STRUCTURAL PROPERTIES OF GROUND PALM KERNEL SHELL (GPKS) MASONRY UNITS

By

THEOPHILUS ADDO QUAYNOR

BSc. Construction Technology

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DECLARATION

I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person nor material which to a substantial extent has been accepted for the award of any other degree or diploma at Kwame Nkrumah University of Science and Technology, Kumasi, except where due acknowledgement is made in the thesis.

THEOPHILUS ADDO QUAYNOR		
(PG1885117)	**………………….**	**……………………….**
Student's Name and ID	Signature	Date

Certified by:

DR. ALEX ACHEAMPONG	**…………………….**	**……………………..**
Supervisor's Name	Signature	Date

Certified by:

PROF. BERNARD K. BAIDEN	**……………………..**	**…………………….**
Head of Department	Signature	Date

ABSTRACT

The study aims to assess how the partial replacement of sand with Ground Palm Kernel Shell (GPKS) affects the physical and other properties of masonry units. The experiment showed, the acceptable GPKS aggregate percentage that can be used for the production of masonry units, 10% - 30% GPKS aggregate replacement is acceptable for the production of 150mm thick solid masonry units and 10% - 40% GPKS aggregate replacement is acceptable for the 125mm thick solid masonry units, 150mm and 125mm thick cellular masonry unit. Also it showed that, the increasing quantity of GPKS aggregate increases the water demand of the mix and this often increased the porosity and water absorption rate of the masonry unit with 40% GPKS aggregate. Generally, porosity, water absorption and capillary action decreased with increasing sand quantity and the water absorption rate of the masonry unit with GPKS aggregate was much slower than that of masonry unit with 0% GPKS aggregate (Control sample). Again it was revealed that, the increase in water demand was as a result of the increase in GPKS aggregate which reduced the workability, hence the demand for more water. Increasing GPKS aggregate content measuring above 30% also reduced the mechanical properties of 150mm and 125mm solid masonry units with GPKS aggregate type A at the 28 days curing period. The increasing GPKS aggregate content also demand increase in water/cement ratio. The 40% GPKS aggregate type was seen to have influenced the 28 days compressive strength of 150mm and 125mm cellular masonry units. In addition, the compressive strength of all the GPKS aggregate masonry units decreased with the increase of GPKS aggregate replacement percentages as compared to the control samples (0% GPKS). With these finding, it was recommended that, GPKS aggregate percentage content of 10% is optimum as partial replacement for masonry unit production, the grinding of GPKS aggregate should be controlled in the way that the particle size distribution curve would fall within the upper and lower limits in relation to standard grading requirement and the best standard sizes that can withstand all the adverse condition was 150mm and 125mm, both solid and cellular with GPKS aggregate type B percentage content of 10%, 20% 30% and 40%.

Keywords: Cellular Masonry Units, Water absorption, Compressive Strength, Ground Palm Kernel Shell.

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DEDICATION

I dedicate this thesis to the Almighty God and my entire family.

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CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND STUDY

Conventional materials such as cement, sand and quarry dust are used for the production of masonry units and bricks as walling and paving units. Sand has become a needful natural resource material for any construction work. The use of sand as a component in various construction materials dates back from centuries and its increasing dependence on sand has been a major challenge for the construction industry in recent times (Gavriletea, 2017). The increasing cost of conventional materials has forced the hands of researchers around the globe to seek out material alternatives available and capable for the production of walling and paving units (blocks / bricks), especially industrial waste, construction waste and that in agriculture. Wood ash, Coconut shell, Rice husk ash, concrete waste from demolition, Palm kernel shells and Sawdust are some of the alternative local materials which have been studied (Cheah and Ramli, 2011; Ali et al.2013; Antiohos et al. 2014; Gastaldi, et al.2015; Muntohor and Rahman, 2014; Dadzie and Yankah, 2015; Adewole, 2016; Sasah and Kankam, 2017).

A study by Emiero and Oyedepo (2012) also revealed that the use of Ground Palm Kernel Shell (GPKS) aggregate as a building material is not common in Ghana and other parts of the world. The use of GPKS aggregate as an alternative to conventional sand in masonry units production reduces environmental degradation and makes construction sustainable. Osei and Jackson (2012) stated that the use of alternative local materials available to substitute normal materials known for infrastructural development must be economical, easily accessible and to reduce the depletion of fertile agricultural lands. Alengaram et al., 2010 cited in Dadzie and Yankah (2015) indicated that many developing and under – developed countries in Africa, it is cheaper to use industrial waste such as palm kernel shells which is agricultural by- product material in the production of masonry units. This confirms the view of Olutege (2010) that the cheaper and locally available materials should be used for engineering construction to enhance the overall reduction in building cost for sustainable development. Palm kernel shell is usually disposed off by stockpiling in open fields, which impact negatively on the environment (Ramli, 2003), and open burning of palm kernel shell which produces harmful smoke that affects human health is also very problematic (Sumiani, 2006). A more environmentally desirable way of disposing it is to use it as a partial replacement of fine aggregate in masonry units production to alleviate the pressure on the conventional materials. The inclusion of palm kernel shell in masonry unit production may not only mitigate environmental damage, but could also preserve the scarce available natural resources (Muntohor and Rahman, 2014).

1.2 PROBLEM STATEMENT

Presently in Ghana the impact of indiscriminate sand winning and its effects on the livelihood of farming communities due to the depletion of lands for agricultural purposes due to land degradation. The growing demand for these conventional materials such as sand and quarry dust for the production of masonry units for housing development is expected to be scarce in the coming years as a result of over utilization of these natural resource (Dadzie and Yankah, 2015).

Sand as a conventional material is posing serious problems with respect to its increasing cost and sustainability for infrastructure development to the construction industry. The quest to reduce the use of these conventional building material has brought up the need for an alternative, non - conventional local materials to meet the desired sustainable development of affordable housing (Alengaram et al., 2010).

The increasing production of palm oil in the past three decades in Ghana is one of the major contributions to the environmental issues. Since palm kernel shell waste disposal has not been well managed, they are dumped near the factories as large volumes are produced every day (Dadzie and Yankah, 2015).

The annual production of crushed rock aggregates by a company in Ghana is about 102,000 cubic metres (m^3). With 178 registered quarry companies in Ghana, annual national consumption of crushed rock aggregates is about 18.33 million cubic metres (m^3) (Adinkrah - Appiah and Adom - Asamoah, 2015; Adinkrah – Appiah et al., 2016).

The United Nations Sustainable Development Goal 9, hinges on Building robust structural development, promoting broad workable economic development and adoptive modernization. However, SDG report 2017 shows that in current past, progressive development have been made in the areas of maintainable growth including physical facilities. Nevertheless, funds are required to build infrastructure in developing countries to ensure doubling of physical facilities in these countries by 2030 through technological development, research and innovation (Sustainable Development Goals Report, 2017)

Sustainable Development Goal 12; aims to safeguard against land degradation and excessive natural materials utilization. The goal assesses and regulates materials utilization to facilitate effective use of natural materials and management, with minimum effect on the human livelihood. Maintainable manufacturing with less materials for the same worth of cost - effective product, and minimize excessive depletion of natural materials. This requires policies to safeguard materials utilization and manufacturing that are incorporated into national and sectorial programmes, based on maintainable activities and life style of consumers (Sustainable Development Goals Report, 2017)

Currently, the increasing use of sand (fine aggregate) for mortar, concrete and sandcrete blocks has been a grave concern to the construction sector, since the material would face possible shortage in the near future (Oyebade and Anosike, 2012).

The SDG 15; focuses on Protecting, restoring and promoting maintainable use of natural ecology, manage forests sustainably, eliminate desertification, and stop land degradation and biodiversity loss. According to SDG 2017 Report, almost one fifth of the land surface vegetation has been loss from 1988 to 2013, as a result of land degradation which affect the safety and growth of every country (Sustainable Development Goals Report 2017)

The utilization of agricultural by - product or non - conventional materials has been encouraged for the production of masonry units, because it can help in reducing the use of conventional materials such as sand and quarry dust. The successful use of GPKS aggregate as partial replacement of sand in masonry unit production would help the construction industry in affordable housing development (Oyedepo et al., 2015)

A good masonry unit has to satisfy certain performance requirements in terms of strength, durability and minimum level of water absorption. Masonry units play an important role in the improvement of building facilities, resulting in the increasing use of huge volumes of sand and quarry dust.

Considering this, investigating alternative cost — effective materials both suitable and accessible within the reach of ordinary people has become an interest of researchers. Therefore, this study investigates the structural properties of partial replacement of sand with Ground Palm Kernel Shell (GPKS) in masonry units.

1.3 RESEARCH QUESTIONS

1. What are the desirable properties of GPKS aggregate?
2. What are the effects of GPKS aggregate on structural properties of masonry units?
3. What is the compressive strength for different proportions of GPKS aggregate on masonry units?
4. What are the desired influence of masonry unit sizes produced with GPKS aggregate on strength properties?

1.4 AIM OF STUDY

The aim of this study is to assess how partial replacement of sand with Ground Palm Kernel Shells (GPKS) affect physical and mechanical properties of masonry units.

1.5 OBJECTIVES

1. To analyze the acceptable percentage of Ground Palm Kernel Shells that can be added to sand for masonry unit.
2. To evaluate the physical properties of Ground Palm Kernel shell masonry units with respect to water absorption, weight and density.
3. To determine the influence of masonry unit sizes produced with GPKS aggregate on strength properties.
4. To assess the compressive and flexural strength of GPKS solid and cellular masonry samples.

1.6 SIGNIFICANCE OF THE STUDY

Sand mining has become a serious environmental problem with respect to its sustainability for infrastructure development.

The study also seeks to minimize the use of conventional materials for the production of masonry units and encourage effective utilization of agricultural waste by - products for sustainable development.

The research finding will serve as a useful reference for the construction industry to use GPKS masonry units and paving blocks for building and paving works. Finally, the positive results of this study will enable the use of GPKS aggregate as a partial replacement for sand in the moulding of masonry units, without damaging its properties and reducing the environmental impact of sand mining and add up to the existing knowledge.

1.7 RESEARCH METHOD

Experimental study was conducted on partially replacement of sand with ground palm kernel shell (GPKS) aggregate in masonry units production. This consist of the impact of the materials used, different mix proportions with respect to the mix design results, moulding of masonry unit samples and testing. Finally, the test results were compared to that of conventional masonry unit sample in terms of weight, density, and water absorption, compressive and flexural strength.

Other studies conducted on Ground Palm Kernel masonry units did not adopt the use the actual standard sized masonry unit. The solid cubes used were not standard solid and cellular masonry units. However, in this experiment, the actual standard size of 455mm x 220mm x (150, 125) mm and 400mm x 190mm x (150, 125) mm solid and cellular masonry units which is preferred by the construction industry due to its economy of use was adopted. The research methodology is further discussed in Chapter three.

CHAPTER TWO

LITERATURE REVIEW

2.0 INTRODUCTION

The purpose of this chapter is to position the study in a proper context by reviewing some of the existing literature related to the research. Issues addressed in this chapter include definition of masonry unit and durability, over use of sand quarry dust, overview of sand mining activities, effects of sand mining on live hoods and the environment, positive effect of sand mining and palm kernel shell as an alternative to conventional sand in masonry units production. Information published from experiments regarding the percentages of PKS that can be used for masonry units production. The literature review of this study brings to light the previous studies on PKS as sand replacement in the production of masonry units to serve as a guide to the researcher.

2.1 OVERVIEW OF PALM KERNEL SHELL (PKS)

Palm oil production has increased over the past three decades in the world. The total production of palm oil has been estimated to about 45.1 billion tons for the year 2009 – 2010, with Indonesia and Malaysia producing about 85% of the total production and the other tropical countries producing 15% including Ghana and Nigeria (World Growth). Recently, because of the growing environmental concerns of the increasing levels at which agricultural waste are being creäted has been a global issue. Therefore, the need to manage palm kernel shell as agricultural by-product for sustainable development (Muntohar and Rahman, 2004).

Two primary types of oils can be extracted from the palm nut. They are the palm oil and the palm kernel oil. The former is derived from the nut’s outer core while the latter is derived from the inner. Palm kernels do possess the palm kernel shell which is a hard endocarp covering. This shell is popularly referred to as the oil palm shell (Olanipekun et al., 2006; Pantzaris and Ahmad, 2001). For the past decade, researchers have been making use of palm kernel shells as unorthodox materials to supplant traditional materials like fine aggregates (sand) and coarse aggregates (stone) in structural elements and road construction in Africa and Southeast Asia.(Mannan et al., 2006; Ndoke, 2006; Teo et al., 2006; Okpala, 1990) Palm kernel shells are one of the wastes produced after processing and extraction oil as an agricultural by-product material which is normally treated as a waste with no economic value.

The shell is like a porous stone, grey or black in colour, flaky and irregular in shapes based on the breaking form of the shell (Mohammed et al., 2011). The outsides of the shells are equally suave for both concave and convex faces. Generally, the cracked pieces are irregular and spiny. The palm nut from which these palm nuts are sourced from is a major determinant of their eventual sizes. As such variety occurs in size spanning between 0.15 and 8mm (Basri et al., 1999; Okpala, 1990)

Palm Kernel Shell (PKS) is a derivative from the extraction process of palm oil at the mills. It is a waste product as palm nuts are crushed. Research points to South East Asia as the most PKS producing location on earth. 4 million tons of this waste product is produced in Malaysia on a yearly basis. Giving due consideration to this, the evidence points to PKS as a cost-effective waste material that can be used on construction projects as compared to other wastes like plastic, rubber, and others. Further research concludes that giving due considerate design of concrete mix, concrete strength of 20 to 30 MPa can be obtained. These studies also stress on the reduced weight effect this material will add. In the 1984, this research was first conducted. It stirred quite the change in the construction industry. Mannan et al., (2006) compounded this by maintaining in their research study that PKS was suitable for low cost construction works since it was able to reach a strength of $18N/mm^2$ in compression. Making use of PKS in itself is profitable way to get rid of PKS as waste material. This research work centers on how the properties of PKS will better improve workability, density, water absorption, compressive strength and others in masonry units. Palm kernel shell is the hard endocarp of palm kernel fruit that surrounds the palm seed. It is obtained as crushed pieces after threshing or crushing to remove the seed which is used in the production of palm kernel oil (Olutoge, 1995).

Palm kernel shells are organic waste materials obtained from crude palm oil producing factories in Asia and Africa. Other researchers have used Palm kernel shells as lightweight constituent to manufacture lightweight concrete. The palm kernel shells were used subsequently after eliminating the dirt and fibres, with the proportions used sorted from 2mm to 5mm subject to the equipment used to crash the nut shells (Alengaram, et al., 2010).

2.2.1 THE GENERAL USE OF PALM KERNEL SHELL

According to Eziefula et al. (2017), Palm Kernel Shell is useful in meeting the rising global demand for cost-effective and non-polluting materials. PKS also contributes to fostering the growth of any economy, maintain competition, and to provide alternate materials for construction projects. Well, in the production of palm oil, quite the number of waste is produced: Palm kernel shell, palm kernel ash and fruit branches. Several countries prefer to pile these wastes in land-fields. This obviously is detrimental to the environment. And knowing that these wastes, particularly palm kernel shell can be used as a substitute for construction materials such as cement and aggregates complicates things. PKS has the potential to reduce construction cost. In doing so be disposed of in the process. Utilizing it this way preserves resources and benefits the environment. Agricultural wastes like PKS has much untapped engineering potential as a substitute for cement or aggregates, and by being an economic benefit, particularly in lightweight non-load bearing concrete works where compressive strength is negligible. Previous research study have indeed pointed to PKS as being useful to lightweight concrete works. The compressive strength derived from the use of palm kernels in lightweight constructions meets the requirements for lightweight concrete. However, a greater range of strength is needed for medium strength structural member (Eziefula et al, 2017). PKS failure in concrete beams showed a ductile behavior. Moreover, PKS gave concrete a lower modulus of elasticity when compared to orthodox means. Yet, PKS in concrete exhibit enough strength to be used as a structural lightweight. In 2011, Shafigh et al in a report stated an unconventional and new manner of producing lightweight concrete made of PKS. The oil palm shells had been crushed and that these crushed oil palm shells allowed better physical bond with the cement paste. Moreover, in the report, a low cement concrete could be produced from these Palm Kernel Shells.

2.2.2 Sources of Palm Kernel Shells

The source of Palm Kernel Shell is the palm tree. The palm tree is of two varieties – Durà, and Tenerà. The palm fruit is edible and it nature is similar to an apricot. The flesh of the fruit is melted off during this crude palm oil process. The initial step is called the steaming treatment. The nut which remains is crushed to extract the kernel inside. The kernels gotten are what is called palm kernel shells. This crushing process is done at the factories as part of the palm oil extraction procedure. The shells or kernels are then piled in a heap at a distant location which is eventual set ablaze.

The palm trees (elaeis guineensis) from which palm kernel shells are gotten are found in West Africa and spreads widely across the tropics. They thrive in the rain forest regions at the coastal areas and along waterways inland.

The oil palm tree generally grows in the rain forest region close to the coastal areas and adjacent to some inland waterways. By nature, these kernels come in various sizes and shapes; they are light in weight. They are a good alternative to construction aggregates in construction lightweight structures. Yet, their use still remains uncommon in the construction industry. This can be attributed to two reason: they occur is less quantities or their use as aggregates is widely discouraged.

In Ghana, these are some of the places where palm kernel shells are found in abundance; Benso oil palm plantation in the western region, Twifo oil palm plantation in the central region, Ghana oil development corporation, Kade in the eastern region (Acquah., et al, 1999). There are also small scale oil producers who also produce considerable quantity of palm kernel shells. These include palm oil producing site at cape coast Abura, Ameen Sangari cape coast and Methodist oil factory at Assin Nyankomase near Assin Fosu (Personal visits).

2.2.3 Types of Palm Kernel Shells

According to Owolarafe et al., (2007), Dura and Tenera are the main varieties of palm fruits. In Nigeria, an estimate of 1.5 million tons of PKS is produced every year. The Dura is characterized by a thick exocarp ranging from 2 to 8mm. The nature of its mesocarp can be credited for this variety's low palm oil content. It takes up 35 – 55% of the entire fruit. Lastly, Dura's endocarp is large, making it ideal for PKS production. The Tenera, however, has thicker mesocarp, thinner endocarp but a well-sized kernel. It makes a good choice for producing mesocarp oil, both so with the kernel oil in contrast to the Dura variety. The Tenera is the preferred choice as planting material. It yields much palm oil than the Dura. Since both palm oil and palm kernel can be extracted from the Tenera and Dura, it becomes imperative to characterize the fruits with a view to understanding the properties that may affect the design of machines to handle the processing of the fruits. Such physical properties as size, shape, spherical, aspect ratio, true density, bulk density and porosity, and mechanical properties such as coefficient of friction angle of repose as well as fracture resistance are very important in the design of processing machines for major agricultural crops (Owolarafe et al., 2007).

2.2.4 Production of the Palm Kernel Shells in Ghana

Large volumes of palm kernel shells produced as waste yearly from the palm oil extraction process. In the year 2020, it expected that 5 million hectors of palm trees would have matured in Malaysia (Ramli, 2003). This corresponds to both increases in palm oil and palm kernel shell production. Given these large quantities of PKS, it becomes critical that some beneficial use such as serving as alternative material for construction aggregates be adopted. Not only will it benefit the environment but it serves the economy as well.

At the Institute of Industrial Research on raw materials, studies were conducted and much of it was centered on wastes such as palm kernel shells, sawdust and coconut shells. In the Ashanti region, Juaben is the primary area producing these wastes. In Western region, it is Benso, Ayiem, Axim and Shama. In the Eastern region, it is Kade. In the Central region, it is Asuansi and Assin Nyankomasi. In the Volta, it is Akame. Palm kernel shells and coconut shell production is basically a function of palm oil and palm kernel oil production as well as coconut oil production respectively. Small scale production of these oils are widespread across the nation. However, the industries do engage in palm oil production. The palm kernels and shells becomes easy to access since these industries do break open the nuts to get to them. The factories go ahead to process further the kernels and proceeds to dispose of the shells as waste. In contrast, coconut shell wastes are not localized like that of the palm kernel shells. They are wide spread across the country which makes their collection complicated. Both shells can be sold by these small scalers as fuel. And they sell between ¢18 and ¢25 for entire peace of dry pod for coconut shells whiles the palm kernel sells for ¢2000 for a bag. Within the factories, however, only 5% of kernel shells are produced while the remainder is set ablaze to provide heat for the boiler. Acquah et al. (1999) said that rest of the waste dumped could be used for activated carbon production at no cost.

Table 2.1. Palm kernel shell generation of some established factories in Ghana.

Factory	Location	Annual shell generation (in tons)
Benso oil palm plantation (BOPP)	Benso (Western region)	4000 – 5000
National Oil Palm Plantation	Ayiem(Western reg.)	1600
Ghana Oil Palm Development Corporation	Kwae(Eastern reg.)	3000
Ghana Oil Palm Development Corporation	Kade(Eastern reg.)	5000 – 6000
Twifo Oil Palm Plantation (TOPP)	Twifo Praso (Central reg.)	4000 - 5000

Source, Acquah, et-al, (1999).

2.2.5 Methods of Cracking the Shells

In Ghana, the production of palm kernel shell starts with the cracking of palm nuts. After the cracking, the kernels are separated from the shells. The remaining shells are either heaped at a place, burnt or used as landfill material. The cracking of the palm nut can be done in two ways. These are;

1.The manual method or

2.The mechanical method

2.2.5.1 Manual method of cracking

This method is employed when small quantity of palm kernel is needed. It is mostly carried out by women in the rural production areas in Ghana. The nuts are heaped at a place and the people who are going to crack sit around with two stones. The nuts are placed on one stone which is big and the other stone is used to hit the nuts on the big stone to crack them. After the cracking, the people separate the shells from the kernel by a method of hand picking. This method of separation gives clean shells and kernels. The separation of the kernel and the shells could also be done by floating method. In the floating method, clay is mixed with water in a tank. The cracked nuts are added to the mixture. Since the shells are denser than the kernel, they settle with the clay while the kernels float. The picking of the kernels is done by stirring the mixture intermittently to bring up the kernels trapped by the clay. In this the clay coats both the shells and the kernels which would need washing before using them (Palm kernel oil producer, Twifo Praso).

2.2.5.2 Mechanical method of cracking

In this the heaped palm nut are cracked with a machine. After cracking the separation is done in the same way as that of the manual method. In advanced countries like Nigeria and Malaysia there are machines which do the cracking and separation at the same time. Developing countries like Ghana are yet to acquire this type of machine by palm kernel producing factories (Tang and Teoh, 1995).

2.2.6 Supply of Palm Kernel Shells

In west Malaysia a research was conducted by Forest Research Institute and found out that, the supply of palm kernel shells to both Rawang Plant and Kantang Plant had been erratic and inadequate to meet the replacement need of fossil fuel by palm kernel shell in 2005. This market study was done based on the current supply behaviour of palm kernel shell traders and the ability of palm oil mill operators to supply Palm Kernel Shells. Palm Kernel Shells production is assumed at 6% by weight of the tonnages of fresh fruit bunches produced. The Malaysia Palm Oil Board (MPOB) publishes the Fresh Fruit Bunch figures on a monthly basis. For year 2004 the total Fresh Fruit Bunch production and processed amount was 42.1 M tons for West Malaysia giving a Palm Kernel Shells production of 2.52 M tons. Of this volume, it is estimated that 50% of the Palm Kernel Shells was consumed by palm oil mill boilers as its primary fuel, 20% is inaccessible due to logistics, 20% is supplied to other heat consuming industries and only 10%, or 252,000 tons are available for Lafarge Malaysia Cement Bhd. Rawang Plant and Kantang Plant, Annual Palm Kernel Shells requirement is about 90,000 tons (inclusive of 8,000 tons for stock) for its fuel replacement needs of 8% and 5% respectively. This requirement is about 3.56% of the total Palm Kernel Shells production by the oil palm industry.

In 2004 the supply of Palm Kernel Shells to both Rawang Plant and Kantang Plant was 36,200 tons against the requirement of 143,000 tons for fuel replacement of 12 %. In 2002 and 2003 the delivery of Palm Kernel Shells was 70,500 tons and 86,000 tons respectively. As fuel oil and diesel prices continued to escalate the other heat consuming industries are increasingly using Palm Kernel Shells as their alternative fuels.

In 2004, the traditional Palm Kernel Shells suppliers to Rawang Plant and Kantang Plant found the new market was, and still is, very attractive with Palm Kernel Shells (delivered) price above RM 80 per ton while Rawang Plant and Kantang Plant prices were still maintained at about RM 60 per ton. The reluctance of suppliers to enter into short term supply contract with LMCB resulted in uncertainty of Palm Kernel Shells supply to both the Plants. When the price of Palm Kernel Shells offered to current suppliers was increased from between RM65 to RM 70 per ton the supply to Rawang Plant showed some improvement. The total Palm Kernel Shells delivered for 2005 was 33,520 tons and 7, 595 tons by the 6 and Palm Kernel Shells suppliers to Rawang Plant and Kantang Plant respectively.

As price is the only success factor for adequate supply of Palm Kernel Shells to the Plants it is critical to establish well-coordinated purchasing by Procurement. This coordinated purchase was achieved with great success in 2001 and 2002 with the delivery of Palm Kernel Shells to the plants exceeding 100,000 tons. With good Palm Kernel Shells management and with aggressive purchasing strategy an annual Palm Kernel Shells delivery of about 90,000 tons is achievable and deliverable. (source)

The mills burn at least 50% of the Palm Kernel Shells produced as its primary fuel, and another 20% is estimated to be lost due to spillages, losses in production, poor quality, logistics and inaccessibility to palm oil mills, full consumption by some mills and etc. The remaining 30% is assumed to be available in the market. The estimated current Palm Kernel Shells volume was 276. Nevertheless, there is no study ever conducted to confirm how much Palm Kernel Shells is actually available in the market. Such study will entail extensive market research on consumption of Palm Kernel Shell by other consumers (Harris, 1995).

Table 2.2 Palm Kernel Shells Received / Consumed from 2000- 2005.

Year	**Received Rawang**	**Consumed Rawang**	**Received Kanthan**	**Consumed Kanthan**
2000	63,174	26,558	37,415	20,842
2001	24,519	41,700	31,466	32,896
2002	32,524	42,195	38,026	51,526
2003	42,154	42,470	43,813	44,618
2004	26,116	25,713	10,471	7,772
2005	33,520	36,443	7,595	7,455
TOTAL	**222,007**	**215,079**	**161,191**	**165,109**

Source: Harris, (1995)

The use of Palm Kernel Shells has risen in the years past. These palm kernel shells are collected by companies together with other biomass at the factories and distributed to industrial buyers. In 2000, using PKS for industrial purposes was restricted giving it a reduced value. However, increasing buyers are emerging to purchase PKS giving it greater value. They have used as fuel source.

The prices for Palm Kernel Shells are gradually tracking along that of oil prices. In last five years, oil prices have increased 300%. The PKS prices have risen similarly. Industries that previously generated steam with diesel and fuel oil are among the prominent industrial buyers of PKS. They have biomass boilers intending to cut down cost. However, the exorbitant prices of diesel and oil are forcing them to seek out Palm Kernel shells as fuel so for which they willing to pay higher prices (Wambeck, 1999)

2.3 PREPARATION OF PALM KERNEL SHELL AS COARSE AGGREGATE

Preparation of Palm Kernel Shell is done by drying, sieving and washing the aggregates with detergents in order to remove dust, oil and mud particles that adhered to the surfaces of Palm Kernel Shell. After washing, the shells are air dried and then stockpiled. Due to the high-water absorption of Palm Kernel Shell (about 25%), pre-soaking of aggregates for about 45 min to 1 hour is mandatory. The absorption during this period of pre-soaking is determined and finds to be in the range of 10 to 12%. Particles with size less than 3.35 mm were removed and not used in mixes due to large relative surface area and high absorption.

2.4 PHYSICAL PROPERTIES OF PALM KERNEL SHELLS

Palm Kernel Shells possess hard characteristics as coarse aggregates. Abdullah (2003), Okafor (1988), Okpala (1990) and Basri et al., (1999) have made attempts to use Palm Kernel Shells as coarse aggregates replacing normal granite aggregates traditionally used for concrete production. (Okafor, 1988; Okpala, 1990) in their investigations found out that, the specific gravity of Palm Kernel Shells varies between 1.17 and 1.37, while the maximum thickness of the shell was found to be about 4mm. Palm kernel shells have smooth and concave and not excluding convex surfaces which are likely to affect the bond matrix with cement.

Shells are one of the wastes produced during processing of palm oil. They range in colour from dark grey to extreme black. The shells could come in shapes of angular nature or perhaps polygonal. Much of this depends on the pattern at which the nuts do break. On both faces of the shells, the convex and concave faces, they are fairly smooth. Nonetheless, there are rough and spiky edges at the broken edge. As already pointed out, thicknesses differ contingent on the specie from which the nut is derived. The ranges are between 0.15 and 8m (Basri et al., 1999, Okpala, 1990).

Within the span of 24 hours, these shells have the capacity to absorb water about 21% to 33% making them more absorbent of water than gravel aggregates. The latter has a water absorption capacity of less 2% (Neville, 2008). The increase pore content of these shells could be credited for their absorbing abilities. Okpala (1990) noted in his report that the shells do have porosities of 37%. The good news is improvements can be made to the quality of these palm kernel shells. Mannan et al. (2006) advised on the use of pre-treatment methods

A high pore content could be credited for the absorption capacity of the shells. Okpala (1990) stated in his report that the shells can have a porosity of even 37%. Mannan et al. (2006) advised that to make improvements to the quality of palm kernel shells, one could use pre-treatment methods. The pointed to the use of poly vinyl alcohol, 20% of it, as a PVS solution. This will have the effect of reducing the absorption of water from 23.3% to 4.2%.

The bulk densities of palm kernel shells, both loose and compacted densities, ranged from 590 to 740 kg/m3. Much of this is due to the shells' higher porosity. Also, the specific gravity spans a range of 1.14 to 1.62. These facts in density indicate that palm kernel shells are lighter than traditional coarse aggregates, 60% lighter. These range of densities means that PKS do fall within the typical density for lightweight aggregates (Okpala, 1990; Okafor, 1988). The shell of palm kernels are hard and resist deteriorating. These shells were tested against crushed stone on the Los Angeles abrasion test. Palm kernel shells were found to be 4.8% and that of crushed stone was 24% (Basri et al., 1999). That is significantly lower that these aggregates and possess great resistance to wear. In addition, PKS had aggregate impact value and crushing value lower than that of traditional coarse aggregates. The underlying significance is that PKS do have excellent absorption capacity to shocks (Teo et al., 2007. Okpala (1990) reported that the indirect compressive strength test of palm kernel shells aggregate was 12.10MPa with a standard deviation of about 2MPa.

The present study aims to investigate the physical properties and the use of palm kernel shells as coarse aggregates in the production of lightweight concrete.

