EXPERIMENTAL EVALUATION OF GALVANIZED AND ANNEALED WIRES TO PRODUCE HOOKED FIBERS AS REINFORCEMENT OF CONCRETE UNDER FLEXION

EVALUACIÓN EXPERIMENTAL DEL ALAMBRE GALVANIZADO Y RECOCIDO PARA PRODUCIR FIBRAS CON GANCHOS COMO REFUERZO DEL CONCRETO A FLEXIÓN

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Abstract

The steel fiber reinforced concrete is a composite material used to build structural elements used commonly in Europe; but in Mexico, the scarce availability of commercial fibers has limited its application. The present paper discusses the feasibility of generating hooked end steel fibers from conventional materials used in the industry -as the galvanized wire and the annealed wire-. The production of the reinforced elements was made with a stamping process using a set of dice. The effects of the incorporation of galvanized and annealed fibers on the mechanical properties of the concrete matrix were experimentally investigated under three-point bending test. Parameters as the fiber materials and the fiber dosage were analyzed in the responses of the maximum load, the residual strength, and the number of fibers at the cracking section. The results showed that concrete samples reinforced with galvanized and annealed fibers have higher post-cracking behavior than conventional concrete, with a better performance of the concrete reinforced with galvanized fibers than those with annealed fibers.

Keywords: steel fiber reinforced concrete, composite material, galvanized and annealed wires, fiber reinforcement.

Resumen

El concreto reforzado con fibras es un material compuesto utilizado para la construcción de elementos estructurales comúnmente utilizado en Europa; pero en México, la escasa disponibilidad de fibras comerciales ha reducido su aplicación. El presente artículo discute la factibilidad de generar fibras de acero con ganchos a partir de materiales comerciales comúnmente empleados en la industria –como el alambre galvanizado y el alambre recocido-. La producción de elementos de refuerzo se realizó mediante un proceso de estampado con un juego de dados. El efecto de la incorporación de fibras galvanizadas y recocidas en las propiedades mecánicas de matrices de cemento fue investigado experimentalmente bajo el ensayo de tres puntos. Parámetros como los materiales y dosis de fibra fueron analizados en las respuestas de la máxima carga, la resistencia residual y la cantidad de fibras en zona de fractura. Los resultados muestran que las muestras de concreto reforzado con fibras de alambre galvanizado y alambre recocido tienen mejor comportamiento post-agrietamiento que el concreto convencional, con un mejor desempeño del concreto reforzado con fibras galvanizada que aquellas con fibras recocida.

Palabras Clave: *concreto reforzado con fibras de acero, materiales compuestos, alambres galvanizado y recocido, fibras de refuerzo.*

1. Introduction

Conventional concrete has diverse mechanical strength when loads in different directions are applied. The concrete has notable strength in compression; but under flexural load, it fails in a brittle manner due to its low tensile resistance (Soutsos, Le, & Lampropoulos, 2012). According to Yoo, Lee, & Yoon (2013), the deficiency of the concrete under flexural load has generated many structural problems in civil infrastructures. Thus, the conventional concrete has been reinforced with elements that improve its performance when it is subject to tension load.

Steel fiber reinforced concrete (SFRC) is a composite material, in which steel fibers are randomly distributed in a concrete matrix (Poveda, Ruiz, Cifuentes, & Yu, 2017). Even though commercial fibers generated a slight decrease in the compressive strength when these elements are mixed with the concrete, the fibers give superior residual strength to the conventional concrete under flexural load. This effect is attributed to the fibers bridging mechanism across the crack surfaces, generating ductility to the concrete matrix (Khaloo, Raisi, Hosseini, & Tahsiri, 2014; Meza et al., 2014; Buratti, Mazzotti, & Savoia, 2011; Meddah & Bencheikh, 2009; Kaur, Singh, & Kaushik, 2016; Arabani & Pedram, 2016). Some applications of SFRC are industrial floors, tunnel lining, pipes, and road pavements (Carmona, Molins, & Aguado, 2016; Nehdi, Mohamed, & Soliman, 2016; Khaloo et al., 2014; Buratti et al., 2011). In spite of the strength capacity documented about the SFRC and its applications; Emon, Manzur, & Sharif (2017) reported a limited distribution of commercial fibers in some local market in the Asian continent. This problem also has been reported by Meza (2015), metallic industrial fibers are difficult to obtain in Aguascalientes, Mexico.

