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Conference Paper · December 2020

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Soil as an innovative sustainable flooring material

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Abstract— The natural material, earth, has been used in the construction industry for thousands of years. There is a great deal of research worldwide, including in Sri Lanka, related to earth as a construction material. Therefore, earth used as a flooring material has been investigated and according to the results obtained in previous studies, it was identified that earth can be used for this purpose. However, there is a need to investigate the requirement of a wash coat and identify a suitable material to surface finish, matching with the service requirement of the floor finish. Hence, this study was focused to have a better understanding of the possibility to use synthetic resin as a surface coating for soil flooring. This paper presents the preliminary experimental results to introduce the top surface finishing layer for the soil floor. Soil floor samples were cast according to the mix design identified for soil flooring in previous research. Novolac resin and Hexamethylenetetramine (HMTA) hardener were used to prepare the surface coating. Samples were tested for several aspects. According to the primary experimental results, it can be concluded that there is a possibility to use this resin as the top surface coating for soil flooring material.

Keywords— *sustainable construction, Stabilized soil, synthetic resin, flooring materials,*

I. INTRODUCTION

Unlike other species, who seek a balance with nature, humans are concerned only with immediate satisfaction of their "needs," even though, that may cause the collapse of the ecosystem of which they are an integral part. At present, unplanned development carried out continuously, due to these unlimited needs, has a tremendous undesirable effect on the environment and ecosystem. Among several industries, the construction industry is one of the largest and most active industries. This industry has a highly unfavorable effect on the environment due to carbon dioxide emissions, a large amount of raw material consumption, etc., clearly resulting in an unsustainable situation. The projected increase in the world's population and their needs, in terms of buildings, will further escalate the consumption of non-renewable materials and the emission of greenhouse gases, as well as accumulation of wastes [1, 2].

Therefore, the continuous on-going urban growth is causing a search for sustainable, low-cost housing delivery systems to fulfill these demands for low-income groups in developing countries [3]. Within this context construction materials and construction techniques are very important towards more sustainable construction and development [2].

However, there are many factors to be considered when introducing sustainable construction systems. Household

financial limitations, together with a lack of support and knowledge, is the most significant factor to introduce and invent appropriate sustainable housing solutions. Further, it is important to support and promote sustainable housing for small housing cooperatives and individual householders who build and renovate their houses. Therefore, researchers or engineers need to invent environmentally-friendly construction materials, techniques, and new technologies, using existing local resources in order to reduce negative impacts on the environment. The innovation of any construction material or techniques should be done by considering several aspects, such as the use of renewable local raw materials, maintaining quality, cost, and suitability of building materials, as well as social aspects such as health and happiness of the residents.

When considering building construction, the floor in a building is the main and also the most frequently used part of a building. At present, there are several conventional floor finishing materials, such as ceramic tile, terrazzo, marble, vinyl, etc. in Sri Lanka as well as worldwide. Most of these, conventional floor finishing materials are not produced in sustainable ways. The production and transport of such materials lead to relatively high levels of environmental pollution, high embodied energy, high initial cost, etc. However, there are some sustainable construction materials such as bamboo and wood, as well as earth and adobe blocks that can be used in some parts of a building. They create local employment and promote local craftsmanship, which can be truly sustainable. These materials and new technologies based on traditional building methods can be developed for the construction of housing, and at the same time they are sustainable and affordable for the urban-poor communities, especially in developing countries.

The use of sustainable and locally suitable building materials, such as bamboo, wood, compressed earth blocks, and adobe blocks can be very promising with regard to sustainability. As a result, this century has witnessed several remarkable achievements in sustainable construction through the development of construction materials that have less harmful effects on the environment, less demand for non-renewable resources, etc. while managing its required properties, maximum user-friendliness, and comfortability. Among several such materials, soil can be considered as the most suitable construction material with respect to the environment, because earth has low embodied energy for its manufacturing method, and also zero embodied energy for being raw material, if earth and only earth is used [4].

Traditional building materials such as loam and adobe can be used in new ways, such as with uniform rectangular Compressed Earth Blocks (CEB) and the Interlocking Stabilized Soil Block (ISSB) system. In both systems, the use of cement is minimized. As a professional mix-preparation is necessary, field and laboratory tests, and training of the labour force is required [5]. However, appropriate earth technologies are being used in many countries including Sri Lanka. Walls made from CEB have excellent thermal performance, reducing heating and cooling costs. If properly constructed, buildings made with CEB can be sustainable and durable. This implies that technological improvements can be used on a small-scale and at the local level, potentially contributing to the construction industry [6, 7].

