University of Zawia Journal of Engineering Sciences and Technology (UZJEST)
Volume 2, Issue 2, (2024), pp 182-188, ISSN 3006-2764

Impact of Glass Nanoparticles on the Elastic Modulus of Concrete

Abdelmoutalib Benfrid *[1,2], Mohamed Bouiadjra[1,2], Mohammed Chatbi[1,3], Zouaoui Harrat[1,2]

[1] Laboratory of Advanced Structures and Materials in Civil Engineering and Public Works, University of Djillali Liabes, 22000 Sidi Bel-Abbes, Algeria.

[2] Thematic Agency for Research in Science and Technology, ATRST, 16000 Algiers, Algeria.

[3] Départment des Travaux Publics, Université Mouloud Mammeri, Tizi Ouzou, Algérie.

*Corresponding author email: benfridabdelmoutalib2050@gmail.com

Received: 15-11-2024 | Accepted: 04-12-2024 | Available online: 15-12-2025 | DOI:10.26629/uzjest.2024.16

ABSTRACT

This research aims to study the effect of glass nanoparticles on improving the mechanical properties of the elastic modulus of concrete. By relying on the Mori-Tanaka model, the elastic modulus is determined based on added volume ratios ranging from 0% to 30%, and the results are compared with an experimental model. The main goal of this comparison is to align theoretical results with reality, allowing researchers to use these models in the future to predict the impact of concrete additives before beginning laboratory experiments, thus saving time and reducing costs. This study uses glass as an additive due to its high silica content and as a means of recycling glass in civil engineering, supporting environmental preservation and ecological sustainability and The Z. Hashin and S. Shtrikman model predicts the mechanical properties of nano-glass-reinforced eco-concrete, aiding sustainable construction by recycling glass waste. It shows performance improvements up to 30% glass addition before experimental validation.

Keywords: Glass nanoparticles, Elastic modulus, Concrete, Glass recycling.

How to cite this article:
Benfrid, A.; Bouiadjra, M.; Chatbi, M.; Harrat, Z. Impact of glass nanoparticles on the elastic modulus of concrete. Univ Zawia J Eng Sci Technol. 2024;2:182-188.

تأثير جسيمات النانو الزجاجية على معامل المرونة للخرسانة

عبد المطلب بن فريد[2,1]*، محمد بويجرة[2,1]، محمد شاطبي[1،3]، زواوي حراث[2,1]

[1]مخبر الهياكل والمواد المتقدمة في الهندسة المدنية والأشغال العامة، جامعة جيلالي ليابس، 22000 سيدي بلعباس، الجزائر

[2] الوكالة الموضوعاتية للبحث في العلوم والتكنولوجيا، ATRST، 16000 الجزائر العاصمة، الجزائر

[3] قسم الأشغال العمومية، جامعة مولود معمري، تيزي وزو، الجزائر.

ملخـــــص البحـــــث

يهدف هذا البحث إلى دراسة تأثير جسيمات النانو الزجاجية على تحسين الخصائص الميكانيكية لمعامل المرونة للخرسانة. من خلال الاعتماد على نموذج موري–تاناكا، يتم استنتاج معامل المرونة وفقًا لنسب الحجم المضافة التي تتراوح من 0% إلى 30%، ومقارنة النتائج بنموذج تجريبي. الهدف الأساسي من هذه المقارنة هو تقريب النتائج النظرية من الواقع، بحيث يمكن للباحثين مستقبلاً الاستفادة من هذه النماذج للتنبؤ بتأثير الإضافات الخرسانية قبل الشروع في التجارب المخبرية، مما يوفر الوقت ويقلل من التكاليف. يعتمد هذا البحث على الزجاج كمادة مضافة نظرًا لاحتوائه على نسب عالية من السليكا، وكمساهمة في إعادة تدوير الزجاج في الهندسة المدنية، وذلك لدعم الحفاظ على البيئة والنظام البيئي ويُبسّط نموذج "ز . هاشين" و"س. شتريكمان" التنبؤ بالخصائص الميكانيكية للخرسانة المدعمة بالنانو–زجاج، مما يدعم البناء المستدام من

خلال إعادة تدوير نفايات الزجاج. ويُظهر النموذج تحسينات في الأداء تصل إلى 30% من إضافة الزجاج قبل إجراء التجارب العملية.

