Impact of plasticizers on the physical and structural properties of concrete used in constructions

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Abstract. Concrete has an important presence in the construction of buildings and civil works, so its application requires taking into account the standards, technical specifications and technologies that guarantee the structural stability expected by the manufacturers of materials and builders, and that is why the use of plasticizers arises as an adjuvant to the physical and mechanical properties of concrete. The objective of this article was to highlight the importance of plasticizers in the main properties of concrete used in construction and the ideal conditions for their use; based on a qualitative and quantitative approach methodology, scientifically validated sources of information related to the subject of the study were analyzed. It was possible to demonstrate significantly favorable results with the application of plasticizers as water reducers that increase mechanical strength, provided that they are used in an adequate proportion of these additives to improve the physical properties of concrete.

1. Introduction

Concrete is a material used in the construction of buildings and civil works; its elaboration is based on the mixture of lime or cement with gravel, sand and water; which hardens and increases its resistance once drying and setting are completed [1]. On the other hand, it is well known that plasticizers are organic compounds that contribute to optimize concrete designs by reducing the need for water and cement to achieve the properties required by the construction [2], these additives have been shown to reduce the viscosity of the cement paste.

Significant advances in construction have demanded over time the compliance with a series of regulatory requirements, technical specifications and the application of new technologies to achieve safer and more durable buildings with modern styles, from the design stage to the completion and delivery of buildings or civil works, a process in which concrete has a very important role given its attributes.

It should also be noted that the physical and structural properties of concrete are affected by certain aspects such as cracks and fissures, being inherent features of concrete, which can affect its durability and stability, which necessarily requires establishing a diagnosis that involves the identification of the causes that originate these affectations, in order to mitigate their effects through preventive measures and avoid their appearance.

Due to the above, the main objective of the present work is to analyze the incidence of the addition of plasticizers as inputs that complement and could improve the quality and properties of concrete

mixtures that are used today in the different civil constructions of society; it is also hypothesized that plasticizers are essential compounds in all civil works, providing better quality and stability conditions to the mixtures used in the construction process.

2. Methodology and materials

The methodological process for developing the research is presented in Figure 1, which shows each of the phases of the study that made it possible to fulfill the proposed aim.

2.1. Methodological approach

The methodology developed for the analysis was qualitative: the data were filtered based on the criteria established by the researchers. This qualitative criterion is related to an investigative attitude for the construction of knowledge and for the understanding of the phenomenon studied [3], a phenomenon defined as the action of plasticizers on the quality of concrete used in construction. [4].

Within this methodological framework, the article applied the deductive method that started with the observation of general phenomena, up to the verification of particular truths involved in the general situation [5], which implies a process based on a first level of knowledge according to secondary sources of information. A documentary approach was considered [6], which allows familiarizing researchers with the phenomenon under study based on the bibliographic review of sources related to the topics of interest related to plasticizers and their application to concrete in constructions as water reducers [7].

2.2. Search and collection of information

Instruments were applied for the synthesis and consolidation of the information associated with the variables considered as critical in the materials under study in Figure 1; allowing the data collected in the sources consulted to be contrasted with the analysis sheet. The analysis variables were the components of plasticizers, the dosage of plasticizers in concrete mixtures and the strength properties of concrete with plasticizers added.

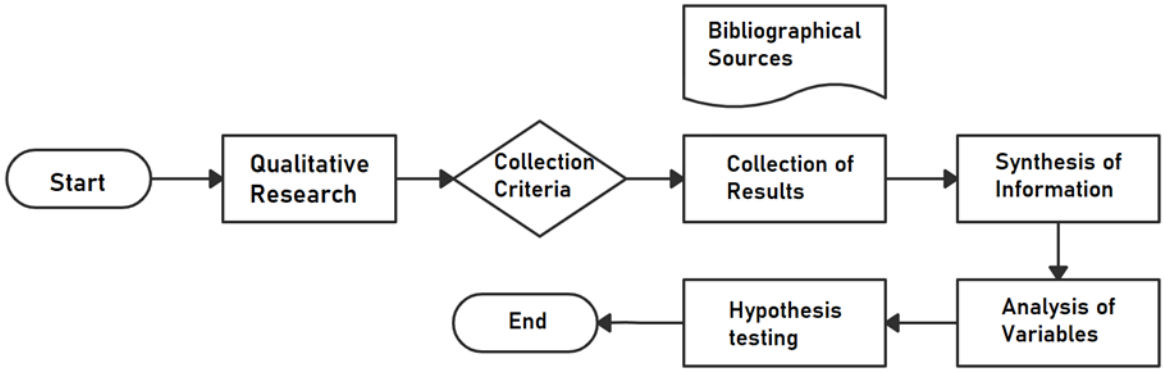

Figure 1. Methodological process of the research.

