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METHODOLOGY APPLIED IN THE CONSTRUCTION OF STRUCTURES USING NATURAL AND ALTERNATIVE MATERIALS FOR STABILIZATION WORKS IN ROAD CONSTRUCTION

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Abstract. The analysis of the current state of applications and the results of studies carried out at international level have led to the approach of an eco-efficient methodology for the recovery of waste generated from construction activities, demolition, and the addition of alternative stabilising materials to obtain optimized structures capable of providing a higher quality of the works carried out. Three types of stabilising slurry agents were selected for the experimental programme: the water-based polymer product AggreBind (AGB-BT), the Terra 3000 solution based on the Power binder, and the Earthzyme polysemantic product. Experimental studies on the use of these types of products in earthworks for stabilizing embankments, building and repairing road systems and industrial platforms have shown significant increases in strength and bearing capacity. The use of these environmentally beneficial alternative materials has led to significant reductions in construction time, decreasing total construction and maintenance costs in the short and long term.

Keywords: *stabilisation, waste, recovery, recycling, road systems, ecological material***.**

Rezumat. Analiza stadiului actual privind aplicațiile și rezultatele studiilor efectuate la nivel internațional au condus la abordarea unei metodologii eco-eficiente de valorificare a deșeurilor generate din activitățile de construcții, demolări și adaosuri de materialelor alternative de stabilizare pentru obținerea unor structuri optimizate capabile să confere o calitate superioară lucrărilor executate. Pentru programul experimental au fost selectate trei tipuri de agenți sub forma de suspensie cu rol stabilizator: produsul polimeric pe baza de apă AggreBind (AGB-BT), soluția Terra 3000 care are la baza liantul Power și produsul polienzimatic Earthzyme. Studiile experimentale referitoare la utilizarea acestor tipuri de produse în lucrările pentru stabilizarea terasamentelor, realizarea şi refacerea sistemelor rutiere, platformelor industriale au evidenţiat creşteri semnificative ale rezistenţei şi capacităţii portante. Utilizarea acestor materiale alternative cu efecte benefice asupra mediului au condus la reduceri semnificative a duratei de execuție, costurilor totale de construcţie şi mentenanţa pe termen scurt şi lung.

Cuvinte cheie: *stabilizare, deșeuri, valorificare, reciclare, sisteme rutiere, material ecologic.*

1. Introduction

The paper is based on a review of the current state of research and a synthesis of the literature on the efficiency of solid waste recovery in construction works. The effect of the uncontrolled use of natural materials in road works and other types of infrastructure is manifested by the gradual depletion of resources, while the costs of purchasing and processing these materials are constantly increasing. Similarly, large amounts of industrial and domestic waste cause serious environmental impacts in terms of disposal and safe storage. Therefore, construction research concerns have focused on the implementation of techniques to use different types of waste as alternative materials with construction applications and natural resource conservation [1, 2].

Traditional building materials such as concrete, bricks, solid blocks, paving blocks and tiles are produced from existing natural resources. Minimising the negative impact of the technological chain attributed to raw materials used in construction (extraction, processing, manufacturing, transportation) and controlled and sustainable waste management contribute to environmental protection and human health [3].

In recent decades, environmental approaches have focused on the conservation of natural resources by recycling various types of solid construction and demolition waste for use in the production or refinement of construction materials. From an economic, sustainable point of view, the use of solid waste for the production of building materials is one of these innovative efforts [4].

The costs of building materials are increasing daily due to high demand, shortage of raw materials, and high energy prices. The use of alternative constituents in building materials is now a global concern, focusing on energy saving and natural resource conservation [5-9]. Extensive research and development studies dedicated to exploring new components are required to produce sustainable and environmentally friendly building materials. In Europe, municipal solid waste accounts for 10% of all waste generated [10]. In 2014, Germany, Austria, Belgium, Switzerland, the Netherlands, and Sweden achieved a recycling rate of 50% for municipal solid waste. The countries that showed the highest increases in recycling rates between 2004 and 2014 were Lithuania, Poland, Italy, the Czech Republic, and the UK [10].

