Evaluating a new binder in the self-leveling mortar mixture

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Abstract. The infrastructure of a country plays an important role in economic growth, contributing as a basis for other actors such as: production, transport and access to services that meet basic population needs. In this article we study the Sika-Colombia company dedicated to the construction material supplies, specifically self-leveling mortars, in relation to an improvement of physical properties (i.e. resistance and consistency) and production costs. The impact of new binder addition in a self-leveling mortar mixture Sika Grout 212 is analyzed experimentally. This approach is justified by the need to improve the granular skeleton of the study product, recover fluidity and maintain the resistance offered to customers. The research results conclude the physical and economic advantages of new binder adding to the mortar mixture as well as optimum composition.

1. Introduction

The infrastructure of a country plays an important role in economic growth, contributing as a basis for other actors such as: production, transport and access to services that meet basic population needs [1]. Some papers mention the relationship between infrastructure development with the economic growth of a country, therefore, a direct relationship is created between infrastructure quality and the country's gross domestic product, considering that they are reinforced. [1, 2].

In response to the relationship between infrastructure and economic development, has been to achieve a consensus among the major Latin American international economic organizations such as the Inter-American Development Bank (IDB), the Development Bank of Latin America (CAF) and the Economic Commission for Latin America and the Caribbean (ECLAC), to study and promote the improvement and infrastructure investment in Latin America and the Caribbean, through the provision and quality of official data about this topics. It is then that INFRALATAM was created, a platform in which data is shared for the general public, which allows "to orient the allocation of public resources, setting priorities, schedule projects, induce private participation and to allow progress monitoring of provision in infrastructure in Latin America and the Caribbean countries" [3].
The main data offered by INFRALATAM are on participation in investment (public and private) in the sectors like water, energy, telecommunications, transportation and other subsectors, for each one of 19 Latin American countries considered. In latest report (2008-2015) highlights that annual investment average in economic infrastructure as a percentage of GDP of the countries analyzed is 3.54% [3].

In this topic, Colombia does not stand out, in fact, your average investment is 3.96%, which, although it is above the Latin American average, is still distant from countries like Bolivia (5.79%), Panamá (5.32%), Honduras (4.9%), Paraguay (4.5%) and Costa Rica (4.14%). Infrastructure investment in Latin America is growing. In the last 10 years, it has been possible to demonstrate an investment around 6.2% of gross domestic product (GDP) per annum, however, to meet the needs of the sector, this investment should be more ambitious and receive a stronger support from private sector. As proof of above, its possible see reflected that by mid-2015 an investment of 1.5% of entries came from public sector, while the remaining 0.8% from private sector [1]. Figure 1 shows the behavior of GDP growth and construction of civil works.

![Figure 1](image-url)

**Figure 1.** Economic indicator in Colombia of GDP and Civil construction. Serfinco DANE calculations (2013)

Figure 1 highlights the proportional trend relationship between annual growth rates in civil works construction respect to the GDP growth in Colombia.

When talking about infrastructure, reference is usually made to set of engineering structures and facilities, created from the techniques, methods, tools and materials that propitiate it [4]. Within this materials group, the most indispensable is Cement, which acts as a binder par excellence for the union bricks. According to the use of the structure and needs, cement is often combined with other elements such as water, sand, gravel and additives, to forming mixtures as grout, mortar and concrete [5].

Mortar is the main mixture with which bricks, stones or concrete adhere; and also for lifting and filling spaces of structures in civil works. The fluid mortar or "grout" is a material with properties, as the name implies, of fluidity, for self-leveling purposes. It is mainly used to fill bases, anchors and
small spaces. The grout is able to perform a uniform and correct transmission of the efforts between supported structures and the foundation or anchors, making the structure more robust [6].

This paper presents an overview about importance and current state of infrastructure in Colombia, in addition to economic growth. Sika company case is presented, is a company dedicated to the manufacture and marketing of materials for civil construction, and the relationship with improvements in developments of mortars, aiming at better performance in characteristics of fluidity and resistance to compression. This approach is justified from the need to improve the mortar self-leveling Sika Grout 212 granular skeleton, regain fluency and maintain the resistance offered to customers stipulated in the data sheet, therefore, it is important to carry out studies and tests, with new materials with better granulometric characteristics, that make the mixtures more robust [6].

2. The problem
In 2014, Sika Colombia in its factory located in Barranquilla began manufacturing one of its most emblematic mortars in the construction sector, seeking to be the ideal support for engineering projects in all country. The following information is specified in the Sika Grout 212 mortar product data sheet:

[...] It is a self-leveling ready for use in anchor fillings and leveling works. It has been specially designed to obtain the appropriate consistency and penetration for each type of application, it maintains its volumetric stability vertically, developing and reaching high initial and final resistances. (p. 1).

Around 2016, applicators on site or customers show that the Sika Grout 212 self-leveling had plastic consistencies, as it had to present fluid consistencies, taking into account the need to fill in confined areas. This problem has been evaluated by trained and trained R&D (Research and Development) personnel, concluding that this novelty is due to the granular composition of the raw materials or to the incompatibility of the cement with the other binders that are in the mixture. The main reason that promote the manufacturing of this mortar in Barranquilla is due to strategic geographical position and export possibilities in Central America, but this inconsistency in the product has led the company to lose the possibility of exporting this product to customers in other countries.

