the control, respectively. It could be observed that increasing the percentage content of the GP in the soil, proportionally increased the dry weight of the specimens. This implies that the dry weight of the brick is directly proportional to the percentage content of the GP, but, inversely proportional to the percentage content of the PEP. This is basically due to the collective roles played by these waste materials in the soil during sintering process. Thus, the PEP, because of its combustible nature when subjected to intensive firing temperature, acted as a pore former, thereby creating several pores or voids in the body of the bricks, while the GP by virtue of the homogeneity of its mixture due to the smaller particle size, acted as pore filler in the body of the brick, hence increasing the density of the brick and as a result the weight.

6.0 CONCLUSION

It is concluded that, combined inclusion of the two waste materials in the soil indicated that 7.5% of GP and 2.5% of PEP by weight of soil produced specimen bricks with good satisfactory results. A very interesting observation made is that most of the bricks engineering properties (Compressive Strength, flexural strength, abrasion coefficient, density, water absorption and porosity) are directly proportional to the percentage content of the granite powder but inversely proportional to the percentage content of the polyethylene powder. This phenomenon is as a result of the pore forming and pour filling roles the two waste materials actively and collectively played in the body of the brick during the sintering process. When the pure water sachet (PWS) plastic powder (combustible waste) burnt out and created several pores in the body of the brick, it reduced the density of the bricks, hence other mechanical properties. The granite powder, because of its mineral compositions, especially quartz and feldspar to the soil material acted as flux and filled the pores within the soil when they sintered at higher temperature, increasing significantly the density of the brick, hence, other engineering properties of the bricks. All the six items developed as the significance of the study have all been satisfied.

Finally, the incorporation of GP and PEP in soil for brick production anticipates less expensive but durable and quality building materials to considerably reduce the high housing deficit problems in Ghana, environmentally friendly recycling products for effective waste management, the solution for future exhaustion of the natural resources and the conservation of not-renewable resources.

6.1 Recommendations

Base on all the detailed experimental works carried out with their corresponding empirical results obtained, the following recommendations are made: The brick, B/0/10 containing the highest PEP could be used in high rise buildings as walling units, since it is light in weight. It could also be used for local bread making ovens usually used in Ghana. The brick, B/10/0 containing the highest GP could be useful in pavement making, retaining walls, substructure walls and load bearing walls. The government, corporate bodies and individuals must encourage and sponsor research into the manufacturing of machines and equipment that will be able to process the pure water sachet (PWS) plastics into the needed forms and aggregates (particle sizes), if their wastes must be used to develop local building units (blocks, bricks, concrete etc.) for the construction industries on commercial basis.

6.2 Further Researchable Areas

In order to validate the possible application of these newly developed GPC (Granite Powder, Polyethylene Powder and Clay) bricks in the construction industries and for that matter on larger scale, further investigations are necessary. These include: Developing an applicable mathematical model to facilitate easy and quality production of these GPC bricks on commercial basis with special emphasis on using this model to determine the most reliable, accurate and standardize mix ratios (proportions) in terms of volume of the various raw material to be used. Investigating the effect of particle sizes of processed pure water sachet rubber on the engineering properties of fired bricks. The effect of varying temperatures on fired GPC bricks.

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