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EFFECT OF CURING TIME ON COMPRESSIVE STRENGTH OF AGROSTONE BUILDING MATERIAL WITH WATER HYACINTH, BAGASSE AND GRASS BIO-FILLERS – A COMPARATIVE STUDY

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Abstract

The construction industry is in a quest for low-cost eco-friendly materials with very good properties required for building construction such as Agrostone. It is made of magnesium oxychloride cement and fillers for reinforcement. In the present work, experimental studies are made on compressive strength of Agrostone made of different bio-fillers like water hyacinth, bagasse and grass to identify a low-cost bio-filler that gives the required properties. It is also aimed to replace the presently used fillers with water hyacinth refuse from Lake Tana, Ethiopia to reduce cost and disposal problems. The specimens are casted as per ASTM C109 standard of 50 mm cube from the three bio-fillers. Twenty-four specimens are prepared for each type and six specimens are selected randomly from each of the three groups with a curing time of 7, 14, 21, and 28 days. The compressive strength of specimens is tested as per ASTM C90 based on the peak load. The average values of compressive strength for water hyacinth Agrostone are 5.26 MPa, 5.34 MPa, 5.52 MPa, and 6.4 MPa at 7, 14, 21, and 28 days of curing, respectively. Agrostone made of bagasse and grass bio-fillers have higher compressive strength compared to that of water hyacinth. The water hyacinth Agrostone specimens after 28 days of curing have comparable strength of class AAA hollow concrete block (5 MPa) of Ethiopian material code. The strength to mass ratio of water hyacinth Agrostone is superior to those of bagasse and grass. The cost of building partition walls using water hyacinth Agrostone will be reduced by 53 % compared to plastered and painted hollow concrete block wall of the same thickness.

Keywords: Agrostone, Bagasse, Compressive strength, Low-cost building material, Pumice, Water hyacinth.

1. Introduction

Ethiopia is one of the Sub-Saharan African countries with annual population growth of 2.9 % [1, 2]. This high growth of population and urbanization [3, 4] is creating scarcity of housing in the towns and putting tremendous pressure on both social and physical infrastructures due to rising cost of building materials [5, 6]. Further, a rapid urbanization and industrialization has posed increasing demand for cement concrete building materials.

The construction sector is facing a severe shortage of conventional building materials due to environmental issues. Construction requires wide range of energy-consuming materials that emit CO2 creating negative impact on environment [7, 8]. In order to support the increasing demand for energy consuming building materials, there is solution to develop cost-effective eco-friendly materials utilizing agricultural waste and other solid materials from local areas to solve disposal problems [9-11]. A low-cost, lightweight eco-friendly construction material, Agrostone technology has introduced in Ethiopia since 2005 for housing projects [2]. Magnesium oxychloride (MOC) is non-hydraulic cement used to produce magnesium oxide boards and Agrostone panels. The production of eco-friendly Agrostone material is simple, energy-efficient and generates low "greenhouse" gases compared to the conventional construction materials [2, 9].

Agrostone construction saves 50 % compared to conventional hollow concrete block walls, and even more if used on large-scale [12]. Agrostone and GFRG have the potential to meet the challenges of mass housing construction at reduced cost. Agrostone and glass fiber reinforced gypsum (GFRG) plays a vital role in reducing the construction cost and time compared to conventional materials. A significant reduction in use of energy intensive materials like steel, cement, sand, and water by utilizing recycled industrial waste gypsum or natural gypsum and less labour input [13-15].

The use of Agrostone material has been already there in several parts of Latin American, Far East, North America and Middle East countries for construction of partition and fire walls [15, 16]. The MOC is also known as Sorel cement or eco-cement, which is formed by mixing the powdered magnesium oxide with concentrated solution of magnesium chloride [17]. Presently, the Agrostone panels are being prepared using agricultural and industrial wastes along with lightweight natural minerals and magnesium oxychloride cement. A suitable proportion of fiberglass is also used for reinforcement. The resulting cement composition has a chemical formula of either $3MgO.MgCl_2.11H_2O$ or $5MgO.MgCl_2.13H_2O$ or a combination thereof [18]. Agrostone materials have sufficient strength and better fire resistance characteristics compared to the conventional hollow concrete blocks [19].

