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Validation of the Ruees-Voight Homogenisation Model for Glass Powder-Based Eco-Concretes

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Abstract: In view of the ecological challenge that our planet has been facing in recent years, environmental protection has become an issue for researchers and scientists in all fields, through the reduction of discharges from factories and the recycling of waste. Among the most common solid waste is glass waste, which is attracting the attention of recycling specialists in various sectors, particularly construction, by incorporating it into the composition of concrete and reusing it as building materials. The aim of our work is to use the RUEES-Voigt homogenization model to estimate the values of the mechanical properties of an eco-concrete based on glass powder and to compare them with the results found experimentally for a replacement of (5% , 10% ,15%,20 ,25%,30%,35%) of the quantity of cement by glass powder with a particle diameter of 2.79 µm. Very interesting experimental results were obtained which validate the effective RUEES-Voigt model proposed, which opens up the possibility of using other homogenization models.

Keywords: Glass powder-based concrete, Environmental protection, Ruees-Voight homogenisation model, Experimental validation.

Introduction

The number one environmental issue is ecological living and environmental protection. The rate of waste is increasing rapidly, as daily use and needs demand many things, as well as industrial needs. One type of waste is glass. First of all it is necessary to give some statics about glass waste. (Planet scope, 2022) states that glass waste represents 13% of all European waste, and that 11.5 million tons of glass in Europe have been reported, lately 70% of glass recycling has been attributed.

Waste key figures (2019) states that around 2025 ,80 000 tons of flat glass will be rejected and recycled by a factor of 56% in the industry sector. In the field of civil engineering and public works, a wide range of studies have been carried out on the subject of glass recycling for the manufacture of concrete using glass powder, as it is rich in silica and can therefore replace cement as well as silica sand. In brief, we cite some of the work that has been undertaken on this subject. The mechanical properties of glass powder are obtained from (KLA

Instruments) who characterized the modulus of elasticity according to the grain size (diameter) of the glass particle for a diameter of d=2.79 µm The modulus of elasticity is experimentally estimated as Eg= 67.31 GPa.

These values will be used in this paper with a poisson's ratio noted in several materials science books that n=0.3. (Khalil et al., 2018) , this study consists of using waste glass to formulate a concrete , the two researchers replace between (10%-15%-20%-25%-30%) of cement by glass powder (75µm) ,the results show that glass powder works as a pozzolan material and the mechanical behavior improves and reaches the maximum at 15% P.V [4]. Dalia Shakir Atwan prepares concretes based on glass waste of 3 diameters (600um, 2.36 mm, 4.75 mm) to replace the fine aggregate of the grading curve by (10%,20%,30%). He found that strength improved when the waste became very fine as a powder (Atwan, 2017). Yassen et al. (2019):work on a concrete based on glass powder, they replaced between (10%,15%,20 and 25%) of cement by P.V (between 75µm and 300µm), they concluded that concrete strength and elastic modulus improve and the optimal value at 20%. Naje et al. (2019) studied the behavior of a waste glass-based concrete; they replaced between 10% and 30% of sand with crushed waste glass (smaller than 5mm). They found that it is possible to replace 30% of sand with glass waste with an increase in the mechanical characteristics of concrete.

Boukhelf et al.(2020) studied the effect of partial replacement of cement by alternatives derived from waste glass and silica fume on the hygrothermal behavior of concrete (Boukhelf et al., 2020). Benbakhti et al.(2016) analyzed functionally graded slabs.(Benbakhti et al.,2017). Benfrid et al. (2023) evaluated the limitation and performance under thermomechanical loading of an eco concrete panel using an analytical model. under thermomechanical loading of an eco concrete panel using an analytical model(Benfrid et al., 2023). It can be seen that most scientific reviews are based solely on the experimental part; moreover, they do not give a known homogenization rule such as the model of (Voigt, 1889) or the model of (RUEES, 1929), or the model that combines the two, called the (RUESS-Voigt) model (Fatima AOUISSI, 2019). In this work, we are interested in applying the (RUESS-Voigt) homogenization model, which must be identical to the experimental resultsbased on an eco-concrete based with 5% , 10% ,15%,20 ,25%,30% and 35% of the quantity of cement replaced by glass powder with a particle diameter of 2.79 µm, the work plan is illustrated in the form of an organization chart in Figure 1.

