Use of Crushed Seashell by-Products for Sandy Subgrade Stabilization for Pavement Purpose

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Abstract*– This research aims to explore an alternative utilization of seashell wastes in sandy subgrade stabilization in order to reduce environmental pollution. Crushed Peruvian Scallop was mixed with silty sand subgrade through mechanical stabilization at 20%, 40%, 60%, and 80% soil subgrade replacement. Seashells were simply washed and sun-dried before being crushed. Evaluation of the crushed seashell (CSS) reveals that it can be considered as a gravel material, with flat but not elongated particles of 25% of Los Angeles Abrasion loss value. Laboratory testing and analysis determined that it meets the American Association of State Highway and Transportation Officials' (AASHTO) requirements for use as a subbase and base coarse material at 45% replacement of fine soil aggregate. The CSS addition in sandy soil increases the maximum density using less water than the control group, with the same compaction energy. The CSS addition also increases the California Bearing Ratio (CBR) of sandy soil from 51% to more than 100%. It can be concluded that crushed waste Peruvian Scallop has the potential to perform as a mechanical soil stabilizer, or for soil modification for pavement applications, simply using washing and sun-drying treatment.

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I. Introduction

The use of shellfish is an expanding economic activity worldwide [1]. The residues that result lead to environmental pollution as a result of unpleasant odor, insects and fungi on open-dump sites [2-9].

More effort is needed to find use for these wastes in such a way as to reduce environmental problems [1, 9]. Using wastes materials in civil engineering offers a low energy consumption alternative to recycling [9-10].

Some research has been done on the use of waste seashells materials in civil engineering: periwinkles, crushed scallop and crepidula shells have been as aggregate replacements in concrete [2-8, 11-17]; in a powder condition as cementitious materials [18, 19, 20] or as filler in hot mixes [21]. The general findings reveal that seashells can be used as an aggregate replacement, but the salt content and chloride ion presence in seashells can be harmful to concrete or asphalt mixes. Some others researchers have explored its uses in pavement subgrade stabilization of clayed or compressive soils [22-25]. The results show that crushed shell can be effectively utilized as a subgrade improvement, reducing plasticity and increasing the bearing capacity. Typically, for subgrade stabilization, lime is used in cohesive clay-type soils, while cement or fly ash is used in non-cohesive sandy-type soils. The amount of cement mixed with the soil is usually 3% to 10% by dry weight of the soil, with higher percentages for finer materials having a greater surface area [38]. But no technical information on the use of crushed waste scallop for pavement base applications was found.

In this research, Peruvian Scallop is used for the stabilization of sandy subgrade in pavement application. In Peru, Peruvian Scallop (*Argopecten purpuratus*) is one of the most important species to be grown, and it is actually exported to China, the United Kingdom, Canada, Iceland, Australia and Chile [26]. In Sechura, Northern Peru, more than 80% of national production is managed, and up to 25 000 metric tons (TM) of empty hard seashell is discarded annually as waste in municipal landfills [27]. New Peruvian government environmental standards have been applied to processing plants which require waste management alternatives [28].

This research aims to explore the effect of the addition of crushed seashell to sandy subgrades through mechanical stabilization for pavement applications.

II. Methodology

A. *Experimental material*

1) Subgrade material: Natural rounded silty fine sand with some calcareous stone from Sechura, Peru was used as subgrade material. This sand is a coastal stratum formed by sedimentation throughout alluvial and air transportation. The main selection criterion was location in an urban area at a limited distance from seashell landfills.

2) Seashell waste: Seashell waste was recovered from municipal landfill located in Sechura. The Peruvian Scallop is a bivalve mollusk with two symmetrical hard shell sections joined at one end by a hinged ligament. The shells are essentially calcareous material [29] in flat and curved shaped of almost 2 to 3 mm thickness. One of the shells is more concave than the other. The interior of the shells is smooth, and the exterior porous, and is ribbed in a radial orientation. Before crushing, the size of the samples used in this research ranged from 8.0 cm. to 12 cm. Fig. 1 shows some samples of Peruvian scallops identified in this research.

