Revista ALCONPAT
www.revistaalconpat.org
eISSN 2007-6835
Revista de la Asociación Latinoamericana de Control de Calidad, Patología y Recuperación de la Construcción

Influence of experimental variables on the mechanical properties of steel fiber reinforced concrete (SFRC) in chloride degradation experiments: bibliographic review and statistical analysis

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DOI: https://doi.org/10.21041/ra.v13i2.641

Received: 04/10/2022 | Received in revised form: 15/04/2023 | Accepted: 23/04/2023 | Published: 01/05/2023

ABSTRACT

This research aims to evaluate the effect of experimental variables in the study of chloride degradation of steel fiber reinforced concretes (SFRCs). The information was collected from different literary sources to be treated through Taguchi's experimental design and regression analysis. The results show that the most influential factors in the degradation of SFRCs by chloride are the load during degradation and the crack width, residual resistance, and maximum flexural load. However, others, such as the water/cement ratio, fiber volume, chloride concentration, and degradation time, showed little influence on the mechanical response of the SFRCs.
Keywords: steel fiber reinforced concrete; degradation; chlorides; experimental variables; mechanical properties.

Cite as: Becerra, O., Meza, A., Salinas, R. (2023), *"Influence of experimental variables on the mechanical properties of steel fiber reinforced concrete (SFRC) in chloride degradation experiments: bibliographic review and statistical analysis"*, Revista ALCONPAT, 13 (2), pp. 143 – 157, DOI: https://doi.org/10.21041/ra.v13i2.641

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Contribution of each author
In this work, the author Oslery Becerra Pérez contributed to the search and compilation of information, with the statistical analysis of said information in around 50%, the discussion of the results in 40%, and the preparation of the draft of the article. The author Alejandro Meza de Luna contributed to the direction and management of the investigation, the discussion of the results 40%, the revision and adjustments of the article 80%, and the functions of the corresponding author. The author Rogelio Salinas contributed to the statistical analysis of all the information found by 50%, the discussion of the results by 20%, and the review and adjustments of the article by 20%.

Discussions and subsequent corrections to the publication
Any dispute, including the replies of the authors, will be published in the first issue of 2024 provided that the information is received before the closing of the third issue of 2023.

Influencia de variables experimentales en las propiedades mecánicas de los concretos reforzados con fibras de acero (SFRC) en experimentos de degradación por cloruros: revisión bibliográfica y análisis estadístico

RESUMEN

La presente investigación tiene como objetivo evaluar el efecto de variables experimentales en el estudio de la degradación por cloruros de concretos reforzados con fibras de acero (SFRCs). La información fue recopilada de diferentes fuentes literarias para después ser tratada mediante el diseño experimental de Taguchi y análisis de regresión. Los resultados muestran que los factores más influyentes en la degradación de SFRCs degradados por cloruro son la carga durante la degradación y el ancho de fisura, factores que impactan estadísticamente sobre resistencia residual y la carga máxima a flexión. Sin embargo, otros como la relación agua/cemento, el volumen de fibras, la concentración de cloruros y el tiempo de degradación demostraron poca influencia sobre la respuesta mecánica de los SFRCs.

Palabras clave: concretos reforzados con fibra de acero; degradación; cloruros; variables experimentales; propiedades mecánicas.

Influência de variáveis experimentais nas propriedades mecânicas do concreto reforçado com fibras de aço (SFRC) em experimentos de degradação de cloretos: revisão bibliográfica e análise estatística

RESUMO

O objetivo desta pesquisa é avaliar o efeito de variáveis experimentais no estudo da degradação de cloretos de concretos reforçados com fibras de aço (SFRCs). As informações foram coletadas de diferentes fontes literárias e tratadas por meio do ábaco experimental de Taguchi e da análise de regressão. Os resultados mostram que os fatores mais influentes na degradação dos SFRCs degradados por cloreto são a carga durante a degradação e a abertura da fissura, fatores que impactam estatisticamente na resistência residual e na carga máxima de flexão. No entanto, outros como relação água/cimento, volume de fibras, concentração de cloretos e tempo de degradação mostraram pouca influência na resposta mecânica dos SFRCs.

Palavras-chave: concreto reforçado com fibras de aço; degradação; cloretos; variáveis experimentais; propriedades mecânicas.

Nomenclature:

Vrr: Variation of residual resistance (%)
Vcm: Maximum load variation (%)
Rac: Water/cement ratio
Vf: Fiber volume (%)
Td: Degradation time (days)
C: Chloride concentration (% w/w)
Cd: Load exerted during degradation (kN)
Ca: Accelerated corrosion (uA/cm2)
Ag: Width of controlled cracks (mm)
Te: Type of experiment

