MECHANICAL PERFORMANCE OF CONCRETE INCORPORATING FLUIDIZED CATALYTIC CRACKING RESIDUE FROM THE PETROCHEMICAL INDUSTRY AS A SUPPLEMENTARY CEMENTITIOUS MATERIAL

Dien Huu Nguyen

Long An University of Economics and Industry, Khanh Hau W., Tay Ninh, Vietnam

ARTICLE INFOR
TYPE: Research Article
Received: 24/9/2025
Revised: 30/10/2025
Accepted: 02/11/2025
Corresponding author:
Email: nguyen.dien@daihoclongan.edu.vn

ABSTRACT

The increasing demand for sustainable construction materials has highlighted the need to reduce the environmental footprint of cement production. This study investigates the reuse of petrochemical residue fluidized catalytic cracking (RFCC) waste as a supplementary cementitious material (SCM) in concrete. RFCC was subjected to two activation methods: high-temperature treatment at 800, 1000, and 1200 °C, and mechanical grinding to enhance pozzolanic activity. Concrete mixtures were prepared with cement replacement levels ranging from 10% to 50% by mass. Fresh properties, including workability and setting time, and hardened mechanical properties such as compressive strength, flexural strength, and elastic modulus, were evaluated at 28 days. Results show that RFCC reduces slump and shortens the setting time of concrete mixtures. At 50% cement replacement, compressive and flexural strengths decreased by up to 45%. However, thermal activation at 1000–1200 °C significantly improved compressive and flexural strengths as well as elastic modulus by 10–20% compared to untreated RFCC. Ground RFCC showed lower early-age strength at 10% replacement but outperformed heat-treated RFCC at higher replacement levels (20–50%). The findings demonstrate that properly treated RFCC waste can replace up to 30% of cement without compromising mechanical performance, offering a viable route for cost reduction, carbon emission mitigation, and sustainable concrete production.

Keywords: *Concrete mechanics, RFCC waste, supplementary cementitious material, compressive strength, flexural strength, sustainable construction.*

@ Vietnam Mining Science and Technology Association

1. INTRODUCTION

Cement production is responsible for nearly 8% of global CO_2 emissions, making the search for alternative supplementary cementitious materials (SCMs) a pressing priority. Various industrial by-products such as fly ash, silica fume, and blast furnace slag have been successfully utilized as partial cement replacements. Recently, residue fluidized catalytic cracking (RFCC) waste from petroleum refining has emerged as a promising candidate due to its aluminosilicate composition and residual pozzolanic activity.

In Vietnam and many developing countries, large quantities of RFCC waste are generated annually from refineries such as Dung Quat, with disposal mainly by landfilling. This not only raises environmental concerns but also wastes a potentially valuable resource. The reuse of RFCC waste in construction aligns with circular economy principles and contributes to reducing cement consumption and environmental emissions.

The mechanical properties of RFCC-based concrete remain underexplored, particularly under different activation treatments. This study evaluates the mechanical performance of concrete incorporating RFCC waste treated through thermal activation and mechanical grinding. The research focuses on both fresh and hardened properties, highlighting the mechanics of strength development and the feasibility of large-scale application.

2. MATERIALS AND METHODS

2.1. Research Methods

Materials

- Cement: Ordinary Portland Cement (OPC) conforming to TCVN/ASTM standards.
- RFCC waste: Collected from petrochemical refinery processes; composition rich in SiO_2, Al_2O_3, and minor Fe_2O_3.
- Aggregates: Crushed stone and natural sand conforming to concrete standards.
- Water: Potable tap water used for mixing.

Source and Characteristics of Materials

The Ordinary Portland Cement (OPC) used in this study was supplied by a local Vietnamese manufacturer and conforms to TCVN and ASTM specifications. It is characterized by a typical chemical composition rich in calcium silicates, with primary oxides including CaO (62–65%), SiO_2 (19–22%), Al_2O_3 (4–6%), and Fe_2O_3 (2–4%). The Blaine fineness was approximately 350 m²/kg, and the specific gravity was measured at 3.15.

