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Comportamiento mecánico del hormigón sometido a altas temperaturas confinado con CFRP. Mechanical behaviour of concrete subjected to high temperatures confined with CFRP.

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***Resumen*— El hormigón es el material estructural más empleado. En el caso de sufrir una agresión térmica, sus propiedades mecánicas se ven modificadas, siendo en muchos casos necesaria su reparación para poder seguir utilizando la estructura. Teniendo en cuenta las premisas anteriores, el objetivo de la presente investigación es determinar la viabilidad del refuerzo de estructuras de hormigón con CFRP, después de haber sido sometidas a una agresión térmica. Para la realización del trabajo experimental se fabricaron probetas cilíndricas de 100 mm de diámetro y 200 mm de altura, la mitad de las cuales fueron sometidas a 250ºC. Una vez enfriadas, la mitad de las probetas patrón y la mitad de las probetas sometidas a 250ºC se reforzaron con fibra de carbono unidireccional SikaWrap-230 C, para posteriormente ensayar todas ellas a compresión y determinar la viabilidad del refuerzo. Los resultados obtenidos muestran que, debido a la agresión térmica, el hormigón pierde parte de su capacidad resistente, reduciéndose su resistencia máxima en un 26%. Una vez reforzadas las probetas, su resistencia máxima aumenta un 105% en el caso de probetas patrón y un 89,5% en el caso del hormigón sometido a 250ºC.**

Palabras Clave— Cemento, temperatura, CFRP, compresión.

***Abstract*— Concrete is the most widely used structural material. In the case of suffering a thermal aggression, its mechanical properties are modified, being in many cases necessary to repair in order to be able to continue using the structure. Taking into account the above premises, the aim of the present research is to determine the viability of reinforcement of concrete structures with CFRP, after being subjected to thermal aggression. For the realization of the experimental work, cylindrical specimens of 100 mm in diameter and 200 mm in height were made, half of which were subjected to 250ºC. Once cooled, half of the standard specimens and half of the specimens subjected to 250ºC were reinforced with SikaWrap-230 C unidirectional carbon fiber, in order to subsequently test all of them in compression and determine the viability of the reinforcement. The results obtained show that due to the thermal aggression, the concrete loses part of its resistance capacity, reducing its maximum resistance by 26%. Once the specimens are reinforced, their maximum strength increases by 105% in the case of standard specimens and by 89.5% in the case of concrete subjected to 250ºC.**

Index Terms— Concrete, temperature, CFRP, compression.

I. INTRODUCTION

Concrete is the most widely used structural material due to its versatility and low cost, in addition to its mechanical properties. In the case of high temperatures, concrete alone provides high protection because it is non-combustible and conducts temperature moderately (Catalán &

Maestro, 2007; ASTM, 2011). In addition, it does not contribute to the fire load, does not emit toxic gases and presents a high capacity to be repaired later (ASTM D5334, 2014; EN 1504. 2009; CEMBUREAU, 2019; NUREG/CR-7031 ORNL/TM-2009/175, 2009).

Despite the protective capacity discussed above, as the minutes pass and the temperature increases, the intrinsic properties of concrete are affected. Among the factors that most influence the increase of temperatures in its mass and thus its cracking are: thermal conductivity, permeability, hydration, saturation, porosity, humidity and density (Khoury 2000; Guo, et al., 2016; Asadia et al. 2018).

The changes that occur in their physical and chemical properties are the result of processes that take place progressively: starting with the loss of free water at approximately 100 ˚C and the detachment of the coating (NUREG/CR-7031 ORNL/TM-2009/175, 2009; Zhang, et al. 2019.; L. Li, et al. 2020; Walz, 2019; Torelli, et al. 2016; Suescum-Morales, et al. 2021). Up to 300 ˚C structural modifications appear. At 450°C the decomposition of calcium hydroxide occurs and at 573˚C the crystalline transformation of quartz. At this stage, the pore structure of the concrete evolves, producing water loss and generating surface cracks. The concrete tends to obtain a pinkish coloration due to changes in the properties of the iron compounds. At around 600 ˚C the quicklime is released, acquiring a reddish color (Anchor, et al. 1986; Ercolani, et al. 2007). Once the threshold of 650 ˚C is exceeded and up to 950 ˚C, an expansion of the aggregates occurs and disintegration appears, with grayish shades. From these temperatures, the destruction of the conglomerate occurs, with a yellowish tone, losing its mechanical properties (Varona & Baeza, 2017). In the cooling process, the thermal variation produced between the exterior and interior of the concrete generates a differential shortening, which produces stress concentrations and cracking of the concrete (Ercolani, et al. 2007).

Malik et al. and numerous authors conclude that the residual compressive strength of concrete decreases significantly from 500 or 600 °C, some of them stating that a thickness of 100 mm of concrete becomes unrecoverable after 30 minutes of exposure to 500 °C (Malik, et al., 2020; Seshu and Pratusha, 2013; Shumuye et al. 2019; Hager et al. 2019; Malik, et al. 2019; FIB 90, 2019).