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1. INTRODUCTION

Concrete is the most used construction material worldwide, mainly due to the availability of the materials that constitute it (Chen et al., 2021). Concrete has properties that have made it the construction material par excellence since it has a high resistance to compression, being able to go decades without requiring practically any maintenance or replacement (Paul et al., 2020). Despite these qualities, concrete has a relatively low flexural resistance due to the tensile stresses. It has become necessary to use reinforcing materials to prepare concrete, which allows for improving its characteristics. (Chen et al., 2021). From the 19th century to the present, steel in the form of bars has been used to reinforce concrete structures. Although reinforcing bars are still the most widely used for this purpose, the use of fibers has had a significant boom in recent decades, generating what is known as steel fiber reinforced concrete (SFRC). , the fibers improve the tensile properties of concrete, fatigue resistance, impact resistance, and toughness and help control cracking (Behbahani & Nematollahi, 2011; Kaur et al., (2012), Ferreira et al., 2018; Zhang et al., 2020). SFRC is used, for example, in tunnel lining, highway construction, and buildings prone to earthquake damage (Berrocal, 2015; Marcos-Meson et al., 2019; Zhang et al., 2020). In addition, the SFRC is applied in infrastructures with aggressive environments, such as industrial floors, buildings to store nuclear waste, and hydraulic and marine structures, such as docks, oil platforms, and gas pipelines (Doo-Yeol et al., 2021; Hou et al., 2021). Among the most commonly used materials for this purpose are steel, polymeric materials, and carbon fibers, although the use of glass, coconut, jute, and asbestos has also been reported (Meza & Siddique, 2019; Paul et al., 2020; Meza & Shaikh, 2020; Meza et al., 2021), as well as agave vegetable fiber (Juárez-Alvarado et al., 2017). Steel fibers have been widely used and studied as concrete reinforcement (Horszczaruk, 2009; Hou et al., 2021). As previously seen, SFRCs are used in infrastructures subjected to aggressive environments; therefore, the scientific community has been in charge of investigating the different degradation processes to which structures made with SFRCs may be subjected. Various investigations indicate that corrosion is the primary mechanism of the degradation of reinforced concrete structures (Paul et al., 2020; Berrocal et al., 2015; Berrocal et al., 2017). Corrosion causes a decrease in the cross-section of the steel reinforcement (Berrocal, 2015), which negatively influences the mechanical characteristics of the concrete reinforced with steel bars and the SFRC. Besides, it is essential to say that the corrosion process affects not only the reinforcement but also the concrete that surrounds them; this is due to the formation of corrosion products, which accumulate at the steel-concrete interface, and as the volume increases, internal pressures originate that cause cracking of the concrete, a process known as spalling (Simões & Santo, 2019), which in turn increases the corrosion rate and thereby causes changes in its mechanical properties, including maximum load and residual resistance (Berrocal et al., 2017; Paul et al., 2020). According to Abbas et al. (2014), the penetration of chlorides in tunnel walls causes the corrosion of the reinforcement, thus reducing its load capacity. Also, other researchers, such as Granju and Balouch (2005) and Carrillo et al. (2017), affirm that corrosive environments can affect the flexural performance of the SFRCs if the steel fibers are corroded since these cause reductions in the maximum peak load accompanied by brittle and brittle post-peak behavior. In addition, studies such as that of Hou et al. (2021) indicate that the decrease in residual resistance in SFRCs is closely linked with the loss of reinforcement mass, pitting corrosion, and deterioration of the adhesion between the reinforcement-concrete-corrosion rate.

On the other hand, several factors influence the corrosion process since this depends on the corroded metal's characteristics and the surrounding environment in which it is found. One of these factors is the presence of external agents, such as salts containing the chloride ion, such as aluminum chloride, iron chloride, ammonium chloride, and sodium chloride. Upon entering the concrete, these salts lower their pH and accelerate the corrosion process of the steel reinforcement

(Salazar-Jiménez, 2015). Specifically, chloride degradation causes the so-called pitting corrosion effect; this occurs when enough chlorides accumulate on the reinforcement surface, thus favoring the corrosive process in a specific area of the material (Berrocal et al., 2015).

The degradation of fiber-reinforced concrete by the action of chlorides has been widely studied due to the exposure of infrastructures to aggressive environments with high concentrations of this anion (Berrocal et al., 2015). For this reason, research has been carried out focused on the effect of degradation on the fibers, concrete, and fiber-concrete set, obtaining that their mechanical properties vary so much after being subjected to degradable processes by chlorides. Dissimilar types of fibers and concrete under different experimental conditions have been put to the test, this has given rise to the results obtained in said investigations being very varied and not always correlated with each other, so it is still not completely clear what they are the experimental variables that most affect the mechanical characteristics of concrete and to what extent they do so which could be solved by carrying out comparative analyzes and research.

For the reasons mentioned above, this study compiles experimental data obtained under laboratory conditions related to the degradation of SFRC under the action of chlorides. The data from different investigations were subjected to a statistical analysis where the experimental variables that most influence the corrosion of the fibers, the general deterioration of the concrete, and the extent to which they affect their properties when subjected to flexural stress were identified. For this, the analysis of experimental data obtained from the bibliography was carried out using Taguchi's robust experimental design, an analysis method focused on maximizing a specific signal-to-noise ratio (S/N) for each variable studied (Kuehl, 2000). The objective of the present investigation is to know the experimental variables that affect the responses, which are the decrease in the maximum load and the decrease in the residual resistance after the degradation process. A regression analysis was also used to represent the results obtained through the experimental analysis. It is hoped that the results achieved serve as a basis for researchers who begin the study of concrete reinforced with steel fibers and their degradation by the action of chlorides since a review and bibliographic analysis of the most relevant published regarding this subject is made theme in recent years.

2. PROCEDURE

As part of the procedure followed in this research, firstly, the experimental variables studied over time were identified by performing flexural tests of SFRCs that have been previously exposed to degradation by chlorides and whose variation directly influences the mechanical properties of maximum load and residual resistance. For the data analysis, the Taguchi experimental design was used with the help of the Minitab Software (Minitab 17.0); a regression analysis was carried out where the influence of the experimental variables on the response variable was corroborated (see Figure 1).

