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Construction of pavers from drilling cuttings as an alternative for environmental management of waste

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Abstract

The management of drilling waste represents a problem of high economic and environmental impact for operating companies. This is due to its polluting components that, besides being dangerous for the environment, must be treated with special care. The cuttings generated during drilling which are normally impregnated with water-based and oil-based muds, represent most of this solid waste. In this work, it is proposed to treat the drilling cuts to be used as raw material for construction of paving stones that can be used as construction material in platforms and facades of buildings or houses, being an alternative of innovative and high impact disposition. For the foregoing, a determined volume of drilling cuttings from a well of a Magdalena Medio field was used as a test, performing all the usual solids control treatment, passing through shakers, desander, desilter and mud cleaner. After treating the perforation cuts, they were dried in an oven between 110 and 150 °C for 24 hours. Then the sample was allowed to cool to grind it and bring it below 45 microns; where it was finally used as material for the construction of the paving stone, to which the resistance tests established in the NTC 2017 standard were carried out. Results show that the use of some drilling cuttings in the construction industry is viable. Conversely, the comparison was made with a conventional way of managing the gravel when it was reused in the production of cobblestones, obtaining a reduction of up to 34% of the associated costs and when there are greater than 12,000 barrels of waste. Additionally, it is used to generate valuable items and avoids the disposal of waste material.

Key words. Drilling wastes, pavers, drilling cuttings.

1. Introduction

Thousands of wells are drilled every year in the world; in 2021 alone, 25 exploratory wells were drilled [1]. This generated thousands of barrels of solid waste, whose management represents a problem of high environmental and economic impact for the operating companies. Almost 590,000 tons of solid waste were generated during drilling in 2019, of which 3,038.42 tons were hazardous waste. Most of these wastes are represented by cuttings generated during drilling [2]. These consisting of small pieces made up of minerals from the drilled formations which include clay, shales, sandstones, carbonates and halides [3], that are usually impregnated with water-based and/or oil-based muds, which have highly polluting components that are not only dangerous for the environment, but must also be disposed of with special care. This cuttings and fluids are disposed of in the soil, which produces changes in their physical, chemical, and microbiological properties, thus altering water quality through runoff-related processes and affecting the adjacent wildlife.
Thus, cuttings generated by drilling processes have been the object of study and treatment in recent years. Research that delves into whether the cuttings could be used as possible raw material for the construction of different materials, which would further avoid the environmental pollution involved in disposing of them in pools, or in reinjection through hydraulic fracturing, processes that require high water content, addition of chemicals and does not ensure that the border areas of the formation are not contaminated [4] [5].

Much of the environmental, technical and economic problems generated by the disposal of drilling wastes motivate the search for different environmentally friendly, innovative and profitable alternatives. Among these, the use of drilling cuttings as raw material for the construction of pavers, complying with the nation's environmental disposal and regulatory regulations.

The process of treatment and preparation of drill cuttings to be used as raw material in the construction of paving stones consists of performing an initial lithological analysis and characterizing the formation samples. Since clay formations are not viable for this project due to their low sand content and high compaction, it makes it difficult to extract materials that are useful in the construction of paving stones.

Several studies have been carried out for the use of drill cuttings in construction. Chen et at. [6] investigated in Taiwan on the use of drill cuttings' residues for the construction of bricks, permeable blocks and as partial substitutes for concrete. In these studies, high contents of iron, aluminium, calcium, magnesium, potassium and manganese were found in the samples. However, they did not fail to comply with the Taiwan regulations. The riprap samples used in this study were dried at 100°C for 24 hours, then milled and used to make bricks according to Taiwanese standards.
Chiappori et al. [7] applied the use of drill cuttings as substrate in the construction of new well locations in Argentina. Here they mixed the drill cuttings with calcareous material to improve the plasticity properties and

increase their density. Subsequently the respective construction tests were carried out in the locations where it was demonstrated that the integrity of the locations was not compromised, reaching the necessary levels of compaction and impermeability.

In Ecuador, a study [8] was carried out using water-based drilling cuttings as brick construction material. This comes from different representative samples during a different disposal period with a variation of moisture content between 21% and 26.4%, in order to identify how the final disposal time of the riprap in the confinement cells affects the confined compressive strength properties, which complied with the NTE INEN 297 standard of Ecuador. Therefore, finally applying them in the construction of interior and exterior walls that are not exposed to extreme rainfall conditions.