On the other hand, one of the most commonly used reinforcement methods in reinforced concrete structures subjected to compression is confinement reinforcement with carbon fiber fabrics (CFRP) (ACI 440R-07, 2007). The most important benefits of carbon fiber with respect to other types of fiber are: high strength and elastic modulus and high thermal and electrical conductivity (Waghmare et al. 2021). As for the resins used, they develop their properties in three phases, having to meet the following parameters ((MIL-HDBK-17-1, 2002): performance indicated by the manufacturer, (Baquer Sistach, 2021), fatigue resistance and sufficient adhesion (UNE-EN 1542, 2000; Ferrier et al., 2016; Abdulrahman & Aziz, 2021) and adequate viscosity (Fiore & Valenza, 2013; Huang et al., 2021). In addition, the resin offers protection to the fibers from abrasion and environmental degradation and allows for the transmission of the shear stress, a parameter based on adhesion and surface roughness (Código Estructural, 2021; Li et al., 2019; Huang et al., 2021; Mugahed et al., 2018; Ostrowski & Furtak, 2021).

Along with the above parameters, the successful use of the system lies in its use at an ambient temperature that is within the service temperature range, and always below the glass transition temperature of the resin, which is between 40 and 72 ºC (Ahmed et al., 2021; López, et al., 2021; SIKA CORPORATE, 2008; Kasper, 2021; ETA-21/0276, 2021).

In the case of columns subjected to compression and the use of unidirectional dry-woven fabrics, it is necessary to take into account the following aspects that condition the effectiveness of the reinforcement: cohesion of the support and surface preparation, increasing considerably the effectiveness of the reinforcement when the support has a high roughness (Jimenez, 2020a; González, 2020; Jimenez, 2020b; CSIC, 2019; Rodríguez et al, 2021; Ma et al., 2017; Mostofinejad et al., 2021; Moghaddas et al., 2021; Ostrowski et al. 2021; Wang et al. 2018). Execution and environmental conditions (Russian et al., 2021, ACI 440R-07, 2007). Section shape and relationship between sides in rectangular sections (Ahmed et al., 2021; Martinez, 2020). And the overlap length (TR 55, 2012; Mai et al., 2021).

Another important aspect is the minimum mechanical performance of the support: minimum compressive strength between 10 and 20 MPa according to different authors and minimum pullout stress of the support of 1.5 MPa (TR 55, 2012; De Diego, 2020; Baquer et al., 2021; Jimenez, 2020).

Regarding the behavior of concrete reinforced by confinement with CFRP, it is known that the confinement of columns using carbon fiber fabrics significantly improves the compressive strength, ductility and energy absorption capacity of concrete, obtaining the most effective results in circular sections (Pendhari et al., 2008; Obaidat, 2022; Eid & Paultre, 2017).

Taking into account the above premises, the aim of the present research is to determine the viability of reinforcement of concrete structures with CFRP, after being subjected to thermal aggression.

II. METHODOLOGY

For the development of the experimental part, cylindrical specimens of 100 mm in diameter and 200 mm in height were made, with a cement/sand/gravel/water dosage of 1:2:3:0.5, carrying out all the experimentation in the facilities of the materials laboratory of the Escuela Técnica Superior de Edificación de Madrid (ETSEM) of the Universidad Politécnica de Madrid. The materials used are listed below:

- Portland cement type CEM-II/B-L 52.5 N (EN 197-1:2011, 2011).
- Coarse aggregate of maximum size 12.5 mm and fine aggregate of maximum size 4 mm (fraction 0-4 mm) (EN 12620:2003+A1:2009, 2009; Proschek. 2019).
- Tap water from Canal de Isabel II de Madrid, as it complies with the general requirements for use in structural concrete (Código Estructural, 2021).
- Dynamon NRG 1015 type superplasticizing admixture (EN 934-2:2010+A1:2012. 2019; Wróblewska & Kowalski, 2020).
- Unidirectional carbon fiber fabrics weighing 230g/m2 (SikaWrap-230 C).
- Two-component resin (Sikadur-330), with Technical Suitability Document No. 604R/19 (CSIC, 2019).

Once the materials were weighed, the aggregates were incorporated into an IBERTEST model CIB-701 vertical shaft planetary mixer and mixed for two minutes. Next, the cement was incorporated, and once a homogeneous mixture was obtained, the water and the superplasticizer additive were added. All the materials were kneaded for 6 minutes. The Abrams cone test was carried out, obtaining a fluid consistency (EN 12350-2:2020, 2020). Once the mixing was completed, the molds were filled in three batches, compacting each one of them and leveling the surface.

Fig. 1. Experimental process. a) Fabrication; b) Heating; c) CFRP reinforcement; d) Compression test.

Once the filling process was completed, the molds were kept for 24 hours in laboratory conditions (22ºC ± 3 ºC and relative humidity of 60%), before being stripped. After this time, the specimens were demolded and placed in the curing chamber, where they remained for a period of 28 days at a temperature of 20ºC ± 2ºC and a relative humidity of 98%. Once the curing process was completed, the specimens were removed from the humid chamber. Half of them were kept at room temperature and the other half were introduced into the IEP control oven, from room temperature, and kept for 180 minutes in the oven at a temperature of 250ºC. After this time, they were removed and allowed to cool to room temperature.