Construction waste is a significant component of solid waste worldwide, comprising 50% of the total waste generated. This waste stream has substantial physical, economic, and environmental implications. According to EU27 data, member states of the European Union produced a combined amount of 530 million tonnes/year of construction and demolition waste. This waste primarily originated from renovation (60%), construction (15%), and demolition (25%). However, only 46% of this waste was reused or recycled [11].

Some countries in Europe achieved high rates of recycling or reuse for construction and demolition waste. The UK had a recycling rate of 75%, while Ireland reached 80%. Germany achieved an 86% recycling rate, Estonia achieved 92%, Denmark achieved 94%, and the Netherlands had the highest rate at 98% [12].

Studies conducted to date on waste stream valorisation have highlighted the use of different types of construction and demolition waste, quarries, wastewater treatment plants, municipal solid waste sources in the process of land stabilization, applicable in the execution of road systems, parking areas, airport runways, and pedestrian walkways [13-18].

Existing experimental research has shown the effectiveness of construction and demolition waste in treating different categories of soils, from expansive clays to granular soils, as well as in improving physical and mechanical properties by increasing resistance to erosion or variations in moisture and temperature (freeze-thaw cycles).

Soil stabilisation using traditional materials such as lime and cement has been extensively studied in the literature [17, 19-21]. However, the substantial increase in the generation of solid waste has necessitated the development of a sustainable approach to efficient waste management and its use in soil stabilization. This approach has been particularly beneficial in developing countries, as it allows for waste reuse, addressing waste disposal issues, and reducing environmental costs associated with construction activities. Several studies have focused on the use of different solid wastes without the addition of primary binders, such as lime or cement, to stabilise land.

Numerous researchers, government organisations, and academic institutions have explored environmentally friendly technologies that minimise environmental impact and incorporate recycled materials in road infrastructure applications [1, 22, 23]. Technological programmes have been developed to obtain green materials that maintain or enhance current practises in construction engineering while offering innovative and environmentally friendly alternatives. These materials or methods resulting from these programmes are cost-effective and provide social, economic, and environmental benefits.

2. Configuration and Modelling of Optimised Structures

By systematising the work steps included in the experimental programme according to distinct sets of combinations of soils, stabilising agents with environmental benefits, and wastes generated from construction activities, it is proposed to simulate multicriteria requirements related to the technical and environmental performance associated with the modelled structures under laboratory conditions.

The configuration of a flexible methodology, correlated with the integration of eco-sustainable materials, solutions, and criteria, allows the efficient reuse and valorisation of construction and demolition waste in order to obtain optimised structures/elements dedicated to construction applications.

In the context of the current strategies adopted worldwide on the implementation of sustainable development practices, the approach to green design principles in the modelling process of alternative compositions consisted in the application of methods for the analysis and control of parametric links between relevant geotechnical characteristics according to the results of experimental simulations.

Depending on the applications in which the newly developed structures will be used, different types of soils, dosages of binder materials and test sets will be considered. The first category of structures modelled in the laboratory consisted of mixtures prepared from clay as the predominant material with different dosages of waste glass, sandstone, concrete, gypsum and materials with a stabilizing role (AggreBind, lime and cement) with potential applications in the manufacture or improvement of new construction elements (bricks, pavers, kerbs) by reusing the waste stream and materials with environmental benefits. The second category of modelled structures is dedicated to foundation stabilisation works, earthworks for roads and industrial platforms, railway infrastructure improvement works (formation of mixtures used in base and form layers of roads and as controlled fills in civil and industrial constructions).

The first step in the design methodology of composite structures focused on the configuration of multiple series of experimental variants consisting of: soils with unstable structure such as expansive clays (soils with high swelling and shrinkage) and clay sands (soils sensitive to wetting), as well as filler soils; stabilizing materials in different dosages: enzymatic product (Earthzyme solution), polymeric product (AggreBind).