This present study was developed because, despite there being evidence of studies and research on the use of drilling cuttings for construction, within Colombia, there are no studies according to the internal regulations – Decree 4741 of 2005 and the NTC 2017 (second update). In this study, it was taken a test of a determined volume of riprap from a field located in VMM, performed all the usual treatment of solids control, oven dried temperatures that were handled between 100 and 150°C for 24 hours, and the sample was taken below 45 microns to be used as material for the construction of the cobblestone. In this way, waste is utilized and recycled so as not to generate alterations and contamination of the soil in the areas of impact.

2. Methodology developed

In order to adapt the drilling cuttings as raw material for the production of pavers, it was necessary to carry out the entire initial treatment process of separation of solids, by sedimentation, sieves and centrifuges. Then, the temporary storage that is usually given to the cuttings once extracted from the well was performed. After storage, the procedure to adapt them as raw material for the construction of pavers was started. The following is a description of each of the processes carried out for their adaptation.

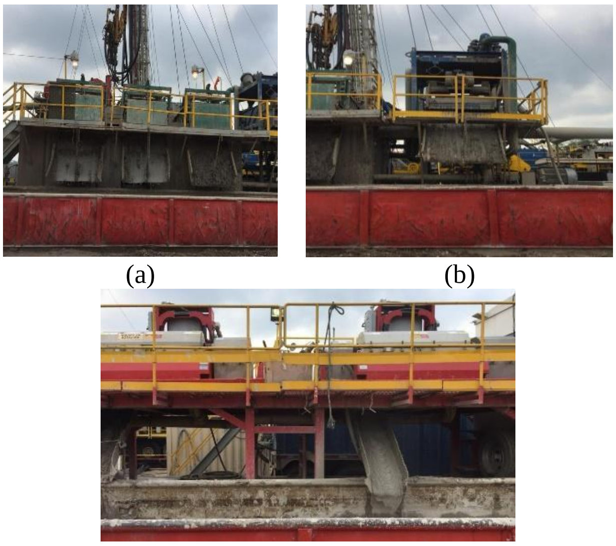
A. Sample lithology

Samples were taken from the La Cira Infantas field, from well RIG-118, extracted and drilled in the Mugrosa formation, in Zone C at a depth of 3970 ft.

The Mugrosa formation is characterized by a sequence of greenish gray sandstones, gray mudstones and layers of conglomerate sandstones interbedded with shales and mudstones. Its top is composed of a shale package that is approximately 200 ft thick, with abundant bioturbation. This is one of the most oil-producing units in the Mares concession. The depositional environment is considered as fluvial continental which is conformed by meandering channels that are characterized by decreasing grains towards the top in the channel facies and increasing grains in the crevasse splay facies [9]. Specifically, Zone C, is composed of gray-greenish sandstone, medium to coarsely grained, sub angular to sub rounded, clayey matrix, regular to poorly sorted, with thin intercalations of greenish gray, dark reddish gray and white claystone with an average thickness of 550 ft [9].

B. *Sample traverse*

After drilling the C formation, the sample rises to the surface with the help of the drilling fluid. The first equipment to receive the sample are the Shale Shakers (Figure 1a), which removes much of the sample in the vibrating screens. Then the fluid passes through the Mud Cleaner (Figure 1b), recovering the liquid phase by which produces drier cuttings, finally passes through centrifuges where it retains the smallest debris, larger than 3 microns (Figure 1c). [10].



(a) (b) (c)

Fig.1. Well Rig-118 solids control equipment

C. *Packaging of the samples*

Sampling was carried out in each of the solids control equipment, individually packed in airtight bags and wrapped in vinipel paper, so as not to lose mass or fluids during transport. Shale shaker samples have a particle size greater than 105 microns, mud cleaner samples have a particle size between 105 and 75 microns and centrifuge samples have a particle size between 75 and 3 microns (see Figure 2).

Fig.2. Rig-118 well cuttings

D. *Sample composition*

After collecting the samples, the geological characterization was carried out, resulting in the composition shown in Table 1.

Table 1. Geologic composition of drill cuttings in well Rig-118

Type	Composition%	Description
Sand	60%	Quartzose, very fine grained, minor fine grained, colorless, sub spherical, good sorting. No hydrocarbon manifestation.
Claystone	40%	Medium to light gray, greenish-gray, moderately firm, sub-blocky; soluble; not calcareous.

3. Results

The most optimal sample was chosen to produce the pavers according to the particle size of the three samples obtained from the solids control equipment. The one chosen was that of the Mud Cleaner since having an average particle size (105-75 microns) met the specifications of the NTC 2017 standard [10].

A. Production of pavers

In order to have the composition normally used for the construction of pavers, the company *Baldosines Santafé*, located in Bucaramanga, provided the ratio of materials used for each kilogram of cement, to which a comparison was made using the material obtained from the drilling cuttings, as shown in Table 2.

