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Improvement of the Mechanical Properties of Concrete for Paving by Adding Interlocking Steel Fibers

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Abstract

This article describes the work carried out to investigate the behavior of concrete by adding interlocking steel fibers in different proportions (0%, 1%, 1.5%, 2% and 2.5%) for rigid pavements, said addition was made in percentage as an addition to the concrete. With an f'c of 280 kg/cm2 for the standard concrete, the tests were carried out to determine its resistance to compression in 28 days, resistance to flexion in 28 days, and resistance to diametral traction in 28 days. It was obtained as results that the optimal percentage for the compression resistance test was 1%, reaching a resistance of 350 kg/cm2 at 28 days, for the flexion test the optimal percentage was 2.5%, the best The value obtained in the tensile test was the addition of 2.5% and finally in the ASTM C944 test it was obtained as a result that the percentage of 2.5% is the best of all where the wear is minimal by 0.010%. The rigid concrete used for concrete paving has a potential use in the construction of road infrastructures and applying the addition of interlocking steel fibers only improves some characteristics of the concrete, such as flexion and traction.

1. Introduction

Concrete is one of the most widely used and versatile materials worldwide due to its mechanical performance both in its fresh and hardened state, which is used within civil engineering for the construction of infrastructure works and buildings, said demand of this material that needs a mixing process is increasing and this is due to the high resistance that this material in a consolidated state can withstand. Said material will always be linked to the technical specifications that are required in works, with which an optimal quality in the concrete can be guaranteed since it must comply with national and international standards such as the RNE, NTP, ASTM, ACI, etc. (Latam Construction, 2019)

Pavements are more than simple structures designed for daily use, they are the source of communication and commerce between towns, cities and countries. Nowadays, pavements are definitely elements of the utmost importance since in them lies an objective that it transcends beyond the social, and they have a structure built on the subgrade of the roads to be able to support and distribute the efforts resulting from heavy or light traffic, its basic constitution is commonly made up of the subbase, base and surface layer. (Choque, 2021)

The objective behind the construction of this type of road infrastructure is generally thinking about providing, safety, quality and the useful life that can be obtained from the construction. Be safe, so that car accidents are the product of human error while driving and not due to the shape or type of pavement used, quality, this means that they must have an optimal cost-benefit ratio, taking into account constant maintenance that, although for In hydraulic concrete paving, maintenance is little is important since it could extend its use time even more, and finally the useful life, the duration in which this type of paving can be used is estimated that

with a correct installation and adequate maintenance can reach 25 years in Mexico, 30 or 40 in the US and approximately 50 years in Europe.(Concreplus, 24)

There are different types of pavements worldwide that, according to some factors such as exposure to the weather, traffic, the speed of light or heavy traffic vehicles, are used, the elements that differentiate one type of pavement from the other are ultimately the properties that they can provide once built, such as their characteristics, their elasticity, the capacity they have against deformation, these differences will be linked to each of their different structures and the materials used for their construction, the types are : rigid pavements, flexible pavements, semi-rigid pavements and articulated pavements. (Lees, 2021)

Rigid pavements or also known as hydraulic concrete pavements have certain advantages over flexible pavements, some of these are that their cost within the construction process is reduced, since they are made of concrete and this is a material that mixes its components. First, it has a manageable consistency, makes its construction process simple, lowering costs also in its maintenance processes, which is why this type of pavement is one of the favorites applied worldwide, both for streets and highways. (Concreplus, 24)

These pavings are characterized by being composed of Portland cement concrete slabs, which can be supported directly on the ground or through base layers or subbases in multilayer solutions. The main advantage of rigid pavements is their ability to efficiently distribute loads on the ground, thus reducing point loads and increasing the useful life of the track. The number of layers and the thickness of this type of paving will depend on the traffic and the type of soil on which it is built. It is important to take into account that the construction of rigid pavements must be carried out by experts in the field, since poor construction can have serious consequences on the safety and durability of the road. In addition, it is necessary to carry out a previous study of the land to determine the characteristics of the soil and thus be able to design an adequate solution to the needs of the project. (Pacasmayo, 2021)

