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Optimization of Mix Designs for Compressive Strength of Standard Concrete Produced at Concrenorte SAS

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Optimization of Mix Designs for Compressive Strength of Standard Concrete

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Summary:

A study was conducted at CONCRENORTE SAS to optimize mix designs by reducing cement in concrete production with a reliability of 85%. To achieve this goal, tests were performed to determine aggregate parameters using the ACI-211 method, and then designs for A/C ratios ranging from 0.35 to 0.75 were developed. The RNL method was used for the use of the combined sand. To verify the curve obtained, a mix design was performed that showed that the expected reliability of 85% was achieved. The mix design was used with 50% limestone sand and 50% Sinu river sand, all in compliance with Colombian technical standard procedures. The aim was to use available materials to adjust the water/cement ratio curve for 28-day strength.

Abstract

Introduction: Constructive evolution has been shown in the different stages of history, from prehistory to contemporary times, men looked for different materials that would adapt to the different demands that arose in the timeline, in the search for raw materials that had a structural function, the ancient builders immersed themselves in a world of great uncertainties and hypotheses, discovering fascinating answers due to the extraordinary qualities of the materials they found, the combination of these became beneficial, obtaining great resistance and durability of the civil works of yesteryear, as proof of this we find buildings that have been standing for centuries. The combination of volcanic ash with lime resulted in a binder, which mixed with sand and water obtained a material with great resistance, this fact dates back to the 2nd century BC when the Roman Empire set out to the task of using this in their magnificent constructions, which for their time were avant-garde, showing great progress in the use of materials for construction, marking a turning point in the history of civil engineering, since the binder developed by the Romans laid the foundations for the creation of what we know today as Portland cement, which was the result of years of research and testing; conglomerated this material with some aggregates formed the famous hydraulic concrete, which revolutionized construction due to its mechanical and physical properties. Because most civil works use concrete, a high demand for this structural element has been created. As a result, concrete producers emerged seeking to satisfy these demands. In turn, great competitiveness was created among concrete producers. In order to remain in the market, they were forced to improve their quality and reduce their costs, giving way to research into the materials used to create concrete. Background: Aggregates with similar characteristics were used in the Study of stone aggregates used in the production of normal concrete, riginating in the municipality of Toluviejo - Sucre, where they mention that the minimum A / C ratio to maintain the workability of normal concrete is 0.35, being the point of lowest value for the elaboration of the A / C curve in this investigation. For the methodology for the elaboration and modeling of an A / C ratio curve, a second degree polynomial trend line was used to model said curve, obtaining an equation that describes the behavior of said graph, said methodology was implemented in this study. For the methodology and procedures, we took as a reference the research Optimization of the A/C ratio in the design of standard concrete, developing the stages of testing the aggregates, in addition to the preparation and testing of concrete cylinders. Justification: The company CONCRENORTE SAS seeks to have optimal quality in the concrete produced at its central plant, one of the main parameters to take into account for quality control is strength. To date, this goal is met, no strength has fallen below design values, but this is achieved at a high cost because normal concretes are being over-designed, with 28-day strengths greatly exceeding the numbers for which they were designed. This situation arises mainly because there is uncertainty about how concrete strengths vary when the A/C ratios change. The research will seek to optimize mix designs for standard concrete by achieving strengths closer to theoretical values. This will be achieved by performing tests proposed in the ACI 211-1 code for concrete aggregates. With reliable results on aggregate properties, dosages for ratios ranging from 0.35 to 0.75 will be obtained. This will allow the company to develop a W/C ratio curve that will help it develop more reliable mix designs. This research is of great importance and scope for mixture design in the region, since there is no documented bibliographic contribution focused on the present topic, marking a starting point for future researchers in the area. The studies are exploratory in nature, since they are research projects with few studies, whose data are taken to draw general conclusions, using an inductive method, with a methodology of quantitative and qualitative data.

