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Authors: Fernando Edilberto Sandoval-Siesquen and Sócrates Pedro Muñoz-Pérez

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Effects of the incorporation of steel fibers with plasticizer additive in concrete
Efectos de la incorporación de fibras de acero con aditivo plastificante en el hormigón

Fernando Edilberto Sandoval-Siesquen[1] https://orcid.org/0000-0002-1393-2267 Sócrates Pedro Muñoz-Pérez [1*] https://orcid.org/0000-0003-3182-8735

[1]Facultad de Arquitectura, Ingeniería y Urbanismo, Universidad Señor de Sipán. Campus Universitario, km. 5 Carrera a Pimentel. Pimentel, Perú

Corresponding author: Sócrates Pedro Muñoz-Pérez
E-mail: msocrates@crece.uss.edu.pe

KEYWORDS
Concrete, mechanical properties, steel fibers, plasticizer additive.
Hormigón, propiedades mecánicas, fibras de acero, aditivo plastificante.

ABSTRACT: The objective of this study is to evaluate the effect of the incorporation of steel fibers at 1%, 2%, 3%, and 4%, as a function of concrete volume plus 1% plasticizing additive as a function of cement weight for control designs of resistance 210 kg/cm² and 280 kg/cm², on compressive strength, tensile strength, flexural strength, and modulus of elasticity. Steel fibers with a length of 60 mm type KF 80/60 CH were used. The addition of the steel fiber did not significantly reduce the workability; however, the temperature showed a reduction with respect to the standard concrete specimen. The results showed that for the 210 kg/cm² and 280 kg/cm² concrete control designs, the optimum proportions were 2% and 4% of steel fibers, which increased the compressive strength, tensile strength, and modulus of elasticity by 14.76%, 14.93% and 1.63% for the 210 kg/cm² strength control design and for the 280 kg/cm² strength control design increased by 16.29%, 16.95% and 13.75% with respect to the standard concrete strength. The results of this study show that steel fibers with a specific dosage of superplasticizer can be used for structural and non-structural concrete, being significantly influential in improving mechanical properties.

RESUMEN: El objetivo de este estudio es evaluar el efecto de la incorporación de fibras de acero al 1%, 2%, 3% y 4%, en función al volumen del hormigón más 1% de aditivo plastificante en función al peso del cemento para diseños control de resistencia 210 kg/cm² y 280 kg/cm², sobre la resistencia a la compresión, tracción, flexión y módulo de elasticidad. Se utilizó fibras de acero con una longitud de 60 mm tipo KF 80/60 CH. La adición de la fibra de acero no redujo significantemente la trabajabilidad; sin embargo, la temperatura mostró una reducción respecto la muestra de concreto estándar. Los resultados mostraron que para los diseños control de hormigón 210 kg/cm² y 280 kg/cm² las proporciones optimas fueron de 2% y 4% de fibras de acero, donde incrementó la resistencia a la compresión, tracción y módulo de elasticidad en 14.76%, 14.93% y 1.63% para el diseño control de resistencia 210 kg/cm² y

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para el diseño de control de resistencia 280 kg/cm² incrementó en 16.29%, 16.95% y 13.75% respecto a la resistencia del concreto estándar. Los resultados de este estudio muestran que las fibras de acero con una dosis específica de superplastificante pueden utilizarse para concretos estructurales y no estructurales, siendo significativamente influyente en la mejora de las propiedades mecánicas.

1. Introduction

Nowadays, concrete structures are increasingly incorporating alternative construction materials [1], [2]; with the aim of having technological advances to achieve low-cost materials that provide better mechanical properties. Concrete exhibits vulnerability in tensile scenarios but demonstrates strength under compression, often resulting in brittle failure. This is unacceptable for any material used in construction. Therefore, methods are necessity for methods to enhance its capacity to endure stresses and fortify its resistance against stresses[3]. The integration of fibers stands out among the prevailing techniques for achieving this goal,. These fibers play a crucial role in preventing crack formation and enhancing the concrete's energy absorption capabilities. The reinforcement of cement-based materials with discrete steel fibers is now a common practice for various applications, including industrial floors, tunnel linings, precast elements, and hydraulic structures. Consequently, the majority of studies focus on evaluating the mechanical performance of fiber-reinforced concrete [4], [5], [6].

Tests such as the slump play a crucial role in assessing the workability of concrete across various proportions of steel fiber, especially when combined with plasticizing admixtures, to achieve a minimum design strength. Additionally, the scarcity of current scientific information on other properties, such as temperature and unit weight, highlights the need for further research to comprehensively understand the behavior of fiber-reinforced concrete. Moreover, adding steel fibers to concrete in combination with a plasticizing admixture improves workability when they do not exceed a dosage of 90 kg/m3, thereby reducing concrete cracking [7]. In terms of mechanical properties, it has been observed that the addition of steel fibers to concrete mix induces a confinement effect. This effect is evident as the percentage of steel fiber dosage increases, leading to a reduction in the Poisson's ratio within the mix[8], other mechanical tests, such as compressive strength, andflexural strength had positive effects with dosages of 0.3%, 0.5%, 0.8%, 1%, 2% 3% of steel fibers, since they slightly increase the resistance against tensile stresses [9], [10], [11]; [12], [13], [14]. This is because the minimum regulatory parameters according to ACI 318S-14 were used [15]. On the other hand, higher strength capacity also depends on the characteristics of the steel fiber, such as its length, diameter, and the dosage of steel fiber that is incorporated into the concrete mix [16].

Hence, due to the limited availability of literature on the engineering properties of commercial steel fiber-reinforced cement composites produced in Peru, this study aims to contribute additional insights. Specifically, it focuses on the effects of incorporating varying doses of steel fiber combined with superplasticizers in structural concrete mixtures. The study investigates their impact on slump, temperature, compressive strength, flexural strength, and modulus of elasticity tests conducted at 7, 14, and 28 days, respectively.

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2. Experimental program

2.1.Materials

Table 1 shows the materials used to design of the standard mix and the mixes with steel fibers. The materials used are shown in Figure 1.

Table 1 Materials for the development of the mix design.

Materials for the preparation of the mixture	
Cement	Type I Portland cement was used.
Water	Potable water was used from the laboratory supply of materials.
Aggregates	The aggregates are a set of stone particles (natural or artificial), which are elaborated or treated, and their dimensions must follow the parameters mentioned by NTP 400.011 [17]. For the selection of the aggregates, a study of quarries was carried out using as fine aggregate (coarse sand) from the La Victoria – Pátapo Quarry and coarse aggregate (½" crushed and/or milled) from the Tres Tomas – Ferreñafe quarry.
Steel fibers	Steel fibers (SF) provide better corrosion resistance in uncracked elements, even, when the structural elements are exposed to salt water [11]. KF 80/60 CH steel fiber of 60 mm length was used, as it is the most used for reinforced concrete structures (slabs, etc.), as shown in Table 2.
Additive	The plasticizing admixture gives the concrete greater workability without modifying its properties during application and without modifying its characteristics in the hardened state [18].

