INVESTIGACIÓN e INNOVACIÓN en INGENERÍAS
ISSN2344-8652

Physical and mechanic characterization of the sterile part of coal, searching for an environmental alternative in civil infrastructure works

Caracterización físico-mecánica del estéril de carbón, en busca de una alternativa ambiental para las obras de infraestructura civil

Andrés Gutiérrez Bayona, Carlos Javier Obando Gamboa, Cristian Jair Moreno Moreno

Fundación Universitaria Agraria de Colombia

Abstract

Objective: The present investigation is focused on physically and mechanically characterizing multiple Samples of the coal waste belonging to the municipality of Lenguazaque (Cundinamarca), with the purpose of identifying the possible use of this material in engineering, especially in road infrastructure works.

Methodology: Normative foundations were used, techniques that generated results and information provided by the Ministry of Mines who indicate that the contribution of mining to the growth of the country's economy has shown high growth in recent years, which contrasts with the negative effect that this practice entails on the environment, taking into account that in the extraction of coal there are solid residues resulting from the exploitation of this mineral, these residues are called "sterile coal", which are mostly removed from the carbon so as not to affect the energy potential of the product.

Results and conclusions: The results of the research are encouraging since its characteristics place the material as an alternative for the construction of low traffic road structures.

Keywords: Oal, residue, sterile of coal, characterizing, road infrastructure, alternative usage.

Resumen

Objetivo: La presente investigación se enfocó en caracterizar física y mecánicamente múltiples Samples del estéril de carbón perteneciente al municipio de Lenguazaque (Cundinamarca), con el propósito de identificar el posible uso de este material en la ingeniería, en especial en obras de infraestructura vial.

Metodología: Se utilizaron fundamentos normativos, técnicas que generaron resultados e información suministrada por el Ministerio de Minas quienes indican que la contribución de la minería al crecimiento de la economía del país ha presentado un elevado crecimiento en los últimos años lo cual hace contraste con el efecto negativo que esta práctica acarrea sobre el medio ambiente, teniendo en cuenta que en la extracción de carbón existen residuos sólidos producto de la explotación de este mineral, a estos residuos se les denomina "estéril de carbón", los cuales en su mayoría se retiran del carbón para no afectar el potencial energético del producto.

Resultados y conclusiones: Los resultados de la investigación son esperanzadores ya que sus características lo ubican como un material alternativo para la construcción de estructuras viales de bajo tráfico.

Palabras clave: Carbon, residuo, estéril de carbon, caracterización, infraestructura vial, uso alternativo.

Open Access:

Recibido:
12 julio de 2017

Aceptado:
22 noviembre de 2017

Correspondencia:
gutierrez.andres@uniagraria.edu.co
obando.carlos@uniagraria.edu.co
moreno.cristian@uniagraria.edu.co

DOI
10.17081/invinno.6.2.3109

Como citar este articulo (IEEE) A. Gutiérrez - Bayona, y C. Obando- Gamboa, C. Moreno- Moreno, "Physical and mechanic characterization of sterile of coal, searching for an en-vironmental alternative in civil infrastructure", Revista Investigación e Innovación en Ingenierias, vol. 6, nº. 2, 2018. DOI: 10.17081/invinno.6.2.3109

Introduction

Colombia is known as a major producer of coal in the region and because it has large reserves of it, this makes it an attractive country for investment in mining. According to data from the Ministry of Mines between 2002 and 2009, coal production grew 84.61%, generating a large contribution to the GDP; For the year 2014 the contribution of mineral coal represented a growth of 3.56%, this was a result of the investment made in different projects in the north of the country. It is known that the coal mineral is of sedimentary origin and organic, constituted by vegetal remains and transformed by the metamorphism [2], and according to its characteristics can have different classifications as they are: thermal coal, implemented for the generation of energy; coal coke and semi-coke also called metallurgical coal, used for the manufacture of steel and cement

As a result of the exploration and exploitation of the coal mineral, residues arise as are the semisolids and solids. The semi-solid residues occur due to the washing of the coal because it has ash or sulfur [3]. Lace rocks are defined as solid wastes [4], also known as coal sterile; this sterile is mostly removed from the coal miner because it affects the energy potential of the final product. The percentages of barren of coal are very variable because they depend on the site from which the mineral is extracted.

