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ON SOIL STABILIZATION WITH ALGINATE AND WOOL FOR CONSTRUCTION INDUSTRY

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Abstract: This paper highlights the importance of traditional and renewable materials to a more sustainable built environment. It reports on research into properties of clay-based composite building material stabilised with alginate and wool, carried out in collaboration between University of Strathclyde and University of Seville.

Keywords: *clay-based composite, polymer, fibre, sustainable, locally sourced.*

1 Introduction

Building with earth dates back to the earliest forms of human dwellings and settlements. In the animal world, species such as termites build their sophisticated nests by combining polymer from their natural secretions with soil. Imagine if humans could have at their disposal a building material that has all the properties of one that termites use for their nest-building. We imagined just that and combined a natural polymer derived from seaweed, with wool of hardy Scottish sheep and with local soil. Our aim was to capture essential, natural qualities of traditional materials through research into enhanced combinations of its components (alginate, wool, soil), all presently under-explored for their potential as building materials that respond environmentally, contain no synthetic toxins, and present desirable aesthetics that may be employed through conventional as well as advanced technology and design.

This research has been envisaged as collaboration amongst material scientists, engineers and architects from the Universities of Strathclyde and Seville, and Centres for advancement of current ecological approaches to sustainable building materials and technologies. The feasibility study was conducted with the aim to explore the potential of our composite material to be used both structurally and for surface finishes. It is important to note that building with earth continues to be widespread in the less affluent parts of the world, typically in arid climatic zones, where people build their own dwellings with cheap, locally available materials. In recent times there has been a renewed interest in building with earth in the affluent countries throughout the world, as the ecological awareness grows among lay people as well as building professionals.

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2 Research Context and Objectives

Our particular interest lies in earth building for wet and temperate climatic zones such as those in UK and northern Europe. Our aim is to create an earth-based composite material which is responsive to climatic changes, yet resilient to water penetration and erosion and has no man-made pollutants added to it. Currently many approaches for earth stabilisation are based on mixing soil with cement, tar and synthetic sealers, all of which change soil's ability to act as a phase-change material and hence negate the natural qualities of traditional earth construction. Our composite material aims to retain all the intrinsic characteristics of natural earth, yet to have polymer and fibre reinforcement that is potentially relevant for prefabrication.

In this feasibility study we conducted experiments with number of alternatives (in terms of proportions) for mixing the components such as alginate, wool and three different soil types all sourced in Scotland. The cast and hardened mixes were tested in the material laboratories for their mechanical properties, in order to select the best mixes that we would use in future investigations of the environmental performance of such composites. The cast and hardened mixes were tested for their mechanical properties in the material laboratories, at the University of Seville.

3 Materials Used in the Composites

The materials used in our composites were as follows:

- **Alginate:** This is a type of natural polymer that is abundant in the cell walls of brown algae. Commercial varieties like the one we used are extracted from brown seaweed.
- **Wool**: The wool was used as added reinforcement in the composite. It was taken from Scottish Blackface Sheep and was used, untreated and straight from the animal's fleece. This meant that no artificial additives were introduced.
- **Lignum Sulfonate**: This treacle-like resin is extracted from tree bark, and is added to improve the workability of soil.
- **Soils (3):** Soils from Errol, Ibstock and Raeburn, were supplied by Scottish brick manufacturers. These soils had different colour, texture and particle sizes. We tested all three soil compositions and examined their bonding with alginate and wool.

3.1 Alginate

In our research we used alginate, a natural polymer, which is locally produced in Scotland and in particular the alginate paste which is a product of the first stage of extraction of algin from seaweed. Natural polymers are used in nature by both insects such as termites and by birds that mix their polymer secretions with soil to build their nests.

Macrocystis Pyrifera, the brown seaweed, which is a major source of algin, has growth characteristics that make it an ideal raw material for environmentally sensitive harvesting. Macrosystis is a perennial plant and thus can be harvested on a continuing basis; its rapid growth permits up to four cuttings per year. Brown seaweed, which is processed in Girvan plant on the West Coast of Scotland, is harvested off the coasts of Iceland and Tasmania. Previously their supply used to be harvested off the coast of Ireland.

In the seaweed, the algin is present as a mixed sodium and/or potassium, calcium and magnesium salt. It is possible to extract sodium alginate from seaweed with a strong solution of a sodium salt.