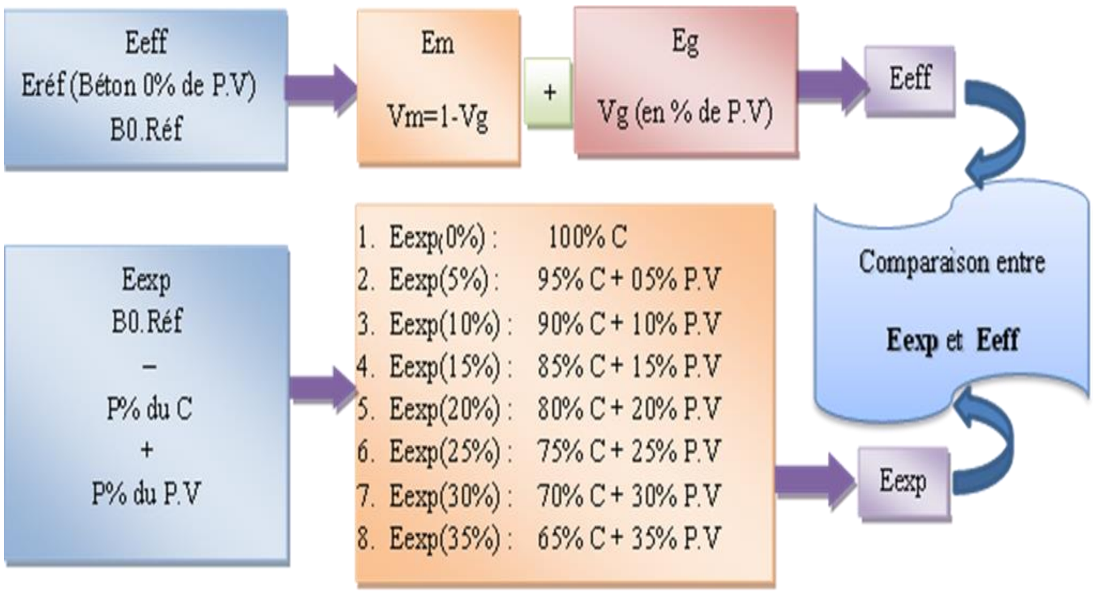

Figure 1. Paper organization

Homogenization Models

It is assumed that the reference concrete with 0% P.V. (matrix) and glass powder is the reinforcement. Knowing that "The total volume of matrix plus reinforcement is equal to unit 1".

$$V_g + V_m = V \tag{1}$$

2-1-Model de REUSS-Voigt [8] :

$$E_p = E_m + V_g^{\frac{2}{3}}(E_g - E_m) \tag{2}$$

$$\frac{1}{E_s} = \frac{1}{E_m} + V_g^{\frac{2}{3}}\left(\frac{1}{E_g} - \frac{1}{E_m}\right) \tag{3}$$

$$E_{rv} = E_m + V_g^{\frac{1}{3}}(E_g - E_m) \tag{4}$$

With

Em: Modulus of elasticity of concrete.
Eg: Modulus of elasticity of glass powder.
Ep : The modulus of elasticity of the parallel part determined by the VOIGT model.
Es : The modulus of elasticity of the part in series determined by the REUSS model.
Erv : The modulus of elasticity determined by the REUSS / VOIGT model.
Eexp : Modulus of elasticity of concrete obtained from experiments.
V : Total volume of mix.
Vm : Concrete volume.
Vg : Glass powder volume.
C: Cement.
P.V: Percentage of glass powder.
Fcj: Compressive strength of concrete at age j:(days).
B.ref: A reference concrete with 0% P.V.
d: Diameter.
Note: E units are taken in [GPa] and Fc in [MPa].

