Journal of Construction in Developing Countries, 22(1), 115–136, 2017

Production and Quality Levels of Construction Materials in Andean Regions: A Case Study of Chimborazo, Ecuador

*Oscar A. Cevallos[1], David Jaramillo[2], Carlos Ávila[3] and Ximena Aldaz[1]

Published online: 30 August 2017

To cite this article: Oscar A. Cevallos, David Jaramillo, Carlos Ávila and Ximena Aldaz. (2017). Production and quality levels of construction materials in Andean regions: A case study of Chimborazo, Ecuador. *Journal of Construction in Developing Countries*, 22(1): 115–136. https://doi.org/10.21315/jcdc2017.22.1.7

To link to this article: https://doi.org/10.21315/jcdc2017.22.1.7

Abstract: An important economic activity in the province of Chimborazo is the manufacturing and production of construction materials such as clay bricks, blocks, pavers and petrous materials (aggregates). These materials must meet minimum quality requirements to ensure proper mechanical behaviour and prolong the lifespan of civil construction projects. In this study, the quality of clay bricks, concrete blocks, paving bricks and natural aggregates for concrete produced in all the factories of the province from 2012 to 2015 was assessed. The results obtained were compared with the quality standards provided by the Ecuadorian Institute of Standardization (INEN). All testing procedures for the characterisation of physical and mechanical properties followed the guidelines set by the American Society for Testing and Materials (ASTM) and the British Standards Institution (BSI). This study presents the outcomes of the quality evaluation of construction materials produced in 258 factories located in the 10 districts (cantons) of Chimborazo. The study revealed that paving bricks and aggregates for concrete performed better than clay bricks and concrete blocks. The concrete block samples had the highest percentage of non-compliance with the specifications and the widest spread of the results. Quality problems in the production of construction materials were found in all the districts of Chimborazo.

Keywords: Quality control, Construction materials, Physical characterisation, Mechanical testing, Ecuador

INTRODUCTION

The Construction industry is the largest and most challenging industry worldwide (Liu et al., 2007; Ofori, 2000; Tucker, 1986), with prefabricated construction materials comprising the basic raw material used in the construction of buildings and civil engineering works. These materials include bricks, concrete blocks used in walls or slabs, pavers for pedestrian or vehicular roads and petrous materials. These types of materials offer numerous advantages to professionals in the construction industry; in fact, the optimisation of resources and reduction of costs and construction times continue to provide conclusive reasons for their extensive utilisation (Illston and Domone, 2010). Construction materials are subject to compliance with technical specifications and are required to undergo periodic quality control. Table 1 shows the minimum requirements set by the Ecuadorian

[1]Facultad de Ingeniería, Universidad Nacional de Chimborazo, Riobamba, ECUADOR
[2]School of Medicine, Faculty of Health Sciences, National University of Chimborazo, Riobamba, ECUADOR
[3]Facultad de Ingeniería Mecánica, Escuela Politécnica Nacional, Quito, ECUADOR
*Corresponding author: ocevallos@unach.edu.ec

Institute of Standardization (INEN), which were used in this study. According to this classification, C-type bricks are solid handmade clay bricks with no perforations or frogs, whereas E-type bricks are hollow clay bricks that can only be used in non-load-bearing walls and lightened reinforced concrete slabs. Additionally, the INEN classification considers D-type concrete blocks as blocks used to build exterior partition walls with coating or mortar rendering, and E-type concrete blocks are blocks used to build interior partition walls with or without coating or mortar rendering (INEN, 1978, 1993).

The INEN functions as the national technical organisation for the quality system of the country (INEN, 2012a). However, there have been frequent problems in the factories of Chimborazo due to either poor monitoring by producers and/or control bodies or the constant search for reduced production costs. As such, in 2009, tests conducted in the Laboratory for Quality Control of Materials (LCCM) of the National University of Chimborazo (UNACH) on clay brick samples from several private companies in the province revealed non-compliance with technical specifications. In this case, none of the samples tested met the recommended minimum compressive strength and exceeded the maximum permissible absorption capacity (LCCM, 2010). Similarly, in 2010, an investigation conducted on concrete block samples produced in various districts of Chimborazo revealed serious problems in the quality of the specimens. Once more, E-type concrete blocks failed to meet the technical specifications for both compressive strength and absorption capacity (Diaz, 2010).

Undoubtedly, the problem of construction material quality can affect the performance of structures and shorten their lifespans. For this reason, quality requirements are becoming more stringent, primarily in Andean countries such as Ecuador, where earthquakes are common (IGEPN, 2016). The high seismic activity is mainly due to the clash of the Nazca plate and the South American plate, causing the subduction of the Nazca plate (Delouis et al., 1996; Yuan et al., 2000). In Ecuador, earthquakes have been categorised by a seismic zonation map (NEC, 2015) obtained from the results of seismic hazards with a 10% probability of exceedance in 50 years and a return period of 475 years. The seismic zones defined on this map consider seismic accelerations of gravity between 0.15 g and 0.50 g, placing the province of Chimborazo in seismic zone IV (0.40 g).

Non-compliance with construction quality specifications promotes rapid deterioration and considerable damage to civil works, resulting in economic losses (Cnudde, 1991; Formoso et al., 2002). Furthermore, 18% of pathological problems found in concrete and masonry buildings, including moisture or leaks in walls or slabs, large amounts of waste residue, poor strength capacity, premature failure of concrete elements and other quality problems present during the construction and/or service phases, are attributed to the quality of building materials (Helene and Figueiredo, 2003). In Chimborazo, the causes of quality problems found in construction materials could be attributed to the uncontrolled rise in the number of producers and factories (INEC, 2011). Here, producers are forced to reduce production costs to compete with market prices, even though the quality of their products is reduced. Furthermore, regional governments have granted operating licenses to producers of construction materials without requiring them to provide laboratory reports that verify the quality of the products. All these factors have contributed to the progressive decline in the quality culture in the province.

Table 1. Technical Specifications for Construction Materials in Ecuador Provided by the INEN

Construction Material	**Type**	**Characteristic**	**Minimum Requirement**	
Clay bricks	C	Compressive strength*	8 MPa	
		Flexural strength*	2 MPa	
		Absorption capacity*	25%	
	E	Compressive strength*	4 MPa	
		Flexural strength*	3 MPa	
		Absorption capacity*	18%	
Concrete blocks	D	Compressive strength^	2.5 MPa	
		Absorption capacity^	15%	
	E	Compressive strength^	2 MPa	
		Absorption capacity^	15%	
Paving bricks	Pedestrian	Compressive strength†	20 MPa	
	Light traffic	Compressive strength†	30–40 MPa	
	Fine aggregates	Acid-soluble portion	25%	
Natural aggregates for concrete	Fine aggregates	Organic impurities	Gardner colour No. 11 – Grade 3 (Colour standard)	
		Materials finer than 75 μm	5%	
		Sieve analysis	**Size**	**Passing (%)**
			9.5 mm	100
			4.75 mm	95 to 100
			2.36 mm	80 to 100
			1.18 mm	50 to 85
			600 μm	25 to 60
			300 μm	10 to 30
			150 μm	2 to 10
	Coarse aggregates	Resistance to degradation by abrasion and impact	50%	
		Sieve analysis	**Size**	**Passing (%)**
			63 mm	100
			53 mm	95 to 100
			26.5 mm	35 to 70
			13.2 mm	10 to 30
			4.75 mm	0 to 5

Notes: ^average of 3 specimens; *average of 5 specimens; †average of 10 specimens
Source: Data were extracted from INEN (1978, 1993, 2014, 2010c, 2012d)

In this study, the results of a quality evaluation of clay bricks, concrete blocks, paving bricks and concrete aggregates produced in Chimborazo from 2012 to 2015 are presented. Here, physical characteristics (absorption capacity, acid-soluble portion, organic impurities, materials finer than 75 μm and granulometry) and mechanical properties (resistance to degradation, compressive strength and flexural strength) of construction material samples produced in 258 factories located in 10 districts of Chimborazo were assessed. The level of compliance with the technical specifications was determined by comparing the test results with the minimum standards recommended by the governmental body of INEN (INEN, 1978, 1993, 2010c, 2012d, 2014). The outcomes of this analysis provided, among other things, a diagnosis of the current quality levels and a baseline for promoting new research projects aimed at improving the quality of construction materials.