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Figure 1 Materials for the elaboration of the mix design.

Table 2 Properties of steel fiber

Fiber type	Length (mm)	Diameter (mm)	Tensile strength (kg/cm^2)
Steel	60	0.50	815.77

2.2. Specimen preparation

The study is an experimental type of research carried out in the laboratory. Two standard mixes were made with a design strength of 210 kg/cm² and 280 kg/cm² with proportions of cement, sand, gravel, and a water/cement ratio (w/c) according to the mix designs made in the laboratory under the ACI 211.1 standard, obtaining the results presented in Table 3.

In the first stage, the materials such as cement, water, and aggregates were mixed in such a way that the amount of water would give the mixture easy handling at the time of mixing, pouring, and demolding, as well as an optimum resistance, always keeping constant the humidity in each of these elements. A control mix design without plasticizer additives was developed.

In the second stage, cement, water, aggregates, steel fibers 1.0%, 2.0%, 3.0%, and 4. 0% based on the volume of concrete, according to ASTM C1116 [19], and a plasticizing additive was added at a dosage of 1.0%, with respect to the weight of cement in order to improve the workability of the concrete; since significant amounts of steel fiber are used to avoid a lack of workability in fresh concrete, following the recommendations [7]. The study considered 1% plasticizers due to the technical specifications that the additive has in order to create a workable mixture. Finally, obtaining a workable concrete with a good

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final appearance, since the additive not only helps in the fresh concrete but also in the hardened concrete, for strengths of f'c=210 kg/cm² and f'c=280 kg/cm².

Table 3 Proportions of each experimental mix design.

Mix design	Cement (kg/m^3)	Water (Lts)	w/c	FA (kg/m^3)	CA (kg/m^3)	SF (kg/m^3)	Plasticizer (kg/m^3)
SC f'c=210	412	261	0.63	645	920	Control	0
SC f'c=210+1%SF	414	262	0.63	642	920	22.4	3.76
SC f'c=210+2%SF	414	262	0.63	642	920	44.8	3.76
SC f'c=210+3%SF	414	262	0.63	642	920	67.2	3.76
SC f'c=210+4%SF	414	262	0.63	642	920	89.6	3.76
SC f'c=280	546	276	0.51	643	780	Control	0
SC f'c=280+1%SF	551	278	0.51	635	780	22.5	5.01
SC f'c=280+2%SF	551	278	0.51	635	780	44.9	5.01
SC f'c=280+3%SF	551	278	0.51	635	780	67.4	5.01
SC f'c=280+4%SF	551	278	0.51	635	780	89.8	5.01

*SC: Standard concrete; FA: Fine aggregate; CA: Coarse aggregate.

The selection of the percentages of steel fibers was defined according to the research carried out, which provided the best results in the studies with steel fibers, as shown [13], [20]. For the preparation of the specimens, the amounts of aggregates, cement, and water were uniformly mixed for the standard concrete. For the composite concrete, steel fibers and the plasticizing admixture were added with the previously mentioned dosages, with the use of an electric mixer for 6 minutes for each experimental mixture.

With the homogeneous mixture, the cylindrical molds with dimensions of 15 cm diameter x 30 cm height the prismatic mold with dimensions of 50 cm length x 15 cm length x 15 cm height were then filled into three layers, compacting each layer with a 5/8" steel rod (25 strokes per layer), leveling the specimen and applying the appropriate finish, until the surface was completely flat, as shown in Figures 2, 3 and 4. After approximately 24 hours, they were demolded, and entered a curing process at 7, 14, and 28 days, in accordance with ASTM C31 [21]. Three specimens were prepared for each experimental design, obtaining a total of 210 prepared specimens. Figure 5 presents the following process flow diagram, displaying the procedure to conduct the research and obtain the results.

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Figure 2 Mold for preparation of cylindrical specimens

Figure 3 Cylindrical specimen prepared.

Figure 4 Prepared Rectangular Beam.

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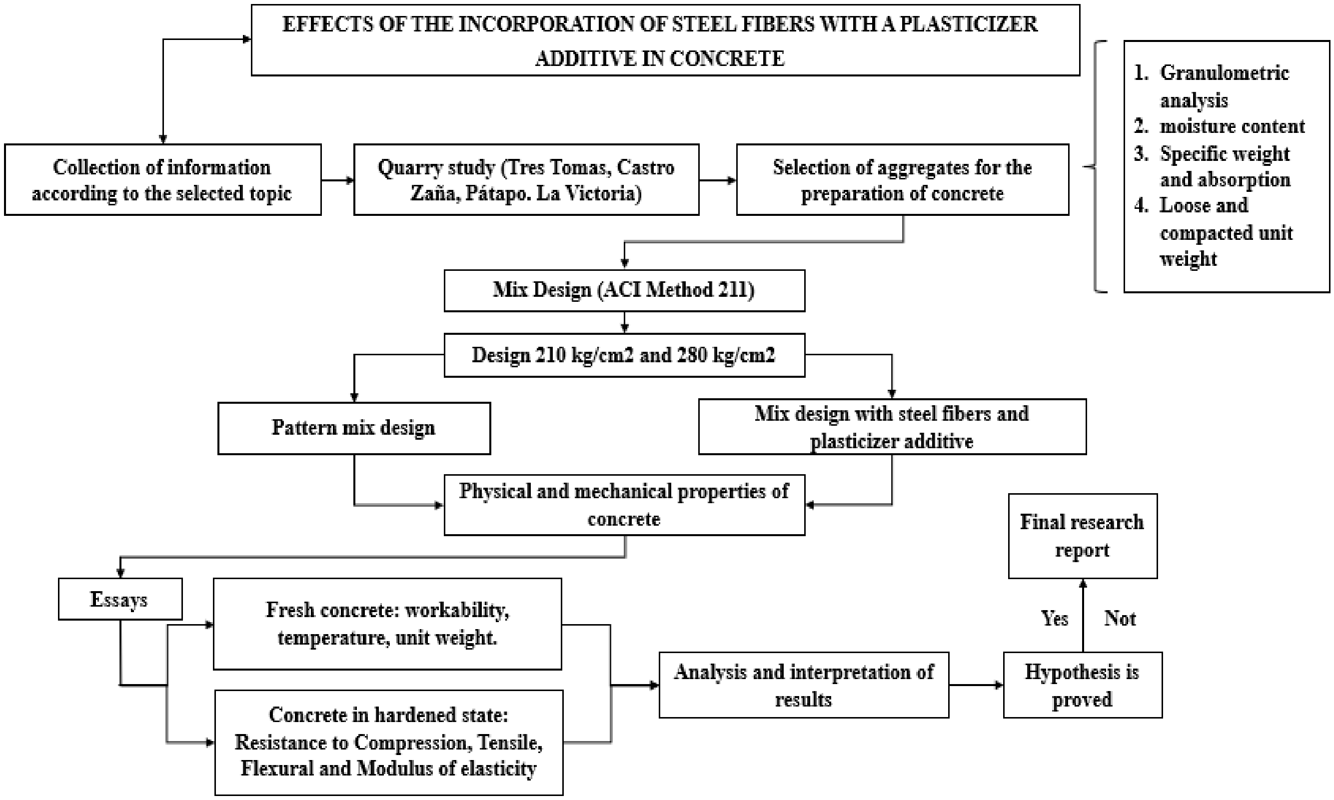

Figure 5 Process flow diagram.

