Modul. Arquit. CUC 32: 25–48, 2024

Uso sostenible de agua subterránea y agua de lluvia en la construcción de hormigón

Sustainable use of groundwater and rainwater in concrete construction

DOI: 10.17981/mod.arq.cuc.32.1.2024.02

Article. Fecha de Recepción: 5/8/2023. Fecha de Aceptación: 29/9/2023.

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Para citar este artículo:
Eljaiek, S., Badillo, D., Abudinen, D. y Cano, H. (2024). Uso sostenible de agua subterránea y agua de lluvia en la construcción de hormigón. *MODULO ARQUITECTURA CUC*, 32, 25–48. http://doi.org/10.17981/mod.arq.cuc.32.1.2024.02

Resumen

Actualmente, la búsqueda de alternativas amigables con el medio ambiente en la industria de la construcción es evidente, especialmente en el uso de agua para las mezclas de hormigón. En esta investigación se fabricaron y caracterizaron cubos de mortero hidráulico, utilizando agua subterránea (ASUB), agua de lluvia (AL-GL y AL-BG) y agua de grifo de diferentes ciudades (AG-BG y AG-GL). Previamente analizadas mediante ensayos físicos y químicos. Asimismo, se evaluó la resistencia mecánica de los morteros mediante ensayos de compresión y se compararon con cubos de mortero de control preparados con agua potable (AG-BQ). Los resultados indicaron que el agua subterránea es apta para la fabricación de morteros ya que la resistencia media de los cubos de mortero elaborados con este tipo de agua fue del 96,5% de resistencia a los 7 días respecto a la muestra patrón, encontrándose así dentro de los límites admisibles según ASTM C1602-18. La caracterización fisicoquímica del agua del grifo (AG-BG, AG-GL), del agua de lluvia (AL-GL, AL-BG) y del agua subterránea (ASUB) mostró valores similares en la mayoría de los parámetros fisicoquímicos medidos, excepto en el oxígeno disuelto y la dureza.

Palabras clave: Agua subterránea; agua del grifo; agua de lluvia; construcciones; resistencia a la compresión; sostenibilidad

Abstract

Currently, the search for environmentally friendly alternatives in the construction industry is evident, especially in the use of water for concrete mixes. In this research, hydraulic mortar cubes were manufactured and characterized, using groundwater (ASUB), rainwater (AL-GL and AL-BG), and tap water from different cities (AG-BG and AG-GL). Previously analysed by physical and chemical tests. Likewise, the mechanical resistance of the mortars was evaluated using compression tests and they were compared against control mortar cubes prepared with drinking water (AG-BQ). The results indicated that the groundwater is suitable for the manufacture of mortars because the average resistance of the mortar cubes made with this type of water was 96.5% resistance at 7 days with respect to the sample. standard, thus being within the permissible limits according to ASTM C1602-18. The physical and chemical characterization of tap water (AG-BG, AG-GL), rainwater (AL-GL, AL-BG), and groundwater (ASUB) showed similar values in most of the physicochemical parameters measured, except for dissolved oxygen and hardness.

Keywords: Constructions; compressive strength; groundwater; rainwater; sustainability; tap water

Módulo Arquitectura CUC no. 32, p. 25–48. Enero - Junio, 2024
Barranquilla. ISSN Impreso 0124-6542, ISSN Online 2389-7732.

Introduction

The lack of water on the planet is an obvious problem, which represents one of the greatest risks of global impact. It affects approximately 4 billion people around the world, who experience difficulties in accessing water for at least one month in a calendar year and affects approximately half of the global population living in areas vulnerable to this phenomenon during the same period, a figure that could increase from 4.8 to 5.7 billion by 2050 (Blanco et al., 2021; Burek et al., 2016; Mekonnen & Hoekstra, 2016). The problems of water scarcity and mismatches between water supply and demand have become increasingly prominent. Globally, the continental regions affected by the scarcity have doubled between 1970 and 2000 and by 2050 it is stipulated that five times as many territories could be affected. Nearly 1.8 billion people in seventeen countries appear to be heading for a water crisis because, although water is known to cover most of the planet, less than 3% is usable freshwater.

Among the different types of water are rainwater, groundwater, and tap water. Groundwater is water found beneath the earth's surface or within rock structures; as well as in deserts and deep humid areas. It is used mainly for human consumption and other industrial processes and is used by more than 50 % of the world's population for water supply purposes. Most of the main aquifers of the planet are under increasing stress, with a percentage of 30% depletion of the largest groundwater reservoirs, where one of the main causes for such depletion worldwide is the use of water for irrigation (Burek et al., 2016).

On the other hand, drinking water is one whose conditions guarantee the absence of external substances or components of biological, chemical, inorganic, organic, or radioactive nature in certain concentrations, such that it has negative health effects.

Conventionally, drinking water is the most used in the construction industry, responsible for 9% of global withdrawals of this type of water, with an estimated 75% to 2050 of water demand for production, coming from regions that are likely to experience water stress. However, it is possible to find within it elements such as salts, organic materials, acids, and others that, if not physically and/ or chemically treated, can be harmful to concrete or the reinforcement of hydraulic mortars, impairing their quality and resistance (Sánchez, 2021). This happens due to the presence of organic substances in certain quantities in the water that can alter the hardening time of the mixture and considerably affect the final strength of the concrete (American Society for Testing and Material [ASTM], 2012). In turn, the lack of access to this resource in some areas results in the use of water of unknown quality and without previous studies for its use in the manufacture of mortars, and in the increase of costs in the development of construction works or for own use in areas not supplied with this resource (Sánchez, 2021).

