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Analyzing the Determination of Compaction Test for Optimum Moisture Content (OMC)

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Abstract

This article is focus material analysis such as sieve analysis, sedimentation (hydrometer analysis), Atterberg tests (liquid limit, plastic limit and shrinkage limit) and compaction (protor method) tests were conducted on the soil and the granite powder so as to obtain all the relevant index properties of the materials under consideration. The raw materials were batched by weight of the soil by replacing 10% by weight of the soil with 10% by weight of the granite powder and polyethylene. In other words, the clayey soil was maintained at a constant percentage of 90% while the remaining 10% was proportionally distributed to the two waste materials in a complementary percentage manner. Thus, (0% + 10%, 2.5% +7.5%, 5% +5%). The bricks were fired at a temperature of 11000C.

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

1.0 INTRODUCTION

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 Moisture Movement

Clay bricks expand on cooling from the kiln as some of the water molecules re-attach themselves after being driven off by the heat of the kiln. This expansion is non – reversible unless the bricks are refired. The magnitude of this movement varies according to the type of brick.

2.1.1 Soluble Salt Content

Most clays used in brick – making contain soluble salts that may be retained in the fire bricks. If brick work becomes saturated for long periods, soluble sulphates may be released. This sulphate attack may cause mortars that have been incorrectly specified or batched and have a low cement content to deteriorate.

2.2 Policy Measures for Controlling/Internalizing Externalities: Pure Water Sachet Plastic

Every internalization measure is a control measure, but not every control measure is an internalization measure. A measure may control pollution or externality but may not take into account, or internalize, the social costs of the pollution-generating activity. For example, measures like direct, regulation may control pollution but do not internalize its social costs. In addition, internalization follows the polluter-pays-principle. It ensures that polluters pay for social costs or the damage they cause. With control measures, externalities will still exist though at reduced level; with internalization, externalities will still exist though at reduced level; with internalization, externality will still exist but will have been internalized, and are thus not called externality since the effects have been 'priced' and paid for. It is when external effects are produced and not compensation for that they are called externalities (Adewuyi, 2001. Using judgement convenience sampling, there are various control measures, economic or otherwise, to externality problems. These are:

2.2.1 Economic Instruments

i. Merger
ii. Taxes / Subsidies
iii. Extending Property Rights (Coase Theorem)
iv. Pollution Permits
v. Deposit-Refunds

2.2.2 Non-economic Instruments (Measures)

vi. Direct Regulation
vii. Suasive Instrument

2.2.3 Merge

A traditional curer for externalities, especially between two firms, is for the two firms to merge in order to internalize the externality. That is, the polluting firm (source of pollution) and the affected firm (the receptor) merge to become a firm. By coordinating the activities of the firms, the profit of the joint enterprise would be higher than the sum of their individual profits when they do not coordinate (Rosen, 1999). This process is also called unitization. Once the two firms have been integrated, the externality has been internalized. That is, the externality has been taken into account by the party that generates it. As a result, the externality would not lead to inefficiency. As Rosen would put it, an outside observer would not even characterize the situation as an externality because all decisions would be made within a single firm.

2.2.4 Pigouvian Taxes / Subsidies

As the name implies the solution was suggested by Pigou (1932). This classic remedy to externality problems remains, until recently, the standard solution most favoured by economists. It is one of several ways in which government can intervene when individuals acting on their own cannot attain an efficient solution. Pigou suggests a tax to be levied on the polluter or the externality-generality activity. He advocates a tax, now called the Pigouvian tax, on each unit of a polluter's externality-generating output in an amount just equal to the marginal damage it inflicts at the efficient level of output. It is unusually levied on the polluting agent in an amount equal to marginal social damage. Practical problems confronting the use of Pigouvian taxes / subsides are used to evaluate their appropriateness. These problems are:

- Measuring damage is difficult, if not impossible. For instance, the monetary value of damage to health and loss of life is very difficult to estimate.

- It is alleged that the Pigouvian taxes overlook a particular contingency that can result in "over-correction".
- The cost of collecting the necessary information and supervision is relatively high.

In addition to the foregoing, there is high tendency for the tax scheme to lead to high price of sachet water, irrespective of whom the tax is levied. Even if the tax is imposed on the producers, they will definitely shift part of the burden to the consumers through price hike. This would worsen the economic welfare of both the consumers and non-consumers; it affects non-consumers through a chain reaction in other sectors of the economy.

2.2.5 Establishing Property Rights/Coase Theorem

In the quest for the best solution to externalities, Coase (1960) points out that the government need not intervene in every case of externality and that many externality problems result from the fact that property rights to certain resources are ill-defined or not defined at all. Clean air, for instance, is a resource not owned by any one. The polluter can, therefore, use the clean air as a method of waste disposal of his noxious gaseous emissions without compensating the affected party who is deprived of clean air. This is because there is no clearly defined owner to demand compensation. The consumers simply drink the water and throw away or litter the sachets. For these reasons advanced above, the use of property rights approach is not application to the sachet-water externality problems.

2.2.6 Pollution Permits

This is another way in which government can intervene when individuals fail to attain an efficient solution on their own. Some economists prefer to use the term ``creating a market`` for this type of measure. This is because the government creates a market for clean air or water that otherwise would not have emerged, by selling permits (to pollute) to producers of the pollution-generating products. Creating markets is deemed necessary because of the belief that it is the lack of markets for externalities that causes the problems (Varian, 2003). Under this scheme, government will announce the auction or sale of pollution permits to spew certain level of pollutants such as sulphur dioxide into the environment, and the highest bidder gets the permits. A market clearing effluent fee is charged so that amount of pollution is equal to the level set by the government.

2.2.7 Deposit-Refund Systems (DRS)

A deposit-refund system is a method of pollution control in which the buyers or consumers of a polluting product pay as surcharge, which is later refunded to them when they return the used packaging of the product or its leftover to a point of purchase or designation centre. The purpose of this is to make the used packaging available for reuse, recycling or proper disposal in order to curb pollution. Deposit-refund scheme is usually adopted for products whose polluting packaging are recyclable, costly to incinerate, generating large volume of waste, and occupying large space in landfills. It is also adopted for products whose packaging contains toxic substances, the control of which poses special problems to waste handlers and the improper disposal which poses serious health hazards (Jerome, 2001). The packaging of sachet water aptly fits into the above description of the products whose pollution can be controlled by the scheme. The deposit-refund scheme is based on user pays-principles (UPP). The UPP emanates from the thinking that the consumers of goods and services that generate pollutions should be made to share in the abatement cost, because waste disposal involves cost that should be borne by those responsible for the waste. The scheme is also based on the principle that incentives should be provided to encourage waste recovery or reclamation, and recycling. The fund represents on effective subsidy to waste recovery effort (Jerome, 2001).

2.2.8 Recycling: The Pivot of the DRS

Recycling is a method of pollution control used where the sources of pollution, such as plastics, are recyclable. Other plastic packaging lends itself to be reused many times over. Here, the already used packaging is collected to produce the same type of packaging or other materials. Such firms that are specialised in collecting the used packaging collect the packaging that has been used and sell them to the recycling firms. Some producers re-claim the packaging of their products from the consumers and reuse

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them for packaging same products. Reuse and reclamation are usually possible where the packing is reusable and recyclable. The government may direct producers to reclaim their form end-users or from the streets. This reduces the number of used packaging littered about. For instance, a law has been passed in Germany to force manufacturers to take back their packaging materials. Nurnberger (1999) however, notes that measures like this upset the economy, but why should society suffer to prop the profits of the elite?

Reusing plastics is preferable because of its economical use of energy and resources. According to Adetunji and Biala (2010) literature reveals four types of plastic recycling, namely, (i) process-scrap (ii) post-use (iii) mechanical, and (iv) chemical or feedstock recycling.

(i) Process Scrap Recycling: It involves the recycling of industrial plastic scraps left over from the production of plastics. This type of recycling, usually described as reprocessing, is relatively simple and economical as a regular and reliable source of relatively uncontaminated materials.

(ii) Post-used Recycling: it is a recycling process where the already used plastics are collected from different sources or locations and recycled into new plastics. Households are the biggest source of getting the materials for this type of recycling. The post use recycling is the type most needed to solve the pollution problems, especially the sachet pollution. We hardly have any Company or local authorities offering some of plastic or polythene collection services in Ghana.