Since this coal sterile is coupled in different sites as a waste material and contaminant, this research proposes the possibility of using it as an element and/or material of benefit within the construction of infrastructure, for this, different laboratory tests have been carried out in order to arrive at comparisons that allow to establish their possible performance in road construc-tion.

Methods and materials

In this section the normative foundations, technical concepts, tests and results, location, characteristics of the area of material supply and protocols are shown.

Normativity

The regulations used are national regulations, and are related to the technical specifications of materials for construction of road infrastructure projects and standards of testing of materials in road infrastructure, which govern in Colombia.

Technical specifications of materials and construction: The quality control requirements are established under standards and pro-cedures of execution and control, in which are framed general aspects of dirt road material, granular base material and granular subbase material, asphalt pavement and various civil works. The standards used in this researching were version 2007 and 2013 [5] of General Road Construction Specifications of the National Road Institute known as INVIAS [6].

Testing standards for road materials: Sampling procedures and laboratory tests adopted for road materials at the National level are taken as standard. The standards used in this researching were version 2007 and 2013 of the National Road Institute – INVIAS [6].

Technical Concepts

The concepts presented below are directly related to the devel-opment of the research:

Stone material: They are denominated in this way the materials used for the construction coming from rocks or stones, are classified according to their origin in natural and artificial. Natural materials have this name because they are in a natural state in the Earth's crust and come from rocks that have formed over many years, are classified in igneous rocks, sedimentary rocks and metamorphic rocks. Artificial materials are man-made materials, either because of a combination of natural materials or a transformation of natural

materials such as glass, ceramics or brick.
Coal Sterile Commonly Selected: The common coal sterile is an inorganic soil mixed with coal residues considered as solid waste product from coal mining. Because coal is located at great depths, it is necessary that the extraction is carried out in an industrialized way by implementing explosives, hydraulic drills, backhoes or with pickaxes and shovels, it is necessary to extract the coal next to its lace rocks, which are named like Inter-mantle or interburden [8].
Selected Coal Sterile: It is an inorganic soil (between-mantles or iterburde) [8], selected from the solid residue (barren of com-mon coal), product of the exploitation of the coal mineral that is at great depths, this differs from the common coal sterile since the visible particles that do not have coal residues.
Physical and Mechanical Characteristics: These characteristics indicate the properties of the materials. These characteristics are very important because based on them can define the best use and implementation of any material.

Tests and calculations

The tests presented below were performed in order to physically and mechanically characterize the coal sterile, all calculations and processes are based on testing standards for road materials in Colombia.
The laboratory tests performed were: Density, Standard I.N.V.E. 222 and 223, Particle Size, Standard I.N.V.E. 213, Humidity, Standard I.N.V.E. 122, Absorption, Standard I.N.V.E. 222 and 223, California Bearing Ratio (CBR), Standard I.N.V.E. 148, Resistance to the degradation of aggregates by means of the Los Angeles machine, Standard I.N.V.E. 218, and Organic Matter, Standard I.N.V.E. 121, all of the National Insitute of Routes of Colombia, INVIAS [6 - 7].

Location

The material was supplied by the industrialized plant belonging to C.I. CARBOCOQUE S.A.S, producer and exporter of coal coke located at kilometer 1 route to Lenguazaque, at a distance of 116 km from Bogota - Cundinamarca. The plant is located in the left margin of the road that communicates Cucunuba with Lenguazaque, passing through the municipality of Ubaté.
Because of the location of the industrialized coal plant, neighboring coal producing regions supply raw material to this coal, it is also important to mention that this washing and screening plant is the only one in operation in the Cundinamarca region.
The economy of Lenguazaque is based on activities such as min-ing for coal mineral, potato farming and, to a lesser extent, willow, maize, barley and wheat [9].

