Evaluation of Destructive and Non-Destructive Methods for Determining Concrete Strength: Sclerometry and Compression Testing in the Department of Nariño, Colombia

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Abstract
This study establishes a correlation between two methods to determine the strength of concrete: the rebound number (NTC 3692) and the compressive strength (NTC 673). To this end, concrete cylinders 30 cm high and 15 cm in diameter were manufactured with two types of mixtures: one with sand from the "El Espino" quarry and crushed from the "Pabón" mine, and another with sand from "El Espino" and crushed from the "Pilcuan" mine. Resistances of 2500, 3000, 3500 and 4000 psi were evaluated, analyzing a total of 20 cylinders by resistance and mixture, of which 10 were subjected to the rebound test and the other 10 to compression. In addition, for the "Pabón" mixture, accelerant tests were incorporated at 7 and 14 days. The results obtained were analyzed by statistical regression, obtaining an exponential correlation equation. This equation was integrated into the Hammerlink software for use with the Silver Schmidt sclerometer, allowing the estimation of concrete strength in a non-destructive manner with a high degree of reliability. It is concluded that sclerometry is a viable alternative for estimating the strength of concrete, reducing costs and minimizing structural damage compared to destructive testing.

Keywords: Concrete**,** Sclerometry**,** Compressive strength**,** Rebound number**,** Non-destructive testing**,** Statistical correlation

1. Introduction

Nowadays, concrete technology has evolved significantly, increasing the standards of quality and resistance required in construction. The strength of concrete is one of its most critical properties, as it determines its ability to withstand loads and ensure structural safety. This strength depends to a large extent on the quality of the materials used, the dosage of the mixture and the curing processes. However, the evaluation of the strength of concrete in existing structures continues to represent a technical and economic challenge for civil engineering professionals.

Conventional methods for evaluating the strength of concrete include compression testing, regulated by NTC 673, which provides a direct and reliable measure of the material's ability to withstand axial loads. However, this method is destructive and requires the removal of cylinders or cores from the structure, which can affect its integrity and lead to additional costs. Faced with this problem, non-destructive methods have emerged, such as sclerometry, governed by the NTC 3692 standard, which allows estimating the strength of concrete by measuring the rebound number of an impact hammer on the surface of the material.

Although the sclerometry test offers advantages in terms of speed and economy, its application requires a precise correlation with the values obtained in compression tests to guarantee its reliability. In this context, the present study aims to establish a statistical correlation between the rebound number obtained by sclerometry and the compressive strength in concrete cylinders. To this end, concrete cylinders have been manufactured with two types of mixtures: one using sand from the "El Espino" quarry and crushed from the "Pabón" mine, and another with sand from "El Espino" and crushed from the "Pilcuan" mine.

The samples were subjected to compression and sclerometry tests at 28 days, in order to develop a correlation equation that allows estimating the strength of the concrete from the rebound number. In addition, tests with accelerant were carried out on one of the mixtures at 7 and 14 days to evaluate their behavior at an early age. The equation obtained was integrated into the Hammerlink software and applied to the Silver Schmidt sclerometer, facilitating the automation of the resistance calculation in the field.

This study contributes to the development of more efficient techniques for structural evaluation, allowing engineers and builders to estimate the strength of concrete without resorting to destructive testing. The results obtained not only improve the accuracy of the use of sclerometry in specific materials, but also offer a useful tool for quality control on site, optimizing costs and times in the construction process.

1.1 Justification

The evaluation of the strength of concrete is a fundamental aspect in civil engineering, as it allows to guarantee the structural safety and durability of constructions. Traditionally, compressive strength is determined by destructive testing, such as coring or compression testing on standardized cylinders, according to NTC 673. However, these methods have significant limitations, since they require the physical affectation of the structural elements, which can compromise their integrity, in addition to implying high costs and long execution times.

Faced with this problem, non-destructive testing has become very important in the construction industry, allowing the evaluation of the strength of concrete without damaging existing structures. Among these methods, sclerometry, regulated by the NTC 3692 standard, has established itself as a fast and economical alternative to estimate the strength of concrete by measuring the bounce number. However, the accuracy of this method depends on an adequate correlation with the values obtained in compression tests, considering variables such as the composition of the concrete, the type of aggregate, the water/cement ratio and the age of the material.

In this context, the present study is of great relevance, since it seeks to develop a correlation equation between the rebound number and the compressive strength, based on tests carried out on concrete cylinders manufactured with aggregates from different sources. By establishing this mathematical relationship, a reliable tool will be provided for the estimation of the strength of concrete on site, optimizing quality control and reducing the need for destructive testing.

In addition, this study is especially important in the field of rehabilitation and evaluation of existing structures, where the extraction of cores may be unfeasible for technical or economic reasons. The implementation of the Silver Schmidt sclerometer together with the Hammerlink software will automate and improve the accuracy of strength calculations, facilitating decision-making in construction and maintenance projects.

From an economic and environmental perspective, the application of non-destructive methods such as sclerometry represents a sustainable alternative that minimizes material waste and reduces the environmental impact associated with the extraction and replacement of concrete cores. Likewise, its widespread use can contribute to the optimization of costs in infrastructure projects, ensuring the quality of the concrete without incurring unnecessary expenses.

For all of the above, this research not only has a high academic and technical value, but also offers a practical solution to the current challenges of the construction industry, providing a reference model applicable to different contexts and types of concrete.

2. Objectives

2.1 General objective

To make a correlation between the rebound number (NTC 3692) and the compressive strength (NTC 673) of concrete using materials from the "El Espino" mine and the "Pabón", "Pilcuan" quarries

2.2 Specific objectives

- Develop 20 concrete cylinders for each strength to be obtained: 2500 psi, 3000 psi, 3500 psi and 4000 psi for each combination of mixture made with the 15 aggregates of the El Espino mine and the Pabón and Pilcuan quarries, whose compressive strength will be measured by the NTC 673 standard after 28 days of curing.

- Develop 20 concrete cylinders for each strength to be obtained: 2500 psi, 3000 psi, 3500 psi and 4000 psi for each combination of mixture made with the aggregates of the El Espino mine and the Pabón and Pilcuan quarries, whose compressive strength will be measured by the NTC 3692 standard after 28 days of curing.

- To find an expression that allows correlating the obtaining of compressive strength, between the NTC 3692 and NTC 673 standard tests, of cylindrical concrete specimens manufactured with the aggregates of the El Espino mine and the Pabón and Pilcuan quarries.

- Perform the compressive strength test of cylindrical concrete specimens (NTC 673) on the same specimens that were tested to measure the rebound number (NTC 3692) to determine if the use of the sclerometer affects the strength of such specimens.