الكلمات المفتاحية: جسيمات النانو الزجاجية، معامل المرونة، الخرسانة، إعادة تدوير الزجاج.

1. Introduction

Additives in concrete play a very important role, whether in enhancing mechanical, thermal, or acoustic properties. In recent years, civil engineering professionals have been working to incorporate efficient materials to improve the characteristics and performance of concrete, such as ceramic waste, glass debris, steel powder, hemp, and more. Several experiments have shown that fine glass powder enhances the characteristics of concrete, with potential additions reaching up to 30%. Benfrid et al.'s study develops an effective modulus for eco-concrete with glass powder, finding the REUSS-VOIGT model most accurate for certain cement and aggregate replacements, aligning well with experiments after 56 days, supporting sustainable cement production [1]. Concrete, mainly composed of cement, is the most widely used construction material. However, cement production significantly raises carbon dioxide emissions due to its high-temperature processing. Research indicates that incorporating fine glass powder can improve concrete's mechanical and thermal properties. In this work, they conclude that the effects of fine glass powder on ordinary concrete, using the Voigt model for homogenization to assess its mechanical and thermal properties, and Bernoulli's model to calculate the deflection of eco-friendly concrete beams [2]. In 2024, Benfrid et al. examined how varying waste glass powder (WGP) content affects the critical buckling temperature loads (ΔTcr) of thin eco-concrete panels. Using small elastic deformation theory, they analytically modeled the panels and assessed thermo-mechanical performance with Hognestad's homogenization model. The study found that ΔTcr decreases with reduced panel thickness and higher width-to-length (b/a) ratios, but increases with higher WGP content in high-performance concrete. These results support using WGP in construction to enhance sustainability by integrating waste materials into concrete [3]. In light of urgent environmental challenges, minimizing emissions and optimizing recycling are key goals, with glass waste recycling gaining particular traction in construction as a component of eco-concrete. In this paper the Ruess-Voigt homogenization model are used to evaluate the mechanical properties of eco-concrete with glass powder. They are examined cement replacement with glass powder at various ratios (5%-35%) and a particle size of 2.79 µm, comparing results to experimental data. Findings support the Ruess-Voigt model's effectiveness, highlighting its potential for broader applications in material homogenization [4]. In another study, Benfrid presents a thorough thermomechanical analysis of glass powder as an additive in concrete. The Eshelby model is applied to determine composite properties, assuming spherical glass powder particles. To simulate reinforced concrete panels, a higher-order shear deformation plate theory is used, ensuring both accuracy and simplicity. Equilibrium equations are derived through virtual work, and energy equations via Hamilton's principle. Navier's techniques are employed for closed-form solutions of simply supported plates. A parametric study explores the effects of glass powder volume, geometric parameters, and thermal loading on thermomechanical behavior. The study highlights challenges in using glass powder for thermomechanical applications and offers numerical results to guide future reinforced concrete research [5]. Chatbi et al. investigate the static behavior of silica-nanoparticle reinforced concrete plates, using Voigt's model to account for agglomeration effects. The plate is modeled with higher-order shear deformation theory and assumed to rest on a Pasternak elastic foundation. Equilibrium and energy equations are derived through virtual work and Hamilton's principle, with closed-form solutions obtained using Navier's technique. Numerical results show that an optimal amount of SiO_2 nanoparticles improves mechanical properties, and the elastic foundation significantly impacts slab bending [6]. Harrat et al. (2021) studied the static behavior of concrete beams reinforced with SiO_2 nanoparticles, using Voigt's model to account for agglomeration effects. The beams are modeled with higher-order shear deformation theory, and the soil medium is simulated with a Pasternak elastic foundation. Numerical results show that SiO_2 nanoparticles enhance concrete's mechanical properties, reducing deflections and stresses. The elastic foundation significantly influences beam bending [7].

In this article, based on Z. Hashin and S. Shtrikman theories [8] to derive and determine all the properties of conventional concrete mixed with nano inclusions of glass powder. This law, established in 1963, remains valid to this day. This work aims to predict and anticipate the results of eco-concrete with added nano inclusions of glass powder. Moreover, this method assists engineers by simplifying their tasks before conducting experiments, saving both time and resources.