There is more evidence to prove that the soil as a natural material, has been used in the construction industry from ancient times. Numerous studies are being done by many researchers worldwide as well in Sri Lanka, to upgrade the use of soil as a construction material [8-11]. Soil properties, such as tensile strength, shear strength, etc., that are strongly dependent on the environmental conditions, should be improved before soil is used as a construction material. According to the literature, soil properties can be improved by stabilizing them chemically or mechanically [12].

In the last decade, more research articles related to earth construction have been published mostly related to rammed earth, and it is a considerable increase compared to the research articles published in the 1990s concerning earth construction. This means more and more research efforts are being dedicated to transform the current building industry towards a more sustainable entity. Earth construction encompasses several techniques such as the wattle and daub, cob, rammed earth, earth bricks (adobe) and compressed earth blocks (CEB). There are many important aspects related to earth construction such as economic advantages, use of renewable resources, low waste generation, reduced energy consumption, carbon dioxide emission, and toxicity, and improved indoor air quality [6, 13].

Mud concrete is a newly invented earth construction technique aimed at addressing the drawbacks of cement concrete, which is commonly used in the construction industry. Currently, mud concrete is used as a sustainable low-cost construction material in indoor constructions as well as outdoor constructions [10, 11].

Among several ancient earth constructions, the earthen floor is an ancient flooring technique that has been revived and modernized in recent years. Earthen floors are made of natural materials that can be sourced locally (gravel, laterite, sand, clay and water). Once the floor covering is assessed with respect to its environmental impact, various aspects of the impact should be considered, such as the depletion of raw materials, cumulative energy requirement, global warming, acidification, tropospheric ozone creation, stratospheric ozone depletion, eutrophication, production of waste and human health [14 -16].

This research was focused to improve the service and durability characteristics of soil flooring material, which is made out of earth stabilized with cement [17]. This paper represents the experimental results obtained to introduce a top surface coating for the soil-based flooring material to meet the service and durability characteristics. The specific

objective of this study is to identify the surface coating for soil flooring.

For the appropriate treatment for the protection of the top surface to achieve the proper service requirement, it is necessary to identify the most suitable surface coating with respect to sustainability, while preserving the aesthetic beauty of mud concrete as much as possible; cost-effectiveness also must be considered. Several important requirements must be fulfilled when selecting the appropriate coating, such as the bonding capacity of the coating with the mud concrete, water absorption, slip resistance, wear resistances, etc. As an approach, among several resins, one synthetic resin [18-21] was selected and applied on top of mud concrete floor samples to investigate the possibility to have smooth durable surface finishes.

II. METHOD

A. Floor base preparation

The previous studies have identified that natural soil can be stabilized with a lesser amount of cement and used as a construction material, named mud concrete [9, 13]. The preliminary studies have identified that natural soil can be used as a floor finishing material. A series of experiments were conducted and a mix design was identified that allows natural soil to be used as flooring material by stabilizing with a lesser amount of cement [17]. Based on these data, this experiment was carried out at the laboratories in the University of Moratuwa.

The required soil was extracted from the university premises, and the extracted soil was analyzed to identify its composition by performing the sieve analysis. Then the extracted soil was determined to have gravel (sieve size $4.75 \text{ mm} \leq \text{gravel} \leq 20 \text{ mm}$) 35%, sand (sieve size $0.425 \text{ mm} \leq \text{sand} \leq 4.75 \text{ mm}$) 60% and fine particles (sieve size $\leq 0.425 \text{ mm}$) 5%. The maximum gravel size used in all mixes were 20 mm, which was identified as the best proportion for mud concrete in previous research [9]. The samples were casted with 18% cement; ordinary Portland cement was used as a stabilizer in all mixes. According to the selected mix proportion concluded in the preliminary studies, the soil floor samples were cast first. Steel moulds in size 150 mm x 150 mm x 50 mm. were used to cast the floor samples. Material preparation, mixing, and casting procedures were described in a previous study [17]. After 24 hrs from the casting, samples were de-moulded and cured under the same conditions. The mud concrete preparation process was shown in Fig. 1 and Fig. 2 showed the prepared soil floor samples and cubical samples.