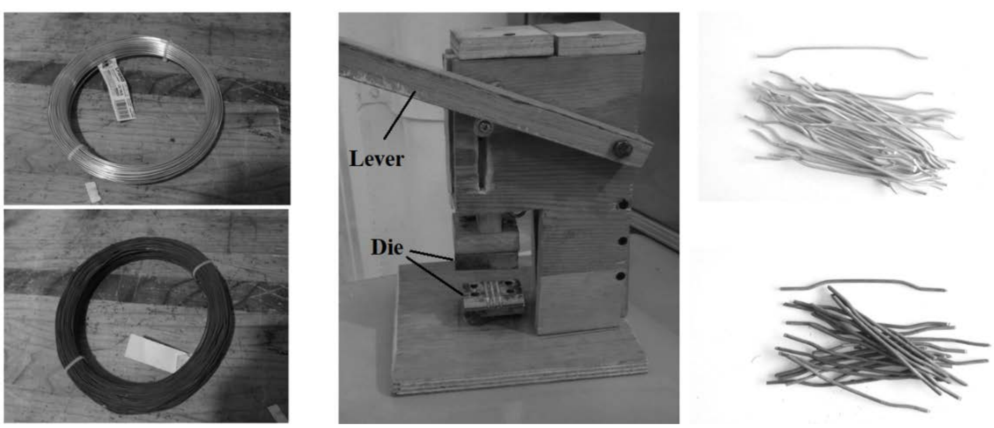
The use of commercial wires (galvanized and annealed wires) to produce fibers is an alternative that this research presents. The galvanized iron wire is mild steel, which is manufactured from rolled steel rods, and covered with a thin coating of zinc (Gelfi, Solazzi, & Poli, 2017). On the other hand, the annealed wire is a material, which its cold formability has been improved (Yang & Liu, 2016). A limited number of studies have been reported on the use of fibers from industrial wires as reinforcement in concrete; the closest reference to SFRC with galvanized elements is the Emon et al. (2017) study, in which straight fibers manufactures with galvanized iron wire were analyzed. Their results showed that the concrete reinforced with these elements had significant improvement compared to normal concrete.

In this research, a device to produce end hooked fibers from galvanized and annealed wires was constructed. Samples of galvanized steel fiber reinforced concrete (GSFRC) and samples of annealed steel fiber reinforced concrete (ASFRC), with different fiber dose, were tested under three-point bending. The results showed a superior mechanical strength of GSFRC and ASFRC than conventional concrete, proving ductility and load capacity after the concrete cracks, indicating viability on the use of galvanized and annealed fibers as reinforcement of the concrete.

2. Methods

Galvanized and annealed fibers

The raw material used to produce the fibers was galvanized wire and the annealed wire, which were placed in a device to produce the hooked end shape. Then, to produce the fibers, the wire was measured with a Vernier and cut manually, with a cutting plier. The device works with the principle of a pressing machine, with a pushing system and a set of dice. The hooked end was formed manually with a lever that activates the superior die to deform the wire and generate the fiber shape. Figure 1 illustrates the raw wires, the pressing device and the fibers produced.



a) Raw wires. b) Pressing device. c) Fibers produced.

Figure 1 Galvanized and annealed fibers procedure.

The average dimensions of the fibers produced were obtained with 20 samples randomly selected, and measured with a digital Vernier caliper. The results indicate that the galvanized fibers have an aspect ratio (relation length/diameter) of 51.3 and the annealed fibers of 36.7. According to ACI (2002) standard, the fibers should have an aspect ratio higher than 20. Figure 2 shows the average dimensions of the fibers produced.