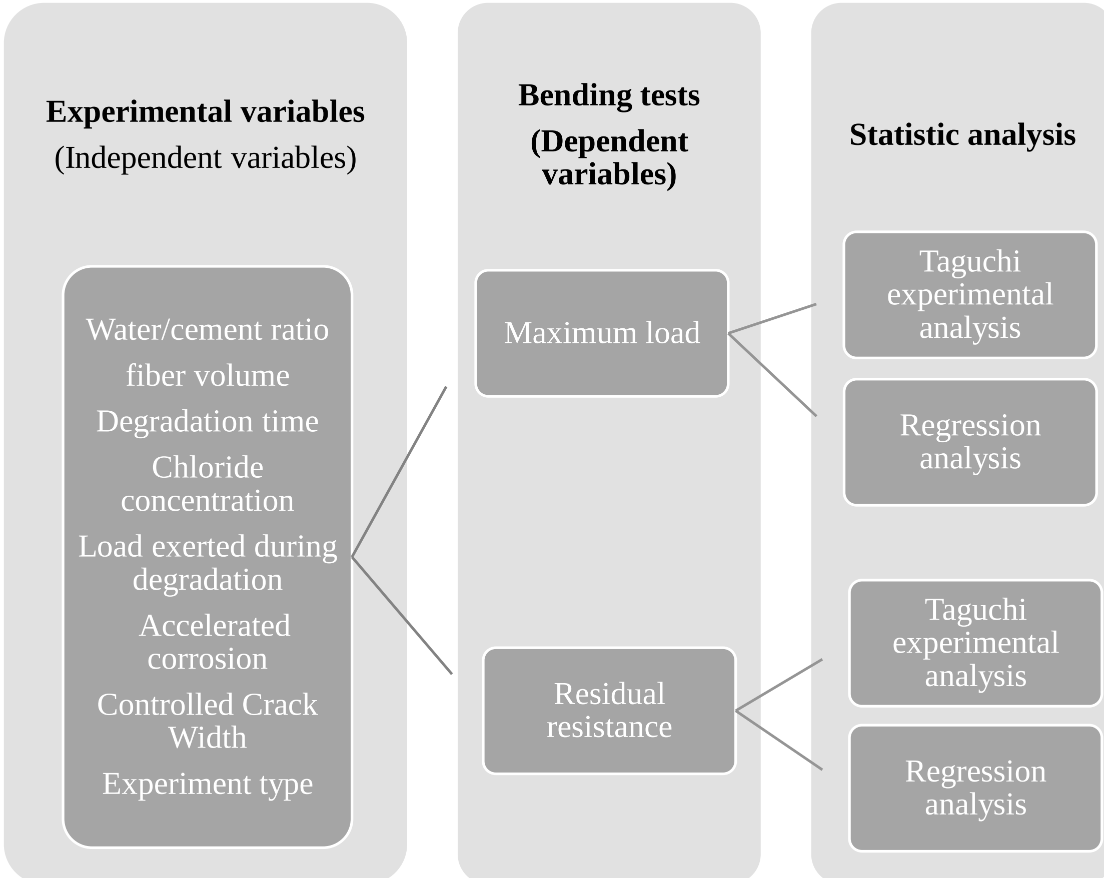

Figure 1. Representative scheme of the procedure followed in the investigation.

