EJAS Journal of Science and Technology
journal homepage: https://ejas.edu.et/

Partial Replacement of Cement with Calcined Clay and Cow Dung Ash for Third Coat Wall Plastering Works in Low-Cost House Buildings

Temesgen Daba Wakuma, Geremu Assefa Tucho and Gamachu Wakoya Fufa

Department of Construction Technology and Management, Mattu University, Ethiopia
email (Corresponding Author): geremuassefa@gmail.com
Submitted: 5 March 2024. Accepted: 7 May 2024. Available online: 16 May 2024.

Abstract

Due to cement is a costly material, people have been using clay and cow dung plaster alone or reinforced with grasses for on-wall plastering, with no mix composition. Having this point to mind, the purpose of this study was, to investigate partial replacement of cement with calcined clay and cow dung ash for third coat wall plastering works in low - cost house buildings. Pre-conditional test of: natural moisture content, gradation, atterberg limit, specific gravity, free swell, silt content, water absorption, moisture content, and unit weight were took place in order to identify the individual properties of the materials used in mortar production. Chemical compositions of the materials were identified: to compare the mineral constituent of the materials replacement with cement. Post - conditional testes such as: consistency and setting time of cement and cement replacement and some cube samples of mortar with:0, 10, 20, 30 and 40 percentage of cow dung ash and calcined brown clay were prepared and subjected to:7,14 and 28 days of period before tested for water absorption, shrinkage, compressive strength and soundness test.The test showed that the compressive strength was decreased as an amount of calcined brown clay and cow dung ash increased in mortar and increased with the curing days. Finally, durability test were performed using visual observations by referring to ASTM specification code. For all, the best test result showed that, for tested properties with 10% proportion and 1:9 equal amount of calcined brown clay and cow dung ash (1CBC:1CDA) to cement mix ratio. Thus, it was low cost alternative materials for third coat wall plastering and under normal weather conditions, it was used as low - cost house buildings, in case of non-structural members.

Keywords: clay, cow dung ash, durability, free swell, liquid limit, and mortar

Introduction

Different researchers investigated the application of new techniques to improve the qualities of low - cost materials which makes them useful to be used for today are housing needs [1].With the rise of low - cost housing and high cost of building materials, it is necessary to understand how low - cost construction can meet the needs of construction industry. Utilization of naturally existing materials such as: clay and cow dung are particularly important in construction industry to overcome through such challenges of high cost of building materials. As a result, one way of life for the future is to find: another alternative of locally available cement substitute material. In some countries, plastering is still done with clay earth mortar, at least for the first coat which is used to minimize cost of the materials [2].

Clay soil has been used since, 4300 BC and still commonly used now [3]. Clay is a commonly available, inexpensive, and easily accessible substance [4].Clay is a substance that contains a variety of minerals and can be utilized as a cement material through the calcination process. [4].When clay is mixed with water, it forms a cohesive sticky substance that is moldable when wet but hardens when dry [5].Some studies showed that, as the amount of clay soil and cow dung in the mortar increased, the strength of the mortars decreased [6].To stabilize strength of cow dung, cement was used and the stabilized material was used for low cost house buildings [7].

Using cow dung ash as cement replacement material, 10% replacement enhanced compressive strength when compared to a typical mortar [7].Experimentally, compressive strength is raised by replacing 5% of cement with cow dung ash, and it is decreased as cow dung ash percentage rises [8].Calcined clays are large scale - materials that can be used to meet the needs of cement - based materials by lowering the clinker content in blended cement or lowering the cement content in the combination [4].

Construction industry in Ethiopia has been rapidly expanding, and it plays an important part in the country's growth. In the construction sector, it is known as cement is high costly materials, and replacing such high - cost materials has not been researched. Particularly in the future to keep up with the fast - growing building industry, resources must be available locally or naturally. The idea behind this is to use plastering as a low - cost, yet high - quality method of building construction [4]. Clay is a naturally occurring material while cow dung is a waste product that is a widely available in the study area.

2. Materials and Experimental Methods

2.1. Materials and Small Tools Needed for the Research

Calcined clay soil, cow dung ash, cement, sand and water were used as raw materials in mortar production. Sample collection tools such as: spade, empty bag, cylindrical jar, axes and shovel were used for: mixing, carrying raw materials, measuring amount of water, excavating the earth and taking the samples respectively. Laboratory materials of: flask, sieve meshes, balance, washing bottle and beaker, funnel psycnometer and thermostatically were also used.

2.2. Field Work

In order to strengthen the research idea, area of the samples were selected from the total point.