Table 1. Centre the caption above the table (Benmansour at al, 2014)

Chemical and mineralogical composition of cement, %.		Physical and mechanical characteristics of cement	Unit	Values		
CaO	54.92	Apparent density	kg/m^3	1020		
SiO_2	24.02	Absolute density	kg/m^3	3000		
Al_2O_3	5.47					
Fe_2O_3	2.83	Normal consistency	%	27		
SO_3	≤ 3.5					
		Surface Spécifique Blaine	cm^2/g	3480		
MgO	0.93					
CaOlibre	1.35	Start of cement setting	h et mn	1 h 40		
		End of cement setting	h et mn	4 h 50		
C_3S	62.12	Mechanical resistance		2 j	7j	28 j
C_2S	16.57					
C_3A	5.71	Compression	MPa	70	24.17	30.25
C_4AF	9.30	Bending	MPa	2.97	5.3	8.12

Experimental Processes

Concrete Preparation

Materials Used

To carry out this work, we used an electric concrete mixer with a capacity of 200 L, cylindrical molds (32×16) cm^3 for making the test specimens, an electric plastic (cellophane) grinder and an electric vibrator.

Materials

Cement

For this work, a cement of the type CPJ - CEM II/A 42.5 was used, complying with Algerian standards. The mineral composition was calculated using the revised Bogue formula, and the results are presented in Table 1 (Benmansour et al., 2014).

Glass Powder

To prepare a glass powder, a 0.5 kg grinding machine (High Speed Powder Machine Electric) was used, followed by sieving through 300 µm fine aggregates. This powder must be fine in accordance with regulations (ASTM-C 1260).

In this case, colored glass was used, as experimental studies by the Colombian Civil Engineering Department show that colored glass is more resistant than non-colored glass, as it reduces the alkali _ silicate reaction (Meyer et al., 2001). We only use pass-throughs with a diameter equal to or less than 300µm to make our concrete.

Aggregates

The standard classification (ASTM: C-294-69) gives a specification of aggregate constituents. The standard (ASTM: C33-87) provides a particle size analysis for sand and gravel [15]. In this formulation, only gravel up to 1 cm in size is used. Table N°02 shows the gravel gradings purely from western Algeria, approved and authorized by the Algerian Ministry of Minerals, and Table N°03 shows the gradings for sand.

Table 2. Granulometric analysis of the gravels used

Sieve diameter	Standard requirements	Percentage of passersby
75 mm	-----	100%
63 mm	-----	100%
50 mm	-----	100%
37.5 mm	-----	100%
25 mm	-----	100%
19 mm	100%	100%
12,5 mm	90%-100%	95%
9,5 mm	40%-70%	68%
4,75 mm	0%-15%	11%
2,36 mm	0%-5%	4%

Table 3. Granulometric analysis of the used sand

Sieve diameter	Standard requirements	Percentage of passersby
4,75 mm	95%-100%	97%
2,36 mm	80%-100%	87%
1,18 mm	50%-85%	65,7%
600 µm	25%-60%	55,4%
300 µm	10%-30%	29%
150 µm	02%-10%	7.3%

Mixing Water

In this case, a quantity of water distilled by evaporation is prepared to avoid any disturbance in the results, with a ratio of water quantity to cement E/C=0.3.

Sample Preparation

Concrete Formulation

Table N° 04 presents the formulation used in the various mixes, for the benefit of the work we will use a super plactifying admixture and we will ensure a concrete dosage of 300 kg/m3, while replacing the quantity of cement progressively by the different percentage of glass powder as explained in figure 1.

Table 4. Granulometric analysis of the used sand

	Cement (kg)	Glass powder (kg)	Sand (0/5)(Kg)	Gravel (3/8) (Kg)	water (l)	admixture (Kg/m3)
B0%	300	0	833,5	831,5	140	33,5
B5%	285	5	833,5	831,5	140	33,5
B10%	270	10	833.5	831,5	140	33,5
B15%	255	15	833.5	831,5	140	33,5
B20%	240	20	833.5	831,5	140	33,5
B25%	225	25	833,5	831,5	140	33,5
B30%	210	30	833.5	831,5	140	33,5
B35%	195	35	833.5	831,5	140	33,5

Forming Concrete Specimens

The standard (ASTM-C-192-180) clearly specifies sample preparation:
1- Mixing.
2- Sampling in two successive layers with vibration.
3- Adjust the level and finish the edges of the molds with a trellis.
4- Measuring plastic to prevent evaporation.
5- Demold after 24 h.
6- Place the samples in a vat of water for 7 days.