Steel fibers are a material widely used specifically in industrial construction and infrastructure, this is because this is a derivative of steel, and can provide or be a great solution for the addition in the construction of industrial floors, tunnels, highways and pavements. (Deacero, 2022)

As a concept, steel fiber serves as a reinforcement in constructions, and has a little more than a century of its existence since its addition to concrete helps improve ductibility and strength; the development and introduction of new tools within concrete pavements are linked to increasingly demanding quality controls, as well as to the strict tests that are carried out on the pavements in order to obtain the values of what is known as the "Service Limit State" and the "Limit State of Breakage", Both calculations serve to understand the maximum state of use that can be given to the construction of a paving; Some of the advantages of the addition of this material is to obtain a greater adhesion between what would be the steel fiber and the concrete, a high value of tensile strength quality that is usually low when testing the concrete without any type of addition but changes when this type of additions are added, As well as it also has the advantage of providing the concrete with a uniform and multidirectional reinforcement without counting that it is also responsible for avoiding the appearance of cracks until the concrete manages to reach the hardened state. (Deacero, 2022)

In Peru, the rigid pavements built at the national level that are registered in the road networks of the country do not last even half the estimated time due to chemical agents such as sulfates and chlorides which weaken the tread layer of this type of paving deteriorating this type of infrastructure. Considering the above, this research aims to add the fibers of interlined steel in order to increase the durability of this type of infrastructure.

It is for this reason mentioned that it is important to evaluate what are all the improvements that can be found in the concrete used for paving purposes when this type of additions are added that help the behavior of concrete in areas where normally due to its characteristics and composition it tends to fail, evaluating if its addition is really important or if it does not bring enough positive results to the concrete and only become more expensive. costs. It should also be emphasized

2. Materials and Methods

This article will present a detailed description of the materials and methods used for the correct execution of the concrete to be tested in the study. All the corresponding standards for the filling of the molds were followed, thus guaranteeing the accuracy of the results obtained.

2.1. Materials Used for Concrete Mix Cement

The cement used for the evaluation of the proposed mechanical properties was of the MS type, this type of cement, has the ability to protect concrete from saltpeter and steels from corrosion, which makes it optimal for use in hot climates, since it also has the characteristic to reduce possible deformations, in addition this type of cemente complies with NTP 334.082. (Pacasmayo, 2023)

Fig. 1 *MS cement andcement for the production of concrete with an f'c of 280 kg/cm2*

Agregados

In this case the aggregates used for the preparation of the concrete were tested by the standards NTP 400.012, NTP 400.017, NTP 400.022, NTP 400.021, among others, in order to later with these data calculate a mixing design with the required f'c, also both fine and coarse aggregates were obtained from the Quarry "Tres Tomas" belonging to the department of Lambayeque – Peru.

In summary, the tests carried out for both the fine aggregate and the coarse aggregate confirmed the quality of the materials and their suitability for use in construction, for which the following table is attached with the results:

Table 1 *Table of results or results of the tests carried out on the aggregates used*

AGGREGATE DATA:	AG	*OF*
01.- Nominal maximum size	3/4"	-
02.- Dry loose unit weight	1364	1560
03.- Dry compacted unit weight	1557	1837
04.- Specific weight of dry mass	2798	2665
05.- Moisture content	0.32	2.73
06.- Absorption content	0.94	1.14
07.- Fineness module (dimensionless)	6.97	2.87

Below are some photos where you can see the procedure that was performed:

Fig. 2 *(a) Granulometry performed for fine aggregates, (b) granulometry performed for coarse aggregates*

Wire Fibers

Wire cutting steel fibers are a material used as an addition to concrete with the reason of increasing the resistance values and improving the durability values of this type of material, they have a special physical

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characteristic and defined characteristic lengths, also used to generate a three-dimensional reinforcement providing ductility to concrete (Deacero, 2022) , for the addition of fibers in this research it was decided to use the addition of steel fibers of the brand SikaFiber® CHO 80/60 NB, which come in paper bags with a weight of 20kg, and have a length of 60 mm with deformed ends and a diameter of 0.75 mm, which as referred to in its technical sheet has a length / diameter ratio of 80, as an additional feature to this fiber is that it has a tensile strength of 1200 Mpa min. (Sika, 2021)

The advantages present in the choice of this type of fibers are that their use would increase the resistance of the concrete to impact, fatigue and cracking.

