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Low-Cost Eco-Friendly Building Material: A Case Study in Ethiopia

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***Abstract*—**This work presents a low-cost and eco-friendly building material named Agrostone panel. Africa's urban population is growing at an annual rate of 2.8% and 62% of its population will live in urban areas by 2050. As a consequence, many of the least urbanized and least developed African countries' will face serious challenges in providing affordable housing to the urban dwellers. Since the cost of building materials accounts for the largest proportion of the overall construction cost, innovating low-cost building material is vital. Agrostone panel is used in housing projects in Ethiopia. It uses raw materials of agricultural/industrial wastes and/or natural minerals as a filler, magnesium-based chemicals as a binder and fiberglass as reinforcement. Agrostone panel reduces the cost of wall construction by 50% compared with the conventional building materials. The pros and cons of Agrostone panel as well as the use of other waste materials as a raw material to make the panel more sustainable, low-cost and better properties are discussed.

***Keywords*—**Agrostone Panel, Low-cost and sustainable Building Materials, Agro-waste for construction

I. Introduction

AFRICA has absorbed relatively high rates of urban growth over the past five decades. Africa's urban population grew from 33 million in 1950 to 373 million in 2007. It means that, in 1950, only 14.7% but by 2007, 38.7% of the Africa population was living in urban areas. According to the latest UN projections, the urban population is expected to grow from 373 million in 2007 to 1,234 million in 2050, at annual growth rate of 2.8%. These projections show that African society will became predominantly urban and by 2050, 62% of the region's population will live in urban areas [1]. Therefore, many African countries will face serious challenges in providing affordable housing as rapid population growth is becoming largely an urban phenomenon concentrated in the developing world.

Sub-Saharan Africa has long been one of the least urbanized and least developed regions of the world. Ethiopia is one of the Sub-Saharan Africa countries with 2.9% annual population growth. The capital city, Addis Ababa is among the least urbanized cities of the world and is one of the oldest and largest cities in Africa. Addis Ababa's population has nearly doubled every decade [2]. This is pumped by both the high level of national population growth and high urban migration. This high growth has been putting a tremendous pressure on both social and physical infrastructures.

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The availability of large numbers of jobs, better access to health and education make the urban migration in Addis Ababa very high which accounts for about 40% of the growth [2]. In addition, its geographic location has made it a hub to hundreds of thousands of people coming from all corners of the Country. Therefore, city of Addis Ababa confronted with critical problem of accommodating the rapidly growing urban populations with adequate shelter and basic urban services.

II. Housing Projects in Addis Ababa

As most of African cities, Addis Ababa also has the world's largest proportion of urban residents living in slums. About 80% of Addis Ababa housing units and neighborhoods in the city are considered to be slums. The majority of the slum houses which is about 70% are concentrated in the inner-city and owned by *Kebele* (the lowest administration level) [3]. These houses are known as *Kebele houses* and occupied by low-income citizens. Almost all slum houses are constructed by "*Chicka*" (mud and wood construction type).

The majority of the houses in the current slums of Addis Ababa are dilapidated. The dilapidated existing houses coupled with scarcity of houses had provoked the housing problems of the city. The number of housing units available in the city in year 2002 was about 60% of the housing needed by the residential or a backlog of about 230,000 housing units [3]. In addition to the house backlogs, the demand of the dwellers for residential houses is increasing by 10,000 annually and that makes the situation more severe [4].

In response to these problems, Addis Ababa city government has been trying to improve the dilapidated inner-city slums as well as to reduce the house backlogs under the Grand Housing Program (GHP) to meet target 11 of the Millennium Development Goal 7, of Cities without Slums. It is commonly known as condominium housing. This programme was primarily introduced to address both the daunting housing backlog of 230,000 and to replace 50% of the total 136,330 dilapidated *kebele houses*. Thus, GHP targeted to construct 300,000 low-cost houses by constructing 50,000 housing units annually [3, 5].