Alginate as a bio-polymer derived from seaweed, is a natural polysaccharide consisting of a linear chain of (1-4)-linked residues ß-D-mannuronic acid (M) and αL guluronic acid (G) in different proportions and sequential arrangements (Ouverx 1998). The biological functions of alginates in a seaweed include preventing dessication, maintaining the integrity of the cells and providing mechanical strength. Ion-exchange functions are also important. Alginic acid from various brown algae contains three kinds of polymer segments. It has been shown, using spectroscopy and computer modelling, that alginic acid salts, such as sodium alginate, in aqueous solution are highly hydrated polyelectrolytes in the extended ribbon conformation.

Effectively, as alginates are polyelectrolytes, the selective binding of certain alkaline earth metal multivalent cations as Ca2+ lead to gel formation. The high selectivity between similar ions from the alkaline earth metals (in the order Mg < Ca < Sr < Ba) is explained by the structural features of the Block GG where ions take place by chelation. This phenomenon, called “egg-box” model, suggests a possible binding site for Ca2+ ions in a single alginate chain (Grant et al. 1973).

Alginates are used in a wide range of applications, particularly in the food, industrial and pharmaceutical fields, because of their capacity to hold water, form gels, and form and stabilize emulsions (McLachlan 1985). One of the most important and useful properties of alginates is the ability to form gels by reaction with calcium salts. These gels, which resemble a solid in retaining their shape and resisting stress, consist of almost 100% water (normally, 99.0–99.5% water and 0.5–1.0% alginate).

Alginate is also used in calcium phosphate cements for implanting of prostheses (bones and teeth). In this instance alginate is added to improve the setting behaviour, the consistency and the mechanical properties of these bio-cements. Friedemann et al. (2006) tested the use of alginate in building materials. They obtained excellent results when they used alginate for internal post-curing of concrete with respect to compressive strength and to its frost de-icing salt resistance in high performance concretes. Alginate was tested for its water-retention properties in post-curing and on temporal moisture requirements of cement during hydration period.

Alginates, in common with other hydrophilic polysaccharides, absorb moisture. Sodium alginates with some residual calcium content start to gel at pH of 5. Sodium alginates with minimum calcium content do not gel until the pH reaches 3 to 4. In chemical reaction with calcium or magnesium alginate forms water-insoluble, three-dimensional matrix that can act as reinforcement. Alginate used in our research, was supplied by FMC BioPolymer, Girvan, Scotland (UK), under the name *seaweed extract*, containing sodium alginate, sodium carbonate, and inorganic salt.

3.2 Wool

Wool - a natural animal fibre – is available in abundance in Scotland, but it is no longer widely used in textile industry and carpet manufacture. In our mixes we tested the feasibility of using these animal fibres in conjunction with a soil matrix to produce composite material suitable for the local climatic conditions. Our specimens have been prepared with an addition of a small amount (0.5-0.25%) of animal fibre (raw, unprocessed wool). Wool supplied directly from Scottish Blackface Sheep was used, untreated and straight from fleece. This breed of sheep was locally available and appropriate for our experiment since all our materials were locally sourced in Scotland. Our feasibility study of the natural, non-toxic and locally sourced composite material, was supported by one year funding from the Scottish Government via SUST initiative.

Scottish Blackface Sheep is one of the most important breeds in the British Isles. Some thirty percent of all sheep in the UK are Scottish Blackface. The Blackface epitomizes the mountain sheep. It has long coarse wool that shields it from water and biting winds. It is able to survive the harshest winters in the most extreme parts of Great Britain. Blackface wool has a robust resilience, which resists high-pressure footfall and is highly retardant to fire without any need for additional treatments.

3.3 Lignum Sulfonate

In our mixes we used 0.5% of Lignum Sulfonate (under name of Additive A, Traffaid 45), a treacle-like resin extracted from wood that was added as dispersing agent (to improve the workability of the soil), as recommended by the Errol brick manufacturer. Lignin is the binding agent in wood and is extracted during the production of cellulose. Lignosulfonate and lignin products are thus based on a natural raw material. Lignum Sulfonate, used in our experiments, was supplied by Borregaard LignoTech, which specialises in wood-based chemicals.

3.4 Soils

Any soil is a mixture of mineral particles (solids), air and water, and is defined by parameters such as Atterberg Limits (measurement of plasticity), clay content and chemical composition.

