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Comparative analysis of stone aggregates for the manufacture of concrete in the construction of civil works

Análisis comparativo de agregados pétreos, para fabricación de hormigones en la construcción de obras civiles

Wellington Leodan Velásquez Álava*
Eduardo Humberto Ortiz Hernández*
Ramona Panchana de Calderero*

ABSTRACT

This research is a comparative analysis between aggregates from the Picoazá - Megarok Basaltic quarry in Portoviejo and from the Ahon Mine in Quevedo, the purpose is to analyze and characterize the stone aggregates from the Picoazá Basaltic quarry and from the Ahon Mine to design concrete mixes and their impact on the performance for construction; an experimental methodology was applied. Samples were tested at the Soil Mechanics Laboratory of the Technical University of Manabi. Among the tests used were: angels machine, coarse granulometry, fine granulometry, specific weights, loose unit weights, unit weights, rodded unit weight, sulfate test, abrasion test, as well as the preparation of specimens to be tested to simple compression and to verify the resistances at ages of 7, 14, 21, 21, 28 days. Obtaining differentiated results, it is concluded that the aggregates of the Picoaza Megarok Basaltic quarry have greater resistance to compression in concretes than the Ahon Mine that come from a riverbed, these resistance drops of approximately 15% with respect

* Maestría de Ingeniería Civil Mención en Vivienda Social, Instituto de Postgrado, Universidad Técnica de Manabí. Portoviejo, Manabí, Ecuador, iron932@yahoo.com, https://orcid.org/0000-0002-6232-5025
* Maestría de Ingeniería Civil Mención en Vivienda Social, Instituto de Postgrado, Universidad Técnica de Manabí. Portoviejo, Manabí, Ecuador, eduardo.ortiz@utm.edu.ec, https://orcid.org/0000-0002-1885-6005
* Maestría de Ingeniería Civil Mención en Vivienda Social, Instituto de Postgrado, Universidad Técnica de Manabí. Portoviejo, Manabí, Ecuador, ramona.panchana@utm.edu.ec, https://orcid.org/0000-0002-0763-5426

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to the Picoaza quarry, are due to the content of silt material present in the aggregate.

Keywords: Aggregates, concrete, compressive strength

RESUMEN

La presente investigación es un análisis comparativo entre agregados de la cantera Basáltica Picoazá - Megarok de Portoviejo y de la Mina Ahon de Quevedo, la finalidad es analizar y caracterizar los agregados pétreos de la cantera Basáltica Picoazá y de la Mina Ahon para realizar diseños de mezclas en hormigón y su incidencia en las prestaciones para la construcción; se aplicó una metodología experimental. Así se ensayaron muestras en el laboratorio de Mecánica de Suelos de la Universidad Técnica de Manabí. Entre los ensayos que se utilizaron fueron: máquina de los ángeles, granulometría gruesa, granulometría fina, pesos especifico, pesos unitarios sueltos, peso unitario varillado, ensayo a los sulfatos, ensayo de abrasión, así como la confección de especímenes para ser ensayados a la compresión simples y verificar las resistencias a edades de 7, 14, 21, 28 días. Obteniendo resultados diferenciados, se concluye que los áridos de la cantera Basáltica Picoazá Megarok poseen mayor resistencia a la compresión en hormigones que la Mina Ahon que son provenientes del cauce de un rio, estas bajas de resistencia que son de aproximadamente un 15% con respecto a la cantera Picoaza, se dan por el contenido de material de limo presente en el agregado.

Palabras clave: Agregados, hormigón, resistencia a compresión

INTRODUCTION

In Ecuador, different research has been carried out on concrete strength using different methodologies that have allowed obtaining favorable or unfavorable results with the use of different aggregates and mines or combinations of them.

The preparation of concrete mixes requires the dosing of cement, sand, crushed aggregates, water and sometimes additives. The production of natural aggregates is generally done by mining or mechanical or manual extraction of these stone materials; the research was based on a comparison between the stone materials from the Picoazá quarries and those from the Ahon quarry. Among the physical and chemical characteristics of the stone aggregates from both quarries, for the elaboration of concrete designs with strengths of 210kg/cm^2 .

This study is based on the Ecuadorian Technical Standard INEN (Instituto Ecuatoriano de Normalización) NTE INEN 1 855-2:2002, which establishes the specifications for the production of ready-mixed concrete in the fresh and non-hardened state.

The realization of this study is of great importance since it contains the results of the laboratory tests applied to both mines being that they keep differences not only for the

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quality of their materials but for their extraction characteristics since while the Picoazá mine obtains the materials by means of the use of rupture of the deposits using dynamite and other materials; the extraction of the Ahon mine is direct from the basin of the river in which this material rests, which affects in its differences in its physical qualities.