Table 2. Ratio of materials used conventionally vs. ratio used with drill cuttings

Ratio of materials per kilogram of cement		
Material	Conventional [kg]	Experimental [kg]
Cement	1	1
Water	0,35	0,35
Sand	5,3	2,5
Cuttings	0	2,5

The test ratio shows that the ratio of cement to sands representing crusher sand and drill cuttings has been decreased. After the materials were mixed, they were placed in the mold and subjected to a pressure of 133446 Pa, extracted from the mold and left to sit for 12 hours. This was done in order to prevent the pavers from being damaged or prematurely dried out by direct sunlight and/or abrasion from strong winds.

Finally, they were left to rest for 10 days in order to reach the desired strength according to the NTC 2017 standard [10]. In total, 6 beveled pavers with a dimension of 10 cm wide, 20 cm long and 5.5 cm high were obtained (See Figure 3).

B. Resistance testing of pavers

Once the pavers are built, it is necessary to evaluate if they comply with the current regulations, according to the NTC 2017 (Second update) [11]. There are different tests that should be practiced to the pavers, such as:

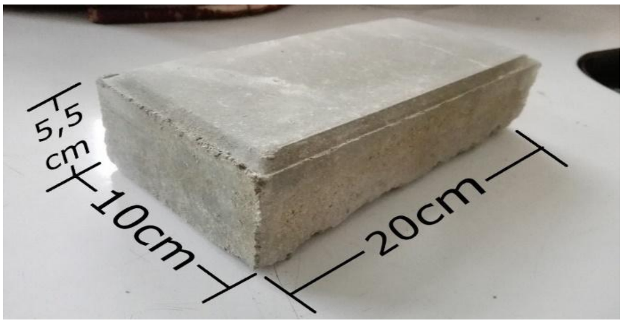


Fig.3. Cobblestone constructed with cuttings from well Rig-118.

Water absorption (Aa%). According to NTC 2017 [11] pavers must have a percentage of no more than 7% of total water absorption (Aa%) as an average value. To perform the test, a representative sample must be taken to which the measurement will be made, a balance with 1g of sensitivity and a ventilated oven with controlled temperature between 100°C and 115°C is required.

Procedure. For the water absorption test it was necessary to perform two steps, drying and saturation. For the drying process all the samples were left to dry simultaneously in a ventilated oven at a temperature between 100°C and 115°C. They should be at least 25 mm apart and they should be dried until a constant dry mass (Ms) is obtained. The samples should then be allowed to cool to room temperature to continue the saturation process.

After obtaining the dry mass, the samples were submerged for 24 hours in a container filled with water at a temperature between 15°C and 27°C, so that the height of the water left over from their entire volume would be between 25 mm and 50 mm.

At the end of the saturation period, the samples are weighed while immersed in water and suspended by means of a wire to obtain the mass immersed in water (Ma). Then the water must be removed, allowed to drain for 1 minute and weighed immediately to obtain the saturated or wet mass (Mh).

The water absorption (Aa) of the total sample mass should be calculated using Equation 1, with an approximation of 0.1% between each sample:

$$Absorption\ (Aa), \frac{kg}{m^3} = \left[\frac{M_h - M_s}{M_h - M_a}\right] * 1000 \qquad (1)$$

Where *Mh* = saturated (wet) mass of the sample in grams, *Ms* = dry mass of the sample in grams, and *Ma* = water immersed and suspended mass of the sample in grams.

The water absorption tests were carried out at the Materials Characterization Laboratory of the School of Civil Engineering of the Universidad Industrial de Santander, where the results presented in Table 3 were obtained. Specimen A is the name given to the pavers built with drilling gravel from well Rig-118 and specimen B to the commercial pavers.

Table 3. Results of the water absorption test on pavers.

Specimen	Dry Weight (kg)	Saturated Weight (kg)	Absorption %
A	2400.8	2452.7	2.12
B	2324.0	2412.3	3.66

According to the results obtained, it is evident that the paving blocks manage percentages in accordance with current regulations, since they do not exceed the 7% established by the NTC 2017.

Flexural strength or modulus of rupture (Mr) test. Pavers must meet the flexural strength or modulus of rupture requirements established by the standard, as set forth in Table 4 [11].

Table 4. Flexural strength requirements, Modulus of rupture (Mr).