Previous studies based on quality control in the construction industry have shown a substantial improvement in standard requirements when quality management methodologies were applied (Burati, Matthews and Kalidlindi, 1989; Koskela, 1992). It is anticipated that similar studies can be replicated in Chimborazo, and thus specific methodologies for a total quality control and an adequate philosophy to improve production in the construction industry could be proposed and implemented.

SAMPLING AND TESTING METHODOLOGY

This study was conducted in the province of Chimborazo, which is located in the Andean region of Ecuador. According to the latest population and housing census of 2010, its population was 458,581 inhabitants (INEC, 2011). The capital of the province is Riobamba, located at 2754 metres above sea level. According to the new territorial organisation of Ecuador, Chimborazo, along with the provinces of Cotopaxi, Tungurahua and Pastaza, belongs to Zone 3 (Cootad, 2010). The study included all 10 districts of the province: Alausí, Colta, Cumandá, Chambo, Chunchi, Guamote, Guano, Pallatanga, Penipe and Riobamba, as shown in Figure 1.

Samples of C-type and E-type clay bricks, D-type and E-type concrete blocks, pedestrian and light traffic concrete paving bricks, and natural aggregates for concrete were randomly obtained from each factory according to published methods (INEN, 1977, 2012c, 2010b, 2010a). The clay brick samples were solid handmade clay bricks with no perforations or frogs (C-type bricks) and hollow clay bricks (E-type bricks) with dimensions of 25 cm in length, 10 cm in width and 8 cm in height. Fifteen specimens were sampled from each factory. Since each clay brick specimen of the entire lot has the same chance of being representative of the sample, the specimens were randomly sampled. The concrete blocks analysed were hollow sandcrete blocks measuring 40 cm in length, 20 cm in width and 10, 15 or 20 cm in height and comprised natural sand, water and cement as a binder. Both pedestrian and light-traffic paving bricks were interlocking concrete pavers with dimensions of 25 cm in length, 25 cm in width and 6 to 10 cm in height. The concrete blocks included 6 specimens from each factory, and the analysis of paving bricks for pedestrian and vehicular traffic consisted of 10 specimens from each factory. Both the concrete block and paving brick specimens were sampled by trained laboratory personnel. The selected specimens were representative of the entire lot of units from which they were sampled. Samples of the fine and coarse aggregates used in concrete were obtained directly from open pit and river mines. Each sample of natural aggregates had an approximate mass of 60 kg, and was used for all tests on aggregates described here. Aggregate samples were collected from conveyor belts. The total sampled amount was placed in sealed plastic bags that prevented loss or contamination of any part of the sample during its transport to the testing laboratory.

For factories in Chimborazo, only the aforementioned construction materials were produced during the investigation. All the tests were carried out in the UNACH LCCM laboratory. For clay bricks, compression, three-point bending and absorption capacity tests were conducted in accordance with American Society for Testing and Materials (ASTM) C67-07 (ASTM, 2014a), whereas in the case of the concrete blocks, compression and absorption capacity tests were conducted according to ASTM C140M (ASTM, 2015). The quality of the concrete paving bricks was assessed in terms of their compressive strength and acid solubility of the fine aggregates used in their manufacturing. These tests were conducted according to the procedures described in ASTM C140M (ASTM, 2015) and BSI 812-119 (BSI, 1985), respectively. Aggregate testing, which included sieve analysis, organic impurities determination, resistance to degradation of small and large-size coarse aggregates by abrasion and impact in the Los Angeles Machine, followed ASTM methods (ASTM, 2014c, 2013, 2011, 2014b, 2012).

Compression and bending tests were conducted using a 3000 kN C089-10N servo-controlled machine and UTM NET software, provided by Matest, Italy. Bending loads were applied to clay brick specimens using a three-point bending test device (Figure 2).

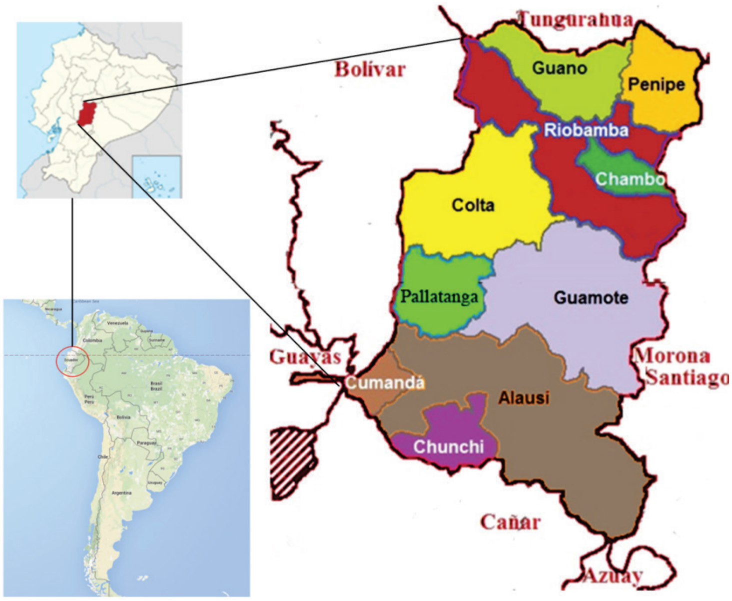


Figure 1: Map of Ecuador and the Province of Chimborazo, Including its 10 Districts

Figure 2. Three Point Bending Test Set-Up Conducted on Clay Brick Samples

Sizing characteristics were determined using Humboldt Manufacturing Company sieves. Statistical analysis was carried out using the software package R version 2.14. Results were considered significant at a level of 5% (95% confidence interval). A brief description of the methodology of each test is provided below:

Compression tests of clay bricks, concrete blocks and paving bricks

Prior to testing, paving brick and block specimens were immersed for 24 hr in water at room temperature, whereas dry bricks were cut in half. To achieve a uniform load distribution, specimens with physical irregularities on their faces were coated with a layer of sulphur-sand mortar or with wooden plates. The compressive strength (*C*) in MPa was evaluated as follows:

$$C = f * \frac{P}{A} \qquad \text{Eq. 1}$$

where *P* is the failure load (Newton), *A* is the contact area (mm^2) and *f* is a factor for thickness-bevel used only in the case of paving bricks (ASTM, 2015). The compressive load was applied at a controlled rate of 15 MPa/min.

