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

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Abstract

An important economic activity in the province of Chimborazo is the manufacture 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 not reduce the lifespan of civil constructions. 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 Standardisation (INEN). All testing procedures for 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 paper presents the outcomes of the quality evaluation of construction materials produced in 258 factories located in the ten districts (cantons) of Chimborazo. The study revealed that paving bricks and aggregates for concrete performed better than clay bricks and concrete blocks. The samples of concrete blocks had the highest percentage of non-compliance specifications and the widest spread of 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 forming 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 optimization of resources and reduction in costs and construction times continue to provide conclusive reasons for their extensive utilization (Domone and Illston, 2010). Construction materials are subject to compliance with technical specifications and are required to undergo periodic quality controls. Table 1 shows...
the minimum requirements set by the Ecuadorian Institute of Standardization (INEN) 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 reinforced concrete lightened 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 as blocks used to build interior partition walls, with or without coating or mortar rendering (NTE INEN 0297, 1978; NTE INEN 638, 1993).

The INEN functions as the national technical organization for the quality system of the country (INEN, 2012). However, problems in the factories of Chimborazo have been frequent due to either the 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 the non-compliance with technical specifications. In this case, all the samples tested did not meet the recommended minimum compressive strength and exceeded the maximum permissible absorption capacity (LCCM report, 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 problems of quality of construction materials can affect the proper performance of structures and shorten their lifespan. For this reason, quality requirements are becoming more stringent, primarily in Andean countries like 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 categorized 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 the seismic zone IV (0.40 g).

The 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, greatest amount of waste residue, poor strength capacity and premature failure of concrete elements, and other quality problems present during construction and/or service phase, 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 be able to compete with market prices, even though it means a reduction in the quality of their products. Furthermore, regional governments have
granted operating licenses to producers of construction materials without requiring them to provide laboratory reports that verify the quality of their products. All these factors have contributed to the progressive decline in the quality culture in the province.

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 \( \mu m \) and granulometry) and mechanical properties (resistance to degradation, compressive strength and flexural strength) of construction material samples produced in 258 factories located in the ten 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 INEN (NTE INEN 0297, 1978; NTE INEN 638, 1993; NTE INEN 643, 2014; NTE INEN 1488, 2010; NTE INEN 872, 2012). 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 et al, 1991; Koskela, 1992). It is anticipated that similar studies can be replicated in Chimborazo, and thus specific methodologies for a Total Quality Control (TQC) and an adequate philosophy to improve production in the construction industry could be proposed and implemented.

**SAMPLING AND TESTING METHODOLOGY**

This research 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 of 458,581 inhabitants (INEC, 2011). The capital of the province is Riobamba, located at 2754 meters above sea level. Chimborazo, along with the provinces of Cotopaxi, Tungurahua and Pastaza belongs to Zone 3 according to the new territorial organization of Ecuador (Cootad, 2010). The study included all ten districts of the province: Alausí, Colta, Cumbanda, 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 (NTE INEN 0292, 1977; NTE INEN 639, 2012; NTE INEN 1484, 2010; NTE INEN 695, 2010). 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 long, 10 cm wide and 8 cm high. 15 specimens were sampled from each factory. Since each clay brick specimen of the entire lot has the same opportunity of being representative in the sample, the specimens were randomly sampled. The
concrete blocks analysed were hollow sandcrete blocks measuring 40 cm long, 20 cm wide and 10, 15 or 20 cm high, which comprised natural sand, water and binder, with cement as a binder. Both pedestrian and light-traffic paving bricks were interlocking concrete pavers, with dimensions of 25 cm long, 25 cm wide and 6 to 10 cm high. Concrete blocks included 6 specimens from each factory, and the analysis of paving bricks for pedestrian and vehicular traffic comprised 10 specimens from each factory. Both concrete block and paving brick specimens were sampled by trained laboratory personnel. The selected specimens were representative of the whole lot of units from which they were sampled. Samples of fine and coarse aggregates used in concrete were also obtained directly from open pit and river mines. Each sample of natural aggregates had an approximate mass of 60 kg, with which all tests here mentioned for aggregates were performed. 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 have been 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 ASTM C67-07 (2014), whereas in the case of concrete blocks, compression and absorption capacity tests were conducted according to ASTM C140M (2015). The quality of concrete paving bricks was assessed both in terms of their compressive strength and acid-solubility of the fine aggregates used in their manufacture. These tests were conducted following the procedures described in ASTM C140M (2015) and BS 812-119 (1985), respectively. Aggregate testing, involving 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 136M, 2014; ASTM C117, 2013; ASTM C40M, 2011; ASTM C131M, 2014; ASTM C535, 2012).

