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Subgrade improvement by the replacement of conventional stone aggregate by biosanitary waste treated

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Abstract. An experimental investigation was made in search of the improvement of the material used for the conformation of the subgrade in pavements. Three separate excavations were carried out 150 m apart in a 510 m stretch located in the Guayabal environmental technology park in the city of San José de Cúcuta, Colombia. In each excavation 2 samples were taken at depths of 0.50 m and 1 m. The soil samples extracted were analyzed in accordance with the regulations of the "Instituto Nacional de Vías" of Colombia in its update of 2013. It was collected material, not superior to 20 mm, of biosanitary residues treated by the Ecosterile machine series 250C located in the environmental technological park Guayabal. Five experimental mixtures were carried out partially substituting 2%, 6%, 8%, 10% and 14% of the weight of the excavated soil with treated biosanitary residues, random percentages taken as initial reference in the experimentation due to the characteristics of the substitute material. The California bearing ratio test was performed on experimental mixtures whose data were tabulated and compared with those obtained in similar tests carried out on the material conventionally used for the improvement of the subgrade in pavements according to Colombian regulations. The tests provided interesting information that concluded in the substitution of 2% of the conventional material to improve the performance of the subgrade in the intervened section, a value that obtained better results in the California bearing ratio test, yielding 79.2% with respect to the result obtained by the conventional material. The exposed results are convenient for the economy of road projects due to the partial substitution of traditional material by residual material, at the same time the use of a hospital waste is implemented as construction material, bringing with it positive environmental and social benefits as far as its final disposition.

1. Introduction

The environmental problem presented by the over exploitation of natural resources for use in the various processes inherent in the manufacture of materials or their direct application in the various activities that make up the construction systems used in civil engineering, is notorious in the gradual deterioration of the biodiversity of our environment along with the significant climate change that is being evidenced in recent years [1]. This ecological crisis, catalogued of great magnitude by environmental experts, is increasing because of the uncontrolled use of both renewable and non-renewable resources, a situation that accelerates environmental depletion causing irreversible damage and others not so much, which are repairable in the long term.

The notable increase in population and economic growth, the latter to which emerging countries are forced [2], leaves, for the most part, a collateral damage evident in the destruction of the environment, negative impact generated by the economic need presented in nations that blinds environmental awareness and promotes the implementation of practices that minimize costs but in turn increase impacts, because the competitive challenge for companies focuses on creating thought oriented to generate value [3]. However, satisfying the demand brought about by the increase in world population proportionally increases the disproportionate and irrational exploitation of natural resources such as the natural material used to make concrete, which is drastically decreasing due to human exploitation activities [4], recognizing that corporate and government policies seek, in addition to generating financial sustainability, the conservation and care of the environment [5].

In the same sense, science, technology and innovation have been implicitly empowered by the environmental damage caused [6], which promotes an international movement to favor the environment by generating inventions, alternatives and technological developments that not only favor humanity but also are friendly to our own and neighboring ecosystems [7], always bearing in mind that constant innovation together with continuous improvement become reference axes for the connection and permanence of companies in the competitive market [8]. In fact, research professionals from different areas have expressed their interest in putting a brake on and providing a prompt solution to the evident environmental problem, seeking efficient, safe, reliable and highly competitive processes that take all production to higher levels with the optimal use of available resources [9]. This appropriation is transmitted through various research focused on the development of materials, products, practices, processes among others, implements new eco-friendly technologies, minimizing in large percentage the waste generated both before and after the finished product, even when the disposal of waste from the construction industry and other waste is one of the environmental problems. current [10].

Thus things, the activities and processes developed in the works executed in the area of civil engineering caused by rapid economic development and the boom in the construction industry [11], have been put under the spotlight, knowing beforehand the use of materials, conventionally used, which went through industrialized processes whose energy consumption was considerable, leaving a large amount of waste that, for the most part, are thrown directly into the environment in a liquid, solid or gaseous state. In that order of ideas, the media have attracted considerable attention in civil engineering [12], due to the constant use of natural materials for the elaboration of compounds such as mixtures of mortars, concretes and asphalts, flagship mixtures, which are essential in the planning, development and execution of different urban works.

In the same sense, natural stone aggregates have been the constituent material commonly used for the design and construction of civil infrastructure systems [13], aggregates that are traditionally extracted from alluvial terraces or quarries for implementation in different composite mixtures. To be precise, the problem of the traditional use of these materials [14] lies in their extraction where a non-renewable natural material is used. Thus, asphalt mix, a material traditionally implemented in the elaboration of flexible pavements as well as the layers that comprise it, subgrade, subbase, base and asphalt layer, make use, like concrete, of natural stone aggregates in the formulation of their designs, a material that, as mentioned above, brings with its extraction and implementation an irreparable environmental damage as it is a non-renewable material. This situation alerted construction companies, most of whom set themselves the goal of ensuring the well-being of the inhabitants and the environment by reducing CO_2 emissions and promoting the use of natural resources [15].