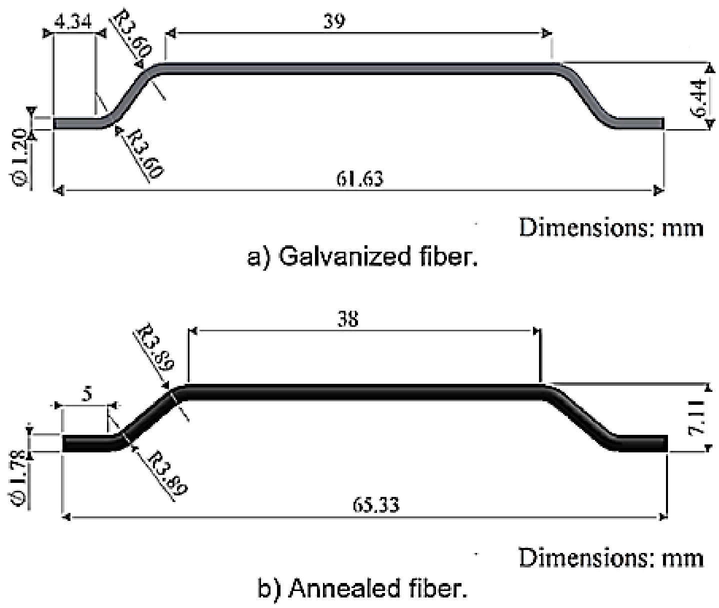


Figure 2 Dimensions of fibers produced with the mechanism designed.

Cement matrix

The concrete used in the present study was set according to specifications of ASTM C150 (2016), with a compressive strength of 40 MPa. The concrete design included four different types de aggregates and an ordinary Portland cement with a water/cement ratio of 60%. Table 1 presents the proportions of the material used for manufacturing the concrete.

Table 1 Concrete mix proportions.

Component	Dosage (kg/m^3)
Portland cement	308.0
Crushed limestone	189.0
River sand	484.4
20 mm crushed rhyolite gravel	531.3
40 mm crushed rhyolite gravel	648.0
Water	185.0

Test program

Ten samples were made, three for galvanized steel fiber reinforced concrete (GSFRC), three for annealed steel fiber reinforced concrete (ASFRC), three for industrial hooked end steel fibers (SFRC), and one of conventional concrete. In the samples with fibers, the fibers dose was varied, with fiber doses of 20, 30 and 40 kg/m^3. The fiber doses are similar than those used in SFRC applications (Meza et al., 2014).

The mixture was made according to the following steps. First, the materials, aggregates, and fibers were mixed for 4 min manually. Then the water was dispensed and mixed for 5 min to get homogeneity, this procedure is similar to the one used by Meza and Siddique (2019). On the other hand, the samples and the flexural test were according to ASTM C-78 (2000), and the curing procedure was according to ASTM C-192 (2000).

3. Results

Three-point bending test

Three-point bending tests were performed at 28 days. The deflection was measured by mean of one dial indicator of 25 mm, located at the bottom part of the specimen center. GSFRC, ASFRC, and SFRC specimens had a fiber dose of 20, 30 and 40 kg/m^3. Conventional concrete sample (CC) was used as a reference element. The fibers used in SFRC samples were Dramix ® (2019). Figures 3, 4, and 5 show the results by mean of load-deflection curves. The results indicate a sudden break of the specimen without ductility. On the other hand, the GSFRC, ASFRC and SFRC specimens demonstrated ductility, while CC shows a deflection capacity of 1.6 mm; the samples reinforced with fibers demonstrate more than 20 mm.

Maximum load strength

The diagram load-deflection of SFRC is characterized by the limit of proportionality, before the concrete cracks (Buratti et al., 2011). The limit of proportionality is represented by the maximum load (Pmax), which was compared between GSFRC, ASFRC, SFRC, and CC in figure 6. The results indicate that the addition of hooked end steel fibers in the concrete increased the Pmax, all the steel fiber reinforced concrete tested had superior Pmax than conventional concrete. On the other hand, the specimens of GSFRC and ASFRC had lower Pmax than SFRC; this was attributed to the lower tensional strength of the galvanized wire and the annealed wire than industrial fibers (DEACERO ®, 2019; Dramix ®, 2019).

