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Assessing the compressive performance of PVC coating on steel wire mesh reinforced concrete

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Abstract: Reinforced concrete RC is a versatile and durable building material widely used in construction. This study investigated the impact of PVC-coated steel wire mesh layers on the compressive strength of RC. Seven cube specimens (70 × 70×70 mm) with varying numbers of PVC-coated layers were tested after a 28-day curing period. Results showed that specimens with two layers of PVC coating exhibited the highest ultimate compression stress and breaking force, indicating a significant 38% increase in compressive strength compared to those without PVC coating. The findings suggest that PVC-coated steel wire mesh provides a sustainable and cost-effective method for reinforcing RC structures. By mechanically enhancing these structures, their overall mechanical properties can be improved. This research highlights the potential of PVC-coated steel wire mesh as an effective reinforcement technique, offering practical solutions for strengthening concrete structures.

Subjects: Material Science; Materials Science; Technology

Keywords: Compression test; concrete; steel wire mesh; steel mesh wire

1. Introduction

Reinforced concrete is a type of concrete that incorporates steel reinforcement bars, also known as rebars, to provide additional strength and durability (Hamid et al., 2018). The steel rebars are placed within the concrete before it sets, and combining the two materials creates a strong and rigid structure commonly used in construction. Reinforced concrete is a versatile building material used in various applications, including foundations, columns, beams, and slabs (Ischenko & Borisova, 2020). It is also resistant to fire, weather, and other environmental factors, making it a popular choice for residential and commercial construction projects. Two main reinforcement types are used in reinforced concrete: Steel Reinforcement and Fiber Reinforcement. Steel reinforcement involves using steel bars or meshes to reinforce the concrete. The steel is added to the concrete to provide extra strength and to resist tension forces. The steel used in reinforced concrete is typically high-strength steel, such as deformed steel bars, welded wire mesh, or steel fibres. The Fiber reinforcement type involves using small glass, plastic, or concrete reinforced with steel fibres to increase its tensile strength, durability, and crack resistance. It also reduces shrinkage and cracking caused by temperature changes and drying. Some common types of fibre reinforcement used in reinforced concrete include Polypropylene fibres (Al-Katib et al., 2018; Sohaib et al., 2018); Glass fibres (Ahmad et al., 2022); Steel fibres (Błaszczyński & Przybylska-Fałek, 2015); Carbon fibres (Branco et al., 2014); and Synthetic fibres (Kirsanov & Stolyarov, 2018). Steel and fibre reinforcement can be used in combination with each other to enhance the reinforced concrete's strength and durability.

The uniaxial compressive strength test is crucial in the construction industry for assessing the strength of concrete. In this test, a compressive force is applied to standard cubic and cylindrical concrete samples until failure. This test ensures that the concrete meets the required strength specifications for the project. The compressive strength of general construction materials ranges from 15 to 30 MPa (Kosmatka et al., 2002).

The studies mentioned in the passage deal with reinforcement materials for concrete (Currie & Gardiner, 1989). used polypropylene fibre mesh to reinforce concrete in low-temperature conditions (Soulioti et al., 2011). investigated the mechanical response of reinforced concrete made with steel fibres of varying volumes and geometries and found that mechanical qualities improved with increasing fibre volume fraction and were influenced by fibre geometry (Yi & Cho, 2013). studied incorporating hybrid fiber sheets and plates into concrete beams to improve their flexural strength and found that reinforced concrete beams had load capacities and strengths significantly greater than those of unreinforced specimens (Al Saadi et al., 2017). analysed the flexural strength of reinforced concrete beams and found that using steel wire mesh is a simple and effective method to enhance existing components (Almalkawi et al., 2018). studied the influence of chicken mesh wires on the ductile behaviour of cement base matrix. They discovered that aerated slurry-infiltrated chicken mesh provides a desirable balance of lightweight and mechanical qualities as a building construction material (Benaimeche et al., 2018). investigated the flexural and fracture characteristics of date palm mesh fibre reinforced cement and found that adding date palm mesh fibre to cement specimens improves post-peak behaviour and ductility compared to plain specimens (Zhang & Sun, 2018). investigated the strength enhancement of concrete reinforced with ultra-high molecular weight polyethylene fibres and wire steel mesh and found that steel fibres provided greater strength enhancements. In contrast, ultra-high molecular weight polyethylene fibre exhibited better ductility. Zhou et al (Zhou et al., 2020). comprehensively evaluated polyethylene fibre-reinforced concrete and suggested this material for structural restoration.