Keywords: Optimization; mix design; A/C ratio; reliability; RNL; strength

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Laboratory Results

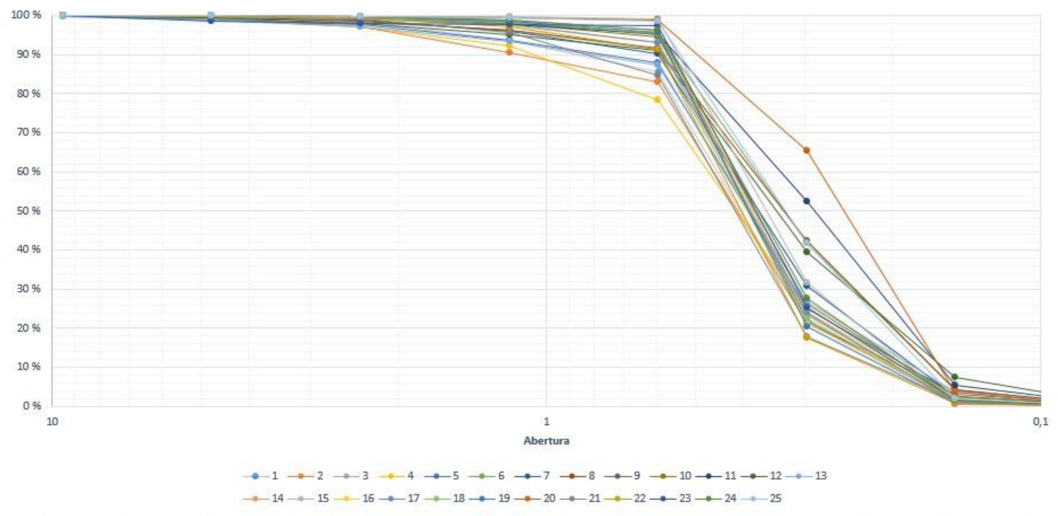
River sand (Lorica)

For each test performed, the mean and standard deviations were found to be used as representative data:

Table 1. Average river granulometry result.

Sieve	Opening (mm)	Average	Standard deviation
3/8"	9.5	99.98	0.079
No. 4	4.75	99.61	0.392
No. 8	2.36	98.88	0.916
No. 16	1.18	96.71	2,395
No. 30	0.6	92.26	5,313
No. 50	0.3	29.42	11,637
No. 100	0.15	2.49	1,612
No. 200	0.075	0.43	0.277

Source: Own elaboration Fineness modulus: 1.81 ± 0.174.



Graph 1. Granulometric distribution curve of river sand. Source: Own elaboration.

Table 2. Results of tests performed on fine aggregate (river sand).

Rehearsal	Average	Standard deviation
Percentage of material finer than the 75 μm sieve	1.44	0.61
Apparent density (kg/m3)	2525.36	32.55
Surface-dry saturated density (kg/m3)	2574.68	32.77
Nominal Density (kg/m3)	2656.77	36.38
Absorption (%)	1.95	0.18
Organic matter content	1	-

Source: Own elaboration.

Limestone sand

For each test performed, the mean and standard deviations were found to be used as representative data:

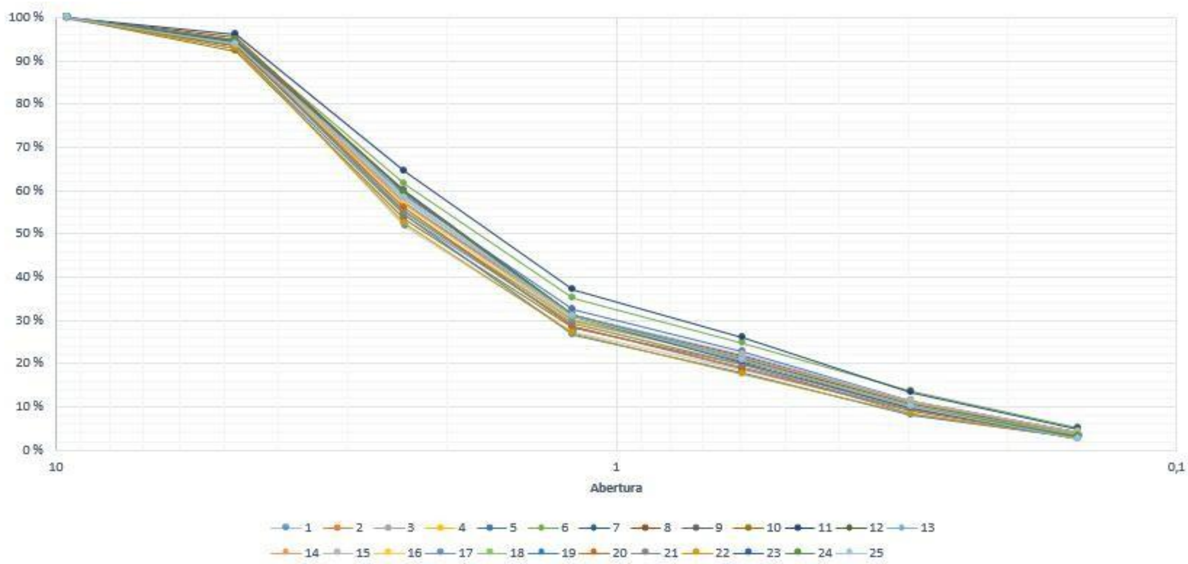
Table 3. Average limestone granulometry result.