In this circumstance, groundwater represents a resource associated with growth opportunities for society in addition to contributing as a source of human consumption in areas lacking drinking water and as raw material for projects in large-scale economic sectors such as agriculture and the energy sector. It represents more than 97% of the available fresh water on the planet and among the uses, it can have is the satisfaction of domestic, industrial, and irrigation needs. Worldwide, its use in these activities is intense, with 50% for human consumption, 20% for irrigation, and 40% for the industry. Based on the knowledge of the composition of water and the substances found in it, the possibility of using it in specific situations is defined.

In this field of construction this can be used in an innovative way for the construction of concrete, to reduce associated costs due to its rapid consumption, since in the Colombian context and specifically in the Atlántico, the excessive costs for the use of cubic meters of water represent difficulties for the development of this type of projects or civil works. Rainwater is water produced from the precipitation of vaporized water from the atmosphere and the soil and condensed in the hydrological cycle that can be deposited on the plant surface, on the land surface, and infiltrate through the soil. The rainwater represents an alternative for use in construction projects because its use reuses a resource provided by nature, which reduces the excessive use of tap water in civil works, costs, and ecosystem degradation without compromising the strength, quality, durability, manageability and other characteristics of structures.

Analyzed the effectiveness of these different types of water on the mechanical strength of concrete compression, obtaining that with the use of drinking water, groundwater and wash water the concretes at one week of manufacture were found to exceed the minimum percentage (90%) and that therefore the totality of the samples cover the requirements of the ASTM C94 standard (ASTM, 2003) for mixing waters, highlighting that although they can be used in concrete mixtures, their effects on hydration mechanisms, durability and other properties in cement still need further in-depth investigation. However, concrete mortars prepared with groundwater showed a high concentration of sodium sulfite, and compression procedures showed representative differences between the water samples, the first achieved by the design strength.

Additionally, with the use of groundwater as the main resource to manufacture units for continuous rock bonding in regions of northern Colombia, it has been exhibited that groundwater negatively affects the strength of the blocks, reducing it in an interval of 11% to 16% compared to standard samples. This is probably associated with the presence of sulfates and chlorides, as well as the type of cement and sand used, whose combination showed a slight 5% increase in strength.

Successively, cylinders manufactured with rainwater exhibited higher resistances compared to those manufactured with drinking water (7.62 y 7.24, respectively) highlighting that this alternative generates exponential reductions in the use of water in construction, as well as costs; it would also contribute to the care of the environment. It was also pointed out that its effect should be tested on the resistance of mortars, bearing in mind the physicochemical characteristics of the rainwater used. The latter can modify its resistance. Regarding turbidity and other physical parameters, such as solids content, these do not represent significant changes in the resistance, but affect the aesthetic and organoleptic properties of water quality, especially if it is intended for consumption. On the contrary, in the chemical parameters, the variation of pH values can influence this behavior, generating delays in the expected resistance at 7, 14, and 28 days of setting when it presents values below 6.5 and an increase in this for basic pH values.

The world situation of water scarcity is unquestionable, and with time, the requirement for this resource presents continuous growth. Its root lies in the rapid increase in the world population rate, which causes the overexploitation of water resources, and it is estimated that this demographic expansion will continue to advance. Likewise, the poor management of the resource in the different communities has an impact on this result. By 2017, 2 100 million people lacked access to drinking water and 4 500 million people lacked quality sanitation. The above, represents a problem, especially in vulnerable areas and territories, where the requirement of drinking water does not match the supply capacity of this, affecting the welfare of the community, which is limited to supplying themselves from external sources in an unsafe and rationed manner; that demonstrates the need for solutions that address a good management of the resource or propose different alternatives for the industry.

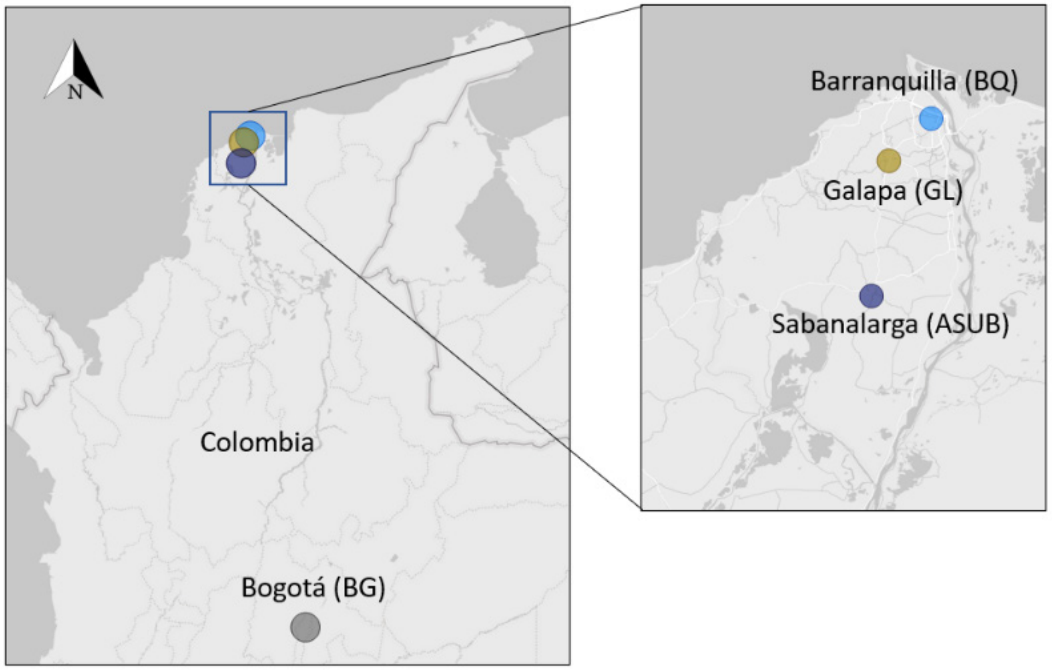
This research article is carried out to seek alternatives to the use of different types of water in the construction and infrastructure sector, in response to the crisis of climate change and scarcity of drinking water in the world. Therefore, this research determines the influence of groundwater, drinking water rainwater from different regions of Colombia in the manufacture of mortars and their relationship with different physicochemical parameters.