Three-point bending test of clay bricks

Brick samples were dried in an oven (110 ± 5°C) for 24 hr and then cooled at room temperature. Using the three-point bending test device shown in Figure 2, the specimens were loaded at mid-span until failure. The rate of loading was 8896 N/min. The flexural strength (*MR*) was calculated using Eq. 2:

$$MR = \frac{3 * P * L}{2 * b * h^2} \qquad \text{Eq. 2}$$

where *P* is the maximum load (Newton), *L* is the distance between the supports (mm), *b* is the length of the specimen (mm) and *h* is the height of the specimen (mm).

Absorption capacity test on clay bricks and concrete blocks

The samples were dried at 110 ± 5°C for 24 hr, and the mass (*M2*) was recorded. The samples were then immersed for 24 hr in distilled water at room temperature, and after the saturated mass (*M1*) was recorded, the water absorption percentage (*Abs*) was calculated as follows:

$$Abs = \frac{M2 - M1}{M1} * 100 \qquad \text{Eq. 3}$$

Acid-soluble portion of fine aggregates used for concrete

A fine aggregate sample (50 g) and a piece of filter paper (Whatman filter No. 40) were dried in an oven (110 ± 5°C) and weighed, and their masses, *M1* and *M2*, respectively, were recorded. The dry sample was then mixed with hydrochloric acid (25 mL) and heated without boiling. The resulting mixture was decanted through the filter paper, and the solid retained was washed five times with 50 mL of hot distilled water. The non-dissolved material was dried at 105°C, and its mass was recorded (*M3*). The percentage of loss in mass due to the effect of acid (*%PS*) was calculated using Eq. 4.

$$\%PS = \frac{M1 - (M3 - M2)}{M1} * 100 \qquad \text{Eq. 4}$$

Abrasion tests of coarse aggregates

Samples of coarse aggregates (4500 g) were washed and then dried at 110 ± 5°C. The samples were subjected to abrasion and impact using 11 steel spheres (abrasive charges) in the Los Angeles Machine. The results were calculated using Eq. 5.

$$V = \frac{A - B}{A} * 100 \qquad \text{Eq. 5}$$

where *V* is the abrasion resistance (%), *A* is the initial mass of the sample (g) and *B* is the mass of the sample after the test (g).

Organic impurities test of fine aggregates

A colourless graduated glass bottle was filled with a sample of fine aggregate (130 mL) and a 3% solution of sodium hydroxide (70 mL). The bottle was then capped, shaken vigorously and left to stand at room temperature for 24 hr. The resulting coloured solution was assessed according to the Gardner scale as follows:

- Gardner colour No. 5 (Grade 1) and Gardner colour No. 8 (Grade 2): low impurities
- Gardner colour No. 11 (Grade 3): Gardner colour standard
- Gardner colour No. 14 (Grade 4) and Gardner colour No. 16 (Grade 5): high impurities

Determination of materials finer than 75 µm in fine aggregates

Samples of fine aggregate (2000 g) were dried at 110 ± 5°C. The material was then washed with water using a sieve (No. 200) until the water was clear. The remaining material was dried again at 110 ± 5°C. The test result was evaluated according to Eq. 6.

$$\%P = \frac{A - B}{A} * 100 \qquad \text{Eq. 6}$$

where *%P* is the percentage of material finer than 75 µm, *A* is the initial dry mass (g) and *B* is the dry mass after washing (g).

Sieve analysis of aggregates used for concrete

Fine (500 g) and coarse aggregate (12000 g) samples were dried at 110 ± 5°C, placed on each of a specified series of sieves (ranges provided in INEN, 2012d) and mechanically agitated for 5 min. The grading curve and fineness modulus were determined and compared with INEN specifications.

RESULTS AND DISCUSSION

Construction Material Factories

Since 2012, a field investigation has been conducted to locate and geo-reference all the factories that produce construction materials in the province of Chimborazo. Table 2 shows the number of factories found in each district according to the type of materials produced.

In the district of Chambo, along with agriculture, clay brick production is the main source of income for its population (INEC, 2011). This was evidenced by the 154 construction material factories in the district, which represent 98% of all clay brick factories operating in the province.

Quantitative analysis of the number of factories of construction materials in Chimborazo is shown in Figure 3. Brick and concrete block production accounts for 87% of all the manufacturing sites, with concrete paving bricks produced in only 5% of the factories located in the province.

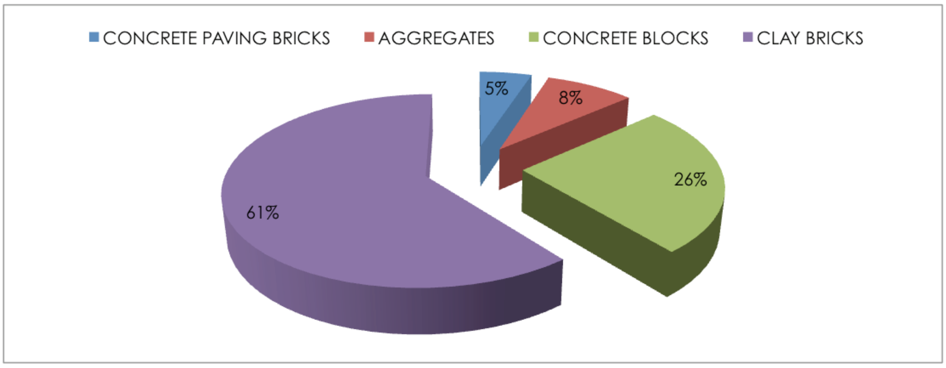


Figure 3. Production of Construction Materials in the Province of Chimborazo

Table 2. Construction Material Factories Located in the Province of Chimborazo

District	Paving Bricks	Aggregates for Concrete	Concrete Blocks	Clay Bricks	TOTAL
Alausí	0	3	6	3	12
Colta	1	1	5	0	7
Cumandá	2	0	1	0	3
Chambo	0	0	0	154	154
Chunchi	0	0	0	0	0
Guamote	0	1	3	0	4
Guano	1	2	5	0	8
Pallatanga	0	3	0	0	3
Penipe	1	2	1	0	4
Riobamba	8	10	45	0	63
Sum	**13**	**22**	**66**	**157**	**258**

Quality of Construction Materials

The number of tests performed on the sampled construction materials is reported in Table 3. The results of a descriptive analysis of the minimum and maximum values of each physical and mechanical property are outlined in Table 4. The levels of compliance with the INEN quality requirements obtained in the factories throughout the province are shown in Figures 4–9.

Of the 258 factories identified in the study, most were present in Chambo (154 sites). Here, clay brick factories represent the greatest number of construction material factories in the province (61%). In these factories, only C-type solid bricks are produced. In addition to the factories in Chambo, clay bricks are also manufactured in the district of Alausí. However, both the level of production and the type of bricks manufactured differ from what occurs in Chambo. In Alausí, only three factories are involved in the production of clay bricks, and these factories produce either C-type or E-type hollow bricks (INEN, 1978).

Cumandá and Pallatanga have the fewest manufacturing locations. In Cumandá, only three factories of paving bricks and concrete blocks were located, whereas in Pallatanga, only three quarries of concrete aggregates are in operation. Paver factories located in Cumandá (3 sites) represent only 5% of the total paver factories in the province (13 sites), with most of the manufacturing locations found predominantly in Riobamba (8 sites). In fact, after Chambo (154 factories), Riobamba is the district with the highest number of construction material factories (63 sites, Table 2).