- Perform the compressive strength test of cylindrical specimens (NTC 673) and the rebound number test (NTC 3692) for cylindrical concrete specimens made only with materials from the El Espino mine and crushed Pabón, for the proposed strengths and with accelerants at 7 and 14 days and thus determine the behavior of the compressive strength with the two tests having used accelerants.

- Carry out an economic analysis of each concrete mixture per m3, taking into account that the prices of the materials vary depending on their origin, also due to the use of additives.

3. Methodology

3.1 Research Design

This study is experimental and correlational, since it seeks to establish the relationship between two methods of measuring the strength of concrete: the compression test (NTC 673) and sclerometry (NTC 3692). Controlled laboratory tests were carried out with concrete cylinders made of different types of aggregates and subjected to different curing conditions.

3.2 Materials and Equipment Used

3.2.1 Study Materials

The following materials were used to manufacture the concrete:

- **Cement:** Portland type 1, Argos brand.
- **Fine aggregates:** Sand from the "El Espino" quarry.
- **Coarse aggregates:** Crushing from the "Pabón" and "Pilcuan" mines.
- **Additives:**
    - **Accelerant:** SIKASET L (used in blends with 7 and 14 day tests).
    - **Fluidizer:** SIKAFLUID (used in 3500 and 4000 psi mixtures to improve manageability).
- **Water:** Potable and free of impurities, in accordance with the quality standards for the manufacture of concrete.

3.2.2 Equipment Used

- **Compression machine:** Pinzuar brand, calibrated by Rossemberg & Reingeniería S.A.S.
- **Sclerometer:** Silver Schmidt model, calibrated for rebound number measurement.
- **Analysis Software:**
    - **Hammerlink:** To process the sclerometry data and generate correlation equations.
    - **Microsoft Excel:** For graphical representation and statistical analysis.
    - **Statgraphics:** For data analysis, hypothesis testing, and elimination of outlier data.

3.3 Preparation of concrete mixtures

3.3.1 Mixing Ratios

Two types of mixtures were manufactured with the following proportions:

Resistencia (psi)	Mezcla 1 (Pabón + Espino)	Mezcla 2 (Pilcuan + Espino)	Relación Agua/Cemento
2500	1:2:3.5	1:2:3.5	0.51
3000	1:2.5:2.5	1:2.5:2.5	0.49
3500	1:2:2	1:2:2	0.45
4000	1:2:2	1:2:2	0.35

Table 1. Mixing ratios
In original language Spanish

For mixture 1 (Pabón + Espino), tests with accelerant were also carried out at 7 and 14 days, using 3% and 2% of the cement weight, respectively.

3.3.2 Cylinder Manufacturing

- Cylinders of 30 cm in height and 15 cm in diameter were made using certified plastic jackets.
- A half-bulk mixer was used, with which 20 cylinders were manufactured for each combination of mixture and resistance.
- Each cylinder was molded in three layers, applying 25 blows with metal rod to guarantee its compaction, complemented by vibration with a rubber mallet.
- After 24 hours, the cylinders were stripped and subjected to temperature-controlled water curing until the test age.

3.4 Tests carried out

3.4.1 Compression Test (NTC 673)

- Compression tests were performed on the testing machine at 28 days for all samples.
- Additionally, for the mixture with accelerant, tests were carried out at 7 and 14 days.
- Each test was carried out by applying a progressive axial load until the failure of the sample, recording the maximum resistance supported.

3.4.2 Sclerometry Assay (NTC 3692)

- The Silver Schmidt sclerometer was used to measure the rebound number in each cylinder.
- 10 impacts were made per sample (5 on the upper face and 5 on the lower side) and the average value of the rebound index (Q) was recorded.
- The results obtained were compared with the resistance values determined in the compression test.

3.5 Data analysis and correlation

3.5.1 Deletion of Outlier Data

To ensure the reliability of the results, statistical filters were applied:

- Values that differed by more than 3.5 MPa from the expected value according to NSR-10 were removed.
- Hypothesis tests were performed with Statgraphics to rule out outliers in each dataset.

3.5.2 Generation of Correlation Models

- Microsoft Excel software was used to graph the data and adjust mathematical regression models.
- An exponential correlation equation was obtained between the rebound number (Q) and the compressive strength (MPa).
- The equation was entered into the Hammerlink software and loaded into the Silver Schmidt sclerometer to estimate resistance in future

4. Results

For the analysis of results, the data filtered in the statistics were graphed, and linear regressions were applied to evaluate how reliable the model is.

The R-squared factor is the result of squaring the R-factor, which is Pearson's correlation coefficient.

The R-squared factor evaluates how reliable the model is and how much relationship there is between the two variables, in this case the compression and the Q-value that the sclerometry gives us.

This value can be between 0 and 1, when it approaches 0, the model is not very reliable and there is no relationship between its variables, on the contrary, if it approaches 1 the model is very reliable and its variables are related to each other. It is impossible to obtain a model with a square R value equal to 1, since the models are not completely accurate, on the contrary, they are close to reality and predict some behaviors.

Next, the analysis of the results is presented using graphs showing trend curves, the degree of accuracy of the model (R2) and the formula of the curve. These factors are determined from the analysis of results made by the graphing software, in this case Microsoft Excel. The exponential curve model used to graph these results is specified in the methodology of the sclerometer used.

4.1 Analysis of results for mixing 1 to 28 days

MIX 1 TO 2500 ps

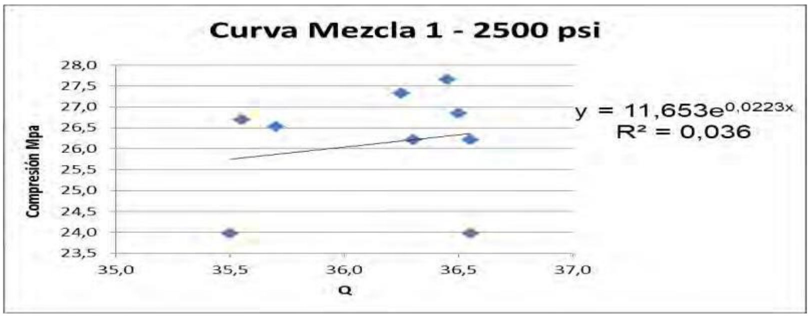

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Figure 1. Trend Curve for Mixing 1 to 2500 psi

In this curve it is observed that this mixture had a dispersion of data that generates a degree of reliability of the model of only 3.6%, this is due to the distance between the scattered points and the amount of data graphed. It should be clarified that the more the amount of graphed data, the degree of reliability of the model increases.