Sieve	Opening (mm)	Average	Standard deviation
3/8"	9.5	99.99	0.073
No. 4	4.75	94.09	0.807
No. 8	2.36	57.22	2,920
No. 16	1.18	30.46	2,267

No. 30	0.6	20.80	1,921
No. 50	0.3	10.34	1,293
No. 100	0.15	3.50	0.701
No. 200	0.075	1.00	0.360

Source: Own elaboration.

Fineness modulus: 3.84 ± 0.091



Graph 2. Granulometric distribution curve of limestone sand. Source: Own elaboration.

Table 4. Results of tests performed on fine aggregate (limestone sand).

Rehearsal	Average	Standard deviation
Percentage of material finer than the 75 µm sieve	6.59	0.97
Apparent density (kg/m3)	2446.46	21.87
Surface-dry saturated density (kg/m3)	2545.63	20.83
Nominal Density (kg/m3)	2716.56	24.07
Absorption (%)	4.05	0.21
Organic matter content	1	-

Source: Own elaboration.

Combined Sand

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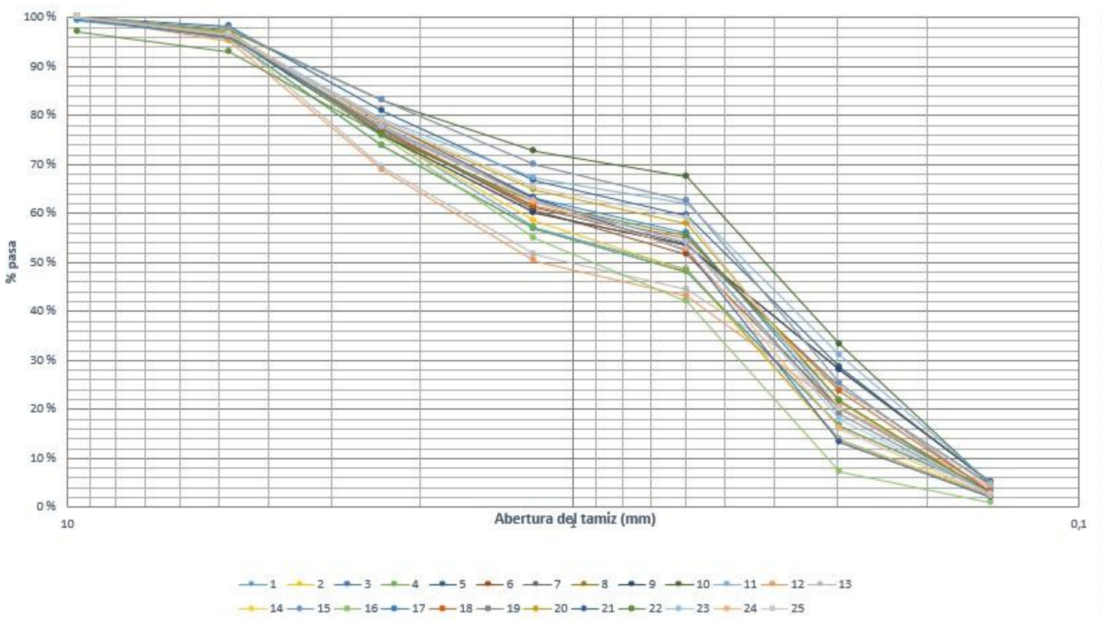
For each test performed, the mean and standard deviations were found to be used as representative data:

Table 5. Average particle size result of the combined.

Sieve	Opening (mm)	Average	Standard deviation
3/8"	9.5	99.82	0.603
No. 4	4.75	96.43	0.936
No. 8	2.36	77.04	3,242
No. 16	1.18	61.48	5,092
No. 30	0.6	53.66	5,995
No. 50	0.3	21.26	6,063
No. 100	0.15	3.26	1,036
No. 200	0.075	0.84	0.325

Source: Own elaboration Fineness modulus: 2.86 ± 0.186.