Figure 1. Brown clay

Figure 2. Black cotton clay

Figure 3. Sample place of cow dung

2.3. Laboratory Work

See the following figures of some laboratory works to have test results.

Figure 4. Gradation test

Figure 5. Liquid limit test

Figure 6. Curing of cubed mortar

Figure 7. Compressive strength machine

2.4. Methods of Experimental Design

The collected samples were: sieved, weighted, mixed and gradually water was added until the workable mortar was achieved. Mixing was done manually in time not greater than 5minutes. The mixture was then poured into the standard metallic mold of 7.00cm x7.00cm x 7.00cm size, compacted for 25 times and kept at room temperature.

Specific gravity test was to determine the degree saturation of cohesive sample, and atterberg limit test was to identify the range of plasticity. Cubes were immersed in water in order to check their water absorption. For shrinkage test, 3 cubes for each sample with: 0, 10, 20, 30 and 40 percentage equal amount of calcined brown clay and cow dung ash. Having 1:3 ratio and the following proportions: 0%, 10%, 20%, 30% and 40% of weights and the mixing ratios of 0:100, 1:9, 1:4, 3:7 and 2:3 with equal amount of cow dung ash and calcined brown clay soil to cement ratios were used for production of new mortar [9].

Calcination of brown clay was by muffle furnace machine, which was at 600℃ and cow dung was by direct burning which was 415℃ took place, to increase the cement cohesiveness property and strength of clay and cow dung.

2.5. Sample Size

Stratified random sample was used, first by dividing the populations into homogeneous groups which were district from each other [10].Experimentally, 45 total cubed mortars with three cubes for each sample of 0%, 10%, 20%, 30% and 40% were prepared to identify compressive strength of cubed mortar for: 7th, 14th and 28th curing periods. To make the more accurate experimental test result, the test results were conducted by using an average sample method: such as sample one, sample two and sample three. Then, summation of the individual three experimental test result and dividing the test result to three. Therefore, the average number of test result was more accurate than the three of the individual experimental test result. .

2.6. Study Variables

Independent variables:-Percentage of the mixes, proportion ratios, amount in gram of calcined brown clay, cow dung ash, cement, sand and water. **Dependent variables**:-Results from independent variable such as: new mortar which was used for: Plastering and all laboratory test result such as compressive strength test results which were resulted by changing the mix proportion, percentage of the mix and amount in grams.

3. Test Results and Discussions

3.1. Pre-Conditional Test as Physical Test Results

Table 1 showing individual property value of the tests

No.		Test results					
	Test Types	Brown clay	Black clay	Fine sand	Cow dung	Cement	Explanations from standard specifications, authors and test results.
1	Natural moisture content of the clays (%)	17.40	43.50	--	--	--	Natural moisture content of brown clay (17.40) is less than black cotton clay (43.50). For construction, minimum moisture content of the clay soil was recommended [11].
2	Gradation test of fine sand	--	--	2.45	--	--	Fine sand indicates that there was no compliance with the standard of sieves. Therefore, it was well graded [12].
3	Plastic index of the clays (%)	28.90	32.09	--	--	--	Both clays were high plasticity index, as it ranges between (20 - 40) [13].
4	Specific gravity of the samples	2.44	2.33	2.66	2.49	2.71	Specific gravity of a most normal fine sand (fine sand) lies between 2.4 - 2.9 [14] and [15].
5	Free swell test of the clays (%)	11.60	103.3	--	--	--	Brown clay had low degree of expansiveness (less than 20), and black cotton clay had very high degree of expansiveness (greater than 50) [16] and [17].
6	Silt content test of fine sand (%)	--	--	4.55	--	--	Silt content of the sample was in the range of ASTM standard (less than 6%) [18] and [19].
7	Water absorption of fine sand (%)	--	--	3.82	--	--	ASTM standard states that the water absorption of good fine aggregate was (0.2 to 4%) [20].
8	Moisture content of fine sand (%)	--	--	1.88	--	`--	Fine sand was in the range of standard value with moisture content (0 to 5%).
9	Unit weight of fine sand(kg/m$^{3)}$	--	--	1575.76	--	--	The range limitations of fine sand was (1520 - 1682) kg/m^3 [21] and [22].