Collection of Samples

Five samples of coal sterile from the discarded material were collected, and collected from different collection sites, each composed of 25kg taken from the base, the middle and the crown of the collection to have representative samples, all the material was stored in tarpaulins outside the affectation of the rain or the sun.
It is believed that the material collected belongs to a series of formations from the Oligocene period which is about 33.7 mil-lion years old, the Eocene which is 53 million years old and the Late Superior that has 96 million years belonging to the Cenozoic period and Cretaceous. The lithological characteristics presented for the Oligocene zone (E1-Sc) are conglomerates interspersed with medium-to-thick laurel sandstones and coal aceous lodolites, for the Eocene (e6e9-Sct) are fine-grained to conglomeratic sandstones with arcillolites and limolites , which occasionally exhibit lenses of iron and coal, and finally for the late upper (k6-Stm) are gray and black arcillolites, variegated with intercalations of fine-grained to coarse-grained quartzites and frequent mantles of coal [10].

Protocols

Some protocols were implemented when specified in the Material Testing Standard adopted did not fit the reality of the samples and their conditions.

Temperature: High temperature is one of the factors that alter the samples, since some tests made that the material is dry with a constant mass, it was necessary to change the temperature to 60 ± 5°c, extending the time the moisture content, density, relative density (specific gravity), absorption of the fine aggregate, and resistance were determined in the samples. To the degrada-tion of the aggregates of sizes smaller than 37.5mm (1 1/2 "), by means of the machine of the angels.

CBR (*California Bearing Ratio*): To adjust the granulometry re-quired in the test standard I.N.V E-148, it was necessary to reduce the size by impact. A compressive energy of 56 strokes and humidities of 7% and 4% was implemented for the realization of the tests. A combination of coal sterile and granular Base 400 was performed.

Organic matter: This test was performed with 10 sub-samples taken from the 5 original samples. The material tested was fine material passed sieve # 4, thick material product of the Machine of the Angels and passed sieve # 4.

Densities and Absorption: This laboratory test was performed 7 times in order to obtain the density of the 5 samples, a test for selected coal sterile and a test to determine the density of the coal, the latter two would serve as points of comparison.

Results and discussion

Next, the results obtained in the physical-mechanical characteri-zation of the coal sterile are shown. These results will show results such as humidity, particle size, density and absorption, wear resistance at the Los Angeles Machine and support capacity (CBR).

Moisture content

The moisture content of the collected samples of sterile of coal are between 7.85% and 18.88%, with an average of 13.65%.

Table 1. Moisture content.

Sample	Moisture Content (%)
1	13,66
2	14,73
3	13,15
4	18,88
5	7,85
Average	13,65

Granulometry

For the physical characterization of the coal sterile, several granulometries were realized, that is, for each one of the 5 samples in order to determine the classification of the material based on the particle size. The results are compared with the INVIAS grades of Granular Base material, Sub-base granular material, dirt road material, and Embankment material. Greater agreement is found with the granulometric range of granular subbase material (SBG-50), and with embankment
material with selected soil, as shown below:

Table 2. Percentage of content according to particle size, for common coal sterile.

Sample	Content of Stones (%)	Sand Content (%)	Fine Soil Content (%)
1	52,11	44,72	3,17
2	44,93	54,64	0,43
3	49,87	46,6	3,53
4	66,57	33,04	0,4
5	70,86	28,25	0,89
Average	52,11	44,72	3,17

Figure 1. Granulometric curves of the 5 analyzed samples.

