Disponible en www.hormigonyacero.com
Hormigón y Acero, 2026
https://doi.org/10.33586/hya.2026.4146

ARTÍCULO EN AVANCE ON LINE

Harmony between Concrete and Reinforcement: From Ferrocemento to 3D Concrete Printing and Cementitious Composites

György L. Balázs

DOI: https://doi.org/10.33586/hya.2026.4146

Para ser publicado en: *Hormigón y Acero*

Por favor, el presente artículo debe ser citado así:
Balázs, G. (2026) Harmony between Concrete and Reinforcement: From Ferrocemento to 3D Concrete Printing and Cementitious Composites, *Hormigón y acero,* https://doi.org/10.33586/hya.2026.4146

Journal “Hormigón y Acero”

Harmony between Concrete and Reinforcement: From Ferrocemento to 3D Concrete Printing and Cementitious Composites

by

György L. Balázs, Prof., Honorary President of ***fib***
Budapest University of Technology and Economics
Faculty of Civil Eng., Dept. of Construction Materials and Technologies
Muegyetem 3, H-1111 Budapest
balazs.gyorgy@emk.bme.hu

SUMMARY

One of the key elements for the performance of reinforced concrete structures is the interaction of concrete and reinforcement. Introductory examples are mentioned for the successful use of reinforced concrete.

Recent developments with 3D concrete printing established two questions concerning the potential use of reinforcements: i) a practical example is presented for 3D concrete printed shell element with tensile chords of FRP reinforcements; ii) interlaminar shear is solved with 3-dimensional reinforcing elements (STAREX). The 3-dimensional reinforcing elements improves the performance of the whole element.

FRP reinforcements are used in increasing amount to avoid electrolytic corrosion of the reinforcement. A new reinforcement is: Carbon fibres in cementitious matrix = CFCM, which does not include polymers as matrix, but a cementitious matrix is used to improve cooperation both the carbon fibres and concrete. The cementitious matrix reduces sensitivity for high temperatures. With carbon fibres in cementitious matrix reinforcement, the reinforced concrete elements can be produced with no or little cover.

This article presents conceptual and technological advances toward the integration of innovative reinforcing materials and technologies in concrete structures.

Keywords: 3D concrete printing, interlaminar shear, 3-dimensional reinforcing elements, Carbon fibres in cementitious matrix reinforcement, no cover.

Título en castellano: ***Armonía entre el hormigón y la armadura: del ferrocemento a la impresión 3D de hormigón y los compuestos cementicios***

Uno de los aspectos clave en el desempeño de las estructuras de hormigón es la interacción entre el hormigón y la armadura. En este artículo se mencionan algunos ejemplos introductorios del uso exitoso del hormigón armado.

Los desarrollos recientes en el hormigón impreso en 3D ponen de manifiesto dos cuestiones relacionadas con el uso de las armaduras:
i) se presentan ejemplos prácticos de láminas de hormigón impreso con cordones de tracción basados en armaduras de FRP;
ii) el esfuerzo cortante entre capas se resuelve mediante un armado tridimensional (STAREX). El armado tridimensional mejora el desempeño de todo el elemento estructural.

Las armaduras de FRP se utilizan cada vez más para evitar la corrosión electroquímica del acero de refuerzo. Un nuevo tipo de armadura consiste en fibras de carbono en matriz cementicia (CFCM), que no utiliza polímeros en la matriz, sino una matriz a base de cemento para mejorar la acción conjunta entre las fibras de carbono y el hormigón. La matriz cementicia reduce además la sensibilidad a las altas temperaturas. Con fibras de carbono en matriz cementicia, los elementos de hormigón armado pueden producirse con un recubrimiento reducido o incluso nulo.

Este artículo presenta avances conceptuales y tecnológicos orientados a la integración de materiales y tecnologías de refuerzo innovadores en estructuras de hormigón.