The three soils, which we used in our experiments, were supplied by Scottish brick manufacturers, namely Errol (from Perthshire), Ibstock (from Glasgow), and Raeburn (from Glasgow). All three soil samples were dried and sieved before they were used in the mixes. Alluvial soil from Tay estuary (on the East Coast of Scotland) has been used by Errol to manufacture unfired and fired bricks since 1850. Local Errol bricks have been made from estuarine clays laid down in the carse after the last Ice Age. Both Ibstock and Raburn brick manufacturers, based in Glasgow, have used soils sourced in the West of Scotland to manufacture fired bricks only.

Physical Characteristics. Clay, (like cement in concrete), acts as a binder for all larger particles in the soil. Silt and sand constitute the filters in the soil and they are simply aggregates lacking binding forces. Depending on which of the three components is dominant, we speak of a clayey, silty and sandy soil. *Errol* soil is classified as clayey as it has significantly higher clay content than *Ibstock* and *Raburn* soils. *Ibstock* soil is classified as silty-sandy and *Raburn* soil is classified as sandy. (Table 1)

Plasticity of each soil type is defined by Atterberg Limits. Any soil can have four states of consistency: liquid, plastic, semisolid and solid. The limits of these states were defined by the Swedish scientist Atterberg. The liquid limit (LL) defines water content at the boundary between liquid and plastic states. It is expressed as a percentage. The plastic limit (PL) is the water content, expressed as a percentage, at the boundary between plastic and semisolid states. The difference between the liquid limit and the plastic limit is called the plasticity index (PI). After the results of soil tests were compared, we realised that the three soils showed a remarkable variation in their index of plasticity (Table 2). The parameters obtained during the tests of the Atterberg Limits explain the difference in behaviour of the *Errol* soil compared with *Ibstock* and *Raeburn* soils. The drier *Errol* soil has significantly higher plasticity index.

Chemical Composition. We observed higher content of Calcium and Magnesium Oxide in *Errol* soil compared with two other soil types. (Table 4)

Table 1: Physical characteristics of the three soils

Physical Characteristics	ERROL	IBSTOCK	RAEBURN
Sand Content	22,50%	27,50%	35,00%
Silt Content	45,00%	47,50%	40,00%
Clay Content	32,00%	25,00%	25,00%
Classification of Soil	Clayey	Silty-Sandy	Sandy

Table 3: Plasticity and liquid limit based on Atterberg tests

CHARACTERISTICS	IBSTOCK	ERROL	RAEBURN
LIQUID LIMIT	25,9%	34,8%	25,9%
PLASTIC LIMIT	16,4%	19,1%	16,8%
PLASTICITY INDEX	9,5%	15,7%	9,1%

Table 4: Chemical composition of three soils (samples dried at 110ºC)

Composition (%)	ERROL	IBSTOCK	RAEBURN
Silicon Dioxide (SiO_2)	54.70	62.83	60.32
Titanium Dioxide (TiO_2)	0.97	0.98	0.96
Aluminium Oxide (Al_2O_3)	19.70	18.49	18.30
Ferric Oxide (Fe_2O_3)	8.63	5.93	5.87
Calcium Oxide (CaO)	0.93	0.38	0.32
Magnesium Oxide (MgO)	3.55	1.86	1.81
Potasium Oxide (K_2O)	3.90	3.41	3.47
Sodium Oxide (Na_2O)	1.78	0.38	0.45
Phosphorus Pentoxide (P_2O_5)	0.17	0.12	0.13
Chromium Sesquioxide (Cr_2O_3)	0.02	0.01	0.01
Manganese Oxide (Mn_3O_4)	0.12	0.07	0.06
Zirconium Oxide (ZrO_2)	0.03	0.05	0.05
Zinc Oxide (ZnO)	0.03	0.01	0.01
Barium Oxide (BaO)	0.08	0.06	0.04
Strontium Oxide (SrO)	0.00	0.01	0.00
Loss on ignition at 1025 ºC	5.04	5.57	5.53

4 Preparation of Composite Material Specimens

Before the specimens were prepared, the ingredients were collected and weighed, and all the measurements were done precisely using a scale. For the reasons of efficiency we collected all the weighed ingredients such as Alginate in 880.0gr bottles, Lignum Sulfonate in 22.5gr test tubes and the Soil in bags weighing 3577.5gr before we started producing the specimens. The wool was hand-cut, by trimming the top 1cm strand of hair as any longer would be too long to create a homogenous mix.

