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Groundnut Shell Ash and Fly Ash Ternary Blended Cement in Making Plaster for Sustainable Construction

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Abstract: *The need to counter the over depletion of scarce resources, bring down the cost of materials and reducing environmental pollution has necessitated research into utilisation of many waste materials that can replace cement as a binder in plaster and concrete mixes. This study looks into the possibility of utilizing combined groundnut shell ash (GSA) and fly ash (FA), partly replacing cement in making plaster. To achieve this study, physical properties of GSA, FA and sand were tested following standard procedures of BS EN 197, BS EN 450-1, and BS EN 12620:2013 respectively. Thereafter, cement: sand plaster (1:3) is made with cement partially replaced with GSA and FA at 10%, 20%, 30%, and 40% in equal proportions. The plaster is tested for initial and final setting times and then compressive strength after 7, 14, and 28 days of curing. The specific gravities obtained were 2.54, 2.24, and 2.56 for GSA, FA and sand respectively, while their bulk densities were 840kg/m3, 1240kg/m,3 and 1510kg/m3 for GSA, FA, and Sand respectively. The initial and final setting times increased with the increase in percentage replacement of cement with the two ashes i.e. initial setting from 121 – 162 minutes and final setting from 228 – 296 minutes at 10% and 40% replacements. The compressive strength was reduced with an increase in ash proportions, i.e. 27.84 - 20.8mpa at 28 days but this strength was way above the minimum strength requirement for plastering masonry walls and also a great improvement from studies that had used GSA only whose strength was as low as 7.5Mpa. The results in this study provide a success story in using agricultural wastes by using FA to improve their properties hence enabling the replacement of expensive non-sustainable cement.*

Keywords: Compressive strength, Groundnut shell ash, Initial and final setting time, Fly ash, Plaster

1. Introduction

Plaster is a finishing material and is mainly composed of fine aggregates, cement, and water which are mixed in a particular proportion to get an actual strength (Adolf, 1975). The cement serves to impart binding strength in the plaster. The materials used as binders must have the capacity to enable chemical compatibility between the mortar used for repairing and also the old materials. The plaster is reported to provide an excellent role in protecting external walls from the influence of weather conditions (Dylewski and Adamczyk, 2014).
This conventional binder cement is known mainly to come from a process of high temperature burning of limestone ore and clay (Van Oss and Padovani, 2002). This process is synonymous with the emission of very high quantities of greenhouse gases of carbon dioxide, approximately about 5-7% of the total emissions (Huntzinger and Eatmon, 2009; Chen et al., 2010). The production of 1 ton of cement is said to require approximately 1.7 tons of raw materials, approximately 4GJ of energy. Consequently, 0.5 – 1 ton of carbon dioxide is

released into the atmosphere, hence environmental degradation plus other pollution challenges (Ashutosh, 2013). In response to that Malhotra and Mehta (2002) asserted that if the construction industry could reduce these emissions if it aimed at consuming low quantities of the natural resources.

2. Literature Review

Several studies have been on-going specifically in line with this desire like the partial replacement of the cement with the industrial waste of fly ash, mineral by-products of slag, silica fume among others. In particular studies with the utilization of industrial waste fly ash showed promising results as it has proved to result in satisfactory or even high strengths with cement replacement proportions up to 40% (Islam and Islam, 2010; Deotale et al., 2012; Pujari and Ponnala, 2016). However, this strength developed at a slower rate in fly ash mixes compared to plasters made without fly ash (Li et al., 2005; Chindaprasirt et al., 2005; Sata et al., 2007; Christy and Tensing, 2010). In some studies, for example fly ash showed the best improvement of concrete at 20% replacement (Zaman and Chetia, 2018); Islam and Islam (2010) obtained optimum replacement at 40% with a 14% compressive strength improvement. The lime generated from cement is said to react with fly ash hence contributing to strength improvement (Islam and Islam, 2010). Hence fly ash serves as a pozzolanic mineral admixture in concrete or plaster in reference to ASTM C125 due to siliceous and aluminous materials in it. High compressive strengths at long curing which is attributed to the fineness of grind (Wiggins and Siddiqi, 2005). The bleeding is kept to a minimum, good surface produced plus low heat of hydration with its usage (Goud et al., 2016). In one of the latest studies fly ash improved most of the properties in both gypsum plaster and plaster of Paris (Al-Obaidey, 2020).