(iii) Mechanical recycling; this refers to processes in which waste plastics are melted, shredded, and granulated. Plastics must be sorted prior to mechanical recycling. The difference between post use and mechanical recycling is that in the former only a particular type of packaging, say used sachets, are collected and recycled. But in mechanical recycling, various plastic packaging is collected and sorted into polymer type and/or colour. After sorting, the plastic is either melted down directly and moulded into a new shape, or melted down after being shredded into flakes and the processed into granules. Indirect recycling converts mixed plastics into materials which do not need a high degree of purity or informality, e.g. Shoe soles, carrier bags, toys, pipes and bicycle saddles.

(iv) Chemical Recycling: this type of recycling breaks down polymer into their constituent monomers, which can be used again in refineries or chemical or petrochemical production. Chemical recycling is capital-intensive and requires very large quantities of used plastics for reprocessing to be economically viable.

A reporter on the production of carrier bags made from recycled rather than virgin polythene concludes that the use of recycled plastic results in the following advantages:

- Conserves non-renewable fossils fuels.
- Reduces energy consumption.
- Reduces the amounts of waste plastic going to landfills.
- Reduces emissions of gaseous pollutants such as CO_2, NO_x and SO_2.
- Reduces the amounts of plastics waste requiring disposal.

2.2.9 Direct Regulation

Direct regulation is another way in which government intervenes in externality problems. This is conventional method widely used all over the world, especially in the industrialized nations, to control pollution or any other externality problems. Government may lay down maximum pollution level or ban outright the production of output that generates pollution. However, it would be prohibitively expensive, if not impossible, to eliminate entirely all traces of some of the pollutants. Optimality does not require that external diseconomies be eliminated, but simply require that their amounts are consistent with the optimal amounts of the good that creates them. However, the cost of discovering and maintaining an optimal amount of the pollution may itself be prohibitive. Taxes, subsidies, and pollution permits are all methods of market-based, indirect regulation designed to induce polluters to weigh the social costs of their activities against their benefits. It is in the light of this that some researchers prefer to call these methods market-based approach, while direct regulation is called command-and-control approach. Regulation is relatively easy to understand.

However, pollution control through regulation has its own peculiar problems. The major constraint of direct regulation is the high administrative cost of enforcing the sets of standards. This is another macroeconomic implication: it can bring about inflation. This implies that regulation is not cheap as it appears. The consumers have to pay for the price increase to avoid loss of welfare that the pollution imposes on them. By reducing the production, the government is indirectly instructing the populace to reduce their water intake without adequately providing the water intake without adequately providing the alternatives. How feasible is this? Governments can legislate against littering, indiscriminate waste disposal or illegal waste dumping. But this will not solve the problems. Legislation cannot effectively work in developing countries like Ghana, where the literacy level is relatively low. Enacting a law against littering or illegal indiscriminate waste disposal is not the problem, but the enforcement of the law. Effective law enforcement is a tall order in corruption-ridden countries like Ghana, where the enforcement agency or their officials are highly corrupt. Thus, there is high tendency for violators to go scot-free or with a bribe.

2.2.10 Suasive Instrument

Suasive instruments include moral suasion, awareness, and anti-litter campaigns. These three strands are lumped together under the name suasive instruments or social conventions. They are more or less the same and serve the same purpose. By moral suasion, the polluters are called upon and cajoled to desist from, or reduce, their externality-generating activities. Both awareness and anti-litter campaigns seek to inform and sensitize the polluters about the causes and effects of the polluting activities. The basic aim is to persuade the polluters to eliminate or reduce pollution voluntarily.

School children are taught that littering is irresponsible and not a nice or proper way of disposing of waste. If this teaching is at all effective then a child learns that even though he bears a small cost by holding on to a biscuit wrapper or a banana peel until he finds a garbage can, he should incur this cost because it is less than the cost imposed on other people by having to view his unsightly garbage (Rosen, 1999).This is evidenced from our Ghanaian cities, where there are various anti-litter campaigns, provision of waste cans, anti-litter inscriptions on bill boards, like ``always keep the cities clean`` or ``don't be a litterbug``. Nonetheless, the cities are still being littered. However, these methods have been partially successful in reducing the amount and sensitizing people to pollution problem.

2.3 Waste Recycling for the Production of Bricks

Due to the demand of bricks as building material, researchers have investigated the potential wastes that can be recycled or incorporated into fired clay bricks. Owing to the flexibility of the brick composition (Lynch, 1994; Dondi et al., 1997a and Christine, 2004) different types of waste have been successfully incorporated into fired clay bricks by previous researchers, even in high percentages. From the literature reviews related to the inclusion of waste materials, they apparently vary from the most commonly used wastes such as the various types of fly ash and sludge, to sawdust, kraft pulp residues, paper polystyrene, processed waste tea, tobacco, grass, spent grains, glass windshields, PVB-foils, label papers, phosphogypsume (waste used by phosphoric acid plants), boron concentrator and cigarette butts. The utilization of these wastes will help to reduce the negative effects of their disposal. Most of the recycled wastes demonstrated both advantages and disadvantages in the brick manufacturing process.

2.3.1 Fly Ash

Several researchers have tried to recycle fly ash into bricks with 100% fly ash as the solid ingredient called FlashBricks. The equipment and techniques used in manufacturing the bricks were similar to those used in the clay brick industry. Samples were fired at 100°C to 1300°C and were formed into moulds. Fired FlashBricks produced bricks that were 28% lighter than standards clay bricks. The results show that FlashBricks improved most of the properties compared to those of a standard brick.

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The compressive strength obtained was 43 MPa and the tensile strength was improved almost three times compared to that of a standard claybrick. In addition, the brick also achieved a bond 44% higher than a standard clay brick and the resistance to salt exposure with zero loss of mass was excellent.

As for Lin (2006) this study used fly ash slag from the municipal solid waste incinerator (MSWI) varied from 10% to 40% and the bricks were fired at 800°C, 900°C and 1000°C. The results of the physical and mechanical properties indicated that using a high amount of fly ash slag increased the dry density and compressive strength value but decreased the water absorption rate. Nevertheless, all the values determined for both parameters met the Chinese National Standard (CNS) building requirements for second-class bricks. The degree of shrinkage in the firing process also decreased with the addition of fly ash slag to the mixture, which is a good indicator of the potential of the waste as a replacement for clay in bricks. All the heavy metal concentrationsmeasured by the Toxicity Characteristics Leaching Procedure (TCLP) met the current regulatory thresholds.

Furthermore, Lingling et al. (2005) used wet quality fly ash ranging from 50% to 80% by volume to replace clay in manufacturing fired bricks. The firing temperature used was 1050°C instead of 900°C as normally used to fire standard clay bricks. The effect of incorporating a high percentage of the pulverised fly ash was investigated and the results show that the addition increased the compressive strength value and decreased the plasticity of the brick mixture and the water absorption rate. Moreover, there was no cracking due to lime addition and a high resistance to frost melting was observed. In addition, another advantage of incorporating this waste was the high resistance of the manufactured bricks to efflorescence.

Dondi et al. (1997a) also reviewed several studies regarding fly ash ratio used in previous research ranged from 10:1 to less than 1:1. One of the advantages of using fly ash is that this waste saves the firing energy as its calorific value ranges from 1,470 to 11,760 kJ/kg. The other properties tested showed an improvement in plasticity, drying and decreased firing shrinkage and crack formation (Sajbulatow et al., 1980; Srbek, 1982; Anderson & Jackson, 1993). However, these depend on the quantities of fly ash added and the use of different compositions in the brick (Anderson & Jackson, 1983; Usai, 1985; Palova, 1996).

