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INCLUSION OF METALLIC, NATURAL AND SYNTHETIC FIBERS TO INCREASE THE MECHANICAL PROPERTIES FOR CONCRETE ARCHITECTURE

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ABSTRACT:
This work aims to know how metallic, natural, and synthetic fibers influence the improvement of the mechanical properties of concrete architecture. The object of the study is to collect information that demonstrates, through a qualitative methodology, the behavior of the study fibers. As a result, it was observed that the mechanical properties of the concrete with different fiber dosages modify its behavior, reducing cracking and fissuring. The fibers give a new vision to develop new alternatives for the architectural construction of alternative and innovative projects.

INTRODUCTION

Nowadays, in the current world where technological innovation occurs exponentially, thanks to the French Monier and Coignet, it was possible to affirm that reinforced concrete began to be applied as a construction material in 1861. Also, are established rules for manufacturing beams, vaults, tubes, and among others. Throughout history, extensive development has been evidenced, and it is currently the material with different applications in the field of construction (Jiménez et al., 2000). During the 20th century, technologies such as prestressed and sprayed concrete have been developed, giving way to the appearance of special concretes such as high-strength, light, heavy, porous, self-compacting, recycled, and fiber-reinforced concrete (Ortiz et al., 2015).

On the other hand, fibers are not a recent material since ~4000 years ago. However, fibers from different materials were already used to improve their properties in different ways. For example, in lower Mesopotamia, baked clay bricks were made and dried in the sun after being kneaded and molded with the addition of straw; Taking the straw as an improvement component for the realization of the same, other elements were also used with horsehair in the production of plaster. These examples were called natural fibers and were used until 1935, being replaced in part by the appearance of synthetic fibers (Ortiz et al., 2015), and in 1874 the first patent for reinforced concrete with metallic elements was made in California by A. Berrad (Fernandez et al., 2003). Fibers are also added in dosages or mixtures to reduce settlement and plastic shrinkage cracking, decrease permeability, and increase abrasion and impact resistance. However, the characteristics of the properties and the behavior of the concrete when adding fiber depends significantly on factors such as the geometry of the fibers, distribution, and density in the concrete mass (Antillón, 2016).

Considering the above, this research seeks not only to highlight the use of fibers but also to identify different routes that articulate new knowledge associated with the customs and traditions that construction personnel have in the presence of new technologies and thus build social fabric with the technological innovation objective for the use of new trends in construction. Furthermore, the research aims to demonstrate the influence of metallic, natural, synthetic, and glass fibers in improving the mechanical properties of concrete, such as resistance to compression, tension, bending, and Young Modulus, which are the properties selected to carry out their respective analysis.

MATERIALS AND METHODS

In this work, an information gathering study was developed to publicize the influence of metallic, natural (sugar cane bagasse), synthetic, and glass fibers in the improvement of the mechanical properties of concrete, which can have an objective observation against the use of new components, generating a change in the traditional construction of reinforced concrete and encourage the use of fibers as a reinforcement material. On the other hand, some representative studies carried out by different authors of the world to justify the diversity of fibrous materials found environment guarantees that can offer when used in concrete for any construction work, compared with traditional concrete types.

On the other hand, for the development of the work five stages were considered. The first stage consists of the investigation of the antecedents of the fiber as a reinforcement material for concrete. In the second stage, the tests and regulations for using fibers as reinforcement material are highlighted to know what regulations govern the different properties required for their study. In the third stage, the influence of fibers (metallic, natural, synthetic, and glass) that can improve the mechanical properties of concrete were identified. The mechanical properties relation between traditional concrete and fiber-reinforced concrete will be developed in the fourth stage, where the main properties, such as compressive strength, tensile strength, bending stress, and Young Modulus mentioned can be evaluated. Finally, in the fifth and last stage, everything related to commercial information about manufacturing and obtaining fibers as reinforcement material for concrete will be mentioned.

