JIRRS
Journal International Review of Research Studies

Received: 01/02/2026 - **Accepted:** 05/03/2026
Vol: 01.02
DOI: 10.66104/gkkj0g48
Pages: 1-9

The elastomechanical properties of concrete expanded with aluminum nano-inclusions.

Abdelmoutalib BENFRID[1]
[1]Doctor in Public Works, graduated from Djillali Liabès University in Sidi Bel Abbès, Algeria.
Corresponding author: benfridabdelmoutalib2050@gmail.com

Abstract

In recent years, nano-inclusion-reinforced concrete has gotten a lot of attention. Researchers have persistently examined the mechanical properties of concrete containing these inclusions. The aim of this research is to ascertain the mechanical properties of concrete augmented with nano-inclusions derived from aluminum waste.The Mori–Tanaka model is the method of homogenization used in this study. It is a common model for composites with spherical inclusions. The results show that the mechanical properties, such as the elastic modulus, shear modulus, and bulk modulus, are consistently getting better.This method gives experimental researchers a way to predict the acceptable volume fractions that can be added to concrete. This makes experiments more efficient and cuts down on unnecessary testing. To keep people safe, the maximum volume fraction is set at 30%.
Keywords: Nano-inclusions, Aluminum waste, Reinforced concrete, Mori–Tanaka model, Mechanical properties.

1. Introduction

Numerous studies have been conducted within the same research framework. Harrat et al. looked into how nanosilica could make concrete beams stronger. The agglomeration effect was the biggest problem that came up during the homogenization process. To fix this, they used a more advanced Voigt-based homogenization formulation [1].Chatbi et al. also used a better Voigt homogenization method [2] to study how nanosilica sticks together in concrete slabs, both in the middle and at the corners.Benfrid et al. looked at concrete that was strengthened with glass powder. They used Eshelby's model to do a thermo-mechanical bending analysis of glass powder-reinforced concrete panels [3].Dine El Hannani Soumia et al. performed an investigation on concrete beams fortified with highly sustainable alternatives that improve structural rigidity. A two-phase homogenization scheme derived from Eshelby's model was established [4].Kecir et al. utilized Eshelby's theory to ascertain the stiffness matrix of concrete plates augmented with nano-inclusions in a separate study [5].Chatbi et al. did an extra study on how concrete plates bend when they are on an elastic foundation and have nanoclay particles added to them. Eshelby's theoretical framework [6] was used for

JIRRS
Journal International Review of Research Studies
Received: 01/02/2026 - **Accepted:** 05/03/2026
Vol: 01.02
DOI: 10.66104/gkkj0g48
Pages: 1-9

the homogenization.Harrat Rabie also studied how adding tiny iron particles to concrete could make it stronger [7].In another study, Benfrid et al. used Piggott's model to find out how plant-based nanofibers and gypsum composites work together [8].Chatbi and others recently used a new way to mix things up to guess the mechanical properties of concrete that has nanoclay in it [9].Using the Reuss and Maxwell–Eucken models, Benfrid et al. did a thermoelastic analysis of concrete panels that had nano-glass particles added to them [10].

The Mori–Tanaka model is frequently employed in scientific literature to achieve uniformity in materials containing nano-inclusions across two phases. Ketir et al. used this method to study lightweight concrete made from a gypsum matrix [11], and Melati used the same theoretical framework to make a steel–tungsten composite system more uniform [12]. Boukhari et al. utilized the Mori–Tanaka model to examine concrete integrated with nano-granite particles in a comparable fashion. Chatbi et al. used the Mori–Tanaka homogenization method to look at how well polymer composites with carbon nanotubes worked [14]. Yakro et al. also used similar homogenization methods to study eco-concrete that was made stronger with waste materials [15]. The Mori–Tanaka model provides a simple homogenization technique for composite materials composed of two phases, namely a matrix and reinforcing inclusions [16].