MIX 1 TO 3000 psi

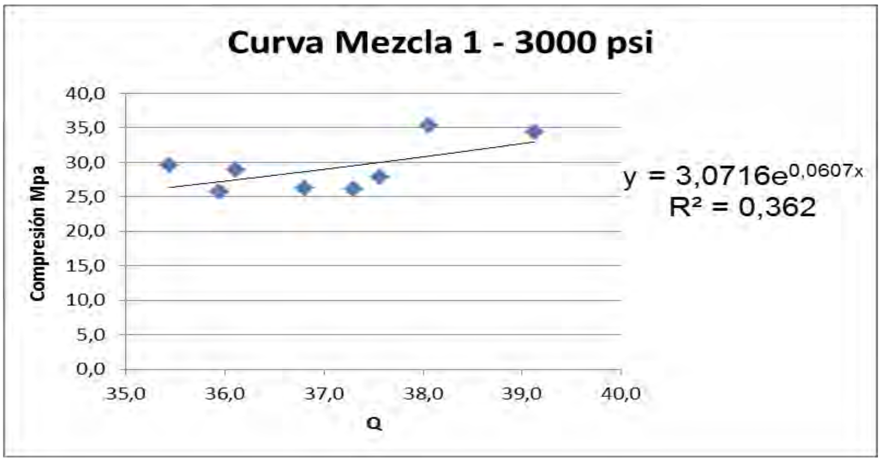

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Figure 2. Trend Curve for Mixing 1 to 3000 psi

In this curve there is an increase in the degree of reliability of the model that is 36.2%, this means that there is more relationship in the data used to graph this curve, there is less dispersion, but even so more data needs to be graphed.

MIX 1 TO 3500 psi

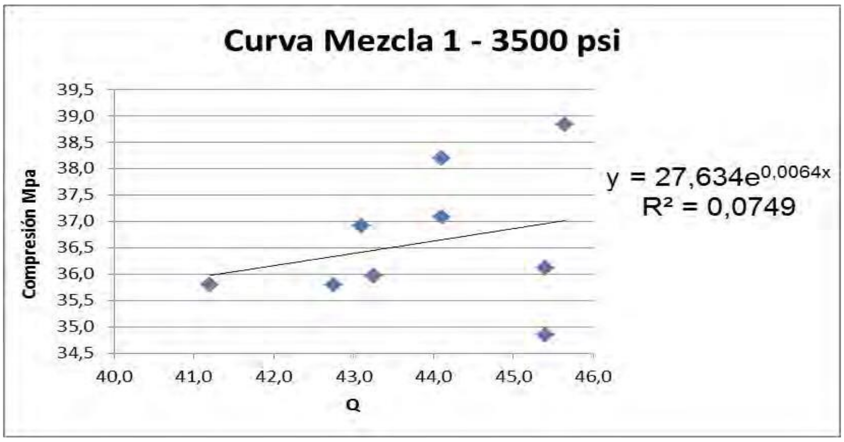

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Figure 3. Trend Curve for Mixing 1 to 3500 psi

In this curve, a larger range of dispersion is observed than in the previous curves, obtaining a degree of reliability of the model of 7.49%. It is clarified that the amount of additive specified by the manufacturer has already been used for this mixture.

MIX 1 TO 4000 psi

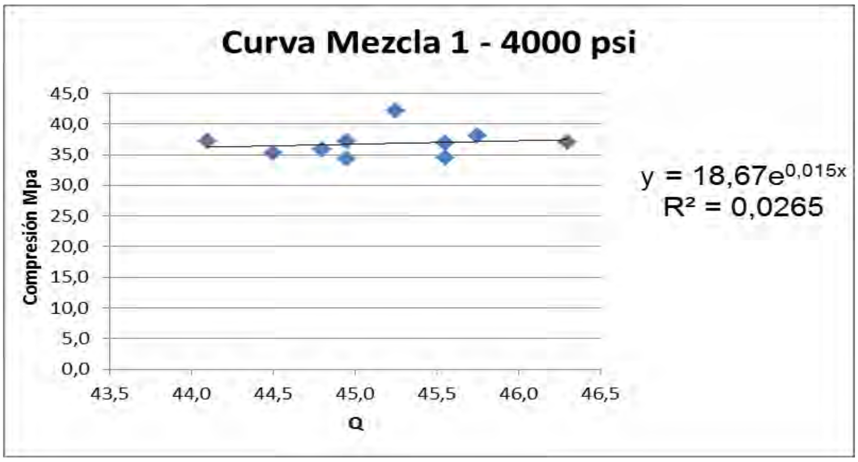

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Figure 4. Trend Curve for Mixing 1 to 4000 psi

In this curve it is observed that the degree of dispersion of the data in the ordinate is not very significant compared to the dispersion observed in the abscissa, due to this the degree of relationship between the data is not very reliable due to the number of graphed results and the dispersion in these. The degree of reliability in this curve is 2.65%.

4.2 Analysis of results for mixing 2 to 28 days

MIX 2 TO 2500 psi

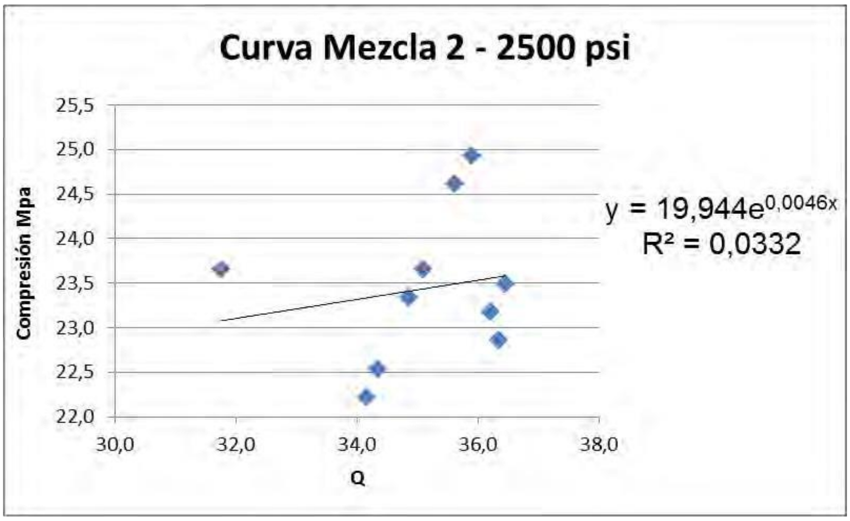

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Figure 5. Trend Curve for Mixing 2 to 2500 psi

In this model, a large dispersion in the data is observed in both X and Y. The reliability grade of the model is 3.32%