"Aggregates make up between 70% and 80% of the volume of concrete". (León, María, 2010), which is why it is important to know their properties and their influence on the properties of concrete to optimize not only their use and exploitation, but also the design of concrete mixtures. "In Ecuador, several civil works are built informally, without considering the quality, physical and chemical characteristics of the aggregates to be used in the elaboration of concrete". (Peña Galván, Diana Isabel., 2015).This could be a cause for the concrete resistance not to reach the value for which it was designed.

Therefore, it is expected that the contributions of this study will be considered to build civil works of better quality by establishing the mechanical and physical differences between the materials of the Picoaza quarry and the Ahon quarry.

MATERIALS AND METHODS

Portland cement was used with the use of stone aggregates from two quarries of Picoaza de Megarok belonging to the canton of Portoviejo and the Ahon mine from the canton of Quevedo; subsequently a concrete with a resistance of 210 kg/cm^2 was designed considering the INEN 1573 specifications. (ASTM C39., 2001)..

In a first analysis, granulometric tests were carried out where technical specifications must be met as shown in table N°1 for coarse aggregates standard (NTE INEN 696., 2011) and table N°2 for fine aggregates (NTE INEN 696., 2011)The table shows the tolerances between the upper and lower limits corresponding to the granulometries. The aggregates from the Picoaza quarries and the Ahon mine were tested by applying the Ecuadorian Technical Standards, among which we have:

- Moisture content according to the standard (NTE INEN 862., 2011).
- Granulometry according to the standard (NTE INEN 696., 2011).
- Unit weight and percentage of voids according to the standard (NTE INEN 858, 2010) .
- Relative density and fine aggregate absorption according to the standard (NTE INEN 856., 2010);
- Relative density and absorption to coarse aggregate according to standard (857., 2010).

- **Table 1.** *Technical specification for fine material.*

Limit Sieve	Lower Limit	Upper Limit
3/8"		
No 4		

No 8		
No 16		
No 30		
No 50		
No 100		

Table 2. *Technical specification for coarse material.*

Limit Sieve	Lower Limit	Upper Limit
2"		
1 1/2"		
1"		
3/4"		
1/2"		
3/8"		
N°4	0	
N°8	0	5

Subsequently, the size fractions of the coarse particles from the Megarok quarry as shown in Table 3 and from the Ahon mine as shown in Table 4 have been determined, whose maximum size for the coarse aggregate used in both concrete designs was a maximum size of ¾". According to these results obtained in the granulometries, it is demonstrated that the coarse materials do not present a grading problem for the sources of materials for concrete mixes.

For the fine aggregate of both sources of materials, aggregate with a maximum size of 3/8" was used. (NTE INEN 696., 2011)The fine material particle fractions were determined in this way, obtaining a fineness modulus for the Megarok quarry from the Picoaza sector of MF =3.10 as shown in Table 5 and for the Ahon mine MF=3.52 as shown in Table 6.

Table 3. *Granulometric test of the Megarok quarry coarse aggregate according to NTE INEN 696:2011.*

TAMIZ	P.RETAINED PARTIAL	P. RETAINED ACCUMULATED	% WITHHELD	% WHAT'S GOING ON	% ESPCFCD
GRANULOMETRY					
3/4"				100,00	
1/2"	340		5,97	94,03	90 - 100
3/8"	2630		46,17	47,86	40 - 70
N°4	1935		33,97	13,89	0 - 15
	621		10,90	2,98	0 - 5
			2,63	**(0,35)**	
PASS N°200			0,35		

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TOTAL	5696,00

Table N°4. *Granulometric test of the coarse aggregate of the Ahon Mine according to NTE INEN 696:2011.*

TAMIZ	P.RETAINED PARTIAL	P. WITHHELD ACCUMULATED	% WITHHELD	% WHAT'S GOING ON	% ESPCFCD
GRANULOMETRY					
3/4"				100,00	
1/2"	301		7.03	92.97	90-100
3/8"	2122		49.53	43.44	40-70
N°4			35.01	8.43	0-15
			4.90	3.52	0-5
	101		2.36	**1.17**	
PASS N°200			1.17		
TOTAL					

Table 5. *Granulometric Test of Fine aggregate Megarok Quarry (NTE INEN 696., 2011).*