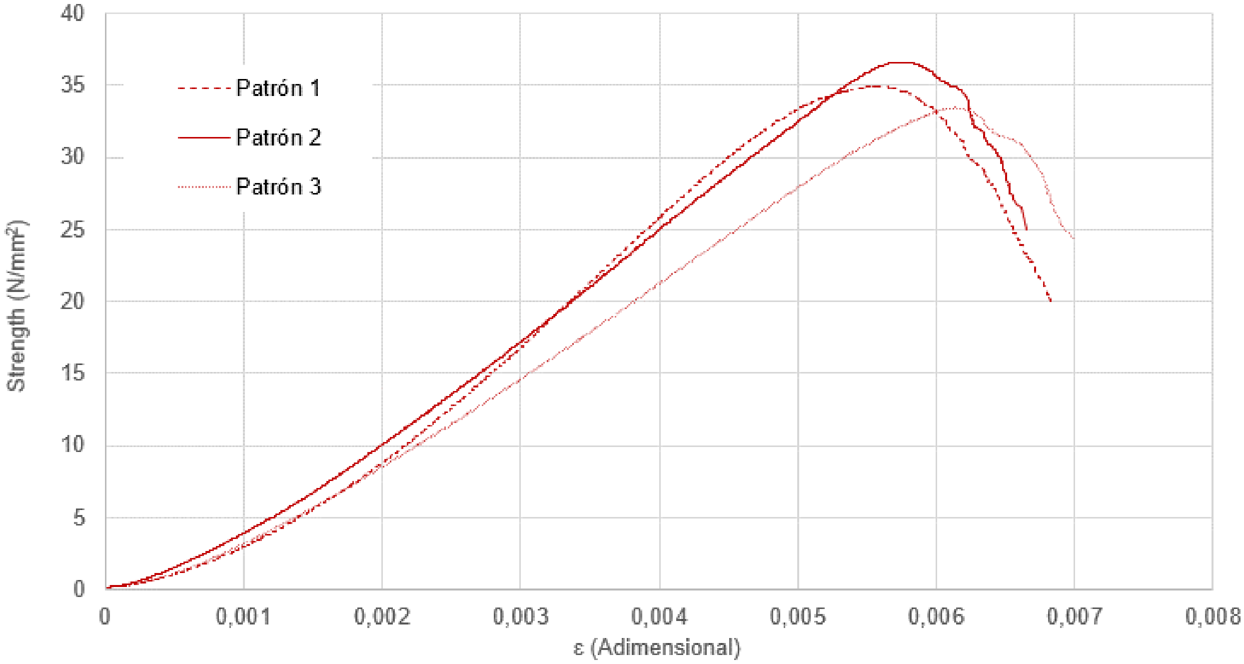

Fig. 2. Evolution strength-strain, corresponding to the compression test on standard specimens.

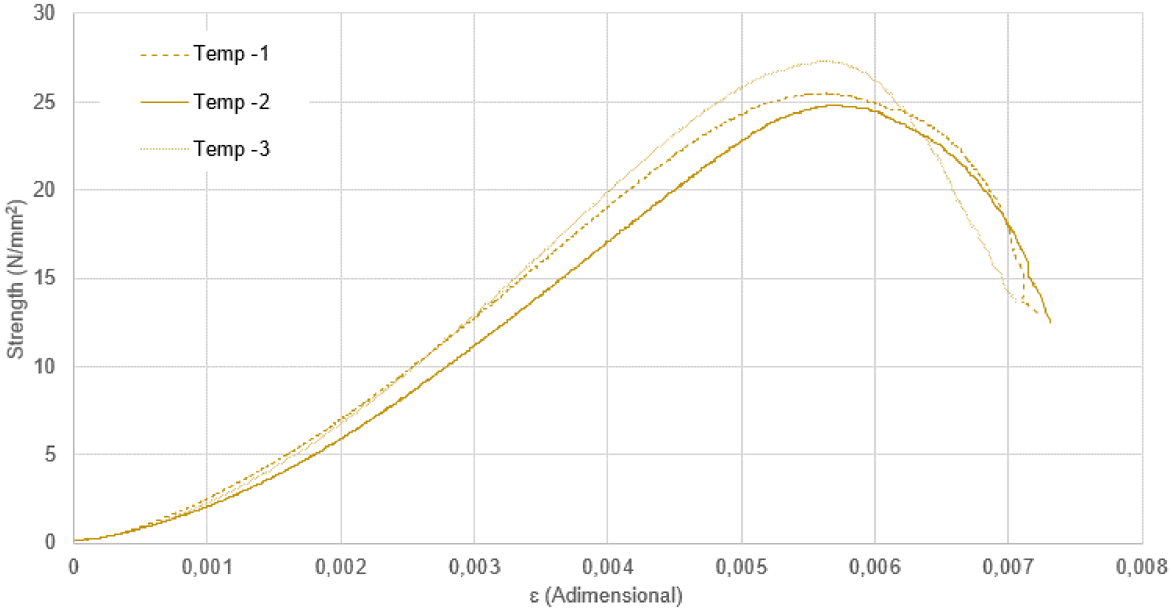

Fig. 3. Evolution strength-strain, corresponding to the compression test on specimens subjected to 250ºC.

Half of the standard specimens and half of the specimens subjected to 250ºC were reinforced with unidirectional carbon fiber fabric strips (SikaWrap-230 C), measuring 180 mm x 420 mm, by applying an epoxy resin with the aid of a roller. The process of using the products and the steps followed were taken from the execution method of the manufacturer of the system used (Jiménez, 2020).

Subsequently, all the specimens were then faced with sulfur mortar (EC 1907/2006, 2006). Once the specimens had been faced, they were tested in compression in the IBERTEST MIB-60/AM universal press (EN 12390-3.2020, 2020). The experimental process can be seen in Figure 1.