Graph 3. Granulometric distribution curve of combined sand. Source: Own elaboration.

Table 6. Results of tests performed on fine aggregate (combined sand).

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Rehearsal	Average	Standard deviation
Percentage of material finer than the 75 µm sieve	3.88	0.48
Apparent density (kg/m3)	2500.53	32.40
Surface-dry saturated density (kg/m3)	2574.68	32.77
Nominal Density (kg/m3)	2701.49	40.00
Absorption (%)	2.97	0.29
Organic matter content	1	-

Source: Own elaboration.

Statistical Analysis

Model Adjusted For Rio Sand

The values of the variables X y Y, when the test was carried out with the river sand are shown in the following table:

Table 7. Values of river sand variables.

X	Y
9,5	0,9998
4,75	0,9961
2,36	0,9888
1,18	0,9671
0,6	0,9226
0,3	0,2942
0,15	0,0249
0,075	0,0043

Source: Own elaboration.

Using equations (2) and (3), the values of the coefficients are estimated β_0 y β, resulting in:

β_0 =0.46014208

β =0.0802043

With these values, the linear model that appears in equation (1) is built, resulting in:

$$Y = 0{,}46014208 + 0{,}0802043X + e$$

The values of the coefficients β_0 y $\beta$are interpreted as follows:

$\beta_0 = 0{,}46014208$: When the sieve opening is 0.0 mm, approximately 46.01% of river sand is expected to pass through.

$\beta = 0{,}0802043$For every mm the sieve size increases, the percentage of river sand passing is expected to increase by approximately 8.02%. Alternatively, for every mm the sieve size decreases, the percentage of river sand passing is expected to decrease by approximately 8.02%.

To verify whether this model explains the response variable Y, the corresponding analysis of variance is performed, with which the following hypotheses are tested:

$H_0 : \beta_0 = \beta = 0$"The model does not explain the response variable Y" or "There is no statistically significant relationship between the size of the sieve opening and the percentage of river sand that passes through each sieve."

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H_i: $\beta_j \neq 0$"The model does explain the response variable Y" or "There is a statistically significant relationship between the size of the sieve opening and the percentage of river sand that passes through each sieve."

The results of the analysis of variance are shown in the following table:

Table 8. Anova.

ANOVA	Suma de Cuadrados	G.L.	Cuadrado Medio	Fo	F(α,1,n-2)	P - Valor
Regresión	0,48598079	1	0,485980793	2,97515399	5,987377607	0,13531205
Error	0,9800786	6	0,163346434			
Total	1,4660594	7				

Source: Own elaboration.

Since the P value = 0.13531205 > $\alpha = 0.05$, the null hypothesis $H_0: \beta_0 = \beta = 0$is accepted, there is no statistically significant relationship between the sieve opening size and the percentage of river sand passing through each sieve. Therefore, no further statistical analysis is necessary for this model.

Model Adjusted For Limestone Sand

The values of the variables X y Y, when the test was carried out with the limestone sand are shown in the following table:

Table 9. Values of the limestone sand variable.

X	Y
9,5	0,9999
4,75	0,9409
2,36	0,5722
1,18	0,3046
0,6	0,2080
0,3	0,1034
0,15	0,0350
0,075	0,0100

Source: Own elaboration.

Using equations (2) and (3), the values of the coefficients are estimated β_0 y β, resulting in:

β_0 =0.13592128

β =0.11034531

With these values, the linear model that appears in equation (1) is built, resulting in:

$$Y = 0{,}13592128 + 0{,}11034531X + e$$

The values of the coefficients β_0 y $\beta$are interpreted as follows:

β_0 = 0,13592128: When the sieve opening is 0.0 mm, approximately 13.6% of limestone sand is expected to pass through.

β = 0,11034531For every mm increase in sieve size, the percentage of limestone sand passing is expected to increase by approximately 11.03%. Alternatively, for every mm decrease in sieve size, the percentage of limestone sand passing is expected to decrease by approximately 11.03%.

To verify whether this model explains the response variable Y, the corresponding analysis of variance is performed, with which the following hypotheses are tested:

$H_0: \beta_0 = \beta = 0$"The model does not explain the response variable Y" or "There is no statistically significant relationship between the sieve opening size and the percentage of limestone sand passing through each sieve."