The Agrostone factory in Bahir Dar, Ethiopia, utilizes bagasse bio-filler brought from Fincha Sugar Factory located far from Bahir Dar. The Agrostone panels are available in 3.5 m length and 0.60 m width with thickness of 0.10 m or 0.15 m.

In order to reduce the handling issues, it is proposed to use water hyacinth (Eichhornia crassipes) which is abundantly available in Lake Tana and Blue Nile River (Abay River) in Ethiopia. Water hyacinth infestation has been officially recognized in 2011, in Lake Tana [20] and in 2012, the estimate of water hyacinth coverage has been about 20,000 hectares and after two years, it was estimated as

50,000 hectares' shore area [21-25]. It was found difficult to completely eradicate water hyacinth [26] once it is present. Many methods have been adopted to control the presence of this weed including mechanical harvesting and physical removal. The removed weed is dumped in a heap, which is again creating pollution issues that can be seen in Fig. 1. Hence, it is proposed to utilize this waste as bio-filler for fabrication of Agrostone panels.

(a) Mechanical harvester. **(b) Dumping site.**

Fig. 1. Integrated mechanical water hyacinth harvester and heaps of the weed, Lake Tana, Shago Menge Kebele, Ethiopia.

Magnesium oxide cement can be engineered to incorporate large proportion of waste materials with fiber reinforcement to add more strength than the conventional concrete. The magnesium oxide and magnesium chloride cements require around 20-40 % of the energy compared to that is required to produce Portland cement [13, 27].

The motivation for utilizing water hyacinth as a suitable bio-filler for Agrostone production has been derived from the past literature where agricultural wastes used as an input for bio-filler. Further, the extracted water hyacinth biomass requires high handling cost hence it is proposed to reduce pollution problems created by water hyacinth infested in Lake Tana and Blue Nile River.

2. Statement of the Problem

To cater for the needs of Ethiopian construction industry and society for producing low-cost, lightweight, eco-friendly material, it is proposed to use water hyacinth biomass from Lake Tana as a suitable alternative for bagasse brought from a far-off sugar plant to Bahir Dar Agrostone factory.

A comparative study is needed to evaluate the compressive strength and the time required for curing of Agrostone specimens made of different bio-fillers such as water hyacinth, bagasse, and grass. Comparing the cost of construction using conventional hollow concrete block partition walls is also required to project the cost effectiveness of Agrostone walls.

3. Materials and Methods

3.1. Materials

Different fillers 14 %, reinforcement 0.8 %, and binders 85.2 %, by weight are being used at present in the Agostone building materials factory at Bahir Dar, Ethiopia. The details of these materials are presented in the following.

3.1.1. Filler

The agricultural residue such as bagasse, grass, water hyacinth and other lightweight natural minerals like pumice and diatomite are used as fillers. Fillers help to form a denser structure. Therefore, the filler increases the strength to a limited extent without taking part in the hardening reactions.

The bagasse is obtained from Fincha sugar factory; Ethiopia located 555 kilometres from Bahir Dar. It has 40 % cellulose, 30 % hemicellulose, and 15 % lignin. The grass is collected from the open yard of the factory. The grass is sun-dried and chopped into small pieces using hammer mill. The freshwater hyacinth is collected from Blue Nile River located at coordinates 11.558880 latitude and 37.4010712 longitudes. It is washed and dried in sun for ten days and then further dried in oven Fig. 2(b) at 105°C for eight hours until the moisture is completely removed. Both the stem and leaf part of water hyacinth plant is used as the bio-filler.

Pumice is found in different parts of Ethiopia where its composition varies based on its location with silicon dioxide as the major ingredient. This pumice has very close chemical composition found in Mathara, Ethiopia [18]. Typical chemical properties of pumice used for making the present sample is tested by X-ray fluorescence spectrometry (XRF) to determine the elements in specimens without dissolution treatment presented in Table 1.

Table 1. Chemical composition of pumice.