Compression and bending tests were conducted using a 3000 kN Matest C089-10N servo-controlled machine. Bending loads were applied on clay brick specimens using a three-point bending test device (Figure 2). Sizing characteristics were determined using Humboldt Manufacturing Company sieves. Statistical analysis was carried out using the software package R2.14. Results were considered significant with a level of 5% (95% confidence interval).

A brief description of the methodology of each test is provided below:

**a) Compression tests on clay bricks, concrete blocks and paving bricks**

Prior to testing, paving brick and block specimens were immersed for 24hr in water at room temperature, whereas dry bricks were cut in half. Specimens with physical irregularities on their faces were coated with a layer of sulphur-sand mortar, or through the aid of wooden plates, a uniform load distribution was achieved. The compressive strength (C) in MPa was evaluated as follows:
\[
C = f \frac{P}{A} 
\]

\text{Eq. 1}

where \( P \) is the failure load (Newtons), \( A \) is the contact area (mm\(^2\)), and \( f \) is a factor for thickness-bevel used only in the case of paving bricks (see ASTM C140M-15, 2015). The compressive load was applied at a controlled rate of 15 MPa/min.

**b) Three-point bending test on clay bricks**

Brick samples were dried in an oven (110 ± 5 °C) for 24hr 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:

\[
MR = \frac{3 \times P \times L}{2 \times b \times h^2} 
\]

\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), \( h \) is the height of the specimen (mm).

**c) Absorption capacity test on clay bricks and concrete blocks**

The samples were dried at 110 ± 5 °C for 24hr, and the mass \((M_2)\) was recorded. The samples were then immersed for 24hr in distilled water at room temperature, and after the saturated mass \((M_1)\) was recorded, the water absorption percentage \((\text{Abs})\) was calculated as follows:

\[
\text{Abs} = \frac{M_2 - M_1}{M_1} \times 100
\]

\text{Eq. 3}

d) Acid-soluble portion of fine aggregates for concrete

A fine aggregate sample (50 g) and a filter paper (Whatman filter No. 40) were dried in an oven (110 ± 5 °C) and weighted, with their masses \(M_1\) and \(M_2\) recorded, respectively. 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 for five times with 50 mL of hot distilled water. The non-dissolved material was dried at 105 °C, and its mass was recorded \((M_3)\).

The percentage of loss in mass due to the effect of acid \((\%\text{PS})\) was calculated using Eq. 4:

\[
\%\text{PS} = \frac{M_1 - (M_3 - M_2)}{M_1} \times 100
\]

\text{Eq. 4}

e) Abrasion tests on 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. Results were calculated using equation Eq. 5.

\[ V = \frac{A - B}{A} \times 100 \]  

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).

**f) Organic impurities test on 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 24hr. 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

**g) 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.

\[ \%P = \frac{A - B}{A} \times 100 \]  

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).

**h) Sieve analysis of aggregates for concrete**

Fine (500 g) and coarse aggregates (12000 g) samples were dried at 110 ± 5 °C, placed on each of a specified series of sieves (ranges provided in NTE INEN 872, 2012) and mechanically agitated for 5 minutes. The grading curve and fineness modulus were determined and compared with INEN specifications.

**RESULTS AND DISCUSSION**

Construction materials factories
Since 2012, a field investigation was 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 of its population (INEC, 2011). This was evidenced in the 154 factories of construction materials 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. Bricks and concrete blocks production accounts for 87% of all the manufacturing sites, with concrete paving bricks produced in only 5% of the factories located in the province.

**Quality of construction materials**

The number of tests performed on the sampled construction materials is reported in Table 3. Descriptive analysis results for 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, the highest number was present in Chambo (154 sites). Here, clay brick factories represent the greatest number of construction materials 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 (NTE INEN 0297, 1978).

Cumandá and Pallatanga have the least number of 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 materials factories (63 sites, Table 2).
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.

Clay bricks

The INEN 0297 (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 exhibited flexural strengths higher than 2 MPa and 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 7 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 (2009) and NTE INEN 643 (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 well 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, 2007 and NTE INEN 152, 2012. 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 et al., 2002; Anosike and Oyebade, 2011; Osarenmwinda and Edigin, 2010). Causes include an absent quality control program 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 like 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.

**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).

Considering 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 in meeting the standard requirements for granulometry and materials finer than 75 μm; in particular were the factories located in Alausí, Guano, Pallatanga and Riobamba, which 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 results found in the order of 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 of its particles, with the abrasion results being only 3.6-19.8% (< 50%), as shown in Figure 11.