$H_i: \beta_j \neq 0$"The model does explain the response variable Y" or "There is a statistically significant relationship between the size of the sieve opening and the percentage of limestone sand that passes through each sieve."

The results of the analysis of variance are shown in the following table:

Table 10. Anova.

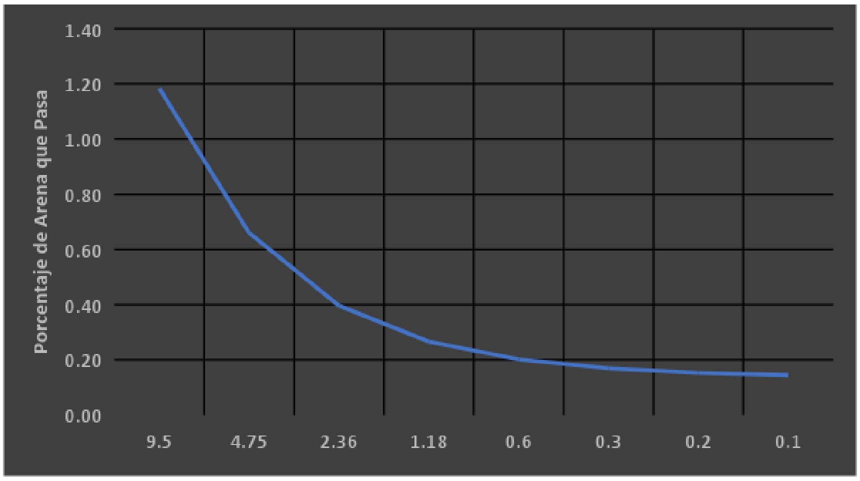
ANOVA	Suma de Cuadrados	G.L.	Cuadrado Medio	Fo	F(α,1,n-2)	P - Valor
Regresión	0,91988069	1	0,919880694	30,42574	5,987377607	0,00149253
Error	0,18140181	6	0,030233634			
Total	1,1012825	7				

Source: Own elaboration.

As the P – Value = 0.00149253≤ α = 0.05The null hypothesis $H_0: \beta_0 = \beta = 0$is rejected if there is a statistically significant relationship between the sieve opening size and the percentage of limestone sand passing through each sieve. Therefore, it is necessary to perform additional statistical analyses on this model.

The value of R^2 for this model is, $R^2 = 0.84$, which indicates that the model explains 84% of the variability present in the response variable Y.

The correlation ρbetween the independent and dependent variables is, $\rho = 0.91$, which indicates that the variables, sieve opening size and percentage of limestone sand that passes, are directly proportional and there is a high relationship of dependence between them.



Graph 4. of the Adjusted Model for the Granulometric Distribution of Limestone Sand Source: Own elaboration.

Model Adjusted For Combined Sand

The values of the variables X y Y, when the test was performed with the combined sand are shown in the following table:

Table 11. Combined sand variable values.

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X	Y
9,5	0,9982
4,75	0,9643
2,36	0,7704
1,18	0,6148
0,6	0,5366
0,3	0,2126
0,15	0,0326
0,075	0,0084

Source: Own elaboration.

Using equations (2) and (3), the values of the coefficients are estimated β_0 y β, resulting in:
β_0 =0.29150871
β =0.09549605
With these values, the linear model that appears in equation (1) is built, resulting in:

$$Y = 0{,}29150871 + 0{,}09549605X + e$$

The values of the coefficients β_0 y $\beta$are interpreted as follows:

$\beta_0 = 0{,}29150871$: When the sieve opening is 0.0 mm, approximately 29.15% of combined sand is expected to pass.

$\beta = 0{,}09549605$For every mm increase in sieve size, the percentage of combined sand passing is expected to increase by approximately 9.55%. Alternatively, for every mm decrease in sieve size, the percentage of combined sand passing is expected to decrease by approximately 9.55%.

To verify whether this model explains the response variable Y, the corresponding analysis of variance is performed, with which the following hypotheses are tested:

$H_0: \beta_0 = \beta = 0$"The model does not explain the response variable Y" or "There is no statistically significant relationship between the sieve opening size and the percentage of combined sand passing each sieve."

$H_i: \beta_j \neq 0$"The model does explain the response variable Y" or "There is a statistically significant relationship between the size of the sieve opening and the percentage of combined sand that passes through each sieve."