Currently, at a commercial level, there is a low demand for this product in the Caribbean region of Colombia. Among the 43 references of products manufactured by the Barranquilla factory, the participation of Sika Grout 212 was 15% in the periods 2014-2015 for months considered as good utility (e.g., October), while in 2017, in the same month, this mortar contributed only 0.45% of total manufactured units.

2.1 Sika grout 212 characteristics.
Sika Grout 212 self-leveling mortar is composed of Sands (coarse and fine), Cement and Pre-mix (i.e., Additive). Therefore, product improvements should be aimed at the reformulation of the mixture or the addition of a new compound that allows to reach the standard of properties and characteristics required by customers. In previous investigations within the company it was possible to verify that pre-mixing and cement were significant factors in the characteristics of consistency and resistance. Hence, the sands group are the main compounds to be reformulated (i.e., Change proportions) or partially replaced by a new compound.

Based on the unprofitable behavior that this product has had in the market due to low performance, it is vital that the company visualize strategies that regain the trust of customers, keep loyalty of the
Construction market and increase the competitiveness of the company's facing the foreign market. Therefore, the impact of new binder addition in the Sika Grout 212 self-leveling mortar mix is analyzed experimentally. Subsequently, the proportions of the compounds in the mortar mixture are determined. After all this, the economic benefit of using the new binder is estimated, showing the possible advantages of applicability and innovation of the binder.

3. Literature review
A detailed analysis was carried out, initially considering a background from different theoretical perspectives, and then recent mortars researches, which constitute one of the most frequent and important elements in the execution of masonry and construction works. For aforementioned, the materials used and the results that have been obtained from the different mixtures were taken into account for the analyzes.

Manuel Perez [7], Austral University of Chile, conducted a paper entitled "Characterization of mortars with addition of combinations of micro-silica and nano-silica". Although the goal of his work was to analyze the behavior of these materials, applied separately in the mortar together with concrete, they analyzed the results to mixed use. This research serves as the basis for analyzing the behavior of our self-leveling mortar Sika Grout 212 with the new binder.

Similarly, José Vásquez Romero [6] performed a job (applied Sika Madrid, Spain) that aimed to analyze the possibilities of optimizing particle size cementitious mortars by applying concepts of interference particles and the addition of filler in order to improve the physical and mechanical properties of these. It was focused on the analysis of commercial self-leveling mortars for floors, and was interesting for the development of this research because the changes in volume, density, fluidity and viscosity could be analyzed in detail due to addition of specific binder.

Tomás Escribano and Alba García [8] developed a working list showing the development of what has been the self-leveling mortar since its first appearance in the 70s, and how their leveling properties with little effort, using little staff and less time employment has led to self-leveling mortars to be based construction processes, positioning them as a technique that increases levels of productivity. The practical application consisted of making use of three types of additives: an aerating one, a setting retarder, and a cracking controller.

Petrement [9] has tested mortars replacing the sand by waste polyurethane foam. The physical and chemical characterization of mortars made shows that the mixtures obtained have properties that can make suitable for use in construction.

Janneth Torres, Ruby and Constanza Gutiérrez [10] presented results of performance evaluation of mortars added with a metakaolin (known by the acronym MK) of Colombian origin. The study showed that resistance of cement is higher in the presence of MK and that this effect is more noticeable by increasing the proportion of this substance in mortar. In another investigation by Bernal, S. Esguerra et al. [11] analyzed the mechanical properties of geopolymeric mortars based on Colombian steel slag (GBFS) and a high purity metakaolin, reinforced with carbon fibers (CF). Showing that the production of mortars with high mechanical resistance is possible.

Puertas and Vázquez [12] in his work entitled "Behavior mortars alkaline cements reinforced with polypropylene fibers and acrylic" found that polypropylene fibers increases the impact resistance greater extent than acrylic fibers.

Furthermore, Izquierdo, Mejía de Gutiérrez, and Torres Agredo [13] analyzed the deterioration of mortars containing catalyst residue catalytic cracking (FCC). Highlighting the increased chemical resistance of mortars with addition of this material.
3.1 Taxonomic summary

Table 1 shows a taxonomic classification of the previous works, which have incorporated and evaluated the granular composition of mortars indications for each of the following taxonomic characteristics are listed:

1. **Approach:** Characteristic in which the work is oriented to achieve the objectives. It is divided into Physical (F), which considers those physical and mechanical properties as resistance, fluidity, among others; Economic (E), which considers minimizing the cost of mortar production. Finally, it is also possible to consider both characteristics at the same time.

2. **Material type:** Rank the materials according to their properties and atomic structure. They are ceramic type (C) and polymers (PO).

3. **Addition:** The material added to the mortar mixtures is specified to achieve fluidity and mechanical strength. Here are considered: Silica (S), Limestone Filler (LF), Polyurethane (PLI), Aerating (A), Setting Retarder (SR), Cracking Controller (CF), Metakaolin (MK), Iron Slag (IS), Polypropylene (PR), Acrylic (AC) and Catalytic Cracking Catalyst (FCC).

4. **Consistency/Fluency:** Basic characteristic for study of mortars, related to the manageability of the mixture. It is presented in a Dry (D), Plastic (PL) and Fluid (FL) way.

5. **Resistance:** Ability to withstand and transmit the loads to which it is subjected mortar according technical standard conditions.
   - 5.1 **Pressure:** Maximum effort that a material can withstand under a crushing load. It is reported in megapascals (mpa).
   - 5.2 **Time:** Time period required to measure the resistance of material.