On the other hand, the utilization of agricultural wastes to partially act as binders in the concrete making has illustrated promising results. Some include cow dung ash (Shubham et al., 2017); rice husk ash (Alireza et al., 2010); and using eggshell and rice husk (Asman et al., 2017).

As for the partial replacements of cement that have been tried out with groundnut shell ash, satisfactory amounts of replacements were reported at 10% replacement levels (Krishnan and Mohamed, 2016; Usman et al. 2019). In Ibrahim and Ahmadai (2018) a 15% optimum was obtained. In others like Mahmoud et al. (2012), low compressive strength in between 4.5 N/mm and 0.26 N/mm2 with optimum replacement obtained at 20%. However, this replacement level is still deficient given approximately 58 tons of groundnut waste generated (Nakoo, 1999). This notwithstanding the fact that this groundnut shell ash possesses pozzolanic potential as evidenced in its microstructure. The high content of calcium oxide (21%), with lower SO3 (5%) and Loss of Ignition (6%), GSA hence loosely be classified as Class C. (Usman et al. 2019). To increase the replacement levels for these agricultural wastes, ternary blends have been studied as they have proved in some cases to improve properties of composite concrete or plaster made. In some cases increased amounts of wastes both agricultural and industrial added. Ternary blended mortars with rice husk ash and waste glass were studied in Younes et al. (2018) and improved in terms of strength at 5% rice husk and 20% waste glass. There are more hydration levels in ternary blended cement mortars as compared to the conventional mortars and also binary blended binders (Younes et al., 2018). The ternary blend of GSA and ripe plantain ash, when used in Ketebu and Farrow (2017), proved to improve strengths than binary mixture of each. In others like Datoke et al. (2018) it was discovered that ternary blends of OPC/ Acha Husk/ Corn Cob Ash produced concrete of strength 96% close to the control mix as compared to binary or single supplementary pozollanic material being used. A blend of 5% was obtained as the optimum. Also in Ramjan et al. (2017) ternary blend of Oil fuel ash and rice husk ash performed better than binary blends of the two agricultural wastes in terms of strength improvement as indicated by the strength activity index which was obtained at 89% at 28days for 10% OPC replacement with the two ashes.

Therefore, this studied aimed at making ternary blended cement for plaster by combining GSA and fly ash. This is because studies on fly ash had shown promising results as far as strength improvement is concerned yet the readily available GSA showed lower strength.
This study is seeking to contribute to the ongoing hunt for sustainable solutions, like the Switch Africa Green Project that is trying to attain sustainable development. This is through adopting consumption plus production patterns that protect and conserve the environment plus other natural resources (United Nations Development Programme, 2015).

3. Materials and Methods

3.1 Materials

Ordinary Portland cement as manufactured by Tororo cement of strength 32.5N conforming to the US: 310-1: 2001 is used as a binder in the plaster mix. This cement was secured from one of the hardware stores in Natete -Kampala city.

Locally sourced river sand satisfying the requirements of upper and lower limit percentages of the sand and passing through 475µmm in accordance with BS EN 12620:2013. The obtained results are used to compute the fineness modulus of the fine aggregates from which a gradation curve is plotted in the middle of the upper and lower limits of percentage passing as specified in BS EN 12620: 2013.

Groundnut shells were obtained from the groundnut mills in Hoima district Central Market in western Uganda located at 1^0 25’ 49.8” Latitude, 31^0 21’ 8.28” Longitude. The shells were packed in bags and transported to the site and sundried (figure 1). The shells were burnt on an iron sheet in open air to ash. The ashes after being packed in bags are stored on timber runners to avoid getting into contact with moisture. For the ash, after burning the one used in the study to cast the test cubes is that passing through a 75µmm BS sieve as per BS EN 196-6:1992.