The residue fluidized catalytic cracking (RFCC) waste was obtained from the Dung Quat petrochemical refinery in Vietnam, one of the country's major refineries generating significant quantities of such by-products annually. RFCC waste is a fine aluminosilicate-based powder composed primarily of SiO_2 (45–55%) and Al_2O_3 (35–45%), with minor quantities of Fe_2O_3, CaO, and trace heavy metals. Its amorphous structure and residual pozzolanic activity make it suitable for use as a supplementary cementitious material. However, in its raw state, RFCC exhibits limited reactivity, necessitating activation methods such as high-temperature calcination or mechanical grinding to enhance its binding potential.

By integrating OPC with treated RFCC waste, the study leverages both conventional cement chemistry and the latent pozzolanic behavior of industrial by-products, aligning with sustainable construction practices and circular economy principles.

RFCC Treatment Methods

- Thermal activation: RFCC calcined at 800, 1000, and 1200 °C. (Fig.1)
- Mechanical activation: RFCC finely ground to increase surface area and reactivity.

Figure 1. Furnace used for RFCC heat treatment.

Mix Proportions

Concrete mixtures were designed with cement replacement levels of 10%, 20%, 30%, and 50% by mass. A control mixture with 0% RFCC was also prepared.

Testing Methods

- Fresh properties: Slump test (ASTM C143), setting time (Vicat method).
- Hardened properties:
  - o Compressive strength (ASTM C39) at 30 days. (Fig.2)
  - o Flexural strength (ASTM C78).
  - o Elastic modulus (ASTM C469).

Figure 2. Experimental testing of compressive strength of concrete using RFCC

3. RESULTS AND DISCUSSION

3.1. Fresh Properties

- RFCC replacement reduced slump, indicating lower workability.
- Both initial and final setting times shortened by 10–15 minutes compared to the control.

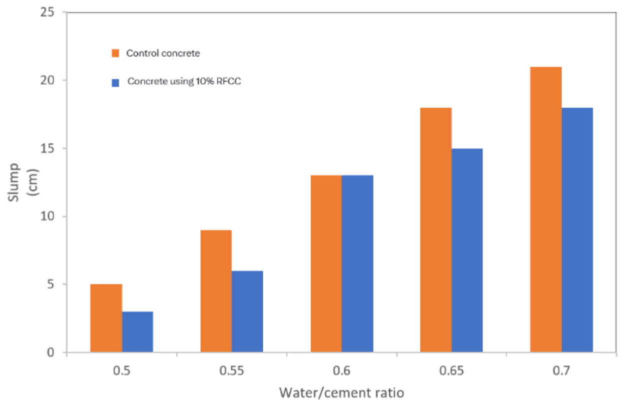

Figure 3. Effect of 10% RFCC on the slump of concrete mixtures

The initial setting time of the concrete mix reaches 130 minutes and gradually increases to 150 minutes as the water-cement ratio increases, as shown in Figure 3. The results in Figure 3 indicate that when the water-cement ratio of the mix varies from 0,5 to 0,7, the initial setting time of the concrete mix also tends to increase gradually. For the concrete mix with 10% RFCC replacement that has undergone heat treatment, the setting time ranges from 142 minutes and gradually increases to 160 minutes.