2.5 DEFINITION OF MASONRY UNIT

Masonry units are made from sand, cement and water. In Ghana, masonry units have an appeal to the construction industry as walling units, mainly due to its ease of manufacture and the availability of sand as the main material component for its production (Andam, 2004). Sand used for masonry units production must be free from silt, clay, dirt and organic materials that will affect the quality of masonry units produced. The National Building Regulation LI.1630:1996, clause 29(1) and (2) noted that any material used in the erection of building shall be of suitable nature and quality for the purposes and conditions in which they are to be used. Section (2) states that, the use of any material should conform to an approved Ghana Standard Code of practice. Masonry units contain about 80% of sand. River sand is used extensively in preference to other sources of sand, particularly the type of sand that is obtained from agricultural lands, along road sides or from drains. The reason for this is that sand obtained from river is already washed and, therefore, contains less silt and other impurities than sand collected from drains which may require washing before use (Bamfo-Agyei, 2015). This makes masonry units beneficial material in building sector (Baiden and Tuuli, 2004), masonry units are relatively cheap when compared to other construction materials. Masonry units provide excellent resistance to damage without any added cost of protection device. They do not rust, decay or provide a home for damaging insects as other building materials. They do not contain any material that is hazardous to the environment (Odeyemi, 2012).

2.6 DEFINITION OF DURABILITY

All building materials must have resistance to weakening and disintegration. BS 7543: 1972 defines durability "as the ability of a building and its parts to perform its required function over a period of time and under the influence of disintegrating agent". While BSI CP3, 1950, defines durability as the inverse measure of the rate of deterioration of a material or component. Kerali (2001) pointed out any definition on durability must be circumscribed to these three key parameters. They are the standardized condition of the material's use, the function of the material, and the time required for the material to fulfill its function.

I. The function intended of a masonry unit depends on the degree of exposure conditions, being it internal or external masonry unit. The characteristics of masonry units are strength, dimensional stability and resistance to weathering (ILO,1987; Carroll, 1992). The quality of materials and manufacturing process used in the production normally affects the properties of the masonry unit (Webb, 1988). It is very important to note that the intended function of a masonry unit is its ability to sustain a distinctive characteristic under service conditions for the service lifetime of a structure. The properties variations of a masonry unit may be due to the evolution of the fabric of the masonry unit as it undergoes changes as a result of exposure conditions. The changes can lead to loss of performance, indicating that every material has its durability limits. The durability limit is the point at which loss of performance leads to the end of the service life of a material (BS 7543-1992).

II. Standardized conditions of use have to be included in the definition of durability. As masonry units, are used on the exterior of buildings are exposed to physical, chemical and natural elements. These elements can sometimes have deleterious effect on the masonry unit under normal conditions of use.

III. The time the masonry unit is expected to fulfil its intended functions (in the definition of durability) have to be specified more clearly to meet the user requirements. In building structures, the time must be expressed in terms of years of satisfactory life. Guidelines on building life categorisation are provided in BS 7543-1992. These ranges from ten (10) years in the case of temporary buildings to over one hundred and twenty (120) years in the case of high-quality buildings. The effect of exposure conditions leading to loss of performance is likely to be gradual but not abrupt. Since the actual conditions of exposure can have adverse effect on the rate of performance of the masonry units.

Omopariola (2014) also support the idea that the durability of a building is to a great extent determined by the properties of the various components of the building of which masonry units are major.

2.6.1 OVERUSE OF SAND AND QUARRY DUST (FINE AGGREGATES)

The typical aggregates are those of fine and coarse aggregates. The fine aggregate consists of sand and the coarse aggregates are the gravels and stone. The latter vary in shape and size. Fine aggregates can range from sand, crushed stone and crushed gravel. To be classified as fine aggregates, 90% -100% of its particles must pass through a 4.75mm IS. Coarse aggregates however are retained on a 4.75mm IS sieve. These aggregates are extracted in their natural state from rock fragments. They are then washed and separated according to sizes for construction projects. These aggregates are mixed with a binding medium, cement or bitumen to make concrete or asphalt (Adinkrah-Appiah et al., 2016).

It is impossible to construct a building and road infrastructure without using natural aggregate-sand, gravel or crushed stone. The quantity of these essential construction materials used annually across the globe is quiet enormous. The annual extraction of aggregate worldwide for construction projects amount to about 15billion metric tons and this account for about half of the non-fuel mining volume in the world (Adinkrah-Appiah et al., 2016). Aggregates are used to build and maintain urban, sub-urban and rural infrastructures including commercial and residential buildings, sidewalks, parking lots, factories and power generating facilities. However, developing countries cannot sustain their level of productivity and the economies of developed nations cannot expand their infrastructural facilities without the extensive use of aggregate. Ghana is a developing country and in the process of building her infrastructure out of a demand of 70,000 housing units per annum, only about 25,000 to 40,000 are provided, and this has led to a deficit of over one million houses over the past decade (Daily Graphic, 2009). This has cause the annual demand for crushed rock aggregates for national consumption to about 18.33million cubic meters, to help accelerate the rate of housing delivery to bridge the gap between demand and supply of housing and maintaining existing infrastructure (Adinkrah-Appiah et al., 2016).

2.7 OVERVIEW OF SAND MINING ACTIVITIES

Sand mining refers to the extraction and transporting of part of the solid earth such as sand and gravel as raw material for infrastructure development (Salifu ,2016). United Nations Environmental Programme report 1992 indicated that, sand mining has affected lands for agricultural purposes and reduces the productivity levels of farming communities. Globally, terrestrial deposits are the basic source of sand for human activities. These are made up of sand from channels of rivers and residual soil deposits on agricultural lands. Sand can also be extracted from deposits at the shores and from the floors of the ocean bed (marine sand mining), marine sand mining consists of sand dredging from the ocean beds, extracting from beaches and inland dunes (Peck et al., 2010; Phua et al., 2004; Gelabert, 1997, cited in Salifu, 2016). The mining of sand and stone in Ghana dates back from centuries.

However, there are no records about the exact period that sand excavation began in the country (Biney et al. 1993; Sakey, 1991; Biney, 1982). This shows that most of the sand miners do not register their activities. Sand from agricultural lands, forest and coastal land in

Ghana are normally excavated for infrastructural development (Peprah, 2013; Mensah, 1997). This practice if not properly managed results in soil and land degradation. The activities of sand miners are persistent in the country's beaches and farming communities. In spite of the potential dangers associated with sand mining, it has also become a major source of income for a lot of people in the various parts of the country (Mensah, 1997).

2.8 EFFECT OF SAND MINING ON LIVELIHOOD

The effects of uncontrolled sand mining by sand miners has destroyed farmlands and the ecosystem along the Nawuni River, which is the main source of raw water for treatment to the residents of the Tamale metropolis, savelugu / Nanton Municipality as well as the Tolon and Kumbungu Districts in the Northern Region of Ghana.

The Nawuni River faces serious environmental threat from sand miners as a result of siltation which has reduced the capacity of its water holding ability. The more worrying situation is the fact that the silting of the river is posing great danger to the residents. The river's future capacity to supply the required volume of water to about 500,000 people are also affected. The shallowness of the river has also resulted into annual flooding of communities along its banks which sometimes led to loss of life and property. In fact, the reduction in the depth of the river has also reduced the amount of water the river feeds into the Akosombo Dam, the Country's major source of hydro-electric power.

A report by the Ghanaian Developing Communities Association in 2013 indicated that in 29 Communities in the Northern Region, about 190 hectares of land has been destroyed through sand and gravel mining activities which has directly affected 177 families. In addition to that Sixty-Eight percent (68%) of all pits that were never reclaimed were dug by sand miners (GDCA, 2013). According to Lawal (2011), the demand for sand is growing rapidly, while at the same time, its exploitation has become an environmental issue.

The Northern Regional Security Council in 2017 issued a one-week ultimatum to the persons engaged in the illegal sand winning activities at the Nawuni raw water intake point to vacate the area or face the full rigours of the law. The measure was to prevent a looming water crisis in parts of the Northern Region, including Tamale (NRSC, 2017)

In under developed and developing countries, where government often lack the capacity to establish and enforce environmental regulations are usually confronted with illegal sand mining operation leading to environmental issues and threat; therefore, special attention is needed to halt and reverse land degradation in these countries (Gavriletea, 2017).

Salifu (2016) has conducted a study on the implications of sand mining on the environment and livelihoods in Brong Ahafo Region. The communities selected for the study were Chiraa in the Sunyani West District; Bepotrim, Tromeso, Amoakrom and Buoku in the Wenchi Municipality. Nsuta and Mangoase were also selected from the Techiman Municipality. These communities were selected based on their longevity and predominance of the activities of sand mining. The study to a greater extent confirm the trends in the adopted sustainable livelihood framework to recognize the various factors and processes which either constrain or enhance poor people's ability to make a living in an economically, ecologically and socially sustainable manner.

Sand mining was identified to have numerous negative effects on the livelihood of these communities and the environment. In the first place, sand mining led to the reduction of fertile agricultural lands as well as the income levels of the farmers working on such lands. This brought financial hardships to the affected farmers due to the fact that, inadequate or no compensations are paid to them. Further negative effects of sand mining include the destruction of water bodies, deforestation, loss of biodiversity and the creation of gullies on agricultural lands. These damages negatively affected the environment, health and productivity of farmers and the communities as a whole.

It was concluded that in matters concerning sand mining and agricultural activities bothers on sustainability discourse and not trade off issues. However, both economic activities are needed for the overall growth and development of these communities, as well as the region and the country as a whole. The study also indicated that the role of the local authorities in these sand mining areas has failed to enact laws to control the activities of sand mining in these communities. Even when these laws existed, they are not enforced by the regulating bodies. Again, these local authorities neither protected the environment nor offered any assistance to the farmers in these sand mining areas.

2.8.1 EFFECT OF SAND MINING ON THE ENVIRONMENT

The main factors that influence demand for sand are rapid population growth and urbanization has cause the increasing demand for the use of sand for constructional purpose (Gavriletea, 2017). This has made sand one of the major exploited natural resource across the globe with associated adverse effects on the environment (Awudi, 2002, Akabzaa, 2000). The negative impacts of sand mining on the environment include the destruction of water bodies, deforestation, and loss of biodiversity, infrastructure, landscape and soil erosion (UNEP, 2014). The activities of sand mining have led to the destruction of vegetation, agricultural and non-agricultural lands (Aromolaran, 2012; Hedge, 2011). Sand mining along streams has led to the destruction of several hectares of fertile streamside land annually. Other valuable timber resources and wildlife habitats have been lost to the activities of sand mining. Sand miners have created gullies on agricultural lands and forest reserve in several places (Tariro, 2013).

The excavation of sand from the ground destroys the vegetation cover and the soil which serve as the habitat for wildlife. This condition destabilizes the ecosystem of living organisms thereby imperiling their lives (Lawal, 2011). Sand mining can also increase flood frequency and intensity by reducing flood regulation capacity. However, lowering the water table is most threatening to water supply (myers et at, 2000). Lack of monitoring systems, regulatory policies and environmental impact assessments have led to indiscriminate sand mining, causing severe damage to the environment and related ecosystem service (UNEP 2014).

2.8.2 POSITIVE EFFECT OF SAND MINING

Sand has become an indispensable natural resource for any society, since it is used as major

component in various construction material (Gavriletea, 2017). Notwithstanding the numerous challenges associated with the activities of sand mining, it is also believed to have significant contributions to livelihood enhancement and economic development of many nations. It may also appear to be surprising, that countries in the middle East surrounded by desert, import large quantities of sand. In 2012, Qatar imported sand and gravel in the value of about $6.5 Billion (Schoof, 2014).

The value of sand, stone and gravel imported by United Arab Emirates in 2014 was around sector continues to grow rapidly. This has made that country the ninth largest sand importer globally (Swanso$456 million (Churchill, 2016). China's cement consumption between 2011 and 2013 exceeds U.S consumption used in the entire 20th century, even though the rate of china's economic growth was slowing its construction n, 2015). This has made sand mining a major source of employment for many people around the globe (Asha, 2011). The significance of sand to the construction industry cannot be ignored. The activities of sand mining in extracting conventional materials such as sand and gravel that are used for infrastructure development will sometimes bring positive effect on livelihood. It can therefore be argued that without sand mining many development projects could not be implemented (Salifu, 2016). Consequently, many Ghanaians are beneficiaries of employments generated through the activities of sand mining. Among those who earn their livelihoods from the activities of sand mining in Ghana include drivers who operate heavy – duty trucks (Peprah, 2013)

The activities of sand mining are also associated with high lucrative profits which could be used for the betterment of people’s livelihoods (Mensah, 1997). However, the huge income obtained through the activities of sand mining helps to secure the livelihoods of the beneficiaries. Sand and stone mining further leads to increasing sales of water, foodstuffs and high patronage of taxi cabs in areas where these activities occur (Asante et al., 2014).

2.9 STATISTICS OF ANNUAL PRODUCTION OF PALM KERNEL SHELL GHANA

Previous study by Abdullah and Sulaiman (2013), on the oil palm waste in Malaysia indicated that solid waste from oil palm industry consist of empty fruit bunches (EFB), mesocarp fruit fibre (MF) and palm kernel shell (PKS). The palm kernel shell waste is currently underutilized; therefore, developing an alternative use of PKS waste is desirable for both economic and environmental reasons. Presently, PKS waste is used extensively as fuel for steam production in palm oil mills.

The major characteristics the agricultural sector is the production of large volumes of processing wastes that have no economic value. In recent years, the increasing volumes of these wastes has created a serious disposal problem due to the fact that open burning of one of the wastes (PKS) is being discouraged globally (Hussain et al., 2002).

Table 2.3 below shows the breakdown of product and waste from each bunch of fresh fruit.

Products/waste	Percentage by weight to FFB (dry basis)
Palm oil	21
Palm kernel	7
Fibre	15
Shell	6
Empty fruit bunches	23
POME	28
Total	100

Table 2.3 Product and waste from each bunch of fresh fruit, (Hussain et al., 2002).

According to the Oil Palm Development Association of Ghana (OPDAG), the country's oil palm industry has the capacity to meet the local demand, indicating that the existing crude palm refineries in Ghana have the combined capacity to refine approximately 615,000 tonnes per annum (OPDAG, 2018). Table 2.4 below shows the annual production details of products and waste from the oil palm industry in Ghana (Products/waste indicated in Table 2.4 was obtained in relation to Table 2.3)

Table 2.4 Products and waste from the oil palm industry in Ghana

Products/waste	**Weight in tonnes**
Palm oil	615,000.00
Palm kernel	205,000.01
Fibre	439,285.73
Shell	175,714.29
Empty fruit bunches	673,571.45
POME	820,000.02
Total	2,928,571.50

Source: Author's constract (2019).

2.10 PHYSICAL AND MECHANICAL PROPERTIES OF OPKS

Researchers have reported the mechanical properties of OPKS such as Abrasion value, Aggregate impact value and Aggregate crushing value. Table 3.1 shows the results obtained by various researchers on the said mechanical properties. Generally, the abrasion resistance of lightweight aggregate (LWA) is lower than that of normal weight aggregate due to lower stiffness of LWA. The range of abrasion values for OPKS aggregates is 3 – 8% (Okpala,1990; Jumaat et al., 2009), aggregate impact value is 2 – 7% (Poh-Yap et al., 2015; Mohammed et al.,2014) and aggregate crushing value is 0.2 – 10% (Aslam et al., 2017; Okafor,1988). Generally, the 24-hour water absorption values of PKS have been reported to be higher, ranging from 14% to 33% (Ndoke,2006; Teo et al., 2006b). However, the high water absorption properties can be attributed to high porosity and large inter-connecting pore structure of the aggregate (Acheampong et al., 2015).

Report by the various researchers on the physical and mechanical properties of PKS are summarized in Table 2.5.

Table 2.5 Mechanical properties of oil palm kernel shell.

Name of author (year)	Abrasive value (Los Angeles) (%)	Aggregate impact Value (AIV)(%)	Aggregate crushing Value (ACV) (%)	Water Absorption%
Okafor (1988)		6	10	27.30
Okpala (1990)	3.05		4.67	21.30
Basri et al.(1999)	4.8			23.32
Mannan and Ganapathy (2001; 2002; and 2004)	4.8	7.86		23.30
Olanipekun (2005)	3.6			
Mannan et al. (2006)		1.04 - 7.86		
Ndoke (2006)		4.5		14.0
Teo et al. (2006 and 2007)	4.9	7.51	8.09	33.0
Jumaat et al. (2009)	8.07	3.91		23.80
Mahmud et al.(2009)		3.91		24.50
Mohammed et al.(2014)	4.8	7.86		26.45
Acheampong et al. (2015)	4.73	3.01	5.3	25.0
Poh-Yap et al.(2015 and 2017)	5	2.11		24.0
Aslam et al. (2017)	5.7	5.5	0.2	

Jaji et al. (2017), in their research used the mix proportions of 1:4, 1:5 and 1:6 by volume with corresponding mix percentages of 0%, 20%, 40% and 50% as GPKS aggregate replacement for sand and water/cement ratio of 0.55 was adopted for the preparation of cellular masonry unit samples. The control mix of 0% GPKS was used to compare the compressive and flexural strength of cement /sand / GPKS cellular masonry unit samples. Based on the test results it was detected that with ratio 1:4 (20% and 40%) partial replacement of sand with GPKS, 28 days compressive strength was found to be 4.91 N/mm^2 and 3.13N/mm^2 which was lower than the control mix (0%) which is 5.54 N/mm^2. However, the compressive strength of 1:4 (50%) GPKS aggregate replacement was 2.31 N/mm^2, lower than the minimum compressive strength of 2.8N/mm^2 according to BS 6073.

With the 1.5 (20%) GPKS aggregate replacement has compressive strength of 3.54 N/mm^2 was lower than the compressive strength 4.98 N/mm^2 (control sample). Meanwhile, the compressive strength of 1:6 (20%, 40% and 50%) GPKS aggregate replacement range from 2.33N/mm², 1.76N/mm² and 0.76N/mm² was lower than the minimum standard strength 2.8N/mm² according to BS 6073. The study concludes that the GPKS aggregate replacement for 1:4 and 1:5 should not exceed 40% and 20% respectively.

Dadzie and Yankah (2015) have analyzed through experimental study of the use of palm kernel shells as a partial replacement for sand in masonry unit production. Mix of percentage replacement of PKS used for the studies are 10%, 20%, 30%, 40% and 50%. Control mix of 0% PKS was used to compare the water absorption, weight, density and compressive strength of PKS masonry unit samples were conducted. From the test results it was observed that 10% to 40% PKS aggregate replacement, the rate of absorption densities are greater than the 130kg/m³ which was the lowest water absorption density of units made with light weight aggregates. The resulting decrease in the PKS content increases can therefore be as a result of the roughness of the PKS aggregates which was likely to make the unit permeable as its content increases. In reference to water absorption levels, the experimental study revealed that masonry units made with more than 40% PKS aggregate replacement for sand quantity is likely to be extra permeable then its water absorption falls below the 130kg/m3. However, the 10% to 40% PKS aggregates masonry units can be used for external and internal masonry walls. With reference to weights and densities of the masonry unit samples used for the study. The greater the weight of a masonry unit, the higher the density. A masonry unit sample of 10% PKS aggregate replacement was established to be weightier and solider (5.999kg and 1.77kg/m³) as compound to the regulating sample of 0% PKS aggregate replacement (5.834kg and 1.728kg/m³). It was again found that, from 20% upward PKS replacement, the densities drop. It shows that for an enhanced limited replacement of PKS percentage for sand in masonry unit, 10% addition is the optimum if the influence was based on the density. From the study it was found that apart from the 50% PKS aggregate addition which has its crushing strength (1.605N/mm²), less than the crushing strength (3.6N/mm2) of the regulating sample (0% PKS aggregate addition), the compressive strength of the 10% to 40% PKS aggregates replacements were higher than that of the control sample. However, the crushing strength result of the 10% to 40% of the PKS aggregates addition greater the approved crushing strength (2.8N/mm²) required by the BS 6073. This confirmed the study by Baiden and Asante (2004), that the extra compact the particles in a material, the greater the density. Other results indicated that, from 0% to 10% PKS aggregate addition, not only are the constituent part become closer; relatively aggregates mix design comes to be all-encompassing aggregates (sand and PKS). Therefore, the resultant effect of both greater densities and greater crushing strength. The study concluded that more 10% addition, the weight and densities of the PKS masonry units drop and the compressive strength of the PKS masonry units was greater than the minimum compressive strength of 2.8N/mm² according to the BS 6073-1, (1981), when the PKS aggregate additions for the sand is not more than 40%.

Ohemeng et al., 2015 have conducted experiments to investigate the performance of palmic concrete pavement blocks using palm kernel shell (PKS) as addition to sand (fine aggregate) in making paving blocks. The mix proportion used was 1:1.5:3 (cement: sand: coarse aggregate). The sand replaced by GPKS from 0%, 10%, 20%, 30%, 40%, 50% and 60% by quantity. Altered water/cement ratios (0.30, 0.40 and 0.45) were used in the investigation and a mass concrete was used as a regulating sample. The density and crushing strength of the paving blocks were tested in according to BS1881-Part 114 (1983) and BS 6717-Part 1 (1986). The permeability levels were tested in according to ASTM C642 (2006). The results of the strength of paving blocks for w/c ratios and PKS additions indicated that the water / cement ratio of 0.40 was establish to be the optimal.

After relating the optimum w/c ratio to the various w/c ratios, the crushing strength drop to around 20%, 14% and 6% while w/c ratios of 0.30 0.35 and 0.45 was used regardless of the quantity of PKS constituent used. In the investigation by Okpala (1990) shows that the amount of water used for mixing the PKS concrete has major influence on its crushing strength. For PKS concrete proportion of 1:1:2, W/C ratio of 0.5 was detected to be the optimal. The crushing strength drop to around 10.8%, 25.7% and 32.9% while w/c ratio of 0.60, 0.70 and 0.80 were used. In similar investigation, with mix of 1:2:4 for similar choice of w/c ratio used, the crushing strength decreased to 12.7%, 31.2% and 39.1% while the w/c ratio of 0.60%, 0.70% and 0.80% was used. Okpala (1990) observed that the influence of w/c ratio on flexural strength of PKS concrete was affected by different w/c ratios used. For concrete proportion of 1:1:2, w/c ratio of 0.5 was the optimum. The flexural strength was decreased to around 10.0%, 18.1% and 24.2% while the w/c ratio of 0.60, 0.70 and 0.80. Mixes prepared with w/c ratios of 0.30 and 0.35 was slight dry triggering inadequate compressive resulting to drop in strengths. Mixes produced with w/c ratio of 0.45 was quiet wet which affected the concrete as a result of excess drying of water from the Paving block after hydration. It was also detected that the compressive strengths of the paving blocks dropped from 39.26N/mm² to 15.14N/mm², 42.90N/mm² to 16.58N/mm², 48.70N/mm² to 19.37N/mm² with w/c ratios of 0.30, 0.35, 0.40 and 0.45 respectively. Shafig et al. (2012)

indicated in their studies that the average crushing strength of PKS concrete was around 21% lower than conventional concrete. The investigation also indicated that the addition of PKS as fine aggregate in concrete diminished the crushing strength in relation to conventional concrete (Ohemeng et al., 2015).

Adewole (2016) have conducted tests on cubes to study the strength of palm kernel shell lightweight masonry mortar and the results were compared with Natural River Sand Masonry mortar. Three different mix ratios of 1:3, 1:4 and 1:5 representing Portland limestone grade 42.5 cement to both PKS fine aggregate and Natural River sand were used for the study. Ten 50mm × 50mm × 50mm cubes each of the PKS and natural river sand masonry mortar were prepared in accordance with the EN 1996-1-1:2005 specifications for the three mix ratios. The test was conducted on 28days cured cubes. From each of the three mix ratios, five samples of PKS and Natural river sand masonry mortar cubes were used for the density test. The remaining five samples each of the PKS and natural river sand masonry mortar cubes were used for the compressive strength test. From the test results it was found that the average densities of the 1:3, 1:4 and 1:5 PKSMM cubes are 1084kg/m^3, 1141kg/m^3 and 1202kg/m^3 as compared to the average densities of the 1:3, 1:4 and 1:5 NRSMM are 1923kg/m3, 1863kg/m3 and 1803kg/m3. However, the average twenty-eight days compressive strength of 1:3, 1:4 and 1:5 PKS masonry mortar cubes are 10N/mm^2, 6N/mm^2 and 2.6N/mm^2. This indicate that the 10N/mm^2 average compressive strength of the 1:3 PKS mm can be used for bonding of masonry units in severe exposure conditions such as the external walls of buildings. The 6N/mm^2 and 3N/mm^2 average compressive strengths of the 1:4 and 1:5 PKS masonry mortar can be used for bonding of masonry units in mild exposure condition such as the internal walls of buildings (EN 1996-1-1, 2005).

The study concluded that the PKS fine aggregate can be used for the production of lightweight PKS masonry mortar to reduce the weight of wall on structural elements such as beams, columns and foundations supporting the walls. However, the recycling and the use of PKS as fine aggregate for masonry mortar production symbolize an effective utilization of waste, thereby reducing the consumption of mined/ quarried fine aggregate. This will encourage sustainability in terms of efficient management of PKS waste and reduce the use of natural river sand commonly used for masonry mortar production.

CHAPTER THREE

METHODOLOGY

3.0 INTRODUCTION

This chapter deals with the materials selection and procedural methods to be used to achieve the results of the various tests conducted in the study. Previous researches on Ground Palm Kernel masonry units did not use the actual standard sized masonry unit but rather used solid cubes, which are not standard solid and cellular masonry units. However, this experimental study seeks to use the actual standard size of 455mm x 220mm x (150, 125) mm and 325mm x 175mm x 125mm solid masonry units and 400mm x 190mm x (150, 125) mm cellular masonry units which is preferred by the construction industry due to its economy of use.

3.1 MATERIALS SELECTION

3.1.1 Cement

The GHACEM cement (42.5N) produced by Ghana Cement Limited as the major producer of cement in Ghana, which is easily accessible in all part of the country was used for the mixes for the experiment. This GHACEM cement (42.5N) used satisfy the recommendations in the British Standard Code (BS EN 197-1:2011)

3.1.2 Sand (fine aggregates)

The Sand used was clean, sharp river sand from Ada in the Greater Accra Region, which is free from clay, dirt and organic materials

3.1.3 Ground Palm Kernel Shells

The PKS used in the experiment was obtained from local palm kernel oil producing community. Before using, the PKS was washed to remove the oil and the dust from the PKS surface. The shells were prepared in batches and washed with water and detergent to remove any unwanted materials that could affect the properties of the masonry units. The shells were earlier open out for air-dry to saturated surface dry condition. Then after drying, the PKS was ground by a grounding machine at the Building and Road Research Institute (BRRI), Kumasi.

Both GPKS aggregates and sand (fine aggregate) samples was oven – dried and the particle size distribution was determined.

3.1.4 Water

Water that passes for drinking is the standard for making the masonry units. Such water should be free from impurities like suspended solids, organic matter and dissolved salts. The presence of such impurities can affect the setting and hardening properties of the masonry units (BSI 1980; Neville 1995). Water used for the experiment was portable water from Ghana Water Company Limited (GWCL) which is noted to be clean, colourless, odourless and free from organic matter. The quality of the water used satisfy the BS EN 1008 (2002) requirement.

3.2 RESEARCH PROCEDURE

All the testing procedure relevant to the experiment were carried out using the following standard codes or best practices:

- BS 6073-1: 1981 – Specification for masonry units.
- BS EN 1015-1: 1999 – Determination of particle size distribution (by sieve analysis).
- BS EN 1052-1: 1999 – Determination of compressive strength.
- BS EN 1052-2: 1999 – Determination of flexural strength.
- BS EN 772-11:2000 – Determination of water absorption of masonry units due to capillary action

3.3 GRADING TEST FOR SAND / GPKS.

For the purpose of this experiment the grading of the aggregate was done to help know the grading sizes of the sand and GPKS aggregate. It is important to use a good grading aggregate that would produce a durable mix than an unwell graded one.

3.3.1 Apparatus

The equipment required for the experiment were;

a. Electronic scale

b. BS sieve

c. Automatic mechanical shaker

3.3.2 Procedure

The following steps below were adopted for the grading test on both the sand and the GPKS aggregate.

- The samples were dried and quartered to get the required potion for the test.
- The quartered sample was weighed and recorded
- The weighed sample was poured into the pre-arranged BS sieve and covered.
- The sieves containing the material was then subjected to five minutes shaking using the automatic mechanical shaker.
- The retained samples in each sieve was weighed and recorded.
- The results of the experiment performed was recorded and used to plot graphs and charts in chapter four.

3.4 MIX PROPORTIONS

The mix ratio 1:8 (ordinary Portland cement: sand) was used for the preparation of the masonry unit samples (one part of cement to eight parts of sand) with a consistent water cement ratio of 0.45. The sand quantity was added with the GPKS aggregate from 0% 10%, 20%, 30 and 40%. The 0% GPKS aggregate replacement was used to serve as the control sample for the study. Fifteen percent (15%) allowance was made on the materials to cover wastage, compaction and bulking of aggregates. Table 3.1 shows the assessed amount of materials for the mix.

3.5 Sample Details

Eighty-one (81) masonry samples were produced from each mix design. This comprises of nine (9) masonry unit samples in size of 455mm x 220mm x (150,125) mm and 325mm x 175mmx125mm solid masonry units and 400mm x 190mm x (150,125) mm, cellular masonry units for compressive and flexural test. In all total of four hundred and five (405) masonry unit samples were moulded for the experiment. The total quantity of materials used for the 36 number masonry units are exhibited in Table 3.2 was attained from table 3.1 was increased by twelve (12). Using Sand, GPKS aggregate type A and B, one hundred and eighty (180) GPKS cellular masonry units were prepared from each mix percentages of 0%, 10%, 20%, 30% and 40% as partial replacement of sand with GPKS aggregate, thirty-six (36) cellular masonry units was prepared from each mix percentage. Masonry unit size of 455mm x 220mm x (150, 125) mm with void area of 15,675 mm^2 and 400mm x 190mm x (150, 125) mm with void areas of 25,752mm^2 and 20,500mm^2, both cellular units were prepared under laboratory condition. Control samples was prepared from mix proportion of 1:8 of cement and sand (0% GPKS). Water/cement ratios of 0.45, 0.5, 0.55, and 0.6 was used for the production of the masonry unit samples. Weight batching was employed, using a plastic cylindrical container. After batching the materials, hand mixing method was used to turned over the materials until a uniform consistency was obtained. The combined materials were again mixed carefully with the shovel and water was added gradually while mixing continued until a homogeneous mix was attained. The weight, density, compressive and flexural strength was carried out on 7, 14 and 28 days cured cellular masonry unit samples.