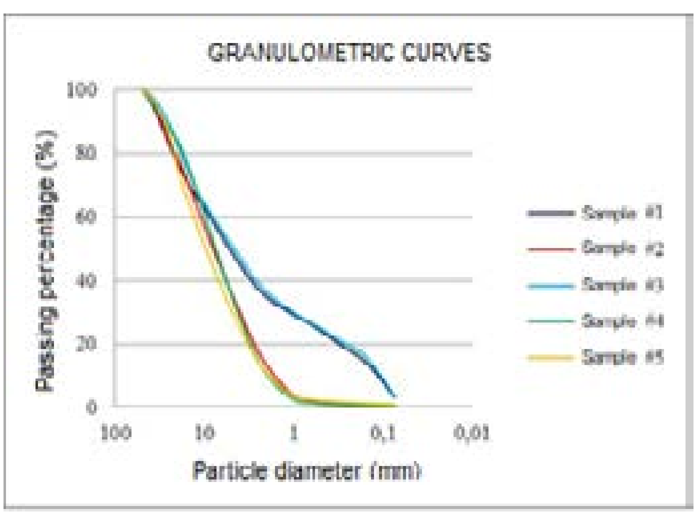


Figure 2. Granulometric curves of the 5 analyzed samples.

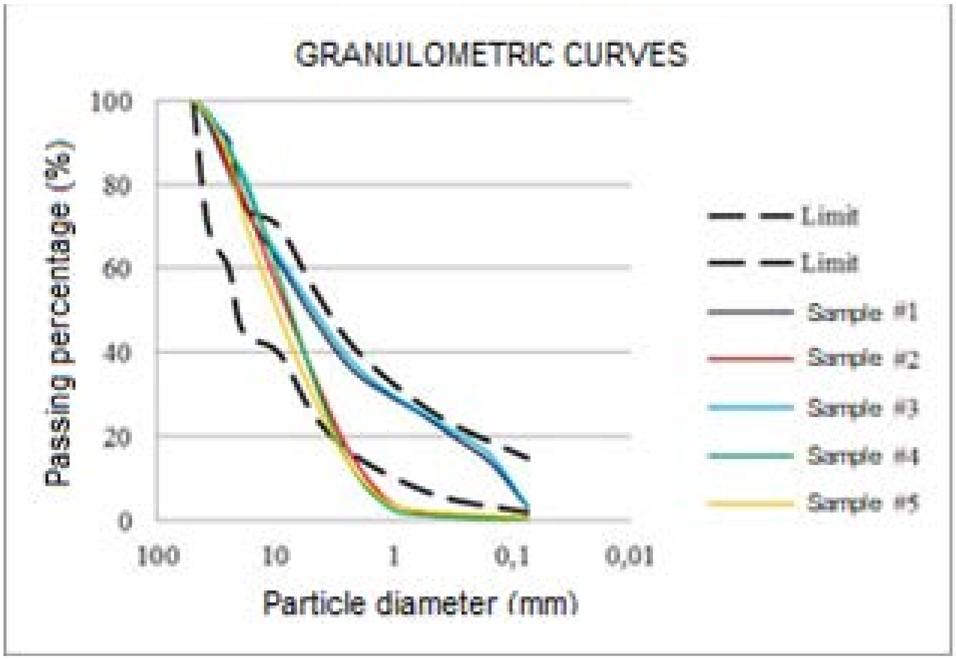
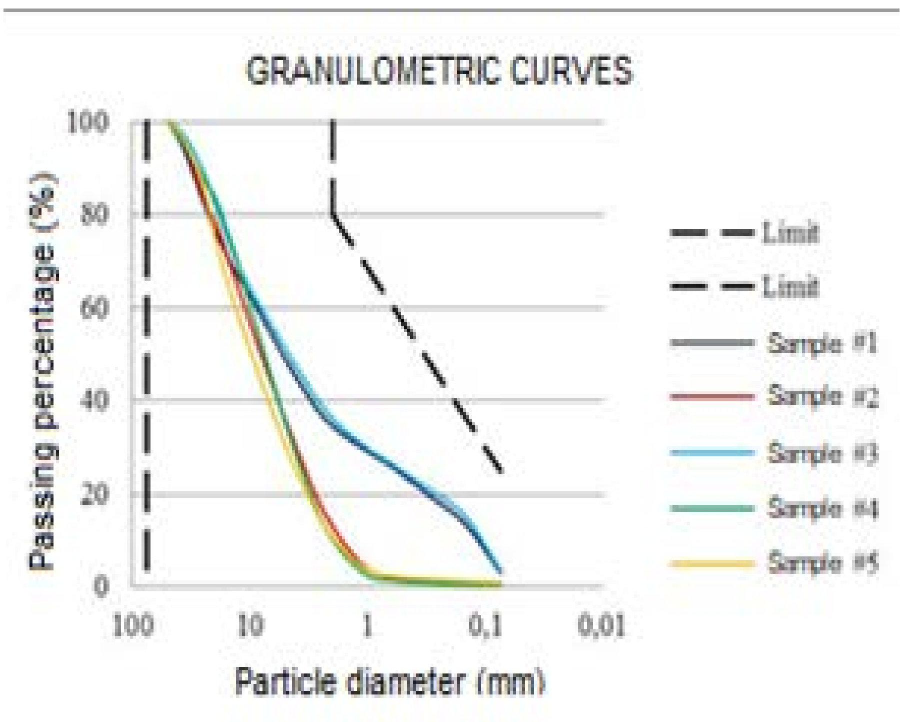