Chemical Composition	Weight [%]
Silicon dioxide, SiO_2	71.80
Aluminium oxide, Al_2O_3	12.35
Ferric oxide, Fe_2O_3	1.98
Calcium oxide, CaO	0.73
Magnesium oxide, MgO	0.14
Sulphur trioxide, SO_3	0.18
Potassium oxide, K_2O	4.30
Sodium oxide, Na_2O	4.47
Others	4.05

3.1.2. Reinforcement

Fiberglass has two categories such as the low-cost general-purpose fibers and the premium special purpose fibers. For this research low-cost E-glass type having aspect ratio 7.05, density 2.58 kg/m^3, compressive and tensile strengths of 1080 MPa and 3445 MPa respectively [18]. It adds to the flexural strength of Agrostone. The fiberglass may be a chopped strand mat or a woven fabric. The chopped strand mat with 20 mm length of fibers is used in the present work. This dimension is proportional to the sample sizes and allows uniform distribution of reinforcement throughout. In the real production, it may not need to chop the fiberglass into small pieces rather used in its original dimension.

3.1.3. Binders

Magnesium oxychloride cement (MOC) is used as a binder obtained by mixing powdered magnesium oxide (MgO) with concentrated solution of magnesium chloride ($MgCl_2$) upon chemical reaction. The quality of MgO influences the rate of reaction and the strength of the product. Adola, PLC of Ethiopia has supplied the light burned MgO produced by calcination process. Although MOC has several good engineering properties, the strength of solidified MOC paste will decrease when it absorbs water [18].

3.1.4. Activated solution

The following are the various chemicals used for the preparation of the activated solution.

a. Magnesium chloride ($MgCl_2$) is atypical ionic halide salt, which is highly soluble in water. The hydrated magnesium chloride can be extracted from brine or seawater. A variety of hydrates are known with the formula $MgCl_2(H2O)_x$, and they lose water with increase in temperature where the subscript x = 12 (-16.4 °C), 8 (-3.4 °C), 6 (116.7 °C), 4 (181 °C), and 2 (300 °C) [15]. Chengdu Onekin Imports/Exports Ltd., China is a major supplier of $MgCl_2$ for the company at Bahir Dar.

b. Sodium hydroxide (NaOH) is also known as caustic soda which is a white solid inorganic compound. It is highly soluble in water and readily absorbs moisture and carbon dioxide from air. Inspire Intrull Trading Company Ltd., China is a major supplier of NaOH flakes.

c. Hydrochloric acid (HCl) is a corrosive, strong mineral acid with widespread industrial use. A colourless, highly pungent solution of hydrogen chloride in water forms hydrochloride salt when it reacts with a base.

d. Hydrogen peroxide (H_2O_2) is a colourless liquid with little more viscous than water. It is the simplest peroxide with its chemistry being dominated by the nature of its unstable peroxide bond.

3.2. Tools and equipment

Different types of tools and equipment used in the present work are listed in the following.

a. Manually operated compression testing machine, Type ADR Touch SOLO 2000 BS EN with digital readout to measure specimen compressive strength.

b. Adam PW254 analytical balance with 0.250 kg maximum weighting capacity and $0.1*10^{-6}$ kg increments to measure the masses of the bio-filler, pumice, fiberglass, and the specimens.

c. Dry oven, DHG-9140A, a convection oven with digital temperature controller for drying the bio-fillers and specimens to meet uniform heating.

d. A sharp vegetable juice blender to grind dry water hyacinth stem and leaf.

e. Graduated cylindrical flasks to measure liquid chemicals and water while preparing the activated solution and the mix.

f. Rotary stirrer with a speed range of 0 to 60 RPM for uniform mixing of the ingredients, which later form the specimens.
g. A carbon steel moulding box of size 50 mm cube to cast the specimens.
h. Vernier calliper with a least count of 0.1 mm to measure the specimen dimensions.
i. Automatic digital humidity and temperature measuring apparatus, which measures the room temperature where the specimens are located.

3.3. Methods

Building design must consider all the design aspects, regulations, and the standard to suit the required function, service and expected economic life. The Ethiopian regulation or the standards and code for building construction do not recognize or specify any alternate low-cost material technologies. ASTM standard is also not available for Agrostone materials. However, the present testing is made as per the ASTM standard for hydraulic cement mortar and concrete by comparing with the Ethiopian technical specification and method of measurement (BATCODA 043321) [28] where the compressive strength of Agrostone made of different bio-fillers is compared with that of conventional materials. The water hyacinth bio-fillers collected from the river is cleaned, dried in sun and desiccated in the oven and ground into small pieces. A systematic approach is adopted for preparing the mix of activated solution of the binder, bagasse, grass, pumice, and fiberglass.