B. *Crushed seashell preparation*

Empty seashells collected from landfill were washed to remove dirt and any organic matter using water. They were then sun-dried. No other washing method or materials were used for cleaning purposes. Although salt content is not harmful to soil stabilization, the washing process was used to eliminate its effect on compaction. Seashells were crushed and sieved using 2" and No. 20 ASTM sieves.

C. *Mixture proportions*

Four mixes were prepared. Soil was replaced with crushed seashell (CSS) in weight (20%, 40%, 60%, and 80%)

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and compared against the control group (0%) without seashells.

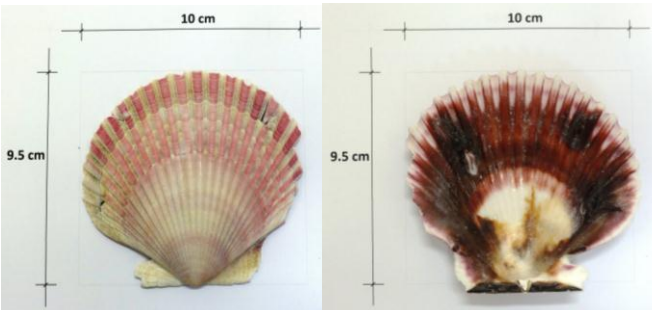

Fig. 1 Sample of Peruvian scallop shell used in the present research. The exterior and interior sides of the shells can be observed.

D. Testing methods

Grain-size distribution [30], Liquid Limit, Plastic Limit, and Plasticity Index [31], and Los Angeles abrasion [32-33] tests were applied to natural sand and also to the CSS materials. In addition, flat and elongated particles [34] in CSS were evaluated in terms of them being a coarse aggregate. California Bearing Ratio (CBR) and moisture-density relations using modified the Proctor compaction test were used, according to ASTM and AASHTO specifications for road applications [35-36] to evaluate the CSS addition effect on natural soil.

III. RESULTS AND DISCUSSION

A. Engineering properties of natural soil and crushed seashell

During crushed seashell preparation, no jaw or mill crushing machines from the laboratory were of use for crushing. A great deal of hand effort using a manual grinder was used (Fig. 2). This indicates a need to break the shell by impact or rolling, as the curved shape can be appropriate for crushing. On site, a rolling machine involving rolling over shells placed on the soil can be a good way to carry out the crushing and mixed process in the same step.

Fig. 2 Manual grinder used to facilitate crushing of seashells.

Table I presents the soil properties of both subgrade soil and CSS material. Neither natural soil nor CSS has plasticity. Some plasticity can be helpful in compaction in terms of reducing the mechanical effort needed to get better density. In natural conditions, a subgrade has a water content of 7.8% in mass, which can be useful for compaction purposes.

TABLE I
PROPERTIES OF NATURAL SOIL AND CRUSHED SEASHELL EVALUATED IN THE LABORATORY

Parameter	Natural soil	Crushed seashell
Liquid Limit (%)	---	---
Plastic Limit (%)	---	---
Plasticity Index (%)	NP[a]	NP[a]
Natural water content (% mass)	7.8	0.3
Specific Gravity (Gs)[b]	2.58	2.50
Percentage < 0.074 mm	17.0	0.0
USCS[c] Classification	SM[d]	GP[e]
AASHTO[f] Classification	A-2-4 (0)	A-1-a (0)

[a]Non plastic.
[b]A dimensional parameter.
[c]Unified Soil Classification System.
[d]Silty sand.
[e]Poorly graded gravel.
[f]American Association of State Highway and Transportation Officials (AASHTO).

The specific gravity of CSS is lightly less than that of natural soil, as seashells is a calcareous material and also is more porous than natural gravel.

Using the Unified Soil Classification System (USCS), natural soil from subgrade is fine silty sand with 14% of gravel and no more than 17% of silt without plasticity (SM). CSS can be considered as gravel with 24% of fine sand and no more than 3% of fines particles without plasticity (GP). Using the AASHTO classification, natural soil qualifies as A-2-4 (0) and CSS material as A-1-a (0). Both are coarse grained soils, and the GI value of zero means that they are also good materials for subgrades.