Figure 3. Granulometric curves of the 5 analyzed samples compared to the granulometric fringes for dirt road material - A38.

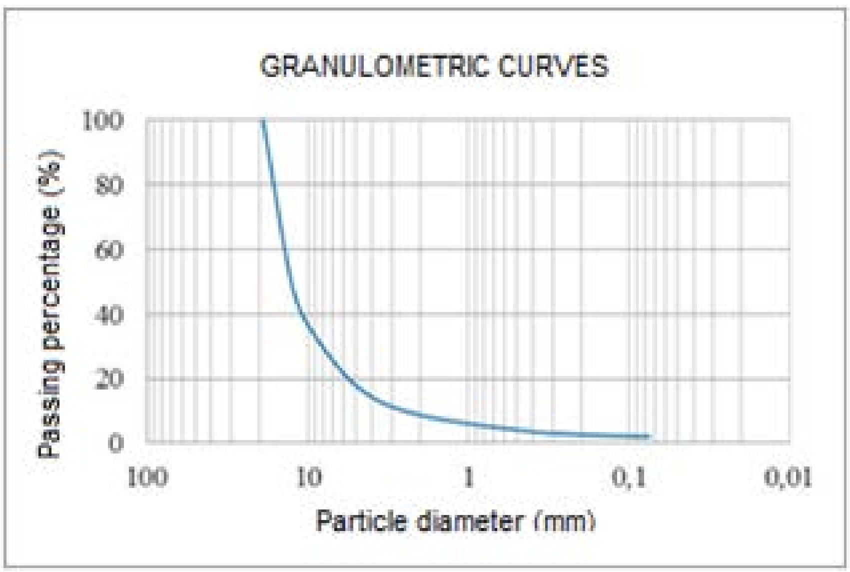


Granulometry of the selected coal sterile, used in the CBR test: Sepa-ration of the selected coal sterile from the common was made, taking all the particles of thick size; particles that in sight did not have coal particles, an adjustment was made to the granulometry obtained by impacting the selected particles and obtaining the granulometry necessary for the realization of the CBR test dictated by the standard I.N.V E-148. Next, the content according to the particle size obtained next to the corresponding particle size curve is shown.

Table 3. Percentage of content according to particle size, for common coal sterile.

Sample	Content of Stones (%)	Sand Content (%)	Fine Soil Content (%)
1	83,14	14,87	1,99

Figure 4. Granulometric curve of the selected coal sterile modified and implemented in the CBR test.