6. **Setting time:** Time period which a mortar has sufficient handleability to be used without further addition of water, in order to counteract hardening effects.

7. **Standard:** For measuring workability of the mortar flow test described in standard NTC 111 in Colombia used. The resistances are obtained from to the test results according to standard conditions UNE-EN 1015-11 [14]. Similarly, ICONTEC [14] suggest that the most widespread international standard is ASTM-270, where the setting times of a mortar are exhibited.

All of the above can be summarized as a qualitative explanation of taxonomy that will be presented in Table 1.
| Reference | Main goal | Focus | Material type | Material | Consistency/Fluency | Resistance | Setting Time | Standard |
|-----------|-----------|-------|---------------|----------|--------------------|------------|--------------|----------|
| Puertas, F., Amat, T., & Vázquez, T. (2000) | Study the behavior of alkaline cement grout reinforced with fibers of different nature (acrylic and polypropylene). | F | PO | PR-AC | x | 50 mpa | 28 days | 48 hours | UNE |
| Manuel Heraldo Pérez Bahamonde Valdivia (2008) | Characterize the mechanical and physical properties of a mortar treated with additions of nanosilica, microsilica and combinations of both. | F-E | C | S | X | X | 3.84 mpa | 28 days | 24 hours | ASTM-NTC-UNE |
| Torres Agredo, Janneth; Mejía de Gutiérrez, Raby; Gutiérrez, Constanza (2008) | Present the results obtained from the performance evaluation in the presence of sodium sulfate from mortars added with MK produced from a kaolin of Colombian origin | F | C | MK | X | 47 mpa | 14 days | 24 hours | ASTM |
| Bernal, S., Esguerra, J., Galindo, J., de Gutiérrez, R. M., Rodríguez, E., Gordillo, M., & Delvasto, S. (2009) | Present the results on the mechanical properties of geopolymeric mortars based on a Colombian steel slag and a high purity metakaolin, reinforced with carbon fibers | F | PO-C | MK-IS | X | 40 mpa | 28 days | 24 hours | ASTM |
| José Vázquez Romero Madrid (2012) | Granulometric optimization of cement-based grouts through the application of concepts: particle interference, the addition of filler. | F | C | LF | x | 46.9 mpa | 28 days | 24 hours | ASTM-NTC-UNE |
| Carlos Junco Petrement Burgos (2012) | Obtain cement mortars with partial or total sand substitution by rigid polyurethane foam residues, in order to achieve viable products that improve the management of these wastes. | F-E | PO | PLI | x | 23.6 mpa | 28 days | 24 hours | ASTM-NTC-UNE |
| Escribano y García (2014) | High conductivity grout | F | PO | A-SR-CF | x | 5 mpa | 8 days | 24 hours | UNE |
| Izquierdo, S., Díaz, J., Mejía de Gutiérrez, R., & Torres Agredo, J. 2016 | Analyze the displacement of grouts added with 10 and 20% of a catalytic cracking catalyst (FCC) residue | F | PO | FCC | x | 56 mpa | 60 days | 24 hours | ASTM-NTC-UNE |
From different materials used in mixtures analyzed, such as polymers and ceramics, it is possible to reach the normative values stipulated by NTC, ASTM and UNE as the case may be. The most frequent targets in the analyzed studies are aimed at physical focus, i.e., consider properties such as fluidity, resistance, among others.

4. Materials and methods
This section defines the stages of the methodology for the design of an experiment, which achieves the proposed physical and economic objectives.

4.1 Stage I: Selection and characterization of materials
This stage described, by a brief description, the materials used by Sika Colombia company for preparation of self-leveling mortar.

(a) Fine sand: Natural material mostly siliceous ratio, dry yellow, angular gradation with 85% between the meshes 50 and 70mm, classified by Sika Colombia specifications as sand 30/140, moisture absorption of 1.13% and wherein the mesh passes 200 mm does not exceed 5%.

(b) Coarse sand: Granular material, characteristic of large stones natural detachment in mines or by the result of a crushing process, 90% gradation between 16 and 30 mm meshes, 0.6% moisture absorption, rough texture, semi angular, resistant and where the mesh passes 200 mm does not exceed 1%.

(c) Cement: Binder resulting from the mixture of limestone and clay having a hardening property upon contact with water. This combination generates a chemical reaction with setting characteristics and high strength, good adhesion and cohesion. It is designed for use in mixtures, mortars and concrete.

(d) New Compound: Material with high calcium content. It has a purity of 90 to 94% CaCO3 clean, gradation 4 mm mesh pass 100%, textured, semi-angular with presence billed faces it helps good adhesion in mixtures.

(e) Pre-mix: Addition to mortars. Confidential use formula in Sika Colombia that improves the characteristics of adhesion manageability and resistance in mixtures.

4.2 Stage II: Selection and justification of experimental design
The experimental design selected is Simplex-lattice, in which the involved ingredients (factors) and each treatment is a particular combination including \(X_1, X_2, X_3, \ldots, X_k\). This design restricts that participation of ingredients (proportions) in a mixture must be greater than 0 and never greater than 1, at the same time, the sum participation of the ingredients must not exceed 1. In other words, it must be fulfilled:

\[
0 \leq X_i \leq 1 \quad \text{ (1)}
\]

\[
X_1 + X_2 + X_3 + \cdots + X_k = 1 \quad \text{ (2)}
\]

These restrictions cause that levels of ingredients \(X_i\) not to be independent of each other. Likewise, the increase in the participation of an ingredient in a mixture conditions or decreases the participation of other ingredients in it. For applications or more information about this type of design, it is recommended to review Gutiérrez & De la Vara [15].
4.2.1 Simplex lattice mixture design.