MIX 2 TO 3000 psi

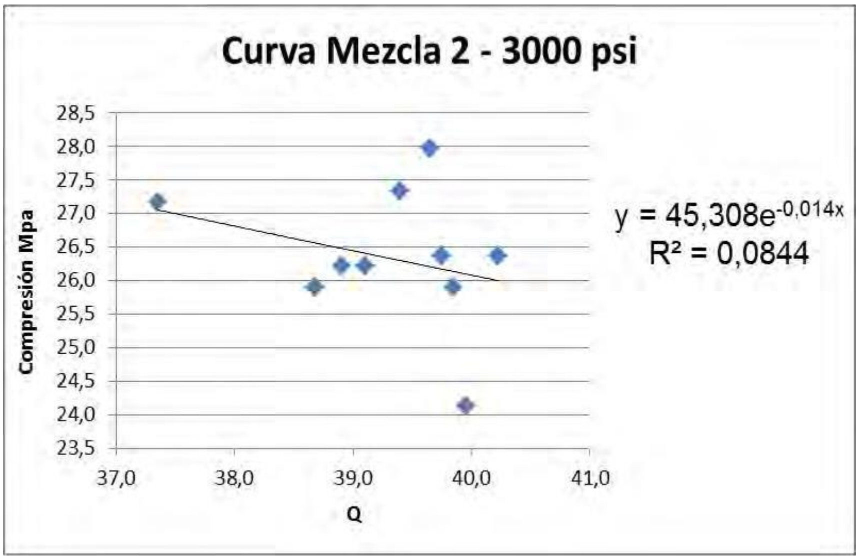

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Figure 6. Trend Curve for Mixing 2 to 3000 psi

In this curve it is observed how the direction of the curve inverts and decays, this is because there is a point that determines the vector of the curve, however, this point was statistically analyzed, and it was determined that it should not be removed because it was within a normal distribution and did not represent an atypical data. The degree of reliability of this model is 8.44%

MIX 2 TO 3500 psi

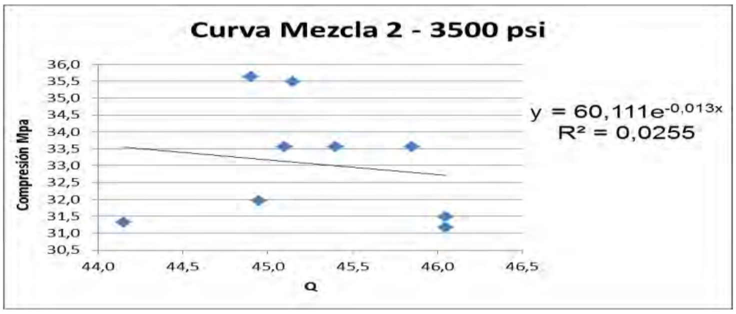

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Figure 27. Trend Curve for Mixing 2 to 3500 psi

In this figure the direction of the curve is also reversed due to the way in which the points are scattered, however, all these are within a normal distribution and do not represent outliers, the degree of reliability is 2.55%

MIX 2 TO 4000 psi

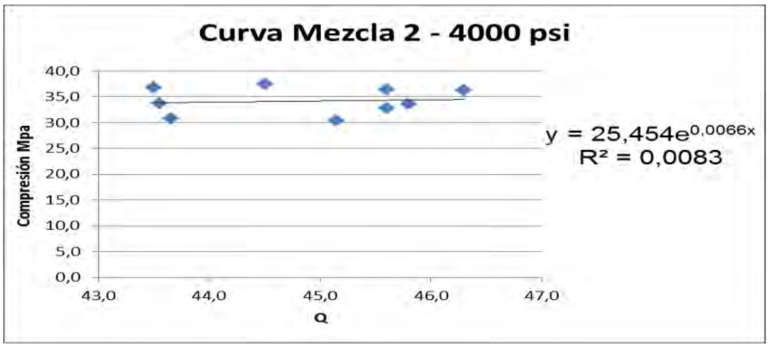

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Figure 8. Trend Curve for Mixing 2 to 4000 psi

An analysis of this model shows that there is dispersion of the data on the sclerometry axis. The reliability degree of the model is 0.83%

4.3 Analysis of results for mixing 1 to 7 and 14 days with accelerant

MIX 1 TO 2500 psi

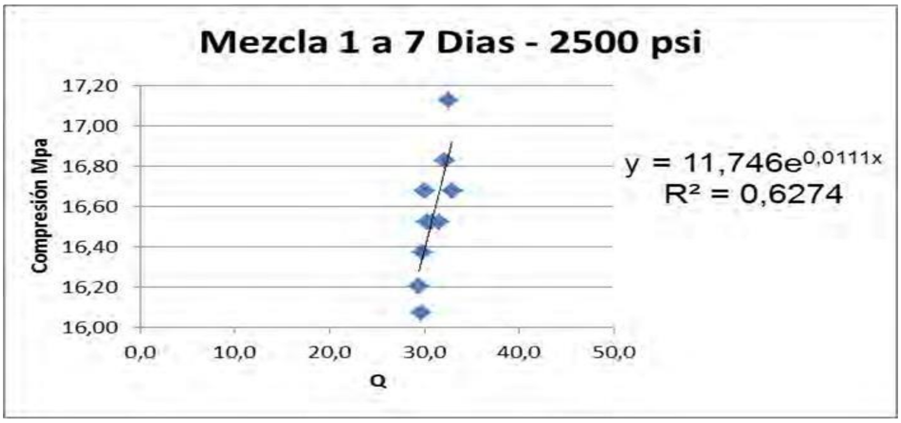

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Figure 9. Trend Curve for Mixing 1 to 7 Days - 2500 psi

This model has a different behavior from the previous curves, since there is a great variability in the values presented in the data obtained from simple compression. However, they do not represent outliers statistically speaking. The degree of reliability of this model is 62.74%, quite large compared to previous models.

MIX 1 TO 3000 psi

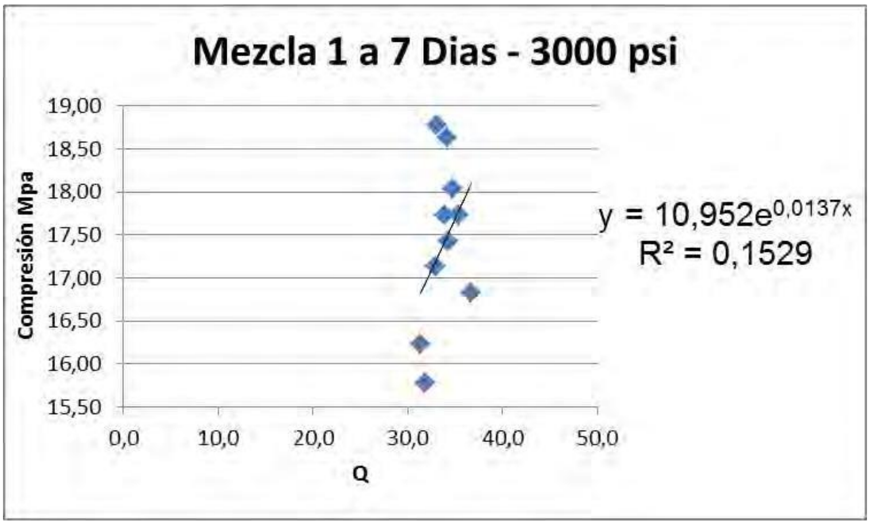

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Figure 10. Trend Curve for Mixing 1 to 7 Days - 3000 psi