Granulometry of common coal sterile combined with granular Base 400, implemented in the realization of the CBR test: A combination of sterile common coal material and Granular Base 400 material was made to obtain 5 samples to perform the CBR test. This combination was made taking as reference the particle size curve in the boundary bands of the dirt road material - A38 because it is in these strips that the granulometry is best adjusted. The sections of material that did not enter the limits were replaced by Base granular 400 (between 10% and 20%). The contents according to the percentage sizes are shown next to the corre-sponding granulometric-metric curves in the particle size ranges.

Table 4. Percentage of content according to particle size for the common coal sterile implemented for the realization of the combination with Granular Base 400 for the CBR test I.N.V.E-148.

Sample	Content of Stones (%)	Sand Content (%)	Fine Soil Content (%)
1	66,26	33,52	0,22

Figure 5 . Granulometric curve of the common coal sterile that will be used in combination with Base granular 400 material

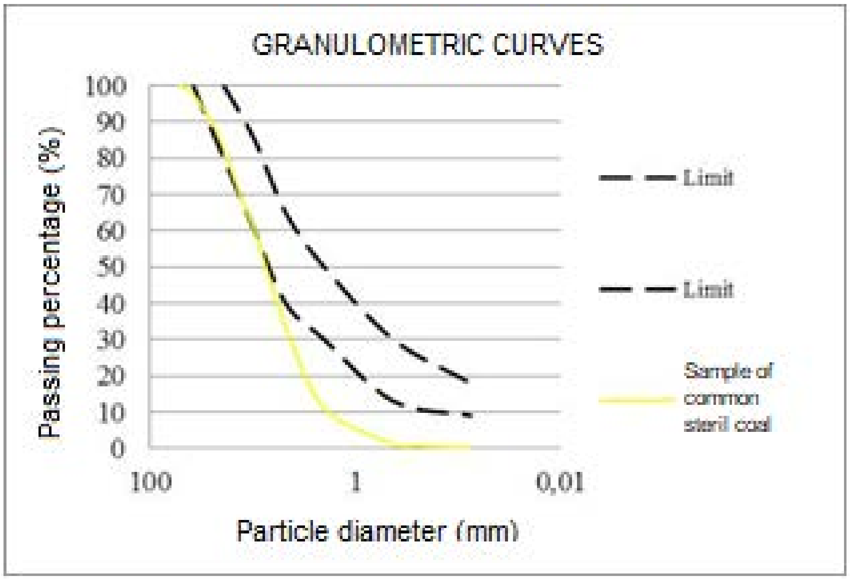
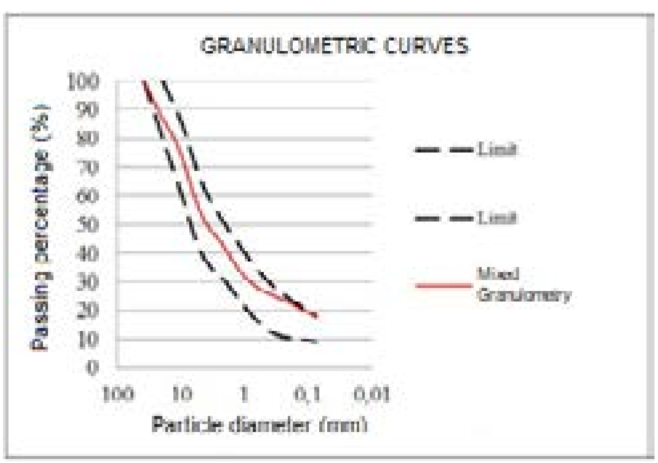


Table 5. Percentage of content according to particle size for the combination of granular base 400, and common coal sterile implemented in the CBR test I.N.V.E-148.

Sample	Content of Stones (%)	Sand Content (%)	Fine Soil Content (%)
1	46,44	35,81	17,75

Figure 6 . Granulometric curve of the common coal sterile that will be used in combination with Base granular 400 material, to be adjusted between the range of granulometric limits of dirt road material A38.