2.3. Components of concrete

The composition formula of concrete basically consists of a combination of a binder (cement), aggregates (aggregate materials such as gravel and sand) and water. The characteristics can be modified by the use of chemical admixtures such as plasticizers and curing agents. It should be noted that by varying the proportions of the above components, concrete acquires different properties, either lightweight concrete (density of approximately 1800 kg/m³), normal concrete (density of approximately 2200 kg/m³) and heavy concrete (density greater than 3200 kg/m³) [8].

Essentially, concrete offers a very good resistance to compressive stresses; however, in order to achieve greater resistance to bending and/or traction, it is associated with steel structures, giving rise to the so-called reinforced concrete; the following advantages of concrete have been highlighted [8]:

- High durability and strength.
- It provides high quality to the buildings in which it is used.
- It is outstanding for its versatility, as it can be used in all types of constructions and buildings.
- It offers anti-seismic protection.
- It has insulating protection, which means that the constructions that use it are well insulated not only thermally but also acoustically.
- It can be easily found in the market.

The strength of a concrete is influenced by other factors such as the amount of water added, aggregate granulometry, homogenization of the mix, water/cement ratio, and organic admixture, among other factors [9-11]. The dosage of aggregates or materials required to achieve typical strengths is presented in Table 1. Concrete may vary according to certain works or regions; therefore, it is imperative to highlight the convenience of indicating the availability of materials in relation to their gradation, physical and chemical properties or a combination of them [11].

Table 1. Concrete dosages for different strengths [10].

pounds per square inch (PSI) resistance required	Cement (Kg)	Sand (m^3)	Gravel (m^3)	Water (litres)
3200	420	0.67	0.67	250
3000	350	0.56	0.84	180
2500	300	0.48	0.95	170
2100	300	0.71	0.71	170
2000	260	0.63	0.84	170
1500	210	0.50	1.00	160

2.4. Plasticizers

Plasticizers for concrete belong to the group of chemical admixtures for construction, which reduce the amount of water needed to obtain a certain consistency in concrete. In other words, plasticizers make the cement paste mix and flow faster by coating the cement particles and making them repel each other. When the particles repel each other, there is less resistance to the flow of the whole (less friction), which in turn results in an elimination of micro-flocculi, which allows the release and better distribution of water, [2]; Table 2 shows the typical chemical composition usually present in these additives.

Table 2. Chemical composition of the plasticizer [12].

Component	Chemical formula	Weight %
Nonoxynol-9	$C_{23}H_{40}O_5$	10
Sodium dodecylbenzenesulfonate	$C_{18}H_{29}NaO_3S$	10
Triethanolamine	$C_6H_{15}NO_3$	10
Water	H_2O	70

Concrete admixtures help to reduce cement consumption and increase strength [12]; technically, most commercial admixtures are based on surfactants such as sodium dodecylbenzenesulfonate [13], which acts as an air-inclusive specifically designed to facilitate the production of precast concrete, together with cement hydration reaction accelerators such as triethanolamine (2, 2', 2"-nitrilotriethanol) [13] and a nonionic agent such as 9-nonoxynol to keep the mixture moist during the concrete block compaction process. The action of these admixtures allows plasticizing and improving the appearance and moldability of fresh concrete mixtures and their dispersion properties, allowing a fast demolding of the presses together with a higher durability of the molds due to the reduction of friction coefficients and an increase in compressive strengths [12].

Consequently, water-reducing admixtures improve the strength of hardened concrete without increasing the amount of cement [14]. Water-reducing admixtures are used to reduce the mixing water content by 5% to 10%, compared to concrete without admixtures, while maintaining the same slump.

Concrete containing a water-reducing admixture is more workable and can improve the pumpability of the concrete, remains more cohesive and is less prone to segregation during placement. By increasing compressive strength and improving workability through the use of water-reducing admixtures, the concrete manufacturer can design mixes with lower amounts of cement and, therefore, a more economical concrete [14].

