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Sisal fibre reinforced soil with cement or cactus pulp in bahareque technique

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Abstract

In order to improve bahareque technique, sisal fibre reinforced soils were stabilised with cement or cactus pulp.

Bending, abrasion resistance, water absorption and erosion tests were performed and the results were compared with those obtained on the traditional plasters used in soil technologies.

The performance capabilities of sisal fibre reinforced soil stabilised with cement are better than those of cactus pulp stabilised soil. The use of cactus pulp as a stabilising agent to improve the behaviour of the soil, however, is very interesting because this is a natural, ecological material.

Keywords: Stabilised soil; Fibre; Cement; Cactus pulp

1. Introduction

An age-old building material—unbaked soil—is attracting fresh interest on account of its important features of compatibility with the environment and living comfort.

A delicate aspect to be taken into account when using soil as a building material is its sensitivity to water: though it can be controlled at the design stage, this factor continues to be a problem, in particular in low-cost housing units produced by self-help, which require higher tolerance margins.

Among the different building techniques that use unbaked soil, one that is used widely in tropical countries is the so-called 'bahareque' technique, which is similar to the 'wattle and daub' technique, that consists of applying by hand to a wooden or bamboo truss a mixture of soil reinforced with vegetal fibres and, possibly stabilising agents. The bond between the soil and the support is not very strong, but stability is ensured by the mechanical connection that is created between the soil and the truss.

This technique proves particularly interesting on account of the smaller quantities of soil employed and the possibilities afforded in terms of site organisation.

However, over time, the deformability of the support—which is often excessive in relation to the intrinsic properties of soil—determines the extensive crack opening and deterioration phenomena which make the housing unit decidedly unhealthy.

Accordingly, to improve this building technique it is necessary to limit the deformability of the supporting structure and, at the same time, to control the tensile strength of the soil mix which, being applied as plaster, calls for a high degree of plasticity.

From this viewpoint, the performance capabilities of the material have to be improved by stabilising the soil matrix (through the addition of cement, lime or other binders) combined with fibre reinforcement.

The present stage of the investigation is not meant to ascertain whether the performance capabilities of the materials tested are sufficient or not, since this will vary

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greatly in the different socio-economic settings as a function of local spending capacity, climate and maintenance requirements.

It seams indispensable, instead, to compare the performances of different materials to obtain useful clues for specific research projects geared to local conditions.

Tests conducted on a series of slabs obtained from five different mixes, involving different types and quantities of reinforcement, let us evaluate the effects of the stabilising products and fibres on the soil matrix in terms of sensitivity to water.

2. Materials and test procedures

The materials used for the tests were:

- Soil
  The soil used was taken from a site in Piedmont (Italy) where soil houses have always been constructed, and some are still standing. Its characteristics are:

Size particle distribution: sand = 42%, silt = 44%, clay = 14%.

Chemical composition (expressed as % by weight): calcination loss = 5.5, SiO_2 = 70.8, Fe_2O_3 = 4.4, Al_2O_3 = 12.1, CaO = 2.4, MgO = 2.5, Na_2O = 1.1, K_2O = 1.0.

Proportion of organic materials, chlorides and sulphates: negligible.

Methylene blue: VB = 1

- Cement
  The cement used was Portland 32.5R-UNI ENV197/1-type II/B-M.
- Fibres
  Two kinds of fibres were used as reinforcement:
  40–50 mm long sisal fibres;
  20 mm-long fibrillated polypropylene fibres.
- Cactus pulp
  Cactus pulp was obtained from *Opuntia ficus indica*, shredded with the aid of a mixer.

2.1. Methodology

The materials listed above were used to produce, in five different compositions, no. 15 slabs measuring 300 × 400 mm and 40 mm thick (no. 3 for each composition) as specified in Table 1.

After the curing period in the laboratory (20 °C average temperature and 50 ± 5% R.H.), the slabs were subjected to bending, water absorption, abrasion and erosion tests.

2.2. Bending tests

Fig. 1 illustrates the equipment used for the bending tests.

Table 1
Slab composition

Components	Bulk density (kg/m^3)
Plain soil (no fibre); water (33%)[a]	1677
Soil; cement (10%);[a] water (33%)[a]	1667
Soil; cement (10%);[a] water (33%);[a] sisal fibre (Vf = 1%)	1587
Soil; cement (10%);[a] water (33%)[a] polypropylene fibre (Vf = 1%)	1531
Soil; cactus (Opuntia ficus indica) pulp (33%);[a] water (5%)[a]	1363

[a] The percentages refer to dry soil weight; the bulk density of the composites depends on the different degrees of compaction made possible by the characteristics of the fibres.