Table 3. Quality Control Assessment of Construction Materials from Factories in Chimborazo

Construction Material	Type of Test Performed	Number of Tested Specimens
Clay bricks	Compressive strength	785
	Flexural strength	785
	Absorption capacity	785
Concrete blocks	Compressive strength	396
	Absorption capacity	396
Paving bricks	Compressive strength	130
	Acid-soluble portion	13
Fine aggregates for concrete	Organic impurities	20
	Materials finer than 75 μm	20
	Sieve analysis	20
Coarse aggregates for concrete	Resistance to degradation by abrasion and impact	15
	Sieve analysis	15
	TOTAL	**3380**

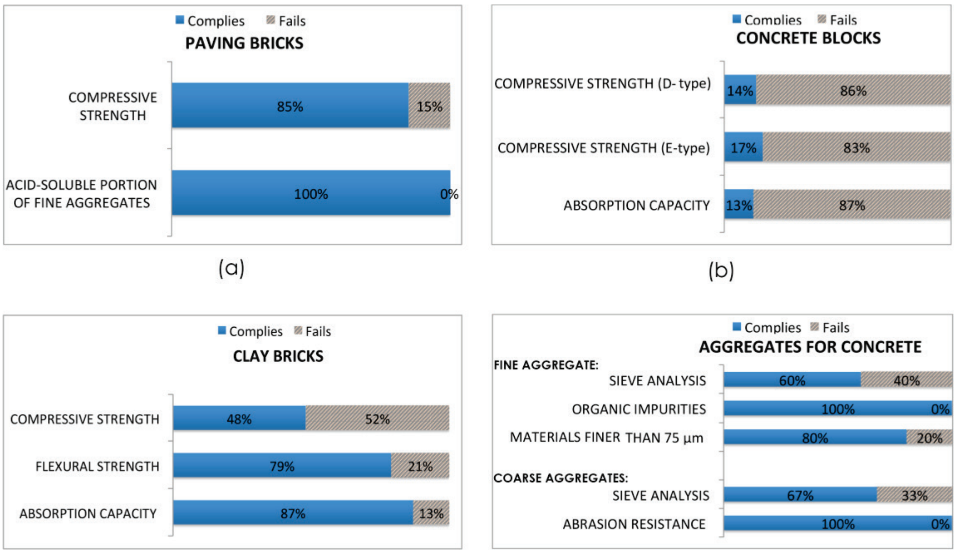
Table 4. Descriptive Analysis of Physical and Mechanical Properties of Construction Materials Analysed in Chimborazo

Building Materials	Range of Analysis		Frequency
Clay bricks	**Compressive strength**		
	7.3–7.9 MPa	Highest	64
	17.8–18.4 MPa	Lowest	1
	Flexural strength		
	3.3–3.5 MPa	Highest	57
	6.9–7.1 MPa	Lowest	2
	Absorption capacity		
	20%–21%	Highest	132
	4%-5%	Lowest	1

(continued on next page)

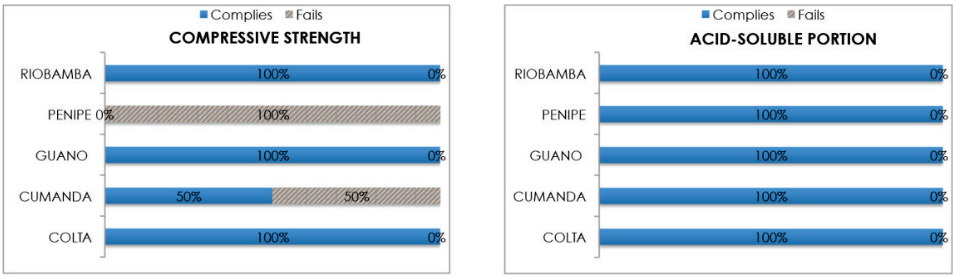
Table 4. (*continued*)

Building Materials	Range of Analysis		Frequency
	Compressive strength - Concrete blocks (D-type)		
	1.1–1.5 MPa	Highest	66
	5.6–6.0 MPa	Lowest	1
	Absorption capacity - Concrete blocks (D-type)		
	24%–26%	Highest	42
Concrete blocks	3%–5%	Lowest	1
	Compressive strength - Concrete blocks (E-type)		
	1.0–1.2 MPa	Highest	33
	2.8–3.0 MPa	Lowest	1
	Absorption capacity - Concrete blocks (E-type)		
	22%–24%	Highest	43
	10%–12%	Lowest	2
	Compressive strength - Pedestrian paving bricks		
	20–25 MPa	Highest	9
	13–15 MPa	Lowest	1
	Compressive strength - Traffic paving bricks		
Concrete paving bricks	38–39 MPa	Highest	17
	30–31 MPa	Lowest	2
	Acid-soluble portion - Fine aggregates		
	11%–12%	Highest	30
	13%–14%	Lowest	10
	Organic impurities		
	Gardner colour No. 5	Highest	18
	Gardner colour No. 8	Lowest	2
	Materials finer than 75 μm		
Fine aggregates	2.8%–4.2%	Highest	9
	7.3%–8.7%	Lowest	1
	Sieve analysis		
	2.36 mm	Highest	9
	300 μm	Lowest	1
	Resistance to degradation by abrasion and impact		
	8%–12%	Highest	7
Coarse aggregates	18%–22%	Lowest	1
	Sieve analysis		
	25 mm	Highest	10
	12.5 mm	Lowest	1



(c) (d)

Figure 4. Compliance Levels for Quality Requirements of Construction Materials Produced in Chimborazo: (a) Paving Bricks, (b) Concrete Blocks, (c) Clay Bricks and (d) Aggregates for Concrete



(a) (b)

Figure 5. Compliance Levels for Paving Bricks Produced in the Districts of Chimborazo: (a) Compressive Strength and (b) Acid Solubility of its Fine Aggregates

