

Serpentine waste from Moa Nickel S.A. company as stone powder substitute in hot asphalt mixes

Desechos serpentiniticos de la empresa Moa Nickel S.A. como sustituto del polvo de piedra en mezclas asfálticas en caliente

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Abstract: This study proposes to evaluate the solid mining waste from Moa Nickel S.A. with the purpose of using it as base aggregate in hot asphalt mixtures. To design the asphalt mixture, the Marshall Method was used. The relevant properties of a hot mix asphalt were considered: stability, durability, flexibility, fatigue resistance, resistance to cracking at low temperatures, resistance to moisture damage, skid resistance, and workability. The results obtained within the range of compositions, particle sizes, and experimental conditions applied in this study, indicate that a 60 %-serpentine waste is the most suitable composition. Serpentine waste from Moa Nickel S.A. possesses the adequate characteristics and properties to be used as a substitute for stone powder in hot asphalt mixtures, due to its similarity to the properties of this material; however, this is not the case for its use as a substitute for coarse aggregate.

Keywords: bituminous materials, construction materials, industrial waste

Resumen: Este trabajo propone evaluar los residuos serpentiniticos de la empresa Moa Nickel S.A. para ser empleados como árido base en las mezclas asfálticas en caliente. Para el diseño de la mezcla asfáltica se utilizó el Método de Marshall. Se tuvieron en cuenta las propiedades relevantes en una mezcla asfáltica en caliente: estabilidad, durabilidad, flexibilidad, resistencia a la fatiga, resistencia al fracturamiento por bajas temperaturas, resistencia al daño por humedad, resistencia al deslizamiento y trabajabilidad. En el rango de

composiciones, granulometrías y condiciones experimentales utilizadas en este estudio los resultados obtenidos indican que la composición de 60 % del desecho serpentinitico resulta la más adecuada. Los desechos serpentiniticos de la empresa Moa Nickel S.A reúnen características y propiedades propicias para ser utilizadas como sustituto al polvo de piedra en mezclas asfálticas en caliente por su similitud con las propiedades de este material, no así como sustitutos del árido grueso.

Palabras clave: materiales bituminosos, material de construcción, residuos industriales

Introduction

It is fundamental for the economic and social development of countries to count on a road network, including that of its industrial zones, with good conditions that allow for safe and fluid vehicular traffic (Andrade *et al.*, 2021; Tobar-Insuasty, 2024; Santana & Machado, 2025). However, the continuous use of industrial avenues leads to wear and tear on the road network due to increased vehicular traffic (Montoya-Alcaraz *et al.*, 2020; Zambrano-Bastidas & Villacreses-Viteri, 2023), especially marked in areas used by heavy transport. Therefore, ensuring the optimal condition of roads is essential for the efficient management of road infrastructure and transportation (Deepa & Sivasangari, 2023; Toral *et al.*, 2023, Ibragimov *et al.*, 2024).

Asphalt is a viscoelastic material derived from petroleum refining which is used in road construction (Shtayat, 2000; Beyra-Fernández *et al.*, 2023). According to Diaz-Romero *et al.* (2022), the correct preparation of raw materials is fundamental for its production. Advances in asphalt technology encourage the use of alternative materials that optimize its properties and contribute to sustainable development (Bobadilla Peña *et al.* 2022). The use of waste materials in asphalt mixtures is an option that not only seeks to improve the asphalt but also offers favorable solutions for environmental conservation (Cardona-Moncada *et al.*, 2023; Rybak-Niedziólka, 2023; Zapata Ferrero, 2024; Cobeña Looor *et al.*, 2025; Milad, 2025).

Furthermore, studies show that wastes from the Cuban nickel industry can have multiple uses (Quintana Puchol *et al.*, 2016; Osorio Ormaza *et al.*, 2024; Pons-Herrera *et al.*, 2024). This paper proposes to evaluate, from a technological perspective, serpentine waste from Moa Nickel S.A. as a usable base aggregate in hot asphalt mixtures.

Materials and Methods

Serpentine waste from Moa Nickel S.A. was used to conduct the research.

Sample size was reduced through two crushing cycles. In the first stage, impact crushing with a sledgexhammer was used until 100-mm fragments were obtained. For the second stage, a TQ jaw crusher was used until a particle size between 10 and 20 mm was obtained. A ball mill with a diameter of 198 mm and a rotation speed of 70 rpm was used for the grinding process. To select particles with a diameter under 0.25 mm, a sieving process was carried out.

Tests performed on the raw material

Granulometric test: it was performed in accordance with NC 178 (2002). An oven with a constant temperature between 105 °C - 110 °C, a balance, a mechanical sieve shaker, and brushes were used. The samples were obtained by the mechanical quartering system (Table 1).