Wen Yu Xu and others say that adding up to 20% aluminum powder to fly ash can make concrete about 42% stronger when it is compressed. This means that adding aluminum powder to the composite material can make it work much better mechanically [17]. Fazel Azarhomayun and others found that adding a hydrophobic substance like calcium stearate makes cracks smaller, reduces free drying shrinkage, and reduces restrained shrinkage. On the other hand, adding aluminum powder to the mix almost completely stops free shrinkage. But restrained drying shrinkage does get a little bit bigger [18]. Hong Jiang and others looked into how to use secondary aluminum ash (SAA) in reactive powder concrete to recycle industrial waste and make it last longer. Their study shows that when SAA is exposed to NaCl and freeze-thaw cycles, it changes its mechanical properties and makes it less resistant to corrosion [19]. The research conducted by Mojtaba Fathi et al. on conductive concrete incorporating recycled aluminum waste, such as chips and aluminum powder, demonstrated enhanced electrical conductivity and thermal performance for deicing pavement applications [20].

This study tackles both environmental and technical issues by encouraging the recycling of aluminum waste and cutting down on the CO_2 emissions that come from making cement. The results show that adding 30% nano-scale aluminum powder as a partial replacement for cement reduces the amount of cement needed by 30% while still providing good mechanical performance. This way of doing things is better for the environment and uses materials more efficiently.

2. Methodology

We use the Mori–Tanaka homogenization method [16] to find the effective elastic modulus of a composite matrix that has spherical nanoparticles as dispersed inclusions. This method works best with materials that are not uniform, like

JIRRS
Journal International Review of Research Studies
Received: 01/02/2026 - **Accepted:** 05/03/2026
Vol: 01.02
DOI: 10.66104/gkkj0g48
Pages: 1-9

concrete, where the cementitious phase is the continuous matrix and nano-aluminum particles are used to strengthen it.

The combined volume of the fresh concrete matrix and the embedded nano-aluminum inclusions is called a representative volume element (RVE).

$$V_m = 1 - V_c \tag{1}$$

The bulk modulus, shear modulus, Young's modulus, and Poisson's ratio are all elastic constants that depend on each other. Mathematicians use their relationships to figure out the material's compressibility and shear parameters.

The composite material is made up of a concrete matrix with small, round bits of aluminum mixed in.

$$K_m = \frac{E_m}{3(1-2\nu_m)}, \quad K_c = \frac{E_c}{3(1-2\nu_c)}, \quad G_m = \frac{E_m}{3(1+2\nu_m)}, \quad G_c = \frac{E_m}{2(1+\nu_c)} \tag{2}$$

The effective bulk modulus (compressibility) (k) and shear modulus (G) are expressed as follows:

$$\frac{K - K_m}{K_C - K_m} = \frac{V_c}{1 + V_m\left(\frac{K_c - K_m}{K_m + \frac{4}{3}G_m}\right)} \tag{3}$$

$$\frac{G - G_m}{G_C - G_m} = \frac{V_c}{1 + V_m\left(\frac{G_c - G_m}{G_m + f1}\right)} \tag{4}$$

Where:

$$f_1 = \frac{G_m(9K_m + 8G_m)}{6(K_m + 2G_m)} \tag{5}$$

The effective modulus of elasticity E and Poisson's ratio ν are determined using the relation:

$$E = \frac{9KG}{3K+G}, \quad \nu = \frac{3K-2G}{2(3K+G)} \tag{6}$$

It is noted that:
E: Homogeneous Elasticity Modulus.
K: Homogeneous Compressibility Modulus.
G: Homogeneous Shear Modulus.
E_m: Matrix Elasticity Modulus.

JIRRS
Journal International Review of Research Studies
Received: 01/02/2026 - **Accepted:** 05/03/2026
Vol: 01.02
DOI: 10.66104/gkkj0g48
Pages: 1-9

E_c: Composite Elasticity Modulus.
K_m: Matrix Compressibility Modulus.
K_c: Composite Compressibility Modulus.
G_m: Matrix Shear Modulus.
G_c: Composite Shear Modulus.
V_m: Matrix Volume.
V_c: Composite Volume.
ν_m: Matrix Poisson's Ratio.
ν_c: Composite Poisson's Ratio.