III. Results and Discussion

The results obtained in the compression test on the unreinforced standard specimens are shown in Figure 2. As can be seen, the mechanical behavior of the different specimens is similar, obtaining average strengths of 35N/mm^2.

Figure 3 shows the compression behavior of the concrete specimens subjected to 250ºC. As can be seen, in spite of having been subjected to thermal aggression, the strengths achieved would allow its use as structural concrete, reaching an average strength of 25N/mm^2.

Table 1 shows the most representative values of the strength-strain graphs of the compression tests, in the standard specimens and in those subjected to 250ºC: maximum strength (σ_{max}), maximum unit strains (ε_{max}), ultimate strength (σ_u), ultimate unit strains (ε_u), maximum strain energy density (E_{max}) and ultimate strain energy density (E_u).

TABLE I

Most representative values of the compression test on standard specimens and specimens subjected to 250ºC

	σ_{max} (N/mm^2)	σ_u (N/mm^2)	ε_{max} x 10^{-3}	ε_u x 10^{-3}	$E_{máx}$ x 10^{-2} (N/mm^2)	E_u x 10^{-2} (N/mm^2)
Patrón-1	34.98	17.49	5.59	6.98	9.12	13.07
Patrón-2	36.63	25.01	6.11	6.66	11.08	12.78
Patrón-3	33.46	24.31	6.15	7.00	9.66	12.23
Average values	35.02	22.27	5.95	6.88	9.95	12.70
Temp-1	25.48	12.89	5.63	7.24	6.90	10.45
Temp-2	24.81	12.47	5.67	6.57	6.33	8.48
Temp-3	27.29	13.65	5.65	7.06	7.19	10.30
Average values	25.86	13.00	5.65	6.95	6.80	9.74

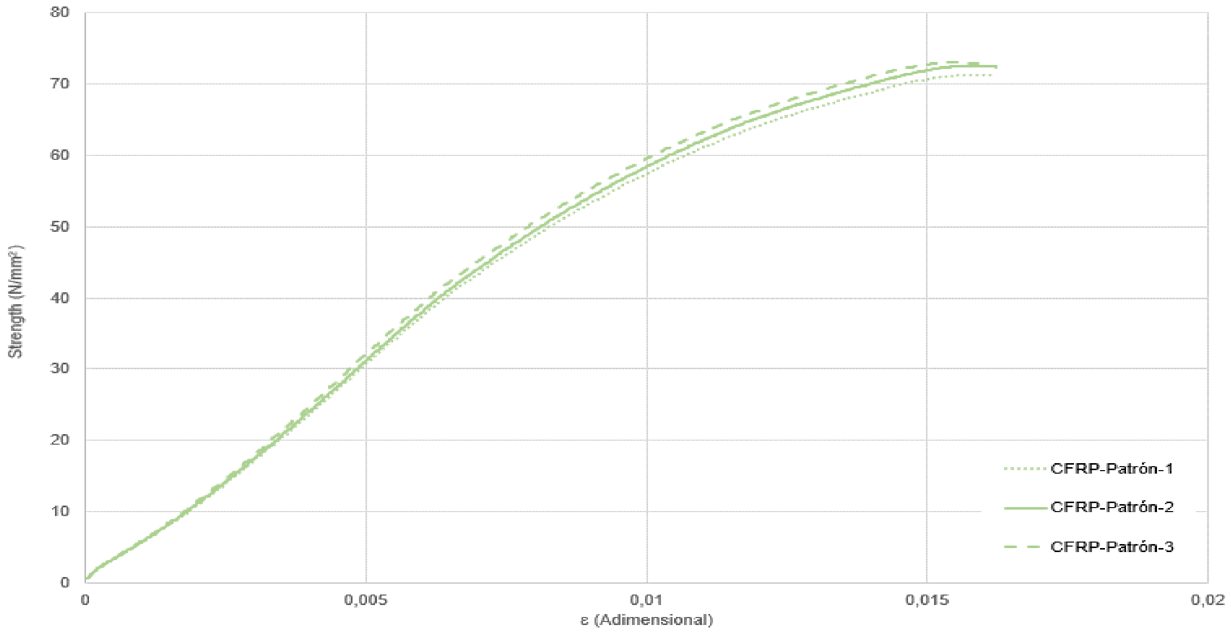

Fig. 4. Evolution strength-strain, corresponding to carbon fiber reinforced standard specimens.

Figure 4 shows the compressive behavior of the standard specimens reinforced with SikaWrap-230 C carbon fiber fabric. As can be seen, the strength reached by the confined concrete reach values of 70N/mm^2, at which point they show brittle failure.

Figure 5 shows the strength-strain graph for specimens previously subjected to 250º and subsequently reinforced with unidirectional carbon fiber fabric. Once again, it can be seen that the reinforcement allows the concrete to reach high strengths until the carbon fiber bursts and brittle fracture of the concrete occurs.

Table 2 shows the most representative values of the strength-strain graphs of the compression tests, in the standard specimens and specimens subjected to 250ºC, after being reinforced with the unidirectional carbon fiber fabric.