The water/cement ratio (Rac) is one of the most studied variables. The proportions of water and cement that are used when preparing the concrete influence the corrosive processes that the structure can suffer; this is because the greater the amount of water, the greater the density of micropores there will be in the concrete matrix, which facilitates the entry of corrosive agents such as chlorides. Furthermore, the greater the amount of water, the greater the moisture in the structure, which is the electrolyte that facilitates the oxidation reaction of the steel fibers. According to Balouch et al. (2010), when there are high water/cement ratios (Rac) (Rac = 0.78), the fibers that are close to the surface of the concrete (< 1 mm), show signs of corrosion, and the more this proportion was reduced, the smaller necessary thickness was so that there was no corrosion in the fibers. Another determinant variable in the degradation of the SFRC is the volume of fibers (Vf) to be used in the preparation of the samples; several authors have directed their studies to determine its influence on the mechanical properties of these concretes. For example, in their study, Chen et al. (2021) concluded that after the degradation process with sodium chloride, using a higher fiber content increases dynamic resistance and hence increases the strain. Also, the concentration of chlorides (C) of the aqueous solution with which the piece of concrete under study is degraded significantly influences the corrosion of the fibers and, therefore, the properties of the concrete studied. It has been shown that the maximum chloride content in conventional concrete structures should not exceed 0.4 to 1.0% by weight of cement, this figure being higher for SFRCs, reaching permissible values of up to 1.7% (Berrocal et al., 2013). On the other hand, in various studies, it has been decided to crack the concrete to obtain higher corrosion rates in shorter periods. For this reason, the width of controlled cracks (Ag) is a variable to be considered in this research; the results show that cracks allow the transport of aggressive agents into the structures (Berrocal et al., 2015; Blagojevic, 2016), demonstrating that if this exceeds a certain crack width threshold, they could be seen. affect the properties of concrete. Investigations have revealed that the chloride diffusion coefficient is similar in uncracked and cracked SFRC with crack widths less than 0.2 mm (Hou et al., 2021), which gives a certain measure of crack width to use in experiments of this type. Another variable to consider is the degradation time (Td) to which the studied sample is subjected; the degradation process of reinforced concrete can be divided into two fundamental stages: initiation and propagation. The first stage is considered the time external agents require to enter the concrete structures and cause the de-passivation of the steel. In the second stage, the propagation of the steel corrosion occurs, and changes begin to occur in the structure that reduces its safety, which indicates that the longer the time spent in degraded conditions, it is to be expected that the damage to the structure is greater (Berrocal et al., 2015). On the other hand, it is important to mention that SFRC structures subjected to degradative environments and under-bending loads could suffer effects on their mechanical properties due to the double influence of corrosion and the application of an external force. For this reason, the charge during degradation (Cd) is a variable investigated in various studies dedicated to this topic. Although the influence of loads during the corrosion process of fiber-reinforced concrete is still not completely clear, it has been shown that the action of forces on experimental beams of SFRCs has increased the width of controlled cracks formed, which could cause an increase in the corrosion rate of the fibers (Li et al., 2018). It is important to note that many researchers use alternative methods to carry out degradation experiments on concrete reinforced with steel fibers; this is because the corrosion process of the fibers is slow, and in some cases, it could take years for there to be appreciable damage effects. in concrete naturally (Taqi et al., 2021). Therefore, accelerated corrosion (Ca) emerges as an appropriate experimental alternative in these cases, which consists of making an electric current flow in the SFRC specimens while they are under the action of chlorides. This combined effect causes the chloride threshold that must be exceeded for the de-passivation of the steel to decrease and, therefore, the corrosion of the fibers to occur more quickly (Tang & Wilkinson, 2020). Finally, another experimental variable to consider in degradation studies is the type of experiment (Te) since there are two ways to perform these tests. One consists of continuous wetting of the concrete piece with sodium chloride (NaCl) solution for a determined time (continuous). The other is based on wetting and drying cycles, submerging the concrete specimens in sodium chloride solutions. NaCl for a certain time and then left to dry for another defined period, so the cycle is repeated several times (wet-dry). It has been shown that this type of experiment is the most unfavorable environmental condition for SFRC structures subjected to degradation conditions caused by the action of chlorides (Balouch et al., 2010). Through the bibliographic review carried out, experimental data was obtained from different works related to the degradation of concrete reinforced with steel fibers (see Table 1). As mentioned, this work focused on the influence of the aforementioned experimental variables on the reduction of the maximum load and the residual resistance after the degradation process in bending tests. In general, the authors relied on the standard EN 14651: 2007 for three-point bending tests (Marcos-Meson et al., 2021), as well as the standards EN 1015-3:1999, EN 413-2 : 2016 and EN 14889-1: 2006 for the use of superplasticizer, the air content and the type of fiber to be used respectively in the preparation of concrete specimens (Marcos-Meson et al., 2020).

Table 1. List of works consulted to obtain the data studied.

Author	Rac	Vf (%)	Td (días)	C (%w/w)	Cd (kN)	Ca (uA/cm^2)	Ag (mm)	Vcm (%)	Vrr (%)
Nguyen, 2018	0.54	1.30	812	3.5	0.0	0	0.00	-	28.79
Nguyen, 2018	0.54	1.30	812	3.5	54.0	0	0.00	-	42.28
Nguyen, 2018	0.54	1.30	812	3.5	89.0	0	0.14	-	66.62
Marcos-Meson, 2021	0.44	1.20	365	3.5	0.0	0	0.15	5.45	9.41
Marcos-Meson, 2021	0.44	1.20	365	3.5	0.0	0	0.30	-22.14	-18.87
Marcos-Meson, 2021	0.44	1.20	365	7.0	0.0	0	0.15	-1.92	2.35
Marcos-Meson, 2021	0.44	1.20	365	7.0	0.0	0	0.30	-32.82	-33.96
Marcos-Meson, 2021	0.44	1.20	730	3.5	0.0	0	0.15	3.25	-11.30
Marcos-Meson, 2021	0.44	1.20	730	3.5	0.0	0	0.30	16.01	1.64
Marcos-Meson, 2021	0.44	1.20	730	7.0	0.0	0	0.15	-21.75	-7.83
Marcos-Meson, 2021	0.44	1.20	730	7.0	0.0	0	0.30	17.20	12.30
Michel, 2013	0.43	0.50	24	3.0	0.0	150	0.07	-	26.44
Michel, 2013	0.43	1.00	24	3.0	0.0	150	0.07	-	20.39
Berrocal, 2017	0.47	0.50	27	3.5	0.0	100	0.00	1.29	17.98
Berrocal, 2017	0.47	0.50	97	3.5	0.0	100	0.00	-23.56	19.10
Bui, 2021	0.50	1.00	28	3.0	0.0	150	0.00	2.66	29.59
Bui, 2021	0.50	1.50	28	3.0	0.0	150	0.00	1.30	19.39
Bui, 2021	0.50	2.00	28	3.0	0.0	150	0.00	0.86	16.33
Doo-Yeol, 2020	0.20	2.00	28	3.5	0.0	0	0.00	-1.90	1.43
Doo-Yeol, 2020	0.20	2.00	70	3.5	0.0	0	0.00	1.24	-10.00
Doo-Yeol, 2020	0.20	2.00	140	3.5	0.0	0	0.00	3.86	22.86
Bernard, 2019	0.50	1.50	176	3.5	0.0	0	0.15	15.31	37.50
Hou, 2021	0.47	0.75	72	3.5	13.6	200	0.06	23.35	1.98
Hou, 2021	0.47	0.75	72	3.5	20.4	200	0.09	13.55	2.97
Hou, 2021	0.47	0.75	72	3.5	27.2	200	0.12	30.51	4.95
Hou, 2021	0.47	0.75	72	3.5	34.0	200	0.14	14.23	5.94