2.3. Mechanical properties of concrete

Tests were carried out to determine the compressive strength, tensile strength, flexural strength, and modulus of elasticity of the concrete according to ASTM C39 standards [22], ASTM C496 [23], ASTM C78 [24], ASTM C469 [25]. The test of resistance to compression, traction, flexural, and elasticity modulus was carried out using a hydraulic press, as shown in Figure 6.

Figure 1 Hydraulic press.

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3. Results and discussion

3.1.Fresh properties of concrete

3.1.1. Workability

Table 4 shows the slumps obtained for the standard concrete of f'c=210 kg/cm² and f'c=280 kg/cm² vs. the standard concrete with the addition of 1%, 2%, 3%, and 4% of steel fibers, where it is observed that the designs with 1%, 2% and 3% of fibers are within the parameters considered for a plastic consistency concrete, having a slump of 3 inches to 4 inches, under the considerations of the ACI 211 standard. 1. In fact, the superplasticizer for the 4% fiber design was not sufficient to be within the normative range as a workable mix. This could be attributed to the fact that the fiber becomes less workable as the amount incorporated in the standard concrete increases. In addition, when randomly placed, the fibers can form fiber blocks, which directly influences the mechanical strength.

3.1.2. Temperature

Table 4 shows the values obtained for the temperature for the standard concrete of f'c=210 kg/cm² and f'c=280 kg/cm² versus the standard concrete by adding 1%, 2%, 3% and 4% of steel fibers, where an average decrease of 3 ºC is observed for the strength of f'c=210 kg/cm² and 6 ºC for the strength of f'c=280 kg/cm², when adding the fibers with respect to the standard concrete, the temperature obtained for the conventional concrete is random according to the parameters established by the ASTM C1064M [26] standard. This reduction may be because it was produced by the plasticizer for the mixtures with fibers, taking into account that the standard mixtures did not use plasticizer because they remained in the range of good workability according to ACI 211.1.

Table 4 Properties of fresh concrete.

Mix design	Slump (Inches)	Temperature (°C)
SC f'c=210	4.00	30.35
SC f'c=210+1%SF	4.00	28.40
SC f'c=210+2%SF	3.80	27.85
SC f'c=210+3%SF	3.50	25.50
SC f'c=210+4%SF	2.90	24.00
SC f'c=280	3.80	29.75
SC f'c=280+1%SF	4.00	21.50
SC f'c=280+2%SF	3.50	25.45

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SC f'c=280+3%SF	3.20	24.10
SC f'c=280+4%SF	2.00	23.40

*SC: Standard concrete; SF: Steel fibers

3.2.Hardened state properties of concrete

3.2.1. Compressive strength

Table 5 shows the average resistance reached at 28 days, where all the mix designs were greater than the design resistance of 210 kg/cm² and 280 kg/cm², which indicates that these designs are suitable for structural use.

Table 5 Compressive strength test values

Mix design	**Resistance (kg/cm²)**		
	7 days	14 days	28 days
SC f'c=210	179.35	197.41	240.03
SC f'c=210+1%SF	182.95	202.52	249.41
SC f'c=210+2%SF	184.37	212.31	275.44
SC f'c=210+3%SF	179.81	210.22	260.05
SC f'c=210+4%SF	153.38	197.65	233.20
SC f´c=280	214.81	252.65	296.02
SC f'c=280+1%SF	178.82	261.75	281.20
SC f'c=280+2%SF	214.39	253.54	294.11
SC f'c=280+3%SF	220.73	281.25	338.28
SC f'c=280+4%SF	234.85	314.92	344.25

*SC: Standard concrete; SF: Steel fibers

Figure 7 shows the results of the compressive strength at 7, 14, and 28 days of curing for a standard concrete with f'c=210 kg/cm² of compressive strength vs. the standard concrete adding 1%, 2 %, 3%, and 4% of steel fibers depending on the volume of the concrete. The design that provided the best results was the concrete with f'c=210 kg/cm² adding 2% steel fiber, showing an increase in compressive strength of 14.76% at 28 days, compared to the standard concrete and in addition, it surpassed all the designs in terms of the resistance obtained for the 28 days of curing.

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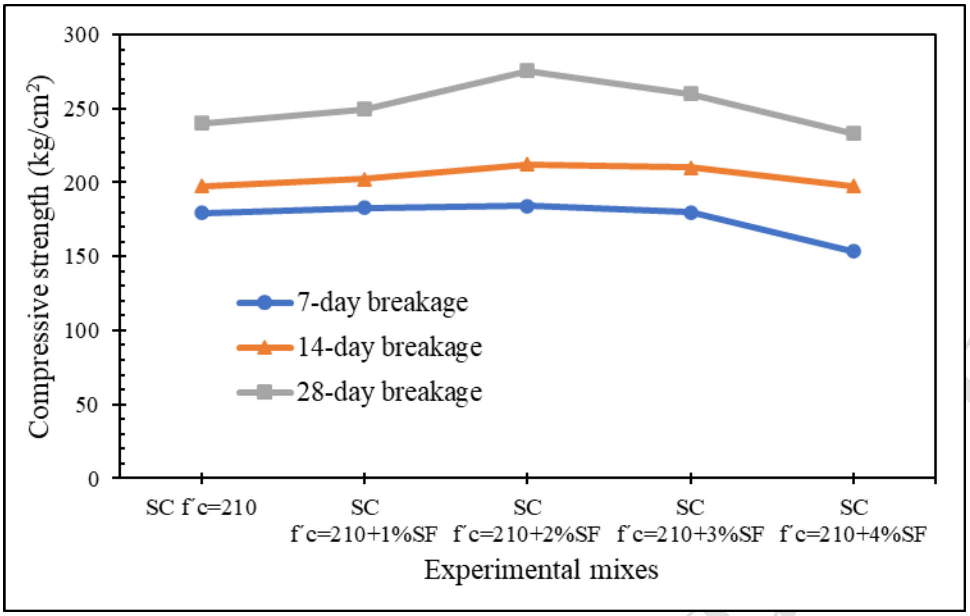

Figure 2 Compressive strength curve for f'c of 210 kg/cm²

The best dosage that provided the maximum resistance at 28 days was 2% equivalent to 44.88 kg/m^3 of steel fibers, having an increase of 14.76%, which is consistent with what was mentioned in the research by Moya et al. [9], where he mentions that for a dosage of 1.2% of steel fibers, it shows an increase of 12.15%, unlike this, it is not related to the investigation of Farfán et al. [12], where in its results it indicates that for a concrete resistance f'c=210 kg/cm² the most optimal dosage was 1% equivalent to 25 kg/m^3, showing an increase of 1.1%, in the same way for the investigation of Araujo [20], varieties of dosages were analyzed up to a maximum of 50 kg/m^3, where he mentions that the higher percentage of fibers adheres to the concrete, the greater resistance will be obtained, which is not related, due to that in the investigation up to a dosage of 4% equivalent to 89.55 kg/m^3 was analyzed and lower resistances were obtained in comparison to the standard concrete and to the optimal dosage that is 2% of steel fibers.