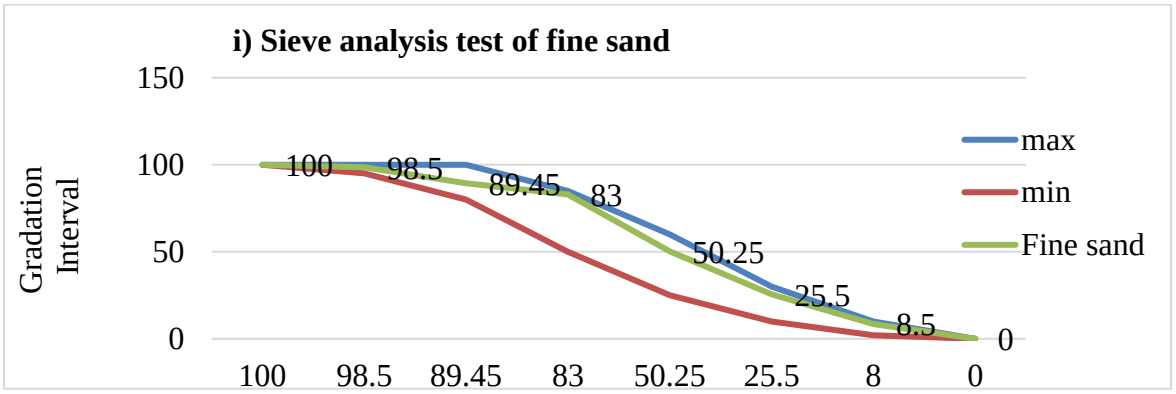

Figure 8 Figure Gradation test result of fine sand

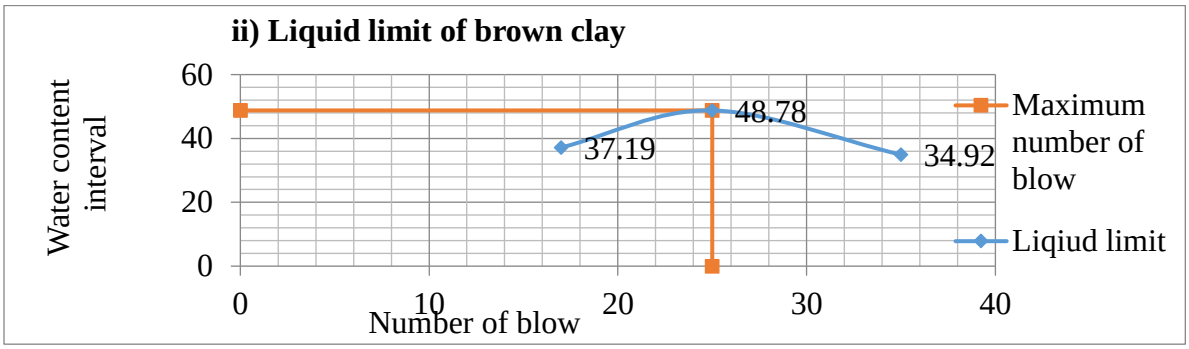

Figure 9 Liquid limit test result of brown clay

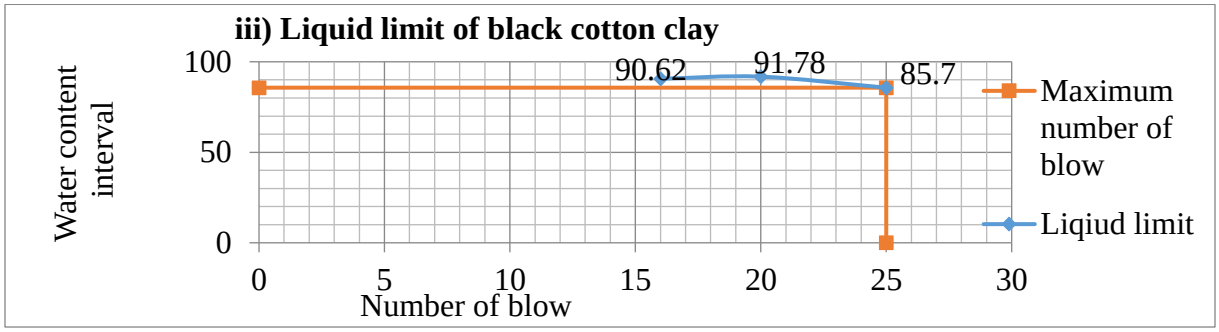

Figure 10 Liquid limit test result of black cotton clay

iv) Plastic index

- Brown clay, (LL) - (PL) = (48.78) - (19.88) =28.90 which is high plastic index.
- Black cotton, (LL) - (PL) = (85.70) - (53.61) =32.09 which is high plasticity index too.

3.2 Post - Conditional Test as A Chemical and Physical Test Results

Due to availability of the materials in the area and test result, calcined brown clay and cow dung ash were going to made to replace cement mortar for third coat wall plastering works which were sieved or passed through 0.15 sieve.