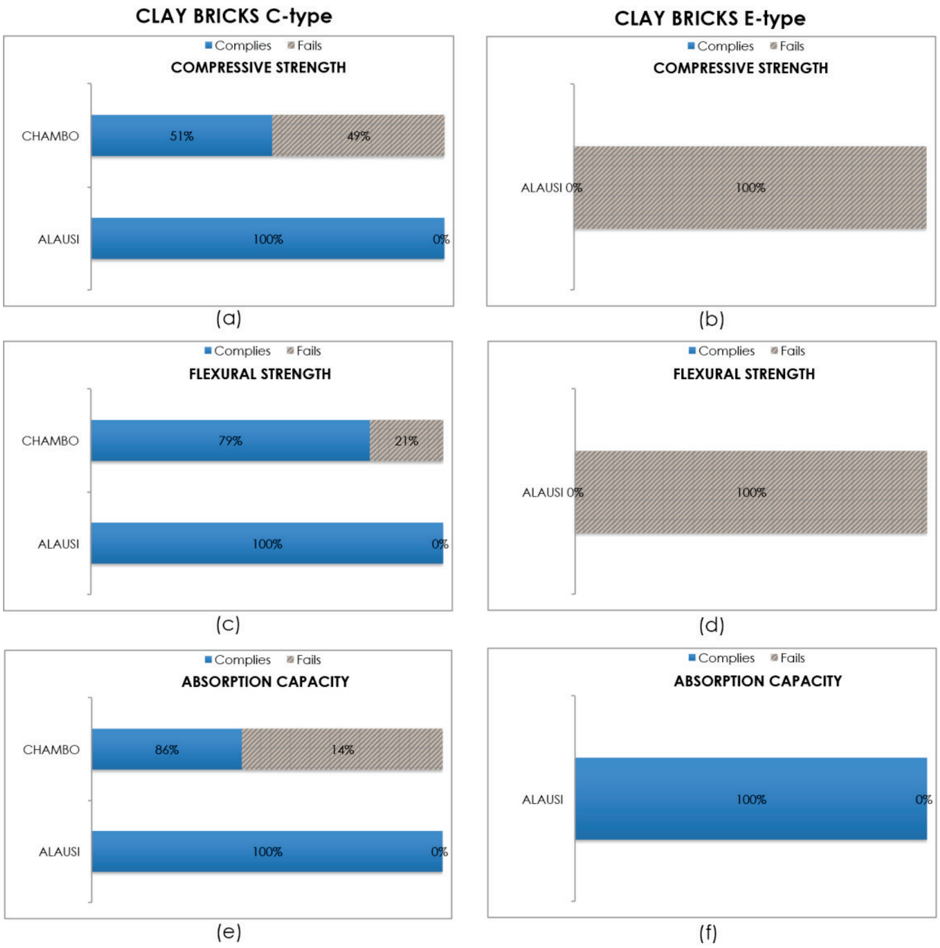


Figure 6. Compliance Levels for C-type (left) and E-type (right) Clay Bricks Produced in the Districts of Chimborazo: (a) and (b) Compressive Strength, (c) and (d) Flexural Strength, and (e) and (f) Absorption Capacity Values

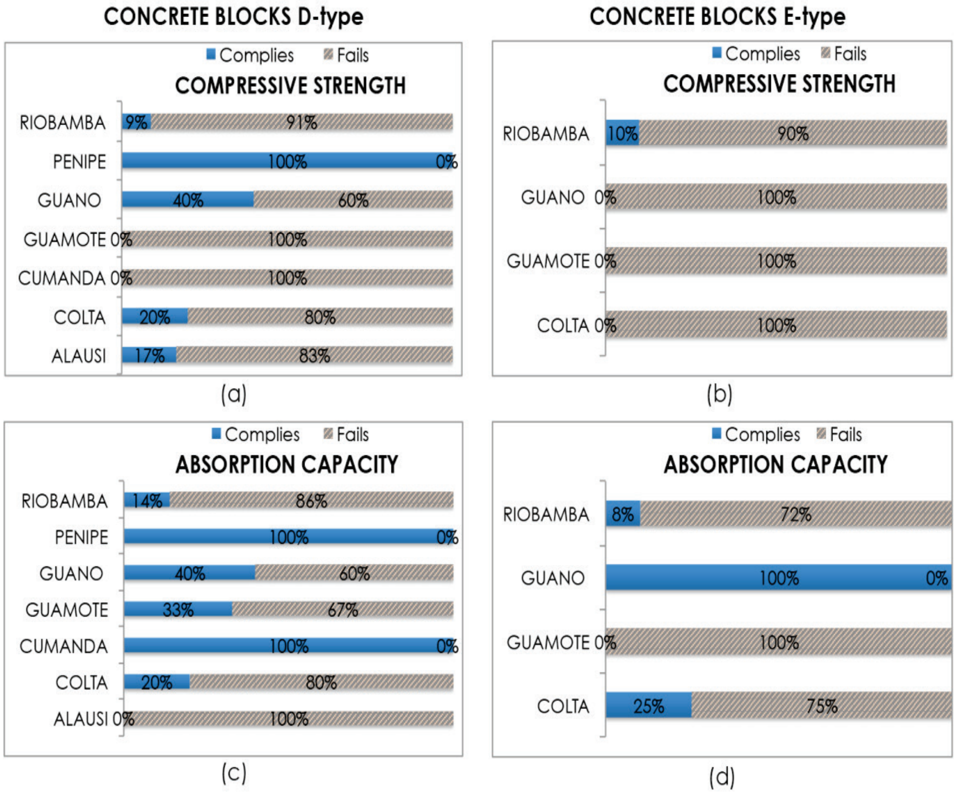


Figure 7. Compliance Levels for D-type (left) and E-type (right) Concrete Blocks Produced in the Districts of Chimborazo: (a) and (b) Compressive Strength, and (c) and (d) Absorption Capacity Values

Concrete Paving Bricks

When analysing the quality of paving bricks, it is also necessary to consider the standards of the fine aggregates used in their manufacture. Factories producing pavers in Chimborazo employed fine aggregates, which, in all cases, were compliant with the technical specifications related to the maximum mass of acid-soluble material extracted (Figures 4a and 5b). For instance, the fine portion (passing a 5 mm test sieve and retained by a 600 µm test sieve) of the aggregate samples had no acid-soluble materials higher than 25%.

For compressive strength testing, the results show that 85% of the evaluated factories produced paving bricks with suitable strengths. Regarding pedestrian paving bricks, most of the tested specimens (36 specimens) show strength values between 20 and 48 MPa, with only four specimens exhibiting poor compressive strength results (13–19 MPa). For vehicular paving bricks, all specimens (90 specimens) met the technical specification for compressive strength. Overall, most of the specimens (73 specimens) exhibited strengths between 35 and 50 MPa.

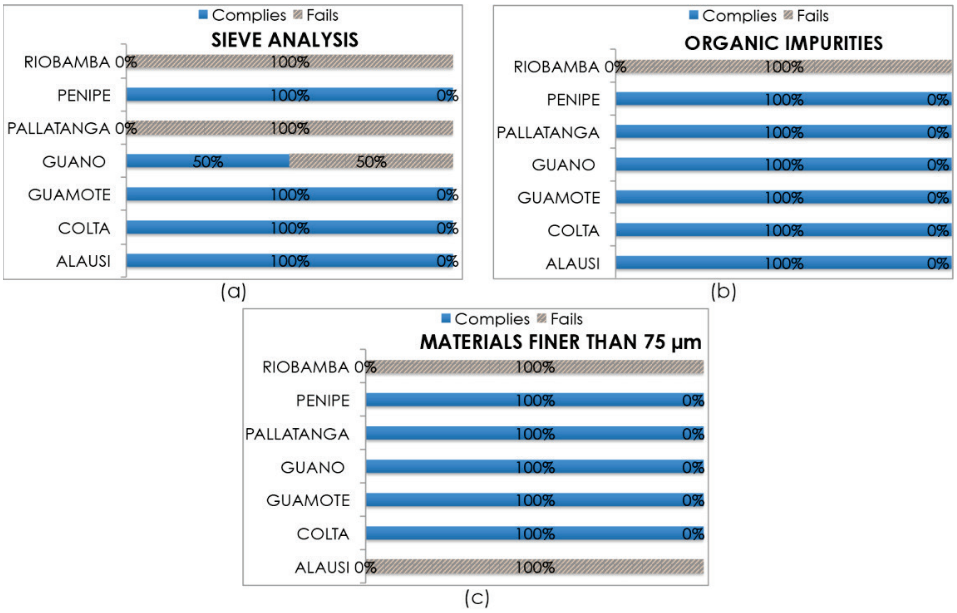


Figure 8. Compliance Levels for Natural Fine Aggregates for Concrete Produced in the Districts of Chimborazo: (a) Sieve Analysis, (b) Organic Impurities and (c) Materials Finer than 75 μm