2.3.2 Sludge

This category includes sludge from sewage treatment plant, sludge from paper industry, iron and arsenic sludge, sludge ash and tannery sludge. Rouf and Hosssain (2003) used 5%, 15%, 25% and 50% of iron and arsenic sludge in clay brick with firing temperatures of 950°C, 1000°C and 1050°C. In this study, they claimed that 15% to 25% by weight with 15% to 18% optimum moisture content is the appropriate percentage of sludge mixture to be incorporated. The compressive strength test indicated that the strength of the brick depends significantly on the amount of sludge in the brick and the firing temperature. The results showed that 15% by weight is the optimum amount of sludge with a 1000°C firing temperature. However, the strength of the brick can be as high as normal clay bricks with up to 25% sludge at a firing temperature of 1050°C. The specific surface area of the corporating mixture, the particle finess and water requirement inreased proportionally to the amount of sludge added to the clay. The water absorption of the brick also decreased when the amount of sludge was reduced with an increased firing temperature.

The quantity of sludge added to the mixture is inversely proportional to the bulk dry density. With the right amount of moisture content in the mixture, any deformation or uneven surface were not seen on the manufactured samples at all firing temperatures.Basegio et al. (2002) discussed the utilization of tannery sludge as a raw material for clay products. Tannery sludge and clay were mixed together with different proportions (9%, 10%, 20% and 30%) as the raw materials in this study. The brick was fired at 1000°C, 1100°C and 1180°C and was shaped in the mould using the hydraulic pressing method. Specific testing for clay bricks was conducted on the samples to determine the mechanical properties. Water absorption increased with increased percentage of sludge. With an increased firing temperature, the water absorption and porosity decreased considerably, a higher firing temperature and a lower amount of sludge showed the greatest dry density of all. The maximum shrinkage occurred between 1100°C and 1180°C. Samples containing 30% sludge showed the lowest dry density and highest linear shrinkage. The bending strength increased with a higher firing temperature and lower sludge addition with a maximum of 25 MPa with 0% and 10% sludge at 1080°C.

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According to Dondi et al. (1997a) in their review of previous researchers, wastes from sewage sludge treatment plants were used in several studies. The wastes are high in economic content, varying from 10% to 20% by mass in the incinerator of solid urban wastes to as high as 60% or even higher for sewage sludge (Mesaros, 1989). Validation on the specific amount of calorific value is hard to verify but an estimated calorific value of 10,000 kJ/kg of dry fraction is estimated to save from 10% (Mearos, 1989) to 40% and could be higher. According to Dondi et al. (1997a), a positive contribution can be achieved from less than 2% up to 25% to 30% Allemen, (1987) and Alleman, (1989) from the waste added to the clay brick. A higher amount of sludge could lead to negative results to the manufactured brick (Mesoros, 1989; Brosnan & Hochlreitner, 1992).

The main advantages are related to the amount of energy saved and the environmentally friendly way for disposing of the sludge waste (Slim & Wakefield, 1991; Churchill, 1994). Increased plascity due to the fibrous nature of the waste added makes brickmoulding easier (Allemen, 1987 &Mesaros, 1989). However, the dry shrinkage results obtained were not in agreement as some cases seemed to involve significant increase in shrinkage with crack formation during the drying process (Mesaros, 1989; Allemen, 1989) while others involved less dry shrinkage and drying sensitivity (Brosnan & Hochlreitner, 1992). In other articles reviewed by Dondi et al. (1997a) that utilised sludge form treatment plants revealed an increased percentage of water absorption and firing shrinkage and a decrease in dry density by 15% (Tay, 1987). The mechanical strength also decreased from 4 to 30%, and with a higher addition of sludge (40%), up to (50%) reduction was observed for the strength (Tay, 1987). Negative aspects of the firing process included the unpleasant odour emitted, efflorescence effect and black coring to the final product (Brosman & Hochlreitner, 1992).

2.3.3 Combination of Pelletised Old Labels and Fly Ash

A combination of pelletised old labels and fly ash obtained good results. No problem occurred during the manufacturing process. The residues utilized reduced the dry density while maintaining similar or achieving an even higher compressive strength. Significant porosity growth was also observed with the burnt out of the label pellets (Demir, 1987).

2.3.4 Crushed PVB-polymer

The PVB-polymer, which was produced from windshield glass, also demonstrated positive results on the fired brick. Energy usage was reduced by recycling the pore forming agent inside the brick due to its high calorific value (28,260 kJ/kg), which contributed to the firing process. Hence, gas emissions have to be monitored as the combustion of PVB-polymer almost completely turned into CO_2 and H_2O. Crushed PVB-polymer additives confer more positive results to the brick. The PVB-pellets improved the dying shrinkage of the green brick tremendously and increased the porosity of the bricks produced accordingly (Mesaros, 1989).

2.3.5 Glass Grit

The usage of the glass grit, another waste produced from car windshields, decreased the plasticity and positively affected the firing process of the manufactured brick. Lower firing temperatures could also be employed with this additive and the brick produced offered similar strength with increased porosity which resulted in better thermal characteristics (Demir, 2008).

2.3.6 Brewery Waste Spent Grains, Fly Ash

Krebs and Mortel (1999) also mentioned that residue from brewery waste, spent grains, have been tested on an industrial scale. The same experimental procedure that was carried out for the label pellets was conducted on the spent grains. The same positive effects were also demonstrated with residue. The resulting light-weight bricks had improved porosity and thermal conductivity without affecting the mechanical strength.

2.3.7 Processed Waste Tea (PWT)

Processed waste tea (PWT) was another waste that was noted by Demir (2006) to be used in clay bricks. The potential of PWT in the unfired and fired clay body was investigated due to the organic nature

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of PWT. The improved compressive strength results, compared to the control samples indicated that the pore forming the PWT in the fired body and the binding in the unfired body have a significant potential in both conditions of clay brick. The firing temperature used was 900°C. It was observed that with higher amounts of PWT the shrinkage water absorption, compressive strength and porosity were increased but the dry density was decreased. The organic characteristics of PWT supplement the heat input of the furnace and act as an organic kind of pore forming additive. The usage of the waste improved the physical and mechanical properties of the environment of the bricks and also one of the environmentally friendly alternatives in brick manufacturing.

2.3.8 Kraft Pulp

Another waste that can be utilised in clay bricks according to Demir et al. (2005) is kraft pulp production residues. Increasing amounts of the waste have been incorporated in clay bricks by 0%, 2.5%, 5% and 10%. All samples were fired at 900°C with another group being left unfired. The required water content and drying shrinkage increased with the increased amount of kraft pulp residue. Ten percent addition is not suitable due to the increased drying shrinkage. However, the addition of up to 5% residue increased the dry bending strength, which is useful for handling purposes of the unfired bricks. The organic nature of the waste supplemented the heat input of the kiln. It can also be effectively used in pore forming for the clay brick at up to 5% addition levels. The compressive strength value decreased with the addition of the waste but still complied with the standards.

2.3.9 Organic Residues

Furthermore, Demir, (2008) also utilised various organic residues such as sawdust, tobacco residues and grass from industrial and agricultural waste. These residue materials have long cellulose fibres. Differing amounts of waste were incorporated in the clay bricks – 0%, 2.5% 5% and 10%. All samples were fired at 900°C while one batch was left unfired. According to Demir (2008), while maintaining acceptable mechanical properties, these wastes could act as an organic pore forming agent in clay bricks and increased the porosity, thus, improving the insulation properties. Adding organic residues increased the plasticity and thus, increased the water content required. A residue addition 10% is not suitable as the drying shrinkage increased excessively due to the effect of cellulose fibres. The dry strength of the brick increased excessively due to the effect of cellulose fibres. The dry strength of the brick fired samples reduced by the addition of the residues. Nevertheless, the compressive strength values still complied with Turkish standards. Five percent of the residue addition was effective for pore forming but further additions reduced the dry density value and increased the porosity.

2.3.10 Sawdust, Stone Mud Papermaking Sludge

Ducman and Kopar (2007) also investigated the influence of the addition of difference waste products to the clay bricks. Four different waste products were selected which were sawdust, stone mud and papermaking sludge waste. Different proportions for each waste were carried out and the influence on the physical and mechanical properties was determined. Sawdust and papermaking sludge were added by up to 30% to the clay and fired around 850°C to 920°C. In contrast, almost 100% silica stone mud was utilised and fired at 900°C. As for granite stone mud, the highest percentage used was 30% and fired at about 1008°C to 1052°C. The shrinkage after drying was reduced with the addition of sawdust but increased with papermaking sludge, silica and granite stone mud. The reduced effect is favourable as it lessened the crack formation during the drying process. The shrinkage and dry density after firing were much lower with the addition of sawdust and sludge, which acted as pore forming agents thereby increasing the porosity. The compressive strength, with 30% of sawdust, was 10.7 MPa. This was less than half that of the control brick, which was 23.9 MPa.