3.2.1 Chemical Composition Test Results

Complete silicate analysis of cow dung ash and calcined brown clay was carried out at Ethiopian Geotechnical Survey to see if the materials could be used as cement alternatives. The table below shows the standard chemical content as well as the chemical makeup of the components.

Table 2 Chemical composition of calcined brown clay and cow dung ash

S/N	Chemical composition	Cement content (%)	Calcined brown clay	Cow dung ash
1	Silica(Sio2)	18.40-24.50	63.24	53.04
2	Alumina(Al2O3)	3.10-7.56	17.92	5.87
3	Iron Oxide(Fe2O3)	0.16-5.78	8.48	3.74
4	Calcium Oxide(CaO)	58.10-68.00	2.12	5.40
5	Magnesium Oxide(MgO)	0.02-7.10	0.24	3.26
6	Sulfate Oxide(SiO3)	0.00-5.35	0.18	2.14
7	Loss of ignition	0.1-0.5	4.87	10.11
8	Sodium Oxide (Na_2O)	0.00-0.78	0.88	0.68
9	Potassium Oxide (K_2O)	0.04-1.66	<0.01	8.76

As ASTM C-618 – 12a standard specification, the summation of Silica(Sio2), Alumina(Al2O3) and Iron Oxide(Fe2O3) should be greater than minimum requirement which is 70.00% as standard. Therefore for calcined brown clay (63.24%) + (17.92%) + (8.48%) = 89.64%, which were much greater than 70% minimum requirements whereas in case of cow dung ash, the chemical composition of elemental oxides of Silicon Dioxide, Aluminum Oxide and Iron Oxides were respectively, (53.04) + (5.87) + (3.74) = 62.65%.Because of cow dung ash was reinforced or mixed with calcined brown clay, there was no problem concerning with the percentage content chemical composition of cow dung ash to replace cement materials. In another way, (89.64% + 62.65%) / 2 = (152.29/2) = 76.145%, which were also much greater than 70% minimum requirements as the standard.

3.2.2 Physical Test Results

Table 3 Weight needed for: shrinkage, water absorption, compressive strength and soundness test

S/N	Percentage replacement	Code	Amount of materials in weight(kg)			
			CBC	CDA	Sand	Cement
1	0	A-0	0	0	6.004	1.858
2	10	B-10	0.0929	0.088255	6.004	1.676845
3	20	C-20	0.1858	0.16722	6.004	1.50498
4	30	D-30	0.2787	0.236895	6.004	1.342405
5	40	E-40	0.3716	0.29728	6.004	1.18912

Table 4 Mix design or weight needed for consistency and setting time

S/N	Percentage replacement	Code	Amount of materials in weight(gm.)		
			CBC	CDA	Cement
1	0	A-0	0	0	400
2	10	B-10	20	20	360
3	20	C-20	40	40	320
4	30	D-30	60	60	280
5	40	E-40	80	80	240

Table 5 Mix design or weight needed for material tests

S/N	Percentage replacement	Code	Amount of materials in weight(kg)			
			CBC	CDA	Sand	Cement
1	0	A-0	0	0	6.004	1.858
2	10	B-10	0.0929	0.088255	6.004	1.676845
3	20	C-20	0.1858	0.16722	6.004	1.50498
4	30	D-30	0.2787	0.236895	6.004	1.342405
5	40	E-40	0.3716	0.29728	6.004	1.18912

Table 6 Mix design or weight needed for visual observation of durability test

S/N	Percentage replacement	Code	Amount of materials in weight(kg)			
			CBC	CDA	Cement	Sand
1	0	A-0	0	0	0.56	1.82
2	10	B-10	0.028	0.03	0.50	1.82

Table 7 Physical test results with explanation of standard specifications

S/N	Test Types	Test results					Explanations from standard specifications, Authors and test results.
		0%	**10%**	**20%**	**30%**	**40%**	
1	Consistency test	28	30	33	38	42	At 0, 10 and 20% of the mix proportion, workability of the calcined brown clay and cow dung ash showed good results ASTM (24 - 33).
2	Initial setting time	1hr 55min.	1hr 50 min.	1hr 37min.	1hr 20min.	1hr	By considering at constant temperature, initial and final setting time of 10 % cow dung ash and calcined brown clay were in line with standard and nearest to 0 % of calcined brown clay and cow dung ash which were 1hr 55min (115min) and 8hr 21min (501min) of initial and final setting time respectively of the mortar without any mixture which was used as standard mortar mix.
	Final setting time	8hr 21min.	7hr 55min.	7hr 30min.	7hr	6hr	
3	Water absorption	11.34	13.90	14.81	15.69	15.43	10% proportion, 1:9 mix ratios and 13.90 water absorption test result showed low water absorption and without cracking was used in mortar production *[23]*.
4	Shrinkage Test	0	0	0	2.52	5.96	As shown from the table, there were no shrinkage test results from (0%) - (20%) which was make them not more liable to cracking than the other *[24]*.
5	Soundness test	0	0	0	2.494	5.818	From (0) - (20%) of the cubed mortar showed that the best soundness test result, because of there were no volume changes of dried cubes.