The specimens are melded in the laboratory of Bahir Dar Institute of Technology, Bahir Dar. The mix design is prepared according to the factory standard by putting all the bio-filler, pumice, fiberglass, and magnesium oxide into the activated solution and stirred until get uniform mix. The mix is poured into the mould and allowed for curing for forty-eight hours and then removed from the mould and stored in the laboratory rack. The room temperature and humidity are measured every day and the mass of each sample is weighted. The compressive strength of the specimens is found after 7, 14, 21 and 28 days of curing and the results are compared with those available in the literature.

3.3.1. Preparation of activated solution

The activated solution consists of magnesium chloride, hydrochloric acid, hydrogen peroxide and caustic soda in the ratio as indicated in Table 2.

Table 2. Composition of the activated solution.

Admixtures	Quantity used per litre of water
Magnesium chloride, $MgCl_2$ (kg)	0.7250
Caustic soda, NaOH (kg)	0.4000
Hydrochloric acid, HCl (L)	0.0004
Hydrogen peroxide, H_2O_2 (L)	0.0006

3.3.2. Mix design

The mix designs are prepared with ground water hyacinth bio-filler, particles of bagasse and grass in Agrostone, pumice, magnesium oxide with activated solution in the proportions indicated in Table 3 [29]. They are mixed uniformly by using a rotary stirrer at 50 RPM for six minutes and the specimens are prepared with three mix designs. The water hyacinth mix required an extra 0.2 litre of activated solution to have a similar texture of mix as of other bio-fillers. This indicates a higher water absorption nature of water hyacinth compared to bagasse and grass fillers.

Table 3. Mix design for Agrostone specimens.

Admixtures per litre of activated solution (kg)	Type I	Type II	Type III	Weight (%)
Magnesium chloride, $MgCl_2$	0.725	0.725	0.725	39.00
Magnesium oxide, MgO	0.860	0.860	0.860	46.20
Fiberglass	0.015	0.015	0.015	0.80
Pumice	0.160	0.160	0.160	8.60
Water hyacinth	0.100	-	-	5.40
Bagasse	-	0.100	-	5.40
Grass	-	-	0.100	5.40

3.3.3. Sample preparation

The factory procedures are adopted for preparing the mix and the specimens are moulded as per ASTM C10. After pouring the mix into the mould, it is thoroughly rammed to make sure absence of voids and the top surface is made even and smooth.

3.3.4. Testing for compressive strength

The compressive strength is the most important properties of Agrostone [3, 15, 18]. Six specimens were tested for each curing during using ADR Touch SOLO 2000 BS EN Compression Testing Machine of 6.8 kN loading capacity shown in Fig. 2(b). The dimensions of the specimens are measured and the ultimate load for failure is recorded for each specimen by gradually applying the load.

(a) Bio-fillers in the drying oven. **(b) Compressive strength testing.**

Fig. 2. Experimental setup for the testing of Agrostone specimens.

4. Results and Discussion

The physical properties like the bulk density of bio-fillers, density of Agrostones and mass after each period of curing at room temperature and humidity. The specimens are then tested for compressive strength.

4.1. Physical properties of different bio-fillers and Agrostones

4.1.1. Bulk density of bio-fillers and density of Agrostone

The physical properties of bio-fillers are measured to get an insight on their influence on compressive strength of Agrostone. The bulk density of bio-fillers is measured by drying in oven at 105°C for 8 hours to complete removal of moisture. The bulk density is calculated by measuring the mass and volume of the fibers placed in a container. Similarly, the melded specimens are dried in oven as per ASTM C109 until the moisture is removed. The density of Agrostone is computed from the mass and volume of the specimens and results are presented in Table 4.

Table 4. Bulk density of bio-fillers and density of Agrostone.