After seven days from casting all the floor samples were ground using a grinder to smoothen the top surface. Fig. 3 showed the floor samples after being ground and sandpapered. After 28 days of curing, the cubes were tested for compressive strength.

In addition, three standard test cubes (150 mm x 150 mm x 150 mm) were cast using the steel mould to determine the compressive strength and three samples were oven-dried at constant temperature (105 °C) for 24 hrs. to calculate the moisture content of the mix.



Fig. 1. Mud concrete preparation process



Fig. 2. Prepared floor sample and cubical samples

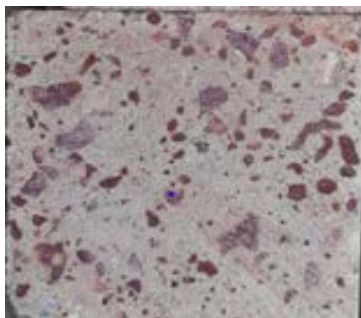


Fig. 3. Floor sample after ground and sandpapered

B. Surface preparation for the top finishing layer

The prepared floor samples were further smoothed by applying clay cement plaster. The clay in size < 0.425 mm was prepared by sieving the soil by a 0.425 mm sieve. Then the clay was mixed with cement in several cement : clay ratios. The clay and cement were mixed thoroughly in dry conditions and then water was added little by a little while mixing thoroughly. Fig. 4 showed the prepared clay cement mix and application process.



Fig. 4. Prepared clay cement mix and application process

Clay plaster was applied in two layers. The first layer was applied and kept 24 hr. in a moist condition for hardening the surface. Then the surface was sandpapered by using No. 180 water sandpaper. Next, same clay cement putty mix was applied as the second layer. After 24 hrs., the second layer was sandpapered by using No. 400 sandpaper. Then The prepared soil floor sample is ready to apply the top finishing layer. Fig. 5 showed the prepared floor samples for the application of the top surface finishing layer.



Fig. 5. Prepared floor samples for application of top surface layer after applying clay plaster

C. Application of finishing layer

1) Materials used: Resin and Hardener

Phenol-formaldehyde novolac resin (commercial novolac resin) of golden colour, as shown in Fig. 6 (a), was selected for initial testing to apply as a top surface coating on the flooring. Hexamethylenetetramine, shown in Fig. 6 (b), was used as an external curing agent. Novolac resin was dissolved in industrial-grade acetone to apply on the floor samples.

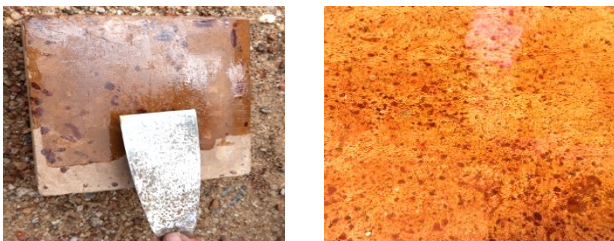
(a) Novolac Resin (b) Hexamethylenetetramine



Fig. 6. Novolac resin and Hexamethylenetetramine

2) Application on the floor sample

Prepared floor samples were cleaned by washing and drying. Then the novolac resin dissolved with industrial-grade acetone was mixed with HMTA in different ratios by weight. The ratios were resin:HMTE 1:4, 1:6, and 1:8. The resin mix was applied evenly over the floor samples using a scraper as shown in Fig. 7 (a) and allowed to air dry. The air-dried floor sample was shown in Fig. 7(b).



(a) Resin Application (b) Air-dried sample

Fig. 7. Novolac resin and Hexamethylenetetramine application

After the surface was dry, the samples were heated using an LP gas flame. Fig. 8 below showed the burning process. Then the samples were sandpapered by No. 1000 sandpaper for smoothing the surface. Next, the same resin mix was applied as the second layer and heated again. The same procedure was applied for resin application and burning for the second layer. This second layer was washed with a tile cleaner liquid. Fig. 9 showed the final surface appearance of the soil flooring.

D. Determination of Compressive strength

To determine the compressive strength, axial compressive strength tests were carried out in accordance with the BSEN 12390-3:2009. An axial compressive load was applied using a universal compressive strength testing machine with a capacity of 2000 kN under a constant rate of 6.8 kN/s until the failure of the specimen. Fig. 10 showed the cube specimen's testing.