B. Grain size gradation

Fig. 3 shows the grain size distribution of both materials. As was noticed before, both materials are coarse grained soils. The subgrade soil has more fine particles than the CSS material. It can be expected that any mix of the materials will increase the gravel particles, and will move the natural soil from sand to gravel.

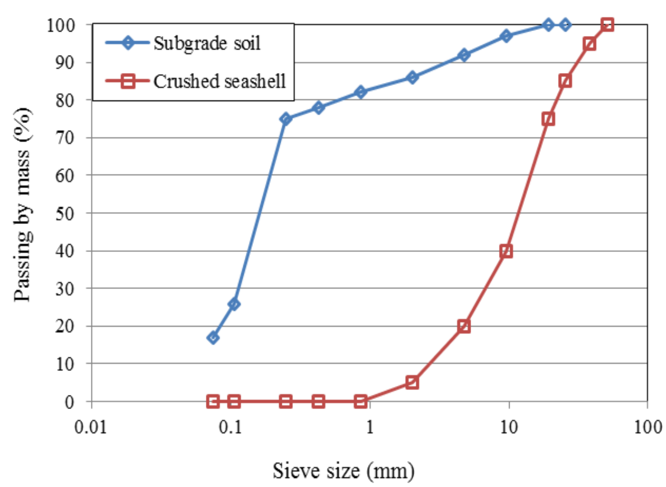

Fig. 3 Grain size distribution of natural subgrade and crushed shell.

On the other hand, as they are non-plastic, more compaction effort will be required or even spreading or a lack of stability of the landfill obtained with compacted mixes can be expected. But, on the other hand, less water will be required for compaction as there will not be fine particles in the mix.

C. Los Angeles abrasion

The original subgrade soil is sand with Los Angeles abrasion ranging from 12% to 37%. The CSS abrasion value was 25.2%. This value means that crushed seashell has a high resistance to abrasion and mass loss, thus is similar to natural soil. Based on only this test, it can be concluded that sea shells have resistive properties when they come to be used as a subbase and base course [32, 38], with some exposure to passing traffic. But again, the absence of fines may promote spreading or a lack of stability of the base course and some kind of binder would be needed.

D. Flat and elongated particles

At a specified test ratio of 3 to 1, it was found that 99% of particles were flat, 0% was only elongated and 0% was flat and elongated. This is a consequence of the shape of the shells, which are laminar, even after crushing. But it also indicates that crushing processes can reduce particles to obtain shapes with enough symmetry to consider them as not being elongated, reducing the amount of elongates particles in the material (Fig. 4).

ASTM specifications [33] requires no more than 20% of flat and elongated particles by weight for the subbase course, and no more than 15% for the base course. This material meets both requirements.

E. Mixture gradation

Fig. 5 presents the grain size distribution of the mixes obtained when CSS is added to natural soil. It can be observed that with increasing CSS content, the soil is less fine. Table II details changes in the soil classification when crushed seashell is added; it varies from a silty sand soil (SM) to a well graded gravel soil (GW).

According to [37], the grain size distribution of mixes should achieve gradations B, C, or D for pavement purposes.

Fig. 4 Flat but not elongated particles of CSS generated after crushing.

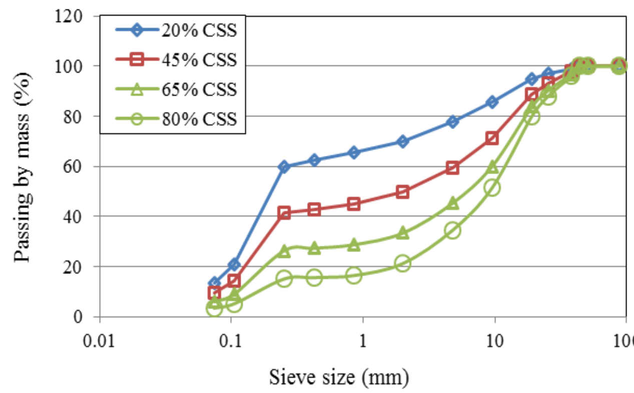

Fig. 5 Grain size distribution of soil and crushed shell combinations.