2. Methods

To predict the mechanical properties of this eco-concrete, the homogenization model developed by Z. Hashin and S. Shtrikman in 1963 is used [8].

The properties of ordinary concrete and glass powder are summarized in Tables 1 and 2, respectively [9, 10].

Table 1. Material properties of ordinary concrete [9]

Young's modulus (GPa) E	25
Poisson's ratio v	0.3

Table 2. Material properties of glass powder [10]

Young's modulus (GPa) E	73
Poisson's ratio v	0.2

3. Homogenization between concrete and glass powder

Eq. (1) ,(2) are used to determine the effective properties by theories of Z. Hashin and S. Shtrikman in 1963 [8]. This theory is very useful in scientific literature. These laws are named after the previous authors who found these relationships, as mentioned below.

$$K^{sup} = K_b + \frac{V_{pv}}{\frac{1}{K_{pv} - K_b} + \frac{3V_b}{3k_b + 4G_{pv}}} \tag{1}$$

$$K^{min} = K_{pv} + \frac{V_b}{\frac{1}{K_b - K_{pv}} + \frac{3V_{pv}}{3k_{pv} + 4G_b}} \tag{2}$$

$$G^{sup} = G_b + \frac{V_{pv}}{\frac{1}{G_{pv} - G_b} + \frac{6(K_b + 2G_b)V_b}{5G_b(3K_b + 4G_{pv})}} \tag{3}$$

$$G^{min} = G_{pv} + \frac{V_b}{\frac{1}{G_b - G_{pv}} + \frac{6(K_{pv} + 2G_{pv})V_{pv}}{5G_{pv}(3K_b + 4G_{pv})}} \tag{4}$$

When:

$E^{sup} = \frac{9K^{sup}}{1+3\frac{K^{sup}}{G^{sup}}}$	(5)
$E^{inf} = \frac{9K^{inf}}{1+3\frac{K^{inf}}{G^{inf}}}$	(6)
$E^{eff} = \frac{E^{sup}+E^{inf}}{2}$	(7)
$G^{eff} = \frac{G^{sup}+G^{inf}}{2}$	(8)
$K^{eff} = \frac{K^{sup}+K^{inf}}{2}$	(9)
$v^{eff} = v_b \times V_b + v_{pv} \times V_{pv}$	(10)

where: K_{pv} is the compressibility coefficient of glass powder [GPa], v_b is the Poisson's ratio of concrete, v_{pv} is the Poisson's ratio of glass powder, V_b is the volume of concrete, V_{pv} is the volume of glass powder, G_{pv} is the shear coefficient of glass powder [GPa], $K^{\sup}$ is the compressibility coefficient superior [GPa], $K^{\min}$ is the compressibility coefficient lower [GPa], $G^{\sup}$ is the superior coefficient [GPa], $G^{\min}$ is the lower coefficient [GPa], $E^{\sup}$ is the superior young module [GPa], $E^{\min}$ is the lower young module [GPa], E^{eff} is the effective young modulus [GPa] and v^{eff} is the Poisson's ratio effective.

4. Results and Discussions

The method to deduce the mechanical properties and calculate the compressibility coefficient and shear modulus, then derive the elastic modulus for both the upper and lower bounds, and finally conclude the averages of all.

- It is observed that the bulk modulus increases as a function of the volumetric fraction of glass powder. The results are recorded in Table 3 and illustrated in Figure 1. The comressibility modulus begins to rise steadily, then a slight increase is observed.

Table 3. Material properties effectives of concrete reinforced by glass powder (compressibility's Modulus).

Volume Fraction v_{pv}	0%	5%	10%	15%	20%	25%	30%
Superior compressibility's modulus (GPa^{-1}) K_{sup}	20.8333	21.5888	22.3632	23.1570	23.9712	24.8065	25.6637
Lower Compressibility's modulus (GPa^{-1}) K_{inf}	20.8333	21.4667	22.1245	22.8080	23.5788	24.2584	25.7388
Effective compressibility's modulus (GPa^{-1}) K_{eff}	20.8333	21.5278	22.2438	22.9825	23.7450	24.5325	25.726

- The shear modulus increases with a 15% addition of waste glass powder, after which it slightly decreases, as demonstrated in Table 4 and Figure 2. The optimal value is at 5%, after which the Coulomb's coefficient stabilizes and increases slightly with the addition of more than 5% glass powder.