The restriction on experimental design selected mixtures is due to a tacit knowledge and previous trials by Sika company Laboratorians Colombia, regarding the involvement of the 5 compounds in the mixture of self-leveling mortar. Considerations about the design variables and factors are explained below:

(a) **Cement**: Fixed ratio 43% of the mixture by cost issues. Its cost is the highest among all compounds so it is not a design factor.

(b) **Coarse sand**: It has a granulometry that, in concatenation of others compounds and water, allows an increase in resistance. Its participation in the mix remains unchanged at 13%, value with which it is normally working in Sika Colombia.

(c) **Fine sand**: Participation in 41% of mixture. It presents a phenomenon called moisture absorption. Ratios between 30% and 35% of the mixture were tested.

(d) **Pre-mix**: Previous experiments have yielded Sika Colombia that the optimal ratio of pre-mixture should be maintained to ensure a stable invariant resistance. To elaborate this conclusion, is possible review the paper by León [16].

(e) **New compound**: The new compound is selected by analysis and internal testing of the company Sika Colombia. Also, by financial issues and experimental intention, the proportion of new compound on total mixture is between 6% and 11%, as opposed to fine sand.

The input factors selected for the design of experiment are: fine sand and new compound, which, concatenated, represent 41% of the mixture. Table 2 shows a summary of treatments based on above restrictions.

**Table 2. Percentage of self-leveling mortar compounds**

| Treatment | Cement | Coarse sand | Pre-mix | Fine sand (x₁) | New compound (x₂) |
|-----------|--------|-------------|---------|---------------|------------------|
| 1         | 43     | 13          | 3       | 30            | 11               |
| 2         | 43     | 13          | 3       | 32.5          | 8.5              |
| 3         | 43     | 13          | 3       | 35            | 6                |

Figure 2 shows the geometric representation of simplex lattice design restricted with two factors selected factors.

![Figure 2. Geometric representation of mixtures experimental design with k = 2](image)

4.2.2 Experimental runs.

Experimental runs based treatments described in Table 2 are performed using statistical software Statgraphics®. Three replications per treatment are considered, as some authors suggest [15]. The order of runs is completely randomized to minimize some kind of correlation between them. Table 3 shows experimental runs order.
### Table 3. Experimental runs order

| Order | Treatment | Cement | Coarse sand | Pre-mix | Fine sand ($x_1$) | New compound ($x_2$) |
|-------|-----------|--------|-------------|---------|------------------|--------------------|
| 1     | 2         | 43     | 13          | 3       | 32.5             | 8.5                |
| 2     | 1         | 43     | 13          | 3       | 30               | 11                 |
| 3     | 3         | 43     | 13          | 3       | 35               | 6                  |
| 4     | 1         | 43     | 13          | 3       | 30               | 11                 |
| 5     | 3         | 43     | 13          | 3       | 35               | 6                  |
| 6     | 3         | 43     | 13          | 3       | 35               | 6                  |
| 7     | 2         | 43     | 13          | 3       | 32.2             | 8.5                |
| 8     | 2         | 43     | 13          | 3       | 32.5             | 8.5                |
| 9     | 1         | 43     | 13          | 3       | 30               | 11                 |

4.3 Stage III: Evidence of physical behavior of mixtures at different ages of resistance failure

This subsection procedurally presents the steps taken to implement the experimental runs.

The mixtures were made under standardized procedures Sika Colombia, for preparation of product study. According to what indicated in technical specification, a sample of 3500gr, formed by the mixture proposal (i.e., fine sand, cement, coarse sand premix, new compound) it is taken. It is mixed in a water / product ratio at 0.17%. With the homogenized and fresh mixture state, 1000gr are taken, which a consistency analysis (i.e. fluidity) is performed, ensuring it complies with technical stipulations sheet (fluid consistency). With the remaining 2500gr, specimens are prepared in bronze cubes 50x50 mm in two layers with 54 strokes each, and finally each mold is obtained.

To measure resistance in the cured state at ages 24 hours, 14 days and 28 days, a universal device is used in compression (6 kg scale with accuracy of 0.01). Waiting for every age reached, the cubes are removed from the curing water. Subsequently, they are taken to test machine where it is sought to place the piston on the more uniform face of the hub. The press of test machine is activated and the device display shows data in Kg. / Cm2 at failure time.

5. Analysis of result

In this subsection, an analysis is performed in three stages of results. Initially in subsection 5.1. the results of experimental runs performed are presented, under the conditions described in subsection 4.2.2. Subsection 5.2. presents an analysis where the impact of the factors studied (in terms of consistency) is identified. In subsection 5.3. It is represented by a mathematical model the relationship between these factors, deriving an optimal latter operating condition. Finally, in subsection 5.4. shows a comparative analysis in terms of costs of the mixtures do not consider or the new compound.