In addition to studies on reinforcement materials for concrete, there have also been several studies focused on the evaluation and prediction of concrete strength (Stolk et al., 1998). used the finite element method to demonstrate that mesh density greatly impacts the response of cement and that mesh refinement can lead to uncertainties in predicting failure based on stresses (Abd & Habeeb, 2014). found that using smaller cylindrical or cube specimens increased the compressive strength of larger specimens (Khormani et al., 2020). suggested that X-ray CT scans could be a suitable technique to predict the ultimate strength of concrete using early-aged specimens, which could be extremely beneficial for supervisory administration. These studies provide valuable insights into improving the accuracy of predicting concrete strength and enhancing quality control in construction projects.

Reinforcing concrete structures has been made possible by innovative composite materials and a recent study by (Qeshta et al., 2014) explored the use of wire mesh epoxy composites with different numbers of wire mesh layers to improve the flexural performance of concrete beams. The results showed that the innovative composites significantly enhanced the load-carrying capacity and stiffness of the beams, with the number of wire mesh layers playing a critical role in determining the extent of improvement. This research suggests that using innovative composites could offer a promising solution for improving the performance of concrete structures, and further studies in this area are warranted. On the other hand (Fraile-Garcia et al., 2016), studied construction materials to isolate low-frequency noises and found that strongly doped materials, such as waste-tire rubber mixed with concrete, were the most effective.

Three different combinations of construction materials with varying rubber content were used to create structures, and sound impact stress and acoustic isolation parameters were measured, demonstrating the ideal properties of strongly doped components for isolating low-frequency noises (Chalah et al., 2022). investigated the impact of sodium chloride exposure on high-performance concrete containing natural pozzolans and fibres. The study discovered that natural pozzolans fill the gaps and create denser products in the cement matrix, reducing the negative impact of fibres. The research examined the mechanical and durability properties of the samples using compressive strength tests for various periods.

Previous research has highlighted the need to identify the best possible combination of reinforcement materials and composites to enhance the mechanical properties of reinforced concrete and predict its failure behaviour. The present study's novelty lies in investigating the impact of adding PVC coating onto steel wire mesh layers to improve compressive strength and decrease fractures in concrete specimens. Additionally, this study explores the influence of the number of mesh layers on compression strength. The study aims to identify sustainable and cost-effective reinforcement materials and composites that can enhance the mechanical properties of reinforced concrete while minimising the environmental impact of construction projects.

The study (El-Sayed & Erfan, 2018), compared stirrups and wire meshes as shear reinforcements for ferrocement-reinforced beams. Compared with reference specimens, beams with welded wire mesh reinforcement have an enhanced shear capacity and reduced crack patterns.

(Erfan & El-Sayed, 2019a) used two groups of ferrocement box beams. Tests were conducted on seven box section concrete beams using a two-point loading system. Deflection, shear capacity, and ultimate failure load were compared between beams with expanded wire mesh and reference/welded wire mesh. Finite element models were validated using Ansys 14.5 software. Analytical and experimental results were in good agreement.

In an experiment and an analytical analysis (Abdallah et al., 2019), they examined ferrocement slab panels' flexural behavior. Simulations and experimental tests use Ansys 14.5 software to investigate the performance of concrete slabs. Expanded steel mesh is used as reinforcement to enhance flexural strength and reduce deflection.

Using steel wire meshes in reinforcing composite concrete columns was investigated by Erfan et al. (2019). Analytical simulations and experimental testing highlight the potential benefits of this reinforcement method.

Shear behavior of box concrete beams reinforced by composite fabrics is described in detail in (Erfan & El-Sayed, 2019b). The experimental and numerical results contribute to a better understanding of the performance of different reinforcement methods and can inform the design and construction of such beams.

The results of (Erfan, Abd Elnaby, Elhawary, & El-Sayed, 2021) show improved ultimate loads for strengthened ferrocement specimens compared to control specimens. Expanded steel wire mesh reinforcement increased the ductility ratio compared to glass fiber mesh. Wire mesh made of glass fiber showed higher first cracking loads, serviceability loads, and load-carrying capacities.

The study (El-Sayed, 2021) investigated RC walls reinforced with ferrocement composites. The expanded or glass fiber wire mesh ferrocement specimens performed better in finite element analysis. In assessing the structural behavior of ferrocement RC walls, the numerical and experimental results were in agreement.