3. Results

The volume fraction is limited to 30% for safety considerations, as exceeding this value leads to a reduction in the mechanical strength of the concrete. It is preferable to use this mathematical model without conducting experiments. The model allows researchers to analyze the material behavior and identify the optimal volume fraction. It is noted that the material is assumed to be homogeneous and isotropic. The Mori–Tanaka model was chosen due to its widespread use in the literature for predicting the effective properties of composite materials.

Table 1. The effective elasto-mecanical properties of new concrete.

V_c	K_{eff} (GPa)	G_{eff} (GPa)	E_{eff} (GPa)	ν_{eff}
0%	11.111	8.333	20.000	0.2000
5%	11.893	8.785	21.147	0.2037
10%	12.732	9.261	22.362	0.2073
15%	13.635	9.765	23.649	0.2109
20%	14.609	10.298	25.016	0.2146
25%	15.663	10.864	26.471	0.2183
30%	16.806	11.465	28.023	0.2221

JIRRS
Journal International Review of Research Studies
Received: 01/02/2026 - **Accepted:** 05/03/2026
Vol: 01.02
DOI: 10.66104/gkkj0g48
Pages: 1-9

Figure 1. The effective Young's modulus of nano-aluminum reinforced concrete versus inclusion volume fraction .

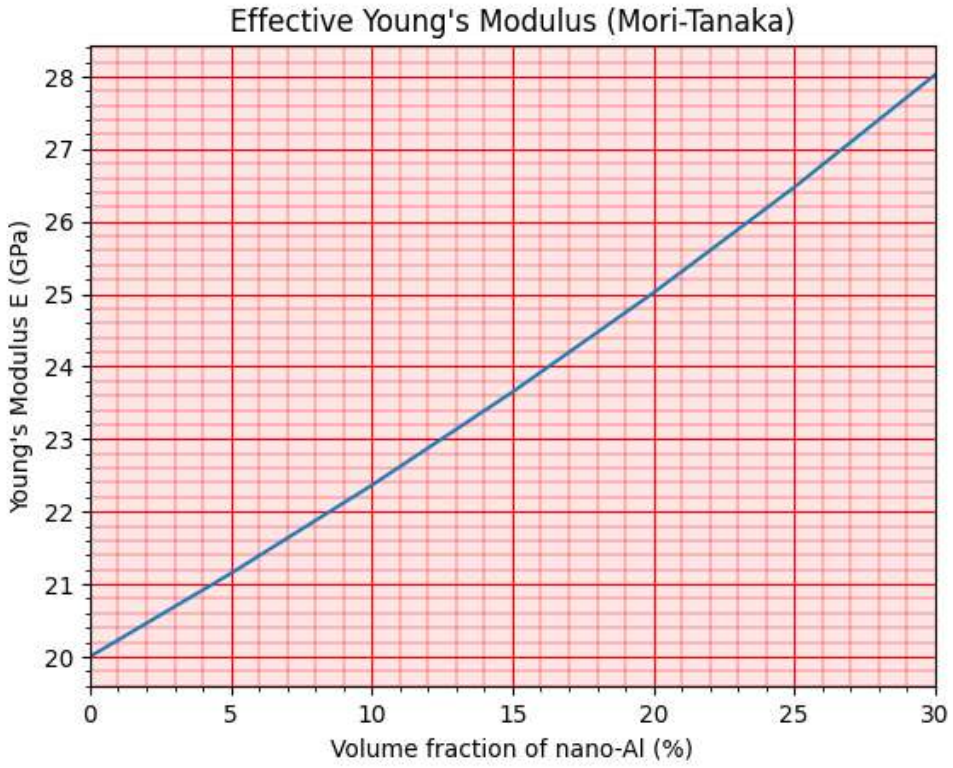
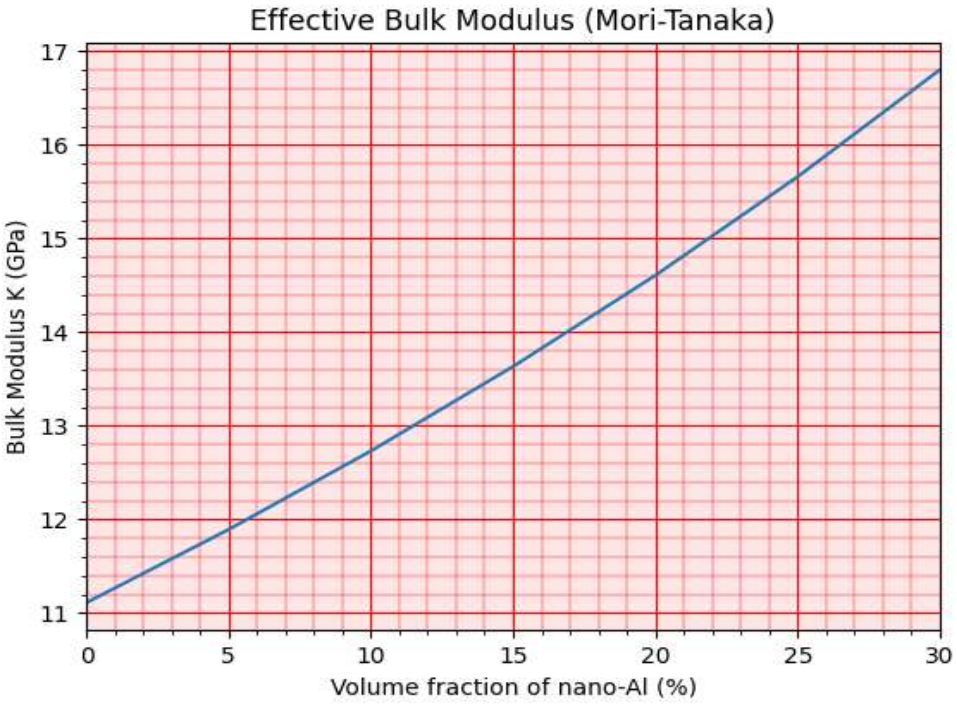