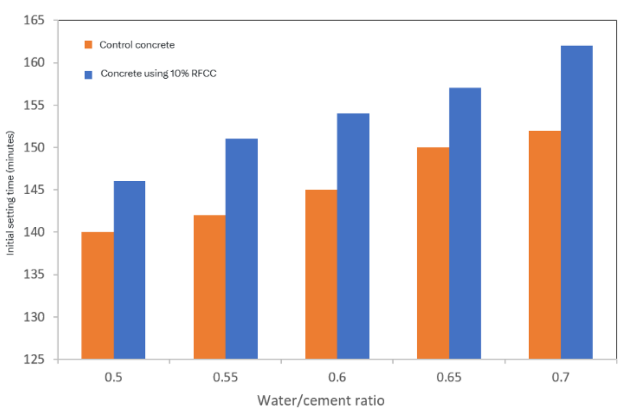

Figure 4. Effect of 10% RFCC on the setting time of concrete mixtures

The results shown in Figure 4 indicate that when the water-cement ratio of the mix varies from 0,5 to 0,7, the setting time of the concrete mix with 10% RFCC replacement is longer than that of the control concrete mix, with a difference of approximately 6–7.5 minutes. However, the setting time of the concrete mix with 10% RFCC replacement, when the water-cement ratio changes from 0,5 to 0,7, shows a relatively small and inconsistent increase. Specifically, at a water-cement ratio of 0,5, the setting time is 87 minutes, while at a water-cement ratio of 0,7, the setting time is 89 minutes.

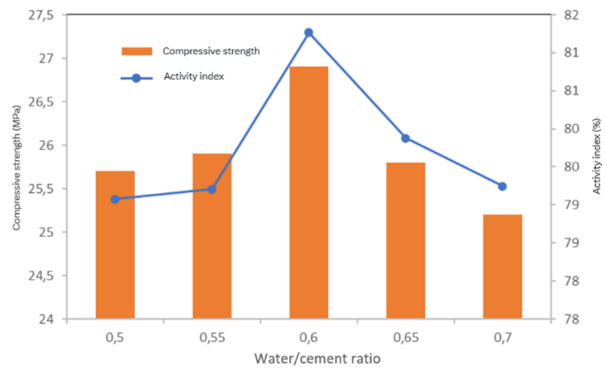

Figure 5. Effect of the activity index of RFCC in concrete

The results shown in Figure 5 indicate that the activity index of the concrete mix using 10% RFCC, when the water-cement ratio varies from 0,5 to 0,7, exhibits a relatively small difference. The highest activity index is observed at a water-cement ratio of 0,6, reaching 81.5%, while at water-cement ratios of 0,5 and 0,7, the activity index is 78%.

It can be observed that changes in the water-cement ratio significantly affect the plasticity and workability of the concrete mix. When 10% RFCC is used as a replacement for cement in the mix, it influences the plasticity and setting time by approximately 11–14%, indicating that RFCC has a less pronounced impact on the properties of the concrete mix. The use of a water-cement ratio of 0,6 results in stable plasticity, setting time, and strength development, as validated through experiments investigating the effects of RFCC in concrete.

3.2. Mechanical Properties

- At 50% replacement, compressive strength decreased by up to 45%.
- Thermal activation at 1000–1200 °C improved compressive and flexural strengths by 10–20% compared with untreated RFCC.
- Ground RFCC showed inferior strength at 10% replacement but outperformed thermally activated RFCC at higher levels (20–50%).

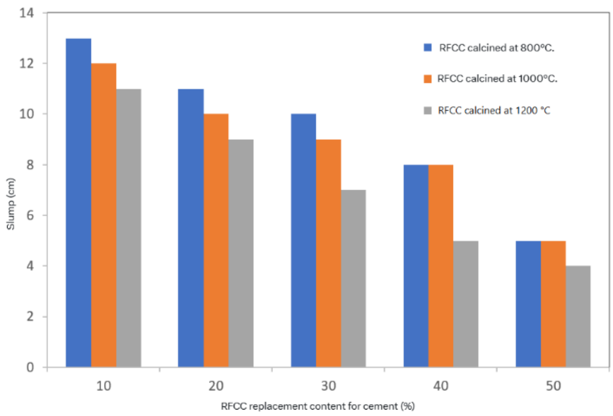

Figure 6. Effect of RFCC processing temperature on slump of concrete mixture

Figure 6 illustrates the slump values of concrete mixtures incorporating RFCC thermally treated at 800 °C, 1000 °C, and 1200 °C, with cement replacement levels ranging from 11% to 49%. Overall, the highest slump was obtained for RFCC treated at 800 °C, followed by RFCC treated at 1000 °C.