3. Results and discussions

Previous experiences have shown significant results based on experimental processes related to the effects on the physical and structural properties of concrete, such as:

- Increasing compressive strength and reducing the permeability of concrete through the reduction of the structure of voids or internal bubbles that are present.
- Controlling cracks caused by shrinkage during concrete drying.
- Control cracking caused by temperature changes in the environment.
- Produce high initial strength concrete from the mixing plant, mitigating the risks caused by accelerated setting.

In the previous results, water management is present as a key factor in the production of concrete mixtures, since it is a variable that influences its characteristics in the fresh and hardened states [15]; in the fresh state it affects positively or negatively its transport and placement, and in the hardened state it affects its stability over time.

In terms of water management, it is common that in construction sites, especially in those of smaller size or some in the informal sector, to try to obtain an acceptable workability of the mixes by adding water, thinking exclusively at the time of their transport and placement on site, but negatively affecting in the future such important characteristics as compressive strength and durability, especially when the content of atmospheric agents such as CO_2 increases annually in the world and, especially, in congested urban centers, as indicated by [15].

According to the experiences mentioned above, it is worth noting that water management in turn has an impact on the physical characteristics of the material, affecting the density due to greater weight, and generally, this greater weight and greater density are directly associated with greater resistance to compressive stress [15]. Given that in small or informal constructions plasticizing additives are not usually used to improve the workability of the fresh mix, it is recommended that the communities be trained to use manual vibration and compaction techniques instead of adding water at the time of making the mix, because, as was shown in this work, this excess liquid, although it lubricates the cement paste and thus promotes greater initial fluidity, affects the physical-mechanical and durability characteristics after hardening [15].

According to the results shown in other experiences, it was observed that at seven days, the compressive strength of the mixture with maximum dose of plasticizer was considerably higher than the strength of the standard mixture, according to [16]. It should be noted that at twenty-eight days, both strengths were similar; however, for ages greater than twenty-eight days, the strength of the mixture with plasticizer was slightly higher than that of the standard mixture, according to [16]. Other observations indicate that unlike the concrete mix with excess dosage of plasticizer, the standard mix achieved slightly higher strength values, for both cases the compressive strength values were 250 Kg f/cm^2 and 280 Kg f/cm^2 , for ages equal to and greater than twenty-eight days respectively according to [16].

It is worth noting that the commercial plasticizing admixture has an effect on the lightweight concrete block in two ways: a) It favors a greater development of the hydration reaction of cement due to its accelerating effect and reduces the amount of water used by its effect of air inclusion and wetting, which is reflected in a significant increase in compressive strengths, and b) It modifies the preferential orientation of the crystalline structures of the aggregate [12].

Finally, the experiences show that the dosage of plasticizers definitely presents a significant final result in terms of the compressive strength of concrete, as stated by [16], in this process it is important to take into account the technical instructions of the admixture manufacturers, it was observed that using quantities greater than those recommended are not producing favorable effects on the final values, in fact it is observed that in both cases, in the long term the standard mixture is tending to have better results than the one with an excessive dosage, as verified by [16]; In this regard, the results related to the compressive strength at 28 days of setting in terms of the use of water/cement (W/C) and cement, as shown in Table 3 [17].

The 0.25 W/C ratio, 9.5 mm maximum aggregate size and 960 kg/m^3 cement achieve the highest compressive strength of 556 kg/cm^2 at 28 days of setting. It has been demonstrated that for normal concrete without plasticizers, the compressive strength should reach 70% of the value for which it was designed at seven days of setting, increasing to 100% at twenty-eight days of setting; however, when additives such as plasticizers are used, variations to this rule may occur, derived from the reactions produced by the inclusion of these new-generation materials, according to [16].

Table 3. Compressive strength at 28 days [17].

W/C	Maximum aggregate size (mm)	Cement quantity (Kg/m^3)	Average strength (Kg/cm^2)
0.20	9.50	1300	550
0.25	19.10	960	434
0.25	9.50	1040	529
0.25	9.50	960	556
0.30	19.10	800	412

4. Conclusions

It is important to establish the saturation point or limits of use of plasticizers, since the benefit is achieved according to the type of dosage, in other words, it is necessary to optimize their application. When selecting a plasticizer, it is necessary to take into account other parameters that influence the compressive strength, such as retention of workability without increasing the setting delay, development of initial strengths, greater or lesser cohesive effect and quality of the materials, among others.