3.6 SAMPLE IDENTIFICATION

For easy identification of masonry units produced, the units of nine (9) set were coded with numbers after molding. The numbers 0, 10, 20, 30 and 40 were used to represent 0%, 10%, 20%, 30%, and 40% GPKS aggregate replacement content. The coding was used to allow for easy identification of both the solid and cellular masonry unit used in the experimental study.

3.7 MIXING PROCESS

Hand mixing method was used for mixing the material for the production of masonry units. According to the cement and concrete institute (2013), it permits the use this method to make masonry units for small works without a mechanical mixer. Though, precautions were put in place to minimize any inaccuracies that may affect or limit the output. Before the mixing, all the materials were weighed in relation to the mix ratio exhibited in the Table 3.2. the real technique to be used are as follows;

1. The mixing was prepared on a hard-concrete platform free from any harmful material which can affect the properties of the mix.

2. The sand was measured according to the mix design and spread evenly on the hard surface using a shovel.

3. For both sand and GPKS as aggregates, the combined constituents were initial mixed carefully till a homogenous mix is attained.

4. The required quantity of cement was then spread out on the aggregates and the combined constituents mixed carefully.

3.8 MOULDING, REMOVAL AND CURING

The masonry unit samples were produced according to the requirement specified in BS 6073-1 (1981). The mix was fed into the moulding machine in layers and thoroughly tamped in place (compacted) in the mould of the machine and smooth off with steel face tool. After the removal from the machine carefully on pallets, the masonry unit samples were marked with their sample reference numbers, the percentage and the date of moulding. The masonry unit samples were left to mature in open space in separate rows with space between each masonry unit for 48 hours. The masonry unit samples were removed from the pallets and were left in the open for curing up to a period of 7, 14 and 28 days before the masonry samples were sent to the laboratory for crushing. For that period, water was sprinkled on the masonry unit samples in the morning and evening for 7, 14, and 28 days to ensure proper curing.

Figure 3.1 Curing and drying process of the masonry units

Figure 3.2 Mixing process

Figure 3.3 Crushing process of the masonry units

3.9 TESTING

The testing of masonry unit samples was conducted according to the requirement specified in (BS EN 5628-1: 2005; BS EN 1015-18; 2002; BS EN 1015-11: 1999). After the 28 days curing and drying, the masonry samples were sent to the laboratory for testing on weights, densities, water absorption, compressive and flexural strength.

Table 3.1 Quantity of materials and water/cement ratio per mix

Mix	**w/c ratio**	**water (kg)**	**cement (kg)**	**sand (kg)**	**GPKS (kg)**	**Design mix**
Regulating mix (0% GPKS	0.45	1.87	4.16	33.28		1:08
10% GPKS	0.45	1.87	4.16	29.95	3.33	1:7.2:0.8
20% GPKS	0.45	1.87	4.16	26.62	6.66	1:6.4:1.6
30% GPKS	0.45	1.87	4.16	23.30	9.98	1:5.6:2.4
40% GPKS	0.45	1.87	4.16	19.97	13.31	1:4.8:3.2

Tables 3.2 Total quantity of constituents for the experiment

Mix	**w/c ratio**	**water (kg)**	**cement (kg)**	**sand (kg)**	**GPKS (kg)**	**Design mix**
Control mix (0% GPKS	0.45	11.25	25	200		1:08
10% GPKS	0.45	11.25	25	180	20	1:7.2:0.8
20% GPKS	0.45	11.25	25	160	40	1:6.4:1.6
30% GPKS	0.45	11.25	25	140	60	1:5.6:2.4
40% GPKS	0.45	11.25	25	120	80	1:4.8:3.2

3.9.1 Testing Apparatus and Procedure

Apparatus: the main apparatus to be used to conduct the test was;

- Digital universal compressive strength testing machine
- Electronic weighing scale
- Oven (for drying cube samples)
- Steel tape measure

3.10 TESTING PROCEDURE

Nine (9) masonry unit samples from each mix proportion was used for compressive strength test, flexural strength test with three (3) each for 7, 14 and 28days crushing. The weights and sizes of the masonry unit samples were first determined by weighing and measuring before the actual testing was done. The test was carried out in the Department of Urban Roads Materials laboratory in Accra

3.10.1 Particle size distribution

The particle size distribution test was carried out on both sand and GPKS aggregates in accordance with BS EN 1015 – 1: 1999.

3.10.1.1 Physical properties

An electronic weighing scale was used to weigh the GPKS masonry unit and the outcome noted. Each GPKS masonry samples was weighed thrice; first 7 days weight, second 14 days weight and third 28 days weight.

3.10.2 Density

The density of the masonry unit samples was determined in accordance with BS EN 1015 – 3 and BS EN 1015 – 6 respectively. Three (3) densities were determined thus: 7 days density, 14 days density and 28 days density. The densities of GPKS masonry unit samples were determined after 7, 14 and 28 days curing. To determine the densities, the volume of the GPKS masonry unit samples were calculated. The masses of the masonry unit samples gained from the weight test was used to determine the densities.

3.10.3 Water absorption

The water absorption was determined as required in BS EN 1015 – 18. Water absorption test was carried out on thirty (30) 75mm x75mm x 75mm cubes made from all the GPKS aggregate mix percentages, with three (3) cubes each from 10%, 20%, 30%,40% and cement and sand ratio was prepared as control samples (0% GPKS). After curing period, the samples were oven –dried and subjected to absorption. The water absorption test was carried out on the cubes subsequently after 28days of moist and oven - dried. Before immersion in water, the weight of the cube samples was determined. The cubes were put in water for 1, 3 and 24 hour

3.10.4 Compressive strength test

The compressive strength test was determined on masonry unit samples in accordance with BS EN 1015 – 1: 1999. Nine (9) set of masonry units were used for crushing strength test with three (3) set for 7, 14 and 28-days crushing. The GPKS masonry unit samples prepared was placed in the Digital universal compressive strength testing machine and a load applied to the masonry unit sample. The masonry samples were carefully place within the location marks on the bottom platern. After placing the masonry unit sample on the bottom platern the moving head (top platern) of the Digital universal compressive strength testing machine was brought into contact with the masonry unit sample. Load was then applied till the masonry unit sample was crushed and the crushing load applied was recorded. The compressive strength was then calculated from each masonry unit sample.

3.10.5 Flexural strength

The flexural strength test was determined as required in BS EN 1015 – 1:1999. Nine (9) block samples was used for flexural strength test. To calculate for the flexural strength a centre line loading applied (F) to the masonry unit sample perpendicular to its length (L), this was divided by the average width (B) and average depth square (D^2). The flexural strength was then calculated.

CHAPTER FOUR

RESULTS, FINDINGS, INTERPRETATION AND DISCUSSION

4.0 INTRODUCTION

This chapter deals with the analysis of the results and findings of the study, their interpretation and discussion of major findings. Tables and figures were used in the analysis, since they help readers to get a true picture from the result of the study.

This chapter also presents the results from the laboratory experiment and useful comprehensive interpretation are given to them in line with the objectives and research questions for the study.

4.1 GRADING TEST

The result of the grading test performed on both the sand and GPKS aggregates (type A and B) used for the study are plotted in figure 4.1, 4.2a and 4.2b below, which was carried out at the Department of Urban Roads (Materials laboratory) in Accra.

4.2.1Grading and sieve analysis

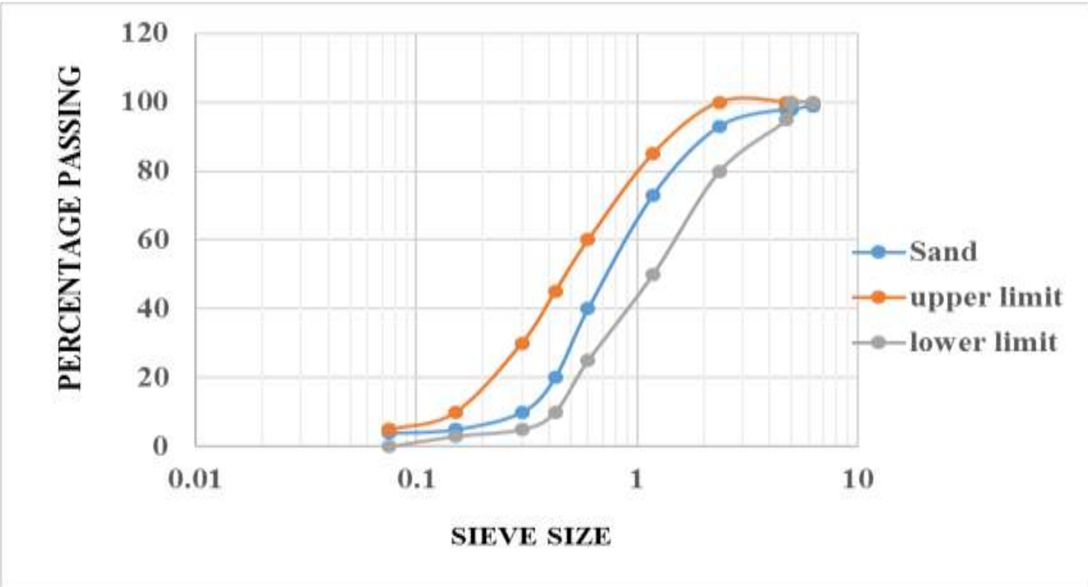

Figure 4.1 Graph of particle size distribution for sand

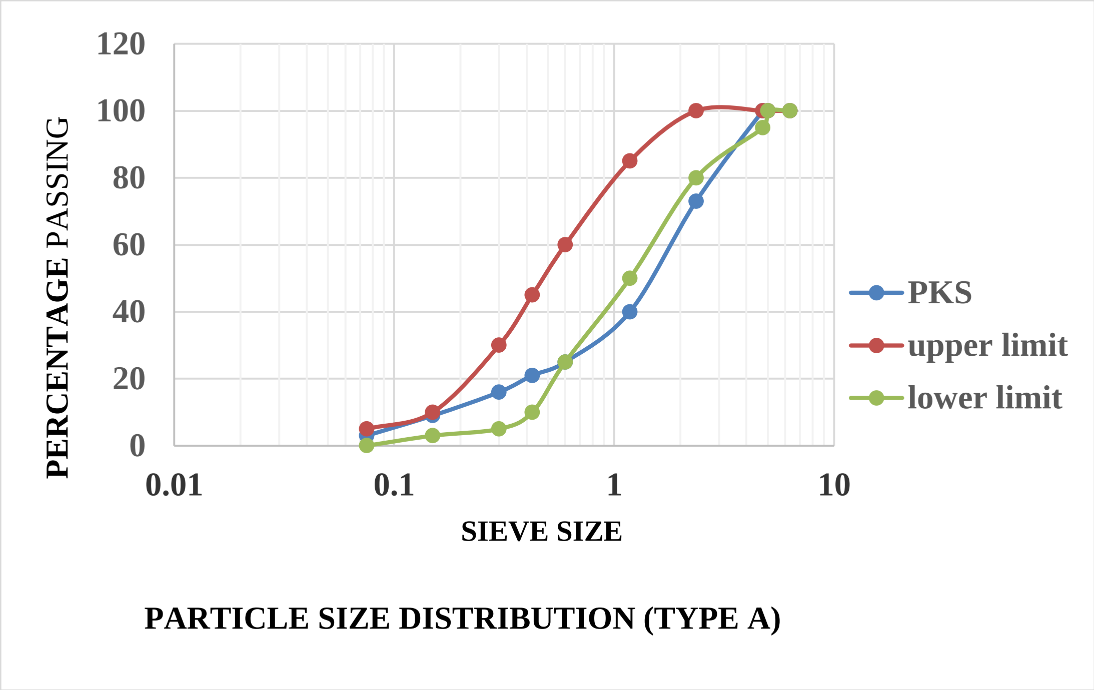

Figure 4.2a, Graph of particle size distribution for GPKS (type A)

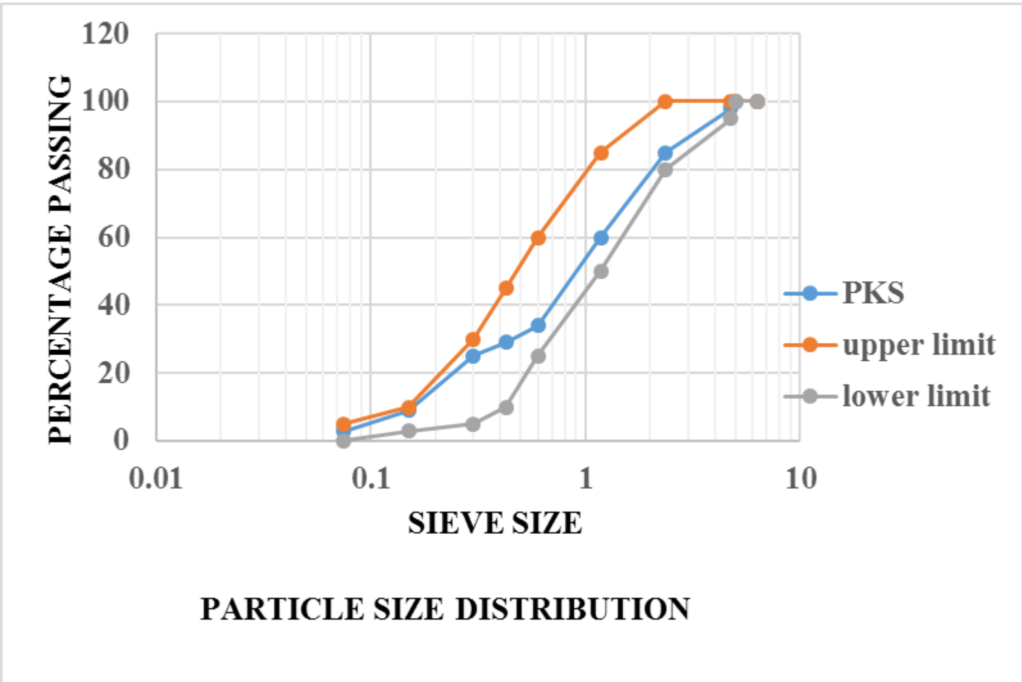

Figure 4.2b, Graph of particle size distribution for GPKS (type B)

Automatic sieve shaker with British standard series of sieves were used to determine the grading curves (Particle Size distribution) of sand and two (2) types of GPKS aggregates in accordance with BS EN 1015 – 1:1999. The particle size distribution of fine aggregate (sand) and GPKS aggregate (type A) and (type B) are shown graphically in figures 4.1, 4.2A and 4.2B. The particle size distribution of sand and GPKS aggregate were compared to the standard grading of fine aggregates in relation to upper limit and lower limit.

4.2.2 Sand

The analysis of particle size distribution curve of river sand sample obtained from Ada used in masonry unit production is illustrated graphically in Figure 4.1, showed a medium grained material in relation to the upper limit and lower limit, since the greater part of the curve falls in the middle of the upper and lower limits of standard grading. The river sand can be termed to be well graded.

4.2.3 GPKS aggregate

From figure 4.2a, the GPKS aggregate particles are finer, as the greater part of the curve falls below the lower limit of standard grading between 2.36mm and 0.6mm. The GPKS aggregate (type A) can be described as fine grained. The GPKS aggregate (type A) was used with the river sand to mould the masonry units with dimensions 455mm x 220mm x (150, 125) mm both solid and cellular.

The particle size distribution of GPKS aggregate (type B) shown in figure 4.2b, was satisfactory as the curve falls close to the lower limit of standard grading. The GPKS aggregate (type B) can be classified as moderate fine grained.

4.3 PHYSICAL PROPERTIES

4.3 .1 Density

From Tables 4.3a, 4.3b, 4.3c and 4.3d shows the physical properties of solid and cellular masonry units, with reference to the densities of the GPKS masonry unit manufactured. It can be appreciated from all the data that; the relations are similar. Expressions from the density values on the figures are presented below. The densities ranges from 1773.56 kg/m^3 to 1830.84 kg/m^3; 1708.96 kg/m^3 to 1752.91 kg/m^3; 1622.38 kg/m^3 to 1665.67 kg/m^3 and 1555.11 kg/m^3 to 1590.41 kg/m^3 respectively for 150mm solid masonry units. It was detected that, as percentage of GPKS aggregate increases the densities drop. This also shows that, for satisfactory addition of GPKS aggregate to sand in masonry unit,10% to 30% replacement is acceptable based on density.

Similar result was seen for the 125mm solid masonry units prepared with aggregate type A and B, as exhibited in figures 3.3a,3.3b,3.5a and 3.5b below for the densities. The densities ranges from 1859.74 kg/m^3 to 1912.49 kg/m^3; 1835.76 kg/m^3 to 31894.11 kg/m^3; 1784.62 kg/m^3 to 1836.56 kg/m^3 and 1699.90 kg/m^3 to 31749.45 kg/m^3 at 7 and 28 days curing period with GPKS aggregate type A, as against the control sample (0% GPKS) densities ranging from 1944.46 kg/m^3 to 2006.79kg/m^3. The densities of masonry units prepared with GPKS aggregate type B ranges from 1958.95kg/m^3 to 1997.19kg/m^3; 1863.16kg/m^3 to 1929.82kg/m^3; 1685.26kg/m^3 to 1729.82kg/m^3 and 1578.25kg/m^3 to 1640.70kg/m^3 as against the control sample 2071.23kg/m^3 to 2121.40kg/m^3. The values of the densities in the study can be attributed to the mix percentages of the GPKS aggregate, because the sand was replaced by lighter weight GPKS which resulted in lighter densities with the mixes.

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4.3.1 DENSITY

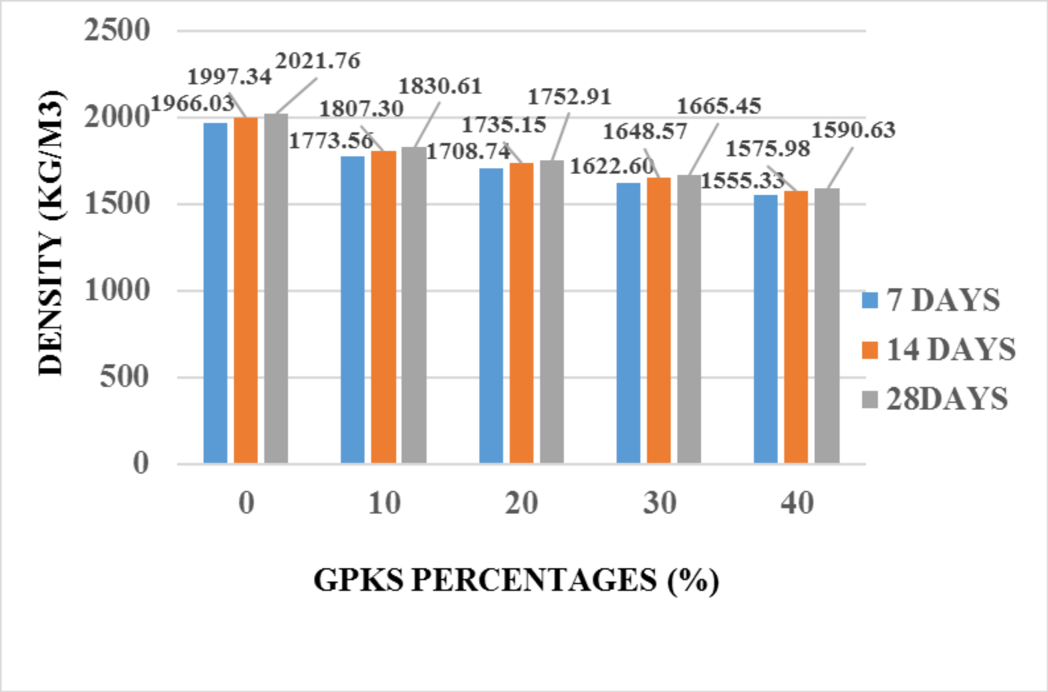

Figure 4.3a, Density of 150mm solid block with sand and GPKS aggregate Type A

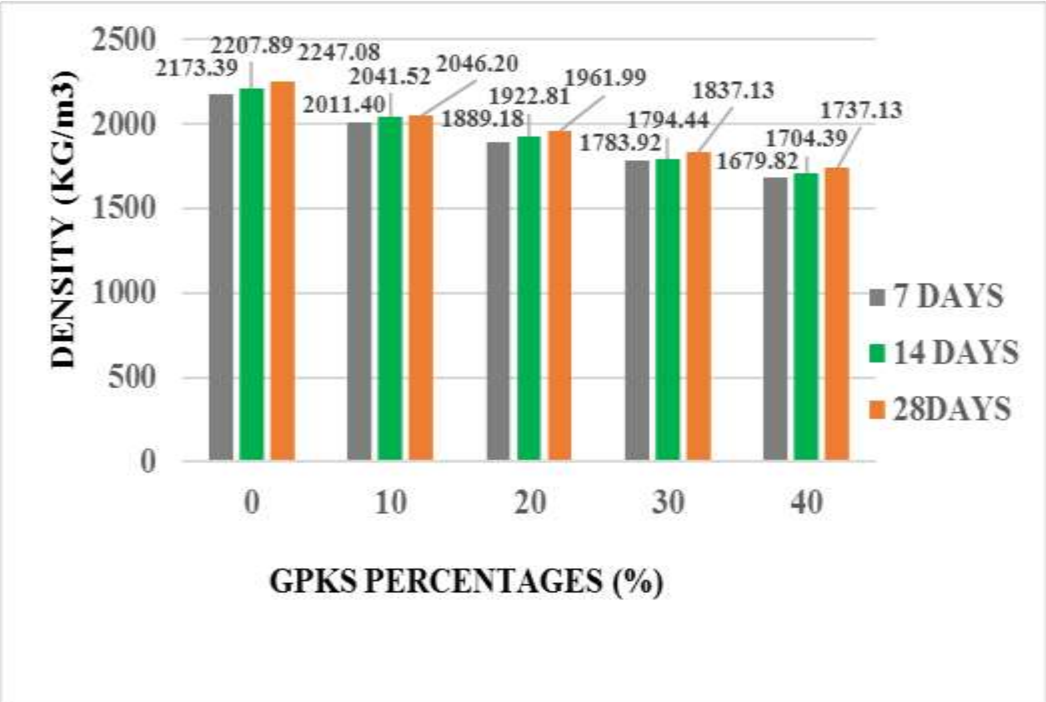

Figure 4.3b, Density of 150mm solid block with sand and GPKS aggregate Type B

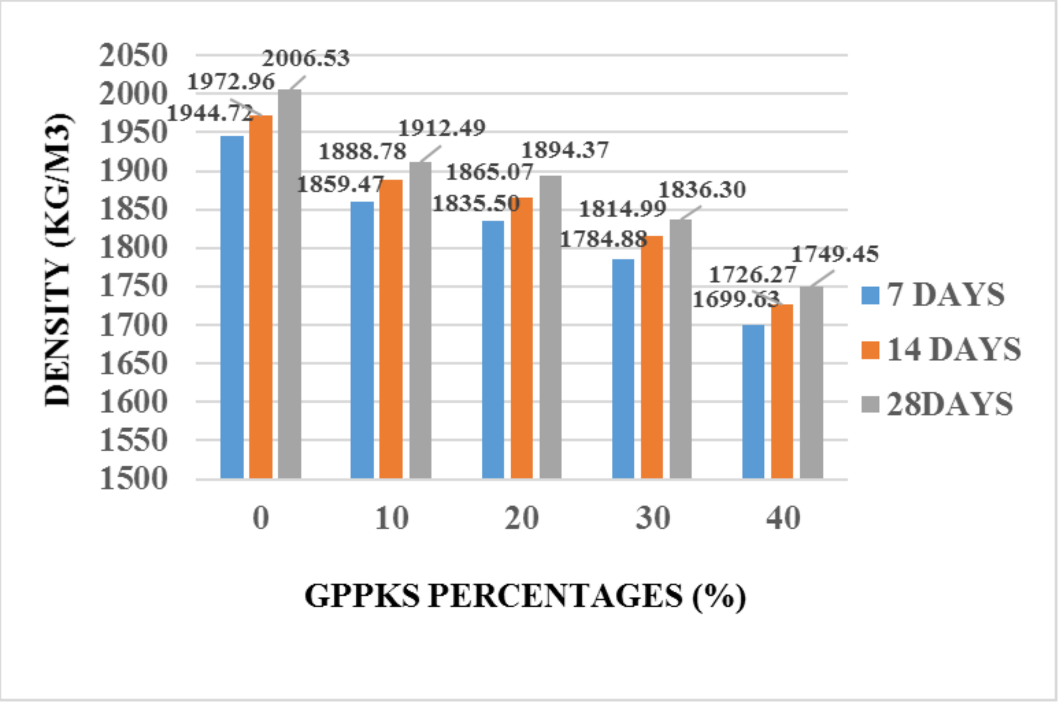

Figure 4.4a, Density of 125mm solid block with sand and GPKS aggregate Type A

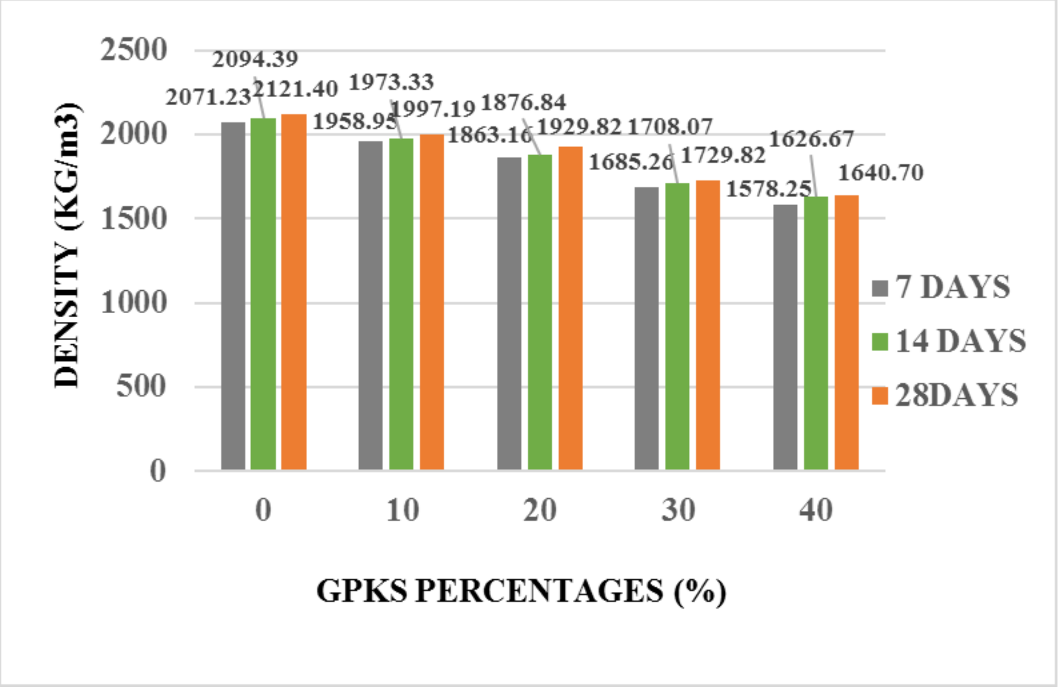

Figure 4.4b, Density of 125mm solid block with sand and GPKS aggregate Type B

From figure 4.4b**,** the result confirms the earlier discussion about the densities. Figures 4.4a and 4.4b shows the results and the relationship between densities of 150mm and 125mm cellular masonry units. The masonry units 0% GPKS aggregate (control sample) the densities ranges 1966.03 kg/m^3 to 2021.98 kg/m^3 at 7 and 28 days curing age respectively as compared to the 10%, 20%, 30% and 40% GPKS aggregate replacement have densities ranges from 1773.56 kg/m^3 to 1830.84 kg/m^3; 1708.96 kg/m^3 to 1752.91 kg/m^3; 1622.38 kg/m^3 to 1665.67 kg/m^3 and 1555.11 kg/m^3 to 1590.41 kg/m^3 respectively for 150mm solid masonry units. The results of 150mm thick cellular masonry units prepared with GPKS aggregates type B. The densities ranging from 13.92 kg/m^3 to 1426.02kg/m^3; 1279.24kg/m^3 to 1337.13 kg/m^3; 1201.75 kg/m^3 to 11242.98kg/m^3; 1127.49kg/m^3 to 1203.22kg/m^3 and 1030.99 kg/m^3 to 1075.44kg/m^3 respectively for 7 and 28 days cured samples. It was observed that, as percentage of GPKS aggregate increases the densities drop.

This also shows that, for satisfactory addition of GPKS aggregate to sand in masonry unit ,10% to 30% replacement is acceptable based on density.

Similar trend can be seen for the results of 125mm cellular masonry units as exhibited in Figure 4.3b with densities. The densities of 10%, 20%, 30% and 40% GPKS aggregate replacement ranges from 11704.96kg/m^3 to 1760.37kg/m^3; 1547.79kg/m^3 to 1630.10kg/m^3; 1446.55kg/m^3 to 1573.36kg/m^3 and 1342.66 kg/m^3 to 1423.11kg/m^3 at 7 and 28 days as against the control sample (0% GPKS) densities of 1806.19 kg/m^3 to 1863.47kg/m^3. The densities of cellular masonry units prepared with GPKS aggregate type B densities ranges from 1348.77kg/m^3 to 1379.65kg/m^3; 1240.70kg/m^3 to 1283.16kg/m^3; 1165kg/m^3 to 1024kg/m^3; 1077.19kg/m^3 to 1103.16kg/m^3 and 1011.93kg/m^3 to 1069.12kg/m^3 for 7 and 28 days cured samples. The values of the densities in the study can be attributed to the mix percentages of the GPKS aggregate.