After the schematization of the work steps and the realisation of the structural models, the experimentation at the macro-structural level consisted of carrying out specific test sets to determine the strength and deformability characteristics, as well as the simulation of various exposure conditions, allowing the estimation of the technical and environmental performances associated with the obtained mixtures.

Through laboratory simulations, it is proposed to estimate the behaviour of the structures under mechanical stress and chemical interactions of the components as a function of the treatment period. Also, at the laboratory scale, unfavourable conditions that may occur in practise have been simulated, with specimens being exposed to normal temperature and humidity conditions, dry-dry cycles by accelerated induction of climatic conditions of excessive heat and dry duration, and alternative freeze-thaw cycles by accelerated induction of low temperature conditions of duration followed by periods of normal temperatures. Optimal recipes by component type were selected based on the maximum values of mechanical characteristics associated with the types of applications for the valorisation and performance criteria appropriate to the principles of sustainable development.

3. Experimental simulations on earth structures (clay) - stabilizing agent - waste concrete and sandstone

In the configuration of the clay-based structures, the water-based polymeric product AggreBind was selected as the stabilizing agent in suspension form. In the laboratory, composite structures modelled from clay, AggreBind suspension with water and construction and demolition waste (concrete, sandstone) were configured with the aim of obtaining two alternative variants with potential applications in the design of new pavement elements and the reuse of waste for stabilisation works in road construction. When configuring structures based on clay as the predominant material, it was established to make a simple set of samples with the addition of 5% stabilising agent of AggreBind type and a multi-composite set with 10% addition of concrete and sandstone waste, crushed and sorted with particle sizes ranging from 0.05-0.5 mm and 0.08-0.25 mm, respectively.

The clay soil was oven dried at 105 ˚C for 24 hours and increased to a particle size of less than 2 mm, adding water to bring the material to high humidity values of 27-36%, excessive moisture conditions were achieved. Determinations of strength characteristics corresponding to structures modeled from clay - AggreBind stabilizing agent and waste concrete and sandstone were carried out under different thermal conditions and treatment periods: (a) immediately after preparation; (b) after heat treatment by oven drying at 105 ˚C for simple compositions; (c) at 7 and 28 days with maintenance under normal temperature and humidity conditions (20-22 ˚C).

The values of the monoaxial compressive strength of the two sets of clay-based composite structures (Figure 1) indicate a marked increase of more than 400% of the strength characteristics after 7 days in the case of simple mixtures with AggreBind, respectively 1200%

in the case of mixtures with waste concrete and sandstone, compared to the values after preparation. Maximum compressive strength is observed to be reached at 28 days, and increases compared to the samples tested at 7 days are 30-60%, highlighting the influence of the treatment period on the increase in strength.

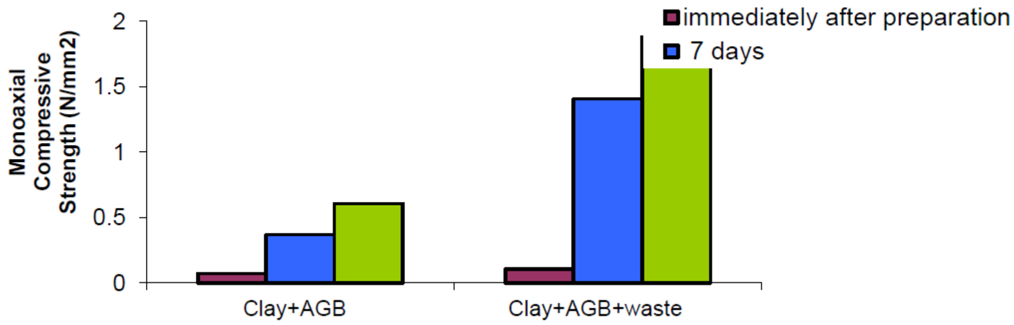

Figure 1. Compressive strength variation for clay-aggregate- waste concrete and sandstone structures.