Plasticizers are not the same, their dosage depends on the characteristics of the materials and of the concrete in general. There are no ideal or perfect plasticizers; rather, there are suitable or unsuitable plasticizers depending on the type of cement, application and jobsite requirements, as well as the concrete specifications. The improvement of the technical part of the project in terms of concrete quality involves the application of different types of admixtures such as plasticizers and curing agents. The use of plasticizers, in addition to improving the physical and structural properties of the concrete, also increases the profitability of the project; experiences have shown that the results in relation to the compressive strength of the concrete have been positive.

In the design stage of a construction project, different alternatives should be contemplated in the design of an adequate concrete to achieve greater financial benefits and greater technical benefits provided by the use of admixtures as plasticizers. It is proposed for future research work to propose alternatives in the combination of additives to improve other physical properties of plasticizers with a view to improving the quality of these materials in the preparation of concrete mixtures to ensure improvements in terms of strength and modulus of elasticity.

References

[1] Pérez J, Merino M 2018 *Definición de Hormigón* (España: Definición)
[2] Sika 2021 *Concreto, Aditivos para Concreto* (Colombia: Sika Colombia S.A.S.)
[3] Hernández R, Fernández C, Baptista M 2014 *Metodología de la Investigación* (México: Mcgraw-Hill)
[4] Báez J 2014 *El Método Cualitativo de Investigación desde la Perspectiva de Marketing: el Caso de las Universidades Públicas de Madrid* (España: Universidad Complutense de Madrid)
[6] Bisquerra R 2009 *Metodología de la Investigación Educativa* (Madrid: Editorial La Muralla)

[7] Ortega G 2017 Cómo se genera una investigación científica que luego sea motivo de publicación *Journal of the Selva Andina Research Society* **8(2)** 145
[8] Méndez C 2007 *Metodología, Diseño y Desarrollo del Proceso de Investigación con Énfasis en Ciencias Empresariales* (Colombia: Limusa)
[9] Burak F, Kamile T, Bülent B, Akin A, Bahadir U 2006 The effect of fly ash and limestone on the viscosity and compressive strength of self-compacting repair mortars *Cement and Concrete Research* **36(9)** 1719
[10] Feldman D, Shapiro M, Fazio P, Sayegh S 1984 The compressive strength of cement blocks permeated with an organic phase change material, energy and buildings *Cement and Concrete Research* **6(1)** 85
[11] Gündüz L, Bekar M, Spaci N 2007 Influence of a new type of additive on the performance of polymer-lightweight mortar composites *Cement and Concrete Research* **29(8)** 594
[10] Bonari M 2021 *La Exacta Dosificación de Concreto nos Sirve para Valorar la Cantidad de Cemento que Necesitaremos para Construir Nuestra Casa* (Argentina: Martinbonari)
[11] Instituto Colombiano de Normas Técnicas (ICONTEC) 2000 *Concretos. Especificaciones de los Agregados Para Concreto, NTC 174* (Colombia: Instituto Colombiano de Normas Técnicas)
[12] Jiménez F, Téllez L 2010 Efecto de un aditivo plastificante comercial sobre la estructura cristalina de la plagioclasa utilizada en la fabricación de blocks ligeros de concreto *Superficies y Vacío* **23(s)** 104
[13] Hewlett P 2003 *Lea´s Chemistry of Cement and Concrete* (United Kindon: Elsevier Ltd)
[14] Toxement 2018 *Aditivos para Concreto* (Colombia: Euclid Group)
[15] Bedoya C 2017 Incidencias del contenido de agua en la trabajabilidad, resistencia a la compresión y durabilidad del concreto *Revista de Arquitectura e Ingeniería* **11(1)** 1
[16] Fernández A, Morales J, Soto F 2016 Evaluación del comportamiento de la resistencia a compresión del concreto con la aplicación del aditivo superplastificante PSP NLS para edades mayores a 28 días *Revista INGENIERÍA UC* **23(2)** 197
[17] Solís R, Moreno E, Arjona E 2012 Resistencia de concreto con agregado de alta absorción y baja relación a/c *Revista de la Asociación Latinoamericana de Control de Calidad, Patología y Recuperación de la Construcción* **2(1)** 21