Figure 8 shows the results of the compressive strength at 7, 14, and 28 days of curing for a standard concrete with f'c=280 kg/cm² of compressive strength vs. the standard concrete adding 1%, 2%, 3%, and 4% of steel fibers depending on the volume of the concrete. The design that obtained the best results was the concrete with f'c=280 kg/cm² adding 4% steel fiber, showing an increase in compressive strength of 16.29% at 28 days, compared to the standard concrete. and at the same time, it surpassed all the designs in terms of the resistance obtained for the 28 days of curing.

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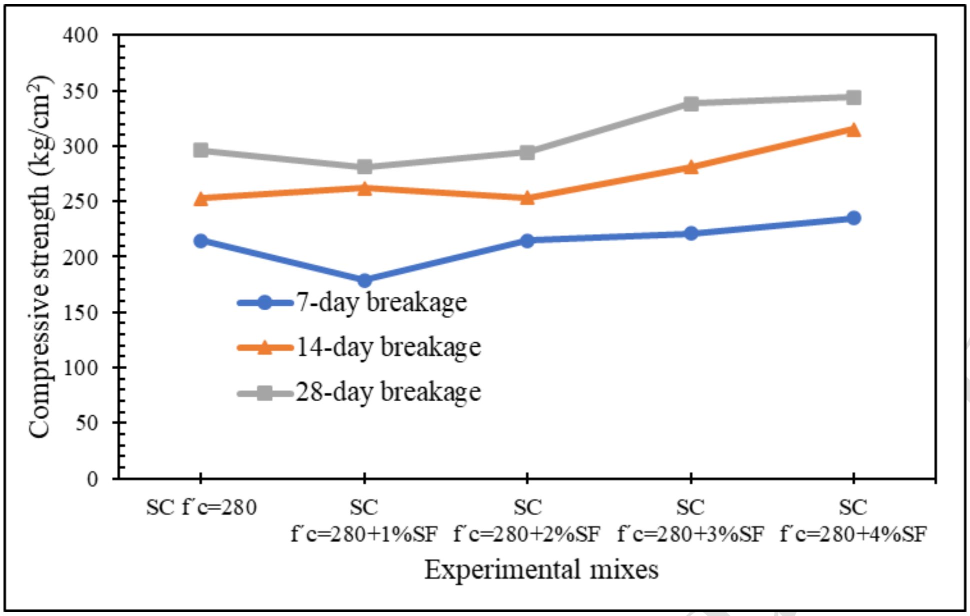

Figure 3 Compressive strength curve for f'c of 280 kg/cm²

Based on the above, other studies showed that they had better results with the addition of 4%, equivalent to 89.80 kg/m^3 of steel fibers, observing an increase of 16.29% for a concrete strength of f'c=210 kg/cm². However, a further increase in fiber content (Vf = 1%) had a detrimental effect by reducing bond performance [27]. Regarding the strength of concrete of f'c=280 kg/cm², it was observed that the maximum compressive strength was when 2% of steel fibers were added, equivalent to 47.64 kg/m^3, showing an increase of 10.86%. The tendency to increase the compressive strength and modulus of elasticity slowed down when the volume fraction exceeded 2%. It was observed that steel fiber can slow down the occurrence and development of cracks when compressing concrete specimens with fiber, which provided a positive effect for the reinforcement of reinforced concrete, but also reduced the flowability of fresh concrete, which is negative for the reinforcement effect [28].

3.2.2. Tensile strength

Table 6 shows the results of the tensile strength of the 210 kg/cm² and 280 kg/cm² design strength concrete, achieved at 28 days. It was observed that for the concrete of f'c= 210 kg/cm², the best performance dosage is 2% of steel fibers, achieving an increase of 14.93% with respect to the standard concrete, and for the concrete of f'c= 280 kg/cm², the optimum dosage is 3% of steel fibers showing an increase of 9.85, respectively at 28 days of rupture.

Table 6 Tensile strength test values

Mix design	Resistance (kg/cm^2)	Variation (%)
SC f'c =210	17.32	100.00%
SC f'c =210+1%SF	16.41	95.09%

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SC f'c =210+2%SF	19.87	114.93%
SC f'c =210+3%SF	16.00	92.34%
SC f'c =210+4%SF	14.88	86.25%
SC f'c =280	22.72	100.00%
SC f'c =280+1%SF	22.21	97.76%
SC f'c =280+2%SF	23.23	101.94%
SC f'c =280+3%SF	24.97	109.85%
SC f'c =280+4%SF	20.79	91.49%

*SC: Standard concrete; SF: Steel fibers

Figure 9 shows the results of the tensile strength at 28 days of curing for a standard concrete of f'c=210 kg/cm² vs. the standard concrete adding 1%, 2%, 3%, and 4% fibers of steel depending on the volume of the concrete. The design that provided the best results was the concrete of f'c=210 kg/cm² adding 2% equivalent to 44.88 kg/m^3 of steel fiber, showing an increase of 14.93% compared to the standard concrete: at the same time, it surpassed all the designs made.