3. RESULTS AND DISCUSION

3.1. Effect of experimental variables on the variation of the maximum load

The values of maximum load decrease that were repeated the most in flexural tests of SFRCs after being subjected to degradation processes by chlorides were selected to determine the effect of the experimental variables on the variation of the maximum load (Vcm). For this, a histogram was made with these values, obtaining that the most significant number of variations are from -6 to 5% (see Figure 2); however, in this work, it was decided not to work with negative values, since this means that there is an increase in the maximum load in the concretes studied after being exposed to chlorides. The study of this behavior is not the objective of the present investigation; therefore, positive values from 0 to 31% were taken, and these data were used.

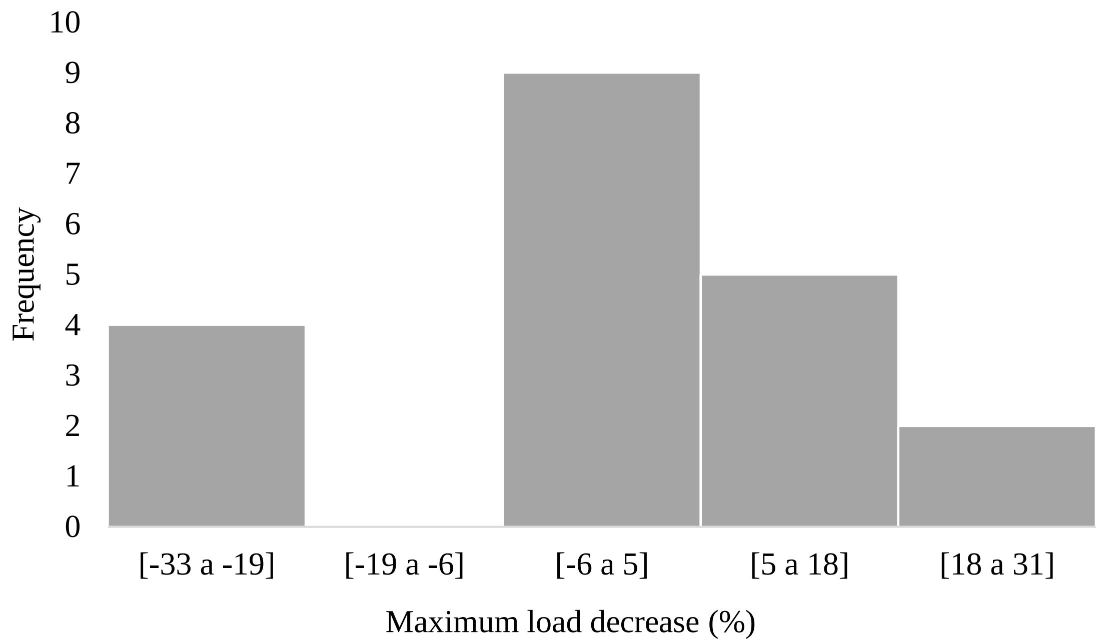

Figure 2. Histogram of maximum load variation.

3.1.1. Signal-Noise Plot Analysis

It is possible to determine which control factors have the most significant incidence on the response variable (the variation of the maximum load) by analyzing Figure 3; this is done by observing the lines in each variable. There is no present effect when the lines are horizontal, and each level affects the response similarly. In contrast, when the lines are not horizontal, if there is a main effect and each level influences the response differently, the greater the distance in the vertical position between the points plotted, the greater the magnitude of the effect (Antony et al., 2006). Therefore, it is possible to affirm that width of controlled cracks (Ag) is the variable with the greatest effect on the maximum flexural load capacity of SFRCs specimens degraded by chlorides. This variable is followed by fiber volume (Vf), degradation time (Td), chloride concentration (C), and accelerated corrosion (Ca) in order of incidence in the response variable, which is those with the greatest separation between their levels. Finally, the water/cement ratio (Rac), the load during degradation (Cd), and the type of experiment (Te) are the factors with the least effect on the variation of the maximum load. However, this work aims to find the values of the experimental variables that cause a significant decrease in the maximum load. These values can be determined by the maximum value of each factor in the signal-noise plot in Figure 3 (indicated by a red circle). Therefore, a recommended experiment design to obtain the most remarkable experimental effects of maximum flexural load variation in SFRCs specimens is the following: Rac (0.47), Vf (0.75%), Td (72 days), C (7%), Cd (27.2 kN), Ca (200 uA/cm2), Ag (0.12) and Te (wet-dry).