RESULTS AND DISCUSSIONS

In the concrete's the most important mechanical properties are compressive strength, Young Modulus, Poisson's Modulus, shrinkage, creep (or yield), tensile strength, and shear strength. However, the value of each property may differ depending on the type of concrete made and the material chosen for its reinforcement since we know that simple concrete has a low tensile strength (tension) and high brittleness (McCormac et al., 2011).

Improvement of concrete with the help of new fibrous compounds

In traditional construction, the materials used in the manufacture of concrete have been of significant development for the improvement, generating new alternatives that guarantee an ideal concrete addressing the requirements given by the regulations governed in each country.

In the 1950s, numerous research works were carried out on concrete reinforced with steel fibers (metal fibers are made of steel in their variants with low or medium carbon content, stainless steel, and galvanized steel) (Fernandez et al., 2003). In the 1970s, in Spain, the use of fiber-reinforced concrete was expanded, leading to its use in industrial-type pavements, port containers, lining for tunnels, and prefabricated elements (Ortiz et al., 2015).

From the technological point of view, synthetic fibers have a great place in different engineering applications, and also a high Young Modulus and high tensile strength. In addition, the low weight and cracking control in concrete and mortar is remarkable (Ortiz et al., 2015). With each of the characters who contributed to the discovery of what we know today as reinforced concrete, also can take another step toward the demands that our environment require (safety and social welfare). For this reason, knowing the background of the development of one of the compounds that have led in the course of history to the development of great civilizations and that with the help of new materials, and then overcome these demands. This first stage contributes to increasing the curiosity of the next generations that will dedicate themselves to the construction world, allowing them to advance and project with new challenges in engineering and visualize the different tools and benefits that they can have in the environment that surrounds them, it is that is, take advantage of the resources that are at hand, to find solutions to existing problems (use of materials that can be incorporated into concrete and used as reinforcement material).

Regulations required to guarantee fibers as reinforcing material in concrete

The use of fibers in the different fields of engineering in construction works has come to think of establishing guidelines to obtain better use of these elements in the behavior of concrete. For this reason, for the second stage, it is important to highlight and make known The Colombian Technical Standard NTC-5541, "Fiber-Reinforced Concrete", it is important to highlight the participation of different entities that participated in the Concrete, Mortar, Aggregate and Fruit Technical Committee. NTC-5541. This standard applies to all forms of fiber-reinforced concrete, whose aggregates must be uniformly mixed and which can be sampled and tested in situ. However, it is noteworthy that it does not include the placement, consolidation, curing, or protection of fiber-reinforced concrete (ICONTEC, 2007).

The Colombian Technical Standards (NTC) were considered because guarantee a better process and determination of tests for these materials used as reinforcement in concrete (ICONTEC, 2007):

- NTC 385, Civil engineering and architecture. Terminology related to concrete and its aggregates.
- NTC 396, Civil engineering and architecture. Test method to determine the settlement of concrete.
- NTC 454, Civil engineering and architecture. Concrete. Sampling fresh concrete.
- NTC 550, Concrete. Preparation and curing of concrete specimens on site.
- NTC 673, Concrete. Test of resistance to compression of normal concrete cylinders.
- NTC 1028, Civil engineering and architecture. Determination of air content in fresh concrete. Volumetric method.
- NTC 1032, Civil engineering and architecture. Test method for the determination of air content in fresh concrete pressure method.
- NTC 1377, Civil engineering and architecture. Preparation and curing of concrete specimens for laboratory tests.
- NTC 1513, Civil engineering and architecture. Test method for the manufacture, accelerated curing and compression testing of concrete specimens.
- NTC 1926, Concrete. Test method to determine the density (unit mass), yield and air content by gravimetry of concrete.
- NTC 3318, Concrete production.
- NTC 3658, Civil engineering and architecture. Method for obtaining and testing extracted cores and sawn concrete beams.
- NTC 4022, Civil engineering and architecture. Structural lightweight concrete unit mass.
- NTC 4027, Civil engineering and architecture. Concrete made by volumetric batching and continuous mixing.