(a) **(b)**

Figure 1: (a) Mound of groundnut shells; and (b) dry mix of cement, sand, groundnut shell ash and fly ash

Fly ash used conformed to BS EN 450-1 (1995), which identifies that pulverized fly ash to be used needs less than 12% of it to pass through a 0.425mm sieve, i.e. if strength and durability were considered more important.

Potable water in the laboratory obtained from National Water and Sewerage Cooperation conforming to BS EN 1008 (2002) is used for the whole work. This portable water needed not to be tested before it's used because it already conforms to BS EN 1008 (2002) requirements.

3.2 Experimental program and Methodology

3.2.1. Proportion of mix

The calculation of the amount of groundnut shell ash and fly ash used as a supplementary cementitious material began by testing of materials to determine their physical properties. The proportioning was made for the control mix and the amounts of the materials for the replacement levels were obtained for partially replacing the weights of the cement using percentages (*Table 1*).

Table 1: The mix proportions of plaster

		Mix Proportions				
ID	**% of Cement**	**Cement (Grams)**	**Groundnut Shell Ash (Grams)**	**Fly Ash (Grams)**	**Fine Aggregates (Grams)**	**Water (Grams)**
CM	100%	525	0	0	1407	213
GFM10	90%	472.5	26.25	26.25	1407	213
GFM20	80%	420	52.5	52.5	1407	213
GFM30	70%	367.5	78.75	78.75	1407	213
GFM40	60%	315	105	105	1407	213

3.2.2 Manufacture and Testing of Material Properties

Preliminary tests on ground nutshell ash, fly ash, fine aggregates are done to ascertain their physical properties, which included Bulk density is carried out following BS EN 1097-3 (1998), using apparatus of weighing balance (*Figure 2a*), tamping rod measuring cylinder and scoop.

Figure 2: (a) Cylinder for measuring bulk density; and (b) a nest of sieves for sieve analysis

Sieve analysis is conducted in accordance with BS EN 933-1 (1997) that gives the procedure for the determination of particle size distribution using the sieving method (*Figure 2b*). The results are tabulated and the gradation curve plotted (figure 3) in relation to the specified upper and lower limits; specific gravity test is conducted in accordance with BS EN 1097-7 (2008) that gives the procedure for the determination of particle density using the pycnometer method.