However, the addition of papermaking sludge improved the strength due to the calcite content. Hence a combination of sawdust, papermaking sludge and clay could produce adequate strength comparable to the control clay brick. A reduction in dry density and compressive strength was observed for the silica and granite stone mud. The compressive strength decreased form 62.5 MPa to 50.7 MPa with the addition of 50% silica stone mud and up to 10% was suggested as the optimal addition for granite stone

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mud to avoid a significant effect on the mechanical properties of the clay brick. In addition, both waste additives demonstrated higher water absorption.

2.3.11 Sawdust from Manufacturing Industry

Dondi et al. (1997) also reviewed about recycling sawdust from the wood manufacturing industry to produce light-weight bricks. The caloric value ranged from 7,000 to 19,000 kJ/kg and saved up to 15% of the energy usage during the entire firing process. The optimum amount of sawdust added was between 4% to 5% by mass. To avoid preliminary grinding, the maximum sizes of the particles must be below 2 mm. Some researchers discovered that the use of this waste improves the workability of the clay and reduces the drying time, while some found the utilization could cause problems during the manufacturing and drying phase. Furthermore, a reduction in the strength properties and an increase in the water content value were also observed (Isenhour, 1979).

The finished product was light-weight with better thermal and acoustic properties. Water absorption was increased and the shrinkage value either remained the same or decreased slightly, however, the mechanical strength decreased considerably by up to 10% to 30%. The studies concluded that only small quantities of sawdust should be incorporated within the body of the brick (Isenhour, 1979) to gain economic and technical advantages. This is because the negative effects were also demonstrated from the added waste involving gas emissions of noxious elements (Kohler, 1988; Mortel and Distler, 1991) and the information of efflorescence (Kohler, 1988). In addition, a small number of Italian brickworks also incorporated sawdust into the body of the brick that could act as an additive as well as furnace fuel.

2.3.12 Textile Industry Fibrous Wool Waste, Wool Wash Water Treatment Sludge

Other waste incorporated in clay bricks include those derived from the textile industry; fibrous wool waste and wool wash water treatment sludge have also been examined and summarized by Donhi et al.(1997a). These wastes are capable of considerable fuel saving (up to 20%) in brick manufacturing. However, caloric values offered vary according to the origin of the wastes. Dependent on the amount of organic substance in the waste, the waste used in the body was less than 1.5% and 10% by mass of the fibrous wool and wool wash sludge, respectively. The existence of textile waste produced a light-weight brick, with increased water absorption but a lower bending strength (about 20%). However, the data concerning the efficiency of recycling the maternal with references to the energy usage and economical aspects are lacking. Most of the drawbacks refer to the transport and treatment costs.

2.3.13 Tanning Industry (Disposal Sludge or Tanned Hide)

Recycling waste produced by tanning plants was also assessed by Donhi et al. (1997a) disposal sludge Komissarov et al. (1994) and Pavlova, (1996) or tanned hide residues are the main waste produced by the tanning industry and it is difficult to recycle these wastes due to the existence of polluting elements, especially chromium. Considering its high calorific value (84,000 kJ/kg), with continuous monitoring of the toxicity and the environmental impact this sludge can be potentially used as a fuel. In this case, the amount of waste depends mainly on the chromium content. Therefore, only 10% of the waste was added to the clay body. The product waste produced a light-weight brick with good heat insulation properties. In the chrome tanned hide residues case, with 2% of mass added, the waste efficiently decreased the plasticity, the shrinkage value, bending strength and increased the porosity of the manufactured brick. Tanning wastes are potentially recyclable in bricks, however, the emission of unpleasant odours and chromium pollution does not comply with the required standards.

2.3.14 Coal-Mining Waste

Dondi et al. (1997a) also reported on the possibility of recycling coal-mining waste. The waste originated from the coal mining and refining processes. The high calorific value from the coal-mining and refining processes exhibited major energy savings that were estimated from 20% to 40% with the highest being 60% (Boldyrev, 1989). The wastes also consisted of inorganic components, mainly clay minerals and quartz. Some of the materials can be used as they are while others have to be refined or ground. Hence, the unusual amount added is between 5% to 15% by mass (Andrade et al., 1994). However, some of the researchers recommended the use of high amounts of this waste as an alternative to the raw materials

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for brick making (Caligaris et al., 1990). Generally, the waste addition improved the drying behaviour and the mechanical strength of the green brick. The porosity value also increased in the fired products, while shrinkage behavior depends on the nature of waste added. These characteristics contributed to the mechanical strength reduction of the fired brick Polach (1990). In terms of the technological and economic value, the utilization of coal waste demonstrated a positive contribution as shown in some cases where low cost and good quality products were produced.

2.3.15 Petroleum Refinery Waste

Dondi et al. (1997a) also observed the incorporation of petroleum refinery waste in the brick bodies and claimed the addition guaranteed efficient fuel savings due to the high calorific value, for example, the calorific value petroleum coke is about 31,000 kJ/kg. The percentage added of this waste is normally not more than 2.5% by mass. In the experiments conducted, the properties of bricks were maintained except for the bending strength (maximum 15%), which did not comply with the standards. Good heat insulating properties resulting from the effect of the increased porosity could be produced with 1% to 2% petroleum was additions. Although an insignificant decrease in the mechanical strength was observed, the presence of this waste improved the drying and firing shrinkage (Almeida & Carvalho, 1991).

2.3.16 Recycled Paper Processing Residues

According to Sutcu and Akkurt (2009), recycled paper processing residues were also used as a raw material and organic pore-forming additive in clay bricks. The proportions utilised ranged from 10% to 30% and were fired at 1100°C. Shrinkage was lower with the additives as were the densities, which were up to 33% less than the control brick (1.28 g/cm^3). The porosity and water absorption value increased with the inclusion of the residues with a resultant decrease in the compressive strength. However, the compressive strength value still complied with the standard strength values. Thermal conductivity was also improved by up to 50% (0.4 W/m-1K-1). The recycled paper processing residues acted as a pore-forming additive in the brick bodies, thereby improving the insulation compared to the control brick without significantly affecting the mechanical strength. Preliminary trials were successfully conducted on an industrial scale producing bricks with good thermal conductivity values.

2.3.17 Polystyrene

One more waste of interest to Veiseh and Yousefi (2003) was polystyrene. The main objective of adding polystyrene foam to clay bricks is to reduce the dry density of the brick as well as improve the thermal insulation properties. The firing temperature used was from 900°C to 1050°C with mixes containing 0.5%, 1%, 1.5% and 2% by mass of the added polystyrene foam. Results from this study demonstrated that although increasing the amount of polystyrene in the clay brick increased the water absorption properties, at the same time, it decreased the strength and dry density of the manufactured brick. Consequently, for the usage of the manufactured brick to be sufficient for load bearing purposes in accordance with the Iranian Standard, only 2% of polystyrene could be incorporated. Better compressive strengths and lower absorption were achieved using higher temperatures during the firing process. An improvement in thermal performance was also obtained with 1.5% recycled polystyrene compared to ordinary bricks.

2.3.18 Phosphogypsume

Abali et al. (2007) used phosphogypsum (waste used by phosphoric acid plants) and boron concentrator wastes to produce light-weight brick production. Firing temperatures were 100°C, 800°C, 900°C and 1000°C using additives of 1%, 3%, 5% and 20%. Boron concentrator waste could not be used in the brick as the addition of this waste resulted in the manufactured samples being crushed during firing. The phosphogypsume used, namely, original phosphogypsume and washed phosphogypsume referred to as OP and WP, respectively, showed good potential in light-weight brick manufacturing. The resulting advantages of incorporating the waste included a reduction in weight, lower water absorption value and shortening of the natural drying process. Since OP and WP both produced similar good quality bricks, OP is to be preferred because of the additional cost incurred in producing WP. The waste also saves fuel due to the burning of the organic substances inside the waste during the firing process. However, the physical properties are not yet proven as the experimental work only emphasised the mechanical properties.