Table 4. The effective properties of concrete reinforced by glass powder (Shear's Modulus).

Volume Fraction v_{pv}	0%	5%	10%	15%	20%	25%	30%
Superior Shear's modulus (GPa) G_{sup}	9.6153	9.6258	9.6373	9.6502	9.6647	9.6812	9.6999
Lower Shear's modulus (GPa) G_{inf}	9.6153	36.6697	32.9740	31.9567	31.4806	31.2045	31.0243
Effective Shear's modulus (GPa) G_{eff}	9.61538462	23.1477	21.3056	20.8035	20.5726	20.4428	20.3621

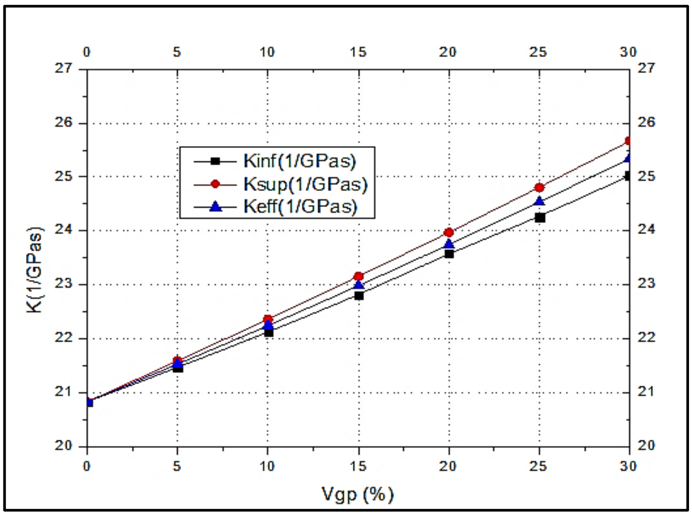

Figure 1. Material properties effectives of concrete reinforced by glass powder (compressibility's Modulus).

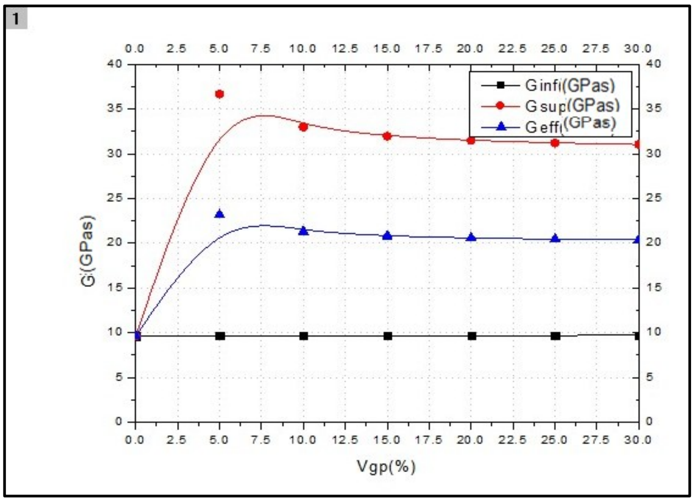

Figure 2. The effective properties of concrete reinforced by glass powder (Shear's Modulus).

- Based on the results from Table 5 and Figure 3, there is an observed improvement in the modulus of elasticity, followed by stabilization at a certain percentage. Furthermore, as indicated by the same table and Figure 4, the Poisson's ratio and uoung's modulus increase linearly. From 0% to 5%, there is a double increase, and beyond 5% glass powder, the increase becomes gradual.

Table 5. The effective properties of concrete reinforced by glass powder (Young's Modulus and Poisson's ratio).