Some gradation requirements are recommended [37] to ensure good performance on the part of base and subbase courses for roads (gradations A, B, C and D). Natural soil gradation is out of specifications, but almost close to gradation D.

It can be observed that when CSS content is increased in the mix, the grain size distribution of mixes transitions from gradation D to A. This means that CSS acts as gravel, giving to the natural soil the coarse material it does not naturally have.

The absence of plastic fines on natural soil and also in the mixes evaluated limits their utilization to base-course or subbase materials. The use of some other stabilizing material such as clay, lime, cement or asphalt available locally, could permit the material to achieve the requirements needed for a surface course layer. The presence of non-plastic fines contributes to the effective use of those binders.

TABLE II
EFFECT OF CSS ADDITION ON GRAIN SIZE DISTRIBUTION OF NATURAL SOIL

Sieve	Opening (mm)	Natural soil	Crushed seashell	CSS Content			
				20%	45%	65%	80%
2	50.8	100	100	100	100	100	100
1 ¾	43.75	100	100	100	100	100	100
1 ½	38.1	100	95	99	97.8	96.8	96
1	25.4	100	85	97	93.3	90.3	88
¾	19.1	100	75	95	88.8	83.8	80
3/8	9.53	97	40	85.6	71.4	60	51.4
4	4.76	92	20	77.6	59.6	45.2	34.4
10	2	86	5	69.8	49.6	33.4	21.2
20	0.85	82	0	65.6	45.1	28.7	16.4
40	0.426	78	0	62.4	42.9	27.3	15.6
60	0.25	75	0	60	41.3	26.3	15
140	0.106	26	0	20.8	14.3	9.1	5.2
200	0.074	17	0	13.6	9.4	6	3.4
USCS classification		SM	GP	SM	SW	GW	GW
AASHTO classification		A-2-4 (0)	A-1-a (0)	A-2-4 (0)	A-1-b (0)	A-1-a (0)	A-1-a (0)

SM: Silty fine sand. SW: Sand well graded.
GP: Gravel poorly graded. GW: Gravel well graded.

On the other hand, as gradation A is for zones above 3000 m.a.s.l. (metres above sea level), it can be considered that the freezing resistance of natural soil can be improved when CSS replacement is increased. It can be also interpreted that an 80% CSS mix has more voids, and can let water freeze inside the material with little effect on its bearing capacity. Using the classification of mixed soil, it can be confirmed that this goes from silty sand (SM) when it is in the form of original soil, to well graded gravel (GW) when 80% of CSS is added.

F. Compaction properties

The moisture and density relations of the original soil and mixes were evaluated. The Modify Proctor Density was evaluated and plotted in Fig. 6; values are detailed in Table III. The results show that CSS increases the maximum dried density of the soil up 45% replacement. More than 45% of CSS in natural soil reduces the maximum dry density. In all cases, less water content is required for compaction. The reason for lower optimum moisture content is a reduction in the fines content.

This effect can be explained because natural soil is sand, and the CSS acts as gravel. Small particles of sand act as a matrix and CSS particles as a dispersed phase. Unless the particles of CSS are flat, they are big enough to permit enough mobility between the continuous phases of the sand. The presence of more than 45% of CSS particles generates more voids, and requires more sand to fill the spaces between the big particles, thereby reducing density.

On the other hand, more CSS particle content in natural soil requires less water content to achieve good compaction (Table III). It can be attributed to the shape and size of the particles. When particles are bigger, a smaller surface in terms of particles is available, and less water in needed to lubricate each particle. So, using CSS in addition to natural soil means that a better density can be obtained using less water with the same compaction energy. This is an important consideration for projects taking place in drier climates where moisture sensitivity is a concern.