Once preparations were completed, the ingredients were placed in a metallic bucket and put into a mortar-mixing machine, thus assuring that each batch had consistently mixed ingredients, giving more homogeneity to the specimens. The mixtures were then compacted into sample trays, measuring 40x40x160mm, before being placed in an Oven at 50°C to dry.

Table 5: Proportions used (in weight)

Proportion	Soil	Alginate	Lignum	Wool	Water
01ERROL	80.0% Errol	-	0.5%	-	19.5%
02ERROL	79.5% Errol	19.75%	0.5%	-	0.25%
03ERROL	79.5% Errol	-	0.5%	0.25%	19.75%
04ERROL	79.0% Errol	19.5%	0.5%	0.50%	0.50%
05ERROL	79.5% Errol	19.5%	0.5%	0.25%	0.25%

To test the mechanical properties of the composite material we prepared the prismatic specimens, using standard moulds, machine mixing and hand compacted (no extra compression was added) and the facilities available in the laboratories of the Escuela Técnica Superior de Arquitectura in Sevilla, Spain. The proportions that were used in composite mixes were the same as ones used for the specimens prepared in the University of Strathclyde, Glasgow.

Table 6: Density and mechanical tests of the five different mixes of the three tipes of soils

	Mix	Density Kg/m^3	Compressive strength MPa	Flexural Strength MPa
ERROL SOIL	ERROL 01	1.820	2,23	1,12
	ERROL 02	1.840	3,77	1,06
	ERROL 03	1.800	3,05	1,10
	ERROL 04	1.790	4,37	1,05
	ERROL 05	1.790	4,44	1,45
IBSTOCK SOIL	IBSTOCK 01	1.880	2,06	0,97
	IBSTOCK 02	1.800	2,50	0,98
	IBSTOCK 03	1.820	1,89	0,96
	IBSTOCK 04	1.790	3,43	1,28
	IBSTOCK 05	1.780	3,59	1,60
RAEBURN SOIL	RAEBURN 01	1.850	2,44	1,12
	RAEBURN 02	1.750	2,26	1,14
	RAEBURN 03	1.840	1,88	0,93
	RAEBURN 04	1.740	2,69	1,02
	RAEBURN 05	1.800	3,75	1,24

5 Testing of Composite Material Specimens

To test the influence of addition of three different elements into the mix, the five different proportions of these ingredients used with each soil type were named and listed (Table 5). Before adding either alginate and/or wool, the initial tests were carried out on the blank specimens, made with soil, water and lignum sulfonate only. In subsequent mixes, wool and/or alginate were added and two different proportions of wool fibre (0.5% and 0.25% respectively) were tried respectively, as shown in Table 5. The cast and hardened mixes were tested for their mechanical properties. Tests deployed were density, bending strength and compressive strength.

Density remained very similar in all the tested samples. Blank samples with soil only generally have the highest density. When alginate and/or wool were added, density decreased, but not significantly.

Bending strength was determined by using the three-point test on the specimens, in agreement with the specifications of EN 83-821-925 Spanish standards for the determination of bending strength of mortars used for rough castings and mortar linings, and in the absence of UNE standards for this type of mortars.

Compressive strength was determined in both halves of each prismatic specimen, after breaking them in a three point bending test strength test. The apparatus used was a Codein S.L., MCO-30/139 compression tester. This test complies with the EN 83-821-925 Spanish standards for the determination of compressive strengths in mortars used for rough castings and mortar linings, being made with lime or hydraulic conglomerate, in the absence of specific UNE standards for this type of mortars. In agreement with the specifications, the charge velocity used was 0,5 MPa/s.

Table 6 show average values of results for the compressive and three-point bending test for all three soil types used in the production of test samples. Note that the same procedure was repeated for all the three soil types tested in our laboratory. Each value represents the average of a total of 7-14 specimens. The number and series of specimens were according to these standards and depending on the number of different mixes (proportions) tested, with a minimum of five specimens per batch.

6 Discussion of the Results

Comparison of Compressive Strength test results shows that adding alginate increases compressive strength only for Errol soil. Ibstock and Raeburn soils show similar results with and without alginate. Adding just wool increases compressive strength only for Errol soil. In fact compressive strengths of Raeburn and Ibstock soils decrease slightly when only wool fibres are added to them. Adding wool and alginate improves significantly – doubles - compressive strength of Errol soil. Better results were obtained with reduced quantity of wool (0.25%). With addition of wool and alginate Ibstock soil specimens improve their compressive strength from 2,0 MPa to 3.5MPa, while Raeburn soil specimens improve their compressive strength from 2.4MPa to 3.75 MPa. So, the best results are obtained with less wool, while wool without alginate (most likely due to its hard workability) does not improve compressive strength.