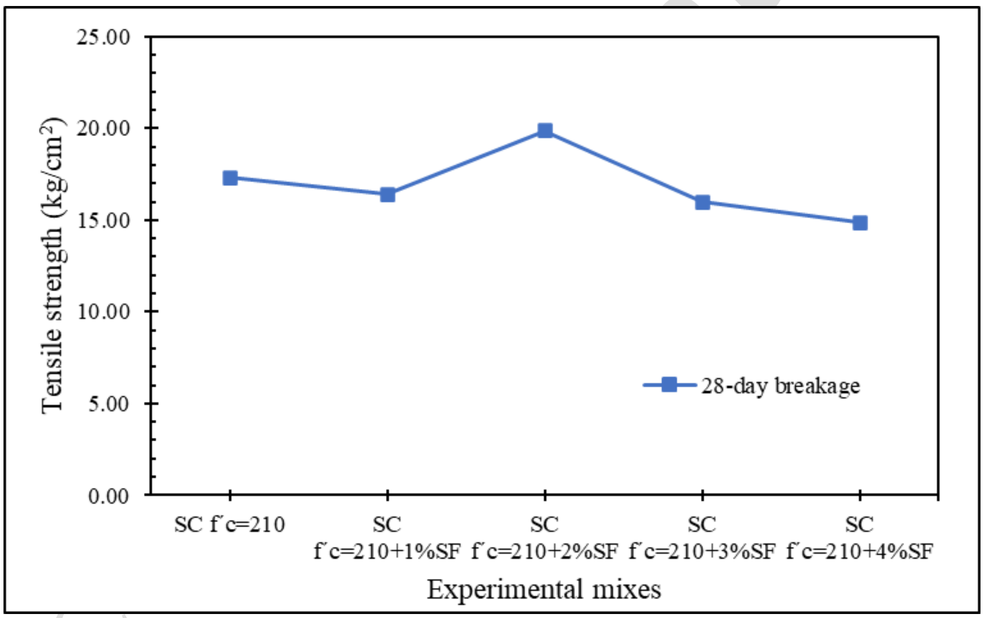

Figure 4 Concrete tensile strength f'c=210 kg/cm²

The dosage that provided the best resistance is referred to the research of Moya and Lara [9], where in their results it is shown that for the dosage of 1.2% of steel fibers for the concrete of f'c=210 kg/cm², the tensile strength increased by 45.05%, in such a way that it agrees with what was mentioned above, because the dosage of 2% equivalent to 44.88 kg/m^3 was the one that provided the maximum resistance, showing an increase of 14.93% in comparison to the standard concrete. Loading the cylinder in a split manner results in lateral tensile stress and vertical compressive stress within the cylindrical samples. This biaxial stress condition notably affects the post-cracking behavior. The vertical compressive stresses, aligned with the cracks, enhance the load-bearing capacity of the fiber reinforcement, bridging the cracks within the mixture before disengagement occurs [29], [14].

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Figure 10 shows the results of the tensile strength at 28 days of curing for a standard concrete of f’c=280 kg/cm² vs. the standard concrete adding 1%, 2%, 3%, and 4% of steel fibers depending on the volume of the concrete. The design that obtained the best results was the concrete of f’c=280 kg/cm² adding 3% equivalent to 67.35 kg/m^3 of steel fibers, showing an increase of 9.85% compared to the standard concrete: at the same time, it surpassed all the designs carried out.

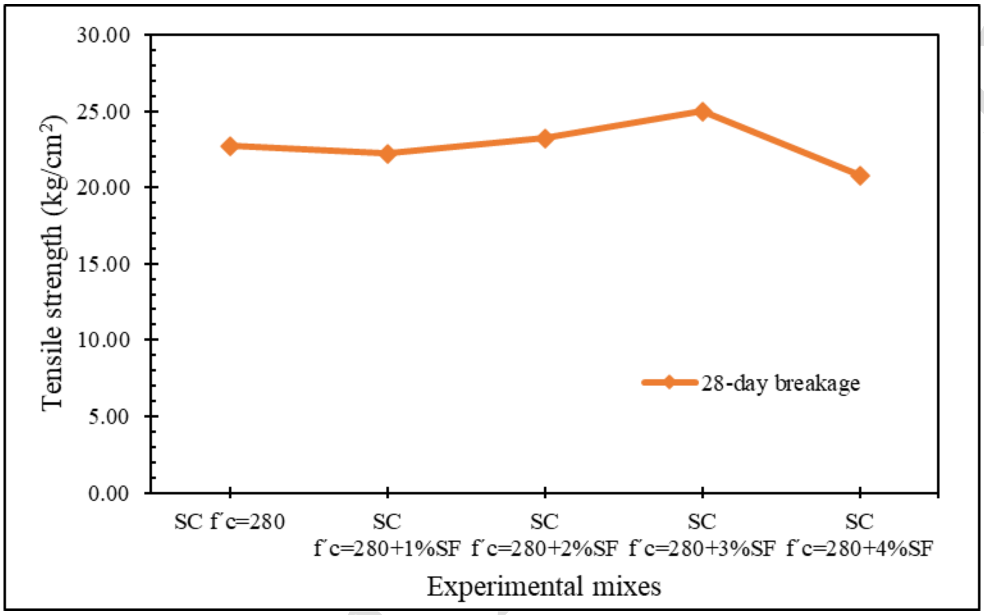

Figure 5 Concrete tensile strength f’c=280 kg/cm²

3.2.3. Flexural strength

Table 7 shows the flexural strength of the concrete of 210 kg/cm² and 280 kg/cm², reached at 28 days, where an increase in resistance is displayed as the higher the percentage of steel fibers added to the concrete. The following analysis was carried out according to the ASTM C78 standard [24] for simply supported beams with loads at the thirds of the span.

Table 7 Flexural strength test values

Mix design	Resistance (kg/cm^2)	Variation (%)
SC f’c=210	52.79	100.00%
SC f’c=210+1%SF	47.62	90.20%
SC f’c=210+2%SF	44.69	84.64%
SC f’c=210+3%SF	53.91	102.12%
SC f’c=210+4%SF	63.01	119.35%
SC f’c=280	60.96	100.00%
SC f’c=280+1%SF	63.70	104.50%
SC f’c=280+2%SF	68.66	112.64%

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SC f'c=280+3%SF	68.89	113.01%
SC f'c=280+4%SF	71.29	116.95%

*SC: Standard concrete; SF: Steel fibers

Figure 11 shows the results of the flexural strength at 28 days of curing for a standard concrete of f'c=210 kg/cm² vs. the standard concrete adding 1%, 2%, 3%, and 4% of fibers of steel depending on the volume of concrete. The design that obtained the best results was the concrete of f'c=210 kg/cm² adding 4% equivalent to 89.60 kg/m^3 of steel fibers, showing an increase of 19.35% compared to the standard concrete: at the same time, it surpassed all the designs made.