For RFCC treated at 800 °C, the slump gradually decreased from 13,5 cm at 11% cement replacement to 5 cm at 49%. For RFCC treated at 1000 °C, the slump declined from 12 cm at 11% replacement to 5 cm at 49%. Similarly, for RFCC treated at 1200 °C, the slump decreased from 11 cm at 11% replacement to 4 cm at 49%.

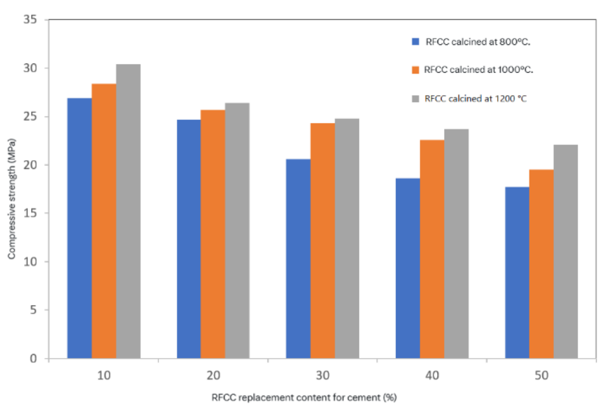

Figure 7. Effect of RFCC processing temperature on compressive strength

Meanwhile, the use of RFCC thermally treated at 1000 °C showed a gradual decrease in compressive strength from 28,4 MPa to 19,5 MPa, corresponding to a reduction of approximately 40% with increasing RFCC content. For mixtures incorporating RFCC treated at 1200 °C, compressive strength values also decreased, from 30,4 MPa to 22,2 MPa, representing a reduction of about 37%. These results indicate that RFCC treated at higher temperatures (up to 1200 °C) exhibits better reactivity with cement compared to treatment at 800 °C. Nevertheless, as the RFCC replacement level increases, the compressive strength consistently tends to decline (Fig.7).

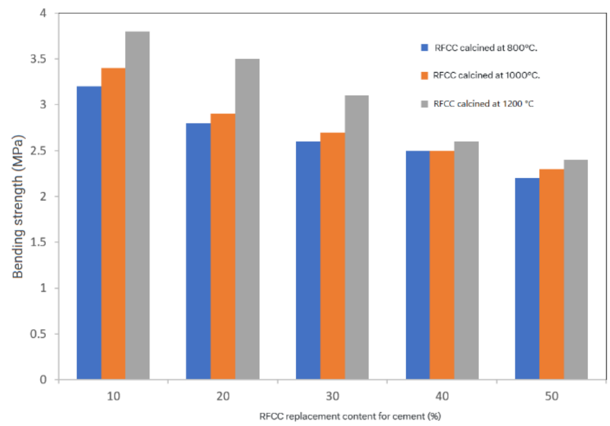

Figure 8. Effect of RFCC processing temperature on bending strength

The use of RFCC thermally treated at 1000 °C showed a gradual decrease in compressive strength from 28.4 MPa to 19.5 MPa, corresponding to a reduction of about 40% as the RFCC content increased. For mixtures incorporating RFCC treated at 1200 °C, compressive strength also decreased from 30.4 MPa to 22.2 MPa, representing a reduction of approximately 37%. This indicates that RFCC treated at higher temperatures, up to 1200 °C, exhibits better reactivity with cement compared to treatment at 800 °C. However, as the RFCC replacement level increases, compressive strength consistently tends to decrease. (Fig.8)

The mechanical behavior of RFCC concrete is governed by its pozzolanic reactivity and microstructural integration with cement hydration products. Heat treatment enhances crystallinity and reactivity, thereby improving strength, especially at moderate replacement levels. Mechanical grinding increases surface reactivity but may induce excessive early-age hydration, leading to reduced strength at lower replacement percentages.

Compared with conventional SCMs such as fly ash and slag, RFCC shows comparable potential, particularly when thermally treated. However, long-term durability and leaching of heavy metals require further investigation before large-scale application.