Comparison of Flexural Strength test results shows that adding only alginate or only wool, without combining them, does not improve flexural resistance at all. Adding wool and alginate increases flexural resistance only when 0.25% of wool is added, but the increase is not significant, except in Ibstock soil specimens, where flexural resistance changes from 0.97MPa to 1.60MPa.

7 Conclusions and Future Directions

One of the significant effects of the inclusion of natural fibres in the soil matrix was the prevention of visible shrinkage cracks due to the drying process. The failure mode of the specimen made with soil and water only was very quick and almost without warning. In contrast, in the case of a composite which contained fibres, after the ultimate load was reached, the specimens still deformed and fine cracks could be seen on the surface. This was the case for all the composite material specimens.

It can be observed that the stress-strain relationship is linear for all the test series up to maximum load. For the specimens made with soil only, the final failure occurs immediately after the ultimate load. However, in tests on soil with natural fibres, softening can be seen. This may be explained by considering the redistribution of internal forces from the soil matrix to the reinforcing fibres. After final failure, the soil-fibre composite did not disintegrate completely in contrast with soil-only specimens. Also it must be mentioned that both alginate and fibres hold soil matrix together and no rupture of fibres occurred although a loss of fibre bond was observed. The bonding between the soil and the wool fibres will be examined in the future research at the microstructure level to establish the factors that influence this. Density remained very similar in all the tests. Blank samples, made with soil and water only, have the highest density. When adding alginate or wool, density decreases but not significantly.

Tests showed that adding alginate increases compression strength and adding only wool also increases compression strength. But the addition of both, wool and alginate improves quite significantly (doubles) Errol soil resistance. Better results were obtained with a lower quantity of wool. Test results have shown that for the Errol soil, the optimum wool/soil ratio, needed to produce a high-strength soil matrix, is just 0.25%.

As expected, adding alginate or wood alone does not improve flexural resistance at all. Mixing wool and alginate increases slightly flexural resistance only in case of 0.25% of wool, but not as significantly as with compression strength. There are sufficient di and trivalent cations, namely calcium, magnesium, aluminium and iron present in all three soil types to effect precipitation of the soluble sodium alginate in the paste extract to an insoluble salt form. In other words, alginate bonds with calcium and magnesium (from the soils) to form a water-insoluble three-dimensional matrix that adds reinforcement to the specimens. It is likely that the differences in compressive strength associated with the different soils, are more to do with soil composition (i.e. clay content). Alginate holds water very well during the curing period and clay needs water. The clayey soil has a lamellar structure of the various clay minerals with their internal electrical attraction, which is activated only by water and movement (Minke 2006).

In this phase of research, we introduced randomly wool fibres (10mm long) throughout the composite specimen. In the future we will investigate different fibre lengths in order to establish the optimum length for maximum strength. The effect of fibre orientation inside the matrix should also be studied. Furthermore, in order to understand better the bond between soil matrix and fibre, a study at the microstructure level is needed. At this stage, our research has focused on mechanical properties of polymer-stabilised earth. Further tests such as thermal conductivity, air permeability, moisture absorption and desorption and resistance to water are being developed at the moment in order to asses the composite material applicability to temperate climatic zones.

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9 References

FRIEDEMANN, K., STALLMACH, F., KÄRGER, F., 2006. NMR diffusion and relaxation studies during cement hydration—A non-destructive approach for clarification of the mechanism of internal post curing of cementitious materials. *Cement and Concrete Research,* 36, pp.817–826.

GRANT, G.T., MORRIS, E.R., REES, D.A., SMITH, P.J., THOM, D., 1973. Biological interactions between polysaccharides and divalent catons: The egg-box model. *FEBS Letters,* 32, pp.195-198.

MCLACHLAN, J., 1985. Macroalgae (seaweeds): industrial resources and their utilization. *Plant Soil*, 89, pp.137-57.

MINKE, G., 2006. *Building with Earth - Design and Technology of a Sustainable Architecture*. Birkhauser, Basel/Berlin.