Figure 6 shows the compression results of all the specimens tested. As can be seen, thermal aggression produces a decrease in compressive strength of 26%, while the maximum and

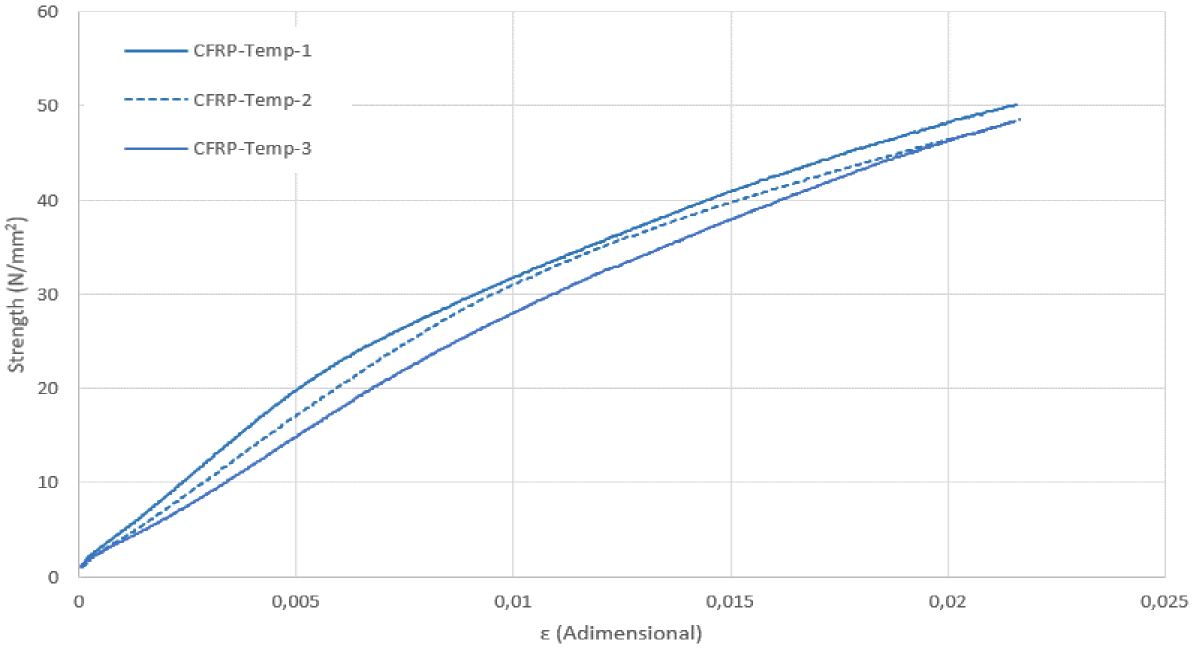

Fig. 5. Evolution strength-strain, corresponding to the compression test on specimens subjected to 250ºC and reinforced with carbon fiber.

TABLE II
Most representative values of the compression test in reference specimens and in specimens subjected to 250ºC, after being reinforced

	σ_{max} (N/mm^2)	σ_u (N/mm^2)	ε_{max} x 10^{-3}	ε_u x 10^{-3}	$E_{máx}$ x 10^{-2} (N/mm^2)	E_u x 10^{-2} (N/mm^2)
CFRP-Patrón-1	71.26	71.05	15.64	16.18	67.13	70.98
CFRP-Patrón-2	72.61	72.40	15.68	16.22	68.60	72.53
CFRP-Patrón-3	73.04	72.83	15.37	15.90	67.64	71.51
Average values	72.30	72.09	15.56	16.10	67.69	71.67
CFRP-Temp-1	48.51	48.51	21.66	21.66	61.67	61.67
CFRP-Temp-2	50.17	50.17	21.57	21.57	66.76	66.76
CFRP-Temp-3	48.33	48.33	21.91	21.91	57.90	57.90
Average values	49.00	49.00	21.71	21.71	62.11	62.11