Table 1. Minimum weight of representative sample for tests in accordance with NC 178 (2002)

Granulometry	Maximum nominal particle size (mm) (passing sieve)	Minimum weight of representative sample (kg)
Fine	2.00 mm (No.10)	0.1
	4.76 mm (No.4)	0.5
Coarse	2.00 mm (No.10)	0.1
	4.76 mm (No.4)	0.5
	9.52 mm (3/8 pulg)	1
	12.7 mm (1/2 pulg)	2.5
	19.1 mm (3/4 pulg)	5
	25.4 mm (1 pulg)	10
	38.1 mm (1.5 pulg)	15
	50.8 mm (2 pulg)	20
	65.5 mm (2.5 pulg)	25
76.2 mm (3 pulg)	30	
88.0 mm (3 ½ pulg)	35	

The sample was separated using the necessary sieves following the specifications for the material use. The procedure for determining the sieve analysis was carried out with a single layer of material. Portions of 4.76 mm were retained. These results allowed for calculating the fineness modulus by using the following expression:

$$\text{Fineness modulus} = \frac{\sum \% \text{ retenidos}}{100} = 3,8 \%$$

To determine the volumetric weight, the loose and compacted densities were calculated with the formula below:

$$D = \frac{P - \text{Tare}}{V}$$

Where:

D: Density (loose or compacted)

P: Weight (loose or compacted)

Tare: container's weight

V: container's volume

Material finer than a No. 200 mesh sieve.

A 500-g sample was extracted, and water was added until the material was completely covered. It was shaken until fine particles were suspended to separate them from the coarser ones by passing the water through the 0.074-mm mesh sieve. The remaining material from the container and the sieve was dried and weighed to calculate the mass loss resulting from washing. The formula to calculate the percentage of material finer than the 0.074-mm mesh sieve is:

$$\% \text{ of material passing through a no. 200 mesh sieve} = \frac{a - b}{a} 100 \%$$

Where:

a: weight of the original dry sample

b: weight of the dry sample after washing

Properties to consider in asphalt mixture design

The relevant properties of a hot asphalt mixture that were considered are: stability, durability, flexibility, fatigue resistance, resistance to cracking at low temperatures, resistance to moisture damage, skid resistance, and workability.

Asphalt Mixture Design

The Marshall Method was used for the asphalt mixture design; hence it was necessary to prepare a series of specimens containing mixtures of aggregates with determined composition and gradation, and different asphalt contents. The optimal asphalt content depends on the gradation and absorption capacity of the aggregate. This content varies from 5 to 6 % of the bituminous concrete total mass.

The trial-and-error method was used for the aggregate combination to add to the mixture. Material from Cerro Calera Bariay quarry was used as base aggregate for the production of hot asphalt concrete, with two gradations: 3/8 gravel with a 5–10 mm fraction (60 %) and stone powder with a 0.075–4.75 mm fraction (40 %) as fine aggregate. Serpentine waste from Moa Nickel S.A. was added in two variants. The first one proposes its use to substitute the stone powder, and the second one to replace 3/8 gravel. Both cases respected the quantity and gradation of the initial aggregate; therefore, this material was used following the same quantity and the same granulometric characteristics as the material from the quarry.

Specimen Preparation

Specimens with a diameter of 101.6 ± 0.25 mm and a height of 65 ± 3.2 mm were placed in 6 trays per each asphalt percentage. The previously dried and cooled aggregate was added to obtain its weight, and they were placed in the oven at a temperature ranging between 170 °C and 190 °C. The asphalt was heated on a heating plate to a temperature between 145 °C and 160 °C. It should not be kept at this temperature for more than one hour, and reheated asphalt should not be used. The asphalt in the container was stirred frequently to avoid local overheating. The aggregate mixture was stirred until a crater formed in the center. The container with the aggregate was placed on the balance, marking the total weight (Tare + Aggregate weight + Asphalt weight).

The necessary amount of asphalt was added —the quantity was determined by weight difference. The temperature of the aggregates ranged between 140 and 155 °C; if it was

lower, it was necessary to increase the asphalt temperature by a range of 5 to 10 °C. The aggregates were mixed with the asphalt until a homogeneous mixture was achieved. Upon completing the mixing, the temperature of the mixture ready for compaction should not be below 120 °C; if lower, the batch is discarded. To achieve uniform results, it was convenient to maintain a consistent mixture temperature.

Before preparing the mixture, the mold assembly and the compaction base were heated to a temperature between 100 °C and 150 °C in a boiling water bath. A 10-cm-diameter filter paper disc was placed on the surface of the mold base, and the freshly mixed mixture was poured, avoiding material segregation and distributing the mixture well inside the mold using a spatula, finally providing a rounded shape to the surface. Under these conditions, the specified number of blows was applied with the sledgehammer. After compacting the first face, the collar was removed, the mold with the specimen was inverted, the collar was replaced, and blows were applied to the other face. Seventy-five blows per face were applied for the compaction of mixtures designed for medium to heavy traffic. After compaction, the collar and base were removed, and the mold with the specimen was submerged in water at room temperature for 2 minutes. The sample was removed from the mold using an extractor jack.