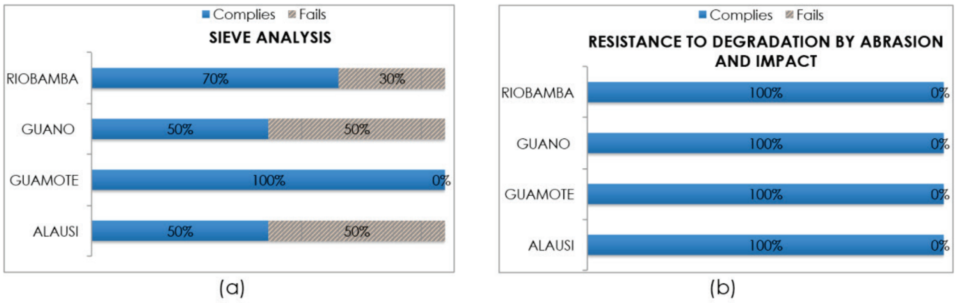


Figure 9. Compliance Levels for Natural Coarse Aggregates for Concrete Produced in the Districts of Chimborazo: (a) Sieve Analysis and (b) Resistance to Degradation by Abrasion and Impact

Clay Bricks

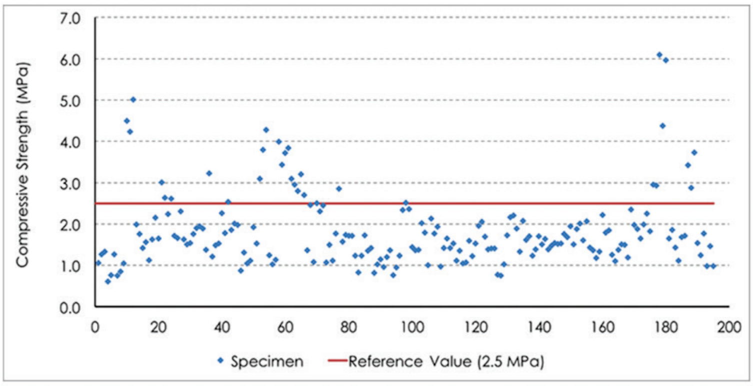
The INEN 0297 (INEN, 1978) standard specifies that C-type ceramic bricks must have a minimum compressive strength of 8 MPa, a minimum flexural strength of 2 MPa and a maximum absorption capacity of 25% (Table 1). Regarding the brick samples analysed (157 factories), 76 factories produced clay bricks that met the specification for compression strength, 124 factories produced clay bricks that exhibited flexural strengths higher than 2 MPa, and the specimens from 135 factories met the water absorption criteria (Figures 4c, 6a, 6c and 6e). On the other hand, serious problems were found with the quality of E-type hollow bricks produced in Alausí (Figures 6b and 6d), with all specimens failing to meet the strength specifications recommended in the INEN standards (Table 1). In terms of compressive and flexural strength, the results obtained were 1.4–1.6 MPa and 0.3–0.6 MPa, respectively. Therefore, E-type bricks only met the specification related to their absorption capacity, as shown in Figure 6f.

Concrete Blocks

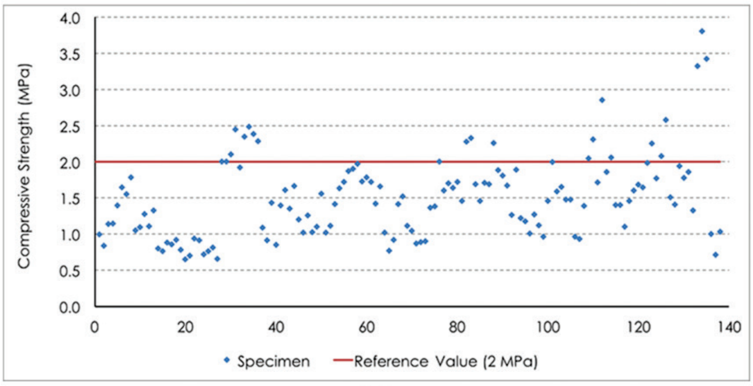
Concrete blocks and fine aggregates are the most common construction materials produced in Chimborazo, with manufacturing sites found in seven districts throughout the province. The concrete blocks produced showed the lowest levels of quality in all the factories tested, with the only exception being the district of Penipe (Figures 7a and 7c). The NTE INEN 638 (INEN, 1993) and NTE INEN 643 (INEN, 2014) standards specify that the minimum compressive strengths of D-type and E-type concrete blocks should be 2.5 and 2 MPa, respectively. However, the compression tests results revealed that only 14% of D-type blocks and 17% of E-type blocks exhibited strengths greater than or equal to the minimum strength specification. From a total of 195 D-type blocks tested, only 31 specimens exhibited compressive strengths above the reference value (Figure 10a). Similar results were obtained from testing E-type concrete blocks, where only 23 specimens (from 138 specimens) demonstrated appropriate quality levels (Figure 10b). For water absorption capacity, 87% of factories failed to meet the mandatory criteria. In this case, 159 D-type and 121 E-type concrete block specimens obtained water absorption values of 15% to 35%.

Since the types of blocks studied were cast using cement as a binder, quality problems, particularly those observed in E-type blocks, might be related to the quality of the cement used. However, this appears unlikely, since in Ecuador, the cement used for concrete production meets the requirements specified in ASTM C150 (ASTM, 2007) and NTE INEN 152 (INEN, 2012a). The cement produced in Chimborazo has been classified as a pozzolanic Portland cement (IP type), meeting quality specifications and being subject to frequent inspections, as reported by the manufacturer (Chimborazo Cement, 2016). As highlighted by Diaz (2010), the quality of E-type concrete blocks is not affected by the quality of cement; furthermore, if a mixture with appropriate proportions of its components is used, the block samples will exceed minimum quality requirements.

In contrast, the results obtained in this study indicated that concrete pavers exhibited higher levels of quality compared to concrete blocks. The production of concrete blocks with poor quality appears to be a common problem in developing countries (Baiden and Tuuli, 2004; Florek, 1985; Usman and Gidado, 2013; Samson, Elinwa and Ejeh, 2002; Anosike and Oyebade, 2011; Osarenmwinda and Edigin, 2010). Causes include an absent quality control programme and poor monitoring by producers, deliberate reduction in the amount of cement in concrete mixes to lower costs, lack of staff in charge of quality control with formal training, the use of non-appropriate production techniques or equipment and a failure to comply to recommended production standards related to moulding, curing and batching methods. According to Anosike and Oyebade, (2012), despite the existence of a quality standard in countries such as Nigeria, where the proportions of mixtures or water-to-cement ratios are specified, the lack of penalties for those who do not meet quality specifications has given producers the leeway to produce blocks of poor quality for commercial use.



(a)



(b)

Figure 10. Compressive Strength Values Achieved for a Total of: (a) 195 D-type Concrete Block Specimens and (b) 138 E-type Concrete Block Specimens

Natural Aggregates for Concrete

All quarries of fine aggregates had no problems associated with the presence of organic impurities, apart from those quarries located in Riobamba (Figure 8b).