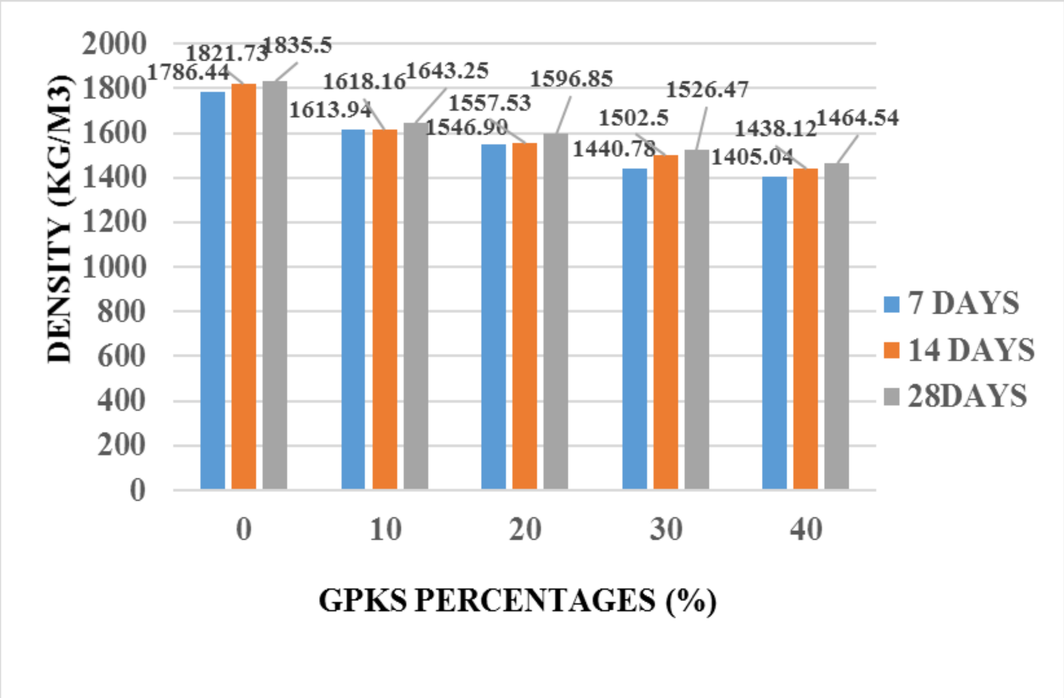

Figure 4.5a, Density of 150mm cellular block with sand and GPKS aggregate Type A

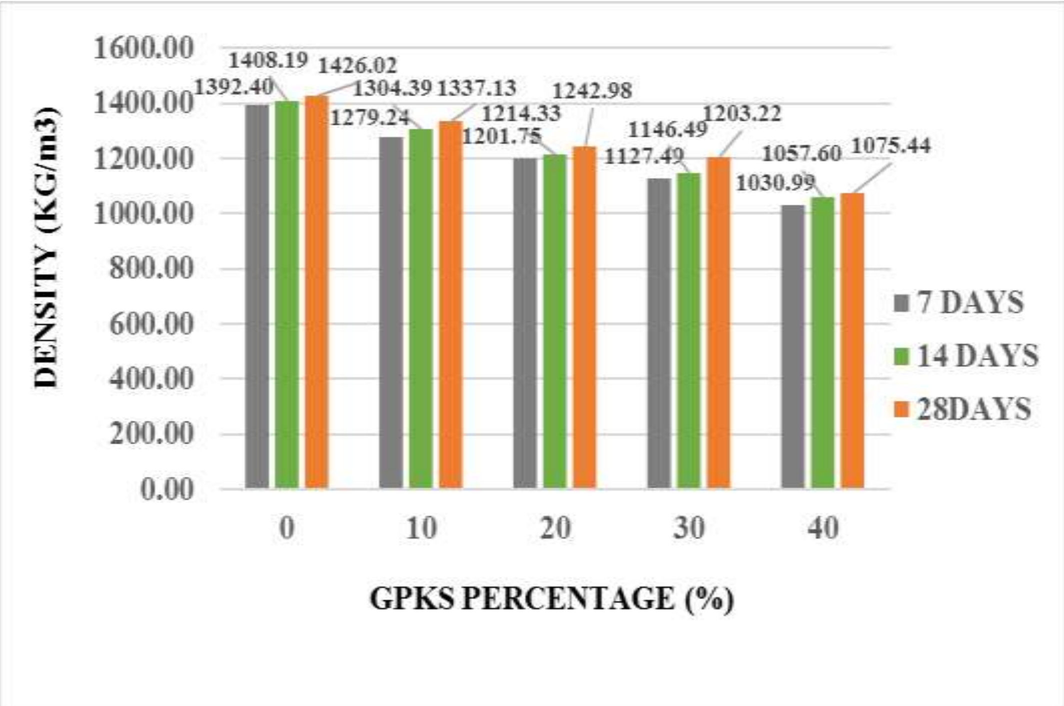

Figure 4.5b, Density of 150mm cellular block with sand and GPKS aggregate Type B

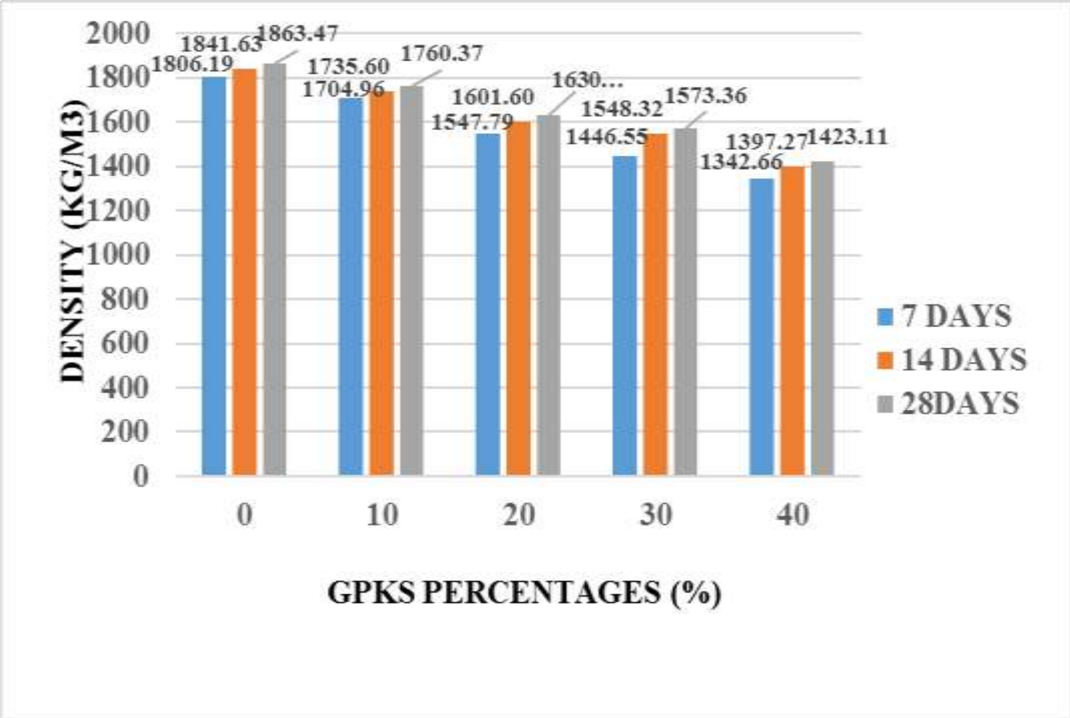

Figure 4.6a, Density of 125mm cellular block with sand and GPKS aggregate Type A

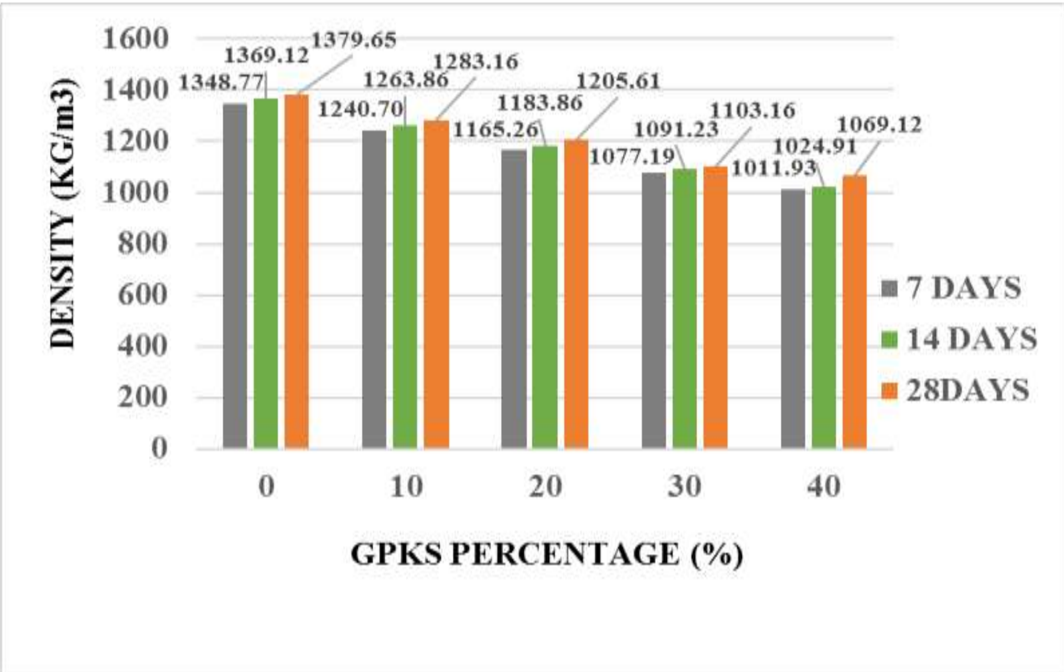

Figure 4.6b, Density of 125mm cellular block with sand and GPKS aggregate Type B

4.4 WATER ABSORPTION

The water absorption was determined according to BS 772 – 11:2000. The results obtained from masonry units produced with GPKS aggregate (type A) is exhibited in Table 4.4. The water absorbed at 1, 3 and 24 hours for masonry units with GPKS percentages of 0%, 10%, 20%, 30% and 40% are 6.64%, 4.79% at 1 hour; 7.08%, 5.85% at 3hours and 7.52%, 9.04% at 24 hours respectively. It was detected that the water absorption increases as the percentage replacement of sand with GPKS aggregate increases. The masonry unit with 40% GPKS aggregate was porous with the absorption rate of 9.04% at 24 hours. However, at 1 hour the water absorption rate was low (3.93%) due to the finer nature of the GPKS aggregate in the pores of the masonry unit.

Figure 3.7b below, shows the results of water absorption rate of the cubes prepared with GPKS aggregate type B are 7.11%, 4.71% at 1 hour; 7.11%, 6.81% at 3 hours; 7.11%, 11.52% at 24 hours. On the other hand, at 1 hour, 3hours and 24 hours the water absorption rate for cubes with 0% GPKS aggregate was the same (7.11%) as a result the nature of particle size distribution of the sand in the pores of the cubes. Generally, the masonry unit with the 40% GPKS was highly porous with the absorption rate of 11.52% at 24 hours due to the poor bonding between the GPKS aggregate and the cement matrix. This absorption rate is lower than 12% required by BS 5628 – 1:2005.

4.4.1 The Impact of GPKS Fines on the Absorption Properties of GPKS Masonry Units

The study showed that the absorption levels of the masonry unit produced from GPKS aggregate type A mix percentages were finer. The observation made was that;

- The masonry unit was slow to absorb water as compared to the control sample this had an impact on wetting of these units
- As the GPKS aggregate replacement increased, the water absorption increased.
- 10 - 40% GPKS masonry units can be used for both external and internal walls

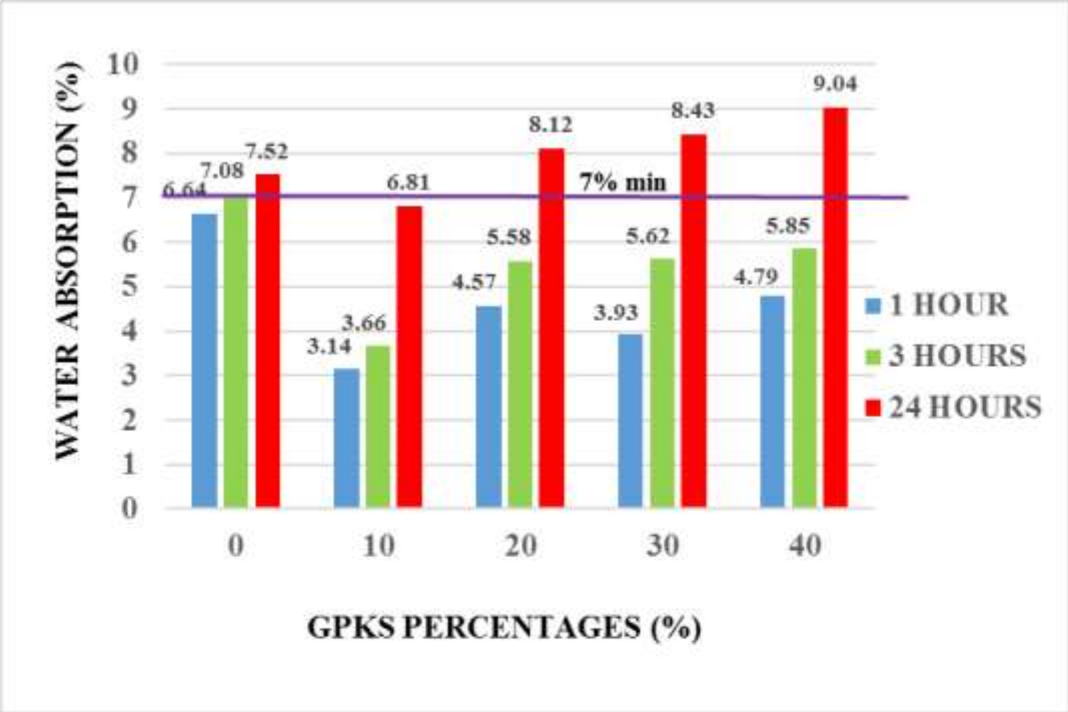

Figure 4.7a Water absorption of cubes produced with GPKS (Type A)

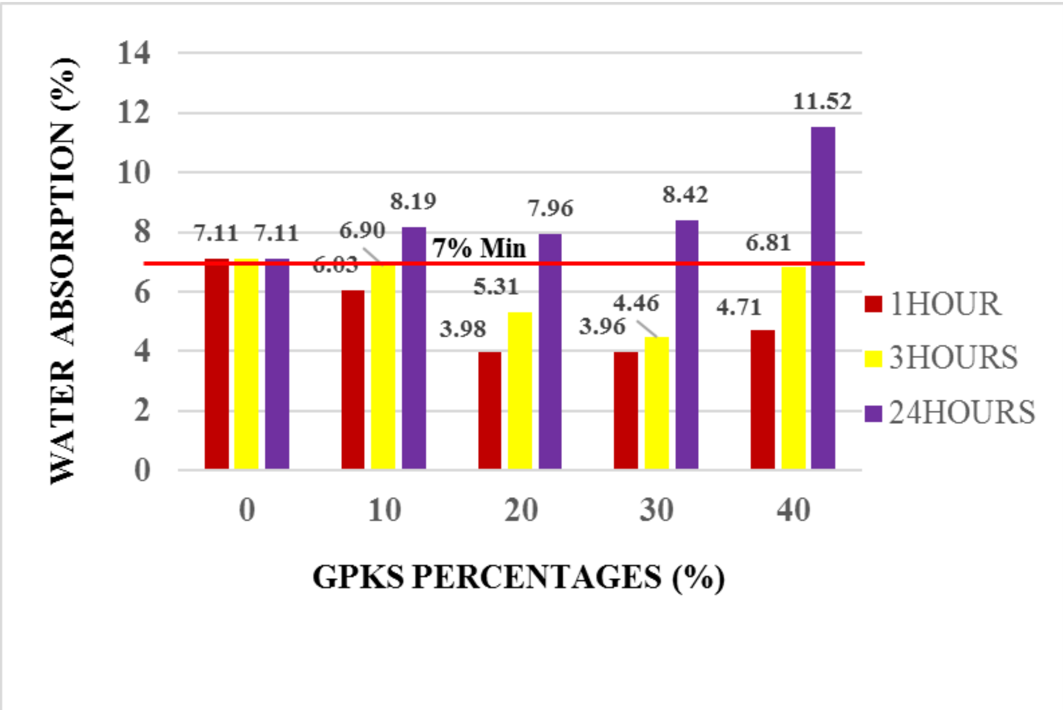

Figure 4.7b Water absorption of cubes produced with GPKS (Type B)

Table 4.1, shows the water/cement ratio, weight of water absorbed and water absorption percentages (%)

GPKS (%)	GPKS AGGREGATE TYPE A			GPKS AGGREGATE TYPE B		
	Water/ cement ratio	**Weight of water absorbed (Kg)**	**Water Absorption Rate (%)**	**Water/ cement ratio**	**Weight of water absorbed (Kg)**	**Water Absorption Rate (%)**
0	0.45	0.057	**7.52**	0.45	0.057	**7.11**
10	0.45	0.043	**6.81**	0.45	0.063	**8.19**
20	0.50	0.053	**8.12**	0.50	0.060	**7.96**
30	0.55	0.050	**8.43**	0.55	0.057	**8.42**
40	0.60	0.057	**9.04**	0.60	0.073	**11.52**

4.5. MECHANICAL PROPERTIES

4.5.1 Compressive Strength

The compressive strength was carried out in accordance to BS EN 1052 – 1:1999. Figures 4.8a and 4.8b shows the results of the compressive strength of 455mm x 220mm x 150mm solid masonry units made with different mix percentages 0%, 10%, 20%, 30% and 40% GPKS aggregate (Type A) material at 7, 14 and 28 days curing ages ranges between 5.13 N/mm^2 to 1.60 N/mm^2 and 6.47 N/mm^2 to 1.90 N/mm^2 at 7 and 28 days.

The compressive strength of 0%, 10%, 20% 30% and 40% GPKS aggregate Type B ranges between 6.58N/mm^2 to 2.13N/mm^2 and 7.66N/mm^2 to 3.04N/mm^2 at 7 and 28 days respectively. However, the lowest crushing strength ranges between 1.60 N/mm^2 to 1.90 N/mm^2 for masonry units produced with mix percentage of 40% GPKS and cured for the same period. It also revealed that for 28 days curing age, masonry units produced with 0%, 10%, 20% and 30% gave results which are consistently higher than the 2.8 N/mm^2 required by BS 6073:1981 and 2.5 N/mm^2 required by GS 297 – 1:2010.

From figure 4.11b below, exhibited the compressive strength results of 455mm x 220mm x 125mm with void area of 15,675 mm^2 and 400mm x 190mm x 125mm with void area of 20,500mm^2 cellular masonry units at 7, 14 and 28 days with mix percentages of 0%, 10%, 20%, 30% and 40% GPKS aggregate type A were showing better strength development ranges from 3.80 N/mm^2 to 2.10N/mm^2 and 5.58N/mm^2 to 2,90N/mm^2 at 7 and 28 days respectively. The crushing strength of 0%, 10%, 20%, 30% and 40% GPKS aggregate Type B ranges from 4.84N/mm^2 to 2.06N/mm^2 and 6.10N/mm^2 to 2.90N/mm^2 at 7 and 28 days respectively. The crushing strength of both GPKS aggregate type A and B were far above the 2.8 N/mm^2 required by BS 6073:1981 and 2.5 N/mm^2 required by GS 297 – 1:2010. The main factors influencing the 28days compressive strength of the four (4) mix percentages of the GPKS aggregate are the particle size distribution of the sand and GPKS aggregates, degree of compaction, amount of water used for the cellular masonry units production and method of curing.

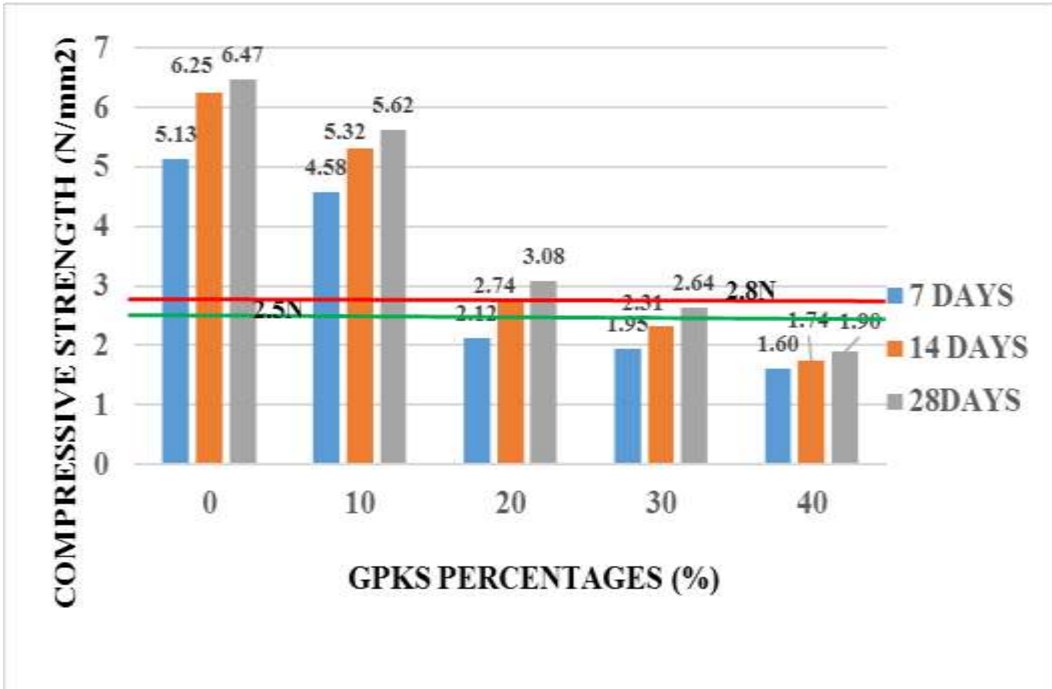

Figure 4.8a, Compressive strength of 150mm solid block with (GPKS Type A)

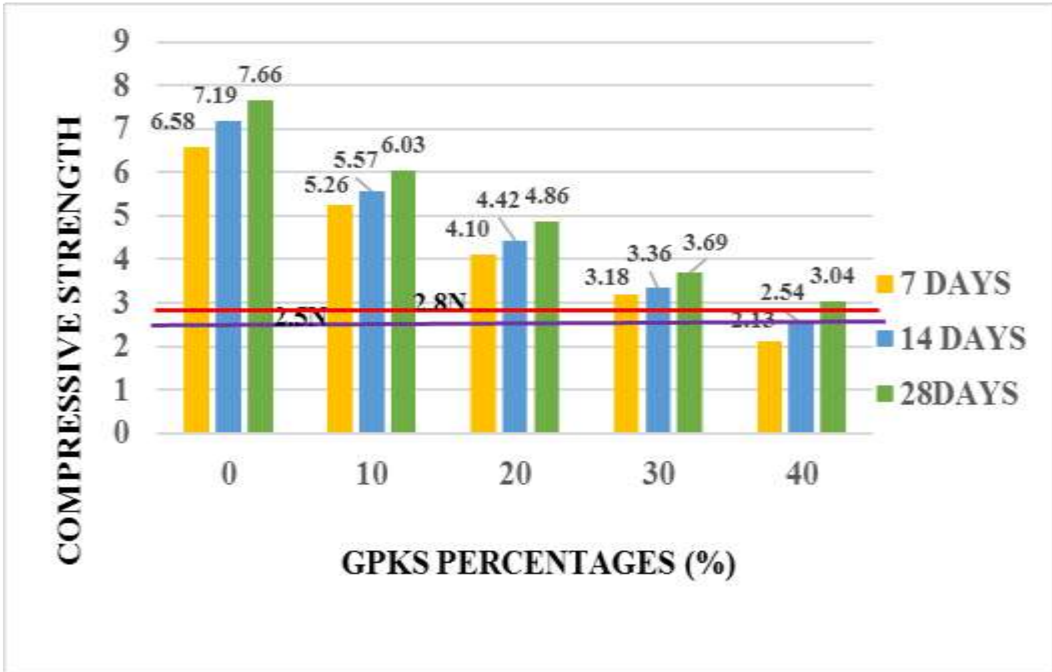

Figure 4.8b, Compressive strength of 150mm solid block with (GPKS Type B)

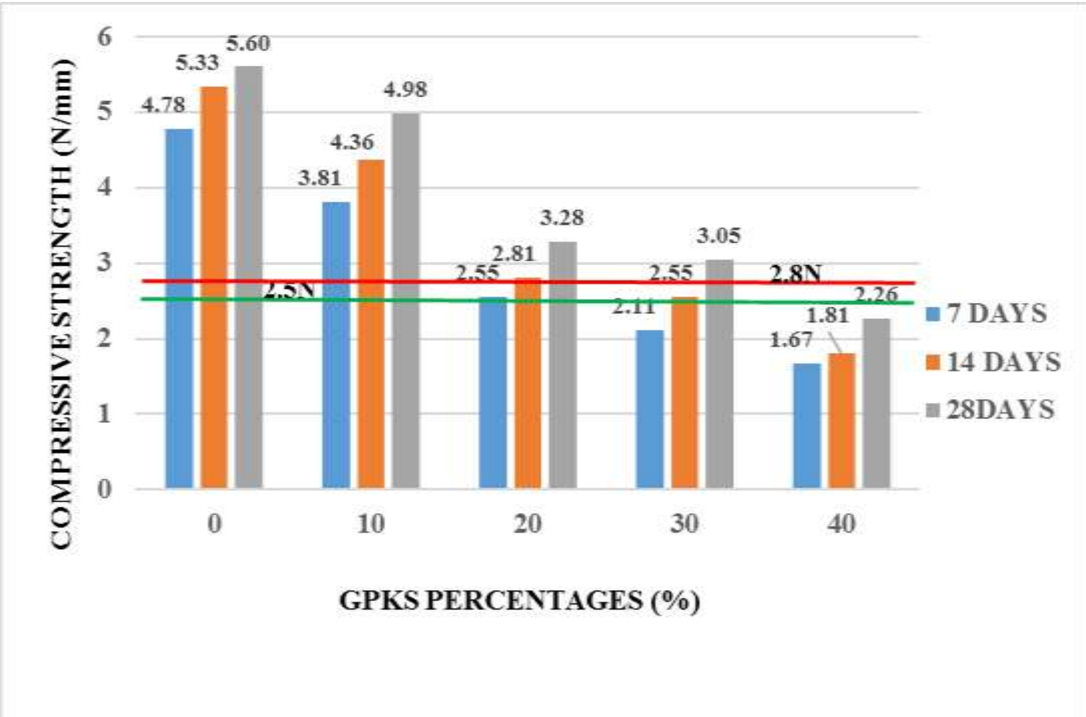

Figure 4.9a, Compressive strength of 125mm solid block with (GPKS Type A)

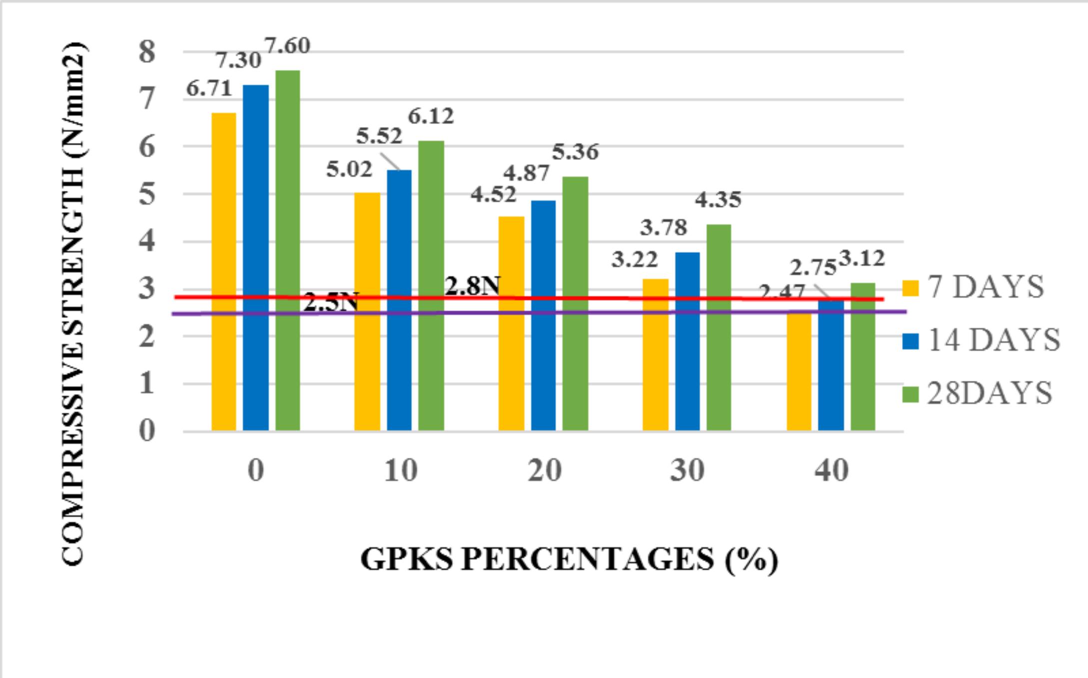

Figure 4.9b, Compressive strength of 125mm solid block with (GPKS Type B)

Figure 4.13a above, exhibited compressive strength test for 455mm x 220mm x 125mm solid masonry units produced with mix percentages of 0%, 10%, 20%, 30% and 40% GPKS aggregate (type A). The result indicated that the compressive strength of 125mm solid masonry units ranges from 4.78 N/mm^2 to 1.67 N/mm^2 and 5.60 N/mm^2 to 2.26 N/mm^2 at 7 and 28 days respectively. The results of 0%, 10%, 20% and 30% at 28 days were far above the 2.8 N/mm^2 required by BS 6073:1981 and 2.5 N/mm^2 required by GS 297 – 1:2010.

Similarly, 400mm x 190mm x 125mm solid masonry units produced with 0%, 10%, 20%, 30% and 40% GPKS aggregate (Type B) in the study are shown in figure 4.13b above. The values appreciated in the compressive strengths ranges from 6.71 N/mm^2 to 2.47 N/mm^2 and 7.60 N/mm^2 to 3.12 N/mm^2 at 7 and 28 days respectively. The 7days and 28 days result of the 40% GPKS aggregate were higher than the 2.8 N/mm^2 required by BS 6073:1981 and 2.5 N/mm^2 required by GS 297 – 1:2010. As discussed before the results was influenced by the grading sizes of the sand and GPKS aggregate, size of the mould, degree of compaction, amount of water used for the masonry units production and method of curing.

The relationship between the compressive strength of masonry units and GPKS aggregate content are shown in Figures 4.12a, 4.12b, 4.13a and 4.13b. It can be observed that 10% - 40% GPKS aggregate (Type A and B) replacement content were lower than the compressive strength of the control sample (0% GPKS aggregate). Generally, the 28 days compressive strength results of 150mm and 125mm thick solid masonry units with 10% - 30% GPKS aggregate Type A and 150mm and 125mm thick solid masonry units with 10% - 40%% GPKS aggregate Type B replacement content was greater the minimum standard compressive strength of 2.8N/mm^2 according to BS 6073-1: 1981 and 2.5N/mm^2 required by GS 297- 1: 2010. It can be noticed that from 10% upwards of GPKS aggregate replacement, relating the outcomes of the crushing strength test to the outcome of density test, the results look similar, therefore 0% - 10% GPKS aggregate replacement in the masonry units, the constituent part are closer. This endorses the conclusion made by Dadzie and Yankah (2015), that 10% GPKS aggregate replacement of sand is the optimum for masonry unit production. It also be observed that from 0% - 10% GPKS aggregate replacement content, the bonding was better. Therefore, the resultant influence on both higher densities and higher compressive strength. They again concluded that PKS aggregate replacement for sand should not exceed 40%.