Accordingly, a condominium regulation was issued in 2004 and in the same year the city administration has proposed and launched a pilot project of 700 housing units including a commercial centre. This pilot project was given to the former GTZ (German Technical Cooperation) as a contract and upon completion the Addis

Ababa Housing Agency (AAHA) [3, 5] continues managing similar projects. Nevertheless, the housing agency cannot manage these projects alone as they are very vast. Thus, Addis Ababa City Government initiated the establishment of the Addis Ababa Housing Development Project Office (AAHDPO) to control two-thirds of the construction and supervision of the project while the distribution and administration is carried out by Addis Ababa Housing Agency.

The housing projects were planned to be modular type with simple standardization to reduce cost and time. It uses pre-cast and onsite production technologies through labor intensive employment by training. A cement product, Hollow Concrete Block (HCB) which is the most widely used building materials in the Country has been utilized for both internal and external wall construction. Due to the scarcity and escalating cost of cement and cement products had caused a challenge to execute the housing projects according to the cost and time schedule.

Indeed, escalation of cement price considerably continued from time to time. For instance, the retail price of a quintal of cement in 2011 is 440ETB (1ETB = 0.04EUR) which is equal to the minimum monthly salary of a civil servant in Ethiopia. The factory price of a quintal of cement is 210ETB but retailers sell a quintal of cement with double price since there is a huge gap between the demand and supply of cement. Even though Ethiopia has huge reserves of raw materials which is required to produce cement (see Table I),

TABLE I
RESERVE OF RAW MATERIALS TO PRODUCE CEMENT IN ETHIOPIA [7]

Raw Materials	Amount (metric tons)
limestone	171,550,000
clay	21,600,000
silica sand	3,400,000
gypsum	57,400,000
pumice	many million tones

local cement producers cannot fulfill the demand of cement in the country as they can produce only 2.7 million tons annually while the demand is 8 million tons in 2011[6]. As a result, activities of many construction sites were stopped for sometime. To reduce this impact, the government imported about 1 million metric tons of cement annually to meet the demand [6]. However, this cannot alleviate the problem and finding other innovative solution is mandatory.

To successfully complete the Addis Ababa housing projects and solve the housing shortage partially, finding locally available raw materials that can be used to produce building materials which do not consume ordinary cement is necessary. The new product needs to have better quality and lower price than the conventional HCB. The Addis Ababa City Government with AAHDPO came up with an alternative building material and produced Agrostone panel from locally available raw materials.

III. AGROSTONE PANEL

Agrostone panel is composed of agricultural/industrial wastes and/or lightweight natural minerals as fillers, magnesium-based chemicals as a binder and fiberglass as reinforcement. The technology of Agrostone panel production had been practiced in Asia and Latin America. All countries adopted the Agrostone panel production technology based on the availability of the raw materials on their own countries. Likewise, Addis Ababa Agrostone production center has adopted this technology based on locally available raw materials which are presented below.

A. Filler

Fillers for Agrostone panel production can be agricultural products and/or lightweight natural minerals like pumice and diatomite. Addis Ababa Agrostone production center uses an agricultural product, bagasse which is available from a number of inland sugar factories. Bagasse has two main advantages. One of the advantages is its high tensile strength and elasticity modulus properties. Besides being filler material, these properties make the bagasse to provide reinforcement. The second advantage is its high resistance against solvent and chemical attacks since it has high proportion of cellulose in its structure. The cellulose fiber makes the bagass to be highly crystalline and stable polymer as cellulose is a linear polyglucose and is highly hydrogen bonded component. Moreover, as bagasse is largely available agro waste material; the production of Agrostone panels is sustainable and eco-friendly, contributing to the socio-economic and environmental well-being of the Country. The availability of baggase will increase significantly as the Country plans to boost the sugar production by sevenfold (2.25 million tons per year) by mid 2015 [8].

Addis Ababa Agrostone production center also partly uses lightweight natural minerals such as pumice and diatomite as fillers. Pumice is found in different areas in Ethiopia and its composition vary depends on the location. Typical chemical properties of pumice deposited in Ethiopia are presented in Table II. Generally, lightweight natural minerals are economically feasible to use them as fillers as they are largely available in the Country.