Compressive Crushing of Concrete

Crushing is carried out in accordance with the standard (B.S 1981.PART(5) /1983). For short-term ageing (7, 14 and 28 days) and also for long-term ageing (56, 90, 120, 150 days) to check the behaviour of glass powder based concrete.

Table 5. Short- and long-term compressive strength and modulus of elasticity determined experimentally.

		Short term			Long term			
Type	Age	7 j	14 j	28 j	56 j	90 j	120 j	150j
B0%	fc (MPa)	28,7	34,1	42,3	44,9	46,1	46,2	46,3
	E (GPa)	33,67	35,67	38,32	39,01	39,44	39,47	39,50
B5%	fc (MPa)	28,1	39,9	41,9	45,1	47,6	47,7	47,9
	E (GPa)	33,44	37,59	38,20	39,15	39,86	39,89	39,95
B10%	fc (MPa)	27,7	38,6	40,9	47,9	49,6	49,9	49,8
	E (GPa)	33 ,28	37,17	37,89	40,55	40,41	40,49	40,47
B15%	fc (MPa)	26,5	38,1	40,2	48,1	48,9	49,1	49,3
	E (GPa)	32,79	37,01	37,23	40	40,22	40 ,38	40,4
B20%	fc (MPa)	26	37,4	38,8	50,1	51,8	51,9	52
	E (GPa)	32,58	36 ,78	37,24	50,55	41	41,03	41,05
B25%	fc (MPa)	25,7	36,7	38,1	51,8	52	52,1	52,3
	E (GPa)	32,46	36,55	37,01	41	41,06	41,08	41,13
B30%	fc (MPa)	25,1	36	36,8	52,1	52, 3	52,6	52,7
	E (GPa)	32,20	36,32	37,01	41	41,06	41,08	41,13
B35%	fc (MPa)	22,4	30,7	28,7	28	27,8	25	23,9
	E (GPa)	31,01	34 ,44	33,67	33,40	33,32	32,16	31,68

Results and Discussion

Long- and short-term compression tests were carried out on (32×16) cm3 cylindrical specimens to determine the mechanical properties of different specimens with different percentages of glass powder replacement (5%, 10%, 15%, 20, 25%, 30%, 35%). The results for crush resistance and young's modulus of elasticity are shown in Table 5. Table 6 illustrates the results obtained by applying the formulas of the homogenization law proposed by Ruess Voigt for different percentages of replacements and for concrete at 7, 14, 28, 56, 90, 120 and 150 days.

Table 6. the effective short- and long-term modulus of elasticity by RUESS-VOIGT.

		Short term			Long term			
Type	Age	7 j	14 j	28 j	56 j	90 j	120 j	150j
B0%	E (GPa)	28	35	43	45	46	46	46
B5%	E (GPa)	28,21	35,17	43,13	41,12	46,11	46,11	46,11
B10%	E (GPa)	28,63	35,55	43,41	45,38	46,36	46,36	46,36
B15%	E (GPa)	29,20	36,05	43,80	45,74	36,70	46,70	46,70
B20%	E (GPa)	29,91	36,67	44,29	46,18	47,13	47 ,63	47,13
B25%	E (GPa)	30,73	37,40	44,86	46,71	47,63	48,20	47,63
B30%	E (GPa)	31,61	38,23	45,52	47,31	48 ,28	48,21	48,20
B35%	E (GPa)	32 .73	39,17	46,25	47,98	48,85	48.22	48,28

A comparison of Tables 5 and 6 shows that the longitudinal elastic modulus E values calculated analytically by Ruess Voigt's law are very close to the values assessed by the laboratory test for concretes with low replacement ratios of 5, 10 and 15, but the difference in values starts to increase for replacement ratios of 20% and above, and is more noticeable for long-term results.