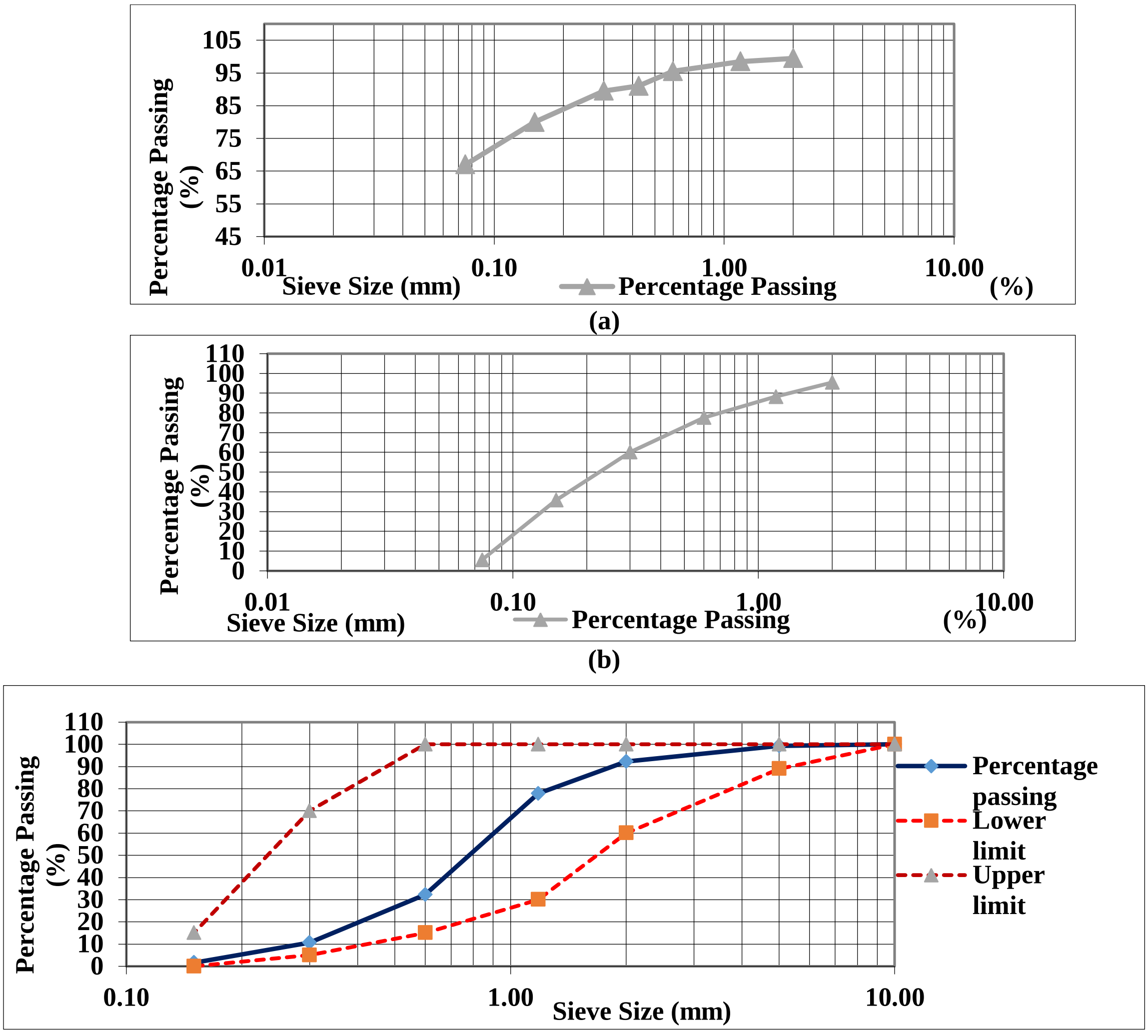
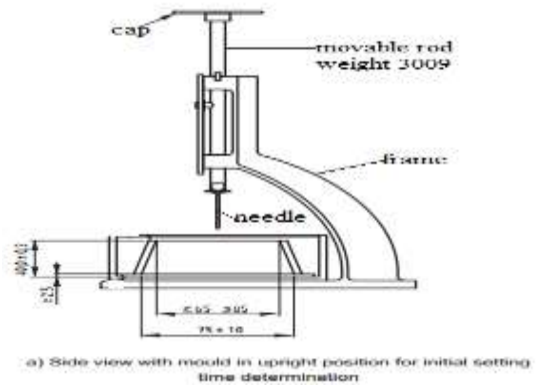


Figure 3: Particle size distribution of a) fly ash; b) groundnut shell ash; c) fine aggregates

3.3. Test Set-Up and Testing Procedure for Properties of plaster

3.3.1 Determination of the initial and final setting time

This test was carried out in accordance with BS EN 196-3:2006 (2005), which gives the methods of testing cement; determination of setting times, and soundness. To carry out this test, the amount of mixing water was first determined that produces a standard consistency. The vicat mold was filled with mortar of standard consistency. The mold and base plate were placed under the needle of the vicat apparatus (*figure 4).*