Materials and methods

Water samples collection

Figure 1 shows the collection points of AG, ASUB, and AL water specimens, respectively, in different sites in Colombia. The ASUB used in this research was collected from the municipality of Sabanalarga, Atlántico in an artisanal well located in the village of Palo Seco, which is surrounded by natural spaces for crops and livestock.

Figure 1. *Sampling locations.*



Source: Authors.

The AL was collected in the municipality of Galapa (AL-GL) and Bogotá city (AL-BG). The water samples were collected between August and September, due to the high rainfall that occurs at that time. These were collected for approximately 1 hour, by preliminarily pouring a container of water through the established channels, seeking to capture water with the least presence of external contaminating agents. The AG was collected in the territories of Galapa (AG-GL), Bogotá (AG-BG), and the Barranquilla District (AG-BQ). The latter was taken as control water, since the entire manufacturing process ensures quality, in addition to fully complying with the stipulated in Colombian environmental regulations through resolution 2115 of 2007 for the control and surveillance of the quality of the AG.

Physicochemical characterization of water

The types of water used in the present research were characterized under current regulations (ASTM, 2018). Table 1 shows the list of analyses performed according to the current standard and the permissible values.

TABLE 1. *Analysis for water characterization.*

Parameters	Test standard	Regulation 2115 of 2007	WHO International Standard	U.S. Regulations	EU Regulations
Conductivity (uS/cm)	ISO 7888	1000 µS/cm	-	-	2 500 µS cm^{-1} a 20 °C
Sulfates	BS 3148	≤ 250 mg/L	-	250 mg/L	250 mg/l
Total solids	BS 3148	-	-	500 mg/L	-
Color	Standard Methods: 2120 Color	15 UPC	15 UVC	15 color units	Acceptable to consumers
Turbidity	ASTM D7315-17	2 UNIT	4 UNT	-	Acceptable to consumers
Nitrite	BS 3148	≤ 0.1 mg/L	3 mg/l	1.0 mg/L	0.50 mg/L
Alkalinity	Standard Methods: 2320 Alkalinity	200 mg/L	-	-	-
Hardness	Standard Methods: 2340 Hardness	300 mg/L	100 mg/L - 300 mg/L	-	-
pH	Standard Methods: 4500-H+ pH Value	6.5-9.0	6.5 - 8.0	6.5 - 8.5	≥ 6.5 y ≤ 9.5
Iron	Standard Methods: 3500 Iron	0.3 mg/L	< 0.3 mg/L	0.3 mg/L	0.2 mg/l

Source: Authors.

Manufacture of mortar cubes

According to ASTM-C270, the mortars used in the construction of reinforced and unreinforced unitary masonry specimens can be classified into 4 mortar types, for two alternative specifications, proportioning specifications and property specifications (ASTM, 2019).

The mortars were manufactured under ASTM C109/C109M-21 (ASTM, 2020). 48 mortar cubes were produced for each type of water. Table 2 shows the dosages used for the preparation of the mortars for the different types of water.

TABLE 2. *Mortar dosage.*

Material	Normalized ratio (in mass)	Dosage for 48 cubes (2” × 2” × 2”)
Cemento	1	4.000 g
Arena	2.75	11000 g
Agua	0.484	1936 ml

Source: Adapted from ASTM (2020).

Cement and sand are components widely used in construction projects as hydraulic mortars since their mixture guarantees the impermeability of the area where they will be placed. Portland cement, used for the manufacture of mortars, has hardening properties when it comes into contact with water by hydration; it is mainly composed of dicalcium and tricalcium silicates, and its relationship with water influences the consistency of the mixture, since the greater the amount of water, the more fluid it will be and the easier it will be to work with, so this relationship ends up affecting the properties of the concrete.

On the other hand, the ratio of cement and aggregate is also important, because too much aggregate ends up hiding the amount of cement and preventing its admixture. For this reason, granulometry influences the properties of concrete, since it affects to a greater or lesser extent its volumetric stability and strength.

Mechanical characterization of Mortars

To analyze the mechanical properties of the manufactured mortars, a compression test based on ASTM C109/C109M-21 was applied (ASTM, 2020). The compressive strength was calculated based on equation (1):