4. CONCLUSION

➢ This study confirms that RFCC waste can be effectively utilized as a supplementary cementitious material in concrete. Thermal activation at elevated temperatures, particularly between 1000 and 1200 °C, significantly enhances its reactivity and contributes to improved mechanical performance. The experimental results demonstrate that cement replacement levels up to 30% can be achieved without compromising compressive strength, flexural strength, or elastic modulus. Beyond this threshold, however, the excessive incorporation of RFCC leads to a progressive reduction in mechanical properties. Overall, the use of thermally or mechanically treated RFCC not only provides a feasible alternative to conventional cement but also delivers notable environmental benefits by reducing CO_2 emissions and supporting sustainable construction practices;

➢ RFCC waste can be used as a supplementary cementitious material in concrete;

➢ Thermal activation at 1000–1200 °C significantly improves mechanical performance;

➢ Cement replacement up to 30% is feasible without compromising strength;

➢ The approach offers both mechanical and environmental benefits, contributing to sustainable construction practices ❒

REFERENCES

[1]. S. K .Antiohos, E. Chouliara and S. Tsimas (2006). Re-use of spent catalyst from oil-cracking refineries as supplementary cementing material. *China Particuology; Vol. 4(2): p. 73 – 76, 2006.*

[2]. H. Al-Dhamri, K. Melghit (2010). Use of alumina spent catalyst and RFCC wastes from petroleum refinery to substitute bauxite in the preparation of Portland clinker, *Journal Hazardous Materials, Vol. 179, pp. 852-859, 2010.*

[3]. K.L. Lin, K. W. Lo, M.J. Hung, T.W. Cheng, Y.M. Chang (2017). Recycling of spent catalyst and waste sludge from industry to substitute raw materials in the preparation of Portland cement clinker. *Sustainable Environmental Research., Vol. 27, pp. 251-257, 2017.*

[4]. Do Doan Dung, Bui Dang Hung, et al. (2018). "Residue fluid catalytic cracking (RFCC) as an alternative additive in cement production: a preliminary evaluation". *Journal Of Science And Technology, Vol. 31 No. 01, pp. 2018.*

[5]. CSI. (2020). *SAFE - Slab Analysis and Design Software*. Computers and Structures, Inc., Berkeley, CA.

[6]. EN 1990. (2002). *Eurocode: Basis of structural design*. European Committee for Standardization.

[7]. Nguyen, H. D. (2025). XFEM Simulation of Functionally Graded Plates with Arbitrary Openings. *VNUHCM Journal of Science and Technology Development 2025, 27, 12085*

[8]. Nguyen, H. D (2025). Extended Finite Element Approach for Simulating Arbitrary Openings in Functionally Graded Plates Int. *J. Mech. Energy Eng. Appl. Sci. Volume 3, Issue No 3*

[9]. Nguyen, H. D.; Huang, S.-C (2021). Extend Finite Element Method for A Plate with Two Holes and Multiple Cracks. *In Proceedings of the Taiwan International Conference on Ocean Governance, Kaohsiung, China, 23 September 2021.*

[10]. Nguyen, H. D.; Huang, S. C (2020). Extended Finite Element Method for Modeling Arbitrary Discontinuities with Center Edge Crack in Finite Dimensional Plate under Tension and Shear. *In Proceedings of the International Conference on Advanced Technology Innovation, Okinawa, Japan, 1 September 2020.*

[11]. Nguyen, H. D.; Huang, S. C.(2023). Use of XTFEM based on the consecutive interpolation procedure of quadrilateral element to calculate J-integral and SIFs of an FGM plate. *Theor. Appl. Fract. Mech. 2023, 127, 103985.*

[12]. Nguyen, H. D (2025). Using Finite Element Method to Calculate Strain Energy Release Rate, Stress Intensity Factor and Crack Propagation of an FGM Plate Based on Energy Methods. *Int. J. Mech. Energy Eng. Appl. Sci. Volume 3, Issue No 2(2025)*

[13]. Bai, X.; Guo, L.; Wang, Z.; Zhong, S. (2013). A dynamic piecewise-exponential model for transient crack problems of functionally graded materials with arbitrary mechanical properties. *Theor. Appl. Fract. Mech. 2013, 66, 41–61.*