To estimate the influence of binder additions on the deformability characteristics, tests were carried out under normal and saturated conditions to determine compressibility indices and swelling pressure. The physical characteristics and parameters determined by the compression-strain test obtained for the sets of structures based on clay, AggreBind polymer product, and waste concrete and sandstone are centralised in Tables 1 and 2, which show the data, and the compression-strain curves are shown in Figure 2.

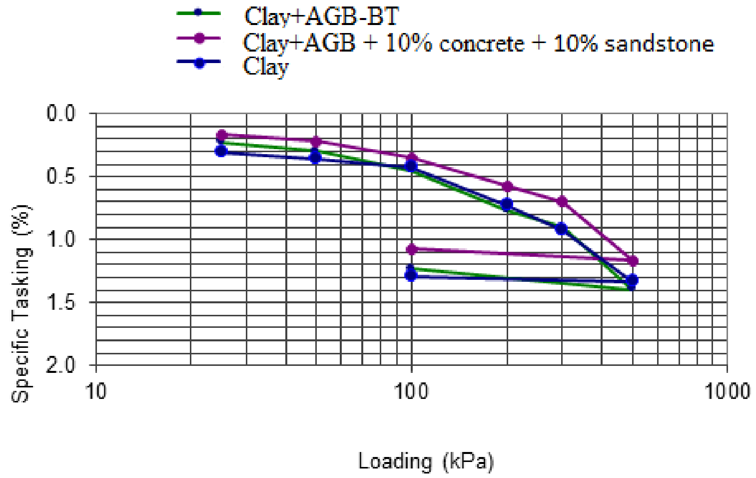

Figure 2. Illustrates the distribution of compression-strain curves obtained for clay-AggreBind-concrete and sandstone structures.

Table 1

Values recorded in compression tests - tamping for clay structures - AggreBind - waste concrete and sandstone

Structure type	Load steps (kPa)	Height difference Δh (mm)	Relative deformation $\varepsilon = \Delta h/h_0$ (%)
Clay + AggreBind	25	0.2218	1.109
	50	0.2968	1.484
	100	0.4487	2.244
	200	0.7618	3.809
	300	0.9025	4,513

Continuation Table 1

	500	1.3930	6.965
	100	1.2300	6.150
Clay +AggreBind+10% of sandstone +10% of concrete	25	0.1656	0.828
	50	0.2209	1.105
	100	0.3496	1.748
	200	0.5748	2.874
	300	0.6949	3.475
	500	1.1664	5.832
	100	1.0762	5.381

Table 2

The compression test on samples of clay-AggreBind-concrete and sandstone slabs provided the following parameters

Characteristic	UM	Natural sample		Clay+ AggreBind		Clay+AggreBind+ 10% concrete+ 10% sandstone	
		Initially	Final	Initially	Final	Initially	Final
Wet weight + tare weight	g	243.960	238.950	239.030	235.380	237.930	235.680
Wet weight + tare weight	g	205.19	205.19	197.29	197.29	198.92	198.52
Tare weight	g	84.52	84.52	81.50	81.50	84.51	84.51
Water contained	g	38.770	33.760	41.740	38.090	39.010	37.160
Wet sample	g	159.440	154.430	157.530	153.880	153.420	151.170
Dried sample	g	120.67	120.67	115.79	115.79	114.41	114.01
Humidity	%	32.13	27.98	36.05	32.90	34.10	32.59
Sample volume	cm^3	76.93	71.82	76.93	71.58	76.93	72.45
Natural density	g/cm^3	2.07	2.15	2.05	2.15	1.99	2.09
Density in dry state	g/cm^3	1.57	1.68	1.51	1.62	1.49	1.57
Porosity	%	41.25	37.07	43.63	39.42	44.30	41.06
Pore index	-	0.70	0.59	0.77	0.65	0.80	0.70
Degree of saturation	%	1.22	1.26	1.24	1.34	1.14	1.24
ε200	(%)	3.623		3.809		2.874	
Eoed200-300	kPa	10277.49		14214.64		16652.79	
mv	1/kPa	9.73E-05		7.04E-05		6.01E-05	
av	1/kPa	1.66E-04		1.25E-04		1.08E-04	

Note: Eoed - oedometric deformation modulus, ε - specific deformation, mv - coefficient of volume compressibility, av - coefficient of compressibility.