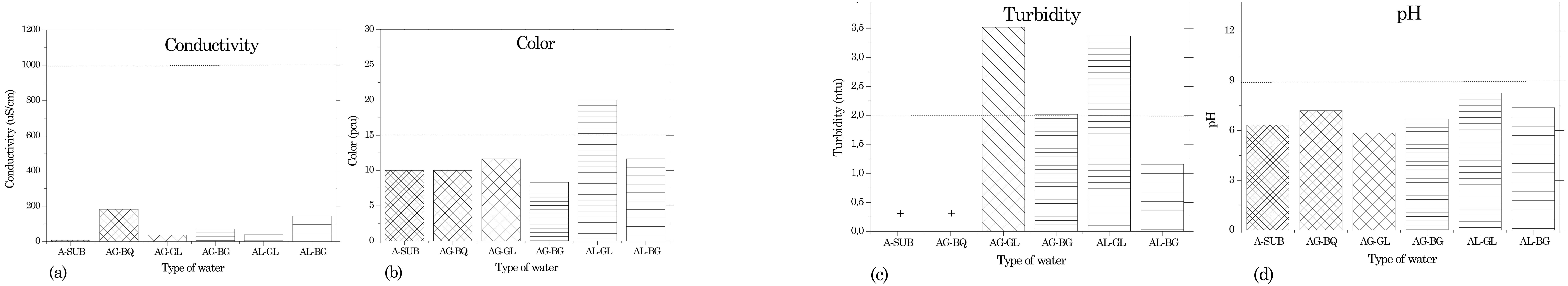
$$\sigma_c = \frac{P}{A} \quad (1)$$

Where is the compressive strength, is the maximum compressive load tolerated by the mortar, is the cross–sectional area of the cube.

A statistical analysis was performed on the results to analyze the reliability of the results. Reliability analysis is widely used to measure the probability of a system meeting design specifications for a specific period without failure (Gramsch, 2018).

Figure 2. *Physico-chemical parameters of water types (1st part).*

Source: Authors.



Results and Discussion

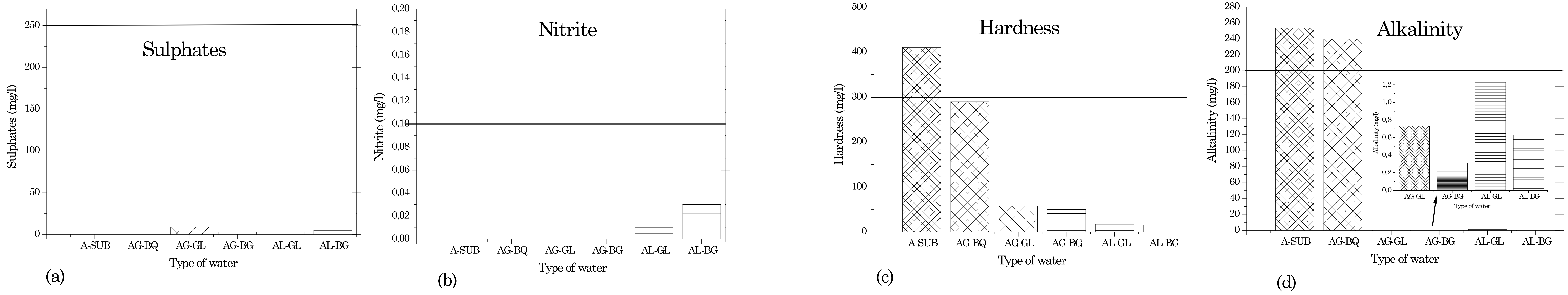
Physicochemical characterization of water

Figure 2 shows the results of the physical characterization of the water. It is observed in item a, that the conductivity of the AG-BQ presented the highest value (182.1 uS/cm), followed by the AL-BG (143.53 us) and lastly the ASUB (6.41 uS/cm). These variations can affect to a lesser extent the mechanical strength of concrete materials, in a way that if the conductivity increases, there will be a decrease in it, demonstrating that this parameter is viable for prediction (Chung et al., 2021). Nevertheless, none of the waters analyzed showed values higher than the established limits in Colombian Resolution 2115, nor in the international framework (Ministerio de la Protección Social & Ministerio de Medio Ambiente Vivienda y Desarrollo Territorial, 2007; Consejo de la Unión Europea, 1998). Based on the results obtained, it is inferred that the ASUB presents the most ideal conductivity conditions since it presented a lower conductivity than the rest of the waters. Regarding color, as shown in Figure 2b, AL - GL obtained the highest value (PCU), exceeding the maximum permissible by Colombian regulations (15 PCU).

Which implies that it may not be suitable for application in concrete manufacturing processes, since it may negatively influence the quality of the concrete, and it is recommended to desist from its use unless there is evidence that it has been previously implemented for concrete manufacturing (Ministerio de la Protección Social & Ministerio de Medio Ambiente Vivienda y Desarrollo Territorial, 2007; Instituto Colombiano de Normas Técnicas y Certificación [Icontec], 2001). On the other hand, AG-GL had the highest turbidity value (3.52 NTU), and AL-BG had the lowest (1.16 NTU). High values of turbidity also affect the strength of the materials; this can be compared with the research of Aldabagh et al. (2022), where the analysis of this parameter as well as others, in wastewater, well water, tap water, and river water, gave values of 117 NTU, 0.092 NTU, 0.55 NTU and 8.4 NTU, respectively, and resulted in the lowest compressive strength for wastewater sources specifically with results of between 36 MPa and 40 MPa at 28 days, being the lowest strengths within the entire study sample.

Figure 3. *Physico-chemical parameters of water types (2nd part).*

Source: Authors.



From the above, it can be inferred that, although the highest turbidity result was 3.52 NTU, it is expected that the mortars made with the AG-GL will present a compressive strength not so high (Aldabagh et al., 2022) (Figure 2c).

For the pH values obtained, AG-GL achieved the smallest value (5.85), placing it as slightly acidic on the pH scale, while the vast majority of the remaining waters presented neutral values (pH: 7), with the exceptions of AL-BQ, which obtained a value of 8.25. Values lower than 7 are considered acidic on the pH scale, and depending on their position on the scale it can influence the deterioration of concrete materials by accelerating possible sulfate attacks, causing damage and affecting the integrity of the structures (Bellmann et al., 2012). It is possible to observe this behavior in AG-GL, since, as previously announced, low pH values are associated with the presence of sulfates, and this type of water showed the highest concentration for this parameter, as presented in Figure 3a.