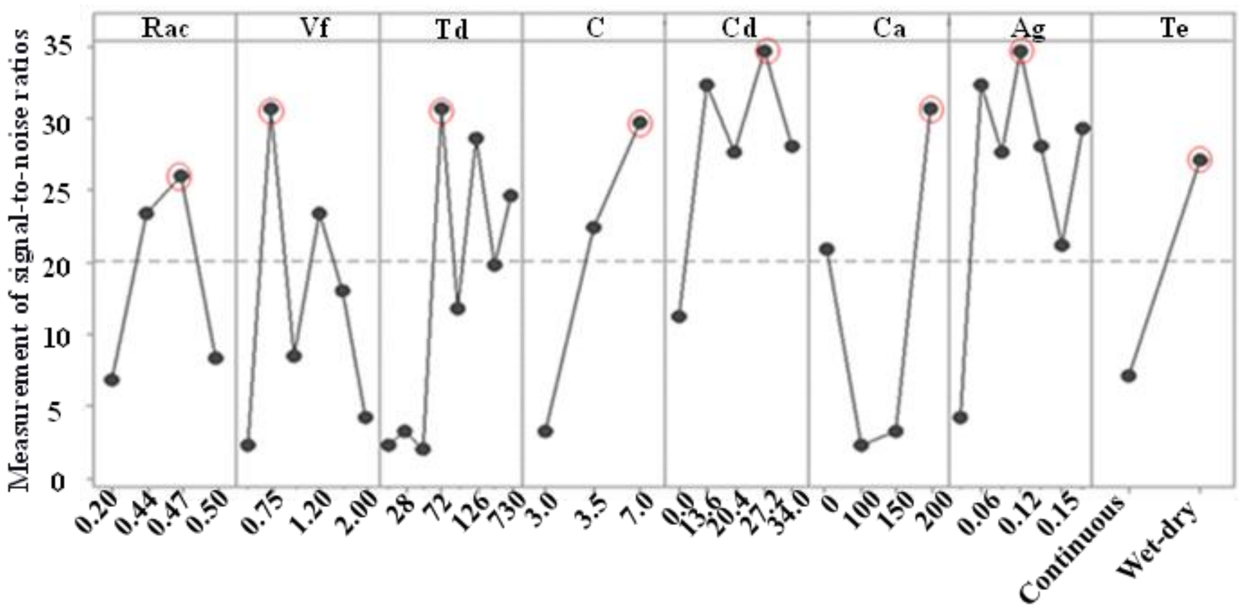

Figure 3. Main effects plot for signal-to-noise ratios for maximum load experiments.

3.1.2. Regression analysis

Analyzing Table 2, which is the result of the analysis of variance for the variables studied, it can be determined that, for none of the variables studied, the p-value is less than 0.05, which means that do not have a statistical impact on the results of variation of the maximum load in flexure. The variable with the greatest statistical impact in the previous figure, the width of controlled cracks, had a p-value of 0.081 in this analysis. In this case, it shows that the analysis of variance is not a useful tool to determine the influence of the explanatory variables on the response variable.

Table 2. Analysis of variance of the variables studied for maximum load variation.

Variables	p-value
Water/cement ratio	0.544
Fiber percentage	0.841
Degradation time	0.305
NaCl concentration	0.963
Charge during degradation	0.812
Accelerated corrosion	0.557
Width of controlled cracks	0.081
Experiment type	0.677

By analyzing the regression equations for the qualitative variable, which in this study is the type of experiment, it is possible to determine which experimental variables have explanatory power over the response variable (see equations 1 and 2). This explanatory capacity can be determined by the variables with a positive coefficient, which are the controlled crack width, NaCl concentration, and accelerated corrosion. These equations were obtained with the data used in this study using Minitab.

The regression equation for the type of continuous experiment variable:

$$V_{cm} = 13.0 - 28.4\ R_{ac} - 1.35\ V_f - 0.027\ T_d + 0.14C - 0.126\ C_d + 0.045\ C_a + 112.0\ A_g \quad \textbf{(1)}$$

The regression equation for the wet-dry type of experiment variable:

$$V_{cm} = 17.6 - 28.4\ R_{ac} - 1.35\ V_f - 0.027\ T_d + 0.14C - 0.126\ C_d + 0.045\ C_a + 112.0\ A_g \quad \textbf{(2)}$$

Therefore, the studies carried out to determine the influence of the experimental variables on the variation of the maximum load, which were the graph of main effects for signal-noise relationships, the analysis of variance, and the regression equations, allow us to conclude that the width of controlled cracks is the experimental variable that has the greatest effect on the maximum load in concrete reinforced with steel fibers that suffer degradation by chlorides. However, no works are explicitly dedicated to studying this variable's influence on the maximum load. In investigations such as that of Hou et al. (2021), contradictory results are shown since when using Ag = 0.06 mm, the decrease in the maximum load is 23.35%, while for crack widths of 0.09 mm, it is 13.55%. For values of 0.12 mm, the variation is 30.51%, which shows that this property's variation does not depend only on this variable. On the other hand, another of the variables with influence on the variation of the maximum load according to the results obtained here is the concentration of chlorides. However, this information has yet to be corroborated due to a lack of bibliographic information; studies such as that of Marcos-Meson et al. (2021) show how this variable negatively influences the properties of the SFRCs studied.

3.2. Effect of experimental variables on the variation of the residual resistance

It was done similarly to the maximum flexural load data to analyze the residual resistance variation data (Vrr) obtained. A histogram of the variation of the residual resistance was made. As observed in Figure 4, the highest frequency of variations is from 0 to 17% and from 17 to 34%; therefore, these are the data taken for continuing this study. It is also observed that there are values below zero and data greater than 34% since these rare results were not used for the abovementioned reasons.