In this curve, a definite upward trend is observed, and it has a degree of reliability of 15.29%

MIX 1 TO 3500 psi

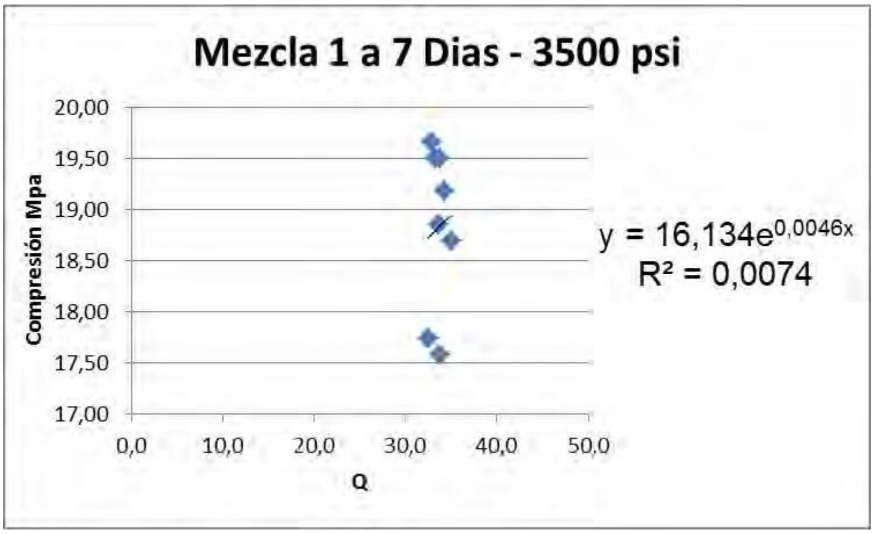

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Figure 31. Trend Curve for Mixing 1 to 7 Days - 3500 psi

In this model we observe a particular case in which the ranges of values in X are not large enough to graph a more significant curve, which is why it represents a degree of reliability of the model of 0.74%

MIX 1 TO 4000 psi

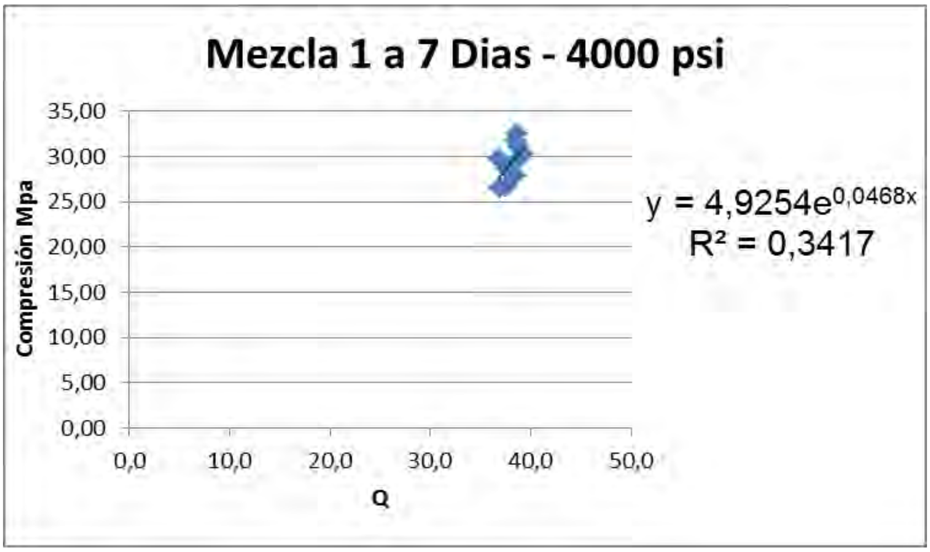

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Figure 32. Trend Curve for Mixing 1 to 7 Days - 4000 psi

In this curve a definite upward trend is observed, and has a degree of reliability of 34.17 %

MIX 1 TO 2500 psi

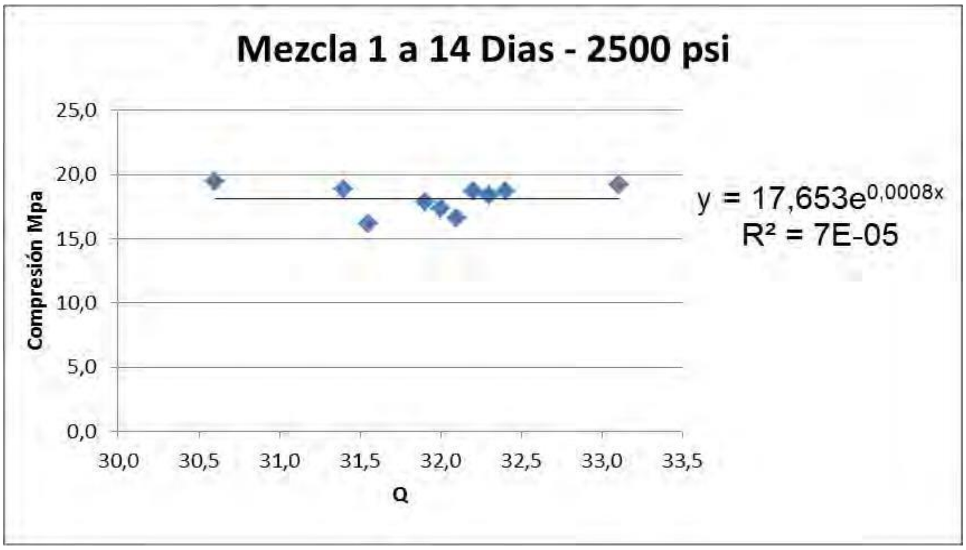

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Figure 13. Trend Curve for Mixing 1 to 14 Days - 2500 psi

This is a model with a large degree of data dispersion. It has a reliability degree of 0.007%.