The results of the analysis of variance are shown in the following table:

Table 12. Anova.

ANOVA	Suma de Cuadrados	G.L.	Cuadrado Medio	Fo	F(α,1,n-2)	P - Valor
Regresión	0,68896094	1	0,688960935	10,2635439	5,987377607	0,01851401
Error	0,40276201	6	0,067127002			
Total	1,09172295	7				

Source: Own elaboration.

As the P – Value = 0.01851401$\leq$ α = 0.05The null hypothesis H_0: β_0 = β = 0is rejected if there is a statistically significant relationship between the sieve opening size and the percentage of combined sand passing through each sieve. Therefore, it is necessary to perform additional statistical analyses on this model.

The value of R^2 for this model is, $R^2 = 0.63$, which indicates that the model explains 63% of the variability present in the response variable Y.

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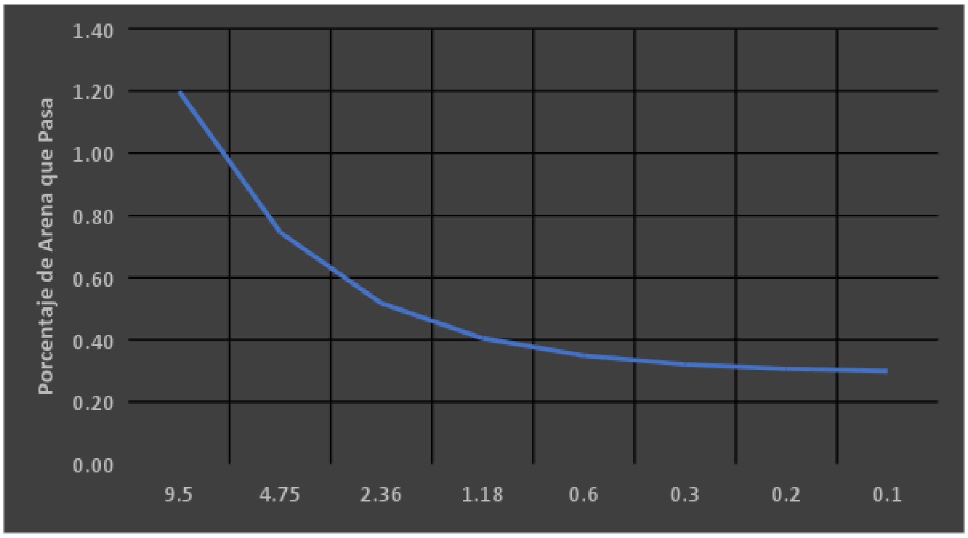
The correlation ρ between the independent and dependent variables is, $\rho = 0.79$, which indicates that the variables, sieve opening size and percentage of combined sand that passes, are directly proportional and there is a high relationship of dependence between them.



Graph 5. Adjusted Model for the Granulometric Distribution of the Combined Sand Source: Own elaboration.

Analysis of Results

Table 13. Results of the average compressive strength at 28 days of the concrete specimens for different A/C ratios.

A/C	Age (Days)	Average strength (MPa)	Standard Deviation
0.75	28	15.90	3.04
0.7	28	24.99	2.67
0.65	28	28.38	2.56
0.6	28	28.80	3.24
0.55	28	36.39	3.40
0.5	28	39.67	3.18
0.45	28	45.81	4.67
0.4	28	55.29	4.68
0.35	28	59.52	8.29

Source: Own elaboration.

Table 14. Results of the average compressive strength at 7 days of the concrete specimens for different A/C ratios.

A/C	Age (Days)	Average strength (MPa)	Standard Deviation
0.75	7	14.07	3.46
0.7	7	19.22	3.88
0.65	7	22.25	3.23
0.6	7	24.44	5.23
0.55	7	31.24	1.56
0.5	7	33.22	1.78
0.45	7	41.16	6.52
0.4	7	51.99	5.47
0.35	7	55.74	9.69

Source: Own elaboration.

Table 15. Average percentage of compressive strength reached at 7 days of age with respect to the average strength reached at 28 days of age, for different A/C ratios.