(El-Sayed, Shaheen, et al., 2023)investigates the performance of ferrocement pipes reinforced with various metallic and non-metallic materials. The research aims to predict the structural behavior of these water pipelines. Experimental testing, analytical modeling using ANSYS 2015 software, and comparisons between the two are conducted. The study emphasizes the effectiveness of different types of mesh reinforcement and highlights the strength of the created ferrocement water pipes.

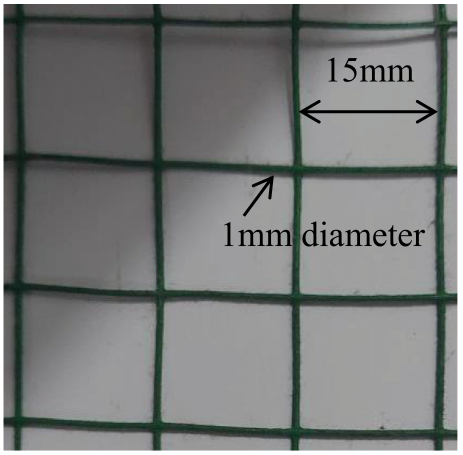

Figure 1. Schematic of PVC coating onto steel wire mesh.

The study (El-Sayed, Deifalla, et al., 2023) focused on the performance of welded steel wire mesh beams compared to geopolymer ferrocement beams. The research also demonstrated the adequacy of nonlinear finite element analysis in estimating the behavior of composite ferrocement geopolymer beams. Additionally, the study discussed the reduction in strength observed in specimens reinforced with Tensar meshes compared to control specimens.

2. Experimental and methods

PVC-coated steel wire mesh panels with 1 mm diameter and 15 mm spacing, as illustrated in Figure 1, were utilised to construct reinforced concrete using Portland cement that meets the ASTM C150 standard specification, fine sand that satisfies the requirements of ASTM C778, and tap water. To create the experimental specimens, a 2-part cast iron mould with clamps measuring 70 × 70x70mm was employed, and the mixing process adhered to the ASTM C109 (Hamid et al., 2018), protocol with the material proportions specified in Table 1. The laboratory mixed a composite of concrete, sand, and water using a rotary mixer with a 0.15 m^3 capacity, and seven cubes with varying reinforcing layers of steel mesh coated with polymer were cast. The cubic dimensions were 70 × 70x70mm, and the PVC coating was added to the steel wire mesh at equal intervals of 0, 1, 2, 3, 4, 5, and 6. These specimens were then stored at room temperature for 24 hours, immersed in water for 28 days, and tested using a compression instrument. Table 1. summarises these details in a simplified format.

In Testing cube compressive strength is a common method used to determine the strength of concrete. Cube compressive strength testing involves subjecting a concrete cube specimen by using a compression testing machine, it is subjected to compressive loads until it fails. Using the cube's cross-sectional area as a proxy for the specimen's compression strength, the maximum

Table 1. Reinforcement cement matrix composites

PVC Meshes No	Mesh weight (Ischenko & Borisova, 2020)	Sand weight(g)	Cement weight(g)
0	0	600	200
1	1.5	598.5	200
2	3.0	597.0	200
3	4.5	595.5	200
4	6.0	594.0	200
5	7.5	592.5	200
6	9.0	591.0	200

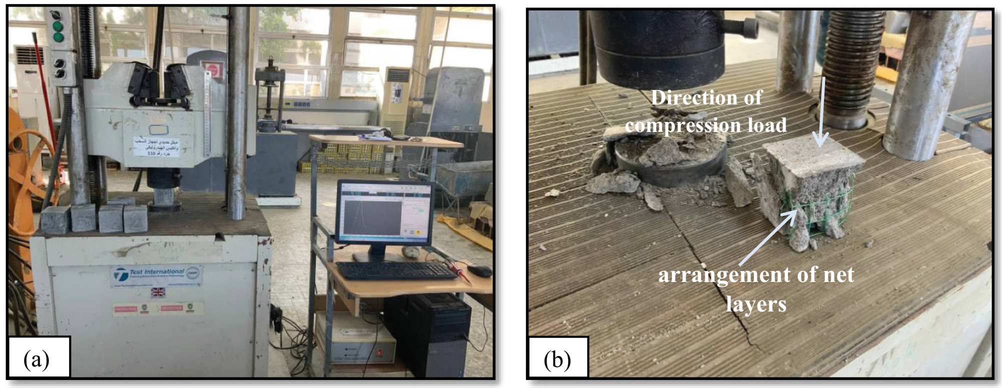

Figure 2. Cube compressive testing a) universal machine, b) specimens before the test, and c)after the test.