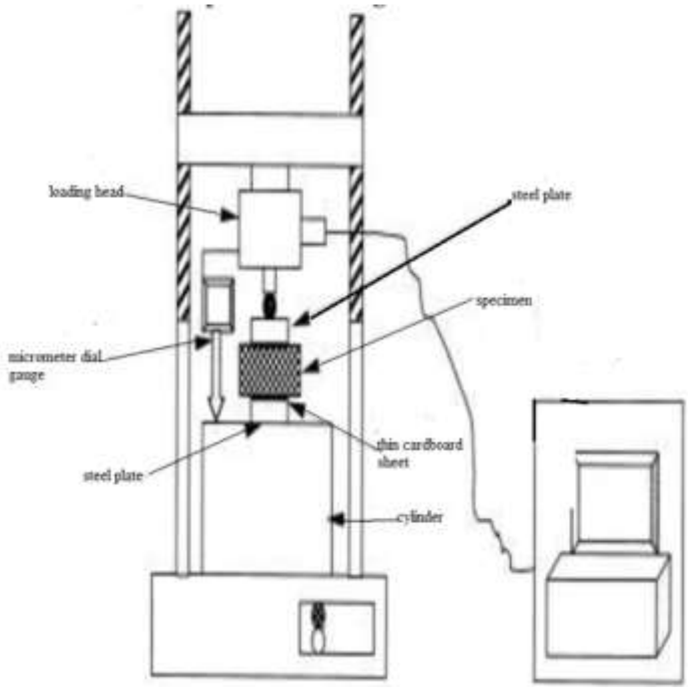


(a) b)

Figure 4: (a) Schematic diagram of a vicat apparatus; b) Performing initial and final setting time with Vicat apparatus

3.3.2 Compressive strength

This test was carried out in accordance to ASTM C109 (2010). Different plaster mixes were made from the cement-sand mix with cement being partially replaced by groundnut shell ash, fly ash in the mix (*figure 1b and Table 1).* Three sets of specimens were cast and tested (*figure 5*) at various ages i.e. tested at 7, 14, and 28 days of curing age.



a) b)

Figure 5: a) Schematic diagram; b) Compressive strength test with mortar cube being crushed

4. Results

4.1 Physical properties of materials used

The physical properties of ground nutshell ash, fly ash and fine aggregates determined included bulk density, sieve analysis, and specific gravity.

4.1.1 Sieve analysis

The results of the sieve analysis of the percentage passing for each material were used to obtain the cumulative percentage passing. In turn this was used to draw the gradation curve as illustrated *figure 3*.

Groundnut shell ash had finer particles than fly ash passing through the sieve size of 0.075mm, the BS recommended sieve for cementitious materials. The fly ash used in this study was class F fly ash since the residue on the 0.425 sieve 9% was below the 12% maximum specified by BS EN 450-1:2005 (2005). It fell in grade I of the physical and chemical specifications because the percentage residue on the 0.425mm sieve was 4.5% lower than that of DUS 2115:2018 which has the maximum percentage residue of 12%.

Meanwhile, the sand also satisfied the overall grading limits as provided in BS EN 12620:2013 and thus was fit to be used for the study. The average size of the particles was between the second and third sieve of aperture size 0.30 and 0.60mm. The fineness modulus of the fine aggregates was 2.68. Hence as per ASTM C33-08 (2010) range of 2.3 to 3.1 thus the fineness modulus of the fine aggregates used in this study was within the limits.

The specific gravity of the sand determined was 2.56 (*table 2*) which is the same as that reported by Oyejobi et al. (2015). The specific gravity of groundnut shell ash was 2.24 that closely relates to that by Nwofor and Sule (2012) at 2.23 but it is higher than that by Orlando and Salome (2017). The specific gravity of fly ash was at 2.54 which was slightly lower than that by reported at 2.6 by Pujari and Ponnala (2016). The specific gravity of groundnut shell ash was within the range of 1.9-2.4 while that of fly ash was above the range for pulverised fuel ash according to Neville (2011).

Table 2: The bulk density, the specific gravity of the materials

Physical properties	Fine aggregates	Groundnut shell ash	Fly ash
Bulk density	1510kg/m^3	840kg/m^3	1240kg/m^3
Specific gravity	2.56	2.24	2.54

The bulk density of the fine aggregates was 1510kg/m^3 which was in the range specified by BS EN 12620:2013, that states the range for normal weight aggregates to be between 1280 and 1920 kg/m3 (for bulk density). Groundnut shell ash had a bulk density of 840kg/m^3 which is higher than that by Nwofor and Sule (2012), reported at 678kg/m^3 but too low compared with that of cement which is 1440kg/m^3. Fly ash had a bulk density of 1240kg/m^3 which is lower than that reported by Bendapudi, and Saha (2011) at 2310kg/m^3 but satisfied the requirement of the DUS 2115:2018 for fly ash used in cement and concrete which specifies that it should not be greater than 2.6g/cm^3. The bulk densities of groundnut shell ash and fly ash were lower than of cement given in the range of 1440 kg/m^3 -1500kg/m^3.