Fig. 8. Heating process



Fig. 9. Mud concrete floor final product



Fig. 10. Compressive strength test procedure

III. RESULTS AND DISCUSSION

The soil-based floor consists of basically three main layers of filler, plaster and washed coat. The filler is having the mud concrete made out of the soil (Gravel 35%, sand 60%, and fine particles 5%) stabilized with 18-20% cement. The thickness of the filler is 75 mm. Moisture percentage was observed as 18%-20%. The compressive strength of mud concrete was 12-15 kN/mm². The compressive strength variation with the cement content is shown in Fig. 11.

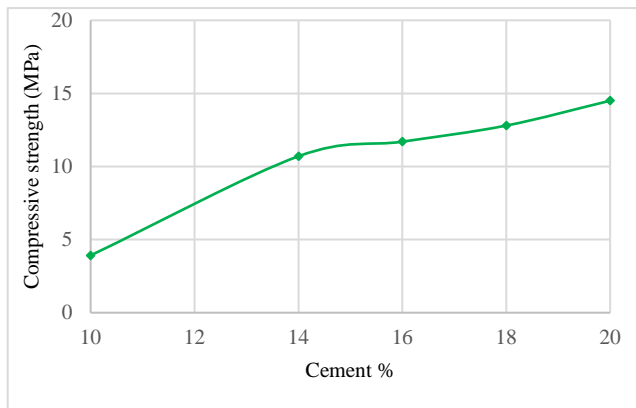


Fig. 11. Compressive strength variation with cement %

The suitable mix proportion for plaster was observed as a 1:2 cement : clay ratio and it should be applied in two coats. The finished top surface (wash coat) with two coats of synthetic resin showed a good esthetic appearance. Further, the floor surface was smooth.

IV. CONCLUSIONS

According to these experimental results, it can be concluded that the soil can be used as a flooring material and resin can be used as a top surface finishing layer. Therefore, the developed soil-based floor finishing construction system will be an innovation to meet sustainable construction with several positive characteristics. Further, production of soil flooring involved a fully manual process hence, energy consumption and waste generation were minimum.

However, further studies are required to determine the properties of the finished top layer under the service conditions and durability requirements. Because the floor of a building normally undergoes a continuous wearing process due to the cleaning with water and/or chemicals.

Finally, a life cycle assessment to be carried out to compare this mud concrete flooring system with the existing flooring materials with respect to sustainability.

ACKNOWLEDGMENT

The authors would like to especially acknowledge Mr. Raveendra Tennakoon (Director Strategic-Initiatives, Mixing Division), Mr. Rupasinghe Perera (Logistic Senior Manager, Mixing and Operational Excellence) and Mr. Ishanth Sameera (RCM Senior Manager, Central Engineering Division) in Camso Loadstar (Pvt.) Ltd. for providing valuable assistance to successfully complete this studies. The authors also would like to acknowledge the support given by Mr. H.T.R.M. Thanthirige, (Technical officer, Building Materials Laboratory), Mr. D.M.N.L. Dissanayaka, (Technical officer, Structural Testing Laboratory), and Mrs. W.B.U. Rukma, (Technical Officer, Construction Management Division) University of Moratuwa, Sri Lanka.

REFERENCES

[1] J. C. Morel, A. Mesbah, M. Oggero, and P. Walker, "Building houses with local materials: means to drastically reduce the environmental

impact of construction," *Build. Environ.*, vol. 36, no. 10, pp. 1119–1126, Dec. 2001, doi: 10.1016/S0360-1323(00)00054-8.

[2] F. Pacheco-Torgal and S. Jalali, "Earth construction: Lessons from the past for future eco-efficient construction," *Constr. Build. Mater.*, vol. 29, pp. 512–519, Apr. 2012, doi: 10.1016/j.conbuildmat.2011.10.054.

[3] J. Bredenoord, "Sustainable Housing and Building Materials for Low-income Households," *J. Archit. Eng. Technol.*, vol. 05, no. 01, 2015, doi: 10.4172/2168-9717.1000158.

[4] M. C. Jiménez Delgado and I. C. Guerrero, "The selection of soils for unstabilised earth building: A normative review," *Constr. Build. Mater.*, vol. 21, no. 2, pp. 237–251, Feb. 2007, doi: 10.1016/j.conbuildmat.2005.08.006.