B. Binder

Agrostone panel uses Magnesium Oxychloride Cement (MOC), also known as Sorel cement as a binder. MOC is non-hydraulic cement which is formed by mixing powdered Magnesium Oxide, MgO with concentrated solution of Magnesium Chloride, $MgCl_2$. There are two methods to produce Magnesium Oxide. One is by calcining magnesite ($MgCO_3$) to a temperature range of 700 – 2000°C, and then they release CO_2 and form MgO. In different range of temperature different types of MgO is produced. The second method is by processing seawater and underground

TABLE II
CHEMICAL COMPOSITIONS (MASS PERCENTAGE) OF PUMICE DEPOSITED IN ETHIOPIA [9]

	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	Na_2O	LOI
I	68.8	9.9	4.7	1.8	0.6	4.6	4.5	4.6
II	61.5	4.1	3.0	1.5	0.6	4.2	-	5.9
III	64.6	16.3	3.9	1.7	2.5	4.2	-	4.1

I = Methara Area, II = Koka Area and III = Kimbibit Area

TABLE III
RAW MATERIALS PROPORTION USED TO PRODUCE AGROSTONE PANEL BY ADDIS ABABA AGROSTONE PRODUCTION CENTER [4]

Raw Materials	Consumption by Weight (%)
magnesium oxide	41.86
magnesium chloride	29.09
fiberglass	2.35
red ash/pumice	19.37
bagasse	7.05
admixtures	0.28

deposits of brine which contains magnesium chloride. Even though brine resource is widely available in Ethiopia, Addis Ababa Agrostone production center uses MgO produced from magnesite which is found with dolomitic marble as white, fine to medium grained crystalline rocks in the Country. There are two MgO factories in Ethiopia which are located in Modjo and Kenticha area. The total estimated reserve in Kenticha area is 1.5 million tons. Presently the production rate of MgO in Ethiopia is about 10,000 tons per day. Like MgO, Magnesium Chloride, $MgCl_2$ can be also produced locally from different sources including evaporation of seawaters or brines, but imported $MgCl_2$ is used for the production of the Agrostone panel. [4].

MOC was discovered by Sorel in 1867 just few years after the ordinary portland cement discovered [10]. MOC have better qualities than portland cement. It has high early strength as well as it creates a good bond with various inorganic and organic fillers such as sand, gravel, marble flour, wood flour, sawdust, pumice, and red ash. Its high fire and abrasion resistance, low thermal conductivity, and high compressive and flexural strength are other superior engineering properties of MOC [10, 11]. Moreover, MOC is suitable to use with fiberglass without aging problems since it has lower PH value of 10 – 11 compared to portland cement with PH value of 12 – 13 [11]. These all properties make MOC an appropriate binder for the production of Agrostone panels.

Although, MOC has several good engineering properties, the hardened MOC pastes strength weakened in water [12]. In fact, the water resistance of MOC can be improved by using additives. Small amount of phosphoric acid and soluble phosphates such as phosphates of alkali metals, alkali earth metals, iron, aluminum and ammonia can improve the water resistivity of MOC considerably. The reaction rate and engineering properties of the MOC is highly influenced by the reactivity of the used magnesium oxide powder in other words by its calcinations temperature and duration [11].

The setting and hardening of the MOC is also dependent on the formation of the phases which in turn affect the strength. The four main crestline phases are in the form of $2Mg(OH)_2.MgCl_2.4H_2O$ (Phase-2), $3Mg(OH)_2.MgCl_2.8H_2O$ (Phase-3), $5Mg(OH)_2.MgCl_2.8H_2O$ (Phase-5) and $9Mg(OH)_2.MgCl_2.5H_2O$ (Phase-9). Phase-3 and phase-5 can be stable in ambient temperature whereas phase-2 and phase-9 are stable only at temperature above 100°C. Various researches confirm that formation of phase-5 crystals is vital to get optimal mechanical properties.The chemical reaction of MgO, $MgCl_2$ and H_2O is not complete as significant amount of MgO particles will not react. Unreacted MgO particles may be considered as one of filler materials whereas surplus chloride ion would cause a problem by corroding iron. Excess MgO and H_2O supposed to be used to produce phase 5 crystalline to minimize the formation of the free chloride ion while increasing the workability. Nevertheless, there is no clear guidance what the molar ratios to be to gain best performance of MgO since it is highly dependent on various properties of each element [11].