Fig. 3 *(a) Wire fibres; (b) Sika Fiber bag CHO 80/60 NB*

F'c Design

The design of concrete mixes is a crucial task in the construction of any concrete structure. To achieve optimal mixing, several factors must be considered, such as the desired compressive strength value (f'c) and the consistency of the mixture (Slump). In this case, the ACI 211.1 method, widely used in industry, was used to achieve a minimum strength of 280 kg/cm2. In addition, a 3" Slump was chosen because the structure to be built was a paving. It is important to note that the design process must be adjusted according to the specific needs of each project and consider other factors, such as the water-cement ratio, the amount and type of aggregates, and the addition of additives.

Table 2 *Mixture Design parat f'c 280 kg/cm2*

DESCRIPTION	***CEMENT (KG/M3)***	***WATER (LITERS)***	***A. UP (KG/M3)***	***A. THICK (KG/M3)***
BOSS	525	266	707	841

Table 3 *Table of settlements (Slump) according to the type of Structure*

TYPE OF STRUCTURE	SLUMP	
	MAXIMUM	MINIMUM
1. Reinforced footings and foundation walls	3''	1''
2. Simple foundations and fittings	3''	1''
3. Reinforced beams and walls	4''	1''
4. Columns	4''	1''
5. Walls and Pavements	3''	1''
6. Cyclopean Concrete	2''	1''

2.1. Mixing Design and Sample Preparation Process to Be Tested

The design of mixture carried out had a design f'c of 280 kg / cm2, and all the corresponding procedure was followed for the elaboration of each of the specimens to be tested in total for the resistance test a total of 12 specimens were obtained for each of the proposed percentages (0%, 1%, 1.5%, 2% and 2.5%); for the bending

test, 3 specimens were obtained for each proposed percentage (0%, 1%, 1.5%, 2% and 2.5%), and finally 3 specimens were obtained for the diametrical tensile test for each proposed percentage (0%, 1%, 1.5%, 2% and 2.5%); making a total of 90 specimens tested.

For the preparation of the concrete after carrying out the process of mixing design to obtain an f'c of 280 kg / cm2, a mixer, buckets (to place properly weighed aggregates, water and fibers), a balance, a steel rod, rubber hammer, etc. were used.

Likewise, a Slump test was carried out on the concrete to corroborate that it had a Slump of 3 '', which is the Slump that all the concrete elaborated for paving purposes within Peru must meet.

It should also be noted that NTP 339.183 was respected for the curing process and preparation of specimens.

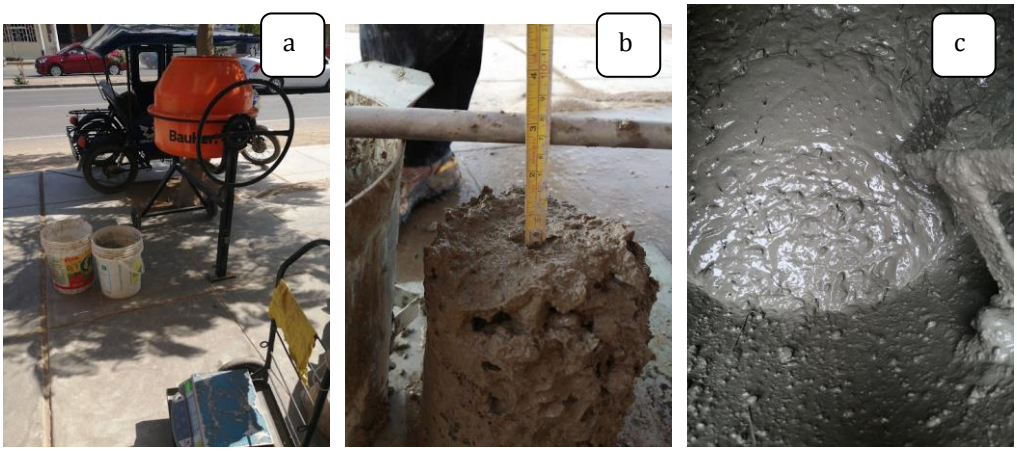

Fig. 4 *(a) Elements used for concrete preparation, (b) Slump measurement, (c) Concrete mixed with fiber additions*

2.2. Tests Carried Out

The following tests were carried out to obtain which are the mechanical characteristics following the provisions of each of the standards, and the percentages established were (1%, 1.5%, 2% and 2.5%).