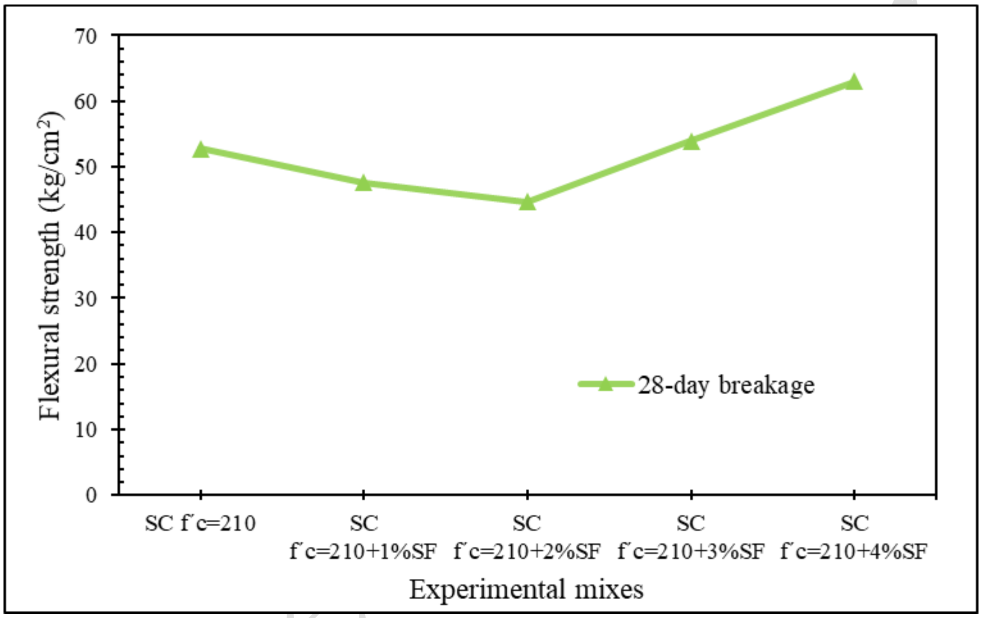

Figure 6 Flexural strength of concrete f'c=210 kg/cm²

Figure 12 shows the results of the flexural strength at 28 days of curing for a standard concrete of f'c=280 kg/cm² vs. the standard concrete adding 1%, 2%, 3% and 4% of fibers of steel depending on the volume of concrete. The design that gave the best results was the concrete of f'c=280 kg/cm² adding 4% steel fiber, showing an increase in the modulus of rupture of 16.95% compared to the standard concrete, at the same time it surpassed all the designs made.

In terms of dosages of 0.3% and 0.8%, equivalent to 5.9 and 18 kg/m^3 respectively, the flexural strength exhibited a slight increase. This marginal improvement can be attributed to dosages lower than 60 kg/m^3 [11], falling short of the minimum quantity required for beams according to the standard ACI 318S-14 [15]. Compared to other studies, the inclusion of 3% straight steel fibers resulted in a notable increase of 81%, 228% and 180% in compressive, tensile, and flexural strength, respectively. These results surpassed those of other studies, indicating the efficacy of the approach [29].

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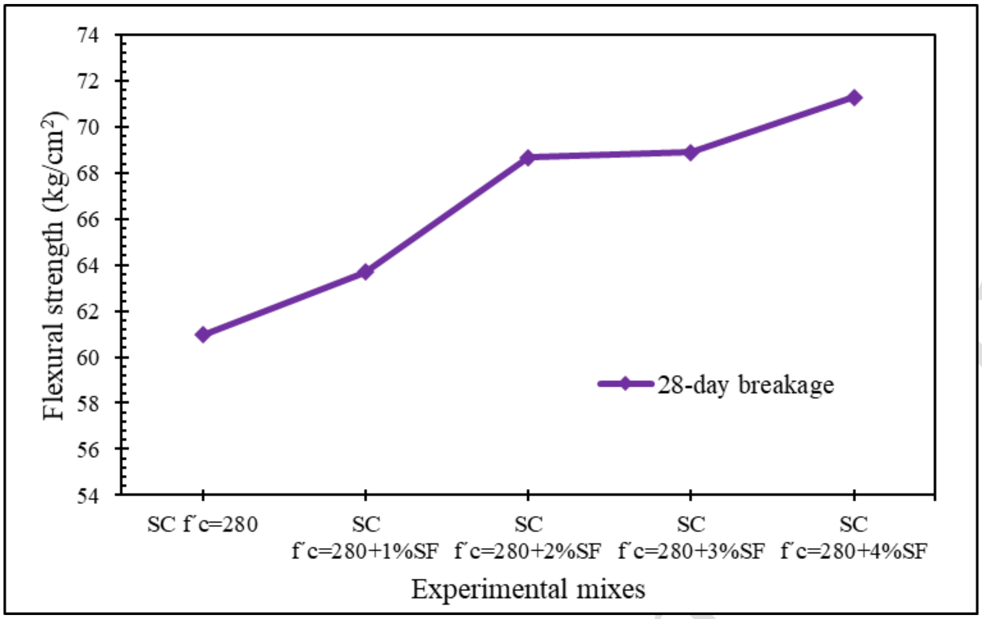

Figure 7 Flexural strength of concrete f'c=280 kg/cm²

3.2.4. Modulus of elasticity

Table 8 presents the modulus of elasticity results after 28 days of curing for concrete designs with strengths of f'c=210 kg/cm² and f'c=280 kg/cm², incorporating 1%, 2%, 3%, and 4% of steel fibers per concrete volume. For a strength of f'c=210 kg/cm², the optimal dosage is found to be 2% of steel fibers, resulting in a 1.63% increase compared to the theoretical modulus of elasticity of standard concrete. Contrastingly, for a design strength of f'c=280 kg/cm², the most effective dosage is 4% of steel fibers, yielding a 3.75% increase.

Table 8 Module of elasticity test values

Mix design	Ec real (kg/cm²)	Ec theoretical (kg/cm²)	% Achieved of real Ec vs. theoretical Ec, with respect to the concrete standard
SC f'c =210	208031.30	232334.19	89.54%
SC f'c=210+1%SF	213733.04	236621.69	91.99%
SC f'c=210+2%SF	236131.23	248934.06	101.63%
SC f'c=210+3%SF	228406.99	241877.89	98.31%
SC f'c=210+4%SF	199871.21	228782.58	86.03%
SC f'c =280	253604.78	258057.03	98.27%
SC f'c =280+1%SF	234202.90	248537.92	90.76%
SC f'c =280+2%SF	254396.04	256780.92	98.58%
SC f'c =280+3%SF	288052.92	275884.88	111.62%

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SC f'c =280+4%SF	293531.72	278289.05	113.75%

*SC: Standard concrete; SF: Steel fibers; Ec: Module of elasticity

Figure 13 illustrates the outcomes for the treatment f'c =210 kg/cm² + 2% steel fiber, equivalent to 44.88 kg/m3 of steel fibers. A real equivalent modulus of 236,131.23 kg/cm² was obtained, representing a 1.63% increase. The theoretical equivalent modulus of standard concrete stood at 232,334.19 kg/cm², marking an 8.63% increase compared to the theoretical modulus of elasticity, which reached 217,370 kg/cm² at 28 days. These calculations are based on the equation of static modulus of elasticity according to RNE.060