Volume Fraction v_{pv}	0%	5%	10%	15%	20%	25%	30%
Superior Young's modulus (GPa) E_{sup}	28.3918	28.4383	28.4874	28.5400	28.5967	28.6585	28.7266
Lower Young's modulus (GPa) Einf	24.9999	70.0961	66.0892	65.3494	65.3044	65.5200	65.8606
Effective Young's modulus (GPa) E_{eff}	26.6959	49.2672	47.2883	46.9447	46.9505	47.0892	47.2936
Experimental(GPa)[4]	/	/	/	/	/	/	47.31
Poisson's ratio n_{eff}	0.3	0.295	0.290	0.285	0.280	0.275	0.270

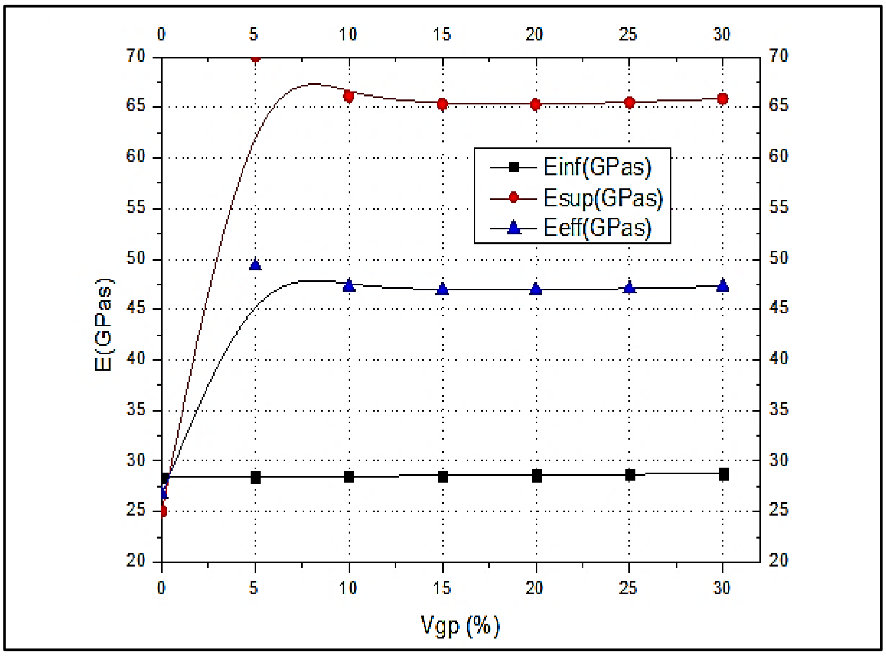

Figure 3. The effective properties of concrete reinforced by glass powder (Young's Modulus).

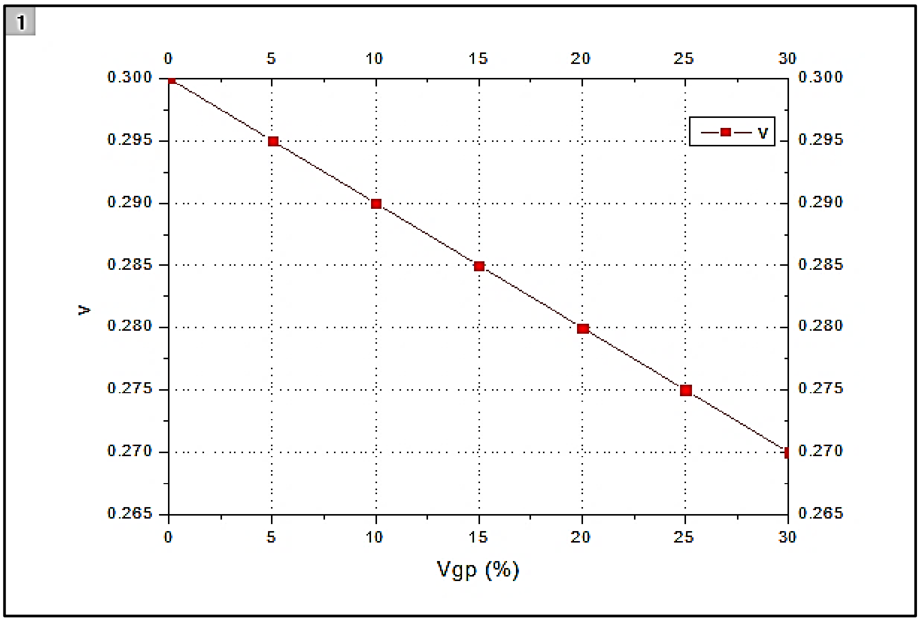

Figure 4. The effective properties of concrete reinforced by glass powder (Young's Modulus).