MIX 1 TO 3000 psi

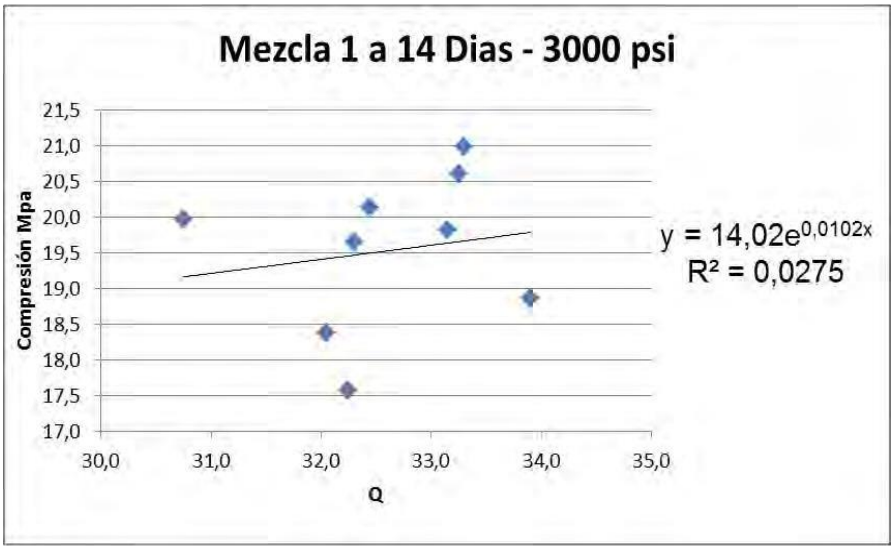

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Figure 14. Trend Curve for Mixing 1 to 14 Days - 3000 psi

This is a model with a large degree of data dispersion. It has a reliability degree of 2.75%.

MIX 1 TO 3500 psi

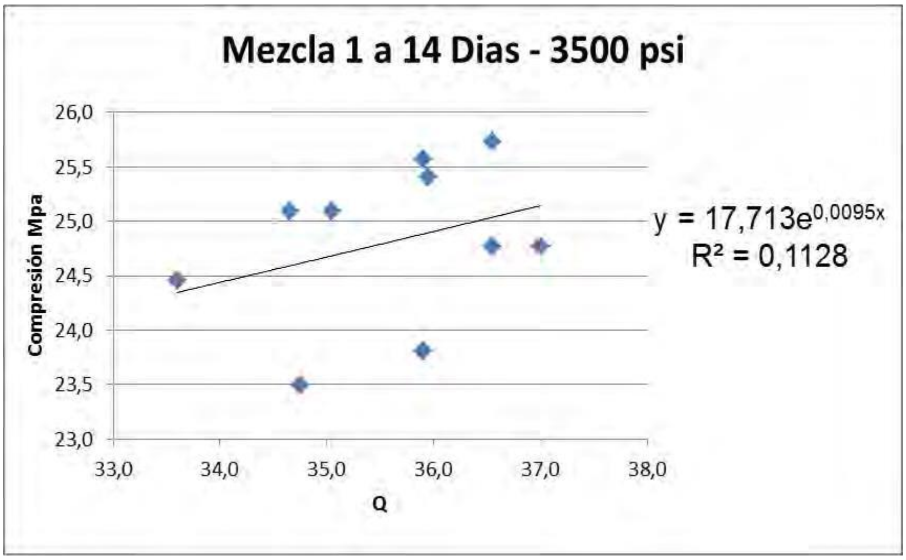

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Figure 35. Trend Curve for Mixing 1 to 14 Days - 3500 psi

In this curve, a linear trend is observed for the 3500 psi data and shows a uniform change in both compression and sclerometry data. It has a reliability rating of 11.28%

MIX 1 TO 4000 psi

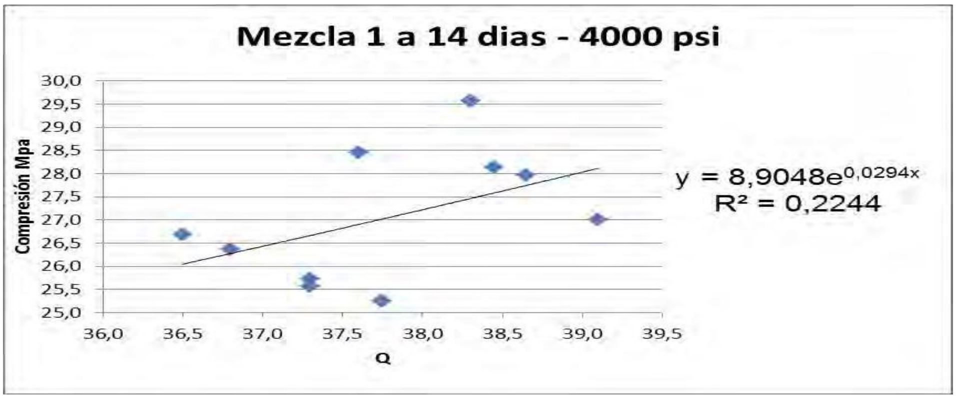

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Figure 36. Trend Curve for Mixing 1 to 14 Days - 4000 psi

Like some of the previous curves, it presents a linear trend with a moderate degree of data dispersion and has a model reliability percentage of 22.44 %

4.4 Overall results for 28-day, 7-day accelerant, and 14-day accelerant blends in ranges of 2500 to 4000 psi

The individual curves presented above each represent a single point on the overall curve, since each one only represents scattered points around a single resistor, due to which such low degrees of reliability of the models were presented. The degree of reliability of a model depends on the number of points, the degree of relationship between the variables "X" (sclerometry) and "Y" (Compression), and also in this case, on the variability of the data or the resistances evaluated.
It is clarified that to evaluate a concrete the individual curves presented above should not be used. The general curves presented below should be used, which represent the totality of the data and plot points for different resistances, these relate the variables in a better way.

GENERAL CURVE MIX 1

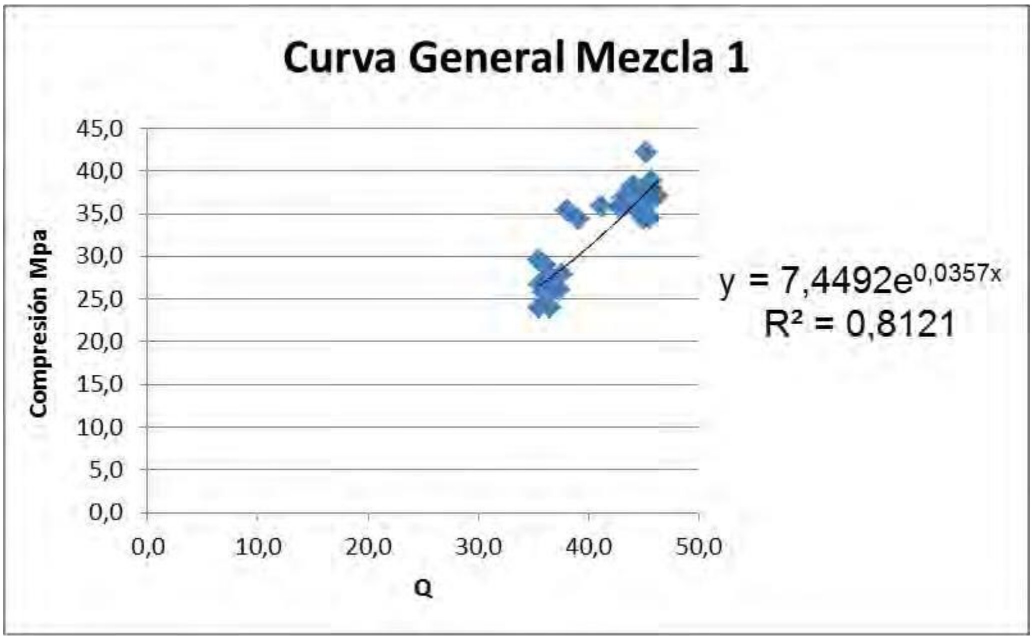

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Figure 17. General curve mixture 1 to 28 days.