Palabras clave en castellano: hormigón impreso en 3D, cortante entre capas, elementos de armado 3D, fibras de carbono en matriz cementicia, recubrimiento nulo

1. INTRODUCTION

Engineering intuition is strongly required for the harmony of materials to choose structural materials like concrete, steel, timber, glass, and FRP, and their combination in composite structures to define the most reasonable one or the most economic one to the given load history or to the given geometry.

Structural design requires a detailed understanding of both the material and the structural behaviours. An additional requirement is to incorporate the new structure into the existing environment as structures like bridges, buildings, halls, or reservoirs, etc.

Reinforced concrete is a composite structural material that has a continuous development considering its constituent materials as well as its technology to fulfil overall requirements of: safety, serviceability, constructability, economics, aesthetics, and nowadays sustainability.

The present paper is a vision how the novel materials and technological developments can provide the basis for scientific innovations for reinforced concrete [1] [2] and improving conceptual future designs [3].

There was already a harmony of concrete and reinforcement from the beginning of applications which resulted many patents and applications worldwide. Nevertheless, concrete became to most frequently used construction material. There have already been publications to advise the successful use of reinforced concrete [4] [5].

Recent novelties in concrete and reinforcement are discussed in the following Chapters Innovative concretes for the future including (i) digital manufacturing in 3D concrete printing, (ii) a new reinforcing element for general use called STAREX and (iii) a new type of non-metallic reinforcement of carbon fibres in cementitious matrix in addition to the presentation of the Palazzo dello Sport as a reference for successful use of reinforced concrete in a bit modified way in the fifties (Fig. 1).

Harmony of concrete and reinforcement

a) Conventional concrete:

Reinforced concrete	Prestressed concrete

b) Innovative concretes for the future:

Digital manufacturing 3D concrete printing with or without reinforcement	STAREX reinforcing elements 3-dimensional reinforcement for general use	CFCM reinforcement = Carbon fibres in cementitious matrix reinforcement

Fig. 1 Conceptual timeline for conventional and novel concretes

2. DESIGNING WITH REINFORCED CONCRETE

A beautiful example for harmonic use of reinforced concrete and the structural system is the *Palazzo dello Sport by Pier Luigi Nervi* is (Fig. 2). He developed the reinforced concrete type for thin concrete elements like the cover of the dome, which is called in Italian *ferrocemento*. It included a small size of aggregate with a small diameter or reinforcement. This concept of material is important even today.