Where, S/N = Serial number, hr=time in hour, min=time in minute and % represents percentage

Compressive strength

Compressive strength properties were determined after the cubes were immersed or cured in the water for $7^{th,}$ 14^{th} and 28^{th} days [25].

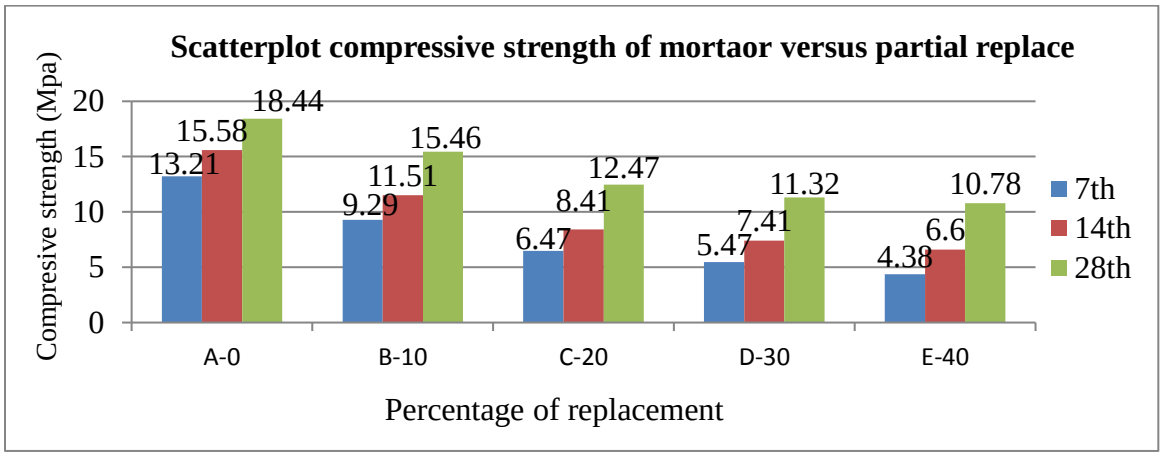

Figure 11 Compressive strength test result at 7th, 14th, and 28 days

Compressive strength was reduced with the increase in the cow dung ash and calcined brown clay content in cement mortar. But it was found that, when the cow dung ash and calcined clay was 10% in cement, the strength initially raised for all partial replacement materials. From the previous view, compressive strength of mortar at seven and twenty-eight day were 9.00 Mpa (1300psi) and 14.5Mpa (2100psi) respectively, also the results gained here were 9.29 Mpa at 7 days and 15.46 at 28 days. Compressive strength was increased with the curing days and also found the 10% cow dung ash and calcined brown clay. This can be due to the chemical or mineral composition. Example, silica mineral showed an increased compressive strength due to its improved strength of its cement paste constituent, but having high amount of silica in calcined brown clay (63.24%) and cow dung ash (53.04) can cause decrement of strength property of mortar.

a) Strength Activity Index (SAI)

It was used to determine whether the mortar mixture would result an acceptable level of strength development when used with hydraulic cement in mortar production.

As shown from the following figure strength activity index of the compressive strength at 28 days for all mixes were:

$$SAI = \frac{\text{Compressive mortar with calcined brown clay and cow dung ash}}{\text{Compressive mortar without calcined brown clay and cow dung ash}} \times 100\% \quad (1)$$

By taking (A-0) =100%, as standard value which has no any mixture:

SAI for mix (B-10) = (15.46mpa /18.44) * 100=83.84%

SAI for mix (C-20) = (12.47/18.44) * 100=67.62%

SAI for mix (D-30) = (11.32/18.44) * 100=61.39%

SAI for mix (E-40) = (10.78/18.44) * 100=58.46%

Therefore, SAI (Strength Activity Index) for mix ratio of 10 % or (B -10) = 83.84% was greater than 75% of minimum standard requirements, ASTM C618-12a.