4.2 Consistence, initial and final setting time

The consistency, initial setting time and final setting time of the control plaster and the other composite plaster mixes were determined as represented in *figure 6*. The control plaster had lower consistency than the samples where cement has been partially replaced. This means that with more and more cement being replaced, more water was required to produce a paste of standard consistency.

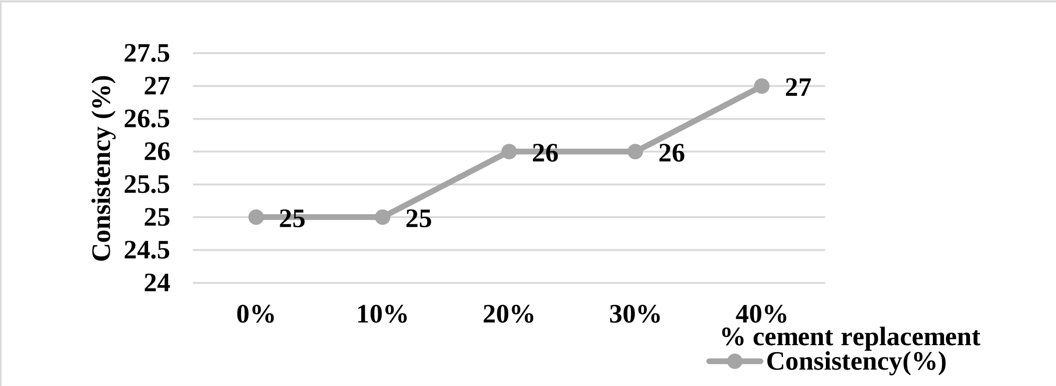


Figure 6: Consistency of the control and mortar mixes with ternary blended cement

However, the consistency level obtained was within acceptable ranges for all replacements provided in BS EN 196-3:2005; which requires that the vicat needle must penetrate to a point at least 5-7mm from the bottom of the vicat mold if the mix was to be of standard consistency. Meanwhile, the increase in the water requirement is attributed to the fact that fly ash of 67% passing through the 0.075mm BS sieve brought in high fineness, plus increased cement- ash content as the ashes have lower densities compared to that of cement (1440kg/m^3).

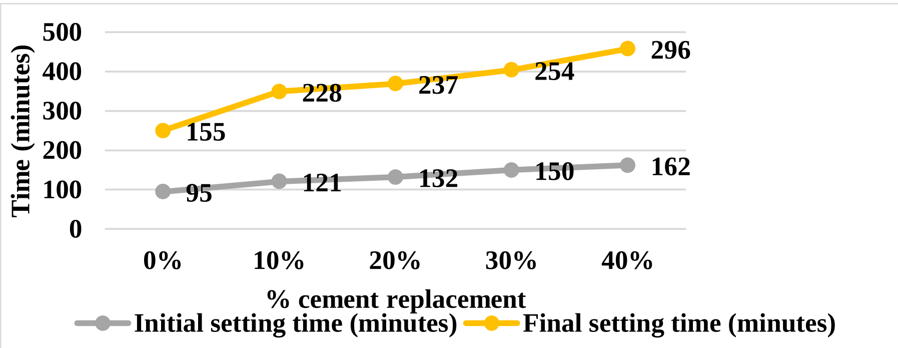


Figure 7: Initial and final setting time

The initial and final setting time increases with the increase in percentage replacement of cement, from 95 minutes for the control to, 162 minutes at 40% cement replacement (*Figure 7*). All the initial setting times were above the BS EN 197-1:2011 recommended initial setting time of 75 minutes. The increase in setting time can be attributed to the increase in carbon content as more cement is partially replaced with the ashes, this water component from the paste to have slower rates of heat-induced evaporation (Dakroury et al. 2008).