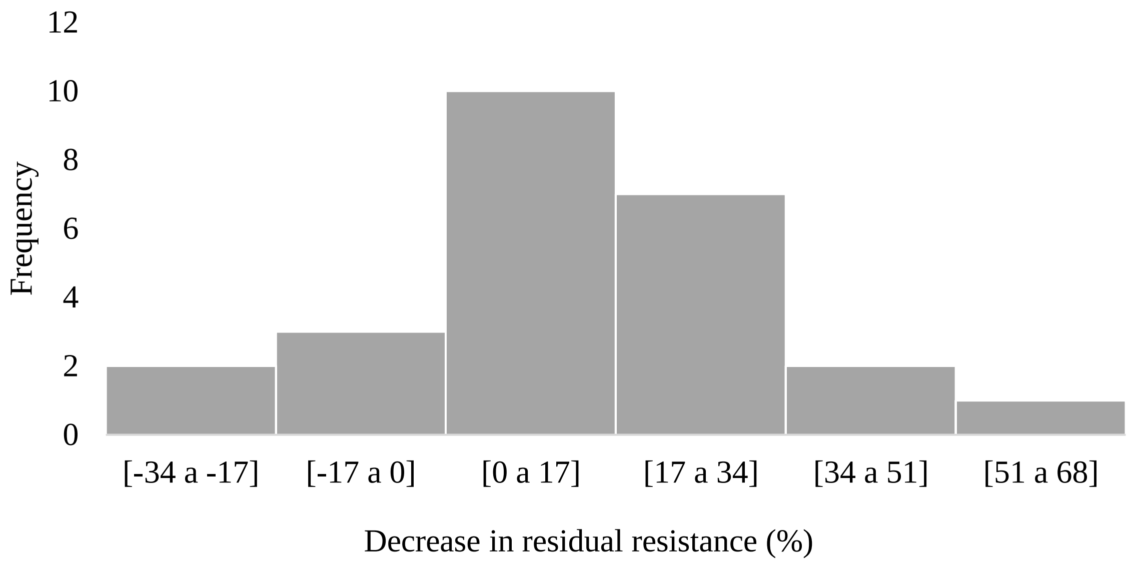

Figure 4. Histogram of residual resistance variation.

3.2.1. Signal-Noise Plot Analysis

It is possible to determine the control factors that reduce variability by analyzing Figure 5; This shows that, first of all, the response variable is affected by the bending load during degradation since it is the one that presents a greater vertical trend in the signal-noise graph.

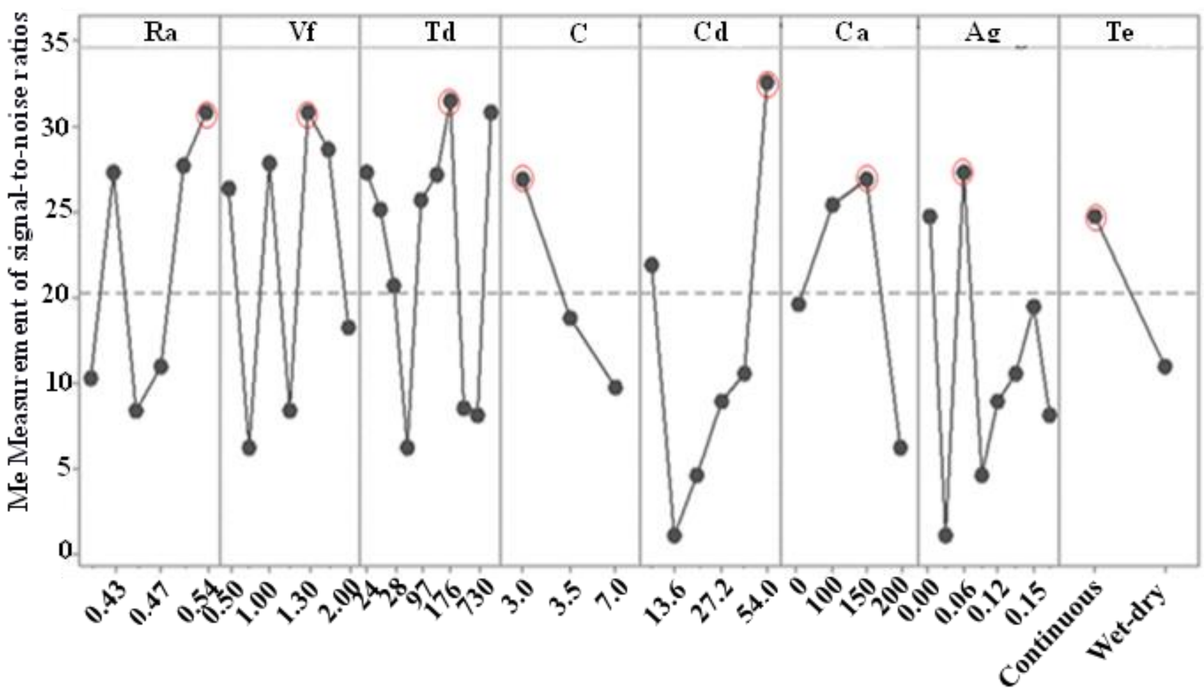

Figure 5. Main effects plot for signal-noise relationships for residual resistance experiments.