load is divided by the cube's compression strength.The current study investigated the effect of using PVC-coated steel wire mesh panels in reinforced concrete using cubic specimens measuring 70 × 70x70mm aged 28 days. The specimens were then subjected to compression stress using a compression testing machine (Cooper Research Technology, United Kingdom), as shown in Figure 2(a). The specimens were set up in the machine as shown in Figure 2(b), the compression load was increased until cracks initiated in a direction parallel to the arrangement of the PVC net layer. The fractures progressed until failure occurred. The study observed that the mesh layer's arrangement might impact the composite material's behaviour under compression stress, as evidenced by the crack initiation and progression.

3. Results and discussions

The results of the study indicated that using PVC-coated steel wire mesh panels in reinforced concrete can have a positive impact on the composite material's compressive strength and breaking force. This work analyzed the stress-strain deformation plot for specimens with varying layers of PVC coating on steel wire mesh.

The study revealed that specimens with two layers of PVC coating exhibited the highest ultimate compression stress and breaking forces. This was compared to specimens with zero, one, three, four, five, and six layers of PVC coating. Figure 3 illustrates this information The thickness of the

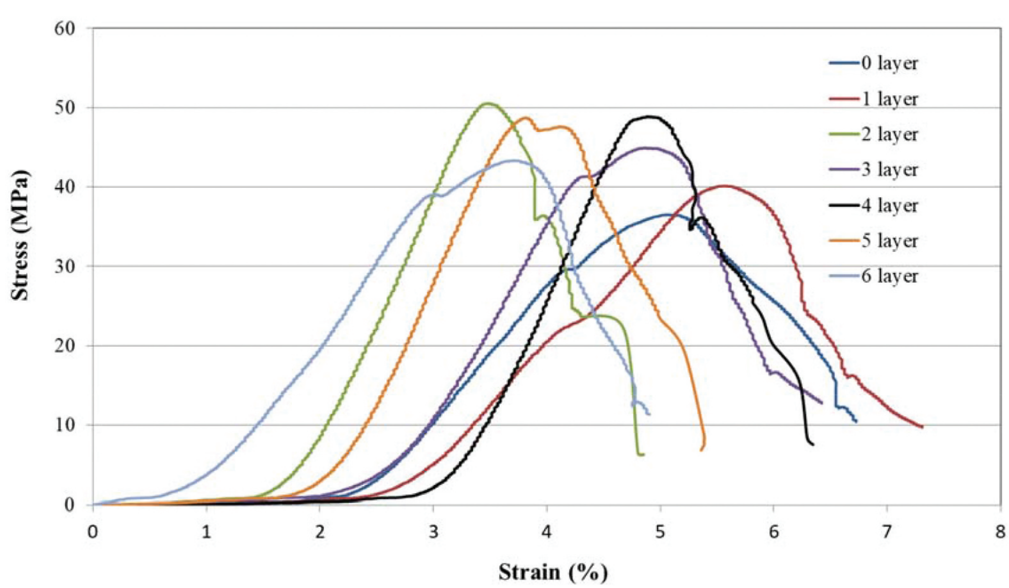

Figure 3. Shows the stress-strain and PVC coating onto steel wire mesh number of reinforced concrete.