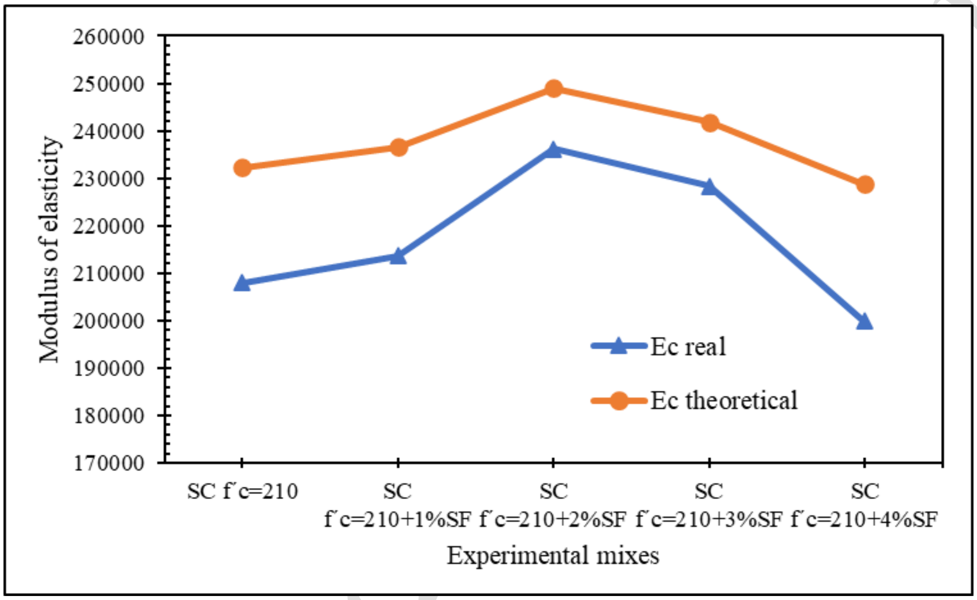

Figure 8 Comparison of the modulus of elasticity (Ec real vs. Ec theoretical) of the concrete f'c =210 kg/cm²

Figure 14 demonstrates that for concrete with a strength of f'c=280 kg/cm² and 4% steel fibers, equivalent to 90 kg/m³, a real equivalent modulus of 293,531.72 kg/cm² was achieved, indicating a substantial increase of 13.75% compared to the theoretical equivalent modulus of standard concrete, which reached 258,057.03 kg/cm². Additionally, it exhibits a 16.95% increase compared to the theoretical modulus of elasticity (250,998 kg/cm²). The addition of steel fibers had a minor effect on compressive strength, with recorded increases of only 10–15% in strain values. The higher steel fiber content led to an increase in peak strain compared to control samples, but it also resulted in a slower decline in concrete strength after reaching peak stress [30]. Previous studies utilizing 65/35 steel fibers achieved up to a 20% increase in modulus of elasticity [7]; however, our current research utilized 80/60 steel fibers, which are longer, have a larger diameter, and are more commonly used in reinforced concrete structures.

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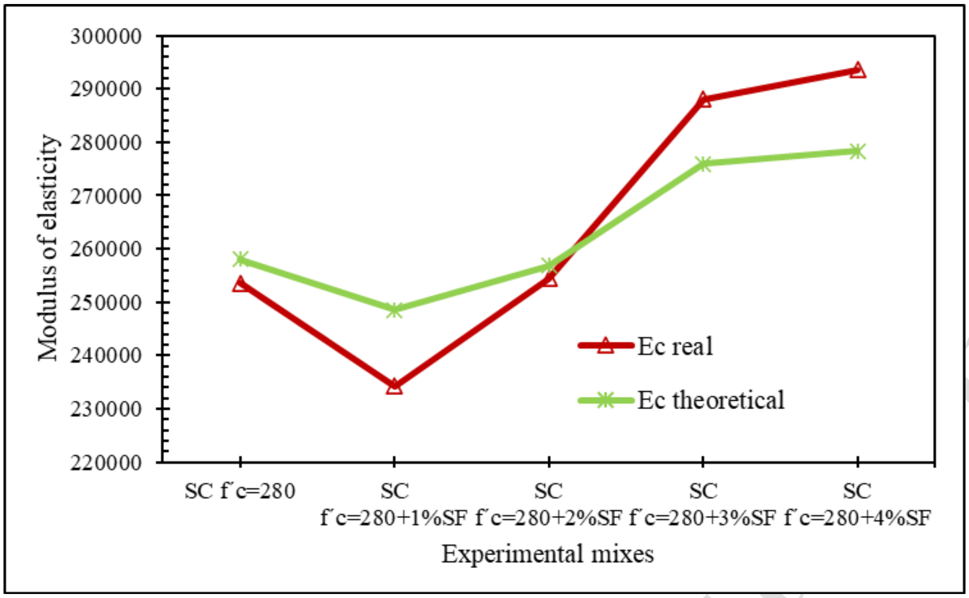

Figure 9 Comparison of the modulus of elasticity (Ec real vs Ec theoretical) of the concrete f'c =280 kg/cm²

4. Conclusions

The study shows findings and confirms the importance of using steel fibers in the preparation of concrete for structural strength: the following are the novelties of the study:

Steel fiber has a significant influence when doses higher than 3% are used, reducing its workability. Using plasticizing admixture for the control mixes was unnecessarybecause they showed an optimum workability within the acceptable range according to design parameters according to ACI.211.1.

It is concluded that the compressive strength and modulus of elasticity show improvements in mechanical strength up to 2% of steel fibers with the use of plasticizer additives with respect to the control sample.

The tensile strength and flexural strength achieved better performance with the maximum addition of 4% of steel fiber, which is significant for the use in the construction industry for structures such as sports slabs, pavements, sidewalks, etc.

The way of placing the steel fibers in a random way causes the formation of clusters and segregation of these if there is a long mixing time after 6 minutes. It is suggested that the mixing time be controlled to avoid this observed problem. This directly influences the physical and mechanical properties of the concrete.

For each mix design f'c=210 and f'c=280 kg/cm^{2,} the optimum doses of steel fiber are variable for the design parameters that each one contains, being 2% and 4%, respectively.

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Further research is recommended to determine durability parameters and microstructural and macrostructural properties in order to have a broader picture of steel fiber in concrete.

5. Declaration of competing interests

The authors declare that we have no significant competitive interests, including financial or non-financial, professional, or personal interests that interfere with the complete and objective presentation of the work described in this manuscript.

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The author F. Sandoval contributed with the original idea of the article, with the development of the necessary essays for the development of the investigation, and with the writing of the article, processing the obtained results, and giving the final conclusions of the investigation.

The author S. Muñoz was the one who directed and gave the necessary guidelines for the effective elaboration of this article, collecting the necessary literature to carry out the investigation.

9. Data available statement

The authors confirm that the data supporting the findings of this study are available within the article and its supplementary materials.

References

[1] S. K. Nayar and R. Gettu, "Mechanistic-empirical design of fibre reinforced concrete (FRC) pavements using inelastic analysis," *Sadhana - Academy Proceedings in Engineering Sciences*, vol. 45, no. 19, pp. 1-7, 2020.