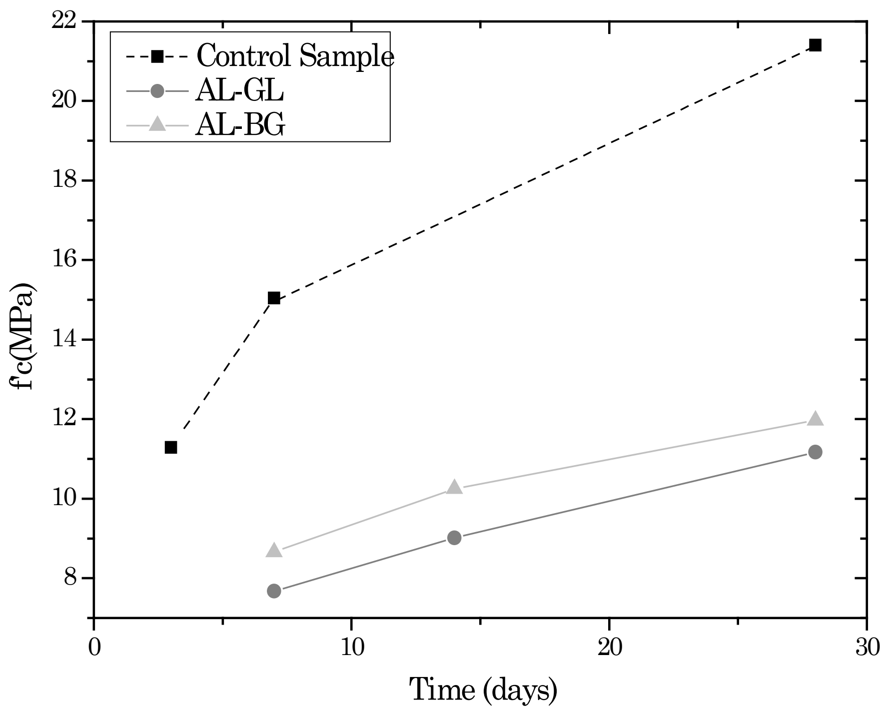
The results reveal in turn that the existence of sulfates AG-GL (9.00 mg/l) obtained the highest value, in contrast to AG-BG (2.67 mg/l) and AL-GL (2.67 mg/l). Previous research reports that the dynamics of hydration products with sulfate ions can generate fractures, cracks, and fissures in concrete, increase its weight, density, and elasticity and intensify its compression by filling the interior of the structures so that the mortar´s resistance varies according to the sulfate's concentration in the different types of water (Sheikh et al., 2020).

Considering the results of the compression tests (Figure 6), it is confirmed that the capacity of opposition to compressive forces of the AG-GL was lower compared to the various types of water studied, this conduct may be due to the concentration of sulfates found in this sample, which reduced its resistance in the investigation of Sheikh et al.,(2020), a similar dynamic was evidenced, in which after combined cycles of sulfate attack, freezing and thawing for a drinking water sample and wastewater sample, the latter had a higher sulfate concentration and subsequently a 31.1% decrease in its compressive strength, while the drinking water had a value of 22.3% (Sheikh et al., 2020).

For the nitrite analysis of the samples (AG-GL, AG-BG, AL-BQ, AL-BG) the drinking water specimens did not present concentrations, however, values of 0.01 mg/l y 0.03 mg/l were observed for AL-BQ and AL-BG, respectively. These values, nonetheless, should not represent significant effects on the resistance of the mortars, according to Table 1.

In the alkalinity analysis, the highest values obtained for this parameter were found in ASUB and AGBQ with results of 253.33 mg/l and 240.00 mg/l respectively, while AG-BG (0.31 mg/l) obtained the lowest value. The latter, together with the smallest values obtained in the rest of the waters (1.23 mg/l for AL-GL, 0.73 mg/l for AG-GL, and 0.63 mg/l for AL-BG) are observed in Figure 3d. Likewise, in the analysis, a maximum of 410.00 mg/l was obtained for ASUB and a minimum of 16.00 mg/l for AL-BG. Saba et al., (2019) results of the analysis of alkalinity and hardness show that when the alkalinity and hardness values are stabilized, the possible deterioration processes of the material decrease so that if high values are obtained in these parameters, the material will not be considered as corrosive, characterized in turn by pH values in the transition state, corroborating the above (Saba et al., 2019). From this, it can be inferred that these parameters of the ASUB water do not induce corrosive processes and that these two variables would not repre-