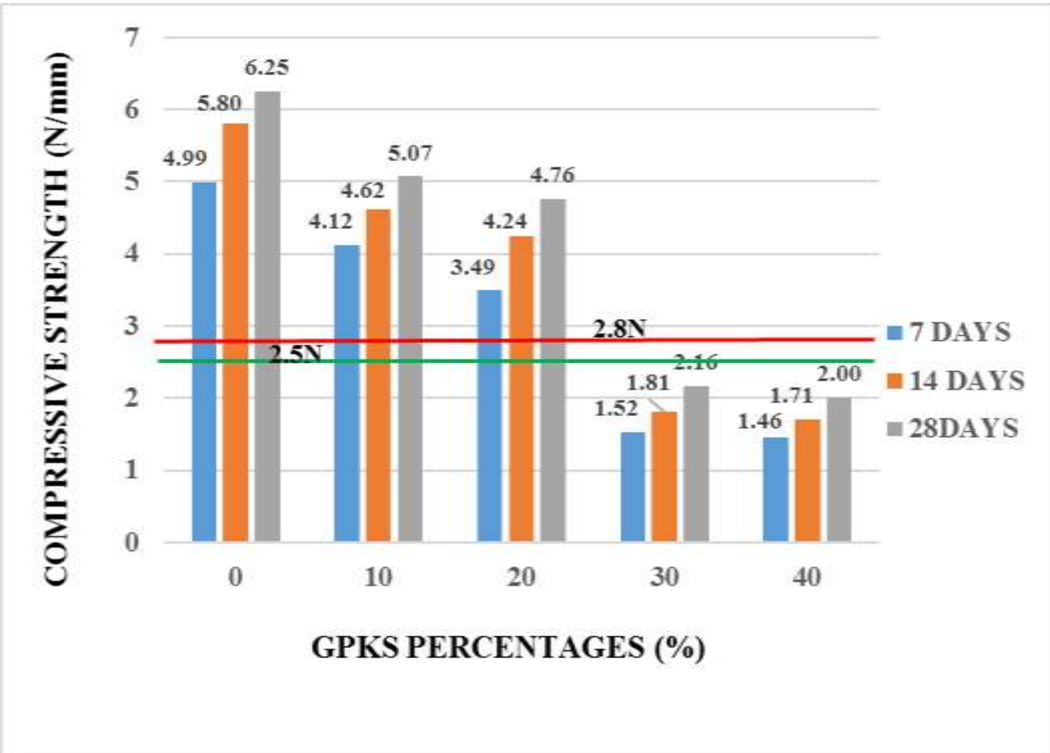

Figure 4.10a, Compressive strength of 150mm cellular block with (GPKS Type A)

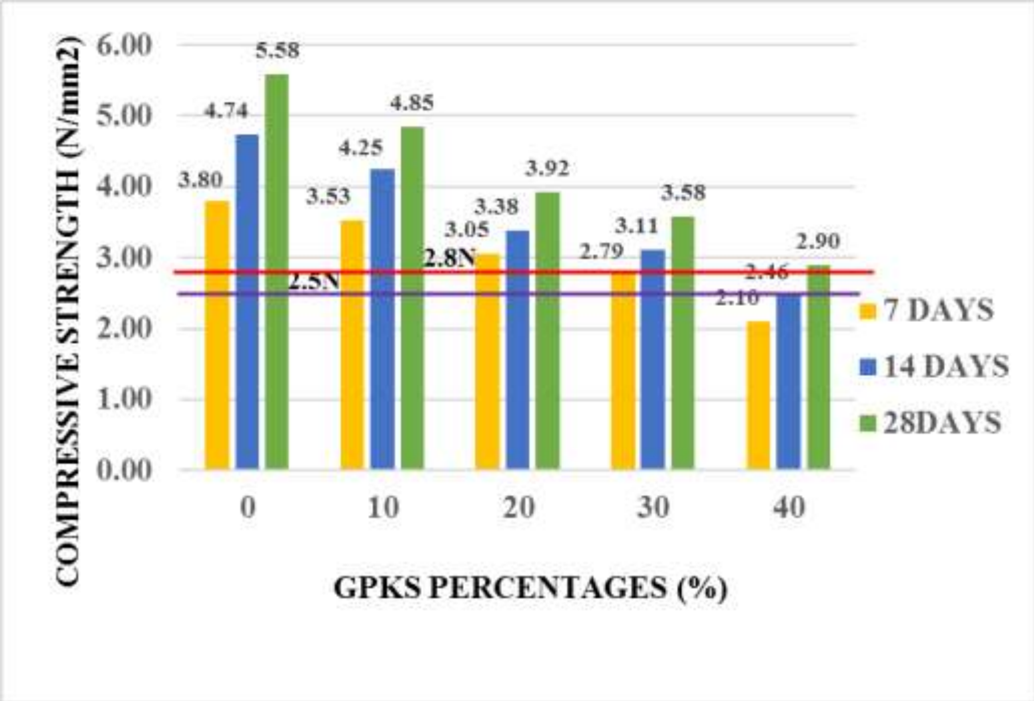

Figure 4.10b, Compressive strength of 150mm cellular block with (GPKS Type B)

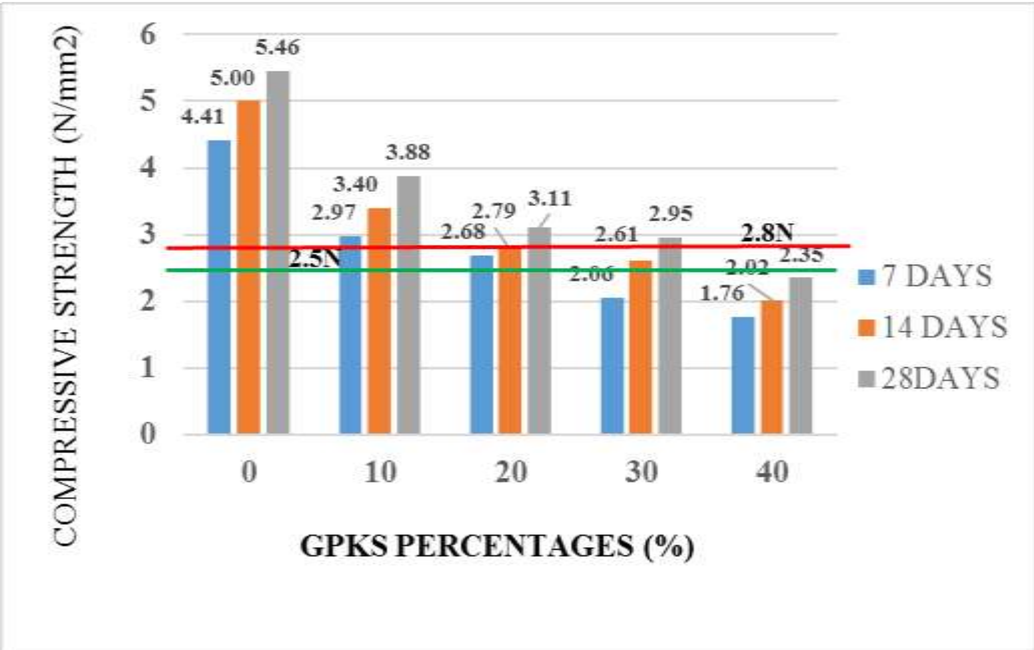

Figure 4.11a, Compressive strength of 125mm cellular block with (GPKS Type A)

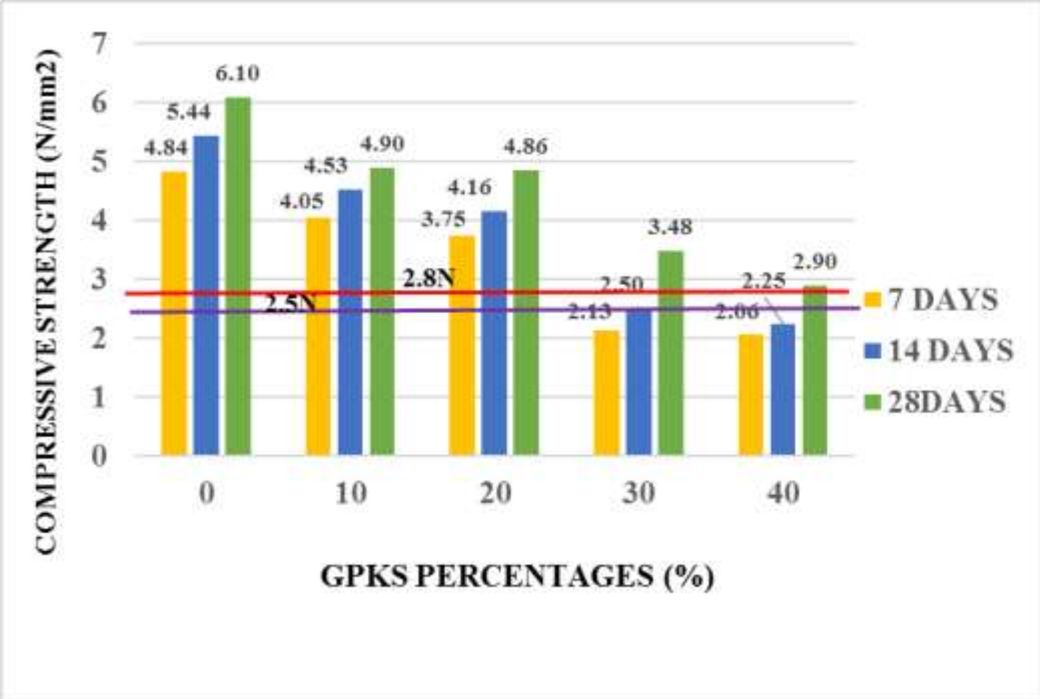

Figure 4.11b, Compressive strength of 125mm cellular block with (GPKS Type B)

Figures 4.10a and 4.10b, shows the results of compressive strength test for 455mm x 220mm x 150mm cellular masonry units produced with mix percentages of 0%, 10%, 20%, 30% and 40%. The result indicated that the compressive strength of 150mm cellular masonry units ranges from 4.99 N/mm^2 to 1.46 N/mm^2 and 6.25 N/mm^2 to 2.00 N/mm^2 at 7 and 28 days respectively. The results of 0%, 10% and 20%at 28 days were far above the 2.8 N/mm^2 required by BS 6073:1981 and 2.5 N/mm^2 required by GS 297 – 1:2010.

Similarly, 455mm x 220mm x 125mm cellular masonry units produced with 0%, 10%, 20%, 30% and 40% GPKS aggregate (Type A) in the study, from figures 4.11a and 4.11b the values appreciated in the compressive strengths ranges 4.41 N/mm^2 to 1.76 N/mm^2 and 5.46 N/mm^2 to 2.35 N/mm^2 at 7 and 28 days respectively. The 28 days result of the 40% GPKS aggregate was lower than the 2.8 N/mm^2 required by BS 6073:1981 and 2.5 N/mm^2 required by GS 297 – 1:2010.

The results of compressive strength test for 325mm x 175mm x 125mm solid masonry units produced with mix percentages of 0%, 10%, 20%, 30% and 40% GPKS aggregate. The result ranges from 3.34 N/mm^2 to 5.68 N/mm^2; 2.39 N/mm^2 to 4.38 N/mm^2; 1.96 N/mm^2 to 3.62 N/mm^2; 1.60 N/mm^2 to 3.12 N/mm^2 and 1.37 N/mm^2 to 2.62 N/mm^2 respectively at 7 and 28 days curing age. From the compressive strength results, it was established that 10% - 40% GPKS aggregate replacement content were lower than the compressive strength of the regulating sample (0% GPKS aggregate). Generally, the 28 days crushing strength results of GPKS masonry units with 10% - 30%% GPKS aggregate replacement content greater the minimum standard compressive strength of 2.8N/mm^2 according to BS 6073-1: 1981 and the 40% GPKS aggregate replacement content was higher than 2.5N/mm^2 required by GS 297- 1: 2010.

4.5.2 FLEXURAL STRENGTH

The flexural strength was determined in accordance to BS EN 1052 – 2:1999, using the masonry unit samples dimensions of 455mm x 220mm x (150, 125) mm and 400mm x 190mm x (150, 125) mm that were prepared with GPKS aggregates (type A) and (type B). The masonry unit samples were cured for 7, 14, and 28 days. Since there was not accessible machine for flexural strength test of the masonry unit in the system, based on the Centre line loading method the flexural strength was determined using the mathematical relationship; where applied (F) to the masonry unit sample perpendicular to its length (L), this would be divided by the average width (B) and average depth square (D^2). The flexural strength was calculated from the formula:

$$\mathbf{FS = 1/3\ (FL) / (2BD^2)}$$

Where;

FS is the flexural strength (N / mm2)

L is the span length (mm)

F is the maximum applied load (N) indicated by the testing machine

B is the average width of the block sample (mm)

D is the average thickness of the block sample (mm)

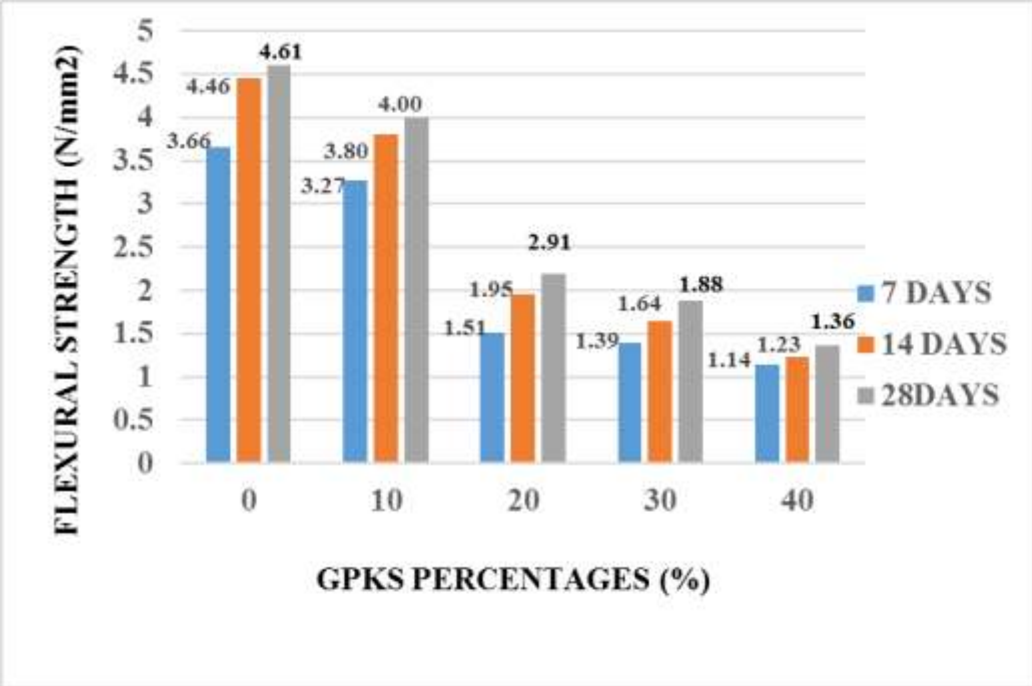

Figure 4.12a, Flexural strength of 150mm solid block with (GPKS Type A)

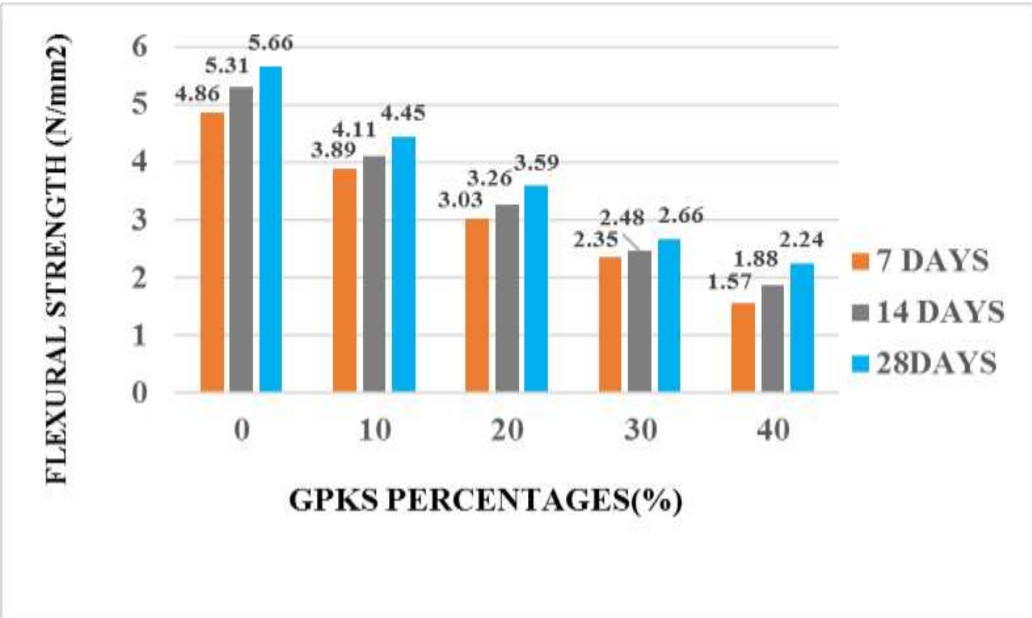

Figure 4.12b, Flexural strength of 150mm solid block with (GPKS Type B)

The flexural strength of 150mm solid masonry unit samples produced with GPKS aggregate in percentages of 0%, 10%, 20%, 30% and 40% is exhibited in figure 4.12a above. It was evident that the flexural strength upsurges as the curing age improved. The flexural strength was noticeable to have improved, the results ranges from 3.66N/mm^2 to 1.14 N/mm^2 and 4.61

N/mm^2 to 1.36 N/mm^2 at 7 and 28 days respectively. The results indicated that the flexural strength improved approximately at 19% and 45% with all the GPKS aggregate percentages as the curing age improved from 7 days to 28 days. Figure 4.12b above, exhibited the result of the flexural strength of masonry units prepared with GPKS aggregate type B ranges from 4.86 N/mm^2 to 1.57 N/mm^2 and 5.66 N/mm^2 to 2.24 N/mm^2 at 7 and 28 days respectively for 0%, 10%, 20%, 30% and 40% GPKS aggregate type B. The results indicated that the flexural strength developed just about 16%, and 43% with all the GPKS aggregate percentages Type B when the curing age increased from 7 days to 28 days. This change was due to the hydration reaction of the cement which increases the strengths of the masonry unit as the curing age increases.

Comparable result was seen for the 125mm solid masonry units produced with GPKS aggregate Type A, as shown in Figure 4.13a below. The flexural strengths recorded ranges from 2.74N/mm^2 to 0.80N/mm^2 and 3.43N/mm^2 to 1.10 N/mm^2 at 7 and 28 days respectively for 0%, 10%, 20%, 30% and 40% GPKS aggregate. The masonry units prepared with GPKS aggregate Type B are indicated in Figure 4.13b below. the flexural strengths ranges from 4.96N/mm^2 to 1.83N/mm^2 and 5.61N/mm^2 to 2.30N/mm^2 at 28days for 0%, 10%, 20%, 30% and 40% GPKS aggregate. The results showed that the trend of the flexural strengths appreciating when the curing age increased with all the GPKS aggregate percentages.

The flexural strength of 150mm cellular masonry unit samples produced with GPKS aggregate Type A in percentages of 0%, 10%, 20%, 30% and 40% is exhibited in Figure 4.14a above. It was evident that the flexural strength improved as the curing was enhanced. The flexural strengths were noticeable to have improved, the results ranges from 3.66N/mm^2 to 3.27 N/mm^2 and 1.14 N/mm^2 and 4.61 N/mm^2 to 1.36 N/mm^2 at 7 and 28 days respectively. The results indicated that the flexural strengths improved approximately at 19% and 26% with all the GPKS aggregate percentages while the curing age was increased from 7 days to 28 days. Figure 4.14b above, exhibited the result of the flexural strengths of cellular masonry units prepared with GPKS aggregate Type B ranges from 4.86 N/mm^2 to 1.57 N/mm^2 and 5.66 N/mm^2 to 2.24 N/mm^2 at 7 and 28 days respectively for 0%, 10%, 20%, 30% and 40% GPKS aggregate type B. The results indicated that the flexural strengths developed just about 16% and 43% with all the GPKS aggregate Type B percentages when the curing age increased from 7 days to 28 days. This change was cause by the chemical reaction of the cement which enhanced the strengths of the cellular masonry unit as the curing age increases.

Figures 4.8a, 4.8b; 4.9a, 4.9b; 4.10a, 4.10b, 4.11a, 4.11b and 4.12a, 4.12b; 4.13a, 4.13b; 4.15a. 4.15b, illustrate the compressive strength and flexural strength development of GPKS masonry units containing 0%, 10%, 20%, 30% and 40% GPKS aggregate percentage content as partial replacement of sand. On overall, all the mix percentages exhibited increases in strength values as the curing age increase from 7, 14 and 28days. Curing was used to ensure continuous hydration process which was responsible for strength development. Assessing the effect of GPKS aggregate on masonry unit strength, it was evident that as GPKS aggregate percentage content increases, the compressive strength of all the GPKS masonry units decreased.

The result indicates that 10% GPKS aggregate as partial replacement of sand was able to produce masonry unit with the highest strength as compared to all the mix percentages of GPKS aggregate. The compressive strength of all the mix percentages of masonry units with GPKS aggregate Type B are less than the control sample. However, the compressive strengths are higher than the 2.8N/mm^2 required by BS 6073 and 2.5N/mm^2 required by GS 297.

Similar observation was made by Dadzie and Yankah (2015), who indicated that as GPKS aggregate percentage quantity increases, the compressive strength decreased. However, decreased in both compressive strength and flexural strength of GPKS masonry units was observed as the result of percentage of sand replaced with GPKS aggregate percentage content of 10% - 40%.

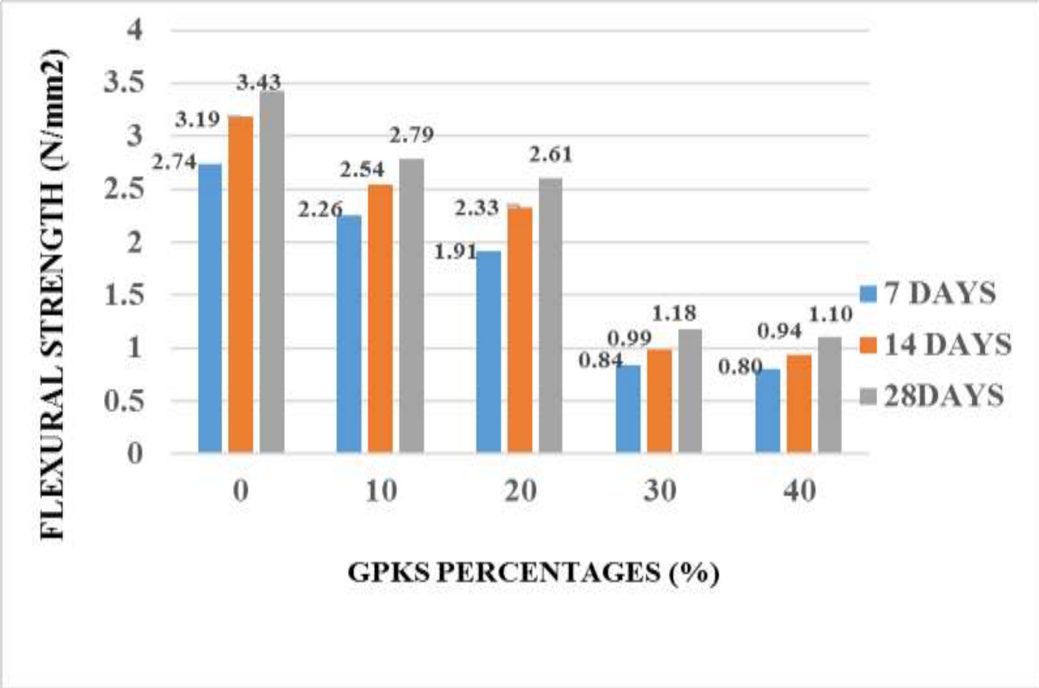

Figure 4.13a, Flexural strength of 125mm solid block with (GPKS Type A)

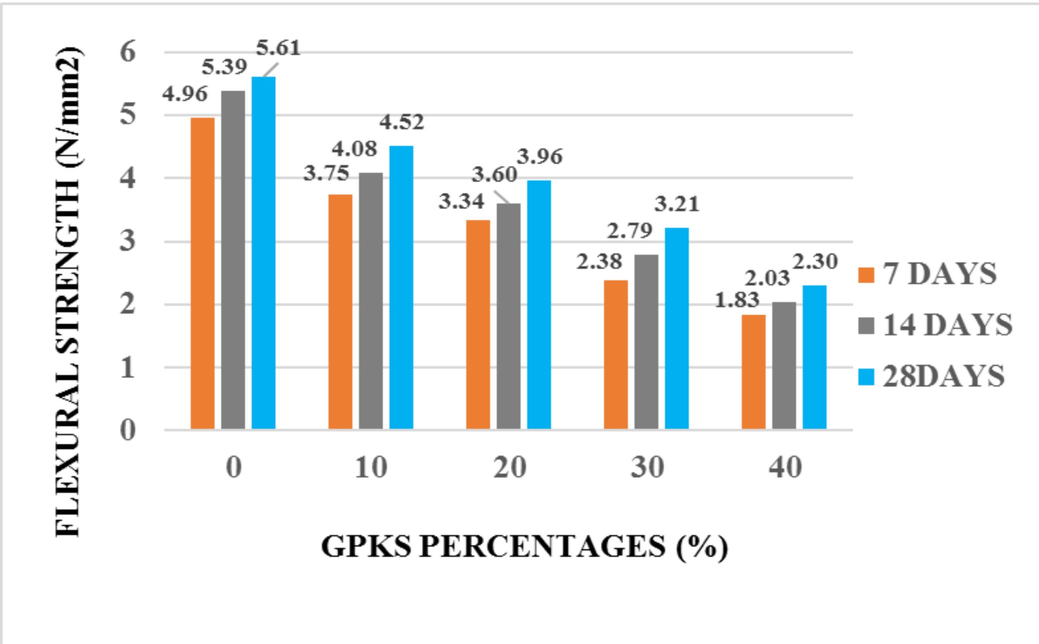

Figure 4.13b, Flexural strength of 125mm solid block with (GPKS Type B)

The interpretation of the chart in Figures 4.18a and 4.18b above**,** supports the trend of the flexural strengths of 150mm and 125mm cellular masonry units appreciating when the curing age increased with all the GPKS aggregate percentages. The flexural strengths of 150mm solid masonry unit samples produced with GPKS aggregate Type A in percentages of 0%, 10%, 20%, 30% and 40% is exhibited in figure 4.18a above. It was evident that the flexural strengths increase as the curing age was enhanced. The flexural strengths were noticeable to have improved, the results ranges from 3.66N/mm^2 to 1.14 N/mm^2 and 4.61 N/mm^2 to 1.36 N/mm^2 at 7 and 28 days respectively. The results indicated that the flexural strengths improved approximately at 19% and 26% with all the GPKS aggregate percentages when the curing age increased from 7 days to 28 days. This change was due to the hydration reaction of the cement which increases the strengths of the masonry unit as the curing age increases.

Equivalent result can be seen for the 125mm cellular masonry units produced with GPKS aggregate Type A, as shown in Figure 4.19a above. The flexural strengths recorded ranges from 2.74N/mm^2 to 0.80N/mm^2 and 3.43N/mm^2 to 1.10 N/mm^2 at 7 and 28 days respectively for 0%, 10%, 20%, 30% and 40% GPKS aggregate. The masonry units prepared with GPKS aggregate type B are indicated in figure 4.19b above, the flexural strengths result ranges from 4.96N/mm^2 to 1.83N/mm^2 and 5.61N/mm^2 to 2.30N/mm^2 at 7 and 28daysrespectively for 0%, 10%, 20%, 30% and 40% GPKS aggregate. The results showed that the trend of the flexural strengths appreciating when the curing age increased with all the GPKS aggregate percentages.