Regarding the granulometric analysis results, concrete aggregates with an adequate particle size distribution were found in 60% of fine aggregate quarries (12 sites) and 67% of coarse aggregate quarries (10 sites).

It should be noted that several factories of fine and coarse aggregates had problems meeting the standard requirements for granulometry and materials finer than 75 µm; in particular, the aggregates from the factories located in Alausí, Guano, Pallatanga and Riobamba showed the lowest levels of quality in the province (Figures 8a, 8c and 9a). However, if all the quarries located in Chimborazo are considered, 80% of the fine aggregate samples (16 quarries) had no problems with materials finer than 75 µm, thus fulfilling the INEN standard; in this case, percentages of materials finer than 75 µm were below 5%, with the average of the results found to be approximately 3.9%.

In contrast, all coarse aggregate quarries produced materials with a suitable abrasion resistance value (Figure 9b). For instance, every coarse aggregate sample had no significant abrasion problems with its particles, with the abrasion results being only 3.6%–19.8% (<< 50%), as shown in Figure 11.

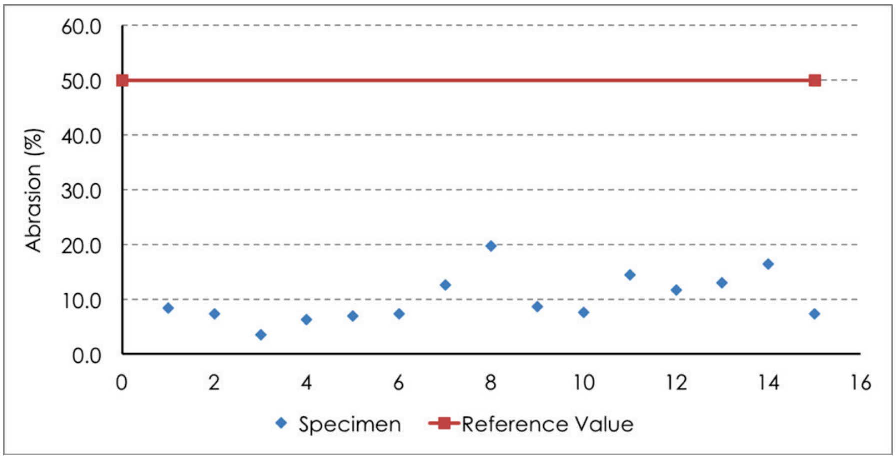


Figure 11. Resistance to Degradation by Abrasion and Impact of Coarse Aggregates Produced in Chimborazo

CONCLUSIONS

Concrete paving brick factories achieved the highest levels of quality in their products, followed by quarries producing fine and coarse aggregates. However, as graphically illustrated (Figures 4–9), all districts of the province of Chimborazo had problems in the quality of the construction material samples analysed in this study. The highest percentage of non-compliance and the widest spread of the results were observed for concrete block samples. Furthermore, the largest number of factories that need to improve the quality of their building products was found in the district of Chambo. In Ecuador, non-industrial production of construction materials such as bricks, concrete blocks, pavers and concrete aggregates is the main source of income for many families. Unfortunately, this has resulted in the rapid and uncontrolled commercialisation of such materials, leading to numerous quality problems, as evidenced by the findings of this work. These problems were observed primarily in the production of concrete blocks and clay bricks.

Until 2011, most factories involved in the production of construction materials in Chimborazo had never monitored the quality of their production and were unaware of the technical requirements that had to be met. Despite many quality problems found, the study reveals the presence of some factories that meet the technical specifications of their products, in terms of physical and mechanical properties of the samples analysed. The results of the tests conducted were passed on to each manufacturer through lab reports. Currently, 100% of the construction material factories in Chimborazo operating between 2012 to 2015 know what technical specifications have to be met and monitor the quality of their production.

The findings obtained in this study have enabled the authors to promote a new research project (Cevallos, Barahona and Castillo, 2014) aimed at establishing the causes of quality problems that are commonly seen, particularly in clay bricks and concrete blocks produced in Chimborazo. Government agencies dedicated to the quality control of construction materials, as well as producers, have been informed of the results of these studies. Nevertheless, the necessary change in the quality culture of the population remains unclear. Government agencies are urged to implement new reforms to laws and ordinances, so that the quality requirements for producers of construction materials in the province become stricter. Regular training programmes, along with routine laboratory reports, should become mandatory before any producers of construction materials have their operating licenses renewed.

Further studies should be conducted in Chimborazo to know the exact impact of the work conducted by the authors on improving the quality of the construction materials assessed in this investigation.

ACKNOWLEDGEMENTS

The authors would like to thank the support provided by the funding body SENPLADES [USD282,054.50] to execute the research project "Database for Quality Control of Construction Materials Produced in the Province of Chimborazo", which validated the work in this article.

REFERENCES

Anosike, M.N. and Oyebade, A.A. (2012). Sandcrete block and quality management in Nigeria building industry. *Journal of Engineering, Project and Production Management*, 2(1): 37–46.

ASTM (American Society for Testing and Materials). (2007). ASTM C150: Standard Specification for Portland Cement.

ASTM. (2011). ASTM C40M-11: Standard Test Method for Organic Impurities in Fine Aggregates for Concrete.

ASTM. (2012). ASTM C535-12: Standard Test Method for Resistance to Degradation of Large-Size Coarse Aggregates by Abrasion and Impact in the Los Angeles Machine.

ASTM. (2013). ASTM C117-13: Standard Test Method for Materials Finer than 75 µm (No. 200) Sieve in Mineral Aggregates by Washing.

ASTM. (2014a). ASTM C67-07: Standard Test Methods for Sampling and Testing Brick and Structural Clay Tile.

ASTM. (2014b). ASTM C131M-14: Standard Test Method for Resistance to Degradation of Small-Size Coarse Aggregates by Abrasion and Impact in the Los Angeles Machine.

ASTM. (2014c). ASTM 136M-14: Standard Test Method for Sieve Analysis of Fine and Coarse Aggregates.

ASTM. (2015). ASTM C140M-15: Standard Test Methods for Sampling and Testing Concrete Masonry Units and Related Units.

Baiden, B.K. and Tuuli, M. (2004). Impact of quality control practices in sandcrete blocks production. *Journal of Architectural Enginnering*, 10(2): 55–66. https://doi.org/10.1061/(ASCE)1076-0431(2004)10:2(53).

BSI (British Standards Institution). (1985). *BS 812-119:1985: Testing Aggregates. Method for Determination of Acid-Soluble Material in Fine Aggregate*. UK: British Standard.

Burati, J.L., Matthews, M.F. and Kalidlindi, N. (1989). Quality management in the construction industry. *ASCE Journal of Construction Engineering and Management*, 117(2): 341–57. https://doi.org/10.1061/(ASCE)0733-9364 (1991)117:2(341).

Cevallos, O.A., Barahona, D. and Castillo, T. (2014). Determinación del Origen del Incumplimiento de las Especificaciones Técnicas en la Elaboración de Ladrillos, Bloques y Adoquines Producidos en la Provincia de Chimborazo. Available at: http://investigacion.unach.edu.ec/index.php/9-yt-sample-data/category1/38-determinacion-del-origen-del-incumplimiento [Accessed on 2 September 2015].