2.3.19 Cigarette Butts (CBs)

In another study, the possibility of recycling cigarette butts (CBs) in fired clay bricks were investigated with very promising results (Abdul and Mohajerani, 2008a, 2008b, Abdul et al., 2009 and 2010 and Abdul and Mohajerani, 2010 and 2011). In this study, four different clay-CBs mixes with 0%, 2.5%, 5.0% and 10% by weight of CBs, corresponding to about 0%, 10%, 20% and 30% by volume were used for making fired brick samples. The results show that the density of fired brick reduced by up to 30%, depending on the percentage of CBs incorporated into the raw materials. Similarly, the compressive strength of bricks tested decreased according to the percentage of CBs included in the mix. The thermal conductivity performance of bricks was improved by 51% and 58% for 5% and 10% CBs content respectively. Leaching tests were carried out to investigate the levels of possible leachates of heavy metals from the manufactured CB bricks. The results found in this study show that CBs can be regarded as a potential addition to raw materials used in the manufacturing of light-weight fired bricks from non-load bearing as well as load-bearing applications, with improved thermal performance and the better energy efficiency, providing the mix is appropriately designed and prepared for the required properties. Recycling CBs into bricks can be part of a sustainable solution to one of the serious environmental pollution problems of the world.

2.3.20 Water Treatment Plant and Rice Husk Ash

Hegazy et al. (2012) used water treatment plant and rice husk ash to be incorporated into the brick. Three different series of sludge to rice husk ash (RHA) proportions were studied with ratios of 25%, 50% and 75% by weight. Each brick proportion was fired at 900°C, 100°, and 1200°C. Higher water absorption was obtained for sludge-RHA brick ranging between 17.41% and 73.33% compared to control brick which were 9.94% and 11.18%. The results were influenced by the firing temperature as well as the proportion of sludge and RHA in the brick. On the other hand, the specific gravity measurements were found to be in inverse correlation with the water absorption. The sludge-RHA bricks manufactured fall into the category of light weight brick (ranged from 0.78 to 1.46) compared to the control brick which ranged from 1.84 to 1.95. As for the compressive strength properties, the results for control clay brick and sludge-RHA ranged from 5.7 MPa to 6.8 MPa and from 2.8 Mpa to 7.7 Mpa respectively.

In this experiment work, increasing the firing temperature ensures the completion of the crystallization process and closes the open pores during sintering thus, reducing the water absorption, the specific gravity due to densification, and compressive strength property by increasing the strength of the crystalline aluminosilicate brick. On the other hand, increasing the sludge ratio reduced the pores in the sludge RHA sinter and consequently increased the compressive strength and density. Furthermore, low portion of RHA particles is preferable compared to sludge as it significant increases the open pore in the sinter, increasing the water absorption thus decreasing density and compressive strength. The optimum sludge-RHA recommended in this study was 75%. Most of the properties tested complied with Egyptian Standard Specifications (E.S.S).

2.3.21 Ash from Mango Tree and Sawdust from Mahogany Wood

Folanrami (2009) investigated on the effect of ashes from the burning of dried mango tree and sawdust from mahogany wood on the thermal conductivity of clay brick. Different percentages of the ash and sawdust were incorporated, which were1%, 5%, 10%, 20% and 30% respectively and fired at 800°C. Thermal conductivity value of clay brick containing ashes ranged from 0.180 to 0.250 W/mK. On the other hand, thermal conductivity of clay brick with sawdust ranged from 0.060 to 0.230 W/mK. All the manufactured clay samples with additives improved the thermal conductivity properties and the clay sample with sawdust additive (30%) gave the best value of thermal conductivity which was 0.006 W/mK.

2.3.22 Natural Fibres (Pineapple leaves (PF) and oil palm fruit bunch (OF))

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Chan (2011) examined the physical and mechanical properties of clay brick containing two natural fibres which were pineapple leaves (PF) and oil palm fruit bunch (OF). The fibre was added within the range of 0.25% to 0.75% and fired at 800°C. Cement also was added as a binder to the mixture at 5% to 15%. Effect of PF and OF on density is not significant as it does not affect the properties even with different percentages in the manufactured clay brick which is different to most of the other studies that used fibre as organic inclusions. Nevertheless, a slight reduction in density was observed thus also increasing the water absorption properties. As for the compressive strength, higher percentages of OF increase the value but higher percentages of PF decrease the strength gradually. Cement addition seems to dominate the effect on all the properties tested. All the bricks only fulfilled the minimum compressive strength of 5.2 Mpa for conventional bricks according to British Standards (BS) and Malaysian Standards (MS).

2.3.23 Briquettes (Charcoal)

Phonphuak and Thiansen (2011) studied the physical and mechanical properties of briquettes (charcoal mixed with clay) including density, compressive strength, water absorption and porosity. Different amounts of charcoal (2.5%, 5.0%, 7.5% and 10% by weight) were added and fired at 900°C to 1100°C. Samples of three different sizes were manufactured which are 1 to 2 mm, 2 to 3 mm and less than 0.5 mm. The firing shrinkage (2.10% to 2.88%), water absorption (18.3% to 40.7%0 and apparent porosity (31.5 to 53.9%) value increased with increasing percentage of charcoal compared to the control brick. On the other hand, bulk density (1.17 g/cm3 to 1.68 g/cm3), apparent density (1.87 g/cm^3 to 2.30 g/cm^3) and compressive strength (2.8 Mpa to 14.1 Mpa) have lower value with higher percentages of charcoal compared to the control brick. The most suitable firing temperature for test fired briquettes is 950°C because they are more durable, porous and stronger than the control bricks. Phonphuak and Thiansen (2011) conclude that charcoal could be used as a pore former additive in clay body and it also produce lightweight fired clay briquettes.

2.3.24 Sawdust, Rice Peel and Sunflower Seed Shell

Experimental investigation was carried out by Banhidi and Gomze (2008) to improve the insulation properties of the conventional brick products. Few renewable agricultural; waste materials such as sawdust rice peel and sunflower seed shell (4% and 7% by weight) were added to the basic clay of the conventional brick mixture. The firing temperature used was 900°C with a 100°C/h heating rate. RAPID-K type of static thermal conductivity measuring instrument was used to determine thermal conductivity value of the manufactured bricks. The thermal conductivity value reduced significantly with higher percentages of the organic by - product thus improving the insulation properties. The ignition of the organic by - product waste addition decreased the energy used during firing by providing extra thermal energy. Pores were created during the firing process thus decreasing the thermal conductivity. The thermal value decreased by 10%, to 31% compared to the control brick with 4% by weight of additives. The largest reduction was found with the addition of sunflower seed shell (37%) followed by rice peel (26%) and sawdust (16%). The thermal conductivity value decreased from 0.27 W/m K to 0.17 W/m K with 7% sunflower seed shell additive. Least improvement was obtained from the insertion of sawdust with 0.27 W/m K to 0.23 W/m K. Unfortunately, the compressive strength value decreased significantly by 26% to 77% and 25% to 48% with 4% and 7% of additives respectively. Nevertheless, in terms of mechanical properties the most suitable additive is sawdust.

2.3.25 Vegetable Matter

Saiah et al. (2010) investigate the usage of vegetable matter of various composition and shapes into fired clay bricks. The reductions of shrinkage and density of brick were acceptable. During combustion, the vegetable matter created pores that increased the porosity from 11% to 18% thus decreasing the thermal conductivity value by up to 32%. The thermal resistance of the manufactured brick improved by 18% to 48%. However, wheat straw additives showed the most acceptable properties with reference to their thermal and mechanical properties.