Tests performed on bituminous concrete

Determination of stability and deformation

The Marshall Stability value is a measure of the load at which a specimen yields or fails. When the load is applied slowly, the upper and lower heads of the apparatus move closer, and the load on the briquette increases, as does the reading on the dial indicator gauge. Once the maximum value is obtained, the load is suspended. The maximum load indicated by the meter is the Marshall Stability value according to NC 261 (2005).

The specimens were submerged in a water bath at 60 ± 5 °C for 30 minutes before testing. The guide rods were greased with a film of oil so that the upper jaw could slide freely. The specimen was removed from the bath and centered on the lower jaw. The load was applied to the specimen on its lateral surface using the Marshall equipment, at a constant speed of 50.8 mm/min until failure occurred. The failure point is defined by the maximum load obtained. Marshall Stability is defined by the following formula:

$$S = Q \cdot Fc \cdot k$$

Where:

Q: Proving ring reading

Fc: Height correction factor

k: Ring constant (kg/mm or kN/mm)

The maximum load occurs at the moment of the first stop or instantaneous maximum observed on the proving ring comparator. The entire stability and deformation test process, which begins upon removing the specimen from the water bath, must be completed within a 30-seconds period.

Determination of specimen's apparent density

The apparent density of a compacted asphalt mixture is determined out of the mass of the specimen and its volume. The specimen's volume is obtained by the ratio of its mass in air to its mass in water. The density of water at 30 °C should be 994.3 kg/m³. The apparent density of the specimens can be performed as soon as the freshly compacted specimens have cooled to room temperature. The Coated Sample Method was used for its determination. The entire surface of the sample was coated with a layer of waterproofing material (paraffin at 58 °C), sufficiently thick to ensure the sealing of all surface voids. The coated sample was air cooled for about 30 minutes, and its mass was determined, designating this value as D. Subsequently, the mass of the paraffin-coated sample in water was determined by submerging it in the balance basket, obtaining value E. The density of paraffin is 1,12 g/cm³ (F). The density was calculated using the following expression:

$$D_a = \frac{A}{\left(\frac{D-E}{\delta}\right)\left(\frac{D-A}{F}\right)}$$

Determination of volumetric parameters

For all calculations where the volume occupied by the aggregates is required, their standard specific gravity will be used. To facilitate the calculation of void percentage, specific gravity value of the combined aggregates (PE_{comb}) is determined using the equation below:

$$PE_{comb} = \frac{100}{\left(\frac{P_1}{PEC_1}\right) + \left(\frac{P_2}{PEC_2}\right) + \left(\frac{P_3}{PEC_3}\right) + \dots + \left(\frac{P_n}{PEC_n}\right)}$$

Where:

P_1, P_2, P_3 : Percentage of aggregates 1, 2, 3... relative to the total weight of aggregates (%)

$PEC_1, PEC_2, PEC_3, PEC_n$: Standard specific gravity of aggregates 1, 2, 3..., n (g/cm^3)

If the values of the effective specific gravity are unknown, asphalt absorption can be assumed as 50 % of water absorption for limestone aggregates and 30 % for aggregates of igneous origin (serpentinite). The percentage of water absorbed by the dry sample is calculated as:

$$\% \text{ absorption} = \frac{B - A}{A} 100$$

Where:

A: Weight of the sample dried in the oven, (g)

B: Weight of the sample saturated-surface-dry

Absorbed asphalt proportion (P_{ba}), in %

$$P_{ba} = \frac{A_b P_a}{100}$$

Effective asphalt proportion (P_{be}), in %

$$P_{be} = P_b - P_{ba}$$

Maximum theoretical density of compacted specimens (DMT)

$$DMT = \frac{100}{\frac{P_a}{PE_{comb}} + \frac{P_b}{PE_b} - \left(\frac{A_b P_a}{100 \cdot PE_b} \right)}$$

Where:

P_a : Percentage of aggregates referred to the weight of the mixture, (%)

P_b : Percentage of total asphalt referred to the weight of the mixture, (%)

PE_b : Specific gravity of asphalt, (g/cm^3)

Percentage of voids in the compacted aggregates (HA)

$$HA = 100 - \frac{P_a D_a}{PE_{comb}}$$

Percentage of voids in the compacted mixture (HA)

$$HA = 100 - \frac{100 \cdot D_a}{PE}$$

Determination of asphalt's specific gravity

Specific gravity is the ratio of the weight of a given volume of material to the weight of an equal volume of water, both being at specific temperatures. To establish specific conditions applicable to a given specific gravity value, the material and water temperature must be indicated. This is one of the factors to determine voids in asphalt mixtures, which is valid to correct the volume when measured at elevated temperatures.