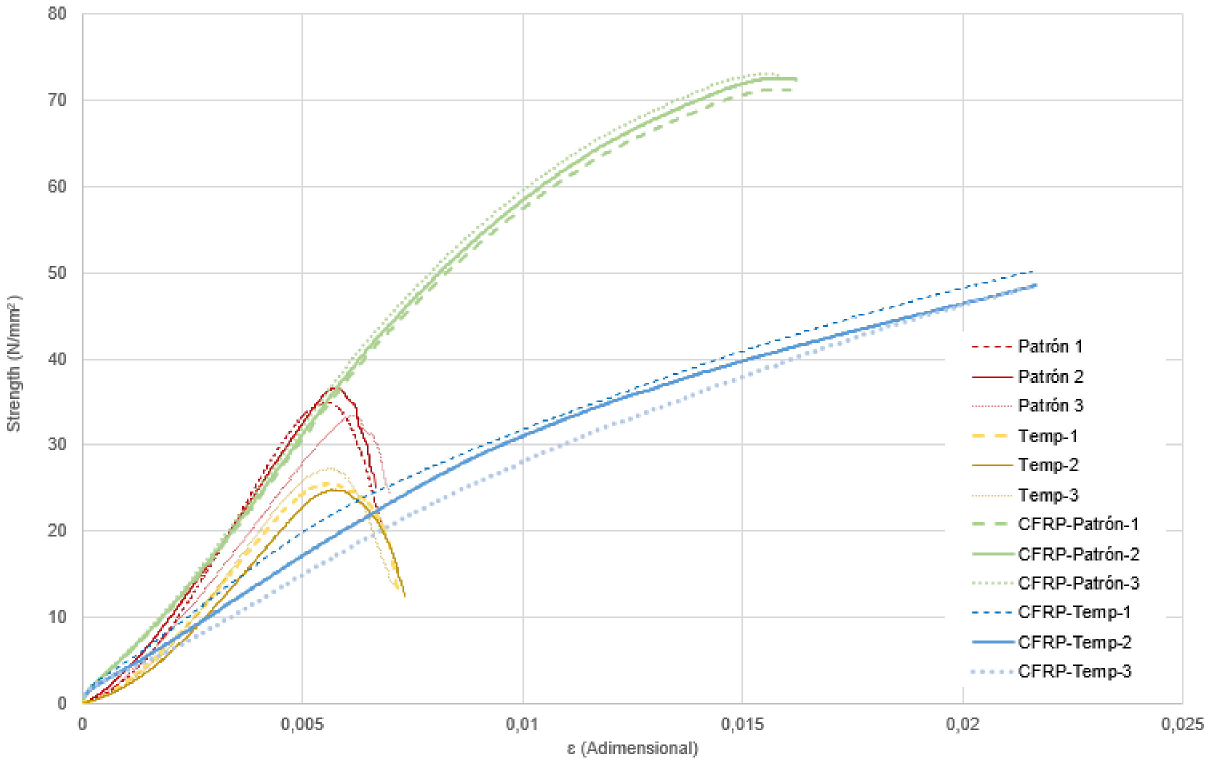

Fig. 6. Evolution strength-strain, corresponding the tested specimens.

ultimate unit strains are maintained. When the standard specimens and those heated to 250º care reinforced, the maximum strengths increase considerably due to the effect of the confinement of the concrete, reaching strengths 105% higher in the case of standard specimens and 89.5% higher in the case of concrete subjected to 250ºC. Unit deformations are higher in reinforced concrete with thermal aggression, but the lower load capacity means that the deformation energy density is higher in reinforced standard specimens.

Figure 7 shows the rupture of the standard specimens and those subjected to 250ºC, once reinforced with carbon fiber. As can be seen, in both cases the breakage is brittle, since the concrete has ceased to resist and what really holds is the carbon fiber.

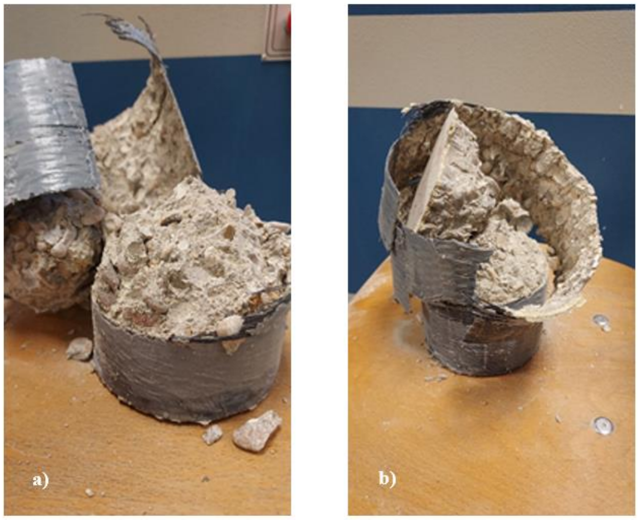

Fig. 7. Brittle fracture in carbon fiber-reinforced specimens. a) Reference; b) Subjected to 250ºC.

IV. CONCLUSIONS

The following conclusions can be drawn from the experimental work carried out:

- The maximum strengths decreases with increasing temperature in concrete, of the order of 26% for concretes subjected to 250ºC. In the case of ultimate strengths, these values decrease up to 46% with respect to the standard.

- The specimens reinforced with CFRP have managed to increase their maximum strength 105% in the case of standard specimens and by 89.5% in the case of concrete subjected to 250ºC.

- As for the maximum unit longitudinal strains, it can be observed that the values obtained in the reinforced standard specimens are about three times higher than those of the unreinforced standard specimens, increasing up to four times in reinforced specimens that had undergone thermal aggression.

- The strain energy density values in all cases show very high increases, reaching values six times higher than those of the specimens before reinforcement.

- The carbon fiber reinforced specimens, when subjected to the compression test, presented explosive ruptures, but in no case did the fiber break in the overlapping zone.

- All this confirms the viability of reinforcing reinforced concrete structures subjected to thermal aggression by means of CFRP fabrics, significantly improving their strength and ductility.

REFERENCES

Abdulrahman B. Q. & Aziz O. Q. (2021). Strengthening RC flat slab-column connections with FRP composites: A review and comparative study. Journal of King Saud University – Engineering Sciences, 33, pp. 471-481.

ACI 440R-07 (2007). Report on FIber-Reinforced Polymer (FRP) Reinforcemen for Concrete Structures.

Ahmed A., Rahman M. Z., Ou Y., Liu S., Mobasher B., Guo S. & Zhu D. (2021). A review on the tensile behavior of fiber-reinforced polymer composites under varying strain rates and temperatures. Construction and Building Materials, 294, 123565.

Anchor R., Malhotra H. & Purkiss J. (1986). Design of structures against fire. Elsevier Applied Science Publisher.

Asadia I., Shafigha P. & Hassana Z. F. B. A. (2018). Thermal conductivity of concrete – A review. Journal of Building Engineering, 20, 81-93.