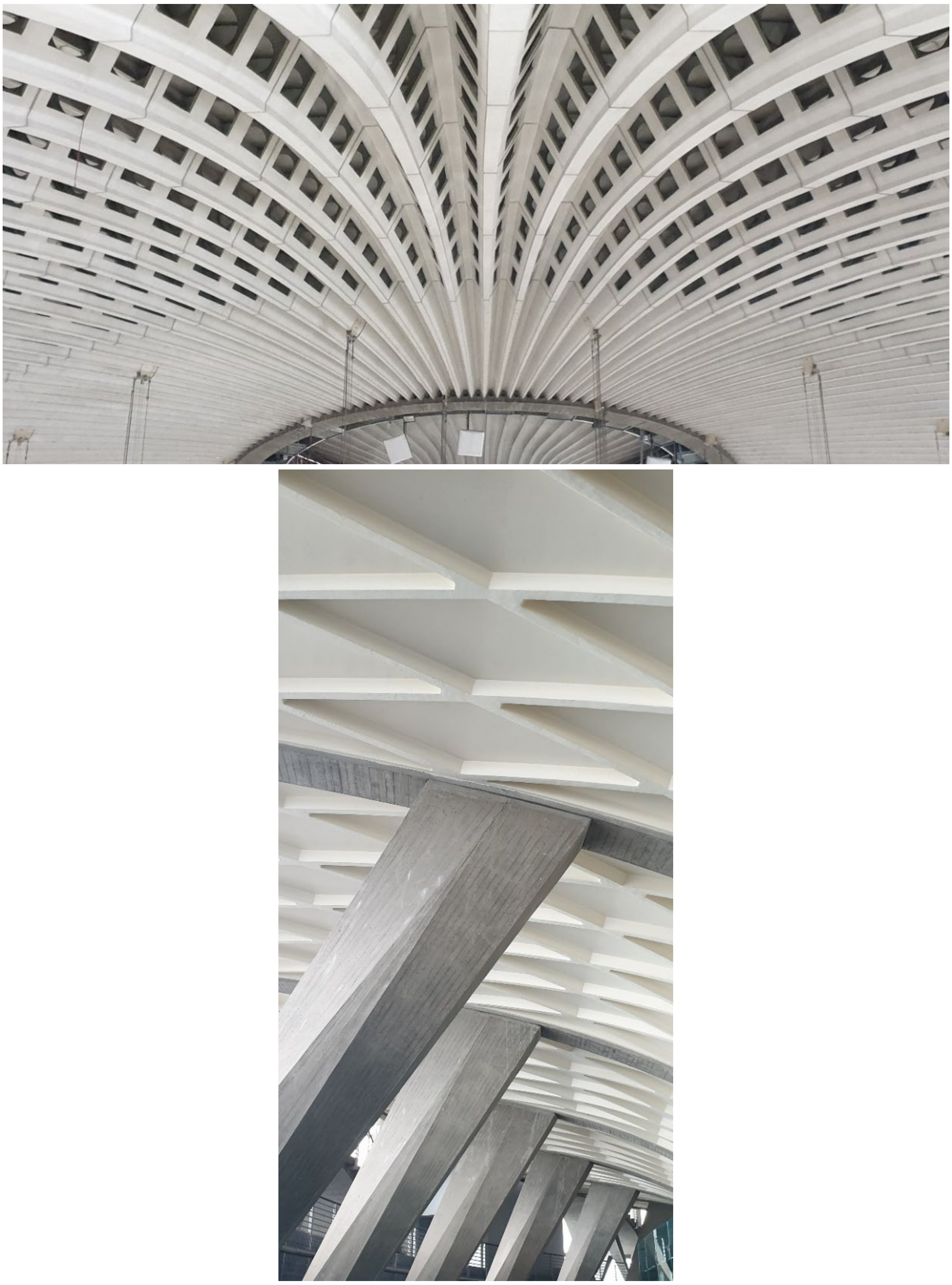


Fig. 2 Palazzo dello Sport, main hall and foyer Roma, Italy (Photo GL. Balázs)

3. DESIGNING 3D PRINTED CONCRETE

The 3D concrete printing is a disruptive technology without using any formwork. It is also often distinguished as an additive technology indicating how the material is proceeded. This is very productive technology whenever the material composition is available supplied continuously.

The 3D concrete printing (often abbreviated as 3D CP) process is controlled by the fresh properties of the concrete. Specifically, the mix, which should have sufficient green strength, must be capable of flowing through a distribution system and then be deposited in layers onto a build substrate without experiencing significant damage while also supporting the weight of subsequent layers.

Formwork in concrete construction constitutes a high percentage of the structure cost [6], often generates substantial waste, and imposes limitations on geometric freedom. Complex geometries may escalate costs and impede construction speed. In addition to that, nearly every stage of the construction process demands significant energy and results in substantial greenhouse gas emissions [7].

Zhang et al. [8] outline various applications of 3D CP, including buildings, bridges, and structures printed with simulated lunar regolith.

Bhattacherjee et al. [9] examined the sustainability of Supplementary Cementitious Materials (SCMs) for 3DCP, using carbon footprint and embodied energy as metrics. Their findings indicate that concretes incorporating fly ash, slags as SCMs, and geopolymer concrete exhibit lower carbon footprints and embodied energy compared to conventional Portland cement-based concretes.