Results and Discussion

Tests Performed on raw materials

A value of 7 % of material passing the No. 200 mesh sieve was obtained.

Analysis of the granulometric test

A 2,000 g sample of serpentine waste was taken. It was sieved, selecting 6 sieves from 4.76 mm down to 0.074 mm. After 10 minutes on the shaker, the retained content was weighed, and the equivalence to cumulative percentage and percentage passing through the sieve were calculated (Table 2).

Table 2. Results of the serpentine waste sample

Sieve (mm)	Mass	Retained (%)		Cumulative
Passed-Retained	retained (g)	Partial	Cumulative	(%)
2.38	232.7	11.635	11.635	88.365
0.63	547.9	27.395	39.03	60.97
0.315	430.7	21.535	60.565	39.435
0.149	327.8	16.39	76.955	23.045
0.074	230.6	11.53	88.485	11.515
Bottom	230.3	11.515	100	0

According to NC 253 (2005), the material does not meet the gradation to be used as filler, because the percentage passing the No. 200 mesh sieve is very small (0.074); however, it could be applied if subjected to a crushing process. On the other hand, it does meet the specifications for fine aggregates, as well as the standard related to stone powder.

Volumetric Weight

For this test, a balance and a container with a mass of 1194 g and a volume of 2720 cm³, were used. It was filled by pouring the material lightly, pointing towards the center; excess material was removed until it was leveled with the container's rim. The loose weight obtained was 1580.4 g. To determine the compacted weight, the container was divided into 3 equal fractions, corresponding to three layers, as the material was poured. Each layer received 25 blows without affecting the previous one until the container was filled; it was then weighed, obtaining a compacted weight of 4458 g. On the base of the weight values obtained, the loose and compacted densities were calculated. The following results were obtained: D Loose = 1.02 g/cm³, D Compacted = 1.12 g/cm³.

Results for the Proposed Variants

Table 3 shows the results of the tests performed on asphalt with serpentine waste as a stone aggregate in both variants.

Table 3. Test results of tests performed to the waste materials

Variants	Asphalt (%)	Actual Density (g/cm ³)	Stability (KN)	Deformation(mm)	% Voids
1	6	2.22	7.51	2.04	6.3
2	5.4	2.57	11.43	3.16	4.8

The current specifications proposed in standards NC 253-2005 and NC 261-2005 for the different tests performed on dense mixture are:

Asphalt percentage: 5-6

Stability: 9.25-11

Deformation: 2-3

Voids in the mixture: 4-6

Density: 2.30-2.32

The first variant complies with the standard in all aspects except for the percentage of voids, whose result exceeds the stipulated value by 0.3%, a small value that may not considerably affect the mixture but is worth noting. The second variant, although not complying with the standard, its values are reasonably close, demonstrating that both variants can be used, prioritizing Variant 1.

Taking into account the results of the asphalt mixture, as well as the tests on the serpentine waste, Variant 1 (5.8 % asphalt cement + 60 % serpentine waste + 34.2 % granite) is proposed as the most appropriate dosage.

Technical Analysis

The results of the Marshall test can be used to perform an analysis to verify the technical quality of the serpentine waste as stone powder substitute in the design of hot asphalt mixtures. To conduct this analysis, the results of the corresponding tests performed on the material are compared, and their conformity is evaluated according to NC-759:2010 provisions. Upon comparison, it is determined that the serpentine waste can be used for substituting stone powder (Variant No. 1). Its usage includes the advantages below:

1. Serpentine waste meets the standard granulometry, sometimes exceeding quality standards, so it is considered a viable alternative option.
2. Unlike stone powder, it meets the requirements of the material-finer-than-the-No.200-mesh-sieve test, which contributes to asphalt savings, increased quality, and reduced costs.
3. It shows similarity to stone powder regarding the percentage of voids (although it manages to slightly minimize them).
4. The material is also compliant with the fineness modulus, a fact that provides it advantage over stone powder; thus, it is considered to contribute to the reduction of the void percentage.

Conclusions

The serpentine waste from Moa Nickel S.A. possesses characteristics and properties favorable to its use as a stone powder substitute in hot asphalt mixtures, due to its similarity to the properties of this material; however, this is not the case for its use as a coarse aggregate substitute.

A dosage proposal was made that allows achieving advantageous results from environmental, economic, and technical perspectives in comparison to a conventional mixture.

Within the range of compositions, particle sizes, and other experimental conditions used in this study, the results obtained indicate that a composition with 60 % of serpentine waste is the most suitable one.

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