ASTM D5334 (2014). Standard Test Method for Determination of Thermal Conductivity of Soil and Soft Rock by Thermal Needle Probe Procedure. USA.

ASTM E1530 (2011). Standard test method for evaluating the resistance to termal transmission of materials by the guarded heat flow meter technique. USA.

Baquer Sistach J. (2021). Monográfico 1. La fibra de carbono en refuerzo de estructuras de hormigón, Barcelona: Asociación de consultores de estructuras.

Catalán L. V. & Maestro M. B. (2007) Seguridad frente al fuego de las estructuras de hormigón. Hormigón, 899, 44-51.

Cembureau (2019). Building carbon neutrality in Europe, Engaging for concrete solutions. Décimo Encuentro de Investigadores y Docentes de Ingeniería, Bruselas, Bélgica.

Código Estructural: Capítulo 8. Estructuras de hormigón. Propiedades tecnológicas de los materiales, España, 2021.

CSIC (2019). Documento de Idoneidad Técnica: nº 604R/19 Sistema SIKA CARBODUR - SISTEMA SIKAWRAP. Instituto de Ciencias de la Construcción Eduardo Torroja, Madrid.

Eid R., Paultre P. (2017). Compressive behavior of FRP-confined reinforced concrete columnsEngineering Structures, 132, 518-530.

EN 197-1:2011: Cement - Part 1: Composition, specifications and conformity criteria for common cements. CTN 80 - Cementos y cales. Spain. CTN 83 – Hormigón, Spain. 2011.

EN 934-2:2010+A1:2012. Admixtures for concrete, mortar and grout - Part 2: Concrete admixtures - Definitions, requirements, conformity, marking and labelling, 2019.

EN 1504 (2009). Products and systems for the protection and repair of concrete structures. CEN/TC 104 – Concrete, Spain, 2009.

EN 1542:200. Products and systems for the protection and repair of concrete structures. Test methods. Measurement of bond strength by pull-off. CEN/TC 104 – Concrete, Spain, 2000.

EN 12350-2:2020. Testing fresh concrete - Part 2: Slump test. CTN 83 – Hormigón, Spain, 2020.

EN 12390-3:2020. Testing hardened concrete - Part 3: Compressive strength of test specimens. CTN 83 – Hormigón, Spain, 2020.

EN 12620:2003+A1:2009: Aggregates for concrete. CTN 146 – Áridos, Spain, 2009.

Ercolani, G. D. Empleo de Ultrasonidos y Esclerometría en el diagnóstico de estructuras de hormigón afectadas por elevadas temperaturas,» de IV Conferencia Panamericana de END, Buenos Aires, 2007.

Ferrier E., Rabinovitch O. & Michel L. (2016). Mechanical behavior of concrete–resin/adhesive–FRP structural assemblies under low and high temperatures. Construction and Building Materials, 127, 1017-1028.

FIB 90 (2019). Externally applied FRP reinforcement for concrete structures. Francia.

Fiore V. y Valenza A. (2013). Advanced Fibre-Reinforced Polymer (FRP) Composites for Structural Applications,» Woodhead Publishing Series in Civil and Structural Engineering, 88-121.

González F. J. (2020). Experiencias en la ejecución de refuerzos de estructuras. BIA 2016-80310-P, Madrid.

Guo F., Yuan Y. & Mang H. A. (2016) Determination of the relative significance of material parameters for concrete exposed to fire. International Journal of Heat and Mass Transfer, 100, 191-1984.

Hager I., Tracz T., Choin M. & Mróz K. (2019). Effect of Cement Type on the Mechanical Behavior and Permeability of Concrete Subjected to High Temperatures, Materials (Basel).

Huang S., Fu Q., Yan L. & Kasal B. (2021). Characterization of interfacial properties between fibre and polymer matrix in composite materials: A critical review. Journal of Materials Research and Technology, 13, 1441-1484.

Huang, X. Pang, P Zhu, Zhang S., Fan Z. & Chen X (2021) Transverse mechanical properties of unidirectional FRP including resin-rich areas. Computational Materials Science, 198, 110701.

Instytut Techniki Budowlanej (2021). European Technical Assessment, ETA-21/0276, Warszawa: EOTA.

Jiménez B. (2020). Procedimiento de ejecución: preparación de superficies para sistemas de refuerzo y pegado rígido. SIKA.S.A.U, Madrid.

Jiménez B. (2020). SIKA® CARBODUR® E, refuerzo de estructuras de hormigón. SIKA. S.A.U, Madrid.

Kasper Y., Albiez M., Ummenhofer T., Mayer C., Meier T., Choffat F., Ciupack Y. & Pasternak H. (2021). Application of toughened epoxy-adhesives for strengthening of fatigue-damaged steel structures. Construction and Building Materials, 275, 121579.

Khoury G. (2000). Effect of Fire on Concrete and Concrete Structures. Progress in, 429-447.

Li L., Shi L., Wang Q., Liu G., Dong J., Zhang H.y Hang G. (2020). A review on the recovery of fire-damaged concrete with post-fire-curing. Construction and Building Materials, 237.

Li J., Xie J., Liu F. & Lu Z. (2019). A critical review and assessment for FRP-concrete bond systems with epoxy resin exposed to chloride environments. Composite Structures, vol. 229, 2019.