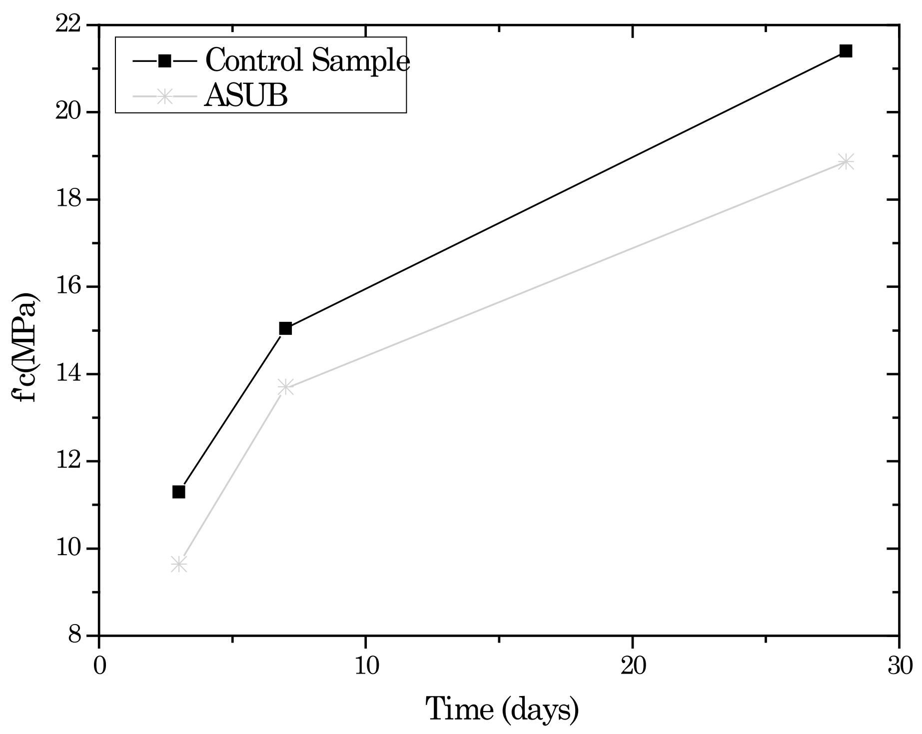
Figure 4. *Compressive strength of rainwater vs. Control sample.*



Source: Authors.

sent potential damage to the material, even so, these values do exceed the limits established by resolution 211, as well as the parameters established by the WHO, presented in Table 1, which is why they differ from the ideal characteristics presented in the control water. Finally, the iron measurements show the presence of iron for the ASUB of 0.78 mg/l, lower in comparison with those obtained in the control water AG-BQ (0.8 mg/l) for the same parameter; however, it does exceed the permissible limits proposed by both Colombian and international regulations, so that, in terms of water quality, it differs consid-

Figure 5. *Compressive strength of groundwater vs. Control sample.*



Source: Authors.

erably from the qualities present in the control water and drinking water in general.

Compressive strength

The mechanical strength test was performed on 96 mortars, for the 6 types of water used (AL-GL, AL-BG, AG-GL, AG-BG, ASUB, AG-BQ). The results of this test are presented below.

Rainwater behavior

Figure 4 shows that, compared to the 28-day strength of the control sample, the strengths of the AL-GL and AL-BG at the same number of days are considerably lower, showing a percentage difference of approximately 55 to 60% for the AL-BG, and a slightly greater difference (between 60 and 65%) for the AL-GL. This indicates that, although both samples had lower compressive strengths than the control sample, the AL-BG proved to be the more suitable of the two.

Groundwater Behavior

For the ASUB behavior, Figure 5 shows that, unlike the AL types of water, this has higher compressive strength at 28 days of curing, so it has a percentage difference, when compared to the control sample, of approximately 25 to 30% and is, therefore, the most suitable for the manufacture of hydraulic mortars.

Likewise, it is observed that the average compressive strength of the mortar cubes manufactured with ASUB, at 7 days of curing, is approximately 96% of the average value of the specimens manufactured with the control water, under the stipulations of section 2.2.2.2 of ASTMC1602/C1602M-12 (ASTM, 2022), which indicates that the ASUB implemented is acceptable as water for concrete. At the same time, it is observed that despite having achieved the maximum values in the analysis of hardness and alkalinity of the water, these did not represent negative effects on the compressive strength of this type of water, on the contrary, they could have influenced in the increase of this one.

Behavior of drinking water

As can be seen in Figure 6, both types of water presented notoriously lower strengths compared to AG-BQ, however, between the two types of water AG-BG presented the highest compressive strength at 28 days, approaching, a percentage difference of approximately 50-55% to the compressive strength of AG-BQ than compared to AG-GL whose percentage difference was approximately 55%-60%.

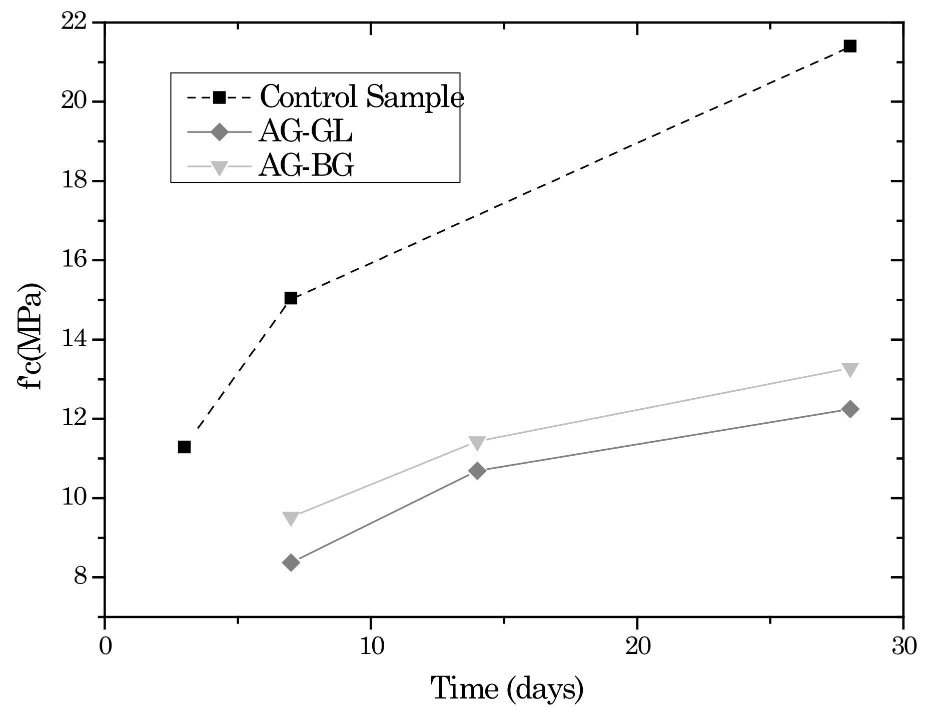
Reliability analysis of compressive strength results

Table 3 presents a simple statistical study of the evidence, based on the value of the standard deviation, classifying it according to the criteria of ACI 214 (Chung et al., 2020). As: Excellent and very good, which establishes an adequate experimental procedure. It is emphasized that the resistance was managed at 28 days since the models contained in the ACI 214 report are valid only for this period or time.