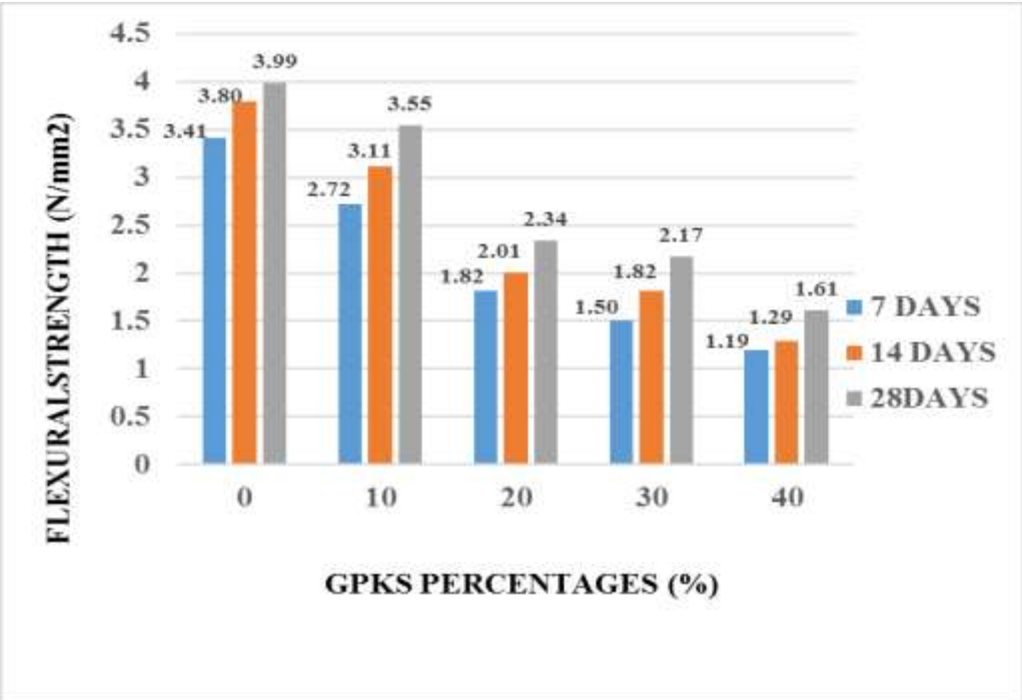

Figure 4.14a, Flexural strength of 150mm cellular block with (GPKS Type A)

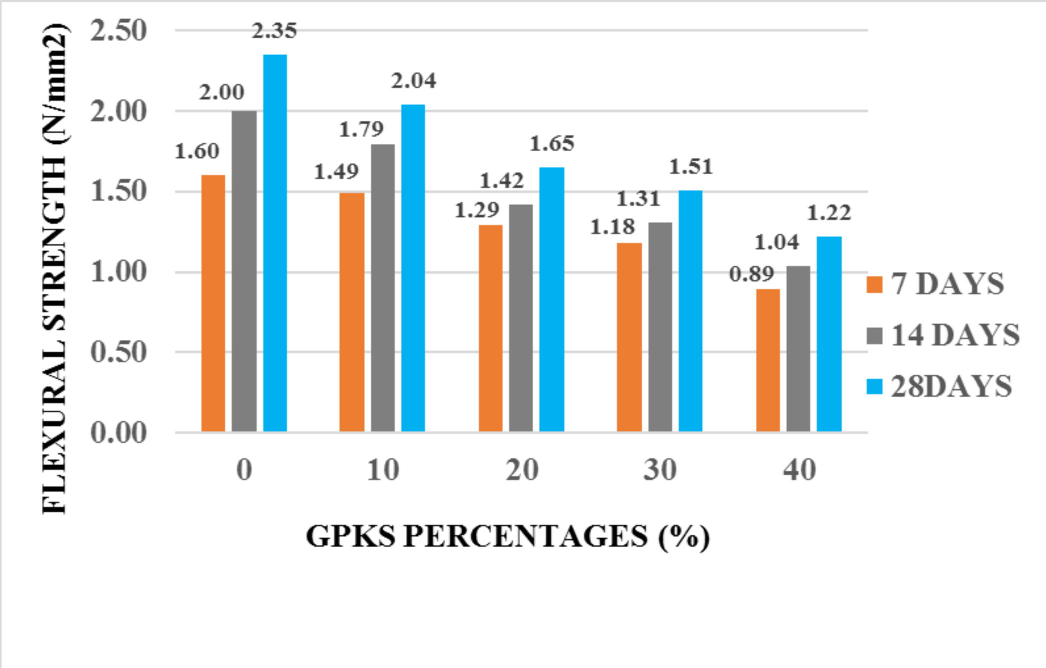

Figure 4.14b, Flexural strength of 150mm cellular block with (GPKS Type B)

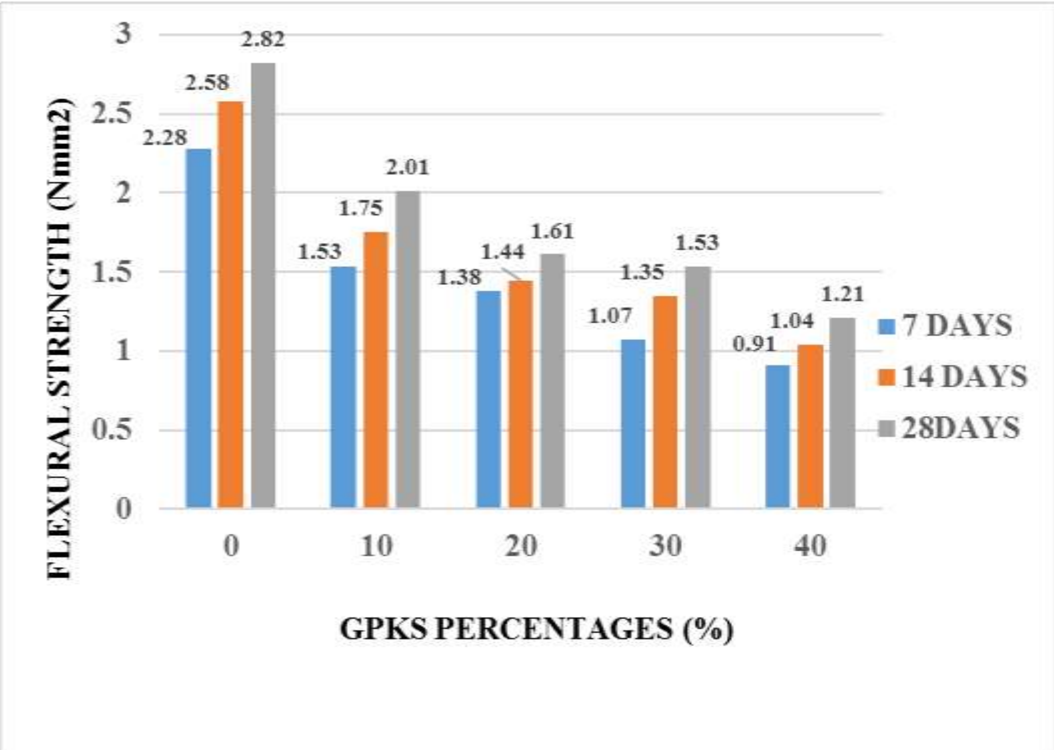

Figure 4.15a, Flexural strength of 125mm cellular block with (GPKS Type A)

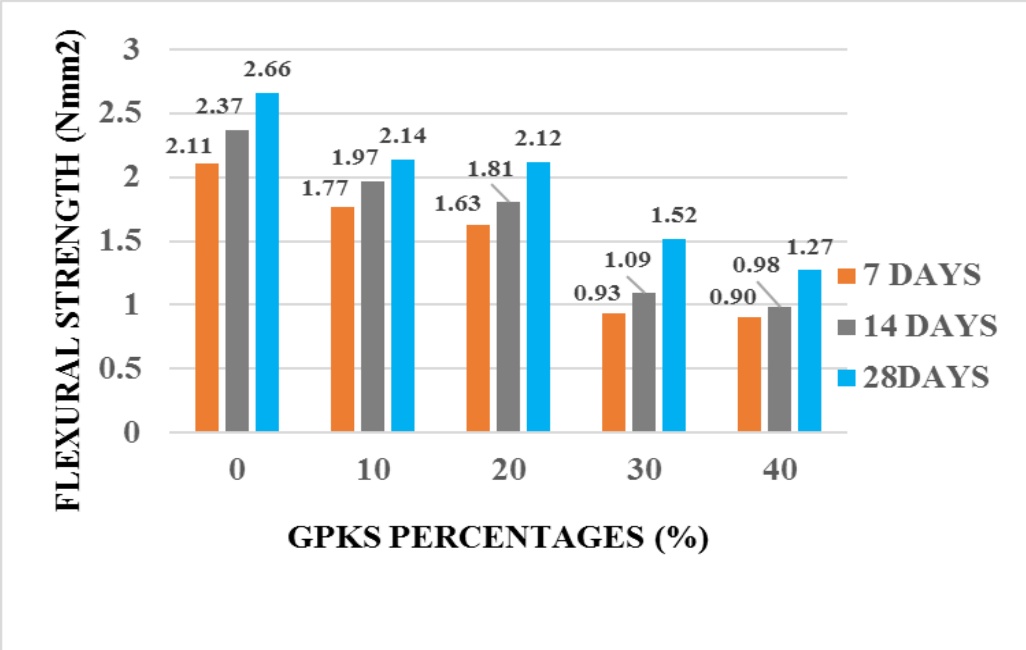

Figure 4.15b, Flexural strength of 125mm cellular block with (GPKS Type B)

4.6 EFFECT OF WATER ABSORPTION VERSES COMPRESSIVE STRENGTH

The effect of water absorbed and compressive strength of GPKS masonry units are plotted and shown in figures 4.16a, 4.16b, 4.17a, 4.17b, 4.18a, 4.18b, 4.19a and 4.19b.

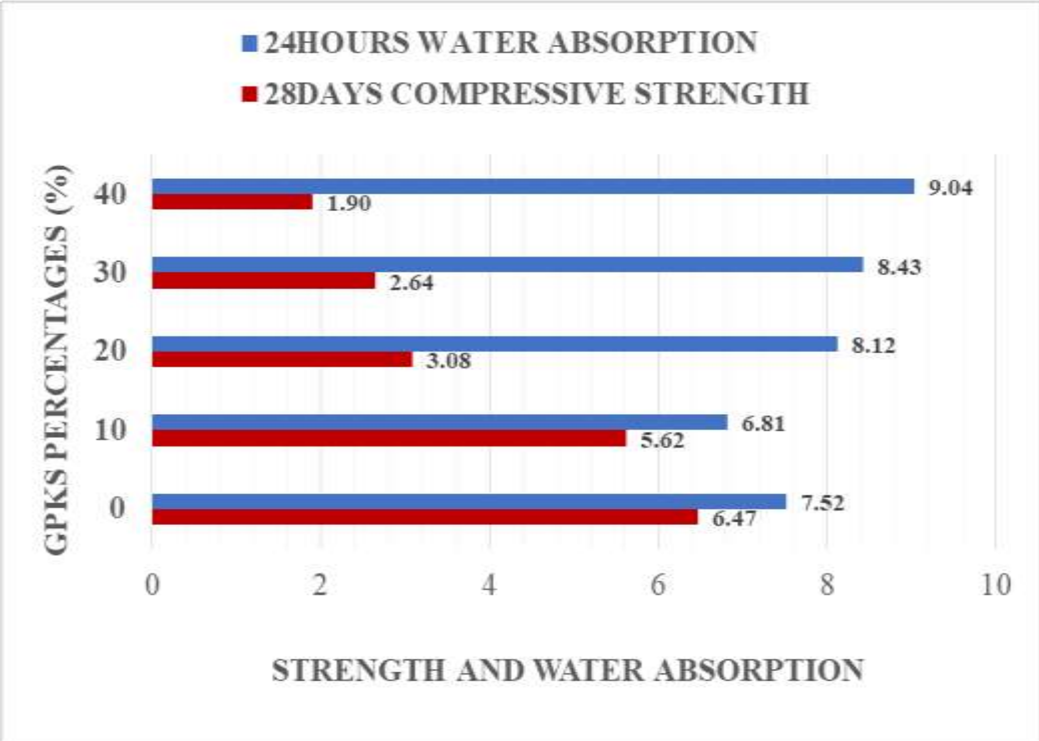

Figure 4.16a, Strength verses Water absorption of 150mm solid block with GPKS aggregate Type A

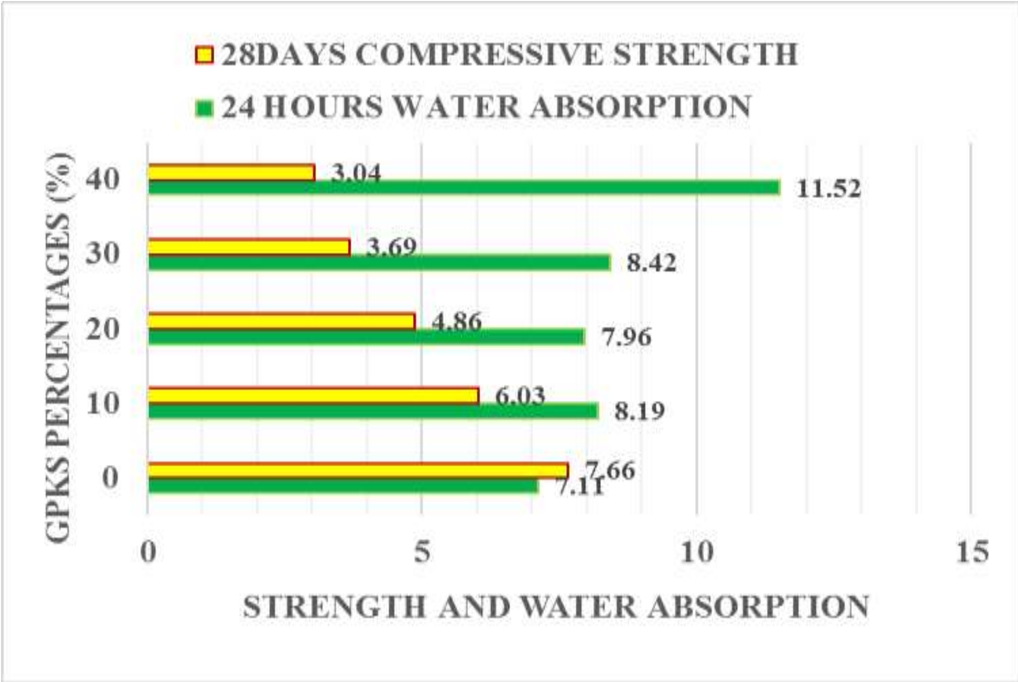

Figure 4.16b, Strength Verses Water absorption of 150mm solid block with GPKS aggregate Type B

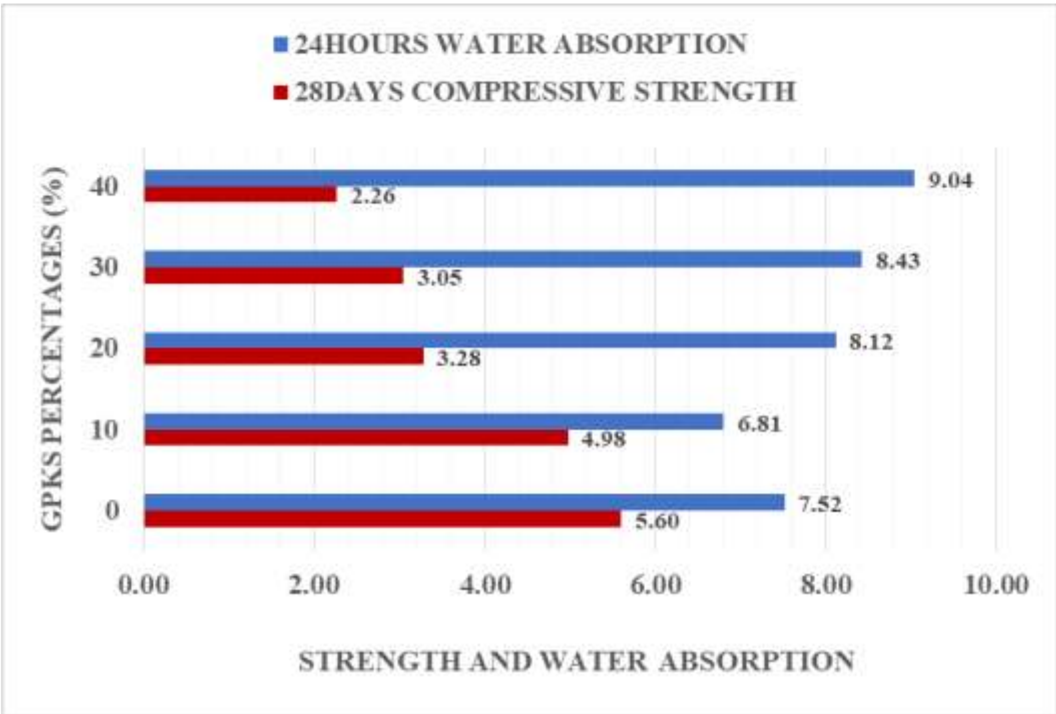

Figure 4.17a, Strength Verses Water absorption of 125mm solid block with GPKS aggregate Type A

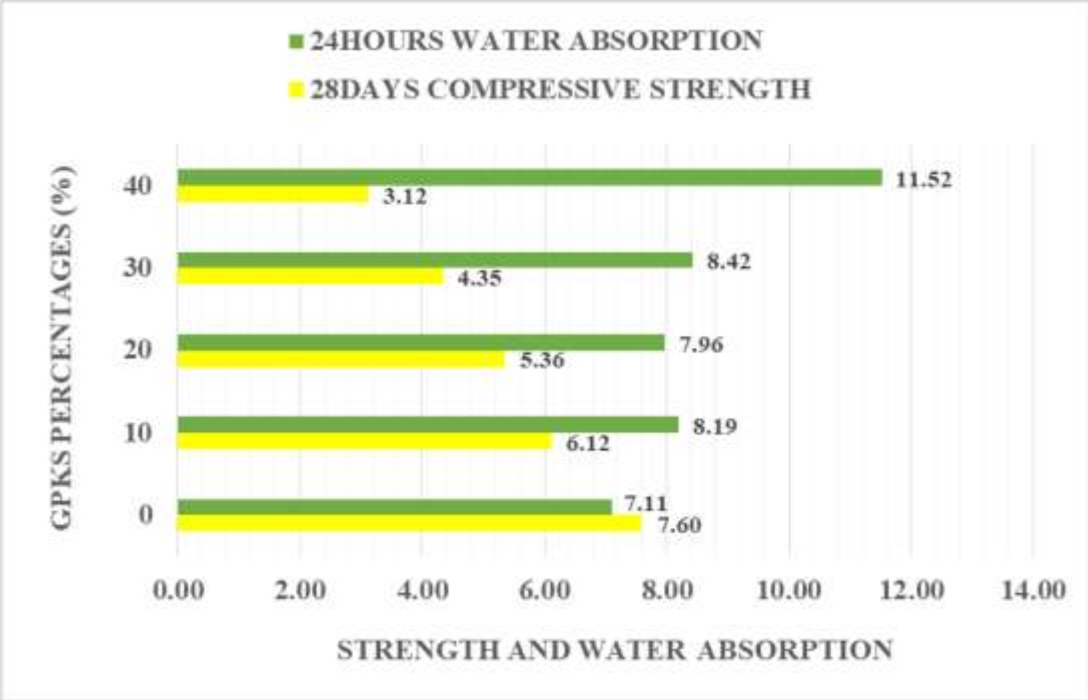

Figure 4.17b, Strength Verses Water absorption of 125mm solid block with GPKS aggregate Type B

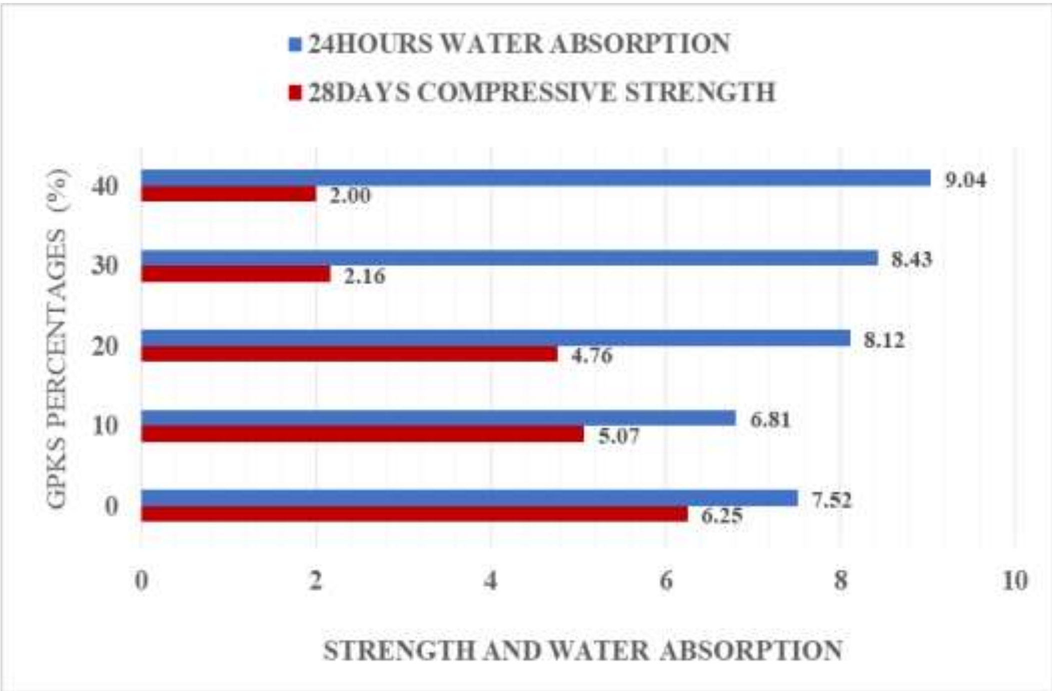

Figure 4.18a, Strength Verses Water absorption of 150mm cellular block with GPKS aggregate Type A

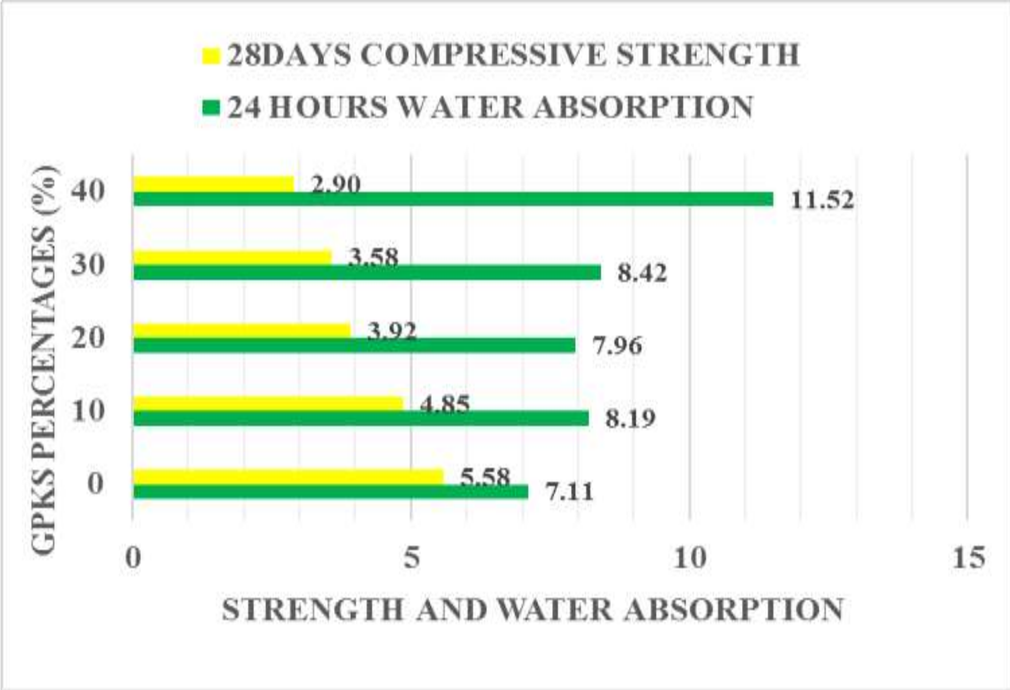

Figure 4.18b, Strength Verses Water absorption of 150mm cellular block with GPKS aggregate Type B

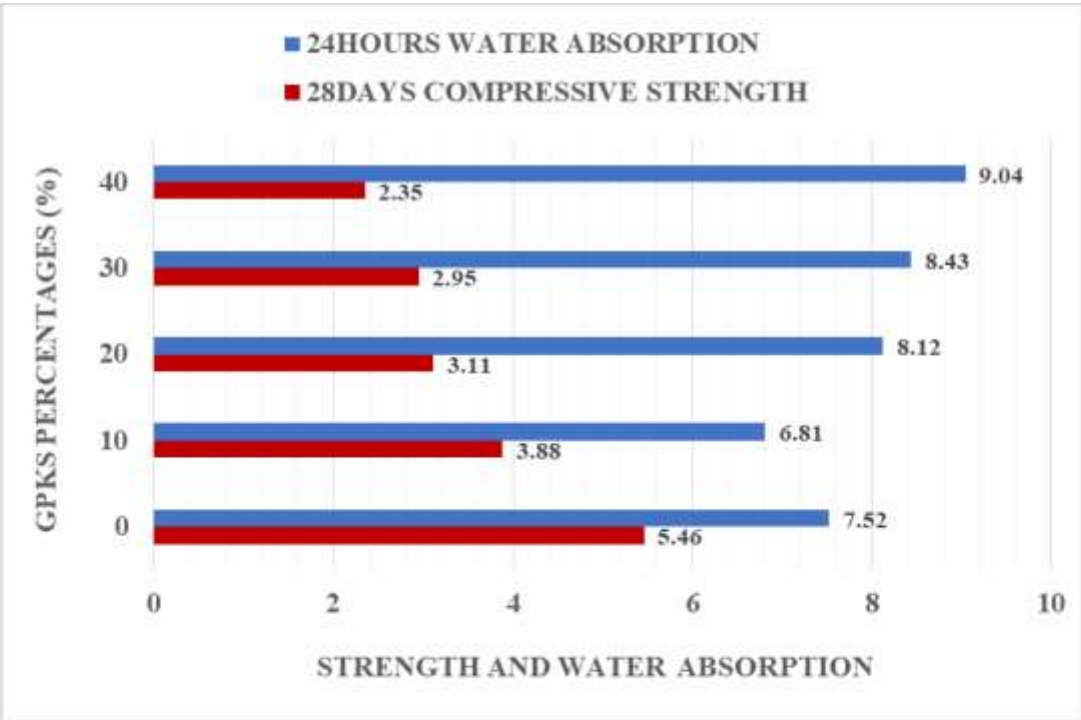

Figure 4.19a, Strength Verses Water absorption of 125mm cellular block with GPKS aggregate Type A

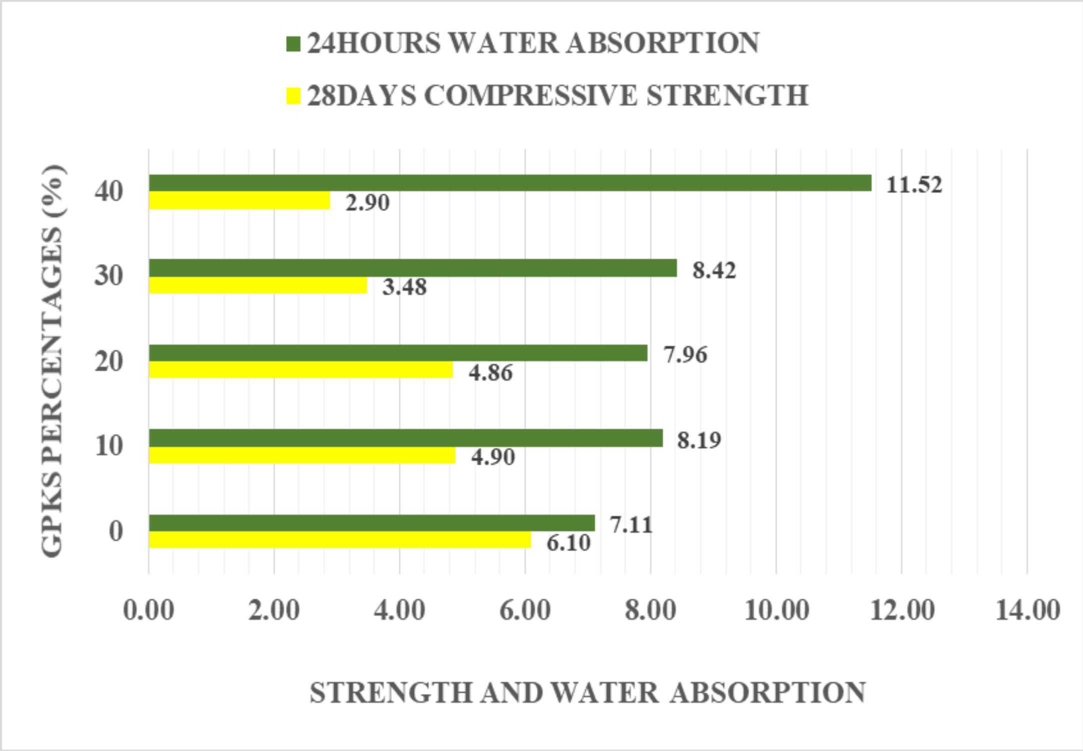

Figure 4.19b, Strength Verses Water absorption of 125mm cellular block with GPKS aggregate Type B

4.7 EFFECT OF MASONRY SIZES ON COMPRESSIVE STRENGTH

The effect of masonry sizes and compressive strength of GPKS masonry units are plotted and shown in figures 4.20a, 4.20b, 4.21a, 4.21b, 4.22a, 4.22b, 4.23a and 4.23b.