Modulus of rupture (Mr), Minimum, MPa	
Average	Individual
5.0	4.2
4.2	3.8

Procedure. The standard [9] establishes that equipment for the determination of flexural strength capable of applying loads of 20Kn must be available. The load should be applied at a speed that produces an increase in stress close to 0.5 MPa/s, i.e. a time of 10 seconds for every 5 MPa, for each paver the modulus of rupture (Mr) should be calculated, according to equation 2.

$$M_r = \frac{[3C_{max} * (li - 20)]}{[(ar + ai) * er^2]} \qquad (2)$$

Where Mr = modulus of rupture in MPa, Cmax = maximum ultimate load in N, li = length of the inscribed rectangle in mm, ar = actual width in mm, ai = width of the inscribed rectangle in mm and er = actual thickness in mm.

This test was carried out at the Materials Characterization Laboratory of the School of Civil Engineering of the Universidad Industrial de Santander. The equipment used for this test is shown in Figure 4 and the test results in Table 5.
The standard [11] establishes a minimum modulus of rupture of 5 Mpa, which complies with Colombian standards.

Table 5. Results of the flexural tensile test on pavers

Specimen	Sample ID	Maximum load (N)	Modulus of rupture (Mpa)
A	L5	6602.1	5.9
B	L6	8603.4	5.5

Fig.4. Flexotraction measuring equipment of the Universidad Industrial de Santander.

Abrasion resistance test. This test consists of subjecting a sample to wear by abrasion, under controlled conditions, by a flow of sand passing tangentially between the surface and the lateral face of a metal disc that exerts pressure against it (see Figure 5). This generates an imprint, with the shape of the curved surface of the metal disk, whose resulting length is inversely proportional to the abrasive wear resistance of the sample [12].

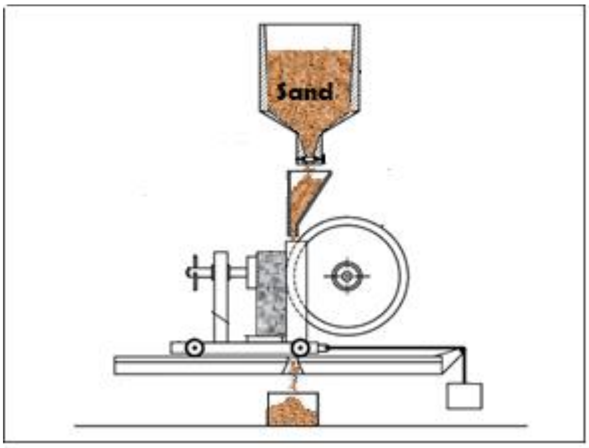


Fig.5. Abrasion test equipment. Source: Colombian Technical Standard 5147, Instituto de Normas Técnicas y Certificación (ICONTEC) 2002. Page 2.

Procedure. It consists in the first instance in filling the storage hopper with the abrasive material, in dry state, and an empty container should be placed under the metal disc to collect the abrasive material that was used for the test. The specimen should be placed in contact with the metallic disc; then the flow control valve should be opened and, simultaneously, the motor should be turned on, so that the metallic disc completes 75 revolutions in 60 s ± 3. After the 75 revolutions of the disc, the flow of the abrasive material should be suspended, and the disc should be stopped [12].

This test was carried out by the Laboratory of the School of Civil Engineering of the Universidad Pontificia Bolivariana, the results are shown in Table 6.

The standard establishes that the average value of the footprint length may not exceed 23 mm, complying with the three technical requirements of NTC 2017 on the requirements in the construction of pavers.

Table 6. Abrasion test results

Sample	Dimensions		Calibration factor	Footprint length (AB)	Corrected length (lh)
	Length (mm)	Width (mm)			
A	105	103	20.30	18.70	18
B	100	101	20.30	17.11	17

According to the previous results, the pavers support a compressive strength (fp) of 300 kg/cm², which generates low maintenance costs, they are resistant to fuels, oils, grease, frost effects, and de-icing salt, while bituminous pavements, without special treatments, degrade. However, one of the limitations lies in their processing, which is done by hand. Another limitation is that pavers do not allow high traffic speeds, but they are perfectly suitable for the usual speed level in cities (up to 60 km/h).

The pavers should not be subjected to a jet of water at high pressure, as it may cause loss of seal in the joints, so one of the limitations is that it can not be used as a water channel that has to withstand large and fast currents type "stream". Otherwise, the pavers can have a useful life of up to 30 years.

C. Economic analysis

At present, the cost of disposing the cuttings from the field under study fluctuates between $4 USD and $6 USD per barrel, which varies depending on the final moisture content at which the cuttings are disposed.

The cost of disposal was determined at different volumes, taking the average cost of $5 USD/BBL of cuts and a TRM of COP $3,000.