Considering the guidelines of the use of a material in the face of a structural request, it is important to be clear about each variable that can intervene and how it should be analyzed for its application. These standards are one of the criteria that fibers must meet to be used as reinforcement material, where they must reach some contribution to be able to be implemented and considered a reinforcement material.

Behavior of fibers (metallic, natural (sugar cane bagasse), synthetic and glass) when incorporated into concrete

For the third stage, the characteristics and behaviors of the fiber when incorporated into the concrete are detailed. Fibers are commonly used as concrete reinforcement using various materials, generally classified as metallic, synthetic, glass, and natural fibers. Adding fibers is not a new technique in the construction world. In the past, materials such as grass, thread, rod, and even animal hair were used, which were added to the adobe to prevent cracking and improve strain resistance (Antillón et al., 2016).

Fibers are also added to reduce settlement and plastic shrinkage cracking, decrease permeability, and increase abrasion and impact resistance. However, the characteristics of the properties and the behavior of the concrete when adding fibers depend greatly on factors such as the geometry of the fibers, their distribution, and density in the concrete mass (Antillón et al., 2016). The metallic fiber consists of strands of steel wire, deformed and cut that are added to the concrete in order to improve its properties. Commonly these fibers are manufactured based on the stretching and cutting of steel wires with typical diameters ranging from 0.25 to 0.76 mm (See Figure 1).

Figure 1. Commercial metallic fibers. Source: Moya et al., 2019.

The most efficient metallic fibers are those with flared ends from 0.15 to 0.30 mm thick by 0.20 to 0.60 mm wide because they provide greater adherence, homogeneity, and workability to the mixture. However, its application in concrete will depend on the structural service the element will fulfill, in which the static and dynamic tensile strength, energy absorption, toughness, and fatigue resistance should be used in most cases (Moya et al., 2019). When cracks occur in the section, the fibers work as a seam, thus increasing the energy absorption capacity (See Figure 3). In addition, this behavior generates that the fibers increase their resistance to adhesion and can act in part as a transverse reinforcement (Caballero et al., 2017).

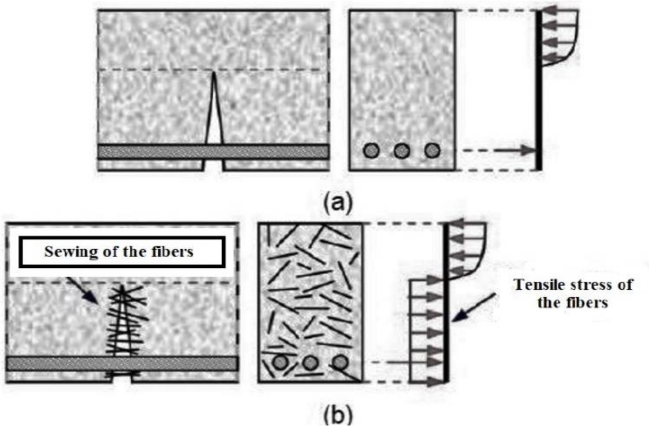

Figure 2. Control of cracking with metallic fibers in concrete. Source: Caballero et al., 2017.

In the case of natural fibers such as sugar cane bagasse, which is very common in different parts of the world and various regions of the Colombian country, as is the case of mills. This fiber, when added to the concrete, has generated in its mechanical properties reductions in density concerning the average density of the concrete (~2100 kg/m^3), which decreases its weight and must be considered in the dead loads due to its weight in the structures (Osorio et al., 2007).

Figure 3. Concrete samples with different percentages of sugarcane bagasse fiber. Source: Hernandez, 2008.

Regarding the compressive strength, this property is affected by the increase in the content of sugar cane gabazo fibers in percentages less than 1.0%, finding optimum values between 0.5 and 0.75%, which reported gains of up to 6.0% of compression resistance in fibers of 1.0 in of length. In the opposite case, when the fiber percentages are greater than 1.0%, the compressive strength is reduced, up to 50% in the case of percentages of 2.0% of added fiber (Narváez et al., 2017).