5.1. Experimental results

The results presented in this subsection correspond to the values of consistency (Kg / cm2) of each of the treatments tested. Table 4 shows the results of the treatments at 24 hours, 14 days and 28 days.
### Tabla 4. Results of experimental runs

| Execution order | % Fine sand ($x_1$) | % New compound ($x_2$) | Consistency Kg/cm² ($y$) |
|-----------------|---------------------|------------------------|-------------------------|
|                 | 24 hrs | 14 d | 28 d |
| 1               | 32.5   | 8.5  | 183 | 511 | 541 |
| 2               | 30     | 11   | 141 | 426 | 477 |
| 3               | 35     | 6    | 175 | 430 | 465 |
| 4               | 30     | 11   | 177 | 439 | 478 |
| 5               | 35     | 6    | 176 | 433 | 488 |
| 6               | 35     | 6    | 198 | 432 | 470 |
| 7               | 32.2   | 8.5  | 169 | 523 | 551 |
| 8               | 32.5   | 8.5  | 208 | 513 | 546 |
| 9               | 30     | 11   | 181 | 429 | 465 |
| Mean            | 178.7  | 459.6| 497.9 |
| Standard deviation | 18.7  | 42.4 | 36.9 |

The average of data proves that the mean value of the fluid consistency (kg / cm²) for both ages 24 hours, 14 days and 28 days exceeded the lower limit of the sheet according to the resistance Sika compression Colombia (i.e., greater than 150, 340 and 430 respectively. See Annex 1). Only one experimental run at 24 hours of age yields a better value than allowed lower limit (141 kg / cm² <150 kg / cm²). This usually happens by outside variables in the formulation and which has a certain permittivity because it failed the first age. The minimum values corresponding to ages of 14 and 28 days exceed the lower limit of compressive strength by a considerable margin.

Standard deviations of treatments 1 and 2 are similar. However, treatment 3 shows inconstant, especially 14 days. Taking this as a decisive factor, this treatment showed less variability to 28 days treatment was 2 standard deviations for treatment and age are presented in Table 5.

### Table 5. Standard deviation by treatment and age of the self-leveling mortar

| Treatment | 24 hrs | 14 d | 28 d |
|-----------|--------|------|------|
| 1         | 22.030 | 6.8068 | 7.2341 |
| 2         | 19.7565 | 6.42910 | 5 |
| 3         | 13 | 1.52752 | 12.0968 |

### 5.2 Analysis of Variance (ANOVA)

The tool par excellence for the analysis of experiments is the Analysis of Variance (ANOVA). The analysis stage is carried out almost entirely using the statistical software Statgraphics®. It should be mentioned that the data entered in Statgraphics® software proportions correspond to values between 0 and 1, not percentages.

A preliminary analysis shows the results of adjusting different data models resistance. The mean model is formed solely by constant. The linear model is first order terms for each of the components (i.e., fine sand for $X_1$ and $X_2$ New compound). The quadratic model adds cross between pairs of component products (i.e., their interrelationships). Each model is shown with a P-value, which tests whether that model is statistically significant when compared to the mean square of the term below. Typically, a model with a P value less than 0.05 is selected, assuming that one works at a confidence
level of 95%. The standard error statistics of estimates and the R-square have been tabulated for each models. Some analysts prefer to select the model that maximizes R-Square adjusted.

(a) ANOVA at 24 hours: According to the P-value in Table 6, no model is suitable for data. Table 7 indicates the standard error statistics for the R-square fitting, the model that best describes the relationship between the factors studied is linear.

Table 6. Estimated effects of the full model for 24-hour resistance

| Source | Sum of Squares | DF | Mean Square | F-Value | P-Value |
|--------|----------------|----|-------------|---------|---------|
| Mean   | 287296,        | 1  | 287296,     |         |         |
| Linear | 413,358        | 1  | 413,358     | 1.22    | 0.3067  |
| Square | 291,309        | 1  | 291,309     | 0.84    | 0.3957  |
| Error  | 2089.33        | 6  | 348,222     |         |         |
| Total  | 290090,        | 9  |             |         |         |

Table 7. Standard error of the 24-hour Full Model

| Model  | ES  | R-Square | R-Square Adj. |
|--------|-----|----------|---------------|
| Linear | 18,4416 | 14.79 | 2.62          |
| Square | 18,6607 | 25.22 | 0.29          |

(b) ANOVA at 14 days: According to the P-value in Table 8, the quadratic model is suitable for the data, as the result yielded Table 9.

Table 8. Estimated effects of the full model for 14-days Resistance

| Source | Sum of Squares | DF | Mean Square | F-Value | P-Value |
|--------|----------------|----|-------------|---------|---------|
| Mean   | 1.90E+11       | 1  | 1.90E+11    |         |         |
| Linear | 0.0255036      | 1  | 0.0255036   | 0.00    | 0.9973  |
| Square | 14168.2        | 1  | 14168.2     | 472.27  | 0.0000  |
| Error  | 180.0          | 6  | 30.0        |         |         |
| Total  | 1.92E+11       | 9  |             |         |         |

Table 9. Results of the Complete Model at 14 days

| Model | ES  | R-Square | R-Square Adj. |
|-------|-----|----------|---------------|
| Linear | 45.27 | 0.00 | 0.00          |
| Square | 5.477 | 98.75 | 98.33         |