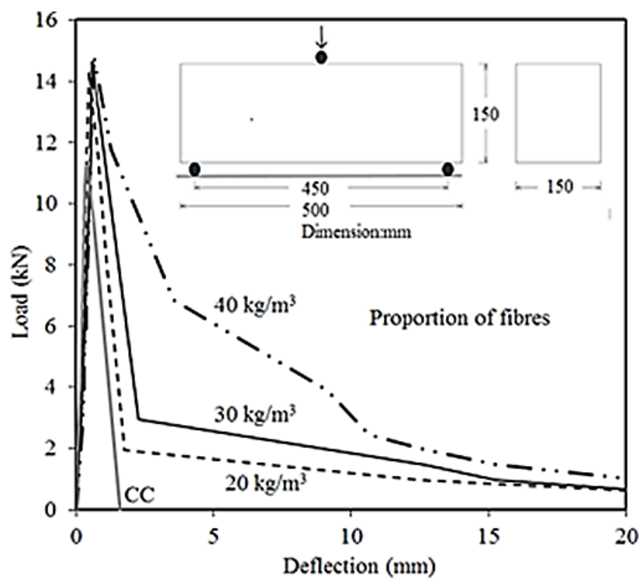


Figure 3 Load-deflection curve for galvanized steel fiber reinforced concrete and conventional concrete.

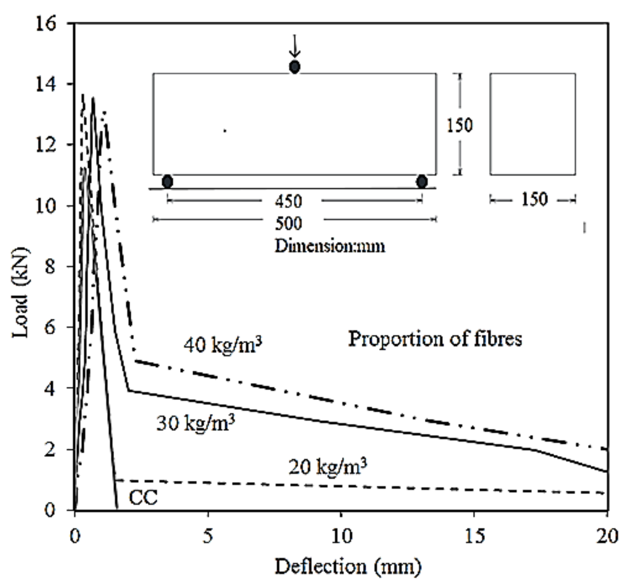


Figure 4 Load-deflection curve for annealed steel fiber reinforced concrete and conventional concrete.

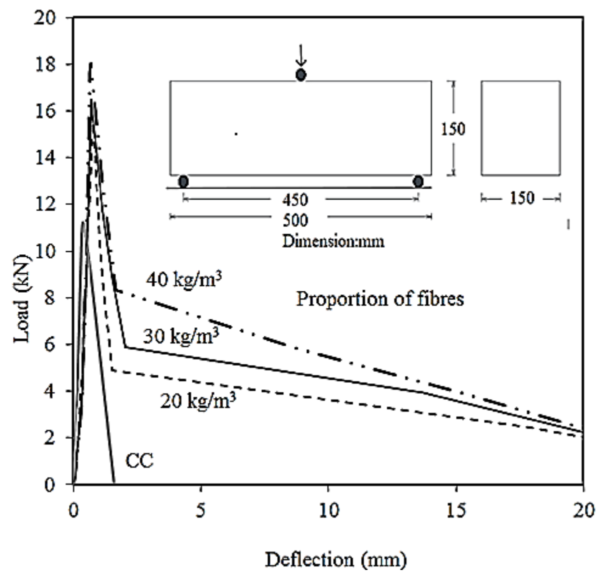


Figure 5 Load-deflection curve for industrial steel fiber reinforced concrete and conventional concrete.

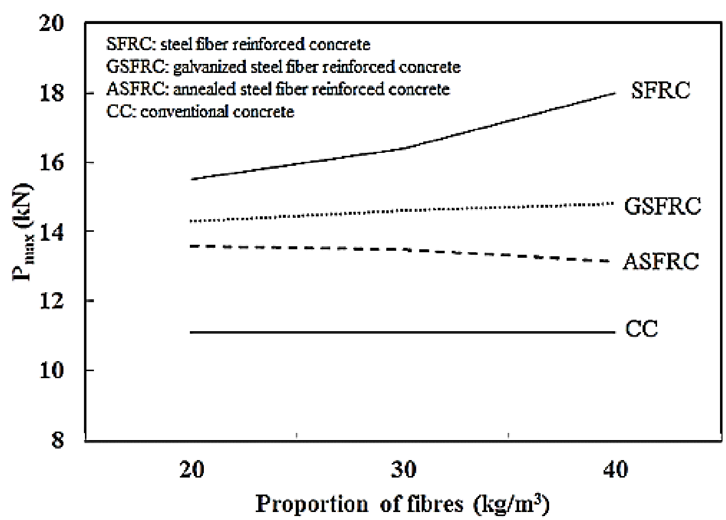


Figure 6 Relationship between the proportion of fibers and maximum load.