Synthetic fibers are made from acrylics, carbon, nylon, polyester, polyethylene, and polypropylene. In general, synthetic fibers are characterized by high tensile strength; among them, two categories are defined: high and low Young Modulus (Mendoza et al., 2011). Furthermore, due to their functionality, synthetic fibers are classified into microfibers and macrofibers. The former is regularly used to control plastic shrinkage cracking and does not add structural capacity to concrete. At the same time, the latter aid to control cracks due to temperature, as well as to improve the post-cracking performance of concrete elements subjected to bending and tension, which allows them to replace the electro-welded mesh and the steel bars (See Figure 4) in a good number of apps (Toxement, 2018).

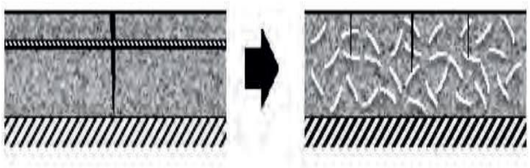

Figure 4. Difference in crack control between conventional reinforcement vs. the addition of synthetic fiber in concrete. Source: Toxement, 2018.

In terms of size, synthetic microfibers have a diameter between 0.02 and 0.05 mm and are regularly offered in lengths from 6 mm to 25.4 bmm. Currently, most microfiber suppliers recommend dosages of 0.6 kg/m^3. Microfibers, on the other hand, are relatively thick, generally available in diameters between 0.5 and 0.7 mm, with typical lengths between 19 and 50 mm (Toxement, 2018). In the case of fiberglass, there are five types of fiber, classified as E, R, D, C, and AR, the one used for its characteristics to reinforce concrete is the AR type, which offers high resistance to alkaline compounds during drying to increase the tensile strength (Arango et al., 2013).

Percentages less than 1.5% of fiber tend to obtain acceptable values in compressive strength but a minor variation regarding tensile strength (Arango Cordoba & Zapata, 2013). The gain in tensile strength as the percentage of added fiber increases not only has an effect on the compressive strength, also its necessary to include the effect on the workability of the resulting mixture, and then is recommended to use lower fiber percentages of around 1.5% (Arango et al., 2013). Another property studied was the Young Modulus, similar to conventional concrete for fiber percentages less than 1.0% glass fiber. Higher percentages tend to have an inappropriate Young Modulus because of the low compressive strength that is obtained as the number of fibers increases (Arango et al., 2013).

The mechanical properties of the concrete can be analyzed to fulfill the fourth stage are the resistance to compression, tension, bending tension, and Young Modulus. The influence of the fibers in the concrete will be compared to a concrete block without adding fiber (conventional). In this way, concrete is the main material used in construction, which is enough to observe the different works found in our country's streets and other countries that handle this material, such as houses, buildings, bridges, pathways, etc. Because the use of concrete, both simple and reinforced, is needed in numerous works, the application of fibers in the production of concrete has been sought to achieve reinforced concrete and improve and optimize its resistance and helpful life (Carrillo et al., 2017).

In Table 1, is shown that the average values of different tests where different percentages of fiber (metallic, synthetic, natural and glass) were used. In order to choose the best results of each of the studies found and determine how much this type of fiber influences, from the dosages incorporated into the concrete. For this analysis, an fc'= 21 MPa was considered, and tested at 28 days of setting.

Table 1: Behavior of concrete according to the percentage of added fiber

FIBER TYPE	Mechanical property	Percentage		Fiber content
		Increase	Reduction	
Metallic	Compression	17.54	-	6% of the aggregate weight
	Strain	42,26	-	6% of the aggregate weight
	Flexion	56,26	-	6% of the aggregate weight
	Young Modulus	7,3	-	1.5% (35 kg) per m^3 of concrete
synthetic	Compression	-	8	0.5% per m^3 of concrete
	Strain	-	4.78	0.5% per m^3 of concrete
	Flexion	22,81	-	0.8% per m^3 of concrete
	Young Modulus	1	-	3 kg/m3 of concrete
Natural (sugar cane bagasse)	Compression	-	14.71	1.50% per m3 of concrete
	Strain	-	1%	3% dry fiber concrete
	Flexion	-	16.87	1.5 per m^3 of concrete
	Young Modulus	-	8.56	0.05% per m^3 of concrete
Glass	Compression	13,84	-	0.05% per m^3 of concrete
	Strain	36,13	-	0.05% per m^3 of concrete
	Flexion	43,83	-	0.05% per m^3 of concrete
	Young Modulus	28,4	-	0.05% per m^3 of concrete