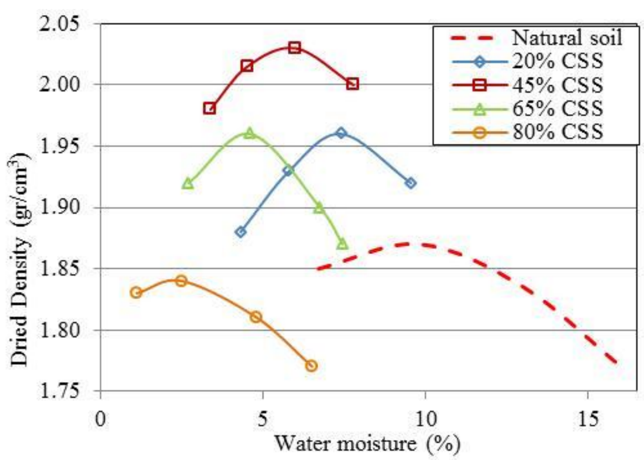

Fig. 6 Effect of soil replacement by CSS on compaction properties.

It can be noted too that, in all cases, optimal water content is less than the natural soil water content (Tables I and III). This can be explained because both materials are coarse grained soils, and the water requirement for the compaction process is very small. It can be interpreted that natural soil meets the water requirements in terms of achieving the maximum dried density during the stabilization process, and no extra water is required. This consideration can be beneficial as no extra water needs to be moved to the work site and the costs of stabilization can be reduced considerably as a result.

TABLE III

COMPACTION PROPERTIES OF MIXES AND NATURAL SOIL

Parameter	Natural soil	CSS addition			
	SM	20%	45%	65%	80%
Optimal water content (%)	9.8	7.4	6.0	4.6	2.5
Dry Density (g/cm^3)	1.87	1.96	2.03	1.96	1.84

The CSS effect on CBR was also evaluated. CBR values were evaluated at 100% maximum dry density and the optimum water content was determined using the modified Proctor compaction test for each replacement (20%, 40%, 60%, and 80%) and in a soaked condition. The values of CBR of samples with CSS additional content are plotted in Fig. 7. Natural soil is represented by 0% replacement.

The CSS addition increases the CBR of natural soil. The specimen with 45% CSS replacement had the highest CBR of 121% which was better than the CBR of 51% for the specimen with 0% replacement. Because the presence of larger particles of CSS act as gravel, the soil with CSS behaves as a high quality material, more like the standard crushed rock material used as comparison in the CBR test.

However, a tendency to get a maximum CBR for a determined CSS content can be observed. More than 45% of CSS tends to reduce the CBR value in the mix, but this is still higher than natural soil. It seems that excess of flat particles found in CSS generates more voids in the soil that could not be filled by sand. On the other hand, the lack of fines reduces the stability of particles, and the soil tends to collapse easily during compaction.

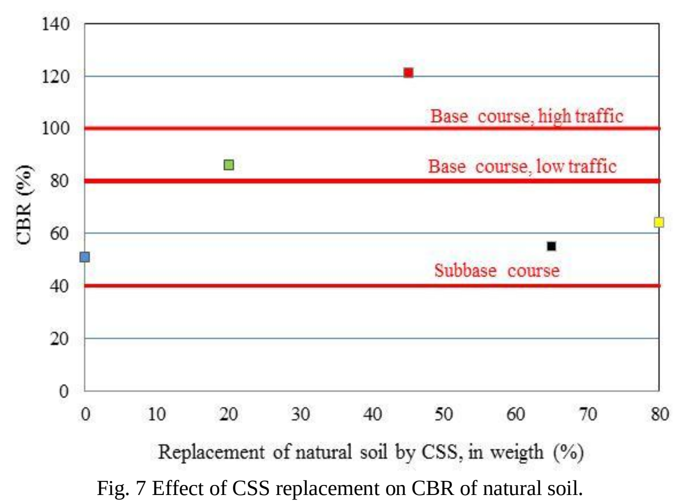

Fig. 7 Effect of CSS replacement on CBR of natural soil.

It is interesting to note that even when the 80% CSS replacement has less maximum dry unit weight than natural soil (Fig. 6), the CBR value is still higher than that of the control group (0%). This can offer the opportunity to include a high proportion of crushed seashells as part of subgrade materials without compromising the quality of the natural soil.