The values of the indices resulting from the compression tests show an increase in the edometric modulus of deformation of 38% and 62%, a decrease in the coefficient of volume compressibility of 27% and 38% and in the coefficient of compressibility of 25% and 35% for the composite structures with AggreBind and construction waste, compared to the values of the clay soil in its natural state. These aspects reflect a significant improvement in the deformability characteristics and the classification of the mixtures in the medium compressibility category. The physical characteristics and parameters obtained from the determination of swelling pressure are centralised in Tables 3.

Table 3

Displays the recorded values obtained during the determination of inflation pressure for clay-AggreBind-concrete and sandstone structures.

Structure type	Loading steps (kPa)	Height difference Δh (mm)	Relative deformation $\varepsilon = \Delta h/h_0$ (%)
Clay + AggreBind	10	-0.2880	-1.440
	25	-0.1500	-0.750
	50	0.1390	0.695
	100	0.3546	1.773
	200	0.5435	2.718
	300	0.7374	3.687
	500	0.9466	4.733
	100	0.7568	3,784
Clay +AggreBind+10% sandstone +10% concrete	10	-0.1810	-0.905
	25	-0.0664	-0.332
	50	0.0185	0.093
	100	0.1592	0.796
	200	0.5982	2.991
	300	0.7649	3.825
	500	1.1100	5.550
	100	0.6233	3.117

Similarly to the results obtained for glass structures, an increase of 25% and 45% was observed in the modulus of oedometric deformation, along with a decrease of 19% and 31% in the volume compressibility coefficient and a decrease of 20% and 28% in the compressibility coefficient, respectively, compared to that of untreated natural earth. The effect of adding stabilising agents and construction waste is observed by a 66% and 70% decrease in swelling pressure, resulting in less active clay-based composites.

Experimental simulations on earth-fill structures - stabilizing agent - clay sand

The configurations of the laboratory-modelled structures with fill soil and clayey sand, together with the Earthzyme dosages, are shown in Figures 3 and 4.

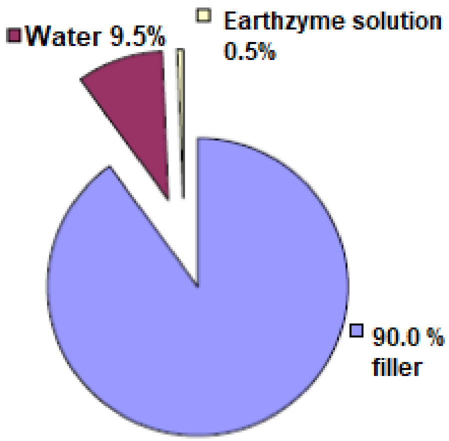

Figure 3. Illustrates structures that have been modeled using earth fill.

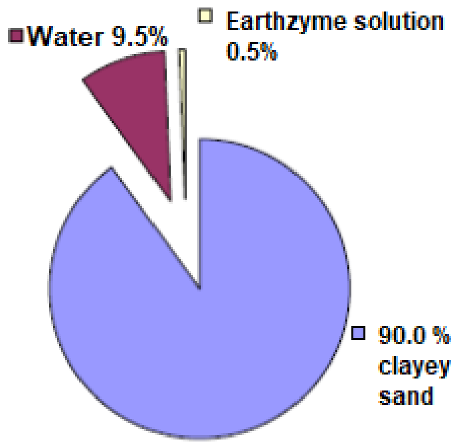

Figure 4. Structures formed with clay sand.