2.3.26 Kaolin-Rice Husk-Plastic Clay

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In Ugheoke et al. (2006) study the suitability of using kaolin-rice husk-plastic clay to produce insulating firebrick was carried out and the optional ratio of these constituents determined. Ten brick samples of different ratio were fired at a temperature of 1200°C. During the observation, three of the samples crumbled during firing. The other seven samples gave the following limits of results: shrinkage 9.7% to 13.6%; effective moisture content: 28.34% to 32.52%; modulus of rupture: 4.23 kgf/cm^2 to 19.10 kgf/cm^2; apparent porosity: 56% to 95.93%; water absorption: 42.27% to 92.12%; bulk density: 1.04 g/cm^3 to 1.14 g/cm^3; apparent density: 2.56 g/cm^{3}to 5.77 g/cm^3; and thermal conductivity: 0.005 W/m K to 0.134 W/m K. The results showed that they all ha good insulating characteristics. Samples with mixing ratio of 4:1:2 (kaolin, plastic clay and rice husk respectively in grams) gave the optimum performance values in most of the properties which are shrinkage, effective moisture content, refractoriness, modulus of rupture, bulk density and thermal conductivity.

2.3.27 Rice Husk and Bagasse

Lertwattanaruk and Choksirwanna (2011) studied the feasibility of incorporating 0%, 1%, 2%, 3% and 6% by weight in brick manufacturing rice husk and bagasse. The replacement of rice husk and bagasse increased the compressive strength up to 2.2 mPa and 3.2 Mpa respectively compared to control brick (1.6 Mpa). On the other hand, the value of shrinkage decreased from 29.99% to 25.63% and from 29.99% to 17.95%, for rice husk and bagesse respectively; when the percentages of agricultural materials increased. A decrease of shrinkage is observed with the increase of fiber proportion, but the positive effect seems to be more noticeable with bagesse. This could be attributed to a sufficient length of bagasse fiber for improving the bond at the fiber-soil interface to oppose the deformation and soil contraction (Bougerra et al., 1998; Bouhicha et al., 2005).

The results obtained also indicate that the highest thermal conductivity of brick containing non-agricultural materials is 0.71 W/m K. As for brick containing rice husk at 1%, 2%, 3% and 6% by weight, the highest thermal conductivity is 0.65 W/m K and the lowest is 0.45 W/m K. The sample containing bagasse shows lower thermal conductivity especially at the percentage repalcement of 2%, 3%, and 6% by weight of materials.the incorporation of bagasse caused the positive effects in binding ability and reduction of soil contraction leading to better refinement of the pore distribution, and regulating in an increase in porosity and lowering the thermal conductivity (Binici et al, 2007; Bouguerra et al, 1998). The moisture absorption of the brick containing rice husk and bagasse also increase accordingly with higher percentages of the material; however, brick with bagasse showed the least moisture accumulation. The best percentages to incorporate both agricultural materials are 3% and 6% for rice husk and bagasse respectively.

2.3.28 Plastic Fibre, Straw and Polystyrene

Binici et al, (2006) studied plastic fibre, straw and polystyrene fabric in different mixtures in mud bricks. Additional material such as basaltic pumice, cement and gypsum were also added to reinforce the manufactured bricks. Mixtures of plastic fibre with additional materials show the highest compressive strength (6.0MPa) compared to the other materials. Traditional mud brick obtained the lowest compressive strength with 1.8 MPa. As for water absorption traditional mud brick have the highest value (38.7%) followed by mud brick containing straw (34.8%), polystyrene fabric (32.5%) and plastic fibre (31.1%) with additional material according to the mixture. The density values do not differ much but the highest value obtained is the plastic fibre mixture (1.263 g/cm^3) and the lowest achieved by the traditional mud brick (1.253 g/cm^3). Mixture of clay, plastic fibre, basaltic pumice and water resulted the lowest thermal conductivity (0.202 kcal/mh°C) compared with the other mixtures. Additional basaltic pumice seems to have strong influence on the plastic fibre mixture to decrease the thermal properties. As a conclusion, different mixtures containing plastic fibre mostly comply with ASTM

2.3.29 Granite and Marble Sawing Powder

Granite and marble sawing powder are produce enormously by industrial process in India. Generally, these wastes pollute and damage the environment due to sawing and polishing processes. Dhanapandian and Gnanavel (2010) carried out an experiment work by collecting granite and marble sawing powder wastes in Salem to be incorporated into the clay brick. Mixtures were prepared with 0%,

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10%, 20%, 30%, 40% and 50% by weight and firing temperature used is between 500°C and 900°C for the briquette samples. Samples of brick also were collected at Salem, Namakkal, Erode and Tamilnadu, India. The compressive strength and flexural strength values are directly proportional to the wastes incorporated as well as the firing temperature except for the result obtained for 10% by weight whereby the compressive strength values were reduced.

The increased value of the strength may be caused by the homogeneity of the mixture due to smaller particle size of granite and marble sawing powder (Russ et al, 2005). This is established by the increased in the bulk density values in this experiment work. On the other hand, water absorption and porosity values were observed to decrease proportionally with the increased of the waste content and also the firing temperature used. It shows that the waste filled the pores in the mixture appropriately thus reflect in the reduction in porosity and water absorption. All the results indicate that granite and marble sawing powder wastes could be incorporated up to 50 wt.% into raw clay materials of India and still producing adequate mechanical properties with no costly modifications in the industrial fabrication line. Furthermore, it is also found that 20 wt.% of the waste materials is the best percentages to be included compared to others.

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

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Fine	Particle which passes a 63um sieve

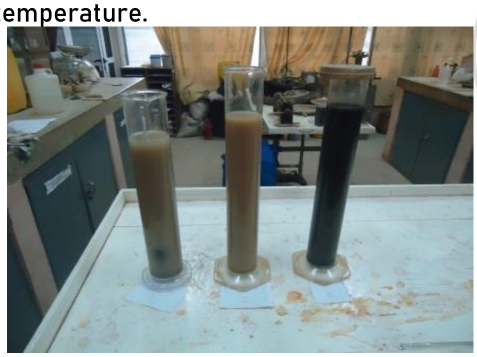
Source: (Head, 1992; Kezdi, 1980 and BS 1377 – 1: 1990 Clause 2.2.22)

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.

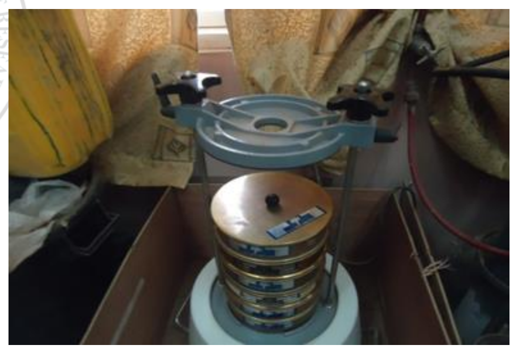
3.1.1 Sedimentation (Hydrometer) Analysis

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)

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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

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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

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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.

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

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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.