In this general curve, the resistance groups graphed above and the sclerometry results are related, a trend is presented with a slight curve that represents a degree of reliability of the model of 81%. That is to say, it is possible to have an 81% certainty that when evaluating a concrete with sclerometry, it can fall within the graph and it is possible to predict its compressive strength with that degree of reliability.
On the other hand, following the methodology explained above of the SILVER SCHMIDT sclerometer, it is observed that there is an exponential curve, which better represents the dispersion of the data. For this reason, a formula of the curve expressed as follows is obtained:

$$Resistencia\ maxima\ a\ la\ compresión = 7.4492\ e^{0.0357\ Q}$$

Where Q is the rebound index obtained from sclerometry tests

GENERAL CURVE MIX 1 TO 7 DAYS WITH ACCELERATOR

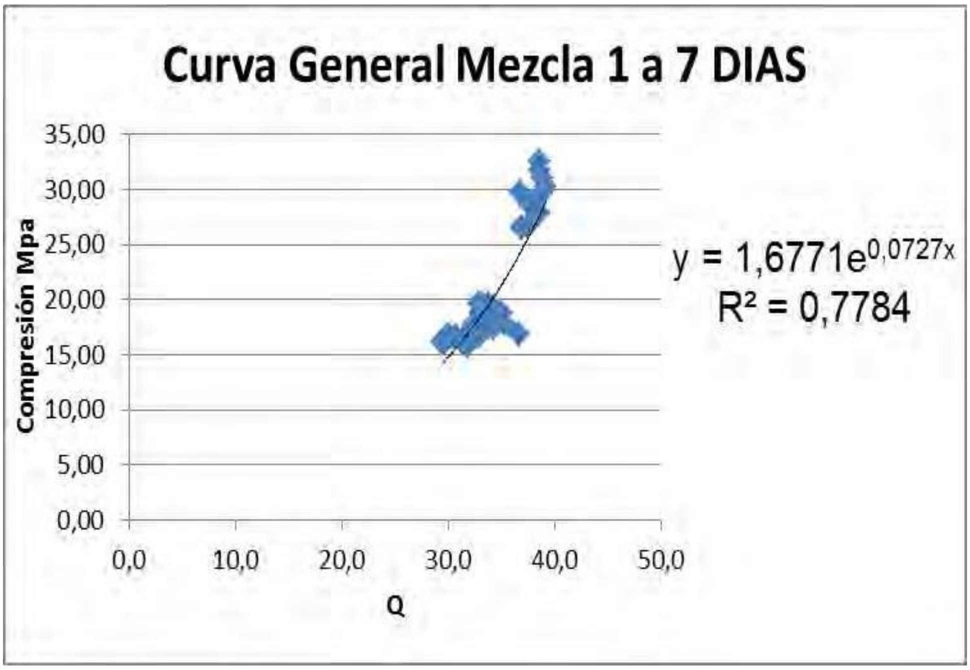

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Figure 19. General curve mix 1 to 7 days with accelerant

This model has a reliability degree of almost 78%, and it is observed that there is a considerable difference between the data of the resistance ranges of 2500 psi to 3500 psi and the data of 4000 psi. Taking into account that for the mixtures of 3500 psi and 4000 psi, in addition to the fluidizing additive, an accelerant was used. This mixture may have influenced the final strength of the concrete obtained, since the dosages for each concrete were different and were those recommended by the manufacturer, however, the manufacturer did not specify exactly to what extent the strength was increased.
On the other hand, following the methodology explained above of the Silver SCHMIDT sclerometer, it is observed that there is an exponential curve, which better represents the dispersion of the data. For this reason, a formula of the curve expressed as follows is obtained:

$$Resistencia\ maxima\ a\ la\ compresión = 1.6771\ e^{0.0727\ Q}$$

Where Q is the rebound index obtained from sclerometry tests

GENERAL CURVE MIX 1 TO 14 DAYS WITH ACCELERATOR

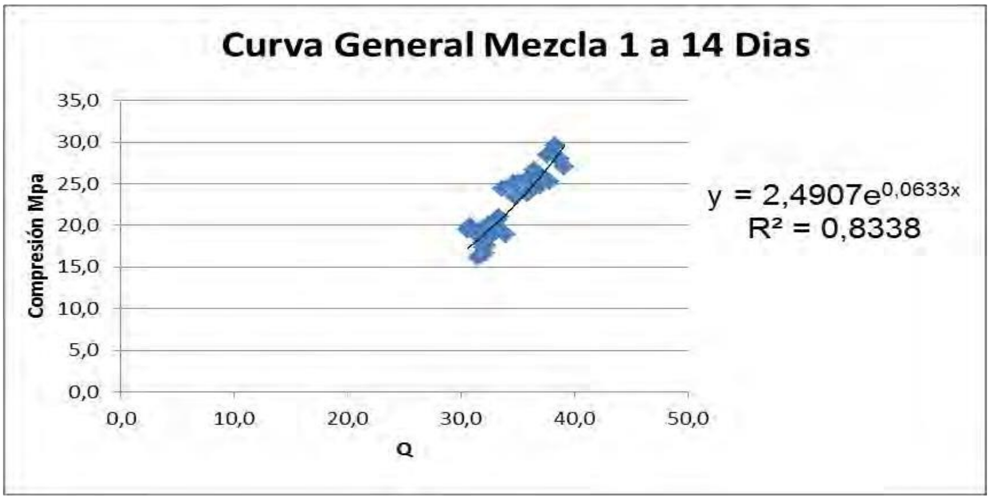

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Figure 20. General curve mix 1 to 14 days with accelerant