For the NTP 339.034 test, specimens with dimensions of 102 x 203 mm were used, and a total of 60 und.

Fig. 5 *Emptying specimens NTP 339.034*

For the NTP 339.078 test, specimens of dimensions of 15 * 15 * 50cm were used for this method, and a total of 15 und was performed.

Fig. 6 *Beams emptying NTP 339.078*

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For the NTP 339.084 test, specimens with dimensions of 152 x 305mm were used in this method, and a total of 15 und.

Fig. 7 *Filling of test specimens for testing NTP 339.084*

For the ASTM C944 test, specimens with dimensions of 5x10 cm were used in this method.

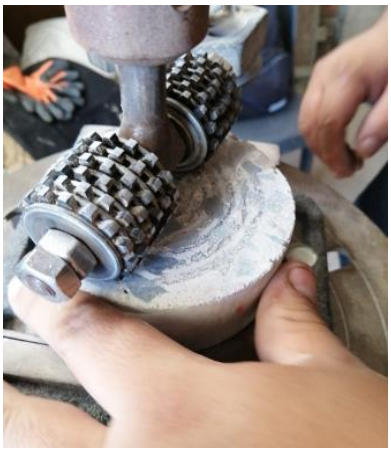

Fig. 8 *Specimens being tested for this method*

3. Results and Discussion

3.1. Resistance to Comprehension Test

In table 4, where a summary of the results found is placed, it can be seen how the best percentage of addition to concrete is 1% where the result at 28 days is 350 kg / cm2, where it can be deduced that while the percentages of addition increase the lower resistance of a specimen when it is subjected to this test.

Table 4 *Results of the Resistance Test*

Description	*Age (days)*	*F'c (kg/cm2)*
0% (Pattern)	7	275
	14	303
	21	316
	28	325
1%	7	295
	14	320

	21	339
	28	350
1.5%	7	247
	14	295
	21	313
	28	331
2%	7	210
	14	264
	21	282
	28	300
2.5%	7	221
	14	253
	21	286
	28	304

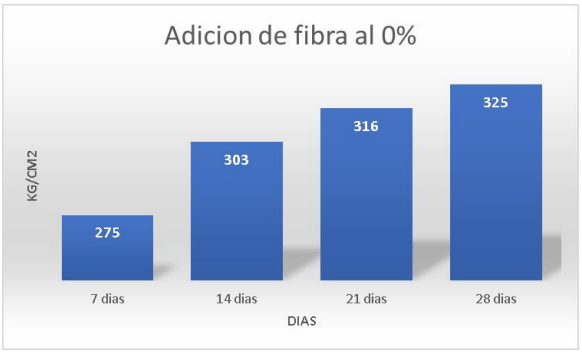

Fig. 9 *Graph of the values obtained by 0% resistance*

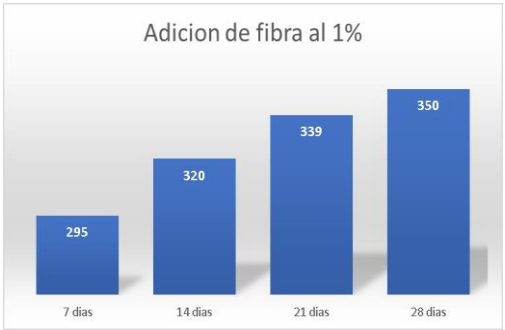

Fig. 10 *Graph of the values obtained by 1% Resistance*

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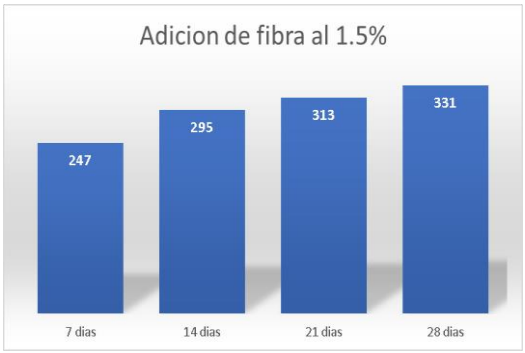