4.3. Compressive strength

The study was carried out on 50mm plaster cubes with cement being replaced by GSA and FA, the compressive strength of the plaster cubes was tested at 7, 14 and 28 days. The results are as shown in *Table 3.*

At 28 days, the results showed that the compressive strength of 10% replacement was 27.8 N/mm^2 and it reduced as the proportion of ashes increased up to 20.8 N/mm^2 for 40% after curing for 28days as shown in *figure 8.*

Table 3: Compressive strength results

Age	Percentage Replacement	Specimen	Average crushing load (KN)	Average compressive strength (N/mm^2)
7 days	0%	CM7	62.1	24.84
	10%	GFM1-7	44	17.6
	20%	GFM2-7	31.25	12.5
	30%	GFM3-7	28.65	11.46
	40%	GFM4-7	20.85	8.34
14 days	0%	CM14	69.5	27.8
	10%	GFM1-14	52.25	20.9
	20%	GFM2-14	49.65	19.86
	30%	GFM3-14	47.15	18.86
	40%	GFM4-14	41.2	16.48
28 days	0%	CM28	85.1	34.04
	10%	GFM1-28	69.6	27.84
	20%	GFM2-28	57.7	23.08
	30%	GFM3-28	54.1	21.64
	40%	GFM4-28	52	20.8

These strength test results were lower than that of OPC plaster at all testing times of 7, 14, and 28 days. At 28 days it was lower by 18%, 39%, 54% and 61% for 10%, 20%, 30% and 40% respectively.

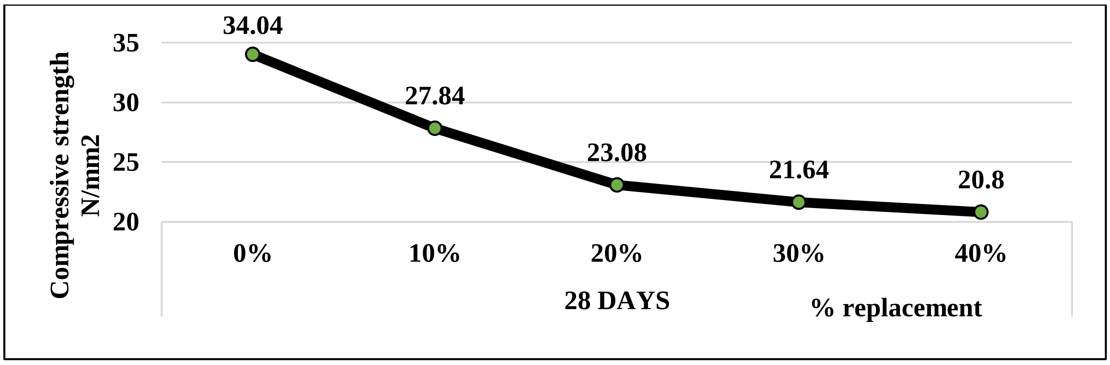


Figure 8: Compressive strength at 28 days

Meanwhile, at all percentages, the compressive strength was way above the minimum strength requirements for plastering walls made with burnt clay bricks, concrete blocks, stabilized soil bricks. The blended mixture (groundnut shell ash and fly ash) had higher compressive strength than the individual groundnut shell ash as established researchers like Nwofor and Sule (2012) who obtained 7.5N/mm^2 at 28 days of 40 % replacement of cement by GSA. A decrease in strength may be attributed to the agglomeration of groundnut shell ash particles. (Younes et al., 2018)

This could be due to the pozzolanicity where fly ash avails enough lime required to chemically react with the pozzolans during the hydration process hence resulting in increased water-cement ratio (Neville, 2011). This is a result of standard consistency being attained while more cement is being replaced and also because the FA particles are finer and can fit in spaces in between the cement particles and GSA (Neville, 2011).