The other variables with explanatory power over the dependent variable are the water/cement ratio, the volume of fibers, the degradation time, and the width of controlled cracks, the following levels being recommended in each case to obtain more significant effects in reducing the residual resistance: Cd (54 kN), Rac (0.54), Vf (1.3%), Td (176 days) and Ag (0.07 mm), respectively. These values were obtained by taking the value of the highest level in each factor from Figure 5, marked with a red circle. On the other hand, the other variables are closer to the mean and have less effect on the signal-noise ratio; however, an experimental design must be carried out also to obtain the highest levels of variation of the residual resistance must be taken into account. Therefore, in the case of chloride concentration, accelerated corrosion, and the type of experiment, the recommended values are 3%, 150 uA/cm2, and continuous, respectively.

3.2.2. Regression analysis

A regression analysis was also carried out where the analysis of variance was studied (Table 3), obtaining that the p-value was less than 0.05 in the variables: load during degradation (0.000) and type of experiment (0.002), which means that these variables have a greater influence on the variation of the residual resistance to flexion than the others. Said result is not coincident with those obtained in the Signal/Noise graph since, in said figure, the type of experiment variable has little influence on the response variable, which is an element to be analyzed in future studies.

Table 3. Analysis of variance of the variables studied for residual resistance variation.

Variables	Valor p
Water/cement ratio	0.401
Fiber percentage	0.452
Degradation time	0.196
NaCl concentration	0.085
Charge during degradation	0.000
Accelerated corrosion	0.907
Width of controlled cracks	0.081
Experiment type	0.002

On the other hand, by analyzing the coefficients of each factor in the regression equations (see equations 3 and 4), it is possible to determine the variables with the greatest influence on the response: the load during degradation, the water/cement ratio and the time of degradation, which agrees with the results obtained in Figure 5 and in part with Table 3.

The regression equation for the type of continuous experiment variable

$$V_{rr} = 19.5 + 23.4\ R_{ac} - 4.93\ V_f + 0.019\ T_d - 2.81C + 0.555\ C_d - 0.006\ C_a - 46.8\ A_g \qquad \textbf{(3)}$$

The regression equation for the wet-dry type of experiment variable

$$V_{rr} = 3.1 + 23.4\ R_{ac} - 4.93\ V_f + 0.019\ T_d - 2.81C + 0.555\ C_d - 0.006\ C_a - 46.8\ A_g \qquad \textbf{(4)}$$

In the studies of SFRCs degradation by the action of chlorides, the experimental variable with the greatest incidence of the variation of the residual resistance is the load to which the concrete specimens are subjected during the degradation. Similar results were found by Nguyen et al. (2018), which obtained a decrease in the load capacity of the concrete studied once cracked by having been subjected to a sustained load while exposed to chlorides; found that steel fibers corroded when the applied load was 50% of the yield load. Similarly, Hou et al. 2021 found that by increasing the levels of sustained load to the concrete and under severe corrosion conditions, the load capacity of these was affected. In the same way, the water/cement ratio has a marked influence on the variation of the residual resistance, according to the results found here. However, no studies in the literature are dedicated to comparing how this variable influences said property. Finally, as has been seen, the degradation time also influences this characteristic, which is contradictory to that obtained by Marcos-Meson et al., 2021, since they got few changes in the mechanical performance of the degraded SFRCs. by chlorides and carbon dioxide for 1 and 2 years. It means that the results obtained in this type of study remain contradictory and future research is required.

4. CONCLUSIONS

Through the analysis of the studies carried out regarding the degradation of concrete reinforced with steel fibers by the action of chlorides, and taking into account the main experimental variables that affect the properties of residual resistance and maximum load of said concretes, it is possible to arrive at the following conclusions:

1. The results found in the bibliography show that the degradation processes by chlorides not only negatively affect the mechanical properties of the SFRCs but that, in some cases, said properties could have an improvement after the degradation; this is attributed to an increased

bond strength between concrete and fiber due to increased surface roughness due to corrosion.

2. Analyzing the results obtained for the experiments where the variation of the maximum flexural load was evaluated, it is found that the variable whose variation affects this property the most is the width of controlled cracks, with the value of 0.12 mm being the most relevant. In the same way, when ordering the variables according to their influence on the variation of the maximum load supported by the CRFAs after degradation processes due to chlorides, it would be as follows: Ag (0.12 mm), Vf (0.75%), Td (72 days), C (7%), Ca (200 uA/cm2), type of experiment (wet-dry) and Rac (0.47).
3. In the case of residual flexural strength, the experimental variable that has the greatest effect on this property is the load during degradation, and it was shown that the higher the load, it is to be expected that the residual strength after the degradation process will be more affected. In the same way, an order of variables was obtained in terms of their influence on the residual resistance, so it is possible to recommend the following values of each variable to be used to obtain the greatest decreases in this property in chloride degradation experiments: Cd (54 kN), Rac (0.54), Vf (1.3%), Td (176 days), Ag (0.07 mm), C (3%), Ca (150 uA/cm2) and type of experiment (continuous). These variables were arranged from highest to lowest influence on residual resistance.
4. Due to the results obtained, it is recommended to continue with the study of the influence of experimental variables such as the material of the fibers, the size and shape of the concrete specimens, and the type of raw material used for the elaboration of these in mechanical characteristics such as durability, toughness, and ductility.

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