A/C	7-day average (MPa)	Average 28 days (MPa)	Percentage Achieved 7 days (%)
0.75	13.54	15.65	86.51
0.7	19.22	24.23	79.30
0.65	22.25	27.82	79.97
0.6	24.44	28.66	85.28
0.55	31.24	36.52	85.53
0.5	33.22	39.67	83.74
0.45	38.25	46.01	83.14

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0.4	48.44	54.59	88.74
0.35	50.99	59.19	86.15
		Average	84.26

Source: Own elaboration.

Preparation and Modeling of the A/C Curve

From the data collected previously, it is possible to construct the curve taking into account the variables A/C ratio on the abscissas and Compressive strength at 28 days on the ordinates. The following table shows the average strength data obtained, as well as their respective standard deviations:

Table 16. Results of the average compressive strength at 28 days of the concrete specimens for different A/C ratios.

A/C	Age (Days)	Average strength (MPa)	Standard Deviation
0.75	28	15.90	3.04
0.7	28	24.99	2.67
0.65	28	28.38	2.56
0.6	28	28.80	3.24
0.55	28	36.39	3.40
0.5	28	39.67	3.18
0.45	28	45.81	4.67
0.4	28	55.29	4.68
0.35	28	59.52	8.29

Source: Own elaboration.

Table 17. Results of average compressive strength, standard deviation, and upper and lower limits at 28 days of concrete specimens for different W/C ratios.

A/C	Average strength (Mpa)	Deviation	upper limit (Mpa)	upper limit (Mpa)

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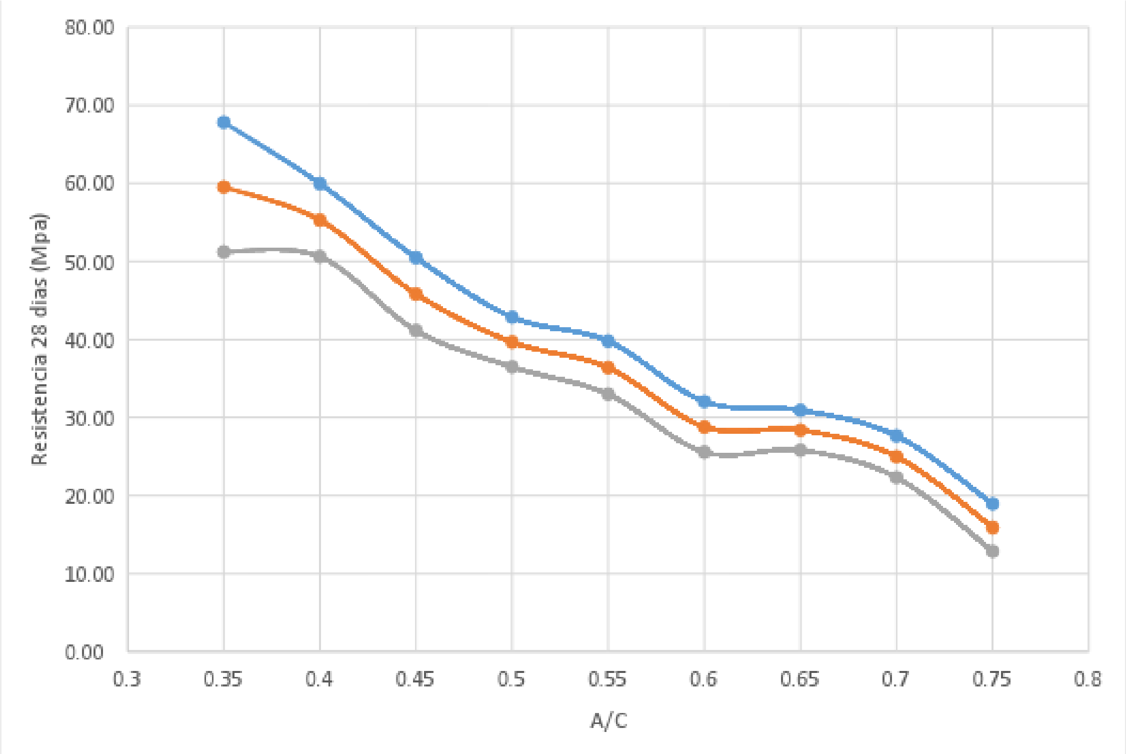
0.75	15.90	3.04	18.94	12.87
0.7	24.99	2.67	27.66	22.33
0.65	28.38	2.56	30.93	25.82
0.6	28.80	3.24	32.04	25.57
0.55	36.39	3.40	39.79	32.98
0.5	39.67	3.18	42.85	36.49
0.45	45.81	4.67	50.48	41.14
0.4	55.29	4.68	59.97	50.61
0.35	59.52	8.29	67.82	51.23

Source: Own elaboration.