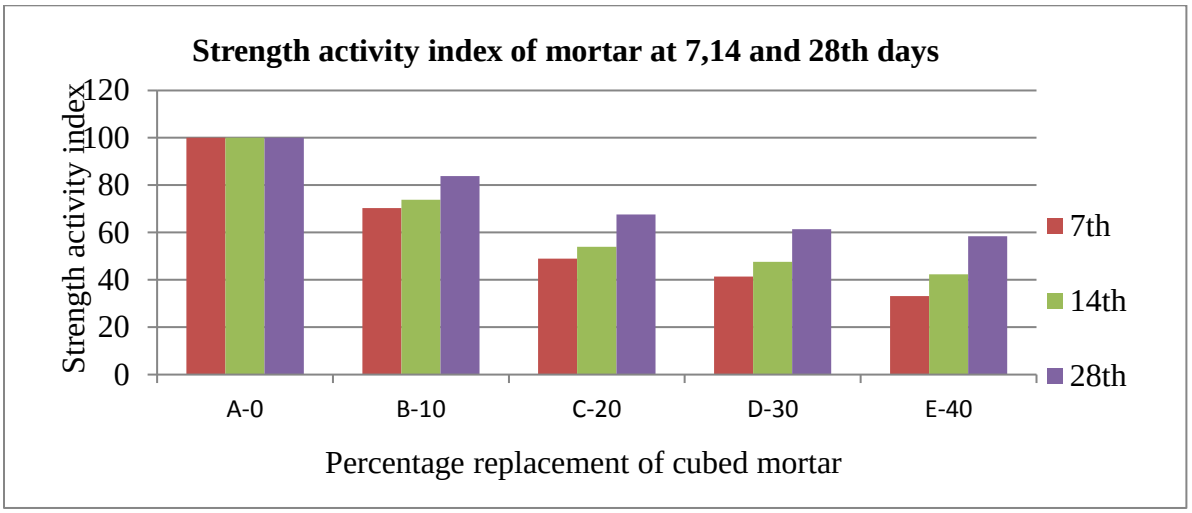

Figure 12 Strength activity index of cubed mortar

b) Optimum analysis of compressive strength at 28 days

To come up with summary of compressive strength at 28 days, the following figure resulted comparing with optimum controller test result, ASTM standard and partial replacement test result at 28 days.

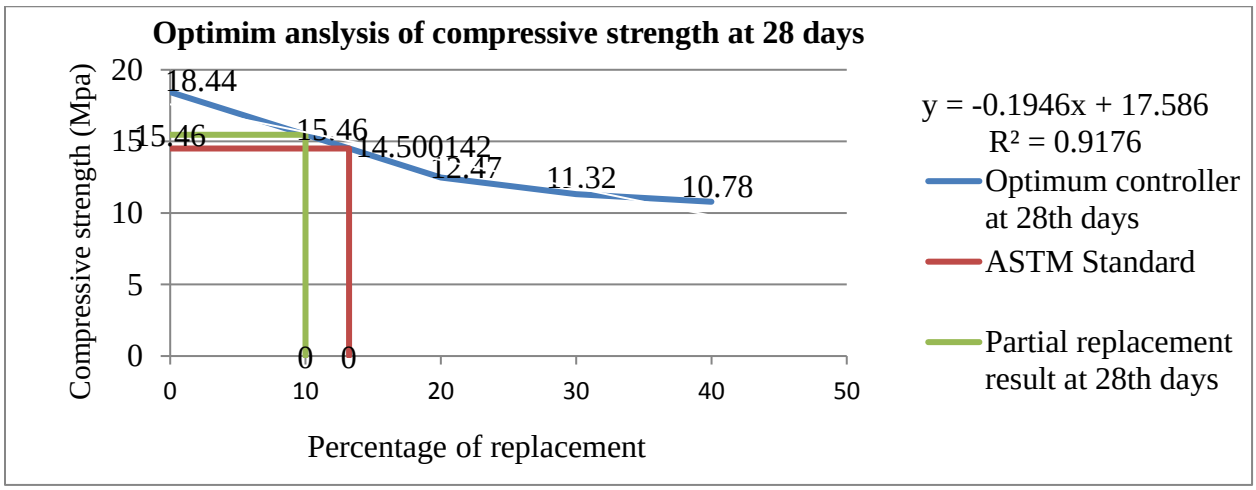

Figure 13 Optimum analysis of compressive strength at 28th days

From the above figure even though, the partial replacement test result at 28 days (15.46Mpa) showed below the optimum controlling test result (18.44), it was greater than the ASTM standard value which was (14.500142=14.5Mpa). As mix ratio increased from 10%-40%, the compressive strength of the mortar at 28 days decreased from 15.46Mpa to 10.78Mpa.