Fig. 11 *Graph of the values obtained by Resistance to 1.5%*

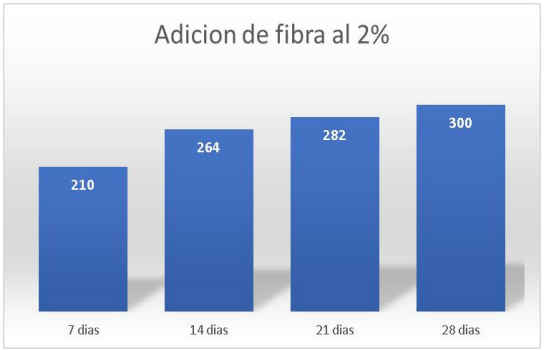

Fig. 12 *Graph of the values obtained by 2% Resistance*

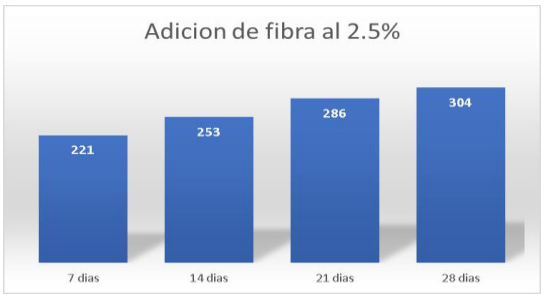

Fig. 13 *Graph of the values obtained by 2.5% resistance*

3.2. Bending Strength Test

In table 5, where a summary of the results found is placed, it can be seen how the best percentage of addition to concrete is 2.5% where the result at 28 days is 112 kg / cm2 compared to concrete without addition whose result was 41 kg / cm2, where it can be deduced that while the percentages of addition increase the lower flexural strength of a specimen when It undergoes this test.

Table 5 *Results of the Bending Test*

		Results in Kg/cm2		
AGE 28 (days)	Addition of fiber to 0%	40	35	41
	Addition of fiber to 1%	43	40	41
	Addition of fiber at 1.5%	46	60	43
	Addition of fiber at 2%	66	64	78
	Addition of fiber at 2.5%	100	112	99