Influence of water chemistry on compressive strength

Figure 7 shows the results of the physicochemical parameters of the waters and their influence on compressive strength. Among the values obtained for conductivity, a wide dispersion was evidenced, where no trend or specific pattern was presented among the analyzed waters, except for two peaks presented in the graph, highlighting that the electrical conductivity is largely implemented to visualize the evolution of porosity in cement fragments and concretes through experimental analysis of 28 days (Chung et al., 2020). Consequently, with large increases in conductivity values, the porosity of materials such as concretes and cement will also increase exponentially, causing vulnerabilities in the structures.

Figure 6. *Compressive strength of drinking water vs control sample.*



Source: Authors.

Table 3. *Statistical analysis of compressive strength.*

Water Type	Mean f'c. (Mpa)	Standard Deviation (Mpa)	ACI 214 – Classification
AL-GL	11.17	0.087	Excellent
AL-BG	11.97	0.095	Excellent
AG-GL	12.25	0.158	Excellent
AG-BG	13.28	0.098	Excellent
ASUB	18.87	0.336	Excellent
AG-BQ (Control Sample)	21.40	1.566	Very Good

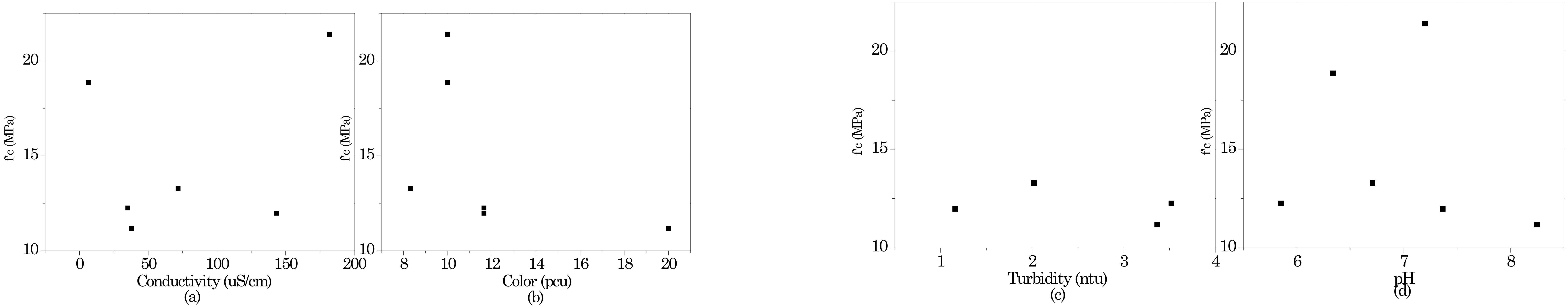
Source: Authors.

Considering the above, except for AG-BAQ (182.1 us/cm), AL-BG (143.53 us/cm) presented the lowest resistance because it is associated with the second-highest conductivity value and, therefore, with porosity, thus decreasing the compressive strength of the mortars in which the sample was applied. On the other hand, ASUB presented the lowest conductivity (6.4l us/cm), so it is to be expected that its resistance would be higher. In the research of Quilla & Quiroz (2021), the resistance of concrete manufactured with groundwater and drinking water was compared where a conductivity of 657 µs/cm was obtained for the first type of water mentioned, so a lower resistance was evidenced compared to that obtained in drinking water (Quilla & Quiroz, 2021).

Otherwise, a non-uniform behavior was observed, with great dispersion of the results for the color analysis (Figure 7b) where the two maximum values presented in the graph consequently correspond to the resistance value of the ASUB and the control water. No significant literature was found on this parameter that demonstrates its influence on the compression of the mortars, so it is inferred that it is not relevant for this characteristic.

Figure 7. *Influence of physical-chemical parameters on compressive strength (1st part).*

Source: Authors.



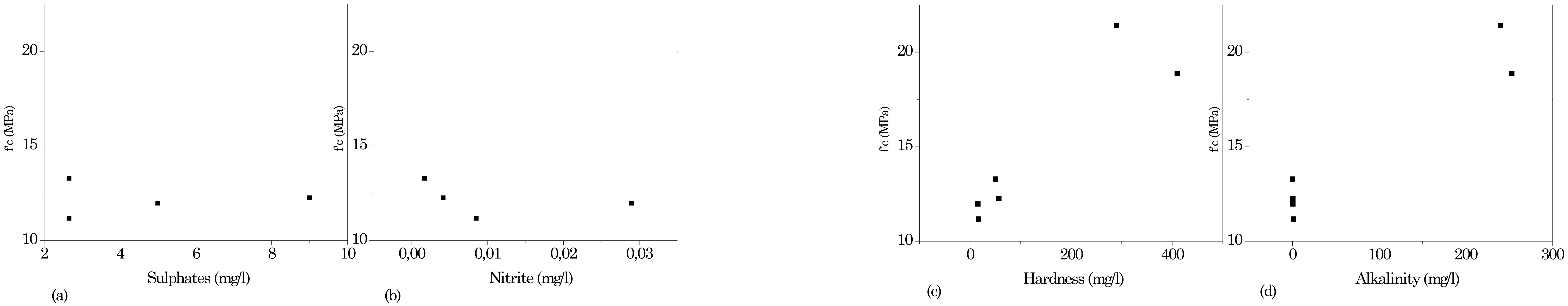
In the case of turbidity, in Figure 7c shows a mostly uniform behavior in comparison with compressive strength, the dispersion of this is not wide in contrast with the previous parameters, however; elevated values can considerably decrease this characteristic, as demonstrated in Aldabagh et al. (2022), and in the results of the present research in section 3.2, generating possible structural failures in the mortars Aldabagh et al. (2022).