This model has a degree of reliability of 83%, and unlike the previous graph for 7 days of setting with an accelerator, a uniform dispersion of the data is observed throughout the range of resistances. However, as for the 7-day resistances with accelerant, it is also clarified that for the mixtures of 3500 psi and 4000 psi, in addition to the fluidizing additive, an accelerant was also used. This mixture may have influenced the final strength of the concrete obtained, since the dosages for each concrete were different and were those recommended by the manufacturer, however, the manufacturer did not specify exactly to what extent the strength was increased.
On the other hand, following the methodology explained above of the Silver SCHMIDT sclerometer, it is observed that there is an exponential curve, which better represents the dispersion of the data. For this reason, a formula of the curve expressed as follows is obtained:

$$Resistencia\ maxima\ a\ la\ compresión = 2.4907\ e^{0.0633\ Q}$$

Where Q is the rebound index obtained from sclerometry tests

4.5 Comparative analysis between cylinders subjected to compression only and cylinders subjected to sclerometry and compression
When reviewing the results obtained from the statistical analysis described above and observing the results, where the type of hypothesis, whether null or alternative, described in the statistical analysis is defined, mostly for almost all mixtures, and for the two types of t-Student and f-Snedecor tests that compare means and standard deviations, respectively, most of the null hypotheses were presented for the two tests, which represent similar means and standard deviations and with minimal variations, however, for the 1 to 28 day mixture at the 2500 psi resistance and for the 1 to 7 days mixture with accelerant for this same resistance, an alternative hypothesis was presented for the f-Snedecor test that evaluates the variations between the standard deviations. Defining the concept of standard deviation, it is a measure of the degree of dispersion of the data with respect to the average value. In other words, the standard deviation is simply the "average" or expected variation with respect to the arithmetic mean. For this reason, it is defined that for these two resistances that presented alternative hypotheses in the f-Snedecor test and taking into account that the means are similar, it is concluded that the result of the F test can be disregarded, also because each mixture has different properties and it is possible that there are test results that are very dispersed from the normal group.

On the other hand, for the 1 to 7 day mixture with accelerant at the resistance of 3500 psi, it was obtained that the statistical analysis favored alternative hypotheses for both the t-test and the f-test. This means that statistically the two results are not similar. However, as can be seen in the resistors of 2500 and 3000 psi, for that same mixture, there were no considerable variations, and taking an earlier idea, the dispersion of the data may be different, as well as the mean of the tests, but when looking at Annex C, it can be observed that the differences between the means are not large and that there are results in both the compression-only tests and the sclerometry plus compression tests, which are similar. For this reason, and based on the results obtained for the other mixtures with the same strength, and in the opinion of the researchers of the present case, the sclerometry tests carried out on the concrete cylinders do not influence, nor do they change their properties, much less the strength measured after compression.

5. Conclusions

The compressive strength of a concrete manufactured with materials from the Pabón quarry and the Espino mine (mix 1) can be predicted, with a degree of reliability of 81% with the sclerometry method.
The compressive strength of a concrete manufactured with materials from the Pilcuán quarry and the Espino mine (mix 2) can be predicted, with a degree of reliability of 84% with the sclerometry method.
The strength of a concrete can be predicted at 7 days of mix 1 with accelerant at 3% of the cement weight with a degree of reliability of 78%.
The strength of a concrete can be predicted at 14 days of mix 1 with accelerant at 2% of the cement weight with a degree of reliability of 83%.
The sclerometry tests done on cylinders from NTC 3692 did not affect the compressive strength obtained after doing the sclerometric tests, this means that the impact made by the sclerometer does not affect the strength of a concrete.
The expression that allows us to find the maximum compressive strength that a concrete withstands at 28 days of setting of mix 1 is:

$$Resistencia\ maxima\ a\ la\ compresión = 7.4492\ e^{0.0357\ Q}$$

The expression that allows us to find the maximum compressive strength that a concrete withstands at 28 days of setting of the mix 2 is:

$$Resistencia\ maxima\ a\ la\ compresión = 6.8871\ e^{0.0348\ Q}$$

The expression that allows us to find the maximum compressive strength that a concrete endures after 7 days of setting with an accelerant of mix 1 is:

$$Resistencia\ maxima\ a\ la\ compresión = 1.6771\ e^{0.0727\ Q}$$

The expression that allows us to find the maximum compressive strength that a concrete endures after 14 days of setting with an accelerant of mix 1 is:

$$Resistencia\ maxima\ a\ la\ compresión = 2.4907\ e^{0.0633\ Q}$$

The material of the Pabón quarry is very porous and angular in shape, so when making concrete with this material, it absorbed a greater amount of water, which

It made the mixture quite dry and its manageability was poor, which increased the vibrating energy needed in the laboratory.

7-day accelerant blends with 2500, 3000 and 3500 PSI strengths achieved at least 80% of the 7-day design strength

The 14-day accelerant mixtures with resistances of 2500 and 3000 PSI, reached 85% of the design resistance at 14 days

The 7-day accelerant mix with 4000 PSI resistance surpassed the design strength at 7 days.

The 14-day accelerant mixtures with resistances of 3500 and 4000 PSI, exceeded the design resistance at 14 days.

The use of fluidizer greatly influenced the manageability of the concrete mixtures in addition to increasing their resistance.
The placement of the 2500 and 3000 PSI concrete mixtures, lacking a fluidizing additive, made it difficult to place and vibrate them because these mixtures were dry, thus requiring greater vibrating energy.

The final furring of the cylindrical specimens is very important for the quality of the results to be good. The two faces of the cylinder must be parallel to each other and perpendicular to the cylinder trunk.

It is important to apply each test exactly according to NTC standards, so that the quality of its results is adequate.

The materials used in this research are of excellent quality since the resistances obtained exceeded the design resistances, in addition to having good physical-mechanical characteristics.

Sclerometry assays account for one-fifth of the cost of removing a core.

Sclerometry tests can be done on any surface or part of the structural member section regardless of where there is steel reinforcement, unlike core extraction in which there are sections of concrete in which cores cannot be extracted because the reinforcing steel prevents drilling.

Sclerometry testing allows agility in quality control and considerably reduces costs compared to destructive testing.

6. Recommendations

To obtain more points of comparison between the sclerometry and compression assays, since the correlation coefficient R squared increases, providing a better degree of reliability of the model.

Use a Silver SCHMIDT sclerometer or similar, since in other models the angle and direction in which the impact is made has a great influence, which would lead to producing data with a greater margin of error.

Use the sclerometer with the results obtained in this research only for concretes manufactured with the same materials used here, since the results may vary due to the characteristics of the aggregates.

Take into account the carbonation of the concrete in the concrete structure or elements where the sclerometer is used as this can lead to errors in the measurement. For this it is recommended to obtain the carbonation index, which can be entered into the Silver SCHMIDT sclerometer system, and thus avoid this type of error. The concretes manufactured in this research used very low A/C ratios in some cases, which in the laboratory were easy to handle although there were very poor concrete manageability, however, for small quantities they could be treated satisfactorily in the laboratory. However, on site it may be the case that depending on the degree of manageability of the desired concrete, these relationships are modified depending on the case.

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