Figure 2. The effective bulk modulus new concrete.



JIRRS
Journal International Review of Research Studies
Received: 01/02/2026 - **Accepted:** 05/03/2026
Vol: 01.02
DOI: 10.66104/gkkj0g48
Pages: 1-9

Figure 3: The effective shear modulus new concrete

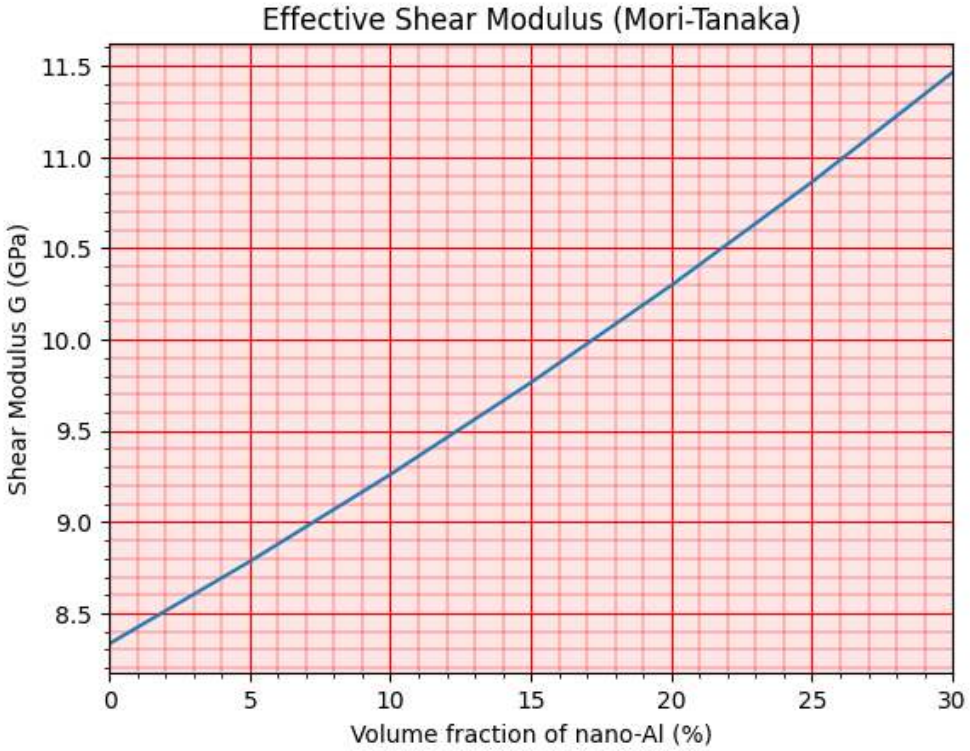
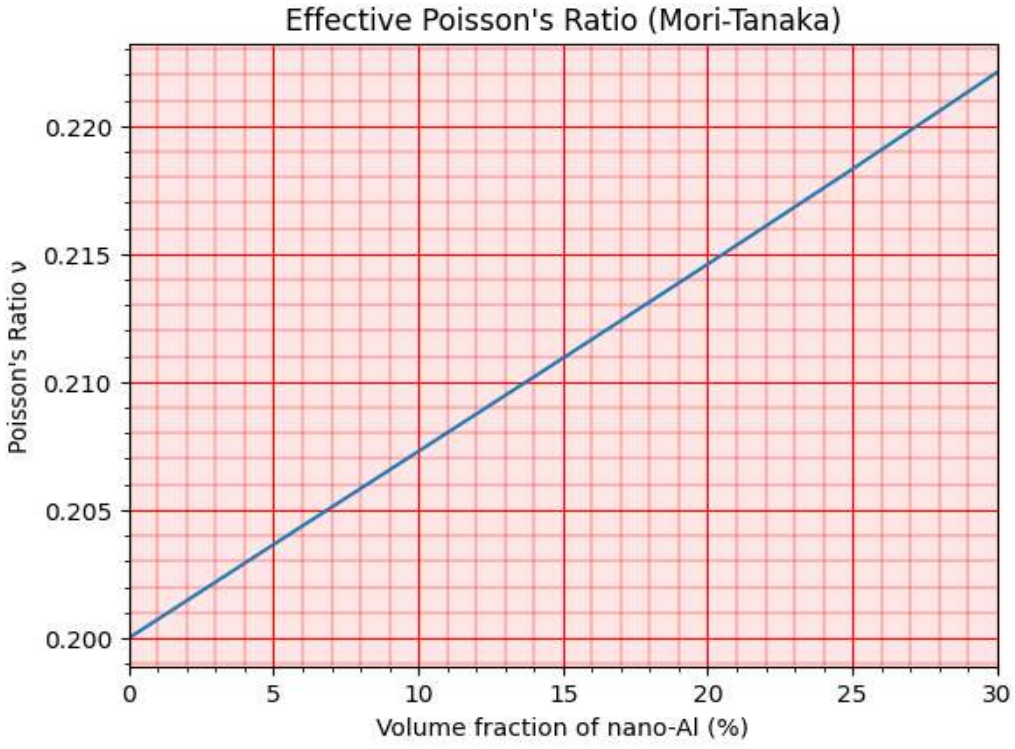


Figure 4. The effective Poisson's ratio in new concrete



JIRRS
Journal International Review of Research Studies
Received: 01/02/2026 - **Accepted:** 05/03/2026
Vol: 01.02
DOI: 10.66104/gkkj0g48
Pages: 1-9

4. Discussion

Table 1 and Figures 1–4 show that the Mori–Tanaka homogenization results show that the mechanical properties of concrete with spherical nano-aluminum inclusions get better and better as the volume fraction goes from 0% to 30%. Table 1 and Figure 1 show that the effective Young's modulus goes up by 40% from 20 GPa to 28.02 GPa. This shows that the aluminum phase, which is stiffer (70 GPa) [4], can easily transfer its stiffness to the concrete matrix (20 GPa) [1]. Table 1 and Figure 2 show that the bulk modulus goes up from 11.11 GPa to 16.81 GPa. This means that aluminum is less likely to change shape when you stretch it and more likely to stay the same shape. Also, Figure 3 and the numbers in Table 1 show that the shear modulus goes up steadily from 8.33 GPa to 11.47 GPa. This means that the material is less likely to bend and that the matrix and inclusions work better together. Figure 4 also shows that Poisson's ratio goes up a little, from 0.20 to 0.222. This means that the composite behavior is slowly becoming more like aluminum ($v = 0.3$), but it is still in the normal range for cementitious materials. The reinforcement is stable, the nano-inclusions are well spread out, and the Mori–Tanaka model's predictions match the physical properties of the particles in the concentration range we looked at, as shown in Figures 1–4 and Table 1. The linear behavior is valid only within the elastic range of the material. It is important to note that this model is purely based on mathematical homogenization.