Freedom of design in 3D printed concrete structural elements is often emphasized. It is a very particular way of designing elements. The designer should draw a continuous line, how the printing head finally does it. The whole construction – or segments of it – must be able to be followed by the method of line drawing.

Fig. 3 indicates the 1st arch bridge in Hungary produced in 3D concrete printing. The specialities of this printing are the different structural elements, i.e. compressed arch, compressed columns and the horizontal deck in final position.

Fig. 3 Arch bridge produced in 3D concrete printing (Lab. of Construction Materials and Technologies, BME, Budapest) (Photo GL Balázs)

4. REINFORCEMENT FOR 3D CONCRETE PRINTING

4.1 3D concrete printing of a cylindrical shell element

The conceptual design in 3D concrete printing is of particular importance. An example is presented in Fig. 4 for a structural element, a shell with constant curvature. The details of the shell element such as actual shape and curvature of the shell, support length, incorporation of tensile element in the anchorage zone are decided during the design printing. It is imperative to acknowledge the pivotal role that effective conceptual design plays in the realm of engineering structures [3] [10] [11].

Parameters, like printing speed, nose shape, nose diameter must be also decided before printing.

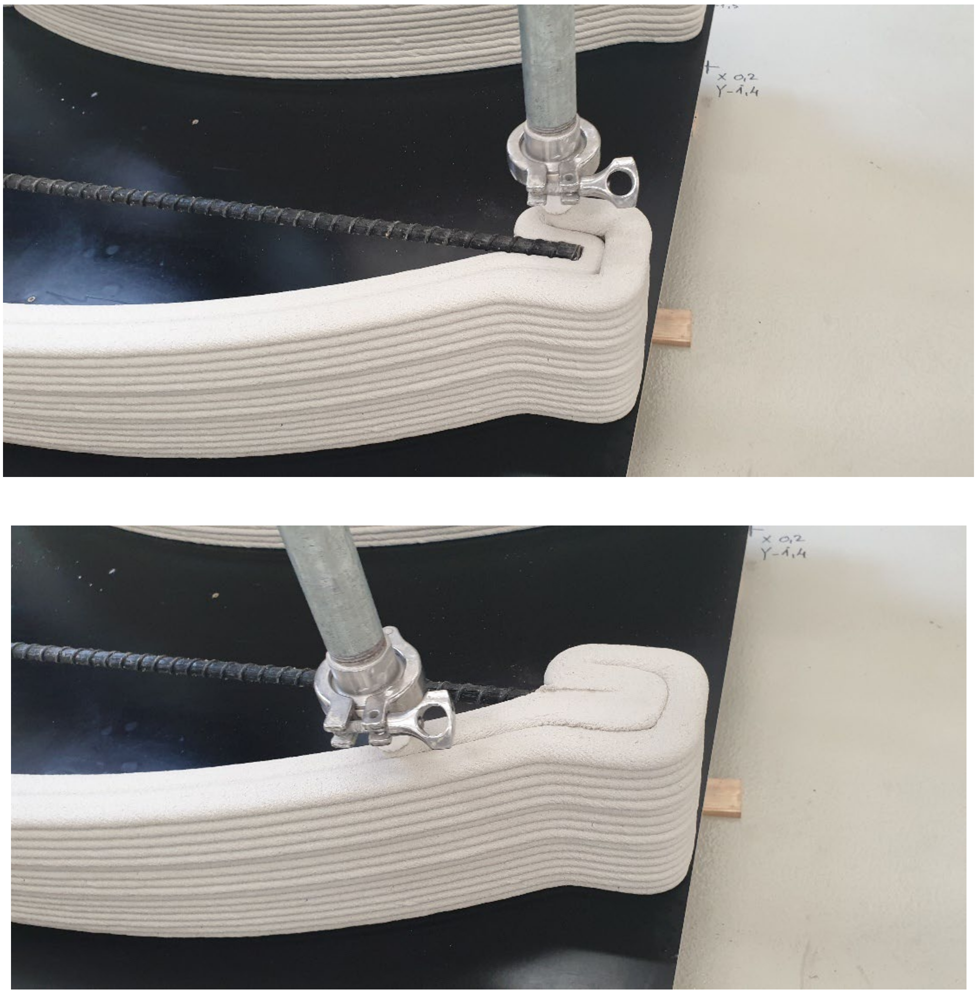


Fig. 4 Anchorage details of 3D concrete printed shell element including tensile FRP reinforcement during the 3D concrete printing process (Lab. of Construction Materials and Technologies, BME, Budapest) (Photo GL Balázs)