The results of the uniaxial compression tests obtained for the composite structures with earth, Earthzyme stabilizer and waste (Figure 5) indicate an increase in values of 27% at 7 days and 44% at 14 days associated with the earth fill composites compared to those corresponding to clay sand.

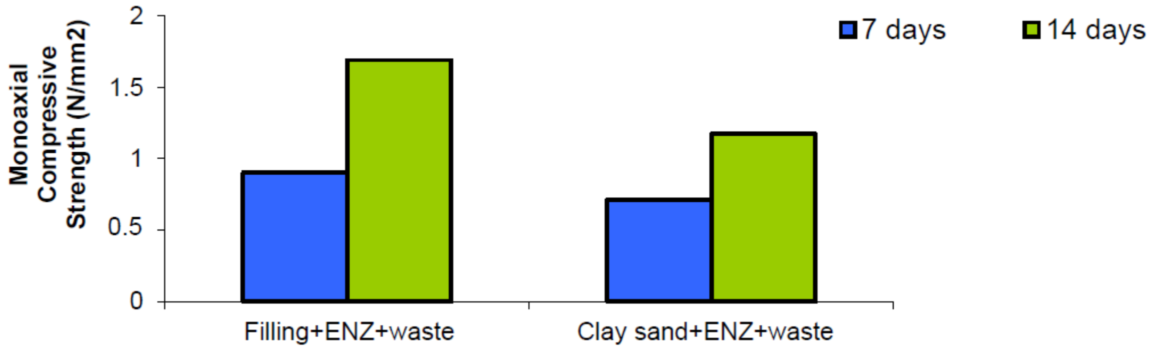

Figure 5. Compressive strength variation for optimal structures of earth-Earthzyme-waste compositions.

The increase in strength characteristics with the treatment period is evidenced by the significant increase of 65% in the case of the values obtained for the clay sand mixtures and 87% for those with filler earth.

4. Conclusions

The laboratory experimentation will consist of conducting macro-structural level experimental tests to determine the physical-mechanical characteristics of the simple and composite mixtures (including natural earth, construction waste, and stabilizing products). Furthermore, the behavior of these mixtures under the influence of mechanical, chemical, and environmental factors will be studied through various simulations under laboratory conditions. Methods of analysis and control will be used to establish parametric relationships between relevant geotechnical parameters, using both numerical and experimental simulations, with the aim of achieving the desired strength and stiffness characteristics. Optimal component recipes have been selected based on maximum values of mechanical characteristics suitable for the intended applications and performance criteria aligned with the principles of sustainable development.

The methodology applied through experimental laboratory modelling of the parametric links between strength, deformability and load-bearing characteristics allowed the configuration of optimized durable structures according to the types of potential applications.

In the case of clay-based composite structures, both those with AggreBind and waste concrete and sandstone, and those with lime, cement and gypsum waste, a similar trend of pronounced increase in compressive strength at 7 and 28 days is observed.

The evident increase in mechanical performance confirms the stability of structures modelled with clay as the predominant material and the possibility of using these types of waste and binders with a stabilising role in improving existing building elements or developing new durable products.

Concerning the second category of composite structures made of fill earth and clay sand, alternative stabilizing materials (Earthzyme) and waste, configured for potential applications in stabilization works of foundation and road layers, the bearing capacity values showed significantly higher strengths corresponding to Earthzyme and waste compositions, with increases of more than 300% compared to untreated earth values.

The bearing capacity performance characteristics of laboratory-modelled configurations for earth stabilisation works for the construction of platforms and parking lots, pedestrian walkways, cycle paths, pavements and road structures will be simulated "in situ" in the next phase of the project. The verification of the bearing capacity "in situ" by means of analyses correlated with the results obtained in the laboratory could not be carried out in the current phase due to procedural difficulties in procurement.

Conflicts of Interest: The authors declare no conflict of interest.

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