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 revealed quality problems in the construction materials samples analysed during this study. The highest percentage of non-compliance and the widest spread of results were recorded for concrete block samples. Furthermore, the highest number of factories that need to improve the quality of its 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 commercialization 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 the 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 from 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 et al., 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 and 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 programs along with
routine production 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.

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**LIST OF TABLES & TABLE CAPTIONS**

**Table 1.** Technical specifications for construction materials in Ecuador provided by the Ecuadorian Institute of Standardisation (INEN)

| Construction material | Type | Characteristic                      | Minimum requirement |
|------------------------|------|-------------------------------------|---------------------|
| Clay bricks            | C    | Compressive strength*               | 8 MPa.              |
| Material               | Flexural strength* | Absorption capacity* |
|-----------------------|--------------------|----------------------|
| 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 MPa-40 MPa. |                      |
| Fine aggregates       | Acid-soluble portion 25% |                      |
| Natural aggregates for concrete | | |
| Fine aggregates       | Organic impurities Colour Gardner 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                | Resistance degradation to by 50% |
Table 2. Construction materials 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** |

Note 1: *average of three specimens; *average of five specimens; †average of ten specimens.

Note 2: Data extracted from: NTE INEN 0297 (1978); NTE INEN 638 (1993); NTE INEN 643 (2014); NTE INEN 1488 (2010); NTE INEN 872 (2012).
Table 3. Quality control assessment on 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 for construction materials analysed in Chimborazo.

| Building materials | Range of analysis       | Frequency |
|--------------------|-------------------------|-----------|
| Clay bricks        | Compressive strength    |           |
|                    | 7.3 MPa-7.9 MPa         | Highest   | 64        |
|                    | 17.8 MPa-18.4 MPa       | Lowest    | 1         |
| Flexural strength  | 3.3 MPa-3.5 MPa         | Highest   | 57        |
|                        | Compressive strength - Concrete blocks (D-type) | Compressive strength - Concrete blocks (E-type) | Compressive strength - Pedestrian paving bricks | Compressive strength - Traffic paving bricks | Acid-soluble portion - Fine aggregates | Organic impurities |
|------------------------|-----------------------------------------------|-----------------------------------------------|-----------------------------------------------|-----------------------------------------------|---------------------------------------|------------------|
| Concrete blocks        | 6.9 MPa-7.1 MPa                                | 1.0 MPa-1.2 MPa                                | 20 MPa-25 MPa                                  | 38 MPa-39 MPa                                  | 11%-12%                               | 11%-12%          |
|                        | Lowest 2                                      | Highest 66                                     | Highest 9                                      | Highest 17                                     | Highest 30                             |                   |
| Absorption capacity    | 20%-21%                                       | 24%-26%                                       | 20%                                           | 30%                                           | 13%                                   |                  |
|                        | Highest 132                                   | Highest 42                                     |                                               |                                               | Lowest 2                               |                  |
|                        | 4%-5%                                         | Lowest 1                                       |                                               |                                               | 10%-12%                               |                  |
|                        | Lowest 1                                      |                                               |                                               |                                               | Lowest 10                              |                  |
| Concrete paving bricks | 5.6 MPa-6.0 MPa                                | 2.8 MPa-3.0 MPa                                | 13 MPa-15 MPa                                  | 30 MPa-31 MPa                                  | 13%-14%                               | 13%-14%          |
|                        | Lowest 1                                      | Lowest 1                                       |                                               |                                               | Lowest 10                              |                  |
| Absorption capacity    |                                               |                                               |                                               |                                               | 11%-12%                               |                  |
|                        |                                               |                                               |                                               |                                               | Highest 30                             |                  |
| Fine aggregates        |                                               |                                               |                                               |                                               | 13%-14%                               |                  |
### Colour - Gardner # 5
- Highest: 18

### Colour - Gardner # 8
- Lowest: 2

### Materials finer than 75 µm
- 2,8% - 4,2%
  - Highest: 9
- 7,3% - 8,7%
  - Lowest: 1

### Sieve analysis
- 2,36 mm
  - Highest: 9
- 300 µm
  - Lowest: 1

### Coarse aggregates

| Resistance to degradation by abrasion and impact | Highest | Lowest |
|-----------------------------------------------|---------|--------|
| 8% - 12%                                      | 7       | 1      |
| 18% - 22%                                     |         | 1      |

### Sieve analysis
- 25 mm
  - Highest: 10
- 12,5 mm
  - Lowest: 1

#### LIST OF FIGURES & FIGURE CAPTIONS

![Map of South America with regions labeled](image_url)
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