With the information provided by the previous table, their respective analysis is carried out, and the averages of the different percentages are plotted for each property and fiber studied. Figures 5 and 6 show that the fibers with the best performance are metal and glass, surpassing more than 10% improvement in resistance to compression and tension. The rest of the fibers are below, but without being very far from the average value of conventional concrete. Giving as a sample that the fibers manage to improve these properties.

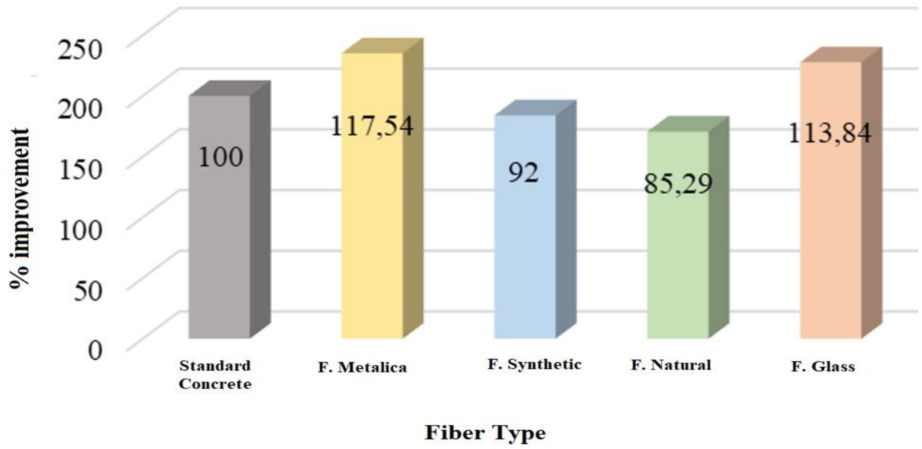

Figure 5. Compressive strength of concrete with fibers Vs. conventional.

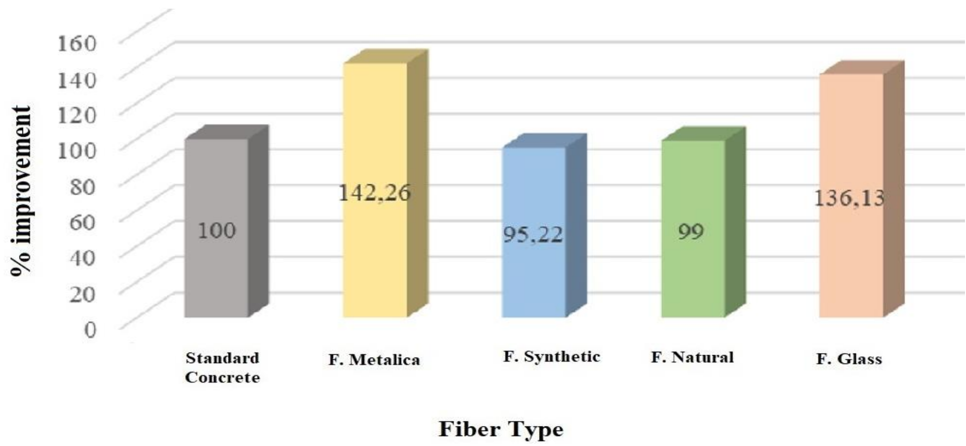

Figure 6. Tensile strength of concrete with fibers Vs. conventional.

In Figure 7, it can be seen that the fibers exceed between 15 to 56% improvement in flexural strength, showing once again that the addition of fibers positively impacts the concrete behavior.