López F. C.-G., Marco J. B. & Rodríguez V. C., (2021). Influence of high temperatures on the bond between carbon Fibre-Reinforced polymer bars and concrete. Construction and Building Materials, 309, 124967.

Ma C.-K., Apandi N. M., Yung S. C. S., Hau N. J. y Haur L. W. (2017). Repair and rehabilitation of concrete structures using confinement: A review. Construction and Building Materials, 133, 502-515.

Mai A. D., Sheikh M. N. & Hadia M. N. (2021). Strain model for discretely FRP confined concrete based on energy balance principle. Engineering Structures, 241,112489.

Malik M., Bhattacharyya S. & Barai, Sudhirkumar V. B. (2020). Thermal and mechanical properties of concrete and its constituents at elevated temperatures: A review. Construction and Building Materials, 270, 121398.

Malik M., Bhattacharyya S. & Sudhirkumar V. B. (2019). Microstructural Changes in Concrete: Postfire Scenario. Journal of Materials in Civil Engineering, 33(2).

Martínez S., (2020). Programa experimental sobre probetas de tamaño intermedio. Ensayos y resultados,» BIA 2016-80310-P, Madrid.

MIL-HDBK-17-1F (2002). Department of defense. United States of America. Composite materials handbook. 1. Polymer matrix composites guidelines for characterization of structural materials, 1 of 5.

Moghaddas A., Mostofinejad D., Saljoughian A. & Ilia E. (2021). An empirical FRP-concrete bond-slip model for externally-bonded reinforcement on grooves. Construction and Building Materials, 281, 122575.

Mostofinejad D. & Arefian B. Generic assessment of effective bond length of FRP-concrete joint based on the initiation of debonding: Experimental and analytical investigation. Composite Structures, 277, 114625.

Mugahed Y. H., Alyousef R., Rashid R. S., Alabduljabbar H. & Hung C.C. (2018). Properties and applications of FRP in strengthening RC structures: A review. Structures, 16, 208-238.

NUREG/CR-7031 ORNL/TM-2009/175 (2009). A Compilation of Elevated Temperature Concrete Material Property Data and Information for Use in Assessments of Nuclear Power Plant Reinforced Concrete Structures. New

York.

Obaidat A. T. (2022). Compression behavior of confined circular reinforced concrete with spiral CFRP rope with different slenderness ratios. Results in Engineering, 16, 100615.

Ostrowski K. A. & Furtak K. (2021). The influence of concrete surface preparation on the effectiveness of reinforcement using carbon fibre-reinforced polymer in high-performance, self-compacting, fibre-reinforced concrete. Composite Structures, 276, 114522.

Pendhari S. S., Kant T. & Desai Y. M. (2008). Application of polymer composites in civil construction: A general review. Composite Structures, 84, 114-124.

Proschek P. (2019). Allgemeine Bauaufsichtliche Zulassung. Deutsches Institut fur Bautechnik, Stuttgart.

Rodríguez V., Guerrero H., Alcocer S. M. & Tapia-Hernandez E. (2021). Rehabilitation of heavily damaged beam-column connections with CFRP wrapping and SFRM casing. Soil Dynamics and Earthquake Engineering, 145, 106721.

Russian O., Khan S., Belarbi A. & Dawood M.(2021). Effect of surface preparation technique on bond behavior of CFRP-steel double-lap joints: Experimental and numerical studies. Composite Structures, 255, 113048.

Seshu D. R. y Pratusha A (2013). Study on compressive strength behaviour of normal concrete and self-compacting concrete subjected to elevated temperatures. Magazine of Concrete Research, 65(7), 415-421.

SIKA CORPORATE, (2008). Glass temperatures of different Sikadur products, Zurich.

Shumuye D., Zhao J. y. Wang Z (2019). Effect of fire exposure on physico-mechanical and microstructural properties of concrete containing high volume slag cement,» Construction and Building Materials 213, 447–458.

Suescum-Morales D., Ríos J., Martínez A., Cifuentes H. y Jiménez J. R. (2021). Effect of moderate temperatures on compressive strength of ultra-high-performance concrete: A microstructural analysis,» Cement and Concrete Research 140.

Torelli G., Mandal, P., Gillie M. & Tran V.-X., (2016). Concrete strains under transient thermal conditions: A state-of-the-art review. Engineering Structures, 127, 172-188.

TR 55 (2012). Technical Report. Design guidance for strengthening concrete structures usig fibre composite materials, 3rd edition, UK.

Varona F. B. & Baeza, F. J. (12017). Study of residual mechanical properties of concretes after exposure to high temperatures. Hormigón y Acero, 286(69).

Waghmare S., Shelare S., Aglawe & Khope P. (2021). A mini review on fibre reinforced polymer composites. Materials Today: proceedings.

Walz S. (2019). Passive Fire Protection Handbook. SIKA S.A.U, Zurich.

Wang X.-L., Zhao G.-Q., Li K. & Li, M.-H.-F. (2018). Effect of damage parameter variation on bond characteristics of CFRP-sheets bonded to concrete beams. Construction and Building Materials, 185, 184-192.

Wróblewska J. & Kowalski R. (2020). Assessing concrete strength in fire-damaged structure. Construction and Building Materials, 254, 119122.

Zhang H., Li L., Long T., Sarker P., Shi X., Cai G. & Q.Wang ,(2019). The effect of ordinary Portland cement substitution on the thermal stability of geopolymer concrete. Materials, 12 (2501).