As illustrated in Fig. 4, the utilisation of FRP (Fibre Reinforced Plastic) reinforcement as tensile reinforcement is evident. The following presentation will provide a detailed overview of the process of applying tensile FRP reinforcement. Bond stresses must be analysed in order to conduct an anchorage analysis.

The incorporation of FRP reinforcement into 3D concrete printed cylindrical shell element is presented in Fib. 5.

Fig. 5 The incorporation of FRP reinforcement into 3D concrete printed cylindrical shell element (Lab. of Construction Materials and Technologies, BME, Budapest) (Photo GL Balázs)

4.2 Interlaminar shear in 3D concrete printing

In the context of 3D concrete printing, a layered technique, interlaminar shear is of particular significance. It is evident that the utilisation of short polymeric fibres, which are incorporated into the concrete mixture prior to printing, may not serve as a viable solution for the interlaminar shear of a beam or wall element.

A new solution is developed in Fig. 6 to improve interlaminar shear capacity of printed concrete layers. The new solution includes distribution of 3-dimensional STAREX reinforcing elements within the printed layers. (The international patent known as STAREX was granted to Csongor Czintos.)

In this way performance of the whole wall or element in 3D concrete printing is improved [12]

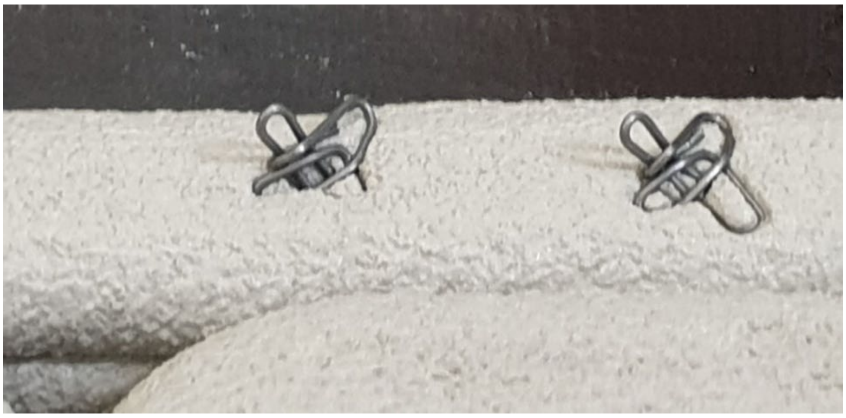


Fig. 6. Increase of interlaminar shear in 3D printed concrete by STAREX elements (Lab. of Construction Materials and Technologies, BME, Budapest) (Photo GL Balázs)

The STAREX reinforcing elements can be produced in different sizes for different applications (Fig. 7). The overhanging hooks, the diameter of wire and even the material are parameters of the production STAREX reinforcing elements.