3/8"					
N°4	11,8	1,37	1,37	98,63	95-100
		19,99	18,62	80,01	80-100
		44,43	24,44	55,57	50-85
	188,2	66,33	21,90	33,67	25-60
	134,8	82,01	15,69	17,99	10--30
		95,62	13,61	4,38	2--10
			3,03	**(1,35)**	
PASS N°200	11,60		1,35		
TOTAL	859,40				

Table 6. *Granulometric test of fine aggregate Ahon mine. (NTE INEN 696., 2011).*

3/8"					
N°4	1140	16,11	16,11	83,89	95-100
	1083	31,41	15,30	68,59	80-100
	993	45,45	14,03	54,55	50-85
	1329	64,23	18,78	35,77	25-60
	2158	94,72	30,49	5,28	10--30
		99,81	5,09	0,19	2--10
	12,8		0,18	**(0,01)**	
PASS N°200	0,77		0,01		
TOTAL	7076,57				

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For the calculation of the fineness modulus corresponding to the fine aggregate, it was obtained by means of equation Eq. (1). Comparing the results of the materials from the Picoaza quarry, these meet the established parameter of "fineness modulus between 2.3 and 3.1 as mentioned in the Technical Specifications of the Ministry of Public Works", in relation to the materials from the Picoaza quarry. (MTOP, 2002)In relation to the materials from the Ahon quarry, the fineness modulus is outside the permitted range, which should be taken into account at the time of batching. The concrete design proposal for both sources of materials was proposed for a strength of 210 kg/cm^2 considering the specifications of the Ecuadorian Technical Standard INEN 1573 (ASTM C39., 2001). opting for a water/cement ratio of (w/c) 0.50.

The coarse and fine aggregates were tested according to the Ecuadorian Technical Norms. (MTOP, 2002). Once the fine granulometries were obtained, the fineness modulus was obtained from the Megarok quarry and the Ahon mine for use in the concrete design, which is illustrated in Table 7.

$$\mathrm{MF} = \frac{\sum \text{\%Retenido Acumulado hasta el tamiz 100}}{100} \quad \text{Eq (1).}$$

Figure 1. Picoazá basaltic quarry in the canton of Portoviejo, Manabí province.

Figure 2. Ahon mine in Quevedo canton, Los Ríos province.

Table 7. *Modulus of Fineness calculation results*

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Source of material	Province	Modulus of fineness
Megarok Quarry	Manabí	3.10
		2.90
		2.8
Ahon Mine	Los Rios	3.2
		3.3
		3.5

With the results of the tests as illustrated in Table 8 show the physical-mechanical properties of the materials used in the design of concrete of 210 kg/cm^2 among these we have: Dry Saturated Density, Degree of Absorption (NTE INEN 856, 2010), Varillated unit weight (NTE INEN 858, 2010).
Table 8 and Table 9 illustrate the laboratory test results of coarse and fine aggregates from the Picoaza quarry and Ahon mine.

Table 8. *Characteristics of coarse and fine aggregates from the Megarok quarry in the province of Manabí.*

Description	Analysis of coarse and fine fine aggregates from the Picoaza Quarry	
Testing	Ripio ¾ "	Concrete Sand
Dsss (g/cm3)	2.564	2.607
Absorption (%)	3.95	7.87
Unit Loose Weight (g/cm3)	1.564	1.486
Compacted Unit Weight (g/cm3)	1.674	1.566

Table 9. *Characteristics of coarse and fine aggregates from the Ahon quarry, Los Rios province.*

Description	Analysis of coarse and fine fine aggregates from the Ahon Quarry	
Testing	Ripio ¾ "	Concrete sand
Dsss (g/cm3)	2.668	2.687

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Absorption (%)	2.26	1.79
Unit Loose Weight (g/cm3)	1.538	1.576
Compacted Unit Weight (g/cm3)	1.551	1.668

Table 10 indicates that after being tested by impacts between the gravel and the twelve steel balls, the wear percentages of the coarse aggregates shall have a wear percentage not greater than 50%, at 500 revolutions, correlating the values with those specified in INEN 860 and 861. The wear by sulfates shall not experience a disintegration or total loss greater than 12% in weight as represented in table 12, when derived from five cycles of the sodium sulfate durability test, as specified in ASTM C88.

Table 10. *Abrasion wear results of coarse aggregate from the Megarock quarry.*

	Sample N°1 Ahon mine	Sample N°2 Megarok quarry
Original weight:	5000	5000
Retained weight sieve n°12 (gr):	3955	3580
Weight passing sieve n°12 (gr):	1045	1420
Percentage of wear (%):	20.90	28.40
Number of balls:		

Table 11. *Sulfate wear test*

Sulfate wear test after five cycles	ASTM Standard C-88		
	Sample N°1	Sample N°2	Specified value
Picoaza Quarry	8.55	10.57	<12%
Ahon Mine	7.25	6.54	

Obtaining the laboratory parameters of coarse and fine aggregates from the Megarok Quarry and the Ahon Mine, 2 concrete designs were made based on the standard. (American Concrete Institute (ACI 211.1-91)). As illustrated in Table 12.