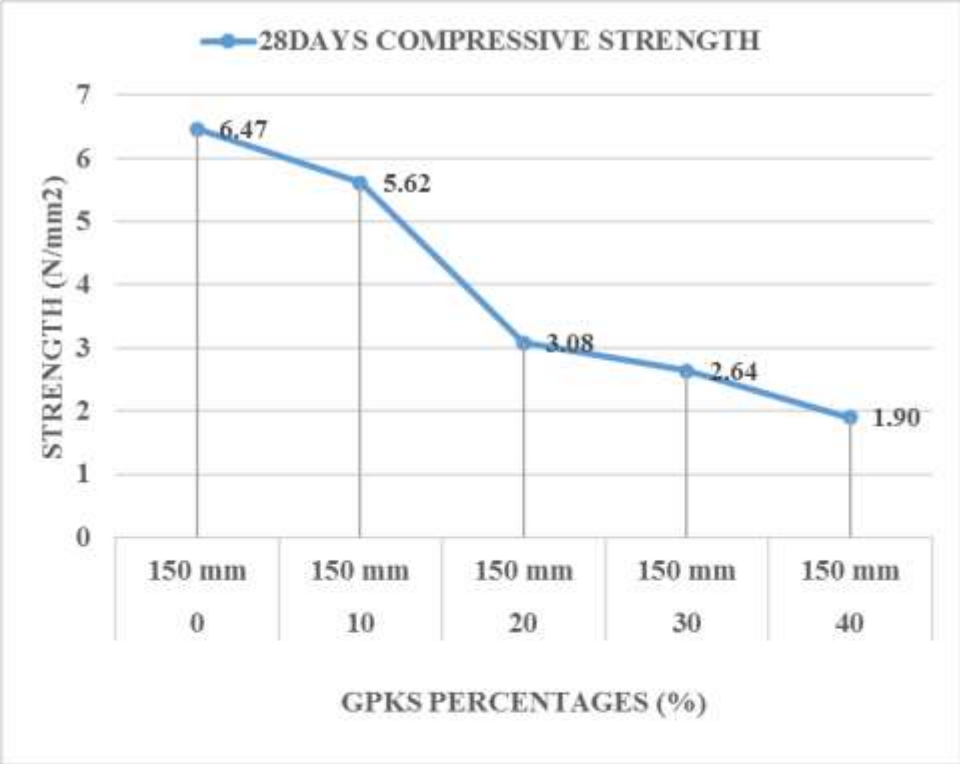

Figure 4.20a, Strength Verses Size of 150mm solid block with GPKS aggregate Type A

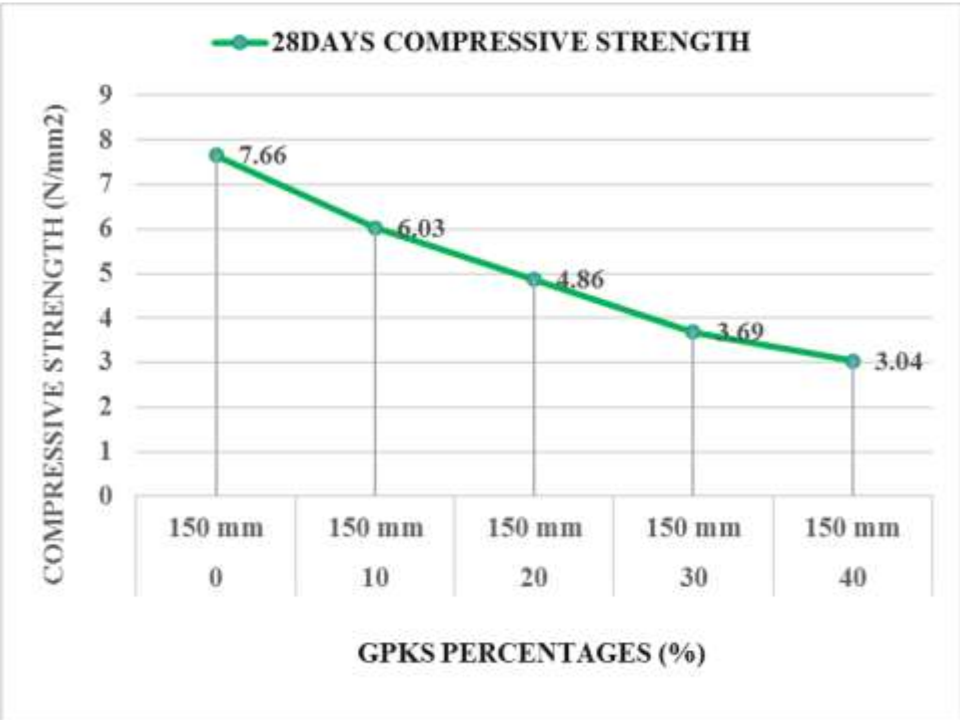

Figure 4.20b, Strength Verses Size of 150mm solid block with GPKS aggregate Type B

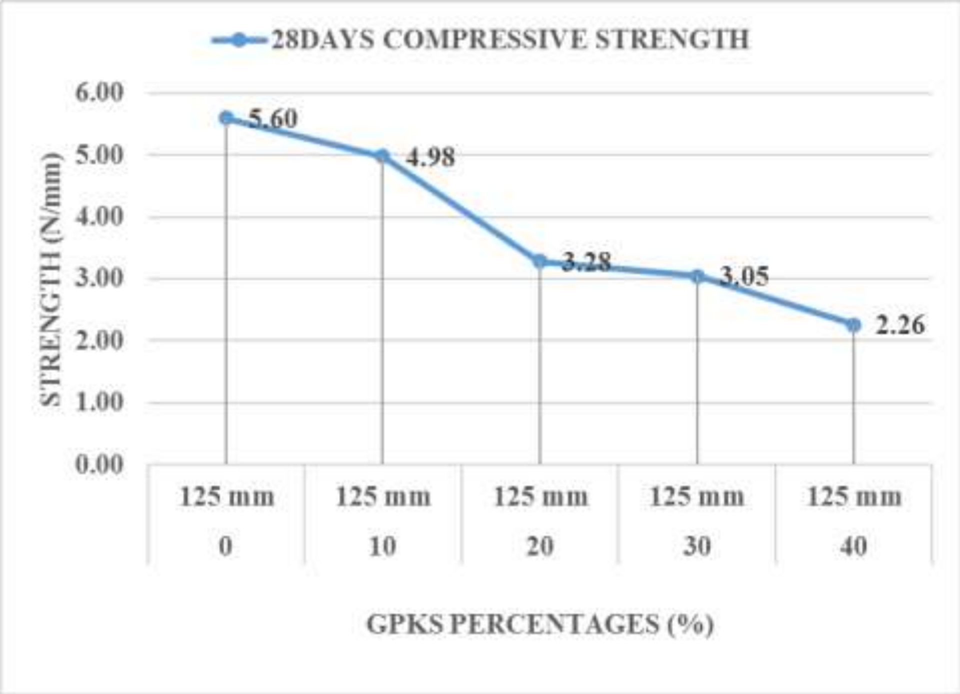

Figure 4.21a, Strength Verses Size of 125mm solid block with GPKS aggregate Type A

Figure 4.21b, Strength Verses Size of 125mm solid block with GPKS aggregate Type B

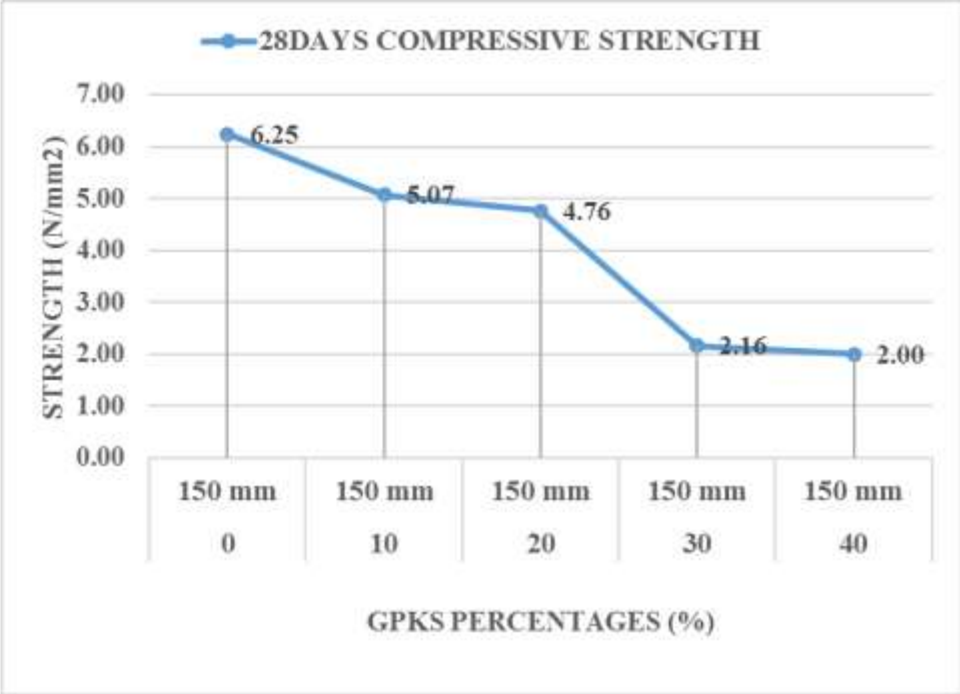

Figure 4.22a, Strength Verses Size of 150mm cellular block with GPKS aggregate Type A

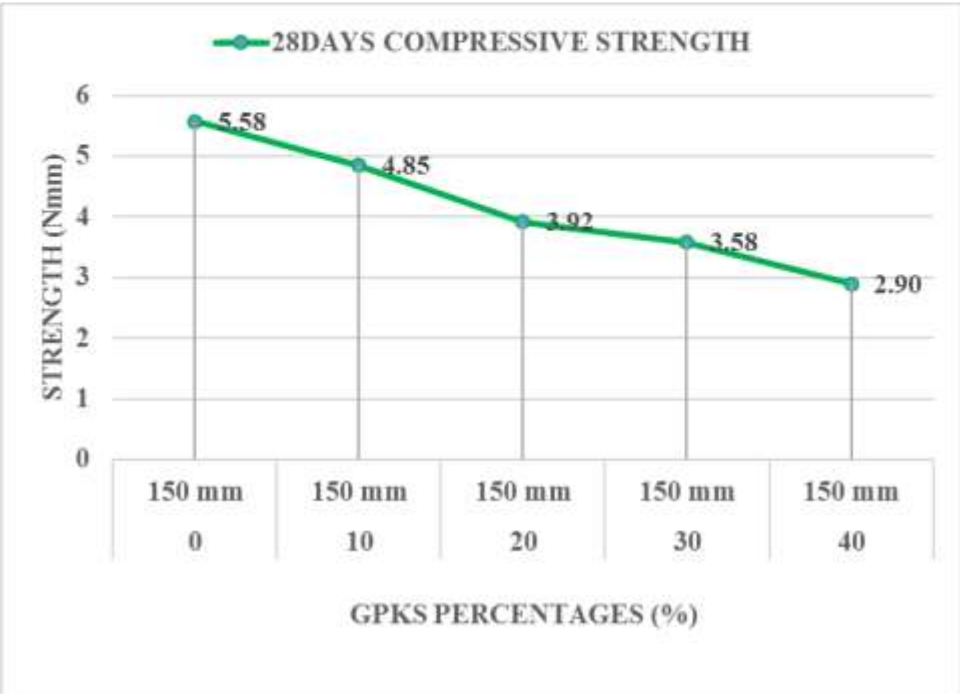

Figure 4.22b, Strength Verses Size of 150mm cellular block with GPKS aggregate Type B

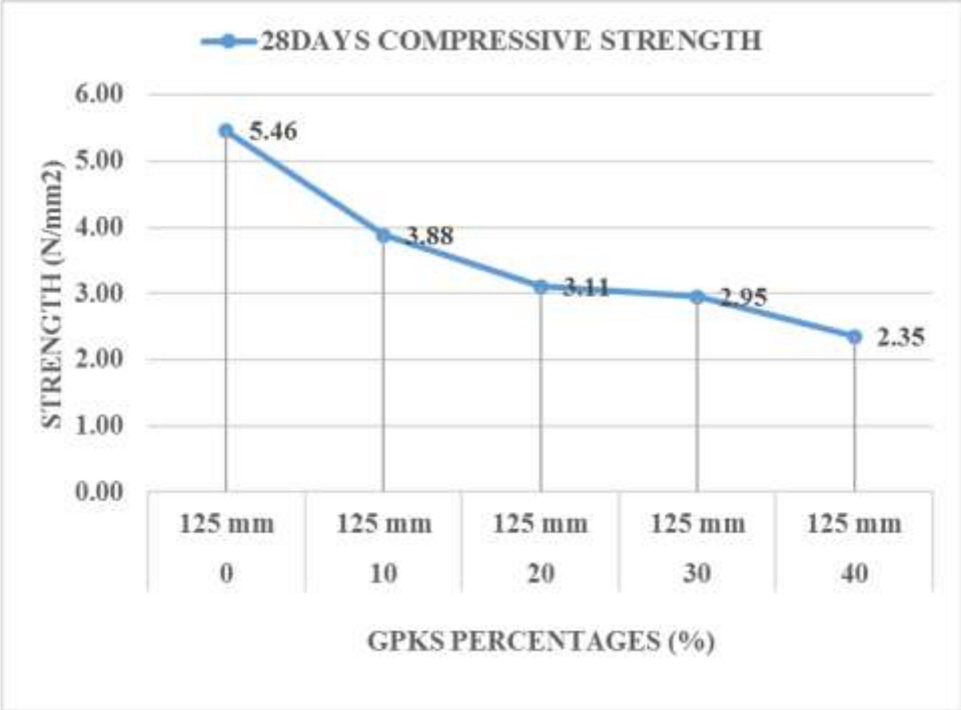

Figure 4.23a, Strength Verses Size of 125mm cellular block with GPKS aggregate Type A

Figure 4.23b, Strength Verses Size of 125mm cellular block with GPKS aggregate Type B

4.8 EFFECT OF WATER ON COMPRESSIVE STRENGTH

The effect of water on compressive strength of GPKS masonry units are plotted and shown in figures 4.24a, 4.24b, 4.25a, 4.25b, 4.26a, 4.36b, 4.27a, 4.27b.

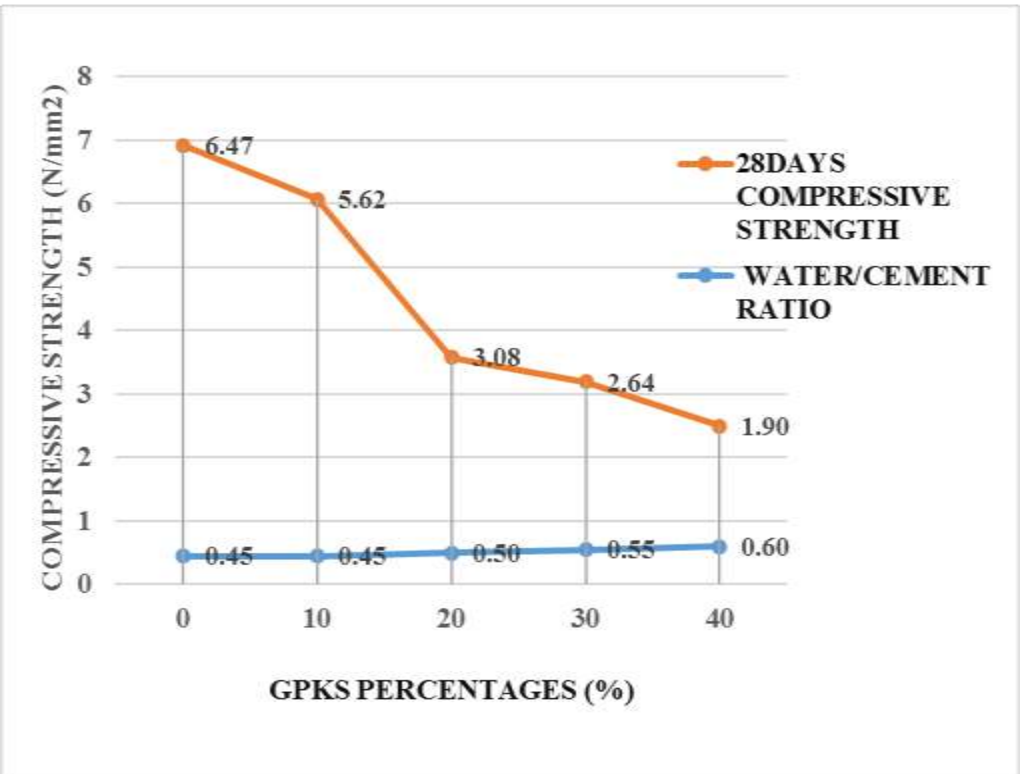

Figure 4.24a, Effect of Water on Strength (150mm solid block with GPKS aggregate Type A)

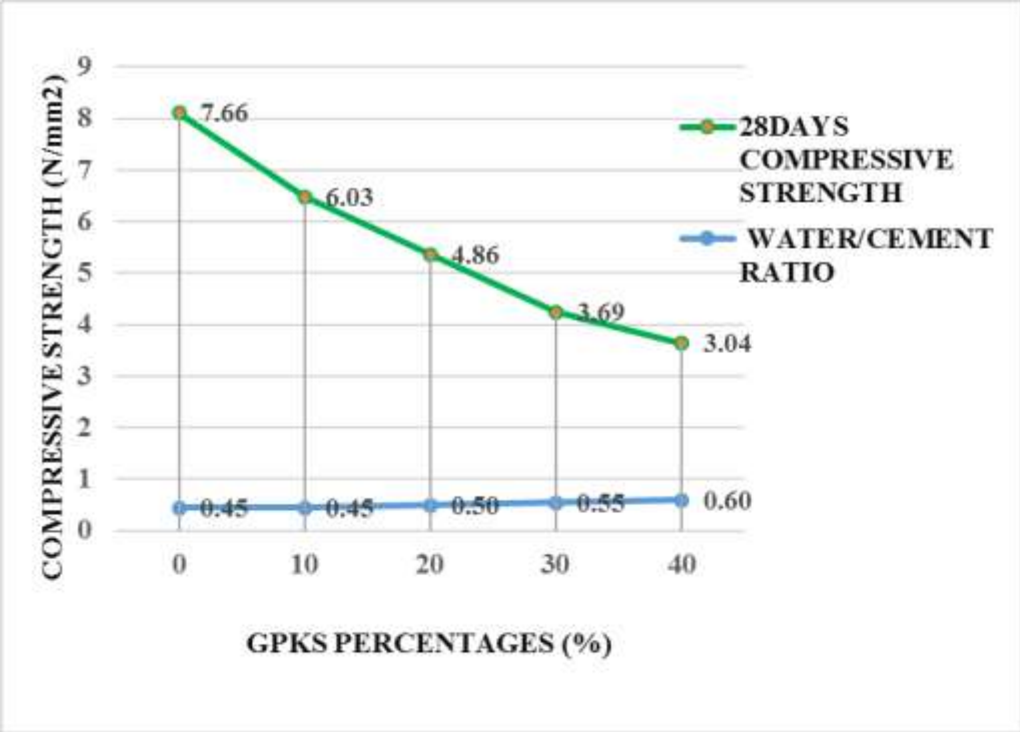

Figure 4.24b, Effect of Water on Strength (150mm solid block with GPKS aggregate Type B)

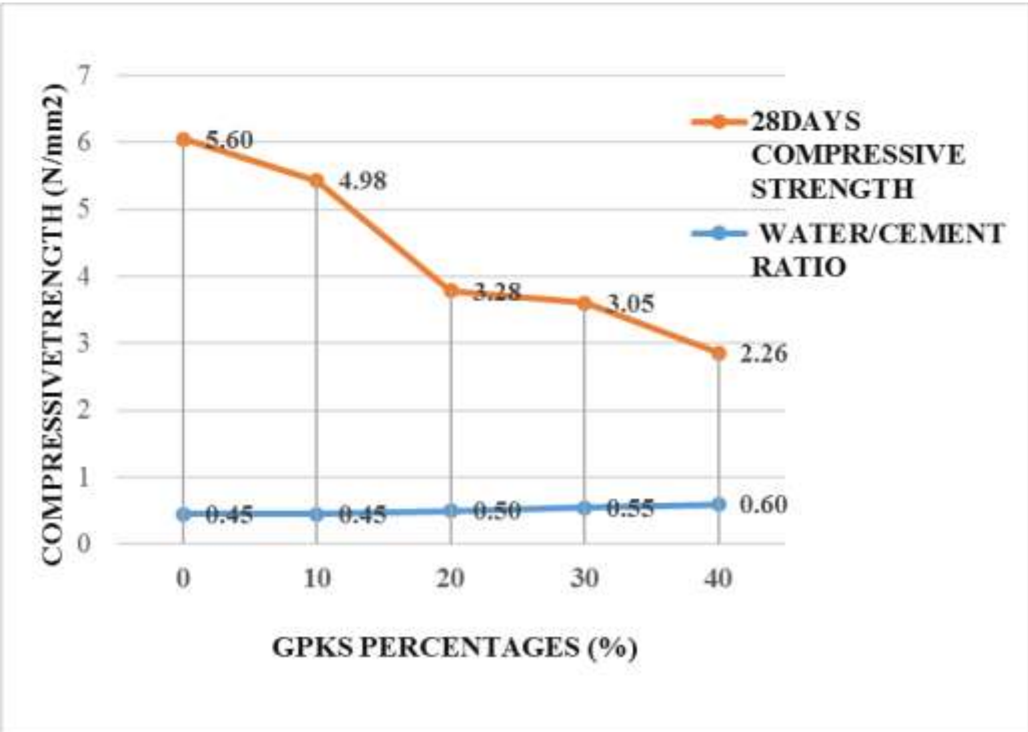

Figure 4.25a, Effect of Water on Strength (125mm solid block with GPKS aggregate Type A)

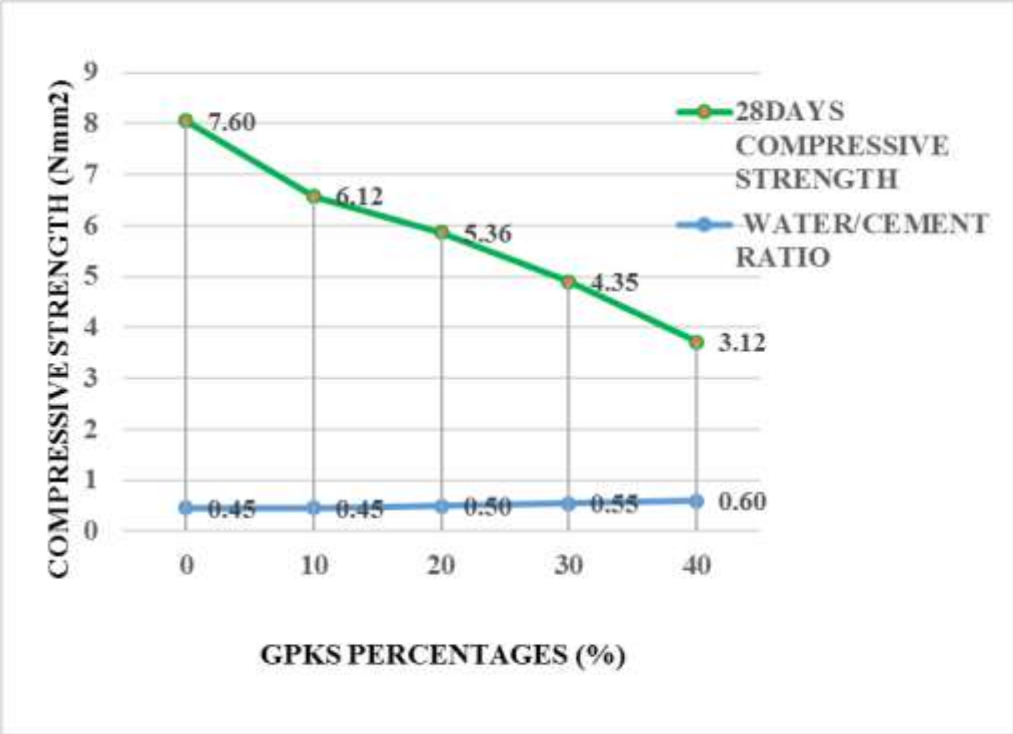

Figure 4.25b, Effect of Water on Strength (125mm solid block with GPKS aggregate Type B)

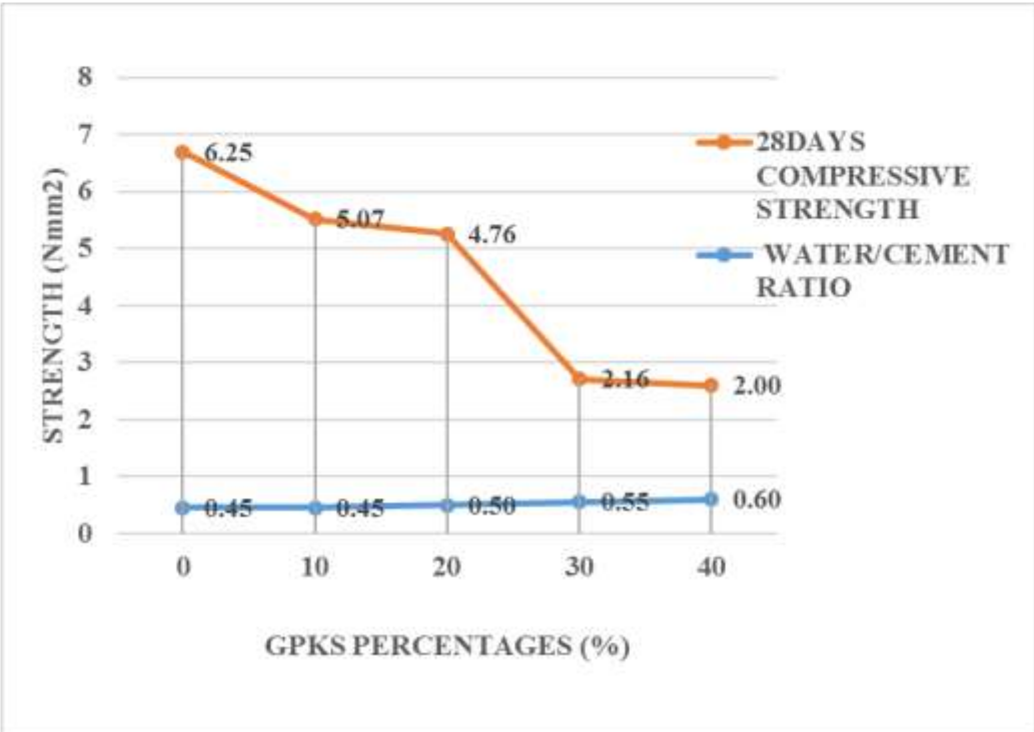

Figure 4.26a, Effect of Water on Strength (150mm cellular block with GPKS aggregate Type A)

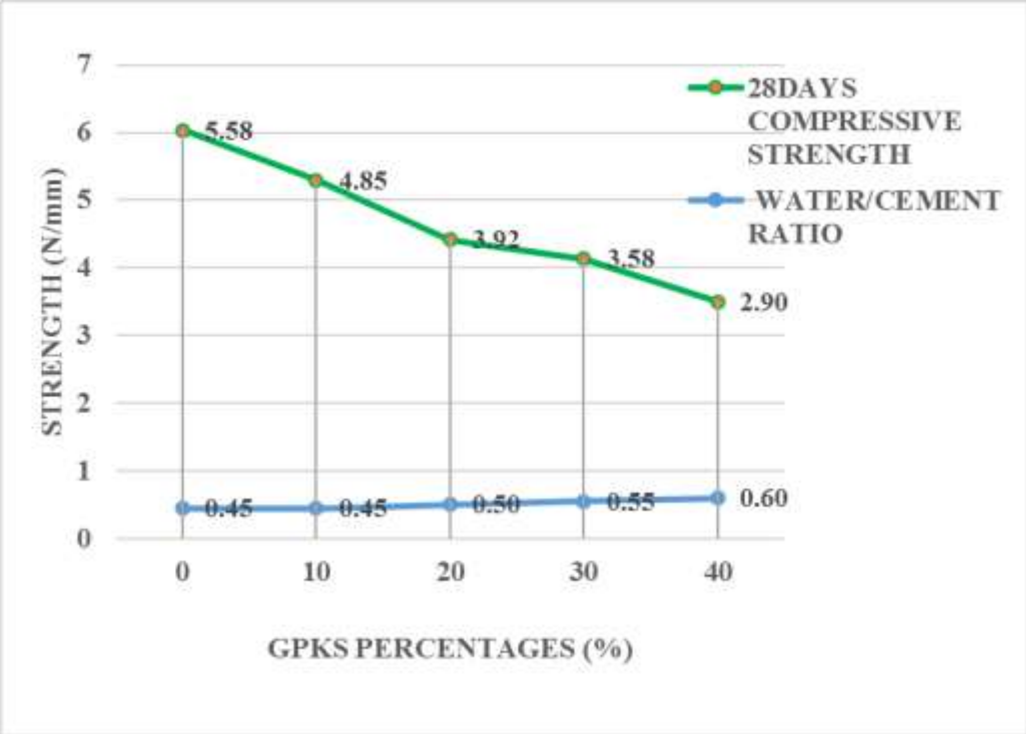

Figure 4.26b, Effect of Water on Strength (150mm cellular block with GPKS aggregate Type B)

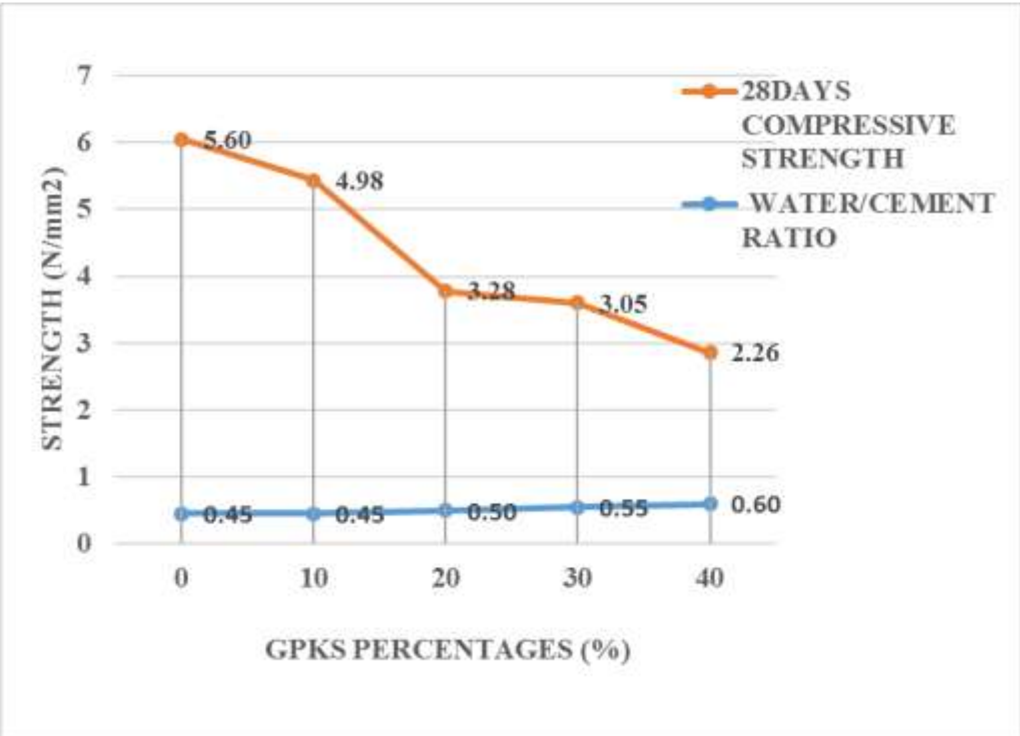

Figure 4.27a, Effect of Water on Strength (125mm cellular block with GPKS aggregate Type A)

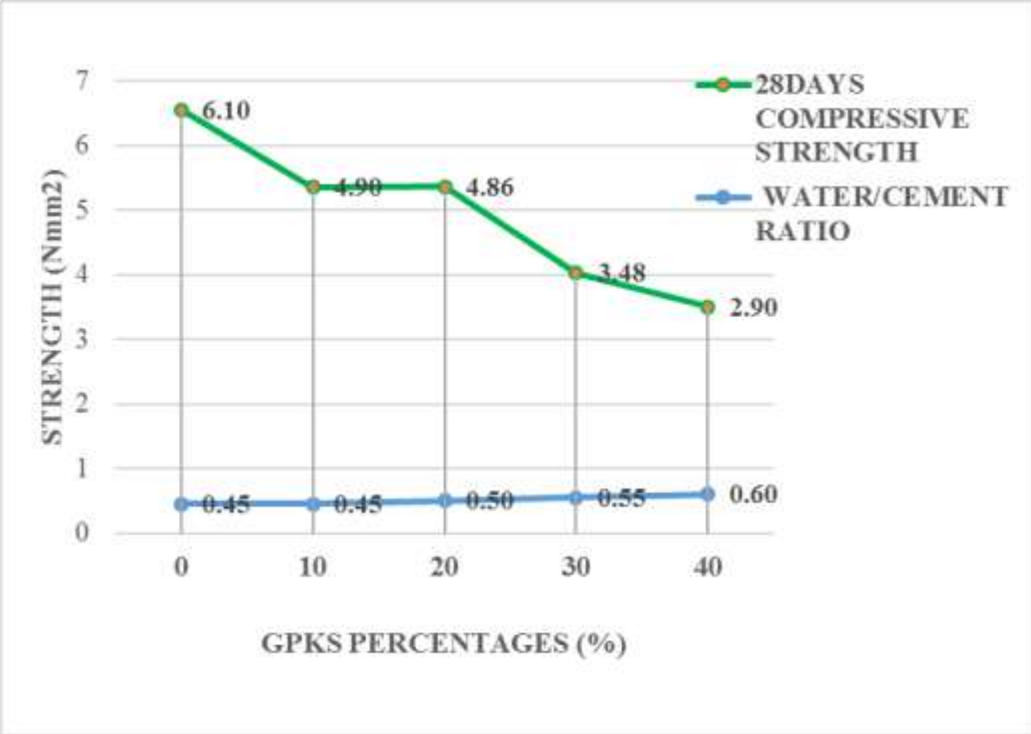

Figure 4.27b, Effect of Water on Strength (125mm cellular block with GPKS aggregate Type B)