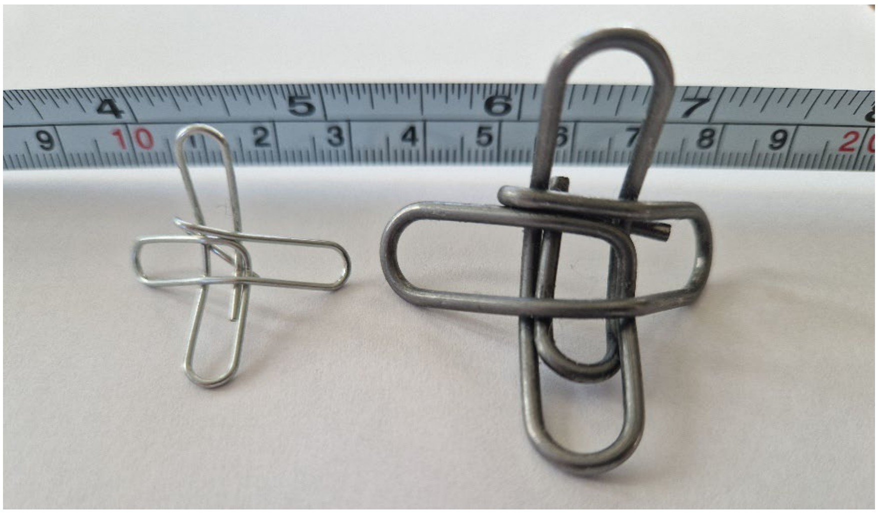


Fig. 7. STAREX reinforcing elements of different sizes (Lab. of Construction Materials and Technologies, BME, Budapest) (Photo GL Balázs)

The potentials of STAREX reinforcing elements for structural applications are mentioned in [13].

5. CARBON FIBRES IN CEMENTITIOUS MATRIX

Carbon fibres in cementitious matrix reinforcement = CFCM reinforcement is a new patent that reduces the temperature sensitivity of FRP reinforcement (CFCM is an international patent). Contrary to FRP reinforcement, the embedding matrix of the fibres is changed to cement-based matrix. In this way the reinforcement has a contact to the concrete by cement (not polymer) binder.

The CFCM reinforcement can be produced in any shape or cross-section, and it has been demonstrated that it provides a strong bond between the reinforcement, which is cement-bound, and the concrete [14]. As demonstrated in Fig. 8, the utilisation of CFCM reinforcement serves to illustrate the spatial shell, thereby signifying the capacity for formability.

Fig. 8 Spherical shell model in CFCM reinforcement [14]

Another example in *Fig. 9* is shown indicating an easy preparation of helical stirrup reinforcement.

Fig. 9 Helical CFCM reinforcement

Whenever the CFCM reinforcement is bonded to concrete the bond layer is extraordinary since the concrete has binder as cement and in the same way the reinforcement has binder as cement (Fig. 10).

Fig. 10 Bond layer of an embedded CFCM reinforcement opened after failure of the element – is still entirely connected to the concrete Lab. of Construction Materials and Technologies, BME, Budapest) [14] (Photo GL Balázs)

Since the CFCM reinforcement is in fresh form within several hours and insensitive for corrosion. there is real chance to a new definition of concrete cover with zero or a small value. Fig. 11 indicates beams with zero concrete cover tested in 4-point bending (Fig. 11.c). Material properties for the CFCM reinforcement as well as for concrete are given in Fig.11.b. The force - deflection diagram indicates bilinear behaviour until failure (Fig. 11.d).

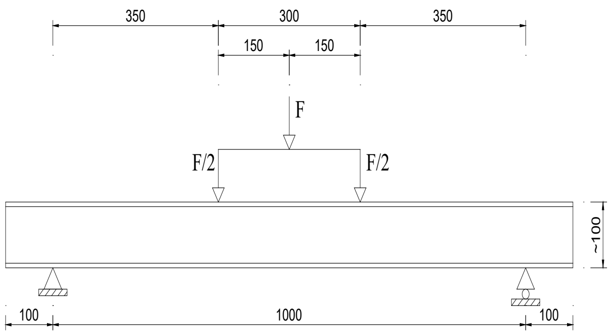
a) Beam with no concrete cover

c) Material properties of carbon fibres (ZOLTEK TORAY Group):

tensile strength: $f_{fib} = 4\ 137$ N/mm^2
modulus of elasticity: $E_{fib} = 242\ 000$ N/mm^2
ultimate elongation: $\varepsilon_{fib} = 1{,}5$ %
diameter of single fibres: 7.2×10^{-6} m
number of fibres in 1 cable: : 50 000