5. Conclusion

The Mori–Tanaka model demonstrates that incorporating nano-aluminum spherical inclusions into concrete significantly enhances its mechanical properties. The effective Young's modulus, bulk modulus, and shear modulus all steadily increase as the volume fraction goes from 0% to 30%. This means that the material becomes more rigid and can resist both volumetric and shear deformation. Poisson's ratio goes up a little, but it's still in the range that is acceptable for cementitious materials. The Mori–Tanaka method is a good way to predict how nano-reinforced concrete composites will behave when they are stretched. In general, nano-aluminum works well as a reinforcing phase.

References

[1]Harrat, Z. R., Amziane, S., Krour, B., & Bouiadjra, M. B. (2021). On the static behavior of nano SiO_2-based concrete beams resting on an elastic foundation. Computers and Concrete, 27(6), 575–583. https://doi.org/10.12989/cac.2021.27.6.575

[2]Chatbi, M., Krour, B., Benatta, M. A., Harrat, Z. R., Amziane, S., & Bouiadjra, M. B. (2022). Bending analysis of nano-SiO_2 reinforced concrete slabs resting on elastic foundation. Structural Engineering and Mechanics, 84(5), 685–697. https://doi.org/10.12989/sem.2022.84.5.685

JIRRS
Journal International Review of Research Studies

Received: 01/02/2026 - **Accepted:** 05/03/2026
Vol: 01.02
DOI: 10.66104/gkkj0g48
Pages: 1-9

[3]Benfrid, A., Benbakhti, A., Harrat, Z. R., Chatbi, M., Krour, B., & Bouiadjra, M. B. (2023). Analyse thermomécanique des panneaux d'éco-béton à base de poudre de verre : Limites et évaluation des performances. Periodica Polytechnica Civil Engineering, 67(4), 1284–1297. https://doi.org/10.3311/PPci.22781

[4]Dine Elhennani, S., Harrat, Z. R., Chatbi, M., Belbachir, A., Krour, B., Işık, E., Harirchian, E., Bouremana, M., & Bachir Bouiadjra, M. (2023). Buckling and free vibration analyses of various nanoparticle reinforced concrete beams resting on multi-parameter elastic foundations. Materials, 16(17), 5865. https://doi.org/10.3390/ma16175865

[5]Kecir, A., Chatbi, M., Harrat, Z. R., Bachir Bouiadjra, M., Bouremana, M., & Krour, B. (2024). Amélioration des performances mécaniques des dalles en béton par incorporation de nanoparticules d'oxyde de fer (Fe_2O_3) : Analyse de la flexion non locale. Periodica Polytechnica Civil Engineering, 68(3), 842–858. https://doi.org/10.3311/PPci.23016

[6]Chatbi, M., Harrat, Z. R., Benatta, M. A., Krour, B., Hadzima-Nyarko, M., Işık, E., Czarnecki, S., & Bouiadjra, M. B. (2023). NanoClay platelet integration for enhanced bending performance of concrete beams resting on elastic foundation: An analytical investigation. Materials, 16(14), 5040. https://doi.org/10.3390/ma16145040

[7]Harrat, Z. R., Chatbi, M., Krour, B., Hadzima-Nyarko, M., Radu, D., Amziane, S., & Bachir Bouiadjra, M. (2023). Modeling the thermoelastic bending of ferric oxide (Fe_2O_3) nanoparticles-enhanced RC slabs. Materials, 16(8), 3043. https://doi.org/10.3390/ma16083043

[8] Benfrid, A., & Bachir Bouiadjra, M. (2025). A new approach for studying plaster beam bending based on DISS Algerian (nano-short-bio-fibres). Modern Journal of Health and Applied Sciences, 2(1), 43–58. https://doi.org/10.70411/MJHAS.2.1.2025183