Compared to AASHTO specifications, more than 20% CSS replacement allows the soil to qualify as a base course. If the CSS replacement goes to 45%, it could meet high load traffic base course requirements. In any case, it is evident that the surface course or the use of some binder material to improve wear and tear is required because of a lack of cohesion in the material.

No expansion was found in all mixes or natural soil. This cannot be attributed to a shortage of either fines or plasticity in the samples.

G. Changes on grain size distribution after compaction

Compaction tests can change the grain size distribution. The application of high compaction energy may break particles, especially if they are flat. In this case, shells can be reduced in size after application of the compaction effort. So, grain size distribution was evaluated in samples with 65% of CSS replacement after compaction (Fig. 8).

A significative reduction in larger particles can be observed. Because of the flat shape of the crushed seashell, compaction energy crushes them even more, reducing the size of these grains further. This can explain the significative unexpected reduction on CBR in respect of the control group (0%). Apparently, the presence of the sand in the mix can act as a shock absorber to protect any shell particles from the compaction energy effect. This can also contribute to the reduction of the CBR when more than 45% CSS replacement is used: seashell particles are broken and reduced in size, limiting its effect on the mix. Even so, a sample with 65% CSS replacement still has a good bearing capacity.

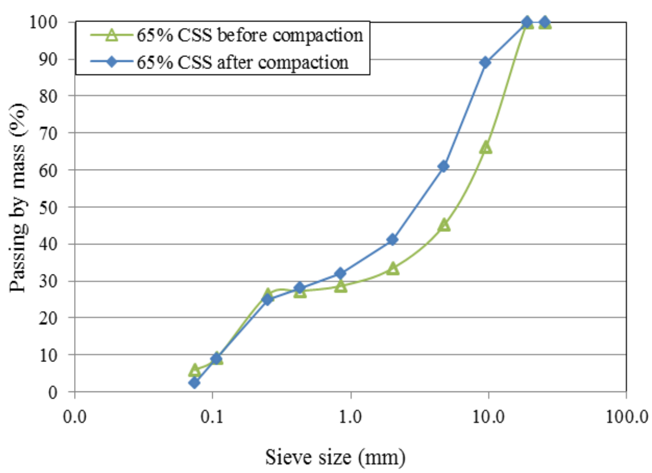

Fig. 8 Grain size distribution of material before and after compaction process.

IV. CONCLUSIONS

CSS can be considered as a gravel material, with flat but non-elongated particles of 25% of the Los Angeles loss value. It meets the requirements for it to be used as a sub-base and base coarse.

CSS addition to sandy soil increases the maximum density of sandy soil using less water than the control group with the same compaction energy. The CSS addition increases the CBR of the sandy soil from 51% to more than 100%.

The CSS addition to sandy soil can be used efficiently as a mechanical stabilization of sandy soil as a way of improving pavement requirements, even for a high load traffic base course.

Lack of cohesion in sandy soil and CSS requires the use of a binder to be used as a surface course in rural roads.

It can be concluded that crushed waste Peruvian Scallop has the potential to perform as a mechanical soil stabilizer or for soil modification. Changes in the physical properties of seashells may be of concern as any variation could have an effect on its mechanical properties. This consideration justifies further research.

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[35] AASHTO T180. Standard Method of Test for Moisture-Density Relations of Soils Using a 4.54-kg (10-lb) Rammer and a 457-mm (18-in.) Drop.

[36] ASTM D 1883 Standard Test Method for California Bearing Ratio (CBR) of Laboratory-Compacted Soils.

[37] ASTM D 1241 Standard Specification for Materials for Soil-Aggregate Subbase, Base, and Surface Courses.

[38] Little, D.N., and Nair, S., Recommended Practice for Stabilization of Subgrade Soils and Base Materials, *NCHRP Web-Only Document 144, National Cooperative Highway Research Program, Transportation Research Board*. Washington, DC. PDF version available: http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_w144.pdf, 2009.