(c) ANOVA at 28 days: The results in Table 10 and 11 allow further strengthen the conclusions generated in the analysis to 14 days. There is a significant relationship between the analyzed factors of quadratic type.
Table 10. Estimated effects of full model for 28-days Resistance

| Source    | Sum of Squares | DF | Mean Square | F-Value  | P-Value |
|-----------|----------------|----|-------------|----------|---------|
| Mean      | 2.23E+11       | 1  | 2.23E+11    |          |         |
| Linear    | 0.544294       | 1  | 0.544294    | 0.00     | 0.9856  |
| Square    | 10417.0        | 1  | 10417.0     | 139.72   | 0.0000  |
| Error     | 447,333        | 6  | 745,556     |          |         |
| Total     | 2.24E+11       | 9  |             |          |         |

Table 11. Results of Complete Model at 14 days

| Model     | ES     | R-Square | R-Square Adj. |
|-----------|--------|----------|---------------|
| Linear    | 393.961| 0.01     | 0.00          |
| Square    | 863.456| 95.88    | 94.51         |

In general, the behavior to 24 hours was inconclusive and, somehow, is a result of observed variability between data in the descriptive analysis. However, the behavior of variability 14 and 28 days remained constant, as was seen descriptively also giving the conclusion fit a quadratic model.

5.3 Mathematical model to 28 days

Table 12. Results of Resistance Model Adjustment

| Parameter | Estimate | Standard | T     | P-Value |
|-----------|----------|----------|-------|---------|
| X<sub>1</sub>: FINE SAND | 474.3 | 4.985 | | |
| X<sub>2</sub>: NEW COMPOUND | 473.3 | 4.98 | | |
| X<sub>1</sub>X<sub>2</sub> | 288.66 | 24.42 | 118.198 | 0.000 |

R-square = 95.88 %
R-Square (adjust g.l.) = 94.51 %
Standard Error = 8.63
Mean Absolute Error = 6.0
Statistical Durbin-Watson = 1.87 (P=0.4298)
Residual Autocorrelation Lag 1 = -0.11

The adjusted mathematical model that relates the new compound and fine sand:

\[
\text{Resistance} = 474.3\times X_1 + 473.3\times X_2 + 288.66\times X_1\times X_2 \quad (3)
\]

Table 13. Estimated results for Resistance

| File | Observed Values (Y<sub>i</sub>) | Adjusted Values (\hat{Y}_i) | Mean | Lower 95.0% | Upper 95.0% |
|------|---------------------------------|-----------------------------|------|-------------|-------------|
| 1    | 465.0                           | 474.33                      | 462.135 | 486.532     |             |
| 2    | 477.0                           | 473.33                      | 461.135 | 485.532     |             |
| 3    | 541.0                           | 546.0                       | 533.802 | 558.198     |             |
| 4    | 488.0                           | 474.33                      | 462.135 | 486.532     |             |
| 5    | 551.0                           | 546.0                       | 533.802 | 558.198     |             |
| 6    | 478.0                           | 473.33                      | 461.135 | 485.532     |             |
| 7    | 470.0                           | 474.33                      | 462.135 | 486.532     |             |
| 8    | 546.0                           | 546.0                       | 533.802 | 558.198     |             |
| 9    | 465.0                           | 473.33                      | 461.135 | 485.532     |             |
5.3.1 Testing statistical assumptions (Residual analysis)

Residual analysis of mathematical model may ensure suitability for estimation and representation of relationships between variables. Most cases can be validated analyzing residues \(e_i = Y_i - \hat{Y}_i\). These assumptions represent the distance of each observation to the fitted line model. To expand the issue of statistical validation of assumptions, it is recommended to review Montgomery [17]. Basically suitability assumptions can be validated in two ways: analytically and graphically.

i. **Normality**: Graphically it validates that the values follow a standard straight (i.e., From the probability distribution Normal) residual. This adjustment is measured in relation to the deviations of line, as evidenced in Figure 3, where the points are close to it. Analytically it could be validated by the Shapiro-Wilk test or the Kolmogorov-Smirnov test.

ii. **Homoscedasticity**: It assumes that, for each value of an independent variable, the variance of the residuals is constant. To validate this assumption, the residuals versus predicted values graph is used, no trend cloud of points should be presented, as can be seen in Figure 4. In an analytical way, Breusch-Pagan test could also be performed, if the data fit a normal distribution, or the Brown-Forsythe test, if they do not comply.

iii. **Independence**: This validates that there is no dependency between errors, that involve an error in taking measurements leading to a trend. Graphically, the residual dispersion, according to observation sequence is analyzed. In Figure 5 it can be seen that there is a marked tendency for the residual values for the adjusted model. Analytically it is possible to apply Durbin-Watson test.

![Figure 3. Probability graph normal-residual](image1)

![Figure 4. Graph of residuals vs. predicted values.](image2)

![Figure 5. Graph of residual sequential](image3)
5.3.2 Optimum operating condition.
It is also important to know the kind of relationship between design factors, including conjecture that maximizes the response variable. Based on the proposed quadratic model (see equation 3) and using the statistical software Statgraphics®, it aims to maximize strength, resulting in an optimal value equal to 546.001 kg / cm².

Table 14 shows the optimization resolved by Statgraphics® based on the proposed model. The optimum operating condition is .7932 .2067 fine sand and New compound. In terms of percentage it would be 32.5% and 8.5% respectively, which is equal to 2 experimental treatments.

| Component       | Low  | High | Optimal |
|-----------------|------|------|---------|
| Fine grit       | 0.7  | 0.8  | 0.793   |
| New compound    | 0.147| 0.267| 0.206   |

5.4 Economic analysis of proposals
The proposed total of 12 samples prepared in the laboratory, either using the control specifications (QA / EPT 1221 edition 4 and AC / ME / Ed code 05.19.05), are compared with the results expressed in the data sheet version 13 / 02/2013 Sika Grout 212.