Filler type	Average bulk density of ground fiber (kg/m^3)	Density of Agrostone composite (kg/m^3)
Water hyacinth	140	645 (620 - 950)
Bagasse	405	885 (710 - 1060)
Grass	340	1160 (1150 - 1165)

The results presented in Table 4 show that water hyacinth bio-filler has less bulk density compared to bagasse and grass. The average density of Agrostone made of bagasse and grass is higher by 37.21 % and 79.84 % respectively compared to the average bulk density of Agrostone made of water hyacinth. The oven dried light and medium weight concrete has a density of 1681 kg/m^3 to 2002 kg/m^3 as per ASTM C90. Results presented in the earlier studies indicate that the bulk density of bagasse is 125 ± 2.6 kg/m^3 [18], which is three times less than the value obtained in the present research. The large variation in the bulk density may to the difference in the size of the particles of bagasse used and level of compaction in their study, which is not indicated. It can be stated that the weight of the super structure will be reduced drastically due to the low density of Agrostone and it may reduce the cost of construction.

Similarly, the density of bricks is about 1920 kg/m^3 that is higher compared to Agrostone materials. The Agrostone walls usually require painting only to protect them from humidity in the environment but otherwise they will have a smooth and clean finish whereas the walls made of concrete hollow blocks requires plastering and gypsum finish which increases the cost of construction. Further, Agrostone construction does not need water unlike the brick or hollow concrete block construction that results in saving in cost of water and curing process [18].

4.1.2. Mass of Agrostones made of different bio-fillers

The mass and average daily temperature and relative humidity of Agrostone specimens for different types of specimens and curing periods are presented in Table 5. The average value of six specimens for each type of Agrostone is considered in the present investigation. The results showed that the mass of the specimens has decreased linearly for 7, 14, and 21 days of curing whereas the mass for 28 days of curing has increased slightly which may be due to increased relative humidity in the atmosphere.

Previous studies show that in spite of its higher strength property; the MOC has been restricted for outdoor applications due to its poor resistance to moisture in the environment [15]. The present increase in mass of Agrostone after 28 days of curing also supports the results of earlier studies of moisture absorption thereby reducing its binding strength and increasing its weight. The rate of drying the specimens has been higher due to higher temperature and high-water content during initial periods of drying.

Table 5. Mass of specimens with respect to curing time, temperature and humidity.

Curing days	Type I (kg)*10^{-3}	Type II (kg)*10^{-3}	Type III (kg)*10^{-3}	Temp (ºC)	Relative Humidity (RH)
7	171.533	169.325	169.278	27.8	69.4
14	160.689	162.022	160.239	26.9	67.5
21	158.242	161.865	158.317	26.4	66.0
28	159.221	163.017	159.113	22.4	70.0

4.2. Compressive strength of Agrostone made of different bio-fillers

Measurement of compressive strength is affected by the test method and conditions of measurement that are usually reported in relationship to a specific technical standard [12]. The present research has been done as per ASTM C109 and the values of compressive strengths of different Agrostone composites corresponding to different curing times are listed in Table 6.

Table 6. Compressive strength of Agrostone (MPa).

Curing days	Type I Av (min-max)	Type II Av (min-max)	Type III Av (min-max)
7	5.26 (5.00 - 5.26)	5.73 (5.43 - 5.90)	7.63 (7.22 - 7.96)
14	5.34 (5.00 - 5.99)	6.32 (6.28 - 6.39)	8.34 (7.43 - 8.81)
21	5.52 (5.46 - 5.58)	6.78 (5.80 - 7.77)	9.16 (8.93 - 9.40)
28	6.40 (6.02 - 6.59)	7.17 (6.88 - 7.62)	9.37 (9.14 - 9.66)

The compressive strength of each type of Agrostone composites is increasing linearly with curing period [3] that be clearly seen in Fig. 3. The average compressive strength of water hyacinth Agrostone composite has 5.26 MPa, 5.34 MPa, 5.52 MPa, and 6.40 MPa for 7, 14, 21, and 28 days of curing, respectively. The values of compressive strength are fluctuating among the same type of specimens, which could be related to variation in the particle size of the contents in the mix, and the homogeneity of the contents in the specimens [15].

The compressive strengths of Agrostone made of bagasse and grass bio-filler have been higher by 9 % and 45 % for 7 days of curing and 12 % and 45 % for 28 days of curing respectively compared to the Agrostone specimens made of water hyacinth bio-filler.

Agrostone made of water hyacinth has attained 82.2 % of its full strength in normal drying within 7 days whereas Agrostones made of bagasse and grass have attained only 74.9 % and 77.2 % of their full strength in normal drying within 7 days. This indicates that Agrostone made of water hyacinth bio-filler with higher strength can be supplied to the construction site faster than Agrostone made by grass and bagasse bio-filler.