Post-cracking strength

The Japanese Concrete Institute (JSCE-SF4, 1983) proposes a test method to measurement the residual strength, with beams in a third-point loading arrangement. According to JCI, the post-cracking resistance is measured with the equivalent flexural strength $R_{e,3}$ (Soutsos et al., 2012). The GSFRC, ASFRC, and SFRC samples were calculated according to JCI, the results indicated that the GSFR samples with dose fiber of 40 kg/m^3 had superior $R_{e,3}$ to those samples with commercial fiber; on the other hand, the fiber dose of 20 and 30 kg/m^3 had similar behavior than SFRC, the maximum difference was 2.4%. Similar behavior was found on ASFRC samples, the fiber dose of 40 kg/m^3 had superior $R_{e,3}$ to those samples with commercial fiber; whereas that the dosage of 20 and 30 kg/m^3 demonstrated a maximum difference of 9.6%. In general, the post-cracking strength of GSFRC was better than AFRC.

After the flexural test was made, the number of fibers at the cracking section was counted. Figure 7 illustrates the results of $R_{e,3}$ and number of fibers. The results indicated that the number of reinforced elements was higher in the GSFRC specimens than in the ASFRC and SFRC, showing a better distribution in the concrete reinforced with galvanized fibers. Also, the data indicate that the $R_{e,3}$ values are incremented with the proportion of fibers, i.e. samples with the highest number of fibers had the best $R_{e,3}$ performance.

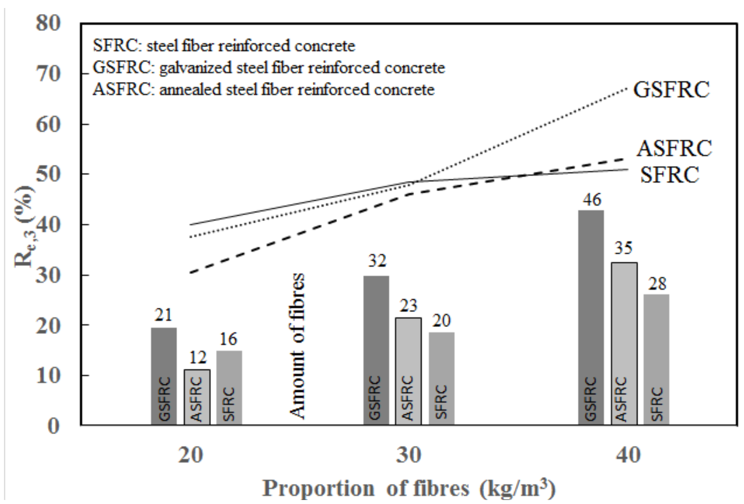


Figure 7 Relationship between the proportion of fibers with the Re,3 and amount of fibers.

4. Discussion

The present work investigated the flexural behavior of beams made of concrete reinforced with galvanized and annealed hooked end fibers in different fiber proportions. All the tests were realized at 28 days in a three-point bending test. The fibers were produced from conventional wires and with the use of a device to generate the hooked end.

The concrete samples reinforced with galvanized and annealed hooked end fibers presented higher maximum load and ductility than the conventional concrete samples. Also, the post-cracking strength, measured with the Re,3, was comparable between the samples of concrete with galvanized and annealed fibers than those reinforced with commercial fibers.

Concrete samples reinforced with galvanized fibers showed better mechanical performance than those with annealed fibers. This effect was attributed to the number of fibers at the cracking section.

The research found that the galvanized and annealed fibers are an opportunity to reinforce the concrete under flexural load. Future directions could consider the optimization of the fiber reinforced concrete with the elements proposed.

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