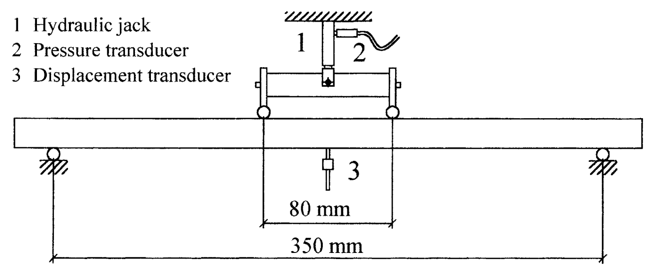

Fig. 1. Testing equipment.

2.3. Water absorption tests

The tests performed to determine the absorption tests of different types of slab were performed with the equipment described by Karsten [1] depicted in Fig. 2.

The results obtained on the slabs were compared with those determined in earlier tests on the plasters (of soil and sand, soil–lime–sand, lime and sand) [2] traditionally employed for the finishing of unbaked soil buildings.

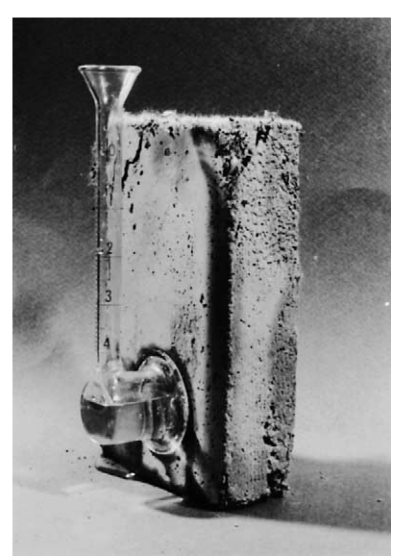

Fig. 2. Absorption testing equipment.

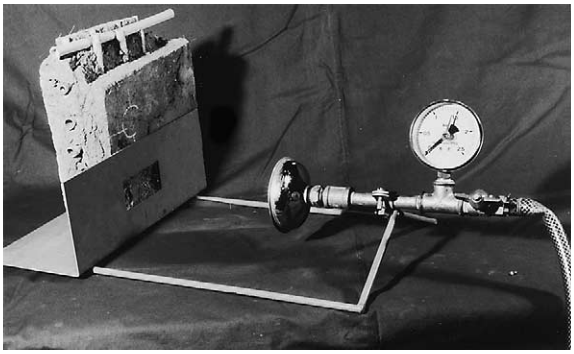

Fig. 3. Erosion test equipment.

The aim of the comparison was to set the values obtained for the composites against a wider framework, so as to be able to evaluate them in relation to the performance capabilities of known and well-tested solutions.

2.4. Abrasion test

The equipment used for these tests—VER-O [3] abrasimeter—makes possible to assess resistance to abrasion by measuring the quantities of materials removed by means of a pre-determined grain size (P120 corundum) abrasive paper rubbed against the surface of the material at a constant force. Each test piece was subjected to 20 abrasion cycles.

2.5. Erosion test

Assuming as reference indication the information provided by CRATerre [4], erosion tests were performed by exposing a limited portion of the specimen surface (80 × 40 mm) to a 1.4 bar water jet water produced with a shower terminal placed at a distance of 180 mm (Fig. 3). The tests were continued for up to 1 h, and the erosion resistance of each slab was evaluated by taking into account the time duration of the test and the weight of the material eroded.

3. Results and discussion

The results of the tests performed according to the methods described above are given below.

3.1. Bending test

Table 2 lists the values of tensile strength in bending.

The diagrams in Fig. 4 illustrate the predictable degree of ductility conferred by the fibres to the composites.

Table 2
Bending tests: failure stress

Reinforcing fibre	Stress [Mpa]
Sisal (l = 40–50 mm)	0.39
Polypropylene (l = 20 mm)	0.50
Soil cement	0.22
Soil cactus pulp	0.10
Plain soil	–[a]

[a] Plain soil slabs were not tested on account of their having been cracked by shrinkage during the curing period.

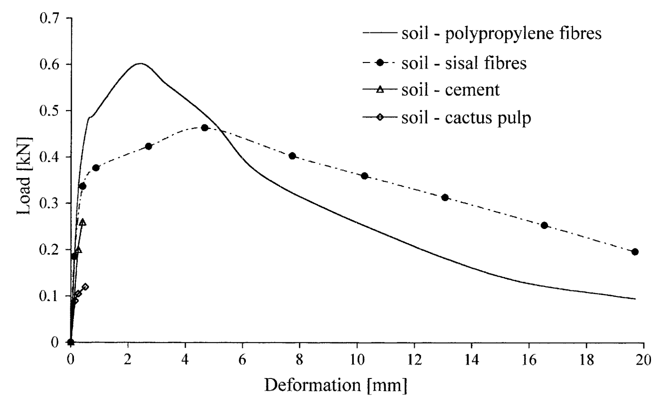

Fig. 4. Behaviour of the different kinds of specimen.