Following this, Figure 7 (subsection d) exhibits a high dispersion of the pH results, with high values in resistance associated with pH figures ranging between 6.5 and 7.5, indicating that neutral pH results have a positive influence on the increase of compressive strength.

Simultaneously, it is noticed that, when presenting very alkaline values or tendencies, the compressive strength tends to diminish (Cagua & Nates, 2017). Even so, they displayed by testing the compression of concrete manufactured with mixing water at different pH, that as the hydrogen potential of the water improves, a rise in the compressive strength is caused, providing numbers between 23.14 MPa and 24.51 MPa for pH values between 6 and 8 (Cagua & Nates, 2017).

Concerning sulfates and nitrites, it is evidenced that, although there are increases in their concentrations, these variables do not have a significant influence on the compressive strength, as shown in Figure 8. Even so,

Figure 8. *Influence of physical-chemical parameters on compressive strength (2nd part).*
Source: Authors.



when observing the detailed results of each sample, it was found the AG-GL obtained the highest amount of sulfates and subsequently a reduction in its strength compared to other samples. On this, Granados (2017) studied the effect that the degree of presence of sulfate has on the compressive strength of various concrete blocks, and when comparing the results between those with the presence of sulfate and those without, general reductions were obtained in the strength at 28 days, so it was concluded that both have an inversely proportional relationship and the less its presence the better the material will be for its use Granados (2017).

For nitrites, it has been shown that the presence of nitrite-based accelerators tends to increase the compressive strength of mortars in their initial phases, however, this behavior tends to decrease with time (Kim et al., 2019). In this case, based on the results of the tests, it cannot be inferred that the presence of nitrite significantly affected the compressive strength of the mortars.

In contrast, the results of hardness and alkalinity in Figure 8c and Figure 8d presented similar tendencies between them. In one instance, little dispersion was evidenced for some of the values that negatively influenced the resistance, on the other, two peaks of maximum resistance and high alkalinity were exhibited, for each of the graphs. When analyzing the results of alkalinity and hardness, it was confirmed that these are related to the resistance achieved for ASUB and AG-BQ, as well as for color. Regarding alkalinity, Fernández-Jiménez & Palomo (2009) affirm that alkaline concretes and cement are appropriate and present higher strengths at early ages, observing values of 45 MPa in the first day of setting, compared to concretes made with conventional cement. This resistance continues to increase gradually with time (Fernández-Jiménez & Palomo, 2009).

Finally, the hardness of the ASUB sample showed a higher result compared to other specimens. This is because groundwater usually contains minerals and salts from soils and subsoils. Likewise, Sánchez (2001) indicates that some salts, such as magnesium and calcium salts, are rarely found in excessive concentrations that can alter the mechanical strength of the concrete

Considering the previous analyses and results of the final mechanical tests obtained for each water studied, alkalinity and hardness stand out as parameters that significantly influenced the increase in the strength of the mortars manufactured with ASUB water, which evidenced the highest strength of the set of samples; therefore, it is inferred that these two parameters have the greatest impact and influence on the compressive strength of the material. The influence of pH on the change of mechanical strength and the negative effect that the existence of sulphur compounds in a water sample can have, generating reductions in the compressive strength of mortars, are also highlighted.

Conclusions

Based on the development of the experimental procedures and the results obtained from them, it was possible to determine that of all the mortars evaluated and the different types of water used, the resistance of the mortars manufactured with ASUB, analyzed at 7 days of curing, is close to 75% of the resistance of the control sample, complying with the established according to the ASTM C1602/C1602M-12 standard (ASTM, 2022), cataloging it as an optimum resource for the manufacture of concrete and hydraulic mortars. In this study, a decrease in the resistance of the mortars was observed as time progressed; however, the resulting resistance at 28 days complies with the minimum values for type M mortars, denoted by title D of ASTM-C270 (ASTM, 2019), and at the same time it showed no effect on the setting time, similar to drinking water.

Concerning the resistances evidenced in the rainwater, it exhibited characteristics that were not suitable for the resistance at 28 days of curing, presenting a percentage of approximately 40% of the resistance of the control sample, so it does not meet the ideal conditions for the manufacture of hydraulic mortars. Likewise, it is important to note that, among the two AL samples, the AL-BG had the best compressive strength. Furthermore, the mortars elaborated with AG showed a behavior similar to the resistances observed for the mortars elaborated with AL. associated with a resistance of approximately 50% to AG-BQ; however, this one had a better performance compared to AL.

Ultimately, through the methodologies implemented, it was specified that, for this research, parameters such as conductivity, pH, hardness, and alkalinity had the greatest impact on the variation of the compressive strength of the mortars, where the increase in conductivity is related to the high porosity of the cement fragments and subsequent degradation of their stability, the increase in hydrogen potential, related to alkalinity and hardness through the presence of minerals and compounds that modify the properties of the mortars, with increases in mechanical resistance and therefore its acceptability for application in the construction industry.

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