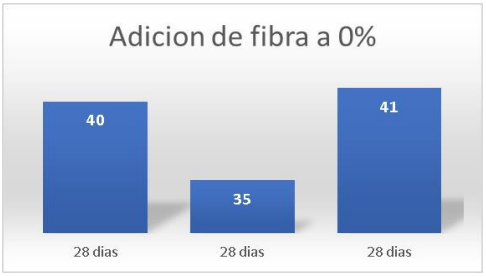

Fig. 14 *Graph of the values obtained by 0% bending*

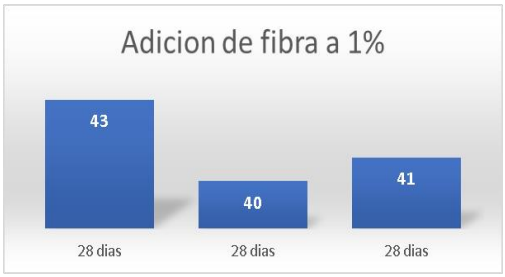

Fig. 15 *Graph of the values obtained by 1% flexion*

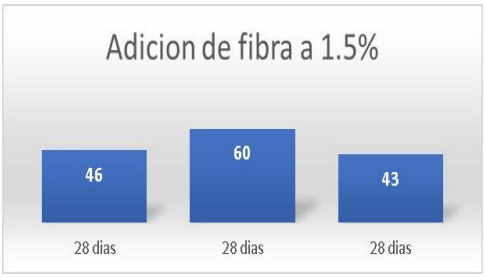

Fig. 16 *Graph of the values obtained by Flexion at 1.5%*

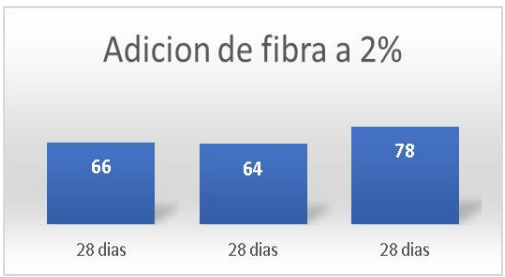

Fig. 17 *Graph of the values obtained by 2% flexion*

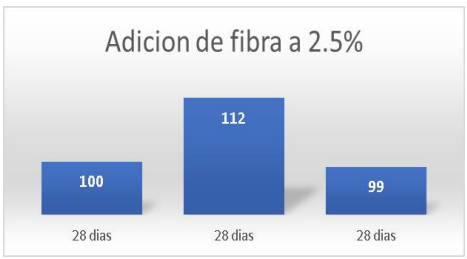

Fig. 18 *Graph of the values obtained by 2.5% flexion*

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3.3. Tensile Strength Test

In table 6, where a summary of the results found is placed, it can be seen how the best percentage of addition to concrete is 2.5% where the result at 28 days is 146 kg / cm2 compared to concrete without addition whose result was 104 kg / cm2, where it can be deduced that while the percentages of addition increase the lower tensile strength of a specimen when It undergoes this test.

Table 6 *Results of the Diametral Tensile Strength test*

Percentage of Addition	*DAYS*	*F'C*
0%	28	104
	28	103
	28	102
1%	28	105
	28	112
	28	104
1.5%	28	131
	28	108
	28	119
2%	28	130
	28	129
	28	128
2.5%	28	135
	28	123
	28	146

3.4. Abrasion Resistance:

In table 7, where a summary of the results found is placed, it can be seen how the best percentage of addition to concrete is 2.5% where the result at 28 days by abrasion gives us a wear of 0.010% compared to concrete without addition which gave a total wear of 0.057%, Therefore, when the addition to concrete increases the abrasion values decrease.

Table 7 *Results for Concrete Abrasion*

Description	*%*
0% (Pattern Concrete)	0.057
1% Addition	0.039
1.50% Addition	0.019
2% Addition	0.013
2.50% Addition	0.010

4. Conclusion

In conclusion, after evaluating the percentages of 0%, 1%, 1.5%, 2% and 2.5% in terms of resistance, it has been determined that the percentage of 1% is the one that yielded the best results in this trial. It has been observed that, by increasing the amount of fiber in concrete, the workability of this decreases, which hinders its filling process. It is possible that the poor results obtained in the highest percentages are due to the fact that an excess of fibers can generate voids in the concrete, which decreases its resistance. It is important to consider these results when designing and building fiber-reinforced concrete infrastructures, as the right amount of fiber can significantly improve the strength of the material, while an excess can have negative effects.

Bending strength tests were performed on concrete with different percentages of interlined steel fibers. The percentages evaluated were 0%, 1%, 1.5%, 2% and 2.5%. The results obtained indicate that the percentage of 2.5% was the one that presented the best results in this type of trials. In conclusion, it can be stated that the

incorporation of wire cutting steel fibers in concrete can be an excellent option to improve its flexural strength, which can have important benefits in the construction of structures that require high mechanical strength.

In the present study, different percentages of interlined steel fibers in concrete were evaluated by diametrical tensile strength test. The percentages evaluated were 0%, 1%, 1.5%, 2% and 2.5%. The results obtained showed that the percentage of 2.5% was the one that yielded the best results in this type of trial. This allows us to conclude that the edged steel fibers do provide the concrete with an improvement in its diametrical tensile strength, reinforcing it in a three-dimensional way. It is important to note that this type of test is relevant in the evaluation of the resistance of concrete to compression and tensile forces, so the results obtained are significant in terms of the quality of the material.

The results by abrasion were obtained that the best percentage that acts is 2.5% making the concrete to be tested present less loose particles in each round evaluated with a total of 0.010% of total wear.

In summary, it can be said that the incorporation of interlined steel fibers in concrete is an effective alternative to improve its strength and durability, which can have important benefits in the construction of structures and civil works. It is necessary to continue researching in this area to continue improving the properties of concrete and ensure its optimal performance in different conditions and applications.

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