However, research carried out on the use of alternative materials to those conventionally used in civil engineering activities, under the premise of sustainable development, sets the standard in the replacement of natural stone aggregates present in asphalt mixtures with non-conventional aggregates resulting from or surplus to industrialized processes or residues of some type of activity, with which mixtures are designed, partially or totally substituting the natural aggregate [16]. Materials which, when treated as waste, do not generate any economic value, but do have a great environmental impact on their final disposal. This is why the construction industry see in urban areas is an ideal sector to promote the rational use of industrial waste and by-products [17] to replace conventionally used materials, putting them in the context of sustainable development, where the use of materials with low environmental impact in the activities inherent to the construction of housing plays an important role in reducing pollution by waste [18].

The present research revealed the use of the biosanitary residues treated (BST) of the Ecosteryl 250C machine located in the Guayabal environmental technology park (GETP) located in the city of San José de Cúcuta, Colombia, by means of its implementation in the improvement of the subgrade layer of the stretch of 510 m of the GETP intervened, reducing this way the 2% of the material conventionally used in this activity by means of its replacement by BST. Being the partial replacement of the 2% of the weight of the conventional material the experimental mixture that yielded satisfactory results for the inclusion of the residual material in the design of this type of material that conforms the subgrade layer of a pavement. A result that would considerably reduce the thickness of the subsequent layers for the construction of a track, the sub-base and base, layers that are traditionally constituted with grinded stone material, being inherent an ecological benefit through percentage reduction in the use of a non-renewable natural material and the use of solid waste as construction material.

2. Materials and methods

An experimental-type investigation was conducted that began with in the GETP field exploration. Three digs were performed, at 150 m (D1), 300 m (D2), and 450 m (D3), in a stretch of 510 m. In each dig 2 soil samples (SS) were taken, one at 0.50 m (S1) and the other at a depth of 1 m (S2). With the help of the dynamic cone was obtained the California bearing ratio test (CBR) in situ to SS. The SS were analyzed under the regulations described by instituto nacional de vias (INV E-13) [19]. The SS were subjected to a test method to determine soil moisture using the microwave oven determined in INV E-135-13 [20]. The plastic limit and plasticity index of the SS were determined by INV E-126-13 [21]. The liquid limit of the SS was tested according to INV E-125-13 [22]. The classification of SS was identified with the indications given in standard INV E-213-13 [23]. The SS density or unit mass was tested in the soil sand cone method according to INV E-161-13 [24]. The modified compaction test was performed with 3 points each of 56 strokes in 5 layers as described in INV E-142-13 [25]. Particles not less than 20 mm of BST were collected in the Ecosteryl 250C machine. Moisture was taken from the BST as well SS. Five experimental mixtures (EM) were made where 2%, 6%, 8%, 10% and 14% of the weight of the soil was replaced by BST, these % were randomly selected due to the characteristics of the substitute material which was a non-conventional residual material for use in engineering works. The CBR were carried out on the SS and on each of the EM, to which the humidity was taken at 12.26% and 56 hits where its density was determined respectively. The data were tabulated and compared where the optimum % of soil replaced by BST was identified for implementation in the subgrade of the stretch to be intervened.

3. Results

3.1. Humidity analysis of samples

Under the INV E-135-13 standard [20], the average humidity of the digs (D1, D2, and D3) was determined. As shown in Table 1, the humidity % between the D1 and D2 of the S1 and S2 had an average difference of 0.41%, unlike the D3 for the 2 samples whose difference was more significant presenting a differential value of 1.91%.

Table 1. Average humidity percentage.

	% humidity	
	S1	S2
D1	5.56	5.76
D2	5.26	5.88
D3	5.55	7.46

Table 2. Atterberg limits.

	D1	D2	D3
liquid limit	22.99	23.35	38.59
plastic limit	15.07	15.22	24.35
plasticity index	07.92	08.13	14.24

3.2. Plastic limit, liquid limit and plasticity index
The test to determine the atterberg limits of soil samples collected at the digs were performed using the INV E-126-13 [21]. Tests that denote the reduced margin as for the difference of data thrown between the D1 and D2, which did not reach to exceed 1% in value.

The opposite case occurred with D3, whose difference is still significant, as in Table 1, where, in the following Table 2, they continue to be significant. These values were due to the type of soil found in D3 whose description given in the consistency limits was named as a clay with traces of sand of medium plasticity, a physical characteristic that is reflected in the Table 2.

3.3. Soil classification
The classification of soil samples was carried out with the INV E-213-13 standard [23]. After the tests made to the soil samples taken by means of the 3 digs it was possible to have important information which was of help to determine the classification of the soil present in each analyzed section with its respective dig.

Table 3, presented below, indicates the classification of the extracted material in each section according to the american associattion of state highway officials (AASHTO), where D1 and D2 are classified as A-4 corresponding to loamy soils, while the soil extracted in D3 is classified as A-6 indicating clay soils. The material analyzed in D1 and D3 have a group index (GI) of 8, while the material extracted in D2 has a GI of 3, these data are of interest for the selection of the materials that will be used in the constitution of embankments, subgrades, subbases and bases for pavements. The 3 digs described are framed in the CL group which represents inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays.