IV. PHYSICAL AND MECHANICAL PROPERTIES OF AGROSTONE PANEL

As Agrostone panel uses different types of raw materials, the mix proportion is highly dependent on the type and the quantity of the materials used. The amount of the basic raw materials input used by Addis Ababa Agrostone production center to produce the Agrostone panel is listed out in Table III. As it can be seen, the raw materials for binding agents accounts for the largest weight proportion of the total weight, about 71% and followed by filler materials which takes about 26% of the total weight. The physical and mechanical properties of Agrostone panel are presented in Table IV. The table consists of the product standard (according to the science and technology department of China) and local test results made by Addis Ababa Agrostone Production Center. From this table, good physical and mechanical properties of the panel can be observed even if there are discrepancies in a number of test results. The reason for this is the amount and the properties of the raw materials applied to produce the Agrostone panel differ in China and Ethiopia.

TABLE IV
PHYSICAL AND MECHANICAL PROPERTIES OF AGROSTONE PANELS OF ADDIS ABABA AGROSTONE PRODUCTION CENTER [4]

No	Technical Specifications	Product Standard	Local test
1	partition wall (10 cm thick)	33 Kg/m^2	36.3 Kg/m^2
2	bending resistance load	4.8 times its weight	780kg/board
3	shock resistance load	clashing 5 times, no crack	clashing 20 times, no crack
4	sound insulation	insulated upto 42DB	-
5	fire endurance	resist fire for 108 minutes	resist fire for 120 minutes
6	one point hanging	800N hanging, no change after 74 hours	294N hanging for 72 hours, no crack
7	sudden cold and sudden hot	no change after 20 cycles	no change after 30 cycles
8	acid and alkali endurances when soaked in 5% HCL and 15% NaOH	immersed for 7 days, no change	-
9	radiation	2.75,2.9, 110 ^oC.Kg.h	No emission of radiation
10	water absorption	<22% (mostly 3-6%)	< 6%
11	durability test	-	no change after several cycles in cold water and steam bathing

V. Testes Carried Out at MRTC

We performed tests on Agrostone panel to get more information on its physical and mechanical properties. The tests are compression strength, flexural strength under two point loading condition and water absorption. They were conducted at Materials Research and Testing Center, MRTC in Ethiopian institutes of Architecture, Building Construction and City Development [EiABC]. Two types of mixes: mix without fiberglass (WOF) and mix with fiberglass (WF) were used to prepare the test specimens. The mix proportions for both types were exactly the same as presented in Table III.

The mould size that was used to prepare the test specimens for compressive strength test was a standard cube size of 15cm and for flexural strength test it was 80cm X 15cm X 10cm. Six specimens were prepared for compressive and flexural tests. Both kinds of test were conducted at the age of 7 and 28 days. The average of the three specimen test results for all tests is shown in Figure I. As it is clearly seen, the flexural strength was larger for specimens that contained fiberglass (F-WF) than the specimens without fiber (F-WOF). The increment was 224% and 161% at the age of 7 and 28 days, respectively. In case of compressive strength test, it was observed that specimens with fiberglass (C-WF) obtained 18% more strength than the non-reinforced ones (C-WOF) for both ages. It can also be observed that, the compressive as well as the flexural strengths are increasing with the age of the specimen. In case of compressive strength tests, at the age of 28 days the strength of C-WOF and C-WF increased by nearly 6% compared with the specimen at the age of 7 days. In case of flexural test the increment was 19% and 47% for F-WF and F-WOF, respectively. All the test values confirmed that the Agrostone panel attained good strength at the age of 28 days.

Bulk density of all the specimens was analyzed and the result, $1.3 g/cm^3$, confirmed its lightweight-ness. Water absorption test were also conducted and the outcome of this test was 9.4%. This figure is higher than the result mentioned by Agrostone Production Center (Table III) but within the product standard.