Chimborazo Cement. (2016). Product Description (in Spanish). Available at: http://www.cementochimborazo.com/index.php/prod [Accessed on 17 July 2016].

Cnudde, M. (1991). Lack of quality in construction: Economic losses. *Proceedings: European Symposium on Management, Quality and Economics in Housing and other Building*. Lisbon, Portugal, 508–515.

Cootad (Código Orgánico de Organización Territorial, Autonomía y Descentralización). (2010). Ministerio de Coordinación de la Política y Gobiernos Autónomos descentralizados (in Spanish). Available at: http://www.ame.gob.ec/ame/pdf/cootad_2012.pdf [Accessed on 17 July 2015].

Delouis, B., Cisternas, A., Dorbath, L., Rivera, L. and Kausel, E. (1996). The Andean subduction zone between 22 and 25°S (northern Chile): Precise geometry and state of stress. *Tectonophysics*, 259(1-3): 81–100. https://doi.org /10.1016/0040-1951(95)00065-8.

Díaz, E. (2010). Elaboración de un bloque hueco de hormigón tipo E que cumpla con especificaciones técnicas. Civil Eng. diss., Universidad Nacional de Chimborazo.

Florek, A.J. (1985). Quality of Hollow Block Manufactured in Northern Nigeria: Federal Ministry of Works and Housing.

Formoso, C.T., Masce, L.S., De Cesare C. and Isatto, E.L. (2002). Material waste in building industry: Main causes and prevention. *Journal of Construction Engineering and Management*, 128(4): 316–325. https://doi.org/10.1061/ (ASCE)0733-9364(2002)128:4(316).

Helene, P. and Figueiredo, F.P. (eds.). (2003). *Manual de Rehabilitación de Estructuras de Hormigón. Reparación, refuerzo y protección*. Brasil: CYTED.

IGEPN (Instituto Geofísico de la Escuela Politécnica Nacional). (2016). Mapa de Sismos del Ecuador. Available at: http://www.igepn.edu.ec/sismos [Accessed on 2 February 2016].

Illston, J.M. and Domone, P.L. (2010). *Construction Materials: Their Nature and Behavior.* United Kingdom: T&F Books.

INEC (Instituto Nacional de Estadísticas y Censos). (2011). Population Census Results (in Spanish). Available at: http://www.inec.gob.ec/cpv/?TB_iframe=true&height=450&width=800%27%20rel=slbox,%202012 [Accessed on 5 June 2015].

INEN (Instituto Ecuatoriano de Normalización). (1977). NTE INEN 0292:1978: Ceramic bricks – Sampling (in Spanish). Available at: https://law.resource.org/pub/ec/ibr/ec.nte.0292.1978.pdf [Accessed on 6 June 2015].

INEN. (1978). NTE INEN 0297:1978: Ceramic bricks – Requirements (in Spanish). Available at: https://law.resource.org/pub/ec/ibr/ec.nte.0297.1978.pdf [Accessed on 6 June 2015].

INEN. (1993). NTE INEN 0638:1993: Hollow blocks of concrete – Definitions, Classification and General Conditions (in Spanish). Available at: https://law.resource.org/pub/ec/ibr/ec.nte.0638.1993.pdf [Accessed on 6 June 2015].

INEN. (2010a). NTE INEN 695:2010: Aggregates – Sampling (in Spanish). Available at: https://law.resource.org/pub/ec/ibr/ec.nte.0695.2010.pdf [Accessed on 6 June 2015].

INEN. (2010b). NTE INEN 1484:1986: Concrete Paving Bricks – Sampling (in Spanish). Available at: https://law.resource.org/pub/ec/ibr/ec.nte.1484.1987.pdf [Accessed on 8 June 2015].

INEN. (2010c). NTE INEN 1488:1986: Concrete Paving Bricks – Requirements (in Spanish). Available at: https://law.resource.org/pub/ec/ibr/ec.nte.1488.1987.pdf [Accessed on 8 June 2015].

INEN. (2012a). La Institución: Misión and Visión. Available at: http://www.normalizacion.gob.ec/la-institucion/ [Accessed on 8 May 2015].

INEN. (2012b). NTE INEN 152:2012: Cement Portland – Requirements (in Spanish). Available at: https://law.resource.org/pub/ec/ibr/ec.nte.0152.2012.pdf [Accessed on 11 June 2015].

INEN. (2012c). NTE INEN 639:1993: Hollow Blocks of Concrete – Sampling, Inspection and Acceptance (in Spanish). Available at: https://law.resource.org/pub/ec/ibr/ec.nte.0639.2012.pdf [Accessed on 21 February 2015].

INEN. (2012d). NTE INEN 872:1982: Aggregates for Concrete – Requirements (in Spanish). Available at: https://law.resource.org/pub/ec/ibr/ec.nte.0872.2011.pdf [Accessed on 6 June 2015].

INEN. (2014). NTE INEN 643:2014: Hollow Blocks of Concrete – Requirements (in Spanish). Available at: http://www.normalizacion.gob.ec/wp-content/uploads/downloads/2014/02/nte_inen_643.pdf [Accessed on 6 June 2015].

Koskela, L. (1992). Application of the New Production Philosophy to Construction. Technical Report No. 72, CIFE Department of Civil Engineering, Stanford University.

LCCM (Laboratorio de Control de Calidad de Materiales). (2010). *Registros de Ensayos de Laboratorio. LCCM Report No. 01–10.* Ecuador, Riobamba: Universidad Nacional de Chimborazo.

Liu, J., Li, B., Lin, B. and Nguyen, V. (2007). Key issues and challenges of risk management and insurance in Chinas construction industry: An empirical study. *Industrial Management and Data Systems*, 107(3): 382–396. https://doi.org/10.1108/02635570710734280.

NEC (Norma Ecuatoriana de la Construcción). (2015). NEC–SE–DS: Peligro Sísmico: Diseño Sismoresistente. Available at: http://www.habitatyvivienda.gob.ec/wp-content/uploads/downloads/2014/08/NEC-SE-DS.pdf [Accessed on 25 May 2015].

Ofori, G. (2000). Challenges of construction industries in developing countries: Lessons from various countries. Paper presented at the 2nd International Conference on Construction in Developing Countries: Challenges Facing Construction Industries in Developing Countries. Gabarone, Botswana, 5–17 November 2000.

Osarenmwinda, J.O. and Edigin, S.A. (2010). Quality assessment of hollow sandcrete blocks produced by block moulding factories in Benin City. *International Journal of Science and Technological Research*, 7(1 & 2): 19–24.

Samson, D., Elinwa, A.U. and Ejeh, S.P. (2002). Quality assessment of hollow sandcrete blocks. *Nigeria Journal of Engineering Research and Development*, 1(3): 37–46.

Tucker, R.L. (1986). Management of construction productivity. *Journal of Management in Engineering,* 2(3): 148–156. https://doi.org/10.1080/01446198600000014.

Usman, A. and Gidado, U. (2013). Quality assurance of hollow sandcrete blocks produced by block moulding factories in Gombe Metropolis. *Journal of Science, Technology & Education*, 2(1): 61–65.

Yuan, X., Sobolev, S.V., Kind, R., Oncken, O. and the ANCORP Working Group. (2000). Subduction and collision processes in the Central Andes constrained by converted seismic phases. *Nature*, 408: 958–961. https://doi.org/10.1038/35050073.