3.2. Water absorption test

The results of the absorption tests are grouped in Fig. 5.

The presence of fibres—whether vegetal or polypropylene—seems to accelerate the absorption of water, which is probably conveyed inward through absorption and/or capillary action.

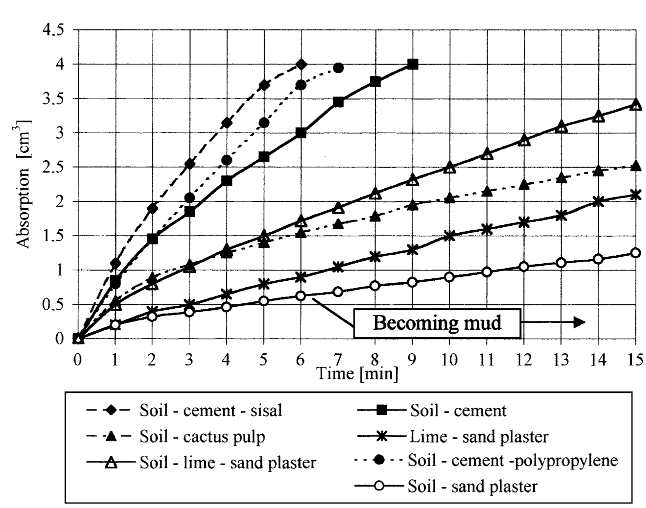

Fig. 5. Results of absorption tests.

Table 3
Abrasion tests

Specimen composition	Quantity of material removed [g]
Panel (a): results obtained on the slabs	
Soil, cement	0.38
Soil, cement, sisal fibre	0.49
Soil, cement, polypropylene fibre	0.34
Soil, cactus pulp	0.39
Panel (b): results obtained on the plasters [2]	
Soil–sand plaster (1:2)	1.10
Soil–lime–sand plaster (3:1:4.5)	0.90
Lime–sand plaster (1:3)	0.26

Altogether different is the behaviour of the slabs reinforced with cactus pulp, displaying better performance capabilities as concerns both the amount of water absorbed and the time it takes for the phenomenon to occur. In absolute terms, the results are comparable to those obtained on soil, lime and sand based plasters.

3.3. Abrasion test

The quantities of materials removed during the tests are listed in Table 3, panels (a) and (b).

By taking as our term of comparison the values relating to test pieces made of soil and cement, it can be seen that the presence of fibres—whether sisal or polypropylene—has negligible results on the resistance to abrasion of the composites; only traditional lime–sand plaster did better.

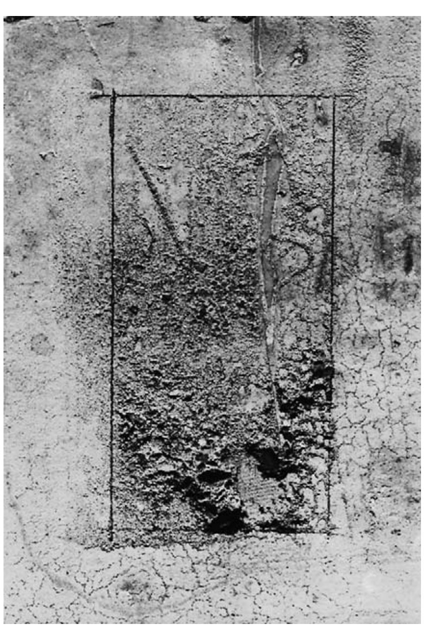

Fig. 6. Soil–cement slab quantity eroded 1.32 g.

3.4. Erosion test

The quantities of material eroded (mean over four values) are given below.

As can be logically expected, the specimen consisting of soil alone was completely eroded in a few minutes' time (13 min). All the other specimens passed the test, although with rather diversified results, as documented in Figs. 6–9.

As already observed in the bending tests, all fibre reinforced slabs exhibited a similar behaviour. Less bril-

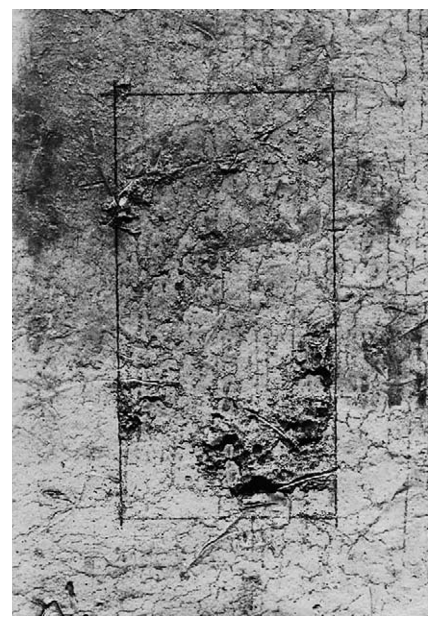

Fig. 7. Soil–cement–sisal fibre slab quantity eroded 0.89 g.