[2] E. Becker, "Patologías habituales en el hormigón armado," *Clarín ARQ*, 2016.

Accepted Manuscript

CC BY NC SA

[3] J. Ahmad, A. Manan, A. Ali, M. W. Khan, M. Asim and O. Zaid, "A Study on Mechanical and Durability Aspects of Concrete Modified with Steel Fibers (SFs)," *Civil Engineering and Architecture,* vol. 8, pp. 814-823, 2020.

[4] C. Frazão, J. Barros, J., J. A. Bogas, V. García-Cortés and T. Valente, "Technical and environmental potentialities of recycled steel fiber reinforced concrete for structural applications," *Journal of Building Engineering,* vol. 45, p. 103579, 2022.

[5] S. Muñoz Perez, J. Garcia Chumacero, S. Charca Mamani and L. Villena Zapata, "Influence of the secondary aluminum chip on the physical and mechanical properties of concrete," *Innovative Infrastructure Solutions,* vol. 45, no. 8, 2023.

[6] J. Garcia Chumacero, P. Acevedo Torres, C. Corcuera La Portilla, S. Muñoz Perez and L. Villena Zapata, "Effect of the reuse of plastic and metallic fibers on the characteristics of a gravelly soil with clays stabilized with natural hydraulic lime," *Innovative Infrastructure Solutions,* vol. 8, no. 185, 2023.

[7] D. J. Ñaupas Tenorio y D. M. Sosa Soto, «Comportamiento mecánico del concreto reforzado con fibra de acero en el análisis estructural de placas en el proyecto de ampliación del Centro Médico San Conrado en Los Olivos, Lima - Perú,» [Tesis de pregrado-Universidad San Martín de Porres], Lima, 2019.

[8] L. P. Gallo Arciniegas, G. Gonzales Penuela and J. Carrillo Leon, "Comportamiento del concreto reforzado con fibras de acero zp-306 sometido a esfuerzos de compresión," *Ciencia e Ingeniería Neogranadina,* vol. 23, no. 1, pp. 117-133, 2013.

[9] J. C. Moya and L. F. C. Lara, "Análisis de las propiedades físicas y mecánicas del hormigón elaborado con fibras de acero reciclado," *Ingenio,* vol. 1, no. 2, p. 5–14, 2019.

[10] D. Y. Yoo, U. Gohil, T. Gries and Y. S. Yoon, "Comparative low-velocity impact response of textile-reinforced concrete and steel-fiber-reinforced concrete beams," *Journal of Composite Materials,* vol. 50, no. 17, pp. 2421-2431, 2016.

[11] J. Carrillo and D. Silva Páramo, "Flexural Tests of Concrete Slabs-on-Ground Reinforced with Steel Fibers," *Ingeniería, Investigación y Tecnología,* vol. 17, no. 3, pp. 317-330, 2015.

[12] M. Farfán Córdova, D. I. Pinedo Díaz, J. Araujo Novoa and J. Orbegoso Alayo, "Fibras de acero en la resistencia a la compresión del concreto," *Revista Gaceta Técnica,* vol. 20, no. 2, p. 11, 10 Octubre 2018.

[13] E. O. Flores Utos, "Mejoramiento de la resistencia del concreto adicionando fibras de acero en la Av. Túpac Amaru, distrito de Independencia, Lima - 2018," [Tesis de pregrado-Universidad César Vallejo], Lima , 2018.

Accepted Manuscript

[14] J. Ran, L. Tingchun, C. Dianhao, S. Liming, L. Weiteng and Z. Qingwen, "Mechanical properties of concrete reinforced with corrugated steel fiber under uniaxial compression and tension," *Structures*, pp. 1890-1902, December 2021.

[15] ACI Committee 318, ACI 318S-14: Requisitos de Reglamento para Concreto Estructural e ACI 318RS-14 Comentario de Requisitos de Reglamento para Concreto Estructural, Comité ACI 318, 2014, p. 588.

[16] B. F. Abad, E. O. Lantsoght and Y. Yang, "Shear capacity of steel fibre reinforced concrete beams," *Concrete - Innovations in Materials*, pp. 1710-1717, 2019.

[17] NTP 400.011, "AGREGADOS. Definición y clasificación de agregados para uso en morteros y hormigones (concretos)," INDECOPI-CNB, Lima, 2008.

[18] A. C. Zapata Gómez, M. V. Reyes Valdes and G. T. M. Baltazar, "Hormigón con aditivos reductores de agua," *Investigación*, p. 4, 2006.

[19] ASTM C1116, Standard Specification for Fiber-Reinforced Concrete, West Conshohocken, PA,: ASTM International, 2003.

[20] A. J. Araujo Novoa, "Fibras de acero y polipropileno en la resistencia a la compresión del concreto, Trujillo - 2018," [Tesis de pregrado-Universidad César Vallejo], Trujillo, 2018.

[21] ASTM C31, Standard Practice for Making and Curing Concrete Test Specimens in the Field, West Conshohocken, PA,: ASTM International, 2012.

[22] ASTM C39, Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens, West Conshohocken, PA: ASTM International, 2006.

[23] ASTM C496, "Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens," ASTM International, West Conshohocken, PA, 2004.

[24] ASTM C78, Standard Test Method for Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading), West Conshohocken, PA: ASTM International, 2002.

[25] ASTM C469, Standard Test Method for Static Modulus of Elasticity and Poisson's Ratio of Concrete in Compression, West Conshohocken, PA: ASTM International, 1994, p. 7.

[26] ASTM C1064, Standard Test Method for Temperature of Freshly Mixed Hydraulic-Cement Concrete, West Conshohocken, PA: ASTM International, 2012.

[27] C. A. Benedetty, P. A. Krahl, L. C. Almeida, L. M. Trautwein, G. H. Siqueira and F. d. A. Silva, "Interfacial mechanics of steel fibers in a High-Strength Fiber-Reinforced Self Compacting Concrete," *Construction and Building Materials*, vol. 301, p. 124344, 2021.

Accepted Manuscript

[28] J. Yang, B. Chen and C. Nuti, "Influence of steel fiber on compressive properties of ultra-high performance fiber-reinforced concrete," *Construction and Building Materials,* vol. 302, p. 124104, 2021.

[29] G. D. Ashkezari, F. Fotouhi and M. Razmara, "Experimental relationships between steel fiber volume fraction and mechanical properties of ultra-high performance fiber-reinforced concrete," *Journal of Building Engineering,* vol. 32, p. 101613, 2020.

[30] M. Usman, S. H. Farooq, M. Umair and A. Hanif, "Axial compressive behavior of confined steel fiber reinforced high strength concrete," *Construction and Building Materials,* vol. 230, p. 117043, 2020.

Accepted Manuscript

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