[9]Chatbi, M., Lozančić, S., Harrat, Z. R., & Hadzima-Nyarko, M. (2026). Computational models for the vibration and modal analysis of silica nanoparticle-reinforced concrete slabs with elastic and viscoelastic foundation effects. Modelling, 7(1), 8. https://doi.org/10.3390/modelling7010008

[10]Benfrid, A., Chatbi, M., Harrat, Z. R., & Bachir Bouiadjra, M. (2025). Selective integration of glass nanopowders from waste into load-bearing wall concrete: Improving thermal efficiency and elasto-mechanical properties for sustainable construction. Periodica Polytechnica Civil Engineering, 69(3), 954–965. https://doi.org/10.3311/PPci.39913

[11]Khetir, H., Benfrid, A., Bachir Bouiadjra, M., & Melati, L. (2026). Contribution to the mechanical performance of a lightweight concrete beam simply supported, reinforced with bio-based nanocomposites. Revista Brasileira de Engenharia de Biossistemas, 19. https://doi.org/10.18011/bioeng.2025.v19.1293

JIRRS
Journal International Review of Research Studies
Received: 01/02/2026 - **Accepted:** 05/03/2026
Vol: 01.02
DOI: 10.66104/gkkj0g48
Pages: 1-9

[12]Lakhder, M., Benfrid, A., Bachir Bouiadjra, M., Chatbi, M., Harrat, Z. R., & Benbakhti, A. (2025). Bending behavior of a new nano-reinforced metal alloy plate incorporating tungsten nanoparticles. NIPES – Journal of Science and Technology Research, 7(3), 423–440. https://doi.org/10.37933/nipes/7.3.2025.1682

[13]Ahmed, B., Hafida, D., Jihad, R., & Abdelmoutalib, B. (2025). Bending performance of concrete beams containing granite waste. Veredas do Direito, 22, e3155. https://doi.org/10.18623/rvd.v22.n2.3155

[14]Chatbi, M., Harrat, Z. R., Ghazoul, T., & Bachir Bouiadjra, M. (2022). Analysis of the free vibrations of composite beams reinforced by randomly aligned and oriented carbon nanotubes, resting on an elastic foundation. Journal of Building Materials and Structures, 9(1), 22–32. https://doi.org/10.34118/jbms.v9i1.1895

[15]Yerkrou, A., Benfrid, A., Krour, B., & Bouiadjra, M. B. (2025). Programming model for the analysis of the mechanical and thermal buckling behavior of eco-concrete panels incorporating recycled materials (glass and red bricks). Veredas do Direito, 22, e3117. https://doi.org/10.18623/rvd.v22.n2.3117

[16] Mori, T., & Tanaka, K. (1973). Average stress in matrix and average elastic energy of materials with misfitting inclusions. Acta Metallurgica, 21(5), 571–574. https://doi.org/10.1016/0001-6160(73)90064-3

[17] Xu W, Wang H, Tian X. The Effect of Secondary Aluminum Ash on the Properties of Reactive Powder Concrete. Materials. 2023; 16(15):5265. https://doi.org/10.3390/ma16155265

[18] Azarhomayun, F., Haji, M., Kioumarsi, M., & Shekarchi, M. (2022). Effect of calcium stearate and aluminum powder on free and restrained drying shrinkage, crack characteristic and mechanical properties of concrete. Cement and Concrete Composites, 125, 104276. https://doi.org/10.1016/j.cemconcomp.2021.104276

[19] Jiang, H., Wang, K., & Wang, H. (2023). The Corrosion Resistance of Reinforced Reactive Powder Concrete with Secondary Aluminum Ash Exposed to NaCl Action. Materials, 16(16), 5615. https://doi.org/10.3390/ma16165615

[20] Fathi, M., Mohammadyan-Yasouj, S.E., Asghari, Y. et al. Mechanical and electrical properties of concrete incorporating aluminum waste. Innov. Infrastruct. Solut. 10, 150 (2025). https://doi.org/10.1007/s41062-025-01948-5