Table 12 *Proposed 210 kg/cm2 concrete design with coarse and fine aggregate from Megarok quarry and Ahon mine.*

Aggregates	**Megarok Quarry**	**Ahon Mine**
QUANTITY OF WATER (Liter)		184

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CONT OF CEMENT (Kg)		368
SAND(kg)	660	
STONE (Kg)	1088	930

The concrete slump test was carried out, the conical mold was moistened and then placed on a flat surface. The mold was held firmly during filling, which was done in 3 layers, each one at one third of the height of the mold, compacted with 25 blows with the compacting rod. After 24 hours, the specimens were removed and marked to be placed in the pool filled with water at a temperature of 25°C. (Cedeño, R. A. P., Hernández, E. H. O., Párraga, W. E. R. R., & Panchana, M. J. C., 2020).

RESULTS

Concrete specimens were made and tested at 7, 14, 14, 21 and 28 days in the compression machine maintaining the 2 to 1 ratio as mentioned in the standard based on the standard. (ASTM C39., 2001).The concrete strengths at the ages of rupture were presented by means of statistical data.

Figure 3. Load resistance test kg/cm2 of the Ahon mine.

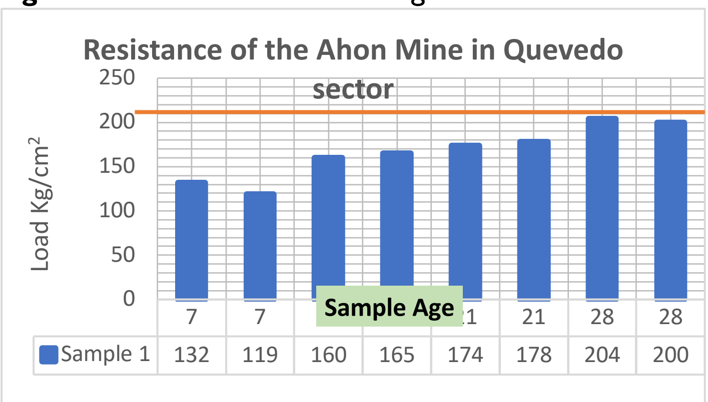

Figure 4. *Megarok Quarry kg/cm2 load resistance test.*

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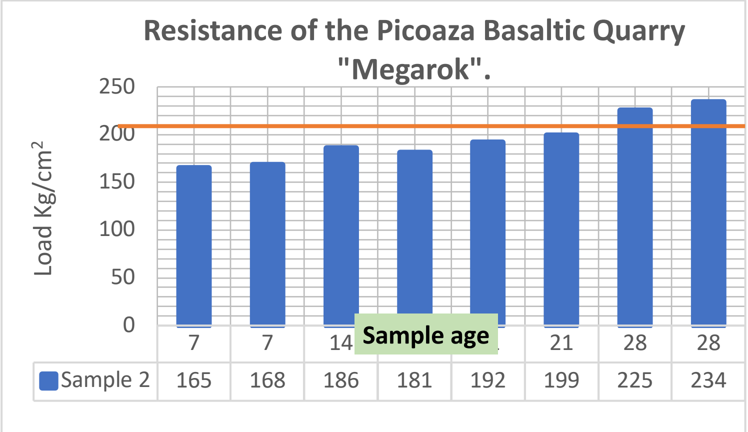

Figure 3 and Figure 4 show the results of concrete strength of 210 kg/cm^2 obtained in the Soil Mechanics laboratory of the Technical University of Manabi, for which samples of specimens were taken and 8 cylinders were made with aggregates from the Ahon mine in the Quevedo canton in the province of Los Rios and the Megarok quarry in the Portoviejo canton in the province of Manabi.

Figure 5. Concrete Cylinder Specimens

Figure 3 shows the results corresponding to the Ahon mine, showing that the samples at 7 days reached 132kg/cm^2 and 119kg/cm^2 , while at 14 days they obtained 132kg/cm^2 and 119kg/cm^2 , at 21 days 160kg/cm^2 and 165kg/cm^2 , while at 28 days they reached their maximum strength of 204kg/cm^2 and 200kg/cm^2 . Figure 5 shows that the samples from the Megarok quarry at 7 days reached a strength of 165kg/cm^2 - 168kg/cm^2 , at 14 days 186kg/cm^2 - 181kg/cm^2 , at 21 days 192kg/cm^2 - 199kg/cm^2 and at 28 days their strength reached 225kg/cm^2 - 234kg/cm^2 .