Table 15 breaks down the current formulation of Sika Colombia for manufacturing the self-leveling mortar, indicating the total cost per unit (Lump 30Kg). Furthermore, Table 16 shows the resistance in each of the different blocks of setting time.

| Resource                          | Consumption per Unit | Total cost per kilo | Total cost per Unit |
|-----------------------------------|----------------------|---------------------|---------------------|
| Bag (Package)                     | 1.00 Unit            | 833.00              |                     |
| Gray Cement                       | 12.90 kg             | 402.94              | 5,197.93            |
| Gross grit 8/30                   | 3.90 kg              | 150.00              | 585.00              |
| Fine grit                         | 12.30 kg             | 75.00               | 922.50              |
| PM                                | 0.90 kg              | 2,700.00            | 2,430.00            |
| Operator 1 - Product manufacturing| - Hours              | 340.97              |                     |
| Operator 1 - Product packaging    | - Hours              | 340.97              |                     |
| Operator 2 - Product manufacturing| - Hours              | 62.78               |                     |
| Operator 2 - Product packaging    | - Hours              | 62.78               |                     |
| Automatic machine operations       | - Hours              | 183.51              |                     |
| Laboratory (quality control, sample analysis) | - Hours              | 19.76               |                     |
| Package 30kg Grout 212            | 1.00 Bag             | 10,979.20           |                     |

Table 16. Compressive strength results of the original mortar formulation

| Resistance 24 hrs (Kg/cm²) | Resistance 14 d (Kg/cm²) | Resistance 28 d (Kg/cm²) |
|-----------------------------|---------------------------|---------------------------|
| 194                         | 547                       | 571                       |

The value of proportions of the compounds to the mortar mix and resistance in each time block for each setting proposal presented in Tables 17, 19 and 21. New compound is used at 2.55, 1.80 and 3.30 kg,
these represent 8.5, 6 and 11% of total sample respectively. In Tables 18, 20 and 22 is added to the formulation New compound manufacturing self-leveling mortar, in order to meet the total unit cost.

(a) Proposal 1

Table 17. Proportions of mortar mix compounds according to proposal 1

| Fine grit (%) | New Compound(%) | Resistance 24 hrs (Kg/cm²) | Resistance 14 d (Kg/cm²) | Resistance 28 d (Kg/cm²) |
|---------------|-----------------|-----------------------------|---------------------------|---------------------------|
| 32.5          | 8.5             | 183                         | 523                       | 541                       |
| 32.5          | 8.5             | 169                         | 511                       | 551                       |
| 32.5          | 8.5             | 208                         | 513                       | 546                       |

Table 18. Manufacturing including the new compound at 2.55 kg.

| Resource                                | Consumption per Unit | Total cost per kilo | Total cost per Unit |
|-----------------------------------------|----------------------|---------------------|---------------------|
| Bag (Package)                           | 1.00 Unit            |                     | 833.00              |
| Gray Cement                             | 12.90 kg             | 402.94              | 5,197.93            |
| Gross grit 8/30                         | 3.90 kg              | 150.00              | 585.00              |
| Fine grit                               | 9.75 kg              | 75.00               | 731.25              |
| PM                                      | 0.90 kg              | 2700.00             | 2,430.00            |
| New Compound                            | 2.55 kg              | 60.00               | 153                 |
| Operator 1 - Product manufacturing      | - Hours              |                     | 340.97              |
| Operator 1 - Product packaging          | - Hours              |                     | 340.97              |
| Operator 2 - Product manufacturing      | - Hours              |                     | 62.78               |
| Operator 2 - Product packaging          | - Hours              |                     | 62.78               |
| Automatic machine operations (silos filling, dosing, mixing) | - Hours | | 183.51 |
| Laboratory (quality control, sample analysis) | - Hours | | 19.76 |
| Package 30kg Grout 212                   | 1.00 Bag             | 10,940.35           |                     |

(b) Proposal 2

Table 19. Proportions of mortar mix compounds according to proposal 2

| Fine grit (%) | New Compound(%) | Resistance 24 hrs (Kg/cm²) | Resistance 14 d (Kg/cm²) | Resistance 28 d (Kg/cm²) |
|---------------|-----------------|-----------------------------|---------------------------|---------------------------|
| 35            | 6               | 175                         | 430                       | 465                       |
| 35            | 6               | 176                         | 433                       | 488                       |
| 35            | 6               | 198                         | 432                       | 470                       |

It is clear that proposal 3 does not meet the minimum specifications in one of its replicas. On the other hand, the proposal 1 present results that exceed the minimum values necessary for mortar studied (see Annex 1), variability between their results is a product unwanted feature. Finally, the proposed 2 (optimum condition found using Statgraphics®) present results with less variability among themselves and with values that meet product requirements.