Design concrete strength of I girder:
compressive strength: 80 N/mm^2

c) Test arrangement (dimensions in mm)



d) Load – midspan deflection diagram of beam with 24 x 50 000 carbon fibres

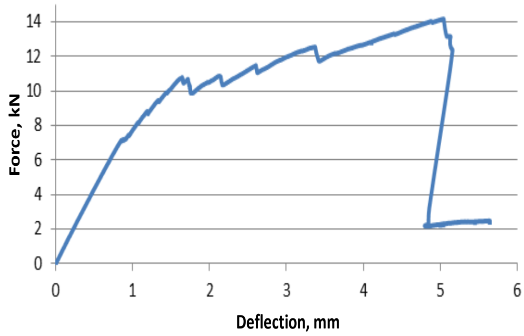


Fig. 11 A concept with no cover of CFCM reinforcement in beam test, (Lab. of Construction Materials and Technologies, BME, Budapest) [14]

CONCLUSIONS

The harmonious integration of concrete and reinforcement led to the global adoption of reinforced concrete across all continents. The requirements for safety, serviceability, constructability, economy, aesthetics and sustainability thus provide a stimulus for new ideas in development and innovation. In this work three disruptive inventions are presented and discussed with applications: 3D concrete printing, a new 3-dimentsional reinforcing element and the reinforcement that has carbon fibres in cementitious matrix.

a. *The 3D concrete printing* is a disruptive technology that does not use any formwork. It is also often distinguished as an additive technology, indicating how the material is processed. This is a very productive technology whenever the material composition is available and supplied continuously. Freedom of design in 3D printed concrete structural elements is often emphasized. The integration of reinforcement within three-dimensional concrete-printed elements presents certain technological challenges, which must be addressed to ensure the successful incorporation of the reinforcement. Two solutions were discussed to overcome these difficulties. An example was shown for printing of a *shell element* where FRP bars were inserted during printing as tensile reinforcement of the shell (see Fig. 4 and 5).

b. As demonstrated by another example, the *overall stability of printed concrete layers* can be enhanced through the incorporation of three-dimensional reinforcing elements, which function as interlaminar shear reinforcement. (see Fig. 6 and 7).

c. The most compatible reinforcement for concrete is provided by a new development, since carbon fibres are embedded into the cement matrix (rather than into a polymer). The cementitious matrix of reinforcement enables improved fire resistance and corrosion resistance. Since the carbon fibres are embedded into the cement matrix, the reinforcement is called carbon fibres in cementitious matrix reinforcement and abbreviated as CFCM. An example is shown for helical CFCM reinforcement (see Fig. 8). Since the electrolytic corrosion is entirely excluded and the temperature sensitivity of the reinforcement is improved, there is a possibility of reducing the concrete cover on the elements by employing CFCM reinforcements, provided that other factors do not necessitate a substantial cover (see Fig. 11).

ACKNOWLEDGEMENTS:

This article is dedicated to my dear friends and colleagues Antonio Marí and Hugo Corres, on the occasion of their retirement and as a tribute to their academic and professional career in concrete structures.
The author acknowledges the support of the Hungarian Research Grant KFI_016-1-2017-0271 “Development of fibre reinforced cementitious composite reinforcements based on Csurgai’s patent for application in concrete products”.
The herein presented new reinforcing element of 3-dimensional form is the patent of Csongor Czintos (Patent Nr.: HU2017/050041). His help is gratefully acknowledged.
The CFCM reinforcement was prepared by the patent of Ferenc Csurgai “Production procedure and machinery to produce cables from single fibres by embedment in a matrix and its application to concrete-composites”. PCT/HU2017/050010 int. (11 April 2016), final patent: P1700140 (dated 7 April 2017).