The coarse and fine aggregates of the Ahon mine reached a maximum resistance of 204kg/cm^2 and 200kg/cm^2 , knowing that it was designed for 210kg/cm^2 , it should be noted that this does not comply with the design established in this research. For the coarse and fine aggregates from the Megarok quarry, these reached a maximum resistance of 225kg/cm^2 and 234kg/cm^2 , exceeding 100% of the load for which they were designed. The results show differences between the aggregates from the Ahon mine and the aggregates from the Picoaza quarry, mainly in the abrasion test in the aggregates where the percentage of wear in the mine is 20.90% and in the Picoaza quarry it is 28.40%. Therefore, the percentage of resistance differs by 15% in both concrete designs. This difference shows that the aggregates from the Picoazá quarry offer greater strength in the concrete design, which would allow a higher quality construction and better characteristics, compared to the concrete design obtained from the aggregates of the Ahon mine.

Finally, the electrical resistivity test was performed. (Ortiz, E., Macias, L., Delgado, D., Zambrano, A., 2020). The Surf ™ Hand - Held Probe measuring equipment was used, which is an advanced laboratory testing device for the measurement of surface electrical resistivity of hardened concrete specimens, using the four-electrode measurement technique where the electrical resistivity technique (AASHTO - TP95-11, 2014).

The electrical resistivity of concrete correlates well with certain concrete performance characteristics, such as chloride diffusion coefficient, water absorption, and corrosion rate of embedded steel. The qualitative relationship between the rapid chloride penetrability, RCP (ASTM C1202, 2012) and the surface electrical resistivity of concrete is depicted in Table 13.

Table 13. *Relationship between surface resistivity and chloride penetrability*

Chloride of Penetration	56 - Days -Chloride of penetrability of past load according to ASTM standard C1202	28 days Resistivity surface
	(Coulombs)	(KΩ.cm)
High	> 4,000	< 10
Moderate	2,000 - 4,000	10 - 15
Under	1,000 - 2,000	15 - 25
Very low	100 - 1,000	25 - 200
Despicable	< 100	> 200

The results obtained in the laboratory show increases from 7, 14 and 28 days to the proposed design, reaching an average surface resistivity of the Picoaza Megarok quarry at 7 days of 14.5 KΩ.cm, at 14 days 18 KΩ.cm and at 28 days 24 KΩ.cm for the Ahon mine, average resistivity values were obtained at 7 days 16.2 KΩ.cm, at 14 days 18.5 and at 28 days 25.40 KΩ.cm.

Once the surface electrical resistivity values were obtained, the results were compared with the specifications as illustrated in Table 13 and mentioned in the specification of the (ASTM C1202, A, 2010)The results obtained for the Picoaza Megarok quarry show a very low penetration chloride corresponding to the design age at 28 days and for the Ahon Mine at 28 days with a very low penetration chloride. The electrical resistivity of concrete correlates well with certain concrete performance characteristics, such as chloride diffusion coefficient, water absorption, and corrosion rate of embedded steel.

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The qualitative relationship between the rapid chloride penetrability, RCP (ASTM C1202, A, 2010) and the surface electrical resistivity of the concrete, is depicted in Table 13.

DISCUSSION

The sources of stone materials were properly identified, both in the Picoazá quarry, which comes from the exploitation and crushing of materials. The Ahon mine is coming from a river source whose origin is natural and the exploitation is direct.

The characteristics of the aggregates from the Ahon quarry and those from the Picoazá quarry differ in their morphology; one of them is rounded and smooth, they are from the Ahon mine, while those from the Picoazá basaltic quarry are morphologically irregular with edges and flat faces.

The strength of the concrete design made with materials from both sources is 210kg/cm2, clearly identifying that the aggregates from the Picoazá quarry offer higher abrasion wear and high compressive strength in terms of concrete exceeding 210 kg/cm2, while the concrete made with aggregates from the Ahon quarry offers lower abrasion wear and lower compressive strength.

It should be considered that in order to develop quality works that offer long lasting benefits in civil works, a meticulous quality control must be carried out on the coarse and fine aggregates, to obtain a quality concrete design, which can be complied with in terms of resistance and durability.

The coarse and fine aggregates from the Megarock quarry in the Picoazá sector, located in the province of Manabí, are suitable for the use of concrete with a resistance of 210 kg/cm2 and durability to penetration chlorides.

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