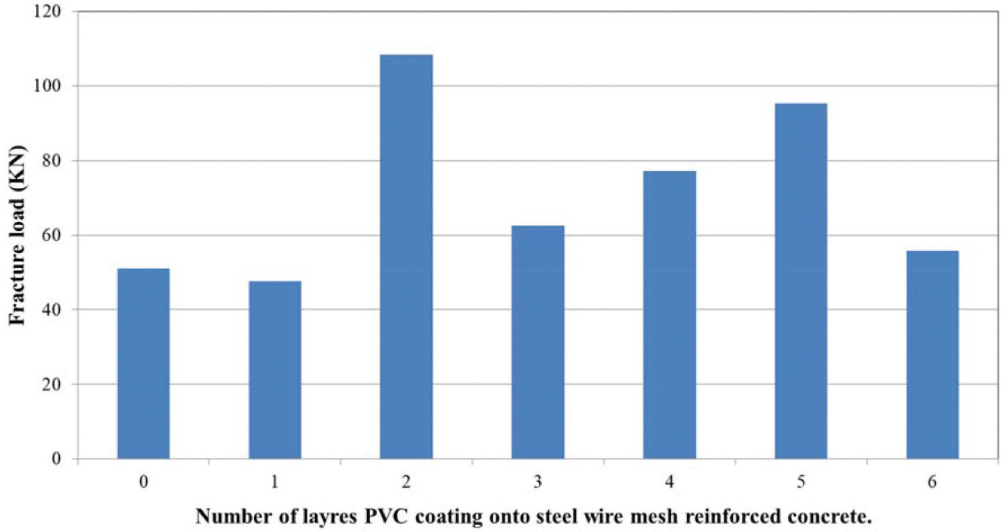

Figure 4. Shows the fracture load of PVC coating onto steel wire mesh reinforced concrete.

PVC coating influenced the mechanical properties of the reinforced concrete specimens. Figure 4. shows that the maximum fracture load is 108.38KN for two layers.

It was observed that specimens with more than two layers of PVC coating experienced a compressive strength reduction. This reduction can be attributed to cracking and failure under load. Two layers of PVC coating provided optimal reinforcement and protection against external factors.

These findings have significant implications for the construction industry. By incorporating PVC-coated steel wire mesh panels with two layers of PVC coating, reinforced concrete structures can be strengthened and durable. This improvement, in turn, enhances the safety and longevity of the structures.

Overall, the study suggests that the use of PVC-coated steel wire mesh panels with an optimal number of PVC coating layers can be a valuable technique in the construction industry to enhance reinforced concrete structures' performance.

The compression test results in Figure 3 were further analyzed to obtain the fracture load and ultimate compression stress, as depicted in Figures 4 and 5, respectively, for all specimens tested. The specimens with two layers of PVC coating on steel wire mesh were observed to have the highest breaking load and ultimate compression stress compared to those with zero, one, three, four, five, or six layers of coating. According to the study, the number of PVC layers had a significant impact on the ultimate compression strength of steel wire mesh reinforced concrete specimens, emphasizing how protective coatings need to be selected and applied properly to guarantee concrete structures' durability and structural integrity.

The results indicate that as the number of grid layers increased from 1 to 6, the compression strength increased by 8%, 38%, 22%, 32%, and 16%, respectively. Table 2. compares the percentage increase in compression strength for various reinforced concrete materials. The results show that PVC coating onto steel wire mesh demonstrated the highest increase in compression strength in this work, with a 38% increase.

In contrast, adding fly ash increased compressive strength by only 2%, according to (Hardjito et al., 2004). Adding super plasticiser increased compressive strength by up to 13%, according to (Ramasamy, 2012). The combination of fly ash and nano-SiO2, nano-Al2O3, and nano-Fe2O3 powders resulted in a 32% improvement in compressive strength, according to (Oltulu & Şahin,

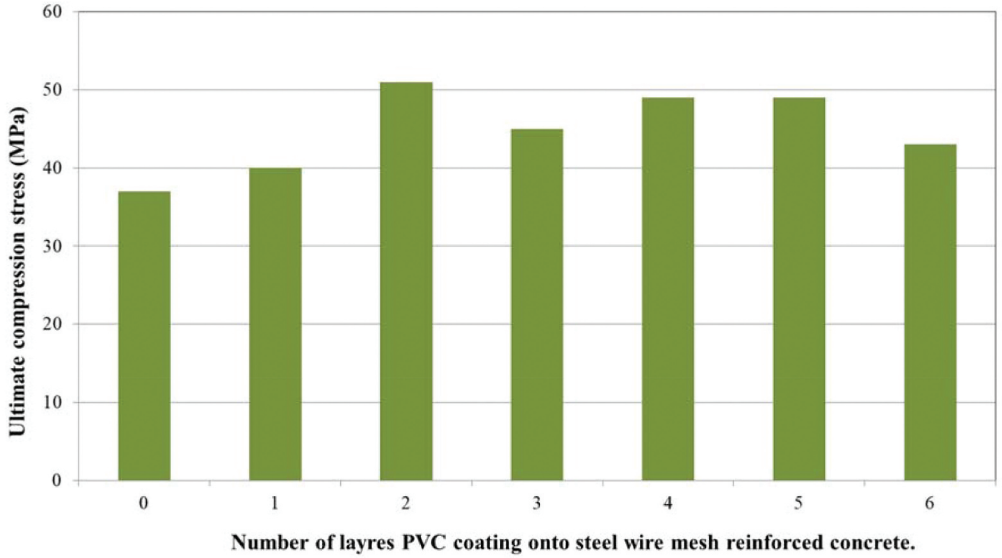

Figure 5. Shows the ultimate compression stress for PVC coating onto steel wire mesh reinforced concrete.