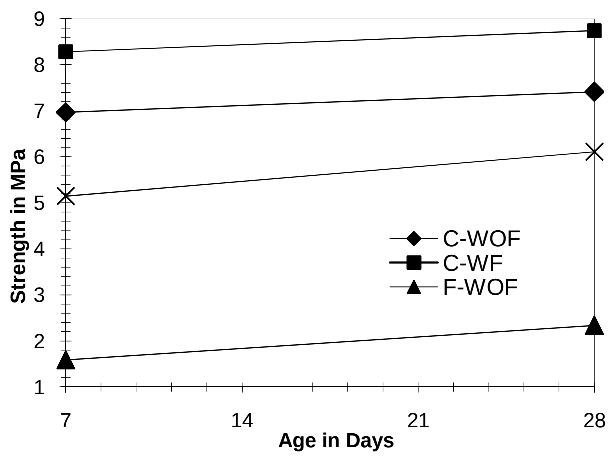

Fig. 1 Compressive and Flexural Strength Test Results of Agrostone at the age of 7 and 28 days

VI. Pros and Cons of the Agrostone Panel

Agrostone panel has several benefits compared to conventional building materials. One of the major benefits of the product is its low-cost production. This in turn contributes towards reducing housing construction costs. Agrostone panel nearly reduces the cost of the wall construction by half compared with the conventional hollow concrete block walls [4]. Unlike the traditional building materials, Agrostone panel do not require cement plastering for finishing work which demands considerable amount of cement. It does not also consume much water during construction. In addition, its production utilizes energy efficient and uncomplicated machinery which can be operated by unskilled workers. All these makes the panel to be cost effective than the conventional ones. In another perspective, its lightweight property enables reduction of costs of building structures. Agrostone panel is also quite easy to assemble and cover large area of wall within short period of time, which in turn reduces the construction time. Its environmental friendly production as well as the above mentioned physical properties of the Agrostone panel makes it better building materials than the conventional materials.

Agrostone panels had been patented for internal partition and non-loading walls use. However, it has been used for external walls in number housing projects in Addis Ababa by treating with different finishing materials to protect from moisture attack. As the water absorption test carried out at MRTC reveled, the Agrostone panels are poor to resist water. Hence, it requires careful surface water resistance treatment in order to use it as an external wall. This incurs additional costs.

The other observed problem is that metals become corrode when they are in contact with Agrostone panel. One of the causes for this is the unreacted chloride ions in MOC since the binding chemicals cannot be reacted completely if the mix proportion is not correct enough.

VII. Future Work

The Country has huge reserves of natural minerals and various types of agricultural wastes which can be used as an alternative fillers, fibers and even binders. There are high possibilities to find better fillers and binders from these materials than the ones in Agrostone panel. Hence, further research has to be conducted in several materials including those that are used in the production of Agrostone panel. The research findings will help to alleviate the observed problems of the Agrostone panel as well as to reduce the production cost further while improving the physical and mechanical properties of the panel. For instance, the applicability of the Agrostone panel for external wall has to be investigated in detail before it is widely used in many housing projects. Applicability of other agricultural wastes such as coffee and rice husks with other natural minerals has to be tested and evaluated. Availability of agricultural wastes like rice husk will increase in Ethiopia as the government is working on increasing rice production. Ethiopia has produced 887,402 tone of rice by 2010 which was 57 times higher than the production of 2005 [13]. It is possible to get about 20Kg of rice husk out of 100 Kg of rice [14]. Rice husk in the form of ash has been used as supplementary cementations materials due to its pozzolanic effect. MRTC will utilize rice husk with other natural pozzolanic minerals for further study. Various matrixes will be prepared and tested. The test results will be analyzed and then the best matrix which improves the physical and mechanical properties of the existing Agrostone panel will be identified. Also their overall cost implication will be studied.

VIII. CONCLUSION

Agrostone panel is an alternative low-cost eco-friendly building material which mainly uses agricultural/industrial wastes and/or natural minerals as raw materials. It reduces the cost of wall construction significantly while attaining the desired physical and mechanical properties. Comprehensive and flexural strength tests were conducted and presented in this work. Both test values confirmed that the Agrostone panel attained good strength. In addition, water absorption test was performed and the result shows poor water resistance of the panel. Hence, further research is needed to improve the properties of Agrostone panel as well as to further reduce the cost. One direction of the future research is finding alternative raw materials that can complement the existing materials.

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