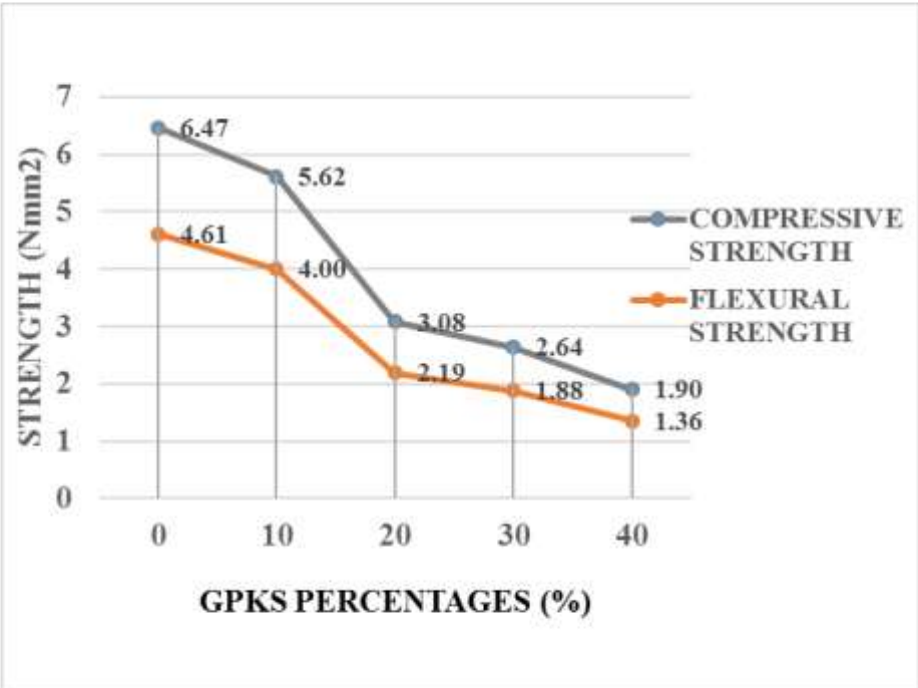

Figure 4.28a, Compressive verses Flexural Strengths (with GPKS aggregate Type A)

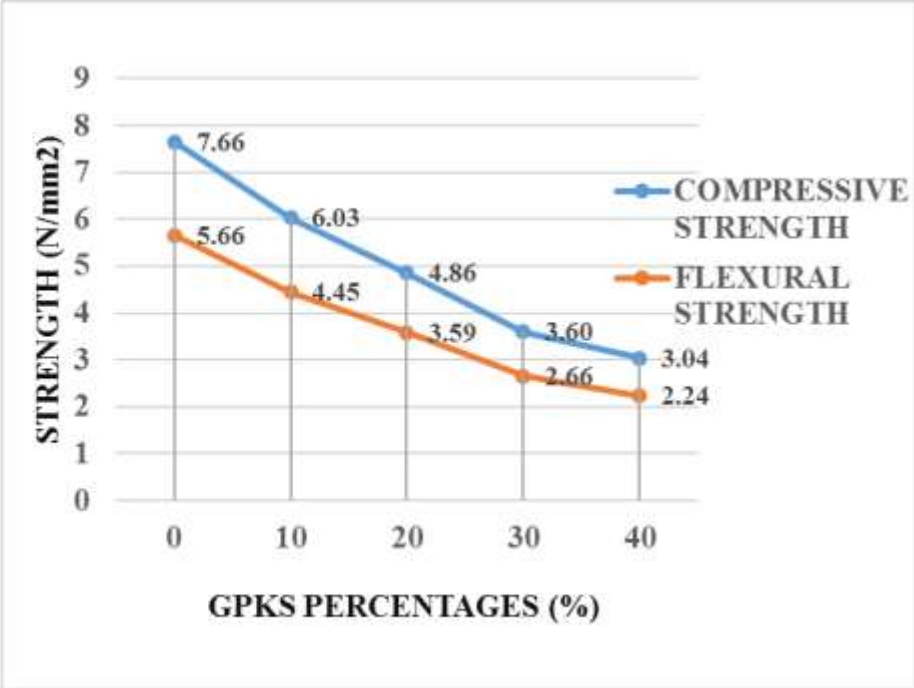

Figure 4.28b, Compressive verses Flexural Strengths (with GPKS aggregate Type B)

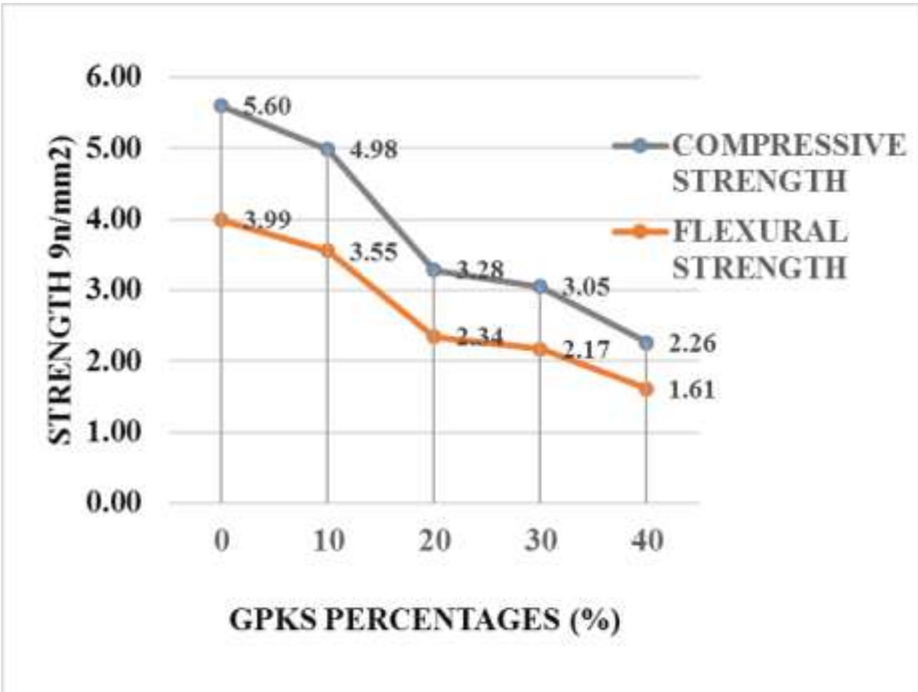

Figure 4.29a, Compressive verses Flexural Strengths (with GPKS aggregate Type A)

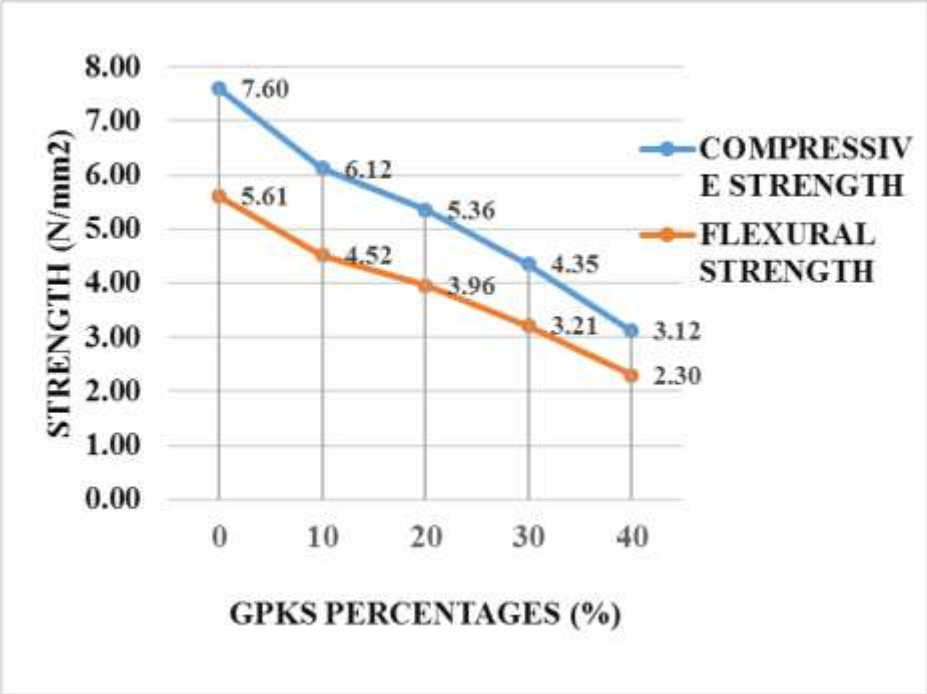

Figure 4.29b, Compressive verses Flexural Strengths (with GPKS aggregate Type B)

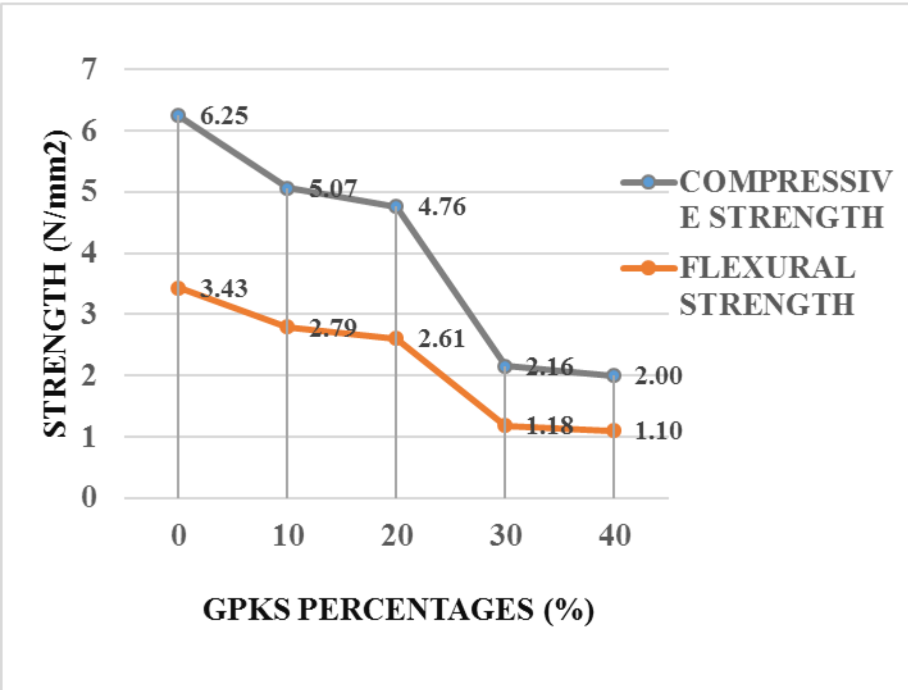

Figure 4.30a, Compressive verses Flexural Strengths (with GPKS aggregate Type A)

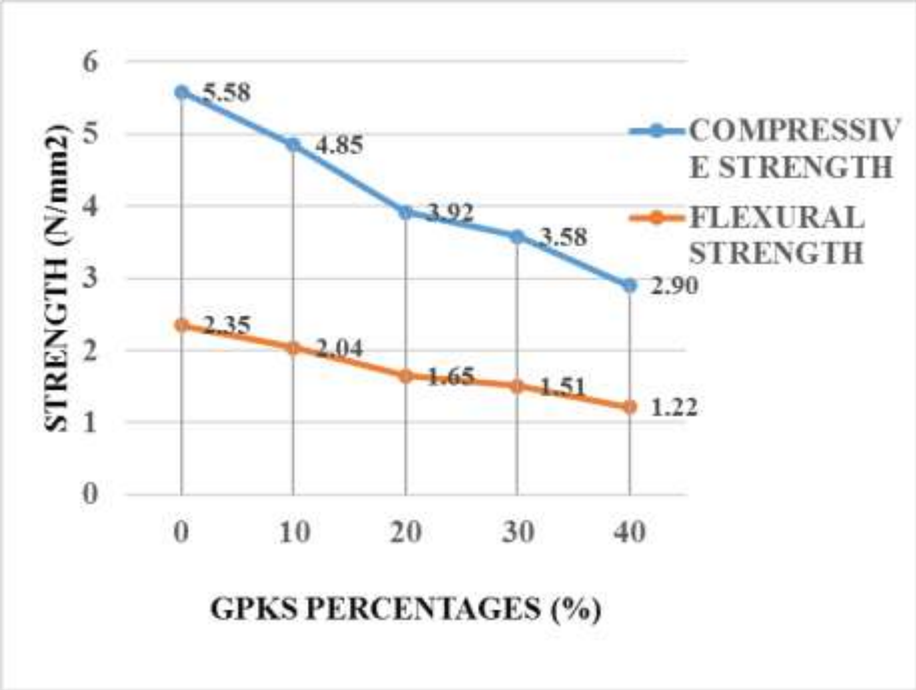

Figure 4.30b, Compressive verses Flexural Strengths (with GPKS aggregate Type B)

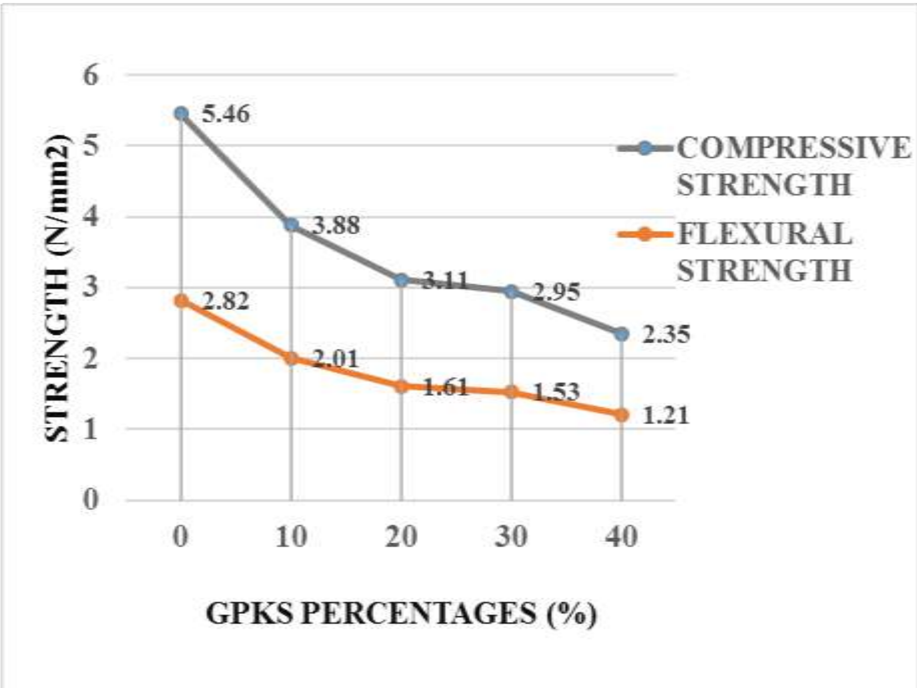

Figure 4.31a, Compressive verses Flexural Strengths (with GPKS aggregate Type A)

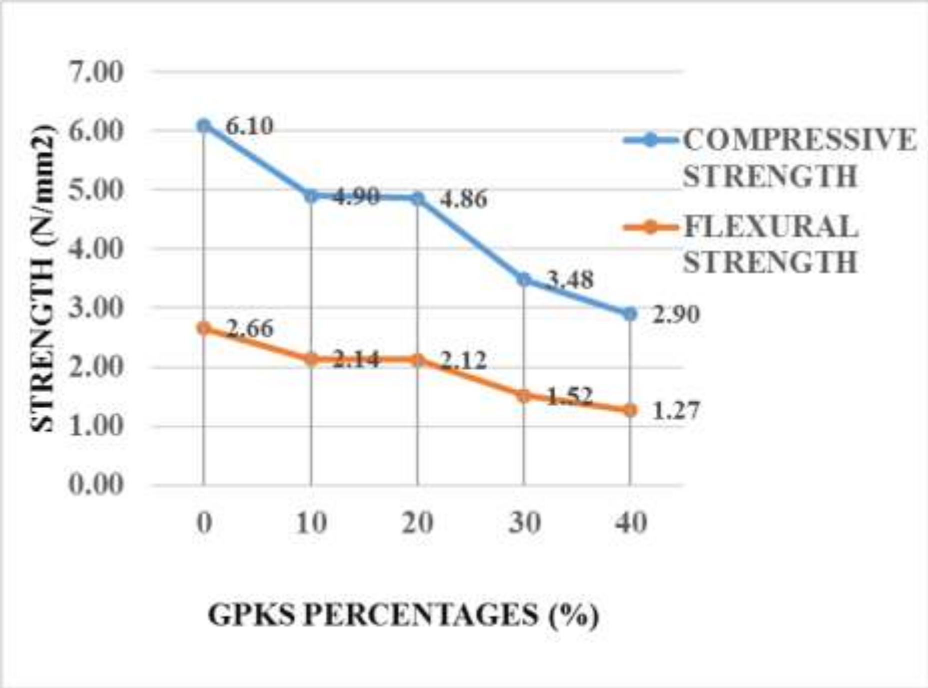

Figure 4.31b, Compressive verses Flexural Strengths (with GPKS aggregate Type B)

4.9 DISCUSSION OF RESULTS

4.9.1 Densities

Densities results shown in figures 4.3a, 4.3b, 4.4a, and 4.4b; 4.5a, 4.5b, 4.6a, and 4.6b above showing the results of the densities. From the test results, it was observed that 7, 14 and 28 days curing age, densities of 150mm and 125mm thick solid and cellular masonry units with all GPKS aggregate mix percentages increases with curing age. However, it was evident that as GPKS aggregate percentage replacement content increases, the densities decreased. GPKS masonry units with 0% GPKS aggregate (control sample) showed higher densities values than masonry units with GPKS aggregate percentage replacement content.

At the same curing period, the densities of 125mm thick solid and cellular masonry units showed similar trend as a result of increases in GPKS aggregate percentage replacement content.

4.9.2 Compressive strength

The relations concerning the crushing strength of masonry units and GPKS aggregate additions are shown in figures 4.8a, 4.8b, 4.9a, 4.9b, 4.10a, 4.10b, 4.11a and 4.11b above. It can be observed that 10% - 40% GPKS aggregate (Type A and B) replacement content are lower than the compressive strength of the control sample (0% GPKS aggregate). Generally, the 28 days compressive strength results of 150mm and 125mm thick solid masonry units with 10% - 30% GPKS aggregate type A the results ranges from 6.47 N/mm^2 to 1.90 N/mm^2 and 5.60 N/mm^2 to 2,26 N/mm^2 and that of 150mm and 125mm thick solid masonry units with 10% - 40%% GPKS aggregate type B replacement content the results ranges from 7.66N/mm^2 to 3.04N/mm^2 and 7.60 N/mm^2 to 3.12N/mm^2, it was observed that all these values exceeds the minimum standard compressive strength of 2.8N/mm^2 according to BS 6073-1: 1981 and 2.5N/mm^2 required by GS 297- 1: 2010. It can be noticed that from 10% upwards of GPKS aggregate replacement, relating the outcomes of the crushing strength test to the density test results, the relation looks similar, therefore 0% - 10% GPKS aggregate replacement in the masonry units, the constituent part is closer. This agrees with the conclusion made by Dadzie and Yankah (2015), that 10% GPKS aggregate replacement of sand is the optimum for masonry unit production. It also be observed that from 0% - 10% GPKS aggregate replacement content, the bonding was better. Therefore, the resultant influence of both greater densities and greater crushing strength. They again concluded that PKS aggregate replacement for sand should not exceed 40%.

4.9.3The effect of GPKS aggregate on Compressive strength

Aggregate are important constituent material in masonry unit production, it gives body to the masonry unit. It is well known that masonry unit contains 80% of aggregate in volume, their impact on physical and mechanical properties of masonry unit is undoubtable. Sand and GPKS aggregate was used for the experiment. The result indicated that the reduction in compressive strengths of GPKS masonry units shows the effect of GPKS aggregate on the compressive strengths. Comparing the mix percentages of 0%, 10%, 20%, 30% and 40% GPKS aggregate content at curing periods of 7, 14 and 28 days respectively, the results shows that the 0% GPKS aggregate replacement content gave a higher compressive strength than the masonry units with all the GPKS aggregate mix percentages.

4.9.4 Compressive strength verses water absorption

From figure 4.16a, 4.16b, 4.17a, 4.17b, 4.18a, 4.18b, 4.19a and 4.19b above, it was observed that as the compressive strength of masonry units increased 19% and 45% from 7days to 28days for 150mm thick solid and 17% and 45% for 125mm thick solid for the same period, with 0%, 10%, 20%, 30% and 40% GPKS aggregate type A replacement content. However, the compressive strengths of masonry units with 0%, 10%, 20%, 30% and 40% GPKS aggregate type B replacement content, increased between 15% and 43% from 7days to 28days for 150mm thick solid and 13% and 35%% for 125mm thick solid. Generally, the compressive strengths of masonry units with GPKS aggregate type B were higher that of GPKS aggregate type A. The 24hours water absorption rate of masonry units with GPKS aggregate type B was higher than that of the control sample (0% GPKS) with higher compressive strength as compared masonry units with GPKS aggregate type A. However, the increasing quantity of GPKS aggregate results in the reduction of compressive strengths whilst the water absorption increased. This was due to the fact that increases in the GPKS aggregate replacement content affected the water demand of the mixtures resulting in increased porosity and water absorption rate of the masonry units thereby reducing the compressive strengths. The decreased in the compressive strengths beyond the 10% GPKS aggregate replacement content was a fact that the optimum for replacing the sand with the GPKS aggregate has reached and beyond this lead to a reduction in the bonding of the composite material as indicated by Dadzie and Yankah (2015), in their studies.

4.9.5 Flexural strength

The test results showed the effect of the GPKS aggregate percentages on the flexural strengths of masonry units. For the 28days flexural strength of 150mm thick solid masonry units containing GPKS aggregate type B ranges between 5.66 N/mm^2 and 2.24 N/mm^2 This was higher than 150mm thick solid masonry units with GPKS aggregate type A which range between 4.61 N/mm^2 and 1.36 N/mm^2. It was observed that flexural strengths values decreased across all the GPKS aggregate replacement content as shown in figures 4.12a, 4.12b, 4.13a, 4.13b; 4.14a, 4.14b, 4.15a, 4.15b;

4.9.6 Compressive strength verses flexural strength

Figures 4.28a, 4.28b, 4.29a, 4.29b; 4.30a, 4.30b, 4.31a, 4.31b above, illustrates the compressive strengths and flexural strengths development of GPKS masonry units containing 0%, 10%, 20%, 30% and 40% GPKS aggregate percentage content as partial replacement of sand. On overall, all the mix percentages exhibited increases in strength values as the curing age increase from 7, 14 and 28days. Curing was used to ensure continuous hydration process which was responsible for strength development. Assessing the effect of GPKS aggregate on masonry unit strengths, it was evident that as GPKS aggregate percentage replacement content increases, the compressive strengths of all the GPKS masonry units decreased.

The result indicates that 10% GPKS aggregate as partial replacement of sand was able to produce masonry unit with the highest strength as compared to all the mix percentages of GPKS aggregate. The compressive strengths of all the mix percentages of masonry units with GPKS aggregate type A and B were lower than the control sample. However, the compressive strengths were higher than the 2.8N/mm^2 required by BS 6073 and 2.5N/mm^2 required by GS 297.

Similar observation was made by Dadzie and Yankah (2015), who indicated that as GPKS aggregate percentage replacement content increases, the compressive strengths decreased. However, decreased in both compressive strengths and flexural strengths of GPKS masonry units was observed as the result of percentage of sand replaced with GPKS aggregate percentage replacement content of 10% - 40%.

4.9.7 Compressive strength verses sizes of masonry unit

The masonry units size of 125mm thick with GPKS aggregate type B have higher compressive strengths compared to 125mm thick masonry units with GPKS aggregate type A. It appears that GPKS aggregate type B has a better particle size distribution according the study result as observed in relation to the study by Muntohar and Rahman (2014). The particle size distribution of PKS used for the investigation are PKS size (1) passing 4.75mm and retained on 2.36mm sieve (size A: small); size (2) passing 9.5mm and retained on 4.75mm sieve (size B: medium) and size (3) retained on 9.5mm sieve (size C: large). The three (3) types of PKS sizes used for the study shows that the smaller size sample behaves more fractured than the large size, since their skin thickness are smaller than the larger size sample. The reduction of values for the compressive strength of 150mm thick masonry units was based on the height to thickness ratio was more of geometrical rather than a material. Given that strength reduction factors such as increased in GPKS aggregate content, increased in water / cement ratio affects the degree of compaction as a result of inadequate bonding of the composite material. The results indicate that 150mm and 125mm thick and height of 190mm size with GPKS aggregate type B was adequate to achieve higher compressive strength.

Figures 4.8b and 4.10b, above, the compressive strengths of 150mm thick solid masonry unit with GPKS aggregate type B at 7 and 28 days the results ranges between 6.03 N/mm^2 and 3.04N/mm^2 for 10%, 20%, 30% and 40% GPKS aggregate replacement content. In the case of 125mm thick solid masonry unit the compressive strengths ranges between 6.12 N/mm^2 and 3.12 N/mm^2 respectively, for 10%, 20%, 30% and 40% GPKS aggregate type B replacement content. This shows that there are variations in the compressive strength between the two (2) masonry unit sizes. It was detected that the 125mm thick masonry unit has higher compressive strength than that of the 150mm thick masonry unit.

4.9.8 Effect of water on compressive strength

GPKS masonry unit is a combined mix of cement, sand, GPKS aggregate and water, which are moulded and allowed to cure. Water is an important ingredient in masonry unit production as it actively participates in the chemical reaction with cement. As water helps to form strength of masonry units, the quantity and quality of water is very important. The result shows that as the water cement ratio increases the compressive strength decreases.

With the increases in water cement ratio, the amount of water in the composite mixture increases, which affected the GPKS masonry unit samples in the following ways: Strength – The strength dropped with the increases in water cement ratio as a result of the increase in GPKS aggregate which reduces the workability, hence the demand for more water; Workability – As the workability upsurges with the increases in water cement ratio, but greater water cement ratio leads to higher porosity due to the bonding constraints imposed by the GPKS aggregate. However, the quantity of GPKS aggregate will influence the amount of water cement ratio; Compaction – Less compaction efforts are required for greater water cement ratio and Void ratio – For high water normally influence the voids in the GPKS masonry unit sample, which will be high after curing period, this in turn will affect the compressive strength.

The variation of the different water cement ratios on the compressive strengths of GPKS masonry units are shown figures 4.24a, 4.24b, 4.25a, 4.25b; 4.26a, 4.26b, 4.27a, 4.27b above, with water cement ratio of 0.45, 0.45, 0.50, 0.55 and 0.60, with GPKS aggregate (type A) mix percentage of 0%, 10%, 20%, 30% and 40%. The compressive strength increases with the curing period, the compressive strength decreased 19% and 26% for 150mm thick solid masonry units from 7days to 28days. For the 150mm thick solid masonry units with GPKS aggregate (type B) mix percentage of 0%, 10%, 20%, 30% and 40%. The compressive strength increases with the same curing period for water cement ratio of 0.45, 0.45, 0.50, 0.55 and 0.60, was 16% and 43% from 7days to 28days. Similar trends were observed in all the GPKS aggregate mix percentages.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 INTRODUCTION

The research was aimed at assessing how partial replacement of sand with GPKS aggregate affect compressive and flexural strength of GPKS masonry units. The methodology employed was experimental study on partial replacement of sand with GPKS in masonry unit production. This consist of materials of different mix proportions with respect to the mix design results, moulding of masonry unit samples and testing. The test results were compared to that of standard codes in terms of weight, density, water absorption, compressive and flexural strength.

5.2 ACHIEVING RESEARCH OBJECTIVES

The conclusions below were drawn based on the results and findings of the experiment:

5.2.1 Objective 1: To analyze the acceptable percentage of Ground Palm Kernel Shell (GPKS) that can be used for masonry unit production.

The GPKS masonry unit is made up of three (3) noticeable different materials, the cement, sand and GPKS aggregate, and there is a tendency to assume that the properties of each is unaffected by the presence of the other. The presence of the GPKS aggregate also affects the cement paste. The cement particles which are suspended in the mix water cannot bond quickly with the GPKS aggregate particles. The GPKS aggregate tend to cause the water to separate from the cement particles, this affected the mix with 40% GPKS aggregate during mixing.

For the acceptable GPKS aggregate percentage that can be used for the production of masonry units, 10% - 30% GPKS aggregate replacement is acceptable for the production of 150mm thick solid masonry units and 10% - 40% GPKS aggregate replacement is acceptable for the 125mm thick solid masonry units, 150mm and 125mm thick cellular masonry unit.

5.2.2 Objective 2: To evaluate the physical properties of Ground Palm Kernel Shell masonry units with respect to water absorption, weight and density.

The increasing quantity of GPKS aggregate increases the water demand of the mix and this often increased the porosity and water absorption rate of the masonry unit with 40% GPKS aggregate. Generally, porosity, water absorption and capillary action decreased with increasing sand content. Finally, as exhibited in Table 4.1, increasing the GPKS aggregate content increases the water demand which is due to bonding constraint that resulted in reduced workability, hence demand for more water during mixing.

The rate of water absorption of the masonry unit with GPKS aggregate was much slower than that of masonry unit with 0% GPKS aggregate (Control sample).

The increasing quantity of GPKS aggregate results in the reduction of both densities and strength.

5.2.3 Objective 3: To determine the influence of GPKS masonry units sizes on strength properties.

The increase in water demand was as a result of the increase in GPKS aggregate which reduced the workability, hence the demand for more water. Increasing GPKS aggregate content between 30% - 40% also reduced the mechanical properties of 150mm and 125mm solid masonry units with GPKS aggregate type A at the 28days curing period. The increasing GPKS aggregate content also demand increase in water/cement ratio. The 40% GPKS aggregate type B was seen to have influence the 28 days compressive strength of 150mm and 125mm solid and cellular masonry units.

5.2.4 Objective 4: To assess the compressive and flexural strength of Ground Palm Kernel Shell masonry unit samples.

Due to the bonding constraints imposed by the GPKS aggregate, there was a difficulty of cement grains quickly bonding with the GPKS aggregate which slowed the hydration process. Higher water / cement ratio will result in higher porosity due to the bonding constraints imposed by the GPKS aggregate. However, the quantity of GPKS will influence the amount of water / cement ratio. The compressive strength of all the GPKS aggregate masonry units decreased with the increase of GPKS aggregate replacement percentages as compared to the control samples (0% GPKS).

5.3 RECOMMENDATION

Based on the results and finding of the study the following recommendations were made to help encourage the use of GPKS as partial replacement of sand in masonry units production:

1. GPKS aggregate percentage content of 10% is optimum as partial replacement of for masonry unit production
2. The grinding of GPKS aggregate should be controlled in the way that the particle size distribution curve would fall within the upper and lower limits in relation to standard grading requirement.
3. The best standard sizes that can withstand all the adverse condition was 150mm and 125mm, both solid and cellular with GPKS aggregate type B percentage content of 10%, 20% 30% and 40%.

5.4 LIMITATION OF RESEARCH

The major constraint faced was particularly with the transportation of the Ground Palm Kernel Shell aggregate to research laboratory and lack accessibility to flexural strength test machine.

However, regardless of the difficulties encountered, none of them adversely affected the validity or accuracy of the data obtained.

5.5 DIRECTIONS FOR FUTURE RESEARCH

1. Ground PKS as fine aggregate in masonry unit manufacturing to determine how GPKS aggregate additions in masonry unit production can influence the properties with respect to water absorption, weight, density and crushing strength to confirm the differences from those attained in the experiment.
2. Elements that influence durability such as inclement weather conditions can be investigated to determine the rate of it effect on the service life cycle of the masonry units

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