7. Visual Observation of durability test

As shown from observation, calcined brown clay soil was mixed with cow dung ash and plastered on the surface of the wall. It looked strong, comparing to the standard cement mortar and it adhered well over the surface of the wall structure. Therefore, referring to ASTM C - 270 standard specifications for mortar test, the proposed mortar of calcined brown clay mixed with cow dung ash was suitable and, therefore, it could be used in low - cost house building, especially in third coat wall plastering works.

Figure 14 Process of making plaster on the wall surface, for third coat plastering

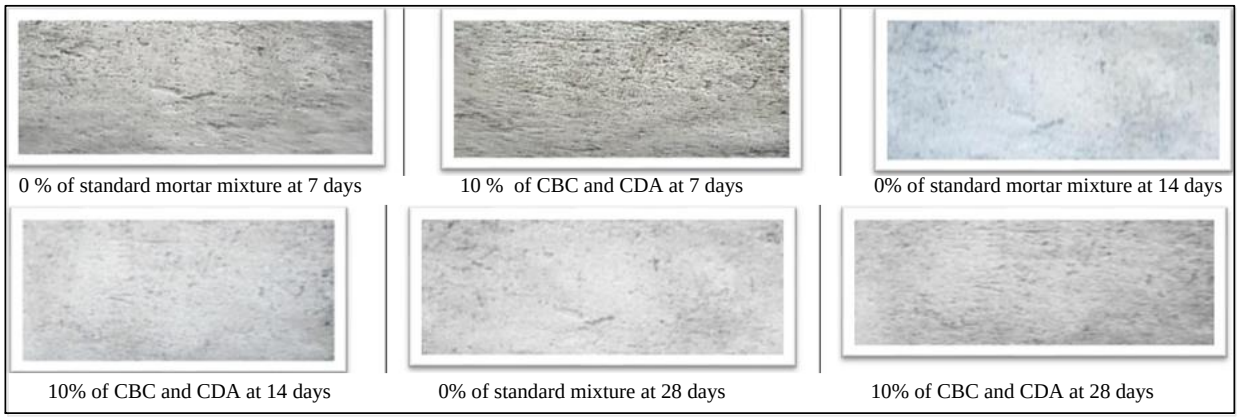

Figure 15 Visual observation of durability

3.3 Cost Analysis

Cost of controller (0% mix proportion) and mix proportion with calcined brown clay and cow dung ash were compared. Because it meets the 15.46 Mpa of compressive strength and compliance standards of ASTM C618 -12a, the mix proportion with 10% calcined brown clay and cow dung ash was the best replacement.

Table 8 Cost of zero percent mix proportion (0%)

No.	Materials	Quantity	Unit	Rate (Ethiopian birr)	Amount(Birr)
1	Cement(OPC)	14.99	Kg	14	209.86
2	Sand	0.02	M3	1500	30
				Total	239.86Birr/kg

Table 9 Cost of ten percent mix proportion (10%)

No.	Materials	Quantity	Unit	Rate (Ethiopian birr)	Amount

1	Cement(OPC)	13.49	Kg	14	188.86
2	CBC	0.74	Kg	1.50	1.11
3	CDA	0.74	Kg	1.50	1.11
4	Sand	0.02	M3	1500	30
				Total	**221.08Birr/kg**

As seen from above table, 10 percent of new mortar mix percentage was 7.83 percent lower than the control mix, or 18.78 birr per kilogram by cost. This clearly demonstrated that, calcined brown clay and cow dung ash could significantly reduce the cost of mortar production.

4 CONCLUSIONS and RECOMMENDATIONS

4.1 Conclusions

1. From the beginning, brown clay and cow dung samples were taken from the local site and chemical test result in percent of major and minor elemental oxides were determined and organic matters was extracted and sieved to make the clay finer, and atterberg limit test was used to determine the clay's cohesive conditions.

2. Having 0%, 10%, 20%, 30 %, and 40% mixture, the best water absorption was determined to be 13.90% on average for all cubes, indicating a concentration of 10% cow dung ash and calcined brown clay. Shrinkage value was constant and increased by 0.00, 0.00, 0.00, 2.52, and 5.96, respectively with increment of percentage mixture. As percentage of calcined brown clay and cow dung ash increased, compressive strength of mortar cubes was decreased. But, as curing period increased from seven to twenty - eight, compressive strength of the cubed mortars was also increased. This was one property of the influence of calcined brown clay replacement with cow dung ash on the mortar replacement and curing period or curing time of cubed mortar made. Visual observation was used to conduct a durability test, which revealed that the plastered mortar had no crack or fractures and was well adhered to the surface of the wall.

3. The best content of 10% with equal amount of cow dung ash and calcined brown clay with 1:9 demonstrated the best or most good properties, better strength and durability of all the properties under normal weather conditions in low - cost house buildings.