Conclusion

From this study, we can see that the RUESS-VOIGT model is the 'homogenization' model that comes closest to estimating the short-term mechanical cleanliness of an eco-concrete based on glass powder with diameters ranging from 75 µm to 300 µm, with a low percentage of replacement. This model can be applied to rates of up to 20% replacement of cement by glass powder to estimate the mechanical behavior of eco-concrete.

Recommendations

Further studies can be carried out to assess the accuracy of this homogenization law for determining the mechanical properties of eco-concretes based on glass powder, but replacing the fine aggregates by different percentages of the latter.

Scientific Ethics Declaration

The authors declare that the scientific ethical and legal responsibility of this article published in EPSTEM journal belongs to the authors.

Acknowledgements or Notes

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References

Aouissi, F. (2019). *Mechanical behavior of concrete prediction and optimization.* (Doctoral dissertation). Université BLIDA 1. Retrieved from https://www.planetoscope.co

ASTM C1260. (2022). *Standard test method for potential alkali reactivity of aggregates (mortar-bar method).* https://www.astm.org/c1260-21.html

ASTM-C294. (2019). *Standard descriptive nomenclature for constituents of concrete aggregates*. https://global.ihs.com/doc_detail.cfm?document_name=ASTM%20C294&item_s_key=00014509

ASTM-C294. (2021). *Test method for effect of organic impurities in fine aggregate on strength of mortar*.

Atwan, D. S. (2017). Effect of particle size of waste glass on compressive strength and modulus of rupture of concrete mix. *Al-Nahrain Journal for Engineering Sciences (NJES), 20*(4), 970-975.

Benbakhti, A., Bouiadjra, M. B., Retiel, N., & Tounsi, A. (2016). A new five unknown quasi-3D type HSDT for thermomechanical bending analysis of FGM sandwich plates. *Steel and Composite Structures, 22*(5), 975-999.

Benfrid, A., Benbakhti, A., Harrat, Z. R., Chatbi, M., Krour, B., & Bouiadjra, M. B. (2023). Thermomechanical analysis of glass powder based eco-concrete panels: Limitations, performance evaluatio. *Periodica Polytechnica Civil Engineering, 67*(4), 1284–1297.

Benmansour, N., Agoudjil, B., Gherabli, A., Kareche, A., & Boudenne, A. (2014). Thermal and mechanical performance of natural mortar reinforced with date palm fibers for use as insulating materials in building. *Energy Build, 81* (2014) 98–104.

Boukhelf, F., Cherif, R., Trabelsi, A., Belarbi, R., & Bouiadjra, M. B. (2021). On the hygrothermal behavior of concrete containing glass powder and silica fume. *Journal of Cleaner Production, 318,* 128647.

Khalil, W. I., & Al-Obeidy, N. F. (2018). Some properties of high strength sustainable concrete containing glass powder waste. *Diyala Journal of Engineering Sciences, 11*(2), 42-32.

Meyer. C., Egosi, N., & Andela, C. (2001). *Concrete with waste glass as aggregate*. In *Recycling and reuse of glass cullet* (pp. 179-188). Thomas Telford Publishing.

Naje, A. G., Rahem, S. A., Thabit, N. H., & Abd, H. J. (2019). Effect of adding different concentrations of waste glass on some properties of concrete. *Journal Irac of Sciences and Technology*, *10*(2), 35-42.

Reuss, A. (1929). Berechnungder fließgrense von mischkristallen auf grund der plastizitätsbedingung für Einkristalle. Z. Angew. *Math. Mech., 9*(1), 49–58.

Voigt, W. (1889). Ueber die Beziehung zwischen den beidene Elastizitatskonstanten Isotroper Korper. *Annalan derPhys., 38,* 573–587.

Yassen, M. M., Mahmoud, A. S., & Hama, S. (2019). Effectiveness of glass wastes as powder on some hardened properties of concrete. *Al-Nahrain Journal for Engineering Sciences NJES, 22*(1)*,* 14-17.

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