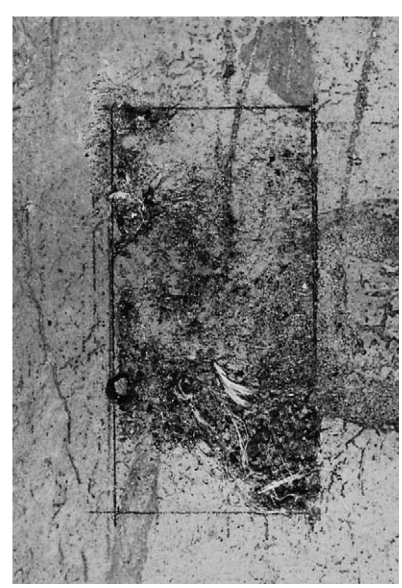

Fig. 8. Soil–cement polypropylene fibre slab quantity eroded 2.31 g.

Fig. 9. Soil–cactus pulp slab quantity eroded 40.89 g.

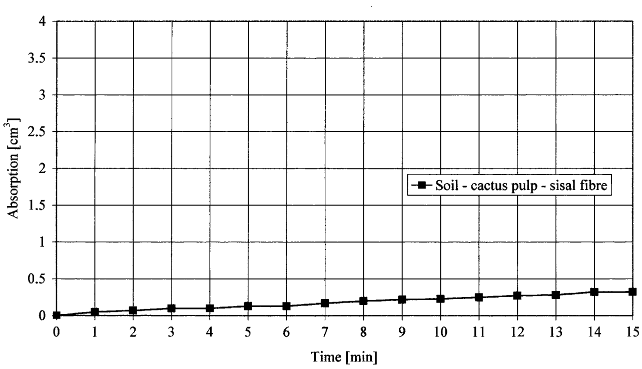

Fig. 10. Soil–cactus pulp–sisal fibre panel absorption.

liant, but still interesting, were the results obtained on specimens stabilised with cactus pulp (Figs. 10 and 11).

4. Performance of test bahareque panels

In order to gain a better understanding of the effects of cactus pulp on the strength of the soil matrix, a small bahareque (1000 × 800 mm, 50 mm thick) panel was constructed using a bamboo truss.

The soil was stabilised by adding, in percentages similar to those adopted for the slabs, sisal fibres and cactus pulp. In this case (in keeping with the indications given in the references [5,6]) the cactus pulp had been subjected to a two-week fermentation process to make it thicker and stickier. This method made it possible to evaluate the effects of fermentation on slab performance.

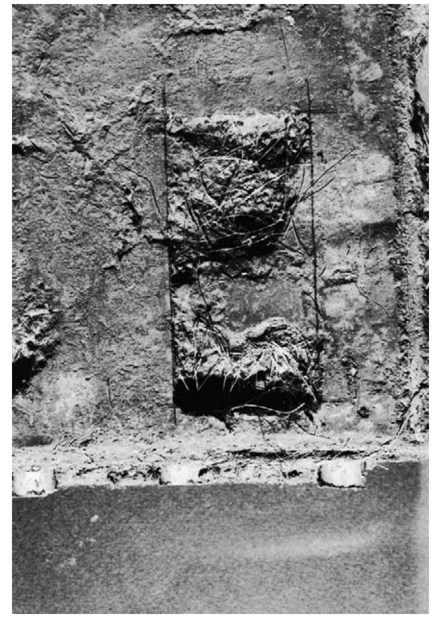

Fig. 11. Soil–cactus pulp–sisal fibre panel erosion quantity eroded 25.6 g.

The panel was allowed to dry in laboratory and was subjected to numerous absorption, erosion and abrasion tests, whose average results are given below.

The result of the abrasion test was 0.18 g.

5. Conclusions

The tests confirmed the effectiveness of fibres in improving the tensile behaviour of unbaked soil as a building material.

The addition of fibres appears to be particularly advantageous for use in connection with the bahareque technique, since it makes it possible to reduce the brittleness of the soil mortar applied to the wooden supporting frame; furthermore, the presence of fibres, combined with that of stabilising agents such as cement or cactus pulp, can greatly improve the durability of buildings.

Surely, the use of cement as a stabilising agent for the soil matrix calls for in-depth checks on its compatibility with the various types of vegetal fibres employed and the adoption of the necessary measures to prevent deterioration phenomena from occurring. In this connection, it seems interesting to investigate further the stabilising effects that can be obtained with cactus pulp alone—a natural, environment-friendly material.

Acknowledgment

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