Earlier study [3] found the Agrostone with bagasse bio-filler has 8.20 MPa and 8.80 MPa after curing for 7 and 28 days respectively which is higher by 43.11 % and 22.73 % compared to the values of present research.

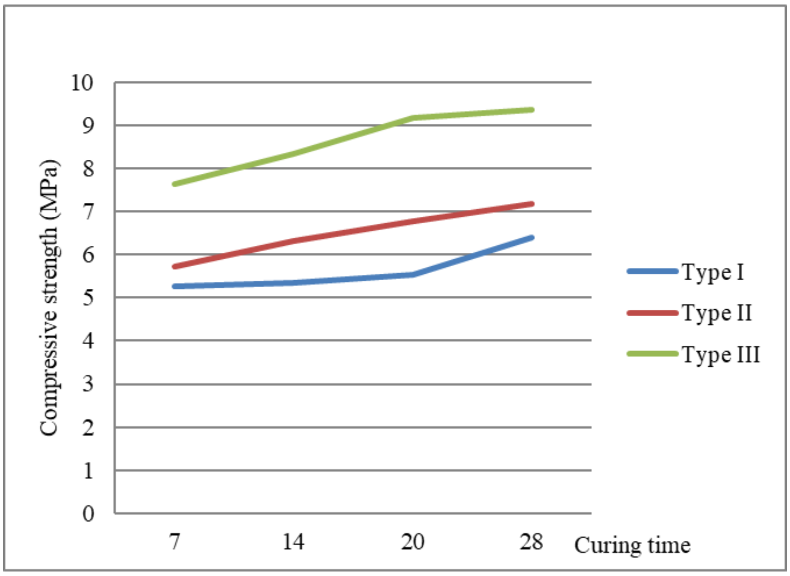

Fig. 3. Effect of curing time on the compressive strength of Agrostone specimens.

Another study [18] showed a compressive strength of 8.77 MPa and 14.33 MPa after curing for 7 and 28 days respectively; these values are also higher than those obtained in the present study. The deviation can be due to variation in test methods, the percentage of composition of different items in the mix and may also be due to the variation in the mix design. No previous studies are available on Agrostones made of grass and water hyacinth.

The load bearing capacities of specimens made of three bio-fillers showed that these Agrostone composites after 28 days of curing are applicable for load bearing structures above the grade beams according to Ethiopian material code for hollow concrete block.

The standard specifies that the average compressive strength of six specimens should be of 5 MPa but not allowed if is below 4.6 MPa for any of the individual specimens [28].

Table 7. Average compressive strength of oven-dried specimens after 28 days.

Type	Compressive strength [MPa]
Type I	9.01
Type II	12.14
Type III	13.75

Removal of moisture content of Agrostone specimens of all three bio-filler materials has shown (Table 7) higher compressive strength compared to that of specimens cured for 28 days. The percentage increase in compressive strength of oven-dried specimens after 28 days of curing has been 40.8 %, 69.3 %, and 46.7 % for water hyacinth, bagasse, and grass Agrostone composites, respectively. These results gave an indication of moisture trapped inside the specimen will greatly reduce the strength of Agrostone [15].

Strength to weight ratio is one of the important criteria for the choice of materials in construction industry. Even though compressive strength of Agrostone specimens made of grass and bagasse are higher than that of water hyacinth, the specific compressive strength, which is the strength to density ratio of Agrostone made by water hyacinth, has been higher. The specific compressive strength is found 0.0140, 0.0137, and 0.0119 for water hyacinth, bagasse and grass made Agrostone, respectively. These results imply that the strength to mass ratio of water hyacinth Agrostone specimens is higher than that of the specimens made of bagasse and grass. Hence, it is generalized that the specific strength of water hyacinth based Agrostone has higher specific compressive strength compared to other currently being used for making Agrostone. Consequently, the water hyacinth bio-filler may be considered as a better alternative to replace bagasse and grass.

4.3. Cost analysis

The most important factor that motivates the stakeholders in construction sector is to use a new material like Agrostone for cost reduction. The cost analysis for hollow concrete block class A and Agrostone made of different bio-fillers are compared by the cumulative cost of raw material and labour cost per meter square. The cost of materials for the analysis are taken from 2019 Bahir Dar town conventional and alternative building material cost break down document [30].