Density, relative density and absorption, for coarse, fine particles of common sterile, charcoal and sterile of selected coal.

Relative density of coal of fine and coarse size:

Table 6. Relative density results for coarse-sized common coal sterile particles.

Sample	**Saturated and superficially dry density (kg/m3)**
1	1976,60
2	1735,55
3	1732,43
4	1759,71
5	1826,18
Average	1806,14

Table 7. Relative density results for fine-sized common coal sterile particles.

Sample	Saturated and superficially dry density (kg/m3)
1	1676,14
2	1453,97
3	1719,52
4	1424,09
5	1473,48
Average	1559,74

Relative density of coal and sterile coal selected:

Table 8. Relative Density Results for coal and selected coal sterile Coarse Size

Sample	Saturated and superficially dry density (kg/m3)
Coal	1402,44
Selected Coal Sterile:	1896,12

Absorption:

Table 9. Absorption results coarse-sized coarse-sized particles of common coal

Sample	Absorption coarse soil, (%)	Absorption fine soil, (%)
Average	4,5	2,88

Table 10. Results of absorption of coal particles and sterile selected coal coarse size.

Sample	Absorption, (%)
Coal	2,13
Selected Coal Sterile:	4,07

Resistance to Degradation by the Los Angeles Machine

Table 11. Results of the degradation loss in the angels machine for the common coal sterile.

Sample	Percentage of loss, (%)
1	55,81
2	65,24
3	57,45
4	61,06
5	64,94
Average	61.00

The maximum percentage of loss according to the INVIAS procedures and standards is: 40% for granular base ma-terial and 50% for granular subbase material and dirt road material.

Determination of organic matter content by means of Ignition

Table 12. Results of organic matter content for coarse-sized common coal sterile.

Sample	Organic matter content, (%)
1	30,12
2	0,76
3	41,59
4	65,67
5	76,25
Average	56,88

Table 13. Results of the organic matter content for fine-particle size common coal sterile.

Sample	Organic matter content, (%)
1	46,17
2	57,14
3	54,37
4	61,60
5	57,52
Average	55,36

Results of the CBR support capacity test

CBR for common coal sterile:

Table 14. CBR for common coal sterile

Sample	CBR corrected to 0.1 ", (%)
1	97,39
2	86,22
3	36,36
4	66,60
5	74,62
Average	72,24

CBR for common coal sterile:

Table 15. Corrected CBR results of selected coal sterile.

Sample	CBR corrected to 0.1 ", (%)
1	42,18
2	41,59
3	47,59
Average	43,66

Table 16. Corrected results of CBR of coal sterile selected i n immersion.

Sample	CBR corrected to 0.1 ", (%)
1	19,36
2	16,25
3	18,29
Average	17,97

After 4 days of immersion, the minimum percentage of CBR is: 80% for granular base material, 40% for granular subbase material and 15% for dirt road material.

CBR, combination between coal sterile and granular Base 400 material:

Table 17. Corrected CBR results of the common coal sterile and granular Base 400 combined.

Sample	CBR corrected to 0.1 ", (%)
1	36,12
2	85,60
3	86,59
4	68,10
5	69,83
Average	69,25

Table 18. Corrected CBR results of common coal sterile and granular Base 400 combined in immersion.

Sample	CBR corrected to 0.1 ", (%)
1	25,46
2	71,20
3	45,22
4	61,54
5	65,13
Average	53,71

According to the INVIAS standards, this average matches with the minimum percentage of CBR for granular subbase material and dirt road material.