[14]. Nguyen, H. D. (2025). Using the eXtended Finite Element Method (XFEM) to Simulate Own Frequency under External Influences of a Closed System based on Dynamic Compensation Method. *J. Int. Multidiscip. Res. 2025, 27, 985*

[15]. Ding, S.; Li, X. (2013). The fracture analysis of an arbitrarily orientated crack in the functionally graded material under in-plane impact loading. *Theor. Appl. Fract. Mech. 2013, 66, 26–32.*

[16]. Nguyen, H. D.; Huang, S. C. Using the Extended Finite Element Method to Integrate the Level-Set Method to Simulate the Stress Concentration Factor at the Circular Holes Near the Material Boundary of a Functionally-Graded Material Plate. *J. Mater.Res. Technol. 2022, 21, 4658–4673.*

[17]. Praveen, G. N., & Reddy, J. N.(1998). Stress analysis of functionally graded plates using the first-order shear deformation theory. Composite Structures. 1998, 43, 333-349.

[18]. Erdogan, F., & Kaya, A. C. (1985). A new boundary element method for elastostatic problems with arbitrary internal cracks*. Journal of Applied Mechanics. 1985, 52, 1*

[19]. S. Raju (1987). “Calculation of strain-energy release rates with higher order and singular finite elements” *Engineering Fracture Mechanics, vol. 28, no. 3, pp. 251-266, 1987.*

[20]. J. H. Kim and G. H. Paulino (2002). “Finite element evaluation of mixed-mode stress intensity factors in functionally graded materials,” *International Journal for Numerical Methods in Engineering, vol. 53, no. 8, pp. 1903-1935, 2002.*

[21]. Nguyen, H. D.; Huang, S. C.(2022). Designing and Calculating the Nonlinear Elastic Characteristic of Longitudinal–Transverse Transducers of an UltrasonicMedical Instrument Based on the Method of Successive Loadings. *Materials 2022, 15, 4002.*

[22]. Nguyen, H. D. (2025). Extended Finite Element Approach for Simulating Arbitrary Openings in Functionally Graded Plates. *Int. J.Mech. Energy Eng. Appl. Sci. 2025, 17, 885.*

[23]. Nguyen, H. D.(2025). Application of the Extended Finite Element Method (X-FEM) for Simulating Random Holes in Functionally Graded Plates,” *International Journal of All Research Writing, Volume-6 Issue-12, 2025.*

[24]. Dai, M. J.; Xie, M. Y.(2025). A novel inverse extended finite element method for structural health monitoring of cracked structures. *Ocean. Eng. 2025, 325, 120786.*

[25]. G.R. Irwin, J.M. Krafft, P.C. Paris, and A.A. Wells (1967). *“Basic Concepts of Crack Growth and Fracture”* NRL Report 6598, Naval Research Laboratory, Washington, DC, (November 21, 1967).

[26]. Bayesteh, H.; Mohammadi, S. (2013). FEM fracture analysis of orthotropic functionally graded materials. *Compos. Part B 2013,44, 8–25.*

[27]. Nguyen, H. D.; Huang, S.-C.(2025). Calculating Strain Energy Release Rate, Stress Intensity Factor and Crack Propagation of an FGM Plate by Finite Element Method Based on Energy Methods. *Materials 2025, 67, 8885.*

[28]. Singh, I. V.; Mishra, B. K.; Bhattacharya, S.(2011). FEM simulation of cracks, holes and inclusions in functionally graded materials.*Int.J. Mech. Mater. Des. 2011, 7, 199–218.*

[29]. Nguyen, H. D. (2025). Analysis for Stress Concentration Factor at the Circular Holes Near Materials Border by Extended Finite Element Method. *In Proceedings of the 4th International Online Conference on Materials, Online, 3–5 November 2025.*

[30]. Nguyen, H. D.; Huang, S. C. (2021). The Uniaxial Stress Strain Relationship of Hyperelastic Material Models of Rubber Cracks in the Platens of Papermaking Machines Based on Nonlinear Strain and Stress Measurements with the Finite Element Method. *Materials 2021, 14, 7534.*