It can be observed from Table 8, that the production cost of 10 cm thick hollow Agrostone partition wall made of water hyacinth is slightly lower by 2 % and 0.5 % respectively compared to the control specimens made of bagasse and grass bio-fillers.

Table 8. Raw materials and production cost of Agrostones.

Item	Consumption qty (kg /m^2)	Unit price (USD/kg)/ (USD/m^2)	Materials and other cost (USD/m^2)		
			Type I	Type II	Type III
MgO	12.00	0.394	4.728	4.728	4.728
$MgCl_2$	8.34	0.399	3.327	3.327	3.327
Fiberglass	0.67	0.401	0.269	0.269	0.269
Pumice	5.55	0.112	0.622	0.622	0.622
Water Hyacinth	2.02	0.035	0.070	-	-
Bagasse	2.02	0.129	-	0.261	-
Grass	2.02	0.061	-	-	0.122
Admixtures	0.08	0.819	0.066	0.066	0.066
Salary	-	0.566	0.566	0.566	0.566
Overhead cost	-	0.244	0.244	0.244	0.244
	Grand Total		**9.892**	**10.083**	**9.944**

The cost comparison of finished Agrostone made of different bio-fillers with hollow concrete blocks of class A is shown in Table 9. The cost analysis shows that the Agrostone with water hyacinth bio-filler will reduce the cost by 53 % compared to the cost of plastered and painted hollow concrete block of the same wall thickness. This finding is in agreement with the earlier research works [3, 12].

Table 9. Cost comparisons of finished Agrostones and hollow concrete blocks.

Description	Type I (USD/m^2)	Type II (USD/m^2)	Type III (USD/m^2)	HCB (USD/m^2)
Width/type (cm)	10	10	10	10/Class A
Product cost	9.892	10.083	9.944	7.179
Mortar/chemical for fitting	1.599	1.621	1.605	0.3267
Labour cost for fitting	0.263	0.263	0.263	3.881
Sub-total I	**11.754**	**11.967**	**11.812**	**11.386**
Mortar for plastering	-	-	-	3.713
Plastering labour cost	-	-	-	4.060
Paint	1.057	1.057	1.057	1.057
Painting labour cost	1.174	1.174	1.174	1.174
Sub-total II	**2.231**	**2.231**	**2.231**	10.004
Grand total	**13.985**	**14.198**	**14.043**	**21.390**

5. Conclusions

The following conclusions are drawn based on the results of the present work.

- The compressive strength of Agrostone composites made of water hyacinth, bagasse and grass bio-filler has increased linearly with increase in number of curing days.
- Complete removal of moisture content has increased the compressive strength by more than 40 % for all the three types of Agrostone specimens. The mean compressive strength has increased to 9.01 MPa, 12.14 MPa and 13.75 MPa for Agrostone with water hyacinth, bagasse, and grass bio-fillers, respectively.
- All the specimens meet the strength requirements equivalent to hollow block class AAA of Ethiopian construction code of 5 MPa compressive strength.
- The strength to weight ratio of Agrostone made of water hyacinth bio-filler is higher than Agrostones made of bagasse and grass bio-fillers.
- Drying of specimens in an atmosphere with higher humidity will hinder the drying process.
- The cost of water hyacinth made of Agrostone with painted partition walls is reduced by 53 % when compared to traditional hollow concrete block of same wall thickness.

6. Future Work

Further investigations may be made to study water absorption, thermal conductivity, sound transmission, and fire resistance properties of water hyacinth Agrostone.

Nomenclatures

Type I	Water hyacinth bio-filler
Type II	Bagasse bio-filler
Type III	Grass bio-filler

Abbreviations

ASTM	American Society for Testing and Materials
Av	Average
GFRG	Fiberglass Reinforced Gypsum
HCB	Hollow concrete blocks
MOC	Magnesium Oxychloride Cement
max	Maximum
min	Minimum
Qty	Quantity
RH	Relative Humidity
RPM	Revolutions Per Minute
Temp	Temperature
USD	United States Dollar
XRF	X-ray Fluorescence Spectrometry

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