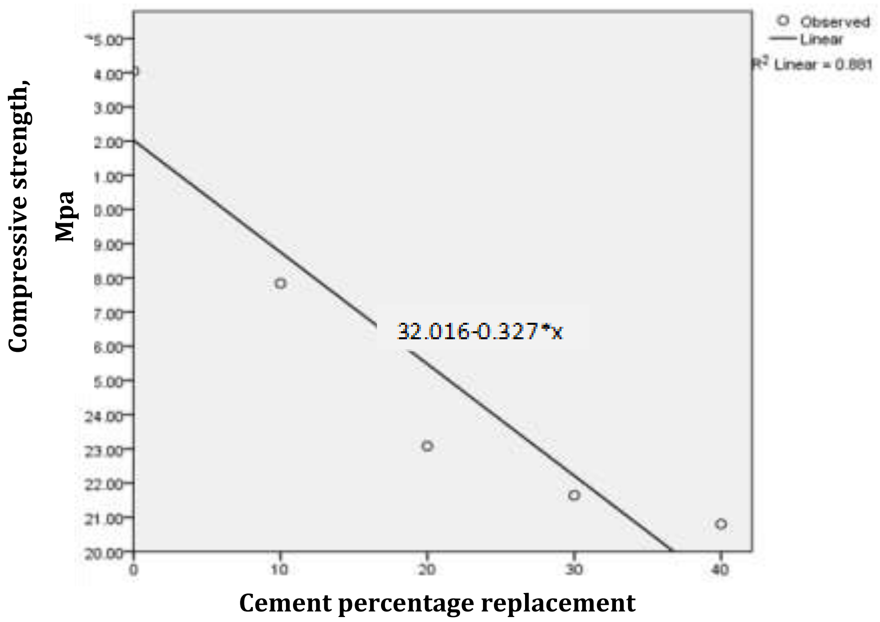


Figure 9: Regression between cement replacement and compressive strength

$$Compressive\ strength = 32.016 - 0.327 * Percentage\ replacement$$

According to the above model equation, when the cement percentage replacement is zero, then the compressive strength of the plaster is 32.016. A unit increase in the cement percentage replacement would on average lead to a 0.327 decrease in compressive strength keeping other factors constant. The relationship is statistically significant since the *p*-value (0.018)>0.05, thus the compressive strength depends on cement percentage replacement. The R square is 0.881, this implies that 88.1% of the variations in compressive strength can be explained by cement percentage replacement hence it was a good fit.

Table 4: Correlation between cement percentage replacement and final setting time

		Final Setting Time	Cement Percentage Replacement
Final Setting Time	Pearson Correlation	1	.949*
	Sig. (2-tailed)		.014
Cement Percentage Replacement	Pearson Correlation	.949*	1
	Sig. (2-tailed)	.014	

*. Correlation is significant at the 0.05 level (2-tailed).

The correlation coefficient between final setting time and cement percentage replacement is 0.949, this implies that there is a high positive relationship between final setting time and the cement percentage replacement and as more of cement is being replaced, the final setting time increases. This relationship is statistically significant at a 5% level of significance since the *p*-value (0.014) <0.05.

5. Conclusions

This study examined the use of GSA and FA ash as a partial replacement of cement for plastering.

Based on the experimental results obtained from this study, observations, and analysis, the highlight of the major findings are;

1) Basing on the experiments that were carried out, the fine aggregates had a bulk density of 1510kg/m^3, a specific gravity of 2.56, fineness modulus of 2.86. All these values fall within the acceptable ranges as per the Uganda standards, Eurocode, and British standards.
2) The physical properties of the groundnut shell ash and fly ash were different from the conventional cementitious materials. GSA and FA had specific gravities of 2.24 and 2.54 respectively which are lower than that of cement that is 3.15 and only that of GSA which lies in the range of 1.9 to 2.4 recommended for pulverized fuel ash by (Neville, 2011).
3) The consistency increased from 25% to 26% as more of the cement was being partially replaced by groundnut ash and fly ash. The water-cement ratio increased from 0.50 to 0.60 for 10% to 40% cement replacement from the conventional 0.50 which means the composite plaster requires more water as more of the cement is being replaced.
4) The addition of GSA and FA increased the initial and final setting times for the plaster from 121 and 228 minutes respectively for 10% partial replacement, to 162 and 296 minutes respectively for 40% cement replacement. However, all the setting times were within the BS EN 196-3:2005 range of 75 and 600 minutes for the initial and final setting time.
5) Replacement of cement with GSA and FA led to a decrease of compressive strength as compared with the conventional plaster from 27.84N/mm^2 to 20.8 N/mm^2 at 28 days for 10% and 40% replacement of cement respectively.

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