In economic terms, the comparison of production costs shows that: a greater amount of new bond in the mix, the cost increases proportionally. Consistent with this proposal 3, with more of new compound, is the most economically attractive without considering the physical requirements necessary section in the product.
### Table 20. Manufacturing including the new compound at 1.80 kg.

| Resource                  | Consumption per Unit | Total cost per kilo | Total cost per Unit |
|---------------------------|----------------------|---------------------|---------------------|
| Bag (Package)             | 1.00 Unit            |                     | 833.00              |
| Gray Cement               | 12.90 kg             | 402.94              | 5,197.93            |
| Gross grit 8/30           | 3.90 kg              | 150.00              | 585.00              |
| Fine grit                 | 10.50 kg             | 75.00               | 787.50              |
| PM                        | 0.90 kg              | 2700.00             | 2,430.00            |
| New Compound              | 1.80 kg              |                     | 108.00              |
| Operator 1 - Product manufacturing | - Hours             |                     | 340.97              |
| Operator 1 - Product packaging | - Hours             |                     | 340.97              |
| Operator 2 - Product manufacturing | - Hours             |                     | 62.78               |
| Operator 2 - Product packaging | - Hours             |                     | 62.78               |
| Automatic machine operations (silos filling, dosing, mixing) | - Hours             |                     | 183.51              |
| Laboratory (quality control, sample analysis) | - Hours             |                     | 19.76               |

Package 30kg Grout 212     1.00 Bag 10,952.20

(c) Proposal 3

### Table 21. Proportions of mortar mix compounds according to proposal 3

| Fine grit (%) | New Compound(%) | Resistance 24 hrs (Kg/cm²) | Resistance 14 d (Kg/cm²) | Resistance 28 d (Kg/cm²) |
|---------------|-----------------|-----------------------------|--------------------------|--------------------------|
| 30            | 11              | 141                         | 426                      | 477                      |
| 30            | 11              | 177                         | 439                      | 478                      |
| 30            | 11              | 181                         | 429                      | 465                      |

Table 22. Manufacturing including the new compound at 3.30 kg.

| Resource                  | Consumption per Unit | Total cost per kilo | Total cost per Unit |
|---------------------------|----------------------|---------------------|---------------------|
| Bag (Package)             | 1.00 Unit            |                     | 833.00              |
| Gray Cement               | 12.90 kg             | 402.94              | 5,197.93            |
| Gross grit 8/30           | 3.90 kg              | 150.00              | 585.00              |
| Fine grit                 | 9 kg                 | 75.00               | 675.00              |
| PM                        | 0.90 kg              | 2700.00             | 2,430.00            |
| New Compound              | 3.30 kg              |                     | 198.00              |
| Operator 1 - Product manufacturing | - Hours             |                     | 340.97              |
| Operator 1 - Product packaging | - Hours             |                     | 340.97              |
| Operator 2 - Product manufacturing | - Hours             |                     | 62.78               |
| Operator 2 - Product packaging | - Hours             |                     | 62.78               |
| Automatic machine operations (silos filling, dosing, mixing) | - Hours             |                     | 183.51              |
| Laboratory (quality control, sample analysis) | - Hours             |                     | 19.76               |

Package 30kg Grout 212     1.00 Bag 10,929.70

6. Conclusions

It was assessed the impact that has the addition of a new binder maintaining the strength in self-leveling mortar Sika Grout 212. For this purpose, a restricted single lattice experimental design, low theoretical and tacit considerations of technical research and development is postulated company in which different ratios of fine sand (30% to 35%) and a new binder (6% to 11%) in the original mixture mortar tested.
The new compound maintains levels of consistency and fluidity required by self-leveling mortar Sika Grout 212. From the results obtained by the proposed experimental design, analysis of variance which shows significant effects at different ratios of fine sand is performed and New compound. The mathematical model that best fits the data (i.e., the relationship between the factors and resistance) was a square arrangement. This regression model met suitability tests on the residual analysis (i.e., Normality Homoscedasticity and Independence).

The optimum operating condition maximizing compressive strength corresponds to 32.5% of fine sand and 8.5% of New compound on the original formulation. As seen in estimating production costs, the formulation of proposal 2 (i.e., the statistically optimum) reduced by 0.24% manufacturing cost compared to the original formulation per package of 30kg. Mortar Sika Grout 212. The nominal economic margin of improvement is quite low, however, translated into an annual production (At least, 300 tons per year) it means a significant cost savings, helping to program development and innovation of company Sika Colombia.

Future research could be aimed at the implementation of experimental designs (Mixtures), based on inferential statistics to perform tests in the search for product improvements, and consider mixtures containing additions of Polymers and Ceramics at the same time. Likewise, future research could consider ecological material based on hemp, which some research assures that it improves physical properties of mortars (Collet et al., 2007; Hamzaoui et al. 2014).

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### 8. Annexes

In this subsection the annexes related to necessary information and cited in the document are presented.

**Annex 1.** Technical information of compressive strength of the self-leveling mortar without shrinkage for precision fillings and anchors

**TECHNICAL INFORMATION**

| Compression Resistance | Plastic consistency (kg/cm²) | Semi-fluid consistency (kg/cm²) | Fluid consistency (kg/cm²) |
|------------------------|------------------------------|---------------------------------|---------------------------|
| 1 day                  | 230                          | 210                             | 150                       |
| 4 days                 | 510                          | 470                             | 340                       |
| 28 days                | 630                          | 575                             | 430                       |

Setting time: 7 - 10 hours

Depending on the consistency of the grout and the temperature of the place this time may vary.

**Source:** Product Data Sheet Sika Grout 212, Sika Colombia