Procedures for Manufacturing Fired Bricks

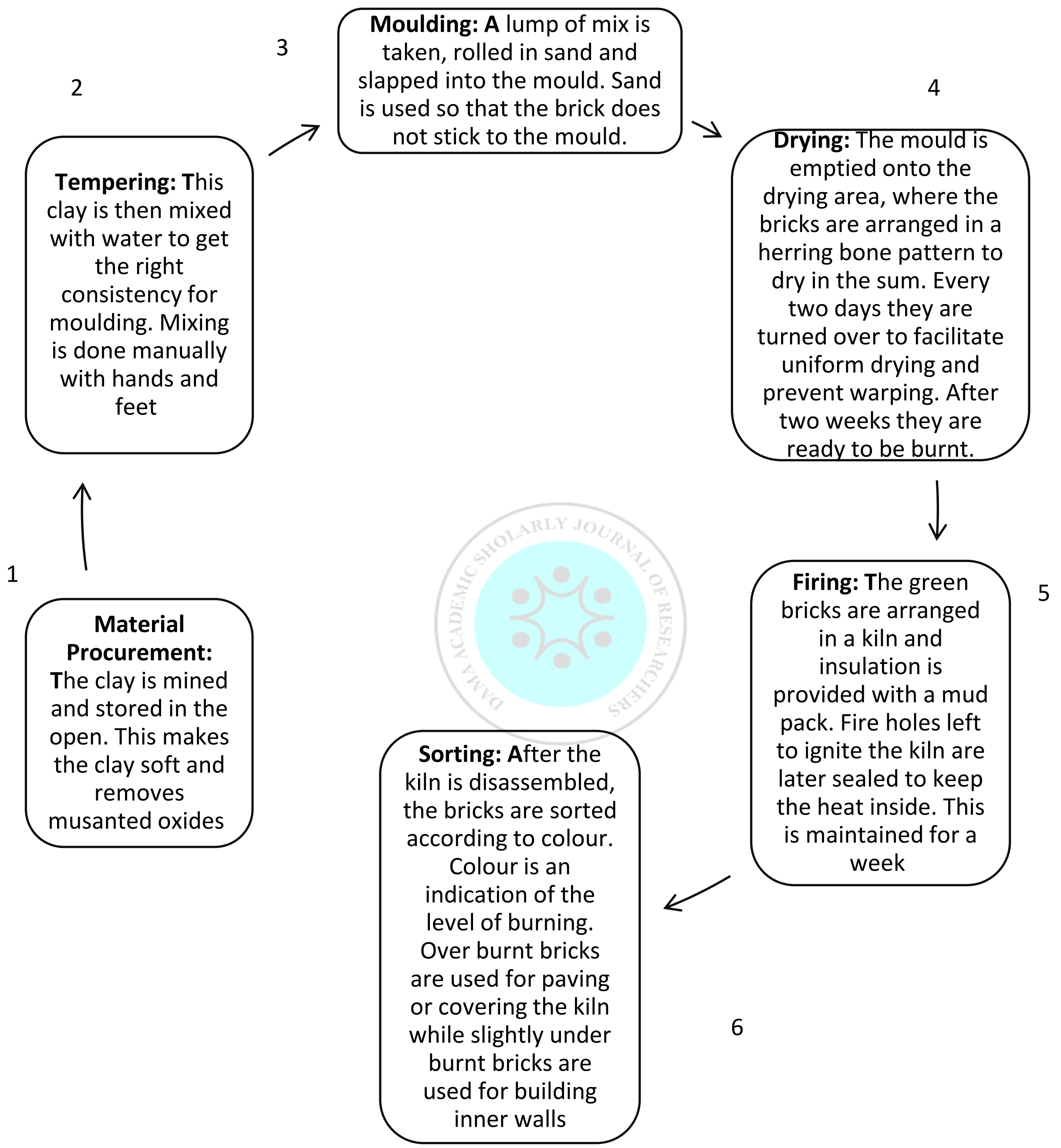

Figure 3.5 Procedures for Manufacturing Fired Bricks.

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

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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.

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

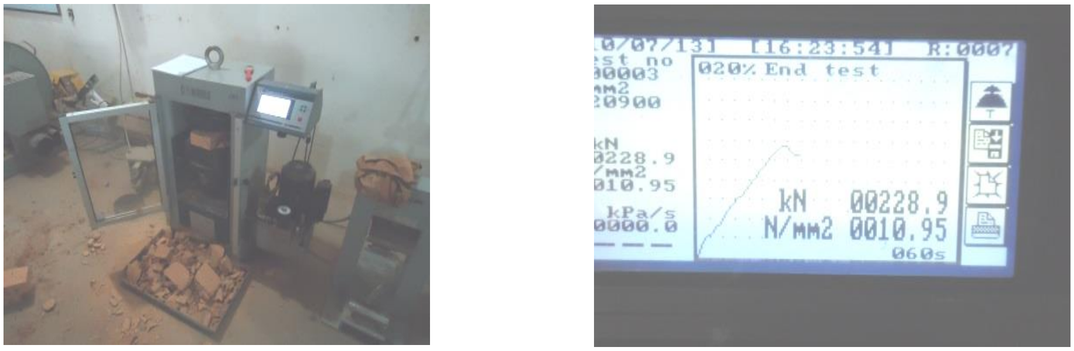

Figure 3.7 Testing Compressive Strength of Bricks and automatic gragh plotted during the test

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.

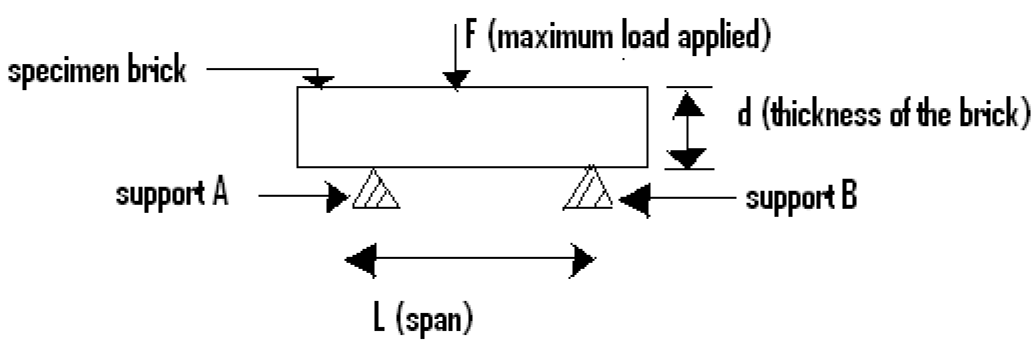

Figure 3.9 Bricks under three – point Bending test

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;

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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 Classification of soil

4.1.1Sieve Analysis

Particle size analysis defines quantitatively the proportion by mass of the various sizes of particles present in the soil. Wet sieve test analysis, sedimentation (Hydrometer analysis) and Atterberg limits were used to classify the type of soil used for the experiments. In accordance with BS1377:2: 1990, section 9.5, the most appropriate method for determining the particle size distribution for all fines (clay and silt) passing through 63um sieve but retained on sieve no. 200 (0.075) is by means of sedimentation (Hydrometer analysis). The results obtained from the dry mechanical sieve analysis tests on the soil and the granite powder are shown in Tables 4.1 and Figure 4.2 respectively.

Table 4.1 Particle Size Distribution for soil.

Sieve Size (mm)	Mass Retained (g)	Mass Passing (g)	Percentage Passing (%)
9.53	0	31.1	100.0
6.35	1.3	29.8	99.81
4.76	2.2	27.6	99.49
2.40	2.4	25.2	99.14
1.20	0.3	23.1	99.14
0.60	0.1	21.1	98.94
0.42	7.1	18.0	84.74
0.30	9.0	9.0	79.06

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0.15	6.3	2.7	69.88
0.075	2.7	1.2	64.00

Table 4.2 Partcle Size Distribution for Granite Powder.

Sieve Size (mm)	Mass Retained (g)	Mass Passing (g)	Percentage Passing (%)
2.40	0	7.1	100.0
1.20	0.5	6.6	99.0
0.60	0.7	5.9	97.6
0.42	0.4	5.5	96.8
0.30	0.8	4.7	95.2
0.15	2.0	2.7	91.2
0.075	2.7	1.2	80.2

For soil and granite powder particles passing through 63µm sieve size, their particle sizes were determined through the hydrometer anaylsis by means of sedimentation. The combined results of both dry mechanical sieve and hydrometer analysis are shown in figures 4.1 and 4.2 for both the soil and the granite powder respectively.

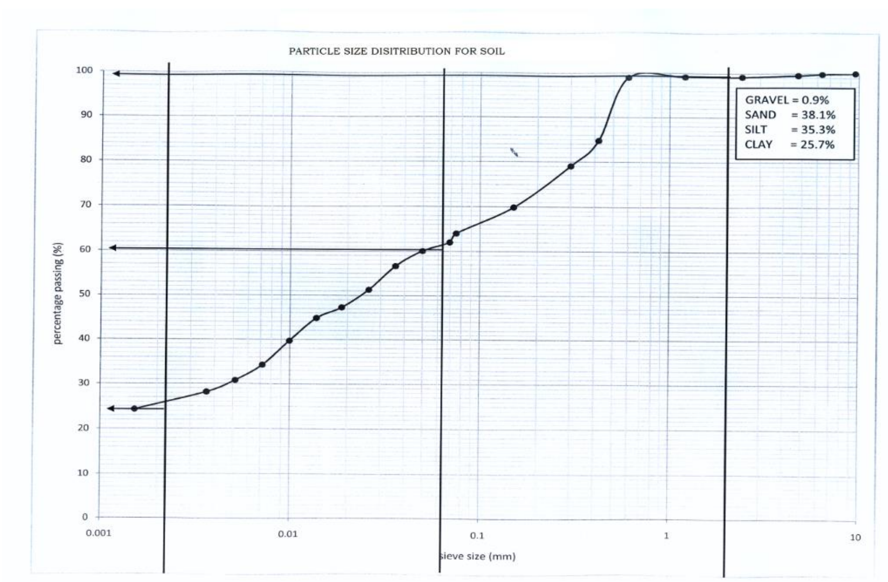

Figure 4.1 Particle Size Distribution for the Soil used.