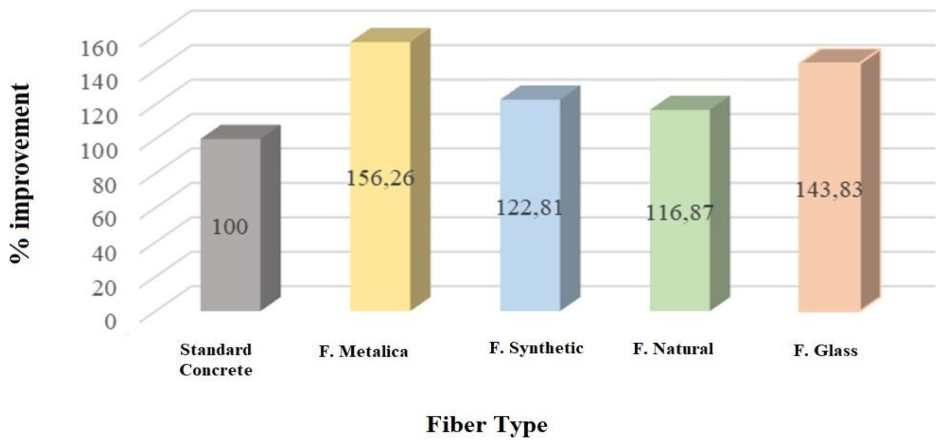

Figure 7. Flexural strength of concrete with fibers vs. conventional.

In Figure 8, it can be seen that the natural fiber does not achieve acceptable behavior to improve the Young Modulus, but it helps increase workability and decreases the element's weight.

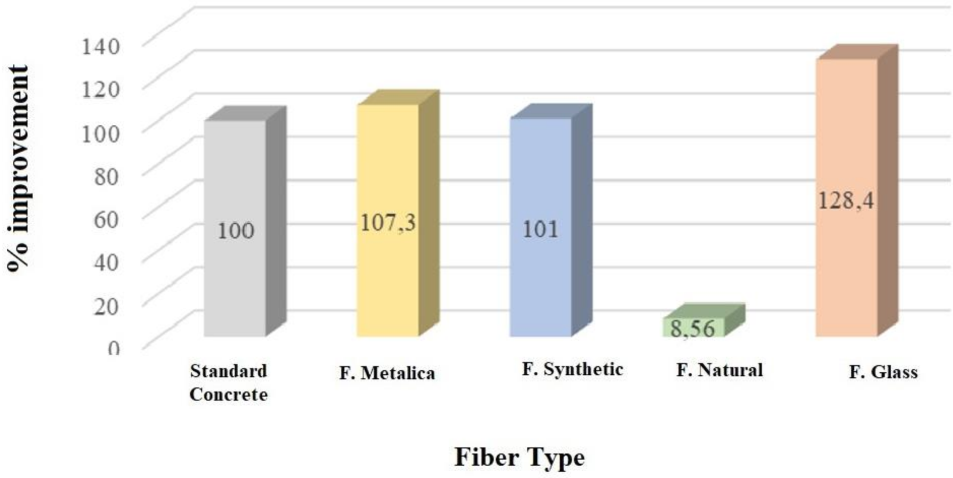

Figure 8. Young Modulus of concrete with fibers vs. conventional.

CONCLUSIONS

Today the world of construction is in constantly changing due to new trends that allow improving the properties of concrete and hoe exhaustive studies of fibers as a new alternative for the development of a country's infrastructure. Also, the recognition of the findings and achievements have been demonstrated to encourage the use and fibers application in the improvement of concrete in the different studies that can be carried out.

The different types of metallic, natural (sugar cane bagasse), synthetic, and glass fibers that have been used to improve concrete allow the concrete particles to remain together at the time of failure without generating detachment and crumbling excessively as concrete without added fibers.

Thanks to these studies of concrete with fibers carried out worldwide, it is possible to take a further step in the evolution of concrete, thus getting closer to a compound that guarantees greater efficiency and contributes to sustainability, and improves the use of our resources.

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