Table 2. Shows the comparisons of compression strength percentage

Reinforcement-type	Compression strength increased up to
PVC coating onto the steel wire mesh	38% (In this work)
Fly ash	2% (Sohaib et al., 2018)
super plasticiser,	13% (Al-Katib et al., 2018)
Powders of nano-SiO2, nano-Al2O3, and nano-Fe2O3 and fly ash of nano-SiO2	32% (Ahmad et al., 2022)
metakaolin	22.91% (Błaszczyński & Przybylska-Fałek, 2015)
HSC	27.5% (Branco et al., 2014)
Silica Fume	13.4% (Kirsanov & Stolyarov, 2018)

2013). The replacement of cement with metakaolin resulted in a 22.91% increase in compression strength, according to (Ganesh et al., 2017).

However (Abaeian et al., 2018), found that plain high-strength concrete experienced compressive strength losses of up to 7.2%, 14.5%, and 27.5% when exposed to temperatures 100, 200, and 300°C. Additionally (Gupta et al., 2022), reported that including silica fume raises compressive strength by 13.4%.

Overall, these results suggest that different types of reinforcements have varying effects on the compression strength of concrete. The PVC coating onto steel wire mesh demonstrated the highest increase in compression strength in this study. However, adding fly ash, super plasticiser, and certain nanoparticles can also significantly affect compression strength. It is essential to consider these factors when designing and constructing concrete structures.

4. Conclusions

The conclusions drawn from this study are as follows:

(i) In specimens with two layers of PVC coating, the compressive strength of reinforced concrete was increased by 38%.

(ii) Reinforced concrete specimens have a significant impact on their ultimate compression stress and breaking strength based on the number of PVC layers used for reinforcement.

(iii) Steel wire mesh layers coated with PVC offer a promising solution for improving the durability and strength of reinforced concrete.

(iv) Steel wire mesh coated with PVC is used in concrete structures to improve quality and safety.

(v) In this study, PVC-coated steel wire mesh was found to be a cost-effective and sustainable method of reinforcing concrete structures.

(vi)A study demonstrates the feasibility of improving the mechanical properties and performance of reinforced concrete structures by mechanically enhancing them.

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References

Abaeian, R., Behbahani, H. P., & Moslem, S. J. (2018). Effects of high temperatures on mechanical behavior of high strength concrete reinforced with high performance synthetic macro polypropylene (HPP) fibres. *Construction and Building Materials*, *165*, 631–638. https://doi.org/10.1016/j.conbuildmat.2018.01.064

Abdallah, A. H., Erfan, A. M., El-Sayed, T. A., & Abd El-Naby, R. M. (2019). Experimental and analytical analysis of lightweight ferrocement composite slabs. *Engineering Research Journal*, *1*(41), 73–85.

Abd, M. K., & Habeeb, Z. D. (2014). Effect of specimen size and shape on compressive strength of self-compacting concrete. *Diyala Journal of Engineering Sciences*, *7*(2), 16–29. https://doi.org/10.24237/djes.2014.07202

Ahmad, J., González-Lezcano, R. A., Majdi, A., Ben Kahla, N., Deifalla, A. F., & El-Shorbagy, M. A. (2022). Glass fibers reinforced concrete: Overview on mechanical, durability and microstructure analysis. *Materials*, *15*(15), 5111. https://doi.org/10.3390/ma15155111

Al-Katib, H. A., Alkhudery, H. H., & Al-Tameemi, H. A. (2018). Behavior of polypropylene fibers reinforced concrete modified with high performance cement. *International Journal of Civil Engineering and Technology (IJCIET)*, *9*(5), 1066–1074.