Table 7. Study field riprap disposal costs

Barrels of cuts (BBls)	Total cost of disposal (COP$)
1000	$15.000.000
2000	$30.000.000
3000	$45.000.000
4000	$60.000.000
5000	$75.000.000
6000	$90.000.000
7000	$105.000.000
8000	$120.000.000
9000	$135.000.000
10000	$150.000.000
11000	$165.000.000
12000	$180.000.000
13000	$195.000.000
14000	$210.000.000
15000	$225.000.000

In the field study a well was drilled to a depth of 7345 ft, and approximately 4640 barrels of riprap were generated, these data were taken as an average and represent significant quantities that can be obtained during a drilling process.

Cost of a paving stone construction plant. To implement a basic plant for the construction of paving blocks, the minimum machinery required is a semi-automatic hydraulic machine model AF 0013, a transported cart and a 10x20x6 cm paving block mold. For the economic analysis, a quotation was requested for the required tools as detailed in Table 8.

Table 8. Quotation for the implementation of a basic paving stone construction plant.

Quantity	Description	Unit Price
1	Semi-automatic hydraulic machine model AF 0013	$120.000.000
1	Conveyor trolley	$500.000
1	Mold for paving stone 10x20x6 cms	$15.000.000
1	Transportation	$2.000.000
	IVA (19%)	$26.125.000
	TOTAL	$163.625.000

Quotations were requested from different paver companies, analyzing the production costs per unit, obtaining ranges between $400 and $600 Colombian pesos. However, by using drilling gravel as raw material for the construction of the pavers, production costs are reduced by up to 85%, since half of the sand is replaced by gravel and no fresh water is required because the humidity of the gravel is sufficient for their construction. Obtaining a unit cost of $60 Colombian pesos.

Knowing that the study field has an average cost of $5 USD/BBl of arranged cuttings, which implies a fixed cost over time. In the case of implementing a paving stone construction plant, an initial investment of $163.625.000 Colombian pesos would be needed.

Equation 3 can be used to determine how many barrels of cuttings produced will equal the initial investment costs for the paving stone plant.

$$Bbls\ of\ cuttings = \frac{initial\ investment}{\$5\frac{USD}{Bbls\ of\ cuttings} * TRM} \quad (3)$$

$$Bbls\ of\ cuttings = \frac{163.625.000}{5 * 3.000} = 10.908\ Bbls$$

Taking into account that to build a paver, water and sand generally represent about 85% of the material needed and the other 15% of cement (percentages in volume); it is possible to calculate how many pavers are built per barrel of cuttings produced. Bearing in mind that: 1 barrel=158987 cm31 barrel=158987, that the paver volume= 1200 cm3 and that the volume of cuttings= 1200 cm3*85%= 1020 cm3 the number of pavers built per barrel of cuttings is as shown in equation 4.

$$Pavers\ built\ per\ barrel\ of\ cuttings = \frac{158987\ cm^3}{1020} = 155\ pavers \quad (4)$$

Having the unit cost of the paver and knowing the production of pavers per barrel of cuttings, the cost of disposing of a barrel of cuttings is determined with the alternative of building the paver plant, as shown in equation 5.

$$Cost\ of\ disposing\ of\ a\ barrel\ of cuttings = Unit\ cost * Pavers \quad (5)$$

$$Cost\ of\ disposing\ of\ a\ barrel\ of cuttings = COP\ \$60 * 155 = COP\ \$9300$$

According to Table 7, the current field disposal cost for a barrel of drill cuttings is approximately COP $15,000 pesos, while the disposal cost for a barrel of cuttings in the paver plant project is COP $9,300 pesos, showing a 38% cost reduction.

4. Conclusion

The results obtained indicate that it is possible to construct pavers using drill cuttings, reducing the environmental impact generated by conventional methods of disposal and treatment of cuttings as well as the costs associated with these treatments. It also avoids the accumulation of drill cuttings in the locations and the consequent affectation of additional areas for their disposal. The possibility of using drilling waste in the manufacture of pavers opens the possibility of generating value through the construction of eco-efficient business models that have recycling at their core.

The lithology required for the construction of pavers with raw material from drilling riprap must be composed in greater proportion of sands to meet the strength requirements of NTC 2017.

According to the results of flexural, water absorption, and abrasion tests, the pavers are suitable for the construction of concrete pavers for foot traffic, vehicular traffic on pneumatic tires (including port and cargo terminal yards, airports, transportation terminals, service stations, warehouses, among others), and distributed static loads (from bulk storage) and have a service life of up to 30 years.

Boreholes drilled with oil-base muds are unfavorable because they contaminate and make the separation between the mud and the cuttings more complicated, affecting the percentage of humidity.

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