Graph 6. A/C ratio curve Source: Own elaboration.

The type of function that was presented as the best option for modeling the curve obtained was the logarithmic one; when applying the modeling, the final graph is the following:

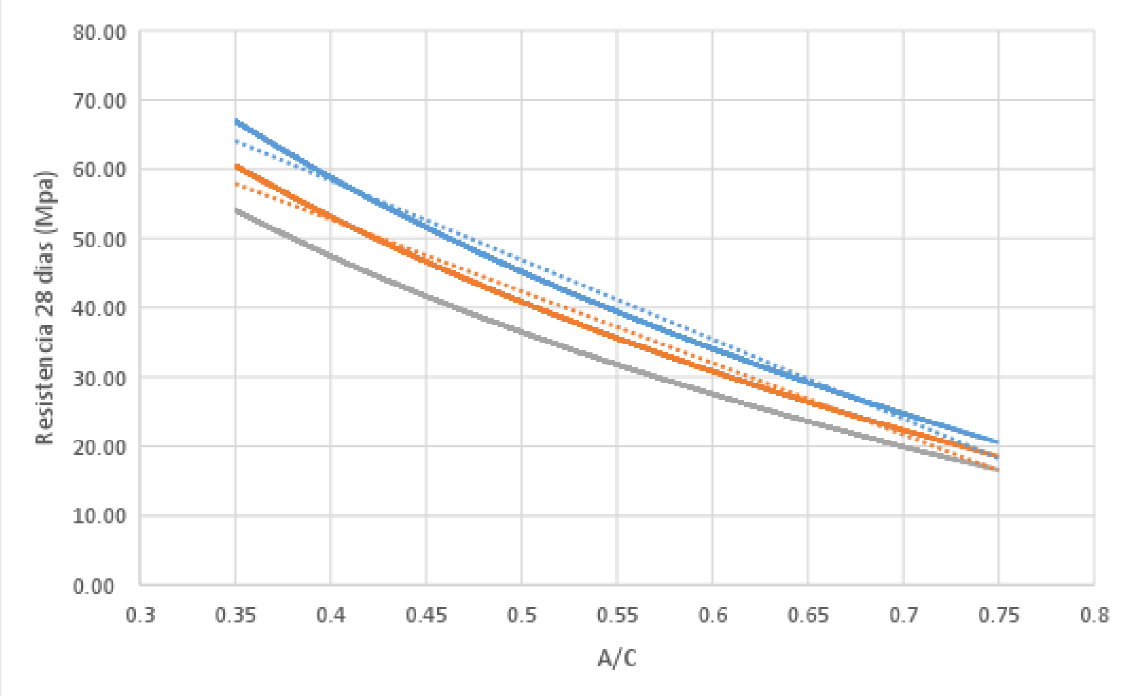


Figure 7. Modeling the A/C ratio curve created by a logarithmic trend line in a scatter plot in Excel. Source: Own elaboration.

Conclusions

The optimization of the proportions of the combined sand was possible thanks to the graphic method proposed by RNL, obtaining combination percentages that were not

very viable for the in situ composition of the combined sand, so the combination used by the company was theoretically optimized, but due to the mixing processes of these two sands, the 50-50 ratio was maintained, which meets the technical specifications for use as fine material in concrete.

Mix designs using the ACI method, varying the A/C ratios, allowed us to know the resistance values that the concrete could offer, allowing the development and modeling of the A/C curve.

The expected reliability was met by most of the cylinders tested, only two of the checked specimens being outside showing a resistance in excess of the expected one, that is, the objective of reaching a reliability of 85% in the compressive strength of the concrete mix designs was achieved as shown in the results obtained.

The materials used in the concrete company are capable of obtaining high-strength concrete designs, a point in favor of the development of construction materials for our municipality.

The optimization of the mix designs based on the data obtained from our curve was achieved, showing higher A/C ratios for the same strength than those provided by the company supporting the research. However, it should be noted that, according to the company's reports, its curve is subject to optimization by additives, unlike ours, which makes the most of the materials used by the concrete plant. The lowest strengths of 14 and 17.5 are outside the experimentally checked limits; these were obtained through the mathematical model presented in the curve, so the relevant checks must be performed.

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