[5] A. A. Raheem, O. A. Bello, and O. A. Makinde, "A comparative study of cement and lime stabilized lateritic interlocking blocks," *Pac. J. Sci. Technol.*, vol. 11, no. 2, pp. 27–34, 2010.

[6] S. Deboucha and R. Hashim, "A review on bricks and stabilized compressed earth blocks," *Sci. Res. Essays*, vol. 6, no. 3, pp. 499–506, Feb. 2011, doi: 10.5897/SRE09.356.

[7] J.-C. Morel, A. Pkla, and P. Walker, "Compressive strength testing of compressed earth blocks," *Constr. Build. Mater.*, vol. 21, no. 2, pp. 303–309, 2007.

[8] J. Khedari, P. Watsanasathaporn, and J. Hirunlabh, "Development of fibre-based soil-cement block with low thermal conductivity," *Cem. Concr. Compos.*, vol. 27, no. 1, pp. 111–116, Jan. 2005, doi: 10.1016/j.cemconcomp.2004.02.042.

[9] A. L. B. Design, "Design and Construction of Mechanically Stabilized Earth Walls and Reinforced Soil Slopes–Volume II," 2009.

[10] C. Udawattha, H. Galabada, and R. Halwatura, "Mud concrete paving block for pedestrian pavements," *Case Stud. Constr. Mater.*, vol. 7, no. Supplement C, pp. 249–262, Dec. 2017, doi: 10.1016/j.cscm.2017.08.005.

[11] F. R. Arooz, A. Ranasinghe, and R. U. Halwatura, "Mud-concrete block construction community centre for war victims communities in Batticaloa Sri Lanka," *Mak. Built Environ. Responsive*, vol. 2015, pp. 1–14, 2015.

[12] A. Guettala, A. Abibsi, and H. Houari, "Durability study of stabilized earth concrete under both laboratory and climatic conditions exposure," *Constr. Build. Mater.*, vol. 20, no. 3, pp. 119–127, Apr. 2006, doi: 10.1016/j.conbuildmat.2005.02.001.

[13] K. Heathcote, "Compressive strength of cement stabilized pressed earth blocks: Strength of cement stabilized pressed earth blocks depends on cement content and compacted density — simple formula presented to predict strength based on variables," *Build. Res. Inf.*, vol. 19, no. 2, pp. 101–105, Mar. 1991, doi: 10.1080/09613219108727106.

[14] J. Potting and K. Blok, "Life-cycle assessment of four types of floor covering," *J. Clean. Prod.*, vol. 3, no. 4, pp. 201–213, Jan. 1995, doi: 10.1016/0959-6526(95)00082-8.

[15] G. M. Birkhauser, "Building with Earth: Design and Technology of a Sustainable Architecture," p. 198.

[16] L. A. Wolfskill *et al.*, "Handbook for Building Homes of Earth. Appropriate Technologies for Development. Reprint R-34.," 1981, Accessed: Jan. 03, 2017. [Online]. Available: <http://eric.ed.gov/?id=ED242877>.

[17] H. Galabada and R. U. Halwatura, "A preliminary study on the use of soil as a floor finishing material," in *2019 From Innovation to Impact (FITI)*, Nov. 2019, pp. 1–4, doi: 10.1109/FIT149428.2019.9037635.

[18] M. Asim, N. Saba, M. Jawaid, M. Nasir, M. Pervaiz, and O. Y. Alothman, "A Review on Phenolic Resin and its Composites," *Curr. Anal. Chem.*, vol. 14, no. 3, pp. 185–197, May 2018, doi: 10.2174/1573411013666171003154410.

[19] R. Burns and E. W. Orrell, "A thermal analytical study of phenol formaldehyde resins," *J. Mater. Sci.*, vol. 2, no. 1, pp. 72–77, Jan. 1967, doi: 10.1007/BF00550054.

[20] "Chemistry of Novolac/Furfuryl Alcohol Resins Cured with Hexamethylenetetramine: A Solid-State NMR Study | Chemistry of Materials." <https://pubs.acs.org/doi/abs/10.1021/cm9800175> (accessed Aug. 13, 2020).

[21] M. I. Aranguren, J. Borrajo, and R. J. J. Williams, "Some aspects of curing novolac with hexamethylenetetramine," *J. Polym. Sci. Polym. Chem. Ed.*, vol. 20, no. 2, pp. 311–318, 1982, doi: 10.1002/pol.1982.170200205.