Table 4.3 Soil Characteristics

Grading Curve	D_{10}	D_{30}	D_{60}	Uniformity Coefficient,Cu	Description
	0.00	0.005	0.049		

From Figure 4.1, it could be seen that D10 which is the particle size corresponding to 10% finer by dry weight could not be obtained for the soil, because, of the presence of over 10% clay size particles for the soil data shown. It therefore implies that using the particle size dimension data (D60, D30, D10), the coefficient of uniformity Cu, ($\frac{D60}{D10}$) and Coefficient of curvature Cc, $\frac{(D30)2}{(D10)(D10)}$could not be calculated.

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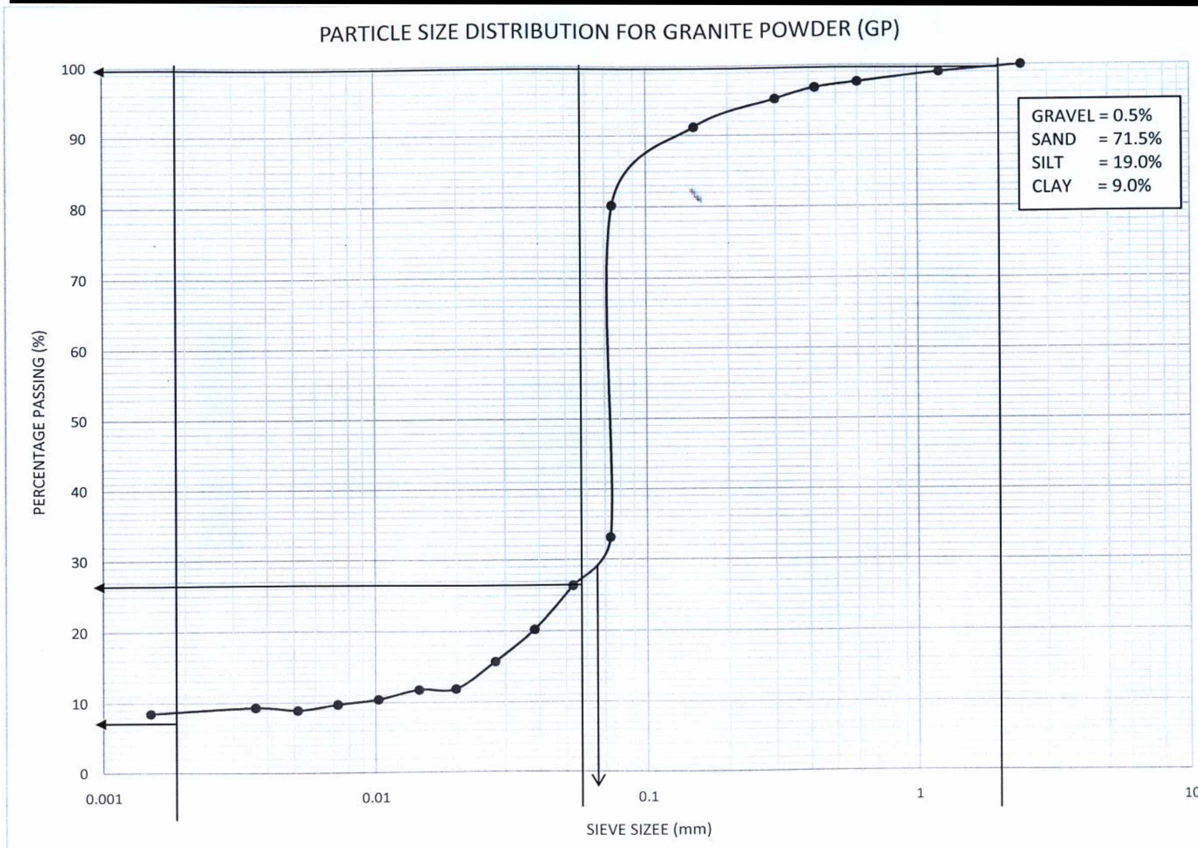

Figure 4.2 Particle Size Distribution for the Granite Powder

Table 4.4 Granite Powder Characteristics.

Grading Cure	D10	D30	D60	Uniformity Coefficient, Cu	Description
	0.010	0.053	0.073	7.3	Not well graded sandy,silty,clayey soil

From table 4.4, the Dust Ratio D_R, the value D_{10}, D_{30} and D_{60} are 0.010, 0.053 and 0.073 respectively. So, the value of coefficient of uniformity Cu (i.e. the measure of the particles size range) from the formula Cu = D60/D10 is 7.3 indicating non-uniformity. The coefficient of curvature Cc (the measure of the shape of the particle size curve) from the formula Cc = $(D_{30})^2$ / (D_{60}) (D_{10}) is 0.20, indicating the granite powder is not well graded. (Note, Cu <5 = Very uniform, Cu=5=Medium Uniformity and Cu>5 = Non Uniform. Cc ranges from 1 – 3 means it well graded).

4.1.2 Result from Sedimentation for the Soil and the Granite Powder

Table 4.5 and Figure 4.1 give the summary of the experimental results from the hydrometer analysis. It could be noticed that the soil used has clay content of 25.7%, 35.3% of silt, 38.1 % of sand and 0.9% of traces of gravels. According to Adeola (1977) soil for burnt bricks production should contain fines (clay and silt) of at least 30% in order to have quality finished products. In all, the percentage of fines (clay and silt) content is summed up to 61% which is far above the one suggested by Adeola.

Table 4.5 Soil Composition

Soil type	Percentage Present (%)
Clay	25.7

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Silt	35.3
Sand	38.1
Gravel	0.9

Table 4.6 Granite Powder Composition

Granite Powder	Percentage Present (%)
Clay	9.0
Silt	19.0
Sand	71.5
Gravel	0.9

From Table 4.6 and Figure 4.2, it is observed that the granite powder used contains 9.0% of clay, 19.0% of Silt, 71.5% of sand and 0.5% of traces of gravels

4.2 Compaction Test for Optimum Moisture Content (OMC) Determination

The laboratory compaction test is the process of compacting a soil at known water content into a mould of specific dimension using determined compaction energy. A repeated process for various water content enables a well-defined compaction curve to be established from which the optimum moisture content is determined. Table 4.12 shows the results obtained from the compaction test conducted on the soil used for the study and it is graphically represented in Figure 4.5. Refer to Table B5 in the appendix for the detailed result on this experiment.

Table 4.12 Compaction test results on the soil.

Water content (%)	Dry density (g/cm^3)
4	1681
8	1733
13	1712
19	1493

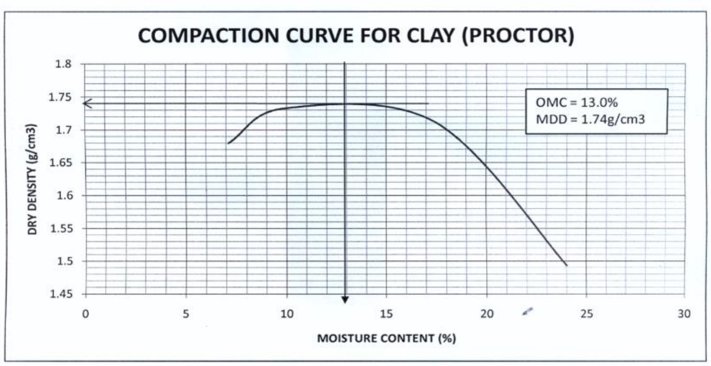

Figure 4.5 Compaction of the Soil.

5.0 DISCUSSION & ANALYSIS

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

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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 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.

5.2 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.

5.3 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^{0}C. 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.

5.4 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.

5.5 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

5.6 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,

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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.

5.0 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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