Almalkawi, A. T., Hong, W., Hamadna, S., Soroushian, P., Darsanasiri, A., Balchandra, A., & Al-Chaar, G. (2018). Mechanical properties of aerated cement slurry-infiltrated chicken mesh. *Construction and Building Materials*, *166*, 966–973. https://doi.org/10.1016/j.conbuildmat.2018.01.101

Al Saadi, H. S. M., Mohandas, H. P., & Namasivayam, A. (2017). An experimental study on strengthening of reinforced concrete flexural members using steel wire mesh. *Curved and Layered Structures*, 4(1), 31–37. https://doi.org/10.1515/cls-2017-0004

Benaimeche, O., Carpinteri, A., Mellas, M., Ronchei, C., Scorza, D., & Vantadori, S. (2018). The influence of date palm mesh fibre reinforcement on flexural and fracture behaviour of a cement-based mortar. *Composites Part B: Engineering*, *152*, 292–299. https://doi.org/10.1016/j.compositesb.2018.07.017

Błaszczyński, T., & Przybylska-Fałek, M. (2015). Steel fibre reinforced concrete as a structural material. *Procedia Engineering*, *122*, 282–289. https://doi.org/10.1016/j.proeng.2015.10.037

Branco, L., Aguiar, L. C., Chahud, E., Lahr, F. A. R., Panzera, T. H., & Christoforo, A. L. (2014). Reinforcement of concretes with carbon fiber composite. *International Journal of Composite Materials*, 4(2), 63–68. https://doi.org/10.5923/j.cmaterials.20140402.04

Chalah, L., Talah, A., & Ghernouti, Y. (2022). Mechanical and durability properties of high-performance concrete incorporating fibers and Algerian natural pozzolans in chloride attack. *International Journal of Engineering and Technology Innovation*, *12*(3), 247. https://doi.org/10.46604/ijeti.2022.9086

Currie, B., & Gardiner, T. (1989). Effect of low temperature on the flexural behaviour of polypropylene mesh reinforced fibre cement composite. *International Journal of Cement Composites and Lightweight Concrete*, *11*(3), 149–152. https://doi.org/10.1016/0262-5075(89)90086-9

El-Sayed, T. A. (2021). Axial compression behavior of ferrocement geopolymer hsc columns. *Polymers*, *13*(21), 3789. https://doi.org/10.3390/polym13213789

El-Sayed, T. A., Deifalla, A. F., Shaheen, Y. B., Ahmed, H. H., & Youssef, A. K. (2023). Experimental and numerical studies on flexural behavior of GGBS-Based geopolymer ferrocement beams. *Civil Engineering Journal*, *9*(3), 629–653. https://doi.org/10.28991/CEJ-2023-09-03-010

El-Sayed, T. A., & Erfan, A. M. (2018). Improving shear strength of beams using ferrocement composite. *Construction and Building Materials*, *172*, 608–617. https://doi.org/10.1016/j.conbuildmat.2018.03.273

El-Sayed, T. A., Shaheen, Y. B., AbouBakr, M. M., & Abdelnaby, R. M. (2023). Behavior of ferrocement water pipes as an alternative solution for steel water pipes. *Case Studies in Construction Materials*, *18*, e01806. https://doi.org/10.1016/j.cscm.2022.e01806

Erfan, A. M., Abd Elnaby, R. M., Elhawary, A., & El-Sayed, T. A. (2021). Improving the compressive behavior of RC walls reinforced with ferrocement composites under centric and eccentric loading. *Case Studies in Construction Materials*, *14*, e00541. https://doi.org/10.1016/j.cscm.2021.e00541

Erfan, A. M., Ahmed, H. H., Mina, B. A., & El-Sayed, T. A. (2019). Structural performance of eccentric ferrocement reinforced concrete columns. *Nanoscience and Nanotechnology Letters*, *11*(9), 1213–1225. https://doi.org/10.1166/nnl.2019.3008

Erfan, A. M., & El-Sayed, T. A. (2019a). Shear strength of ferrocement composite box section concrete beams. *International Journal of Engineering Research*, *10*, 260–279.

Erfan, A. M., & El-Sayed, T. A. (2019b). Structural shear behavior of composite box beams using advanced innovated materials. *Journal of Engineering Research & Reports*, *5*, 1–14. https://doi.org/10.9734/jerr/2019/v5i216920

Fraile-Garcia, E., Ferreiro-Cabello, J., Defez, B., & Peris-Fajanes, G. (2016). Acoustic behavior of hollow blocks and bricks made of concrete doped with waste-tire rubber. *Materials*, *9*(12), 962. https://doi.org/10.3390/ma9120962

Ganesh, Y., Durgaiyya, P., Shivanarayana, C., & Prasad, D. (2017). Compressive strength of concrete by partial replacement of cement with metakaolin. *Paper presented at the AIP Conference Proceedings*, Andhra, Pradesh, India.