[31]. Nguyen, H. D. (2025). Using Matlab to Study of the Response of the System to Oscillatory Influences be an Oscillatory Effect on the Resting Antenna. *Int. J. Multidiscip. Res. Growth Eval. 2025, 27, 885*

[32]. Nguyen, H. D. (2025). Finite Element and Fictitious Component Methods for Solving the Poisson Equation in a Rectangular Domain, Mining Industry Journal, 2025

[33]. Nguyen, H. D.(2025). Finite Element Method for Stress Analysis of an Infinite Plate with an Elliptical Hole Using Functionally Graded Materials, *Journal of International Multidisciplinary Research, 2025*

[34]. Nguyen, H. D.(2025). XFEM Simulation of Functionally Graded Plates with Arbitrary Openings, *VNUHCM Science & Technology Development Journal, 2025*

ĐẶC TÍNH CƠ HỌC CỦA BÊ TÔNG SỬ DỤNG CHẤT THẢI TỪ QUÁ TRÌNH CRACKING XÚC TÁC TẦNG SÔI CỦA CẶN DẦU MỎ LÀM VẬT LIỆU XI MĂNG BỔ SUNG

Nguyễn Hữu Điện

Trường Đại học Kinh tế Công nghiệp Long An, Phường Khánh Hậu, Tây Ninh, Việt Nam

THÔNG TIN BÀI BÁO
CHUYÊN MỤC: Công trình khoa học
Ngày nhận bài: 24/9/2025
Ngày nhận bài sửa: 30/10/2025
Ngày chấp nhận đăng: 02/11/2025
Tác giả liên hệ:
Email: nguyen.dien@daihoclongan.edu.vn

TÓM TẮT

Nhu cầu ngày càng tăng đối với vật liệu xây dựng bền vững đã làm nổi bật nhu cầu giảm dấu chân môi trường của quá trình sản xuất xi măng. Nghiên cứu này điều tra việc tái sử dụng chất thải của quá trình nứt xúc tác lưu hóa dầu (RFCC) làm vật liệu xi măng bổ sung (SCM) trong bê tông. RFCC được đưa vào hai phương pháp hoạt hóa: xử lý nhiệt độ cao ở 800, 1000 và 1200 °C và nghiền cơ học để tăng cường hoạt động puzzolan. Hỗn hợp bê tông được chuẩn bị với mức thay thế xi măng từ 10% đến 50% theo khối lượng. Các tính chất mới, bao gồm khả năng làm việc và thời gian đông kết, và các tính chất cơ học đã đông cứng như cường độ nén, cường độ uốn và mô đun đàn hồi, đã được đánh giá sau 28 ngày. Kết quả cho thấy RFCC làm giảm độ sụt và rút ngắn thời gian đông kết của hỗn hợp bê tông. Ở mức thay thế 50% xi măng, cường độ nén và uốn giảm tới 45%. Tuy nhiên, hoạt hóa nhiệt ở 1000–1200 °C đã cải thiện đáng kể cường độ nén và uốn cũng như mô đun đàn hồi từ 10–20% so với RFCC chưa qua xử lý. RFCC đất cho thấy cường độ ban đầu thấp hơn ở mức thay thế 10% nhưng lại vượt trội hơn RFCC đã qua xử lý nhiệt ở mức thay thế cao hơn (20–50%). Các phát hiện chứng minh rằng chất thải RFCC được xử lý đúng cách có thể thay thế tới 30% xi măng mà không ảnh hưởng đến hiệu suất cơ học, mở ra một hướng đi khả thi để giảm chi phí, giảm thiểu phát thải carbon và sản xuất bê tông bền vững.

Từ khóa: *Cơ học bê tông, chất thải RFCC, vật liệu xi măng bổ sung, cường độ nén, cường độ uốn, xây dựng bền vững.*

@ Hội Khoa học và Công nghệ Mỏ Việt Nam