5. Conclusions

Finally, six important points were withdrawn from this work, which are as follows:

1) **Simplified predictive model**: The Z. Hashin and S. Shtrikman model simplifies predicting the mechanical properties of concrete reinforced with glass powder without requiring immediate experimental validation.
2) **Theoretical validation first**: Once validated through the theoretical model, it becomes possible to proceed with cost-intensive experimental testing.
3) **Effective for eco-concrete**: The model effectively predicts the mechanical properties of eco-concrete reinforced with nano-glass particles.
4) **Performance improvement**: The study shows that nano-glass enhances all mechanical properties, with performance gains observed up to a 30% addition.
5) **Ecological goal**: Eco-concrete aims to protect ecological and environmental integrity.
6) **Sustainable solution**: Using nano-glass in concrete production offers a sustainable solution to reduce glass waste and recycle this material in construction applications.

6. Acknowledgment

This study was supported by Laboratory of Advanced Structures and Materials in Civil Engineering and Public Works, Djillali Liabes University, 22000 Sidi Bel-Abbes, Algeria.

REFERENCES

[1] A. Benfrid and M. B. Bouiadjra, "Development of effective modulus of elasticity for an eco-concrete based on glass powder." [Online].Available: http://www.doi.org/10.62341/abmb2110.
[2] A. Benfrid, M. B. Bouiadjra, M. Chatbi, and Z. R. Harrat, "Mechanical and thermal properties of glass powder-reinforced concrete for producing eco-friendly concrete: A Voigt model," in *Sebha University Conference Proceedings*, vol. 3, no. 2, pp. 264-270, Oct. 2024. (Arabic: الخصائص الميكانيكية والحرارية للخرسانة المدعمة بمسحوق الزجاج لإنتاج خرسانة صديقة للبيئة بنموذج فويط).
[3] A. Benfrid and M. B. Bouiadjra, "Investigation of instability in waste glass-based eco-concrete panels under thermomechanical buckling loads," *Studies in Engineering and Exact Sciences*, vol. 5, no. 2, pp. e6886-e6886, 2024.
[4] B. Abdeldjalil, B. Abdelmoutalib, M. Chatbi, and Z. R. Harrat, "Validation of the Ruees-Voight homogenisation model for glass powder-based eco-concretes," *The Eurasia Proceedings of Science Technology Engineering and Mathematics*, vol. 26, pp. 93-99, 2023. [Online]. Available: https://doi.org/10.55549/epstem.1409404.
[5] A. Benfrid, A. Benbakhti, Z. R. Harrat, M. Chatbi, B. Krour, and M. B. Bouiadjra, "Thermomechanical analysis of glass powder-based eco-concrete panels: Limitations and performance evaluation," *Periodica Polytechnica Civil Engineering*, vol. 67, no. 4, pp. 1284-1297, 2023.
[6] M. Chatbi, B. Krour, M. A. Benatta, Z. R. Harrat, S. Amziane, and M. B. Bouiadjra, "Bending analysis of nano-SiO2 reinforced concrete slabs resting on elastic foundation," *Structural Engineering and Mechanics: An International Journal*, vol. 84, no. 5, pp. 685-697, 2022.
[7] Z. R. Harrat, S. Amziane, B. Krour, and M. B. Bouiadjra, "On the static behavior of nano-SiO2-based concrete beams resting on an elastic foundation," *Computers and Concrete*, vol. 27, no. 6, pp. 575-583, 2021.
[8] Z. Hashin and S. Shtrikman, "A variational approach to the theory of the elastic behavior of multiphase materials," *Journal of the Mechanics and Physics of Solids*, vol. 11, no. 2, pp. 127-140, 1963.
[9] BAEL 91, "Règles BAEL 91 révisées 99," DTU P 18-702, Fascicule 62, Titre 1er du CCTG - Travaux section 1: Béton armé, Feb. 2000.
[10] ENSCR School, "The glass courses," launched May 6, 2014. [Online]. Available: http://mecblondu21.free.fr/proprietes.html.