Conclusions

From the comparison of the laboratory results with the technical specifications for road construction of the National Road Institute, it can be concluded that the sterile coal product of coal production (coal coke and thermal coal) can be used as material for low traffic roads without significant reduction in the mechanical capacity of the structure.
Due to sterile coal's good resistance evaluated by the CBR test, its usage is possible to improve the subgrade support instead of other improving procedures.
Sterile selected or sterile unselected can be used in dirt roads and Embankments, since the characteristics of the material such as particle size, hardness, and strength make it acceptable to do so without having to grind or pre-wash.
Sterile of Coal, in combination with a granular Base material (between 10% and 20%) as the Granular Base 400 material used in the tests, showed a good perfor-

mance comparing with INVIAS standards, which makes this material suitable even as a granular subbase material for high traffic roads.
The use of sterile of coal in granular materials can reduce the cost of construction in infrastructure, as well as promote the protection of natural resources by proposing an alternative to the exploitation of mineral resources.
The coal sterile could be used as a fertilizer or as a com-plement to the soil, as long as the chemical characterization is realized, such as CO, P, bases course (K, Ca, Mg, Na), change acidity, texture (Cu, Fe, Mn, Zn and B), electrical conductivity, nitrate, cation exchange capacity and organic coal.
At this point, the usage of these "waste materials" could be analyzed facing other external agents because pollutants damage constantly civil infrastructure, maybe mine sterile could be resistant to pollutants like, acid rain or carbon gas [11 - 12].
It is time to see this material as a useful material instead of a waste material, thereby avoiding some harmful se-quences against native flora and fauna.

Bibliographic references

1. Dirección de la minería empresarial. Análisis del comporta-miento del PIB minero en el año 2014, segundo semestre y cuarto trimestre de 2014., 2015. https://www.minminas.gov.co/analisis-minero.
2. J.M. Gutiérrez, W.F. Mora., y L.I. Rodríguez, "Aprovechamiento de las partículas de ultra finos de carbón de una planta lavadora en la aducción de coque metalúrgico", Ingeniera e Investigación, vol. 31, 2010.
3. Mendieta, García, Avelino, Gómez, Afectación de la minería de carbón en las propiedades físicas y químicas de los suelos de la cuenca hidrográfica del rio Rodrigatos (El Bierzo, León). Madrid, Editorial: Marcos Mejudo Mendieta, 2003, pp.13.
4. Castells, Los residuos mineros. Madrid, Editorial: Díaz de Santos, 2012, pp.650.
5. Instituto Nacional de Vías, Especificaciones técnicas de construcción de carreteras, Colombia: Ministerio de transporte., 2013.
6. A.G. Gutiérrez, Evaluación de estructuras de pavimento flexible usando técnicas no destructivas utilizando el deflectómetro de impacto ó fwd (falling weight deflectometer)". Tesis de maestría presentada para optar al título de Magister en ingeniería, Geotecnia, Universidad Nacional de Colombia Sede Bogotá., 2011.
7. Instituto Nacional de Vías, Standards de Ensayos de Materiales para Carreteras, Colombia: Ministerio de transporte., 2013.
8. Ministerio del Medio Ambiente, Ministerio de Minas y Energía, Mineracol. Guía ambiental para minería subterránea de carbón. Bogotá, Editorial: Ministerio del medio ambiente, 2001, pp.109.
9. Alcaldía de Lenguazaque, Nuestro Municipio Información general, Economía del municipio de Lenguazaque, 2016, Dis-ponible en: http://www.lenguazaque-cundinamarca.gov.co/informacion_general.shtml#historia.
10. D. Montoya y J. Reyes, Geología de la Sabana de Bogotá. Bogotá, Editorial: Instituto Colombiano de Geología y Minería, pp. 81., 2005.
11. C. Obando, "Influencia del agua en el desempeño de los pavimentos: lluvia ácida", Revista Investigación e Innovación en Ingenierías, Vol. 5, n°. 2, 2017.
12. Viloria and W. Quintero, "Gestión de información sat río Manzanares", Investigacion e Innovación en Ingenierias, vol. 4, no. 2, p. 128, 2016. DOI: 10.17081/invinno.4.2.249