Gupta, M., Raj, R., & Sahu, A. K. (2022). Effect of rice husk ash, silica fume & GGBFS on compressive strength of performance based concrete. *Materials Today: Proceedings*, *55*, 234–239.

Hamid, M., Joudah, A., & Mohammed, A. (2018). Reinforcement bars tying types in reinforced concrete. *Paper presented at the MATEC Web of Conferences*, Share el-Shiekh,Egypt.

Hardjito, D., Wallah, S. E., Sumajouw, D. M., & Rangan, B. V. (2004). Factors influencing the compressive strength of fly ash-based geopolymer concrete. *Civil Engineering Dimension*, *6*(2), 88–93. https://doi.org/10.1080/13287982.2005.11464946

Ischenko, A., & Borisova, A. (2020). Application of fiber-reinforced concrete in high-rise construction. *Paper presented at the E3S Web of Conferences*, Tallinn, Estonia.

Khormani, M., Jaari, V. R. K., Aghayan, I., Ghaderi, S. H., & Ahmadyfard, A. (2020). Compressive strength determination of concrete specimens using X-ray computed tomography and finite element method. *Construction and Building Materials*, *256*, 119427. https://doi.org/10.1016/j.conbuildmat.2020.119427

Kirsanov, A., & Stolyarov, O. (2018). Mechanical properties of synthetic fibers applied to concrete reinforcement. *Magazine of Civil Engineering*, 4(80), 15–23.

Kosmatka, S. H., Panarese, W. C., & Kerkhoff, B. (2002). *Design and control of concrete mixtures* (Vol. 5420).

Oltulu, M., & Şahin, R. (2013). Effect of nano-SiO2, nano-Al2O3 and nano-Fe2O3 powders on compressive strengths and capillary water absorption of cement mortar containing fly ash: A comparative study. *Energy and Buildings*, *58*, 292–301. https://doi.org/10.1016/j.enbuild.2012.12.014

Qeshta, I. M., Shafigh, P., Jumaat, M. Z., Abdulla, A. I., Ibrahim, Z., & Alengaram, U. J. (2014). The use of wire mesh–epoxy composite for enhancing the flexural performance of concrete beams. *Materials & Design*, *60*, 250–259. https://doi.org/10.1016/j.matdes.2014.03.075

Ramasamy, V.-W. (2012). Compressive strength and durability properties of rice husk ash concrete. *KSCE Journal of Civil Engineering*, *16*(1), 93. https://doi.org/10.1007/s12205-012-0779-2

Sohaib, N., Seemab, F., Sana, G., & Mamoon, R. (2018). Using polypropylene fibers in concrete to achieve maximum strength. *Paper presented at the Proc. of the Eighth International Conference on Advances in Civil and Structural Engineering*, Labour, Malaysia.

Soulioti, D., Barkoula, N., Paipetis, A., & Matikas, T. (2011). Effects of fibre geometry and volume fraction on the flexural behaviour of steel-fibre reinforced concrete. *Strain*, *47*, e535–e541. https://doi.org/10.1111/j.1475-1305.2009.00652.x

Stolk, J., Verdonschot, N., & Huiskes, R. (1998). Sensitivity of failure criteria of cemented total hip replacements to finite element mesh density. *Journal of Biomechanics*, *1001*(31), 165. https://doi.org/10.1016/S0021-9290(98)80332-1

Yi, S.-T., & Cho, S. G. (2013). Effect of hybrid fibre reinforcement on capacity of reinforced concrete beams. *Proceedings of the Institution of Civil Engineers-Structures and Buildings*, *166*(10), 537–546. https://doi.org/10.1680/stbu.12.00013

Zhang, K., & Sun, Q. (2018). The use of Wire Mesh-Polyurethane Cement (WM-PUC) composite to strengthen RC T-beams under flexure. *Journal of Building Engineering*, *15*, 122–136. https://doi.org/10.1016/j.jobe.2017.11.008

Zhou, S., Xie, L., Jia, Y., & Wang, C. (2020). Review of cementitious composites containing polyethylene fibers as repairing materials. *Polymers*, *12*(11), 2624. https://doi.org/10.3390/polym12112624