REFERENCES:

[1] Marí, A., Bairán, J., Cladera, A., Oller, E., Ribas, C. (2014), “Shear-flexural strength mechanical model for the design and assessment of reinforced concrete beams”, J. *Structure and Infrastructure Engineering: Maintenance, Management, Life-Cycle Design and Performance*, Taylor and Francis, http://dx.doi.org/10.1080/15732479.2014.964735

[2] Cladera, A, Marí, A., Ribas, C., Bairán, J., Oller, E. (2015), "Predicting the shear–flexural strength of slender reinforced concrete T and I shaped beams", *J. Engineering Stuctures*, Vol. 101 pp. 386-398., Elsevier, http://dx.doi.org/10.1016/j.engstruct.2015.07.025
[3] Corres, H., Todisco, L., Fivet, C. (Eds.) (2019), "Conceptual Design of Structures 2019", Madrid, September 26-28, 2019, Proceedings
[4] Ritter, W. (1899), *Construction method of Hennebique (Die Bauweise Hennebique), Schweizerische Bauzeitung*, February 1899, pp. 41-61.
[5] Mörsch, E. (1908), *Reinforced concrete – Theory and application (Der Eisenbetonbau – Seine Theorie und Anwendung)*, Verlag von Konrad Wittwer, Stuttgart, pp. 146-215.
[6] Nematollahi, B., Xia, M., J. Sanjayan, J. (2017), "Current Progress of 3D Concrete Printing Technologies," in Proceedings of the 34th International Symposium on Automation and Robotics in Construction (ISARC), Jul. 2017, pp. 260–267, 10.22260/ISARC2017/0035
[7] Yan, H., Shen, Q., Fan, L.C.H., Wang, Y., Zhang, L. (2010), "Greenhouse gas emissions in building construction: A case study of One Peking in Hong Kong", Build. Environ. 45 (4) (2010), pp. 949–955, https://doi.org/10.1016/J.BUILDENV.2009.09.014.
[8] Zhang,J., Wang, J., Dong, S., Yu, X., Han, B, (2019) "A review of the current progress and application of 3D printed concrete", Compos. A Appl. Sci. Manuf. 125/2019, 105533, https://doi.org/10.1016/j.compositesa.2019.105533.
[9] Bhattacherjee, S. et al. (2021), "Sustainable materials for 3D concrete printing", Cem. Concr. Compos. Vol. 122, No. June (2021), 104156, https://doi.org/10.1016/j.cemconcomp.2021.104156.
[10] Fivet, C, D'Acunto, P., Fernandez Ruiz, M., Ohlbrock, P. O. (Eds.), "Conceptual Design of Structures 2021", Attisholz Areal, Switzerland, September 16-18, 2021, Proceedings
[11] Thajeel, M. M., Alimrani, N. S. and Balázs, G.L. (2022), "3D Concrete Printing Structural and Non-Structural Solutions," *J. Concrete Structures,* Vol. 23, pp. 47-53. www.fib.bme.hu/folyoirat/cs/cs2022/cs2022_7.pdf
[12] Balázs, G.L., Czintos, Cs., Pfeffermann, O., Sólyom, S. (2025), "New reinforcing element for automated production of reinforced concrete", Proceedings of Symp. Conceptual Design Rio de Janiero
[13] Balázs, G.L. (2025), "Future reinforcement for concrete", Proceedings of the *fib* Symposium 2025, June 16 to 18, 2025, Antibes, France, pp. 167-1773.
[14] Balázs, G.L., Csurgai, F. Sólyom, S. (2022), "Bond of CFCM", Proceedings (Eds. Hoffmann, J, and Plizzari, G.), "Bond Anchorage Detailing", 5^{th} In Conf. Bond in Concrete 2022, Stuttgart, 25-27 July 2022, IWB Stuttgart University, pp. 945-954.