4.2 Recommendations

1. Due to the availability of the calcined brown clay and cow dung ash, such a research tittle was very important, especially for the plastering purpose of low - cost house buildings, as well as for users and contractors who engaged in plastering works of low - cost house buildings but not of low quality.

2. For future time, another study can be carried out with different amount of the mixed proportion of calcined brown clay and cow dung ash under the same title with the objective of improving the experimental test result of long - term durability of cement - based containing calcined brown clay and cow dung ash.

3. It is also suggested that in order to achieve the best percentage replacement, proportion and ratio of calcined brown clay and cow dung ash, and the required value of mortar properties, selecting the correct samples was an important for the research tittle's, objectives and result outcomes.

References

[1] D. G. K. A. D. W. Akhildeep Kurup, "Study of Low Cost Housing : A Review," International Journal of Science Technology & Engineering, vol. Volume 4, no. Issue 7, January 2018.

[2] L. Mbereyaho, " Protection Against Natural and Man Made Disasters for Basic Housing Construction Instruction in Rular Areas," Rwanda Housing Authority, 2012.

[3] K. A. J. U. Kirakowiak, "Multitechnique investigation of extruded clay brick Microstructure," Academic Journals Inc, pp. 94:3012-3022, 2011.

[4] D. J.-N. A. Y. Y. Roman Jaskulski, "Calcined Clay As Supplementary Cementitious Material," Faculty of Civil Engineering, Mechanics and Petrochemistry., Vols. 5b,02-106, 23 October 2020.

[5] Olokode, Olocode, O.S.P.O.Aiyedun, D.M.Raheem, F.T.Owoeye and a. B. Anyanwu, "Production and characterization of clay-cowdung," Academic Journals Inc., pp. 1:162-167, 2012.

[6] V. K. A. A. A. D.P. Katale, "Investigation on the Use of Clayey Soil Mixed with Cow Dung to Produce Sustainable Bricks; Trends in Applied Sciences Research," University of Rwanda,College of Science and Technology, Department of Civil, Environmental, and Geomatics Engineering., vol. 9(8), pp. 406-424, 2014.

[7] D. I. E. H. A. J. M. Leopold Mbereyaho, "Assessment of Cohesive Soil - Cow Dung Mortar Properties as Replacement of Cement Mortar for Simple Plastering Works," Rwanda Journal of Engineering, Science, Technology and Environment., vol. Volume 3, no. Issue 2, 2020, p. 89, 2015.

[8] R. H. R. A. D. B. P. Thej Kumar, "A Study on the Replacement of Cement in Concrete by Uing Cow dung ash," International Journal of Scientific Engineering and Applied Science, pp. 2395-3470, December 2015.

[9] Adinkrah-Appiah, " Structural Characteristics of Earth Improvement," International Journal of Science and Research, pp. 1119-1126, 2013.

[10] Bboxleiter, "Stratified random sample," 2016.

[11] A. S. T. C.-5.-8. A. D. T. Material, "Code of specification for moisture content of the materials".

[12] G. Lemma, "Study of Partial Replacement of Sand with Wanza Sawdust to Produce Concrete," p. 10, June, 2019.

[13] Burmister, "Atterberg limits and consistency indices," 1949.

[14] E. S. E. A. A. D. 8. T. M. C, "Portland Cement, General Requirements," D5. 201, 1990.

[15] B. Birhanu, construction materials II, Addis Abeba, 2005-2009.

[16] P. S. R. Sivapullaiah, "Standard Code of specification for free swell test," American Society for Testing and Materials ISSN:0149-6115, vol. 10, no. 2, pp. 80-85, 1987-6.

[17] Https://Wwww.Engineeringcinil.Com/Determine-Free-Swell-Index-Of-Soil, "Determine Free Swell Index Of Soil," 1977.

[18] E. Standard, "Silt content of the materials".

[19] A. S. T. C. A. A. S. T. M. C.-3. Material, "Code of specification for silt content".

[20] A. S. T. M. C. Material, "Code of specification for specific gravity and water absorption of fine aggregate".

[21] A. S. T. M. C-33-02a, "Code of specification for Unit Weight".

[22] M. S. Shetty, Concrete Technology,Theory and Practice, S. Chand & Company, New Delhi, 1982.

[23] A. S. T. M. C1506, "Code of specification For Water Absorption," vol. 04.01, Updates Effective May 25, 2018.

[24] A. S. T. M. C-596-01, " Standard Test Method For Drying Shrinkage Of Mortar," Updates Effective May 25, 2018.

[25] A. C. 1329, "Physical properties of mortar cements," in Portland Cement Association , Skokie, September 2002.