Table 3. Soil classification.

	D1	D2	D3
AASHTO	A-4	A-4	A-6
IG	8	3	8
USC	CL	CL	CL
% gravel	05.68	38.08	00.23
% sand	15.52	11.92	05.41
% fine	78.80	50.00	94.37

Table 4. Dry density.

	Material dry density (g/m^3)
D1	1.87
D2	1.85
D3	1.76

3.4. Determination of the dry density of the material
This method is used to determine the density of compacted soils used in the construction of embankments, subgrades, pavement underlayment's and structural fillers. Table 4 shows the decrease in dry density of the extracted material in the 3 digs. Decrease caused by the type of material present in the tranches, which were classified in table 3 previously presented.

3.5. California bearing ratio test results comparison
The CBR result of the SS was compared with the results of the EM where 2%, 6%, 8%, 10%, and 14% of the weight of the SS was replaced by BST. The EM were named, EM-2 for the addition of 2% substitute material in the SS, EM-6 for the addition of 6% substitute material in the SS, using the same variable name in % for the other EM.

The CBR for all mixtures, both SS and EM, was determined under the addition of 12%, 14%, and 16% moisture. In the following Table 5, the values of the CBR obtained by the SS and the EM are appreciated, where it is possible to identify the diminution of the results of the SS with respect to the EM-2, having this last one an advantage of almost 100% in the values reported in the CBR obtained with the addition of 12% of humidity. The EM-6 had similar values and some were lower, but in minimal difference, with respect to the EM-2.

Table 5. California bearing ratio test results.

mixture	humidity		12%	14%	16%
	density (g/m^3)	density (lb/ft^3)	California bearing ratio test		
SS	1.79	112	0.90	1.40	1.45
	1.83	114	1.00	1.45	1.60
	1.86	116	1.10	1.50	1.65
EM-2	1.68	105	1.80	2.10	2.50
	1.75	109	2.20	2.70	2.70
	1.81	113	2.30	2.60	2.80
EM-6	1.70	106	1.80	2.25	2.35
	1.71	107	1.90	2.30	2.45
	1.73	108	2.10	2.35	2.50
EM-8	1.57	098	1.10	1.70	1.90
	1.60	100	1.50	1.85	2.10
	1.65	103	2.00	2.20	2.35
EM-10	1.49	093	1.30	1.40	1.50
	1.54	096	1.58	1.60	1.80
	1.59	099	1.70	1.90	2.10
EM-14	1.47	092	1.75	1.85	1.90
	1.49	093	1.85	2.00	2.00
	1.51	094	2.00	2.10	2.20

3.6. Percentage improvement of the California bearing ratio test with respect to the soil sample

Performing the average sum of the densities and the values of the CBR obtain by the addition of the 3% of humidities 12%, 14% and 16%, it is obtained the improvement of the CBR test of the EM with respect to the SS.

Table 6. Percentage improvement over conventional mix.

Mixture	Average density (g/m^3)	Average California bearing ratio test	% California bearing ratio test improvement over conventional
SS	1.83	1.35	-
EM-2	1.75	2.42	79.2
EM-6	1.71	2.22	64.4
EM-8	1.61	1.85	37.0
EM-10	1.54	1.64	21.5
EM-14	1.49	1.97	45.9

Table 6, presented below, shows the results in % of the improvement of the CBR of the EM in comparison with the SS, where the increase of the CBR is appreciated with the partial addition of the BST in weight of the material used for the elaboration of the SS, where it is evidenced that all the EM manage to surpass in average, the results of the CBR obtained by the SS, being notorious the advantage in value that presents the EM-2 over the other SS. The EM-6 maintains a reduced gap with respect to the result captured by the EM-2.

4. Conclusions

The laboratory tests carried out for the study of soil in the GETP comply with the guidelines established by the instituto nacional de vias, Colombia, classifying the soil as a clay of low compressibility and establishing the parameters for the performance of conventional CBR. With the tests carried out, by means of CBR a dosage was established for the improvement of the subgrade with BST content. Once the 5 dosages (2%, 6%, 8%, 10% and 14%) were established, it was concluded that the adequate dosage for this purpose was of CBR at 2% BST, improving CBR by 79.2% with respect to conventional CBR. With this dosage, the mechanical properties of the soil are improved compared to the other 4 dosages established; in order to improve a soil, it must comply with premises such as they are: Reduction of voids, reduction of porosities, increase of resistance and increase of CBR. Comparisons of SS CBR results and EM CBR were made using statistical methodologies such as mean to find mean CBR and densities based on laboratory results. The prevention and minimization of the generation of hazardous and similar waste is a priority in any waste management system. This research seeked the implementation of BST material with new technologies for the benefit of the environment, reduce the content of waste in the cells of final disposal of the sanitary landfill and its application to improve the load-bearing characteristics of the subgrade of the section of 510 m intervened.

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