Data article

Experimental data on strength properties of mussel shell concretes and specimen size effect

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A B S T R A C T

In the present project two series of laboratory tests were performed. The first series aimed at investigating the feasibility of using waste mussel shells as aggregates in the production of concrete. Specimens were prepared by using various types of cements and shells of different size. Their 28-day unconfined compressive strength and stress-strain response was evaluated and compared with the one of specimens composed with compatible calcareous sand or gravel. The second series was carried out on specimens of cement grouted soils with different particle sizes to assess how the size of specimens used for strength testing influences the measured strength and stress-strain response. The model that was utilized to relate the size effect on the compressive strength is the one proposed by Carpinteri.

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Specifications Table

| Specification          | Description                                                                 |
|------------------------|-----------------------------------------------------------------------------|
| Subject                | Civil and Structural Engineering                                             |
| Specific subject area  | Construction Materials                                                       |
| Type of data           | Tables, figures                                                              |
| How data were acquired | Laboratory tests                                                             |
| Data format            | Raw, calculated, analysed, tabulated, plotted                                |
| Parameters for data collection | Data were obtained from unconfined compression tests on grouted soil specimens and on specimens of natural aggregate concretes, mussel shell concretes and mussel shell concretes proportioned with different amounts of acrylic resin alone or in combination with a superplasticiser. |
| Description of data collection | Unconfined compressive strength, elastic modulus and porosity of natural aggregate or mussel shell concretes were measured in relation to the aggregate size, cement type and additive dosages. Unconfined compressive strength and elastic modulus values of different diameter grouted soil specimens were collected and a model evaluating the size effect on strength is proposed. |
| Data source location   | Faculty of Environmental Engineering, International Hellenic University, Thessaloniki, Greece |
| Data accessibility     | With the article                                                            |

Value of the Data

- This data allows for the comparison between the strength properties of natural aggregate concretes and that of mussel shell aggregate concretes over a wide range of mix compositions.
- It highlights the effect of some parameters, such as aggregate size, cement type and acrylic resin content either combined or not with a superplasticiser on the strength properties of mussel shell concretes.
- The report presented herein will provide guidelines and directions for future research contributions concerning the use of waste mussel shells for the partial or total replacement of natural aggregates in non-structural concrete.

1. Data Description

Table 1 presents the compositions of the three cement types and mussel shell used in the experiments. Table 2 lists the mix proportions of the natural or mussel shell concretes. Table 3 shows the porosity of the concretes. Tables 4-6 summarize the 28-day compressive strength and elastic modulus of the various concretes. Fig. 1 depicts the different fractions of mussel shell aggregates used for the production of mussel shell concretes.

![Mussel shell fractions](image)

**Fig. 1.** Mussel shell fractions; (a) Gravel 4.76/12.7 mm; (b) Gravel 2.38/4.76 mm; and (c) Sand 1.19/2.38 mm.
### Table 1
Composition of cements and mussel shells.

| Oxides (%)/Components (%) | Cement type | Mussel shells | Parameter | Concentration |
|---------------------------|-------------|---------------|-----------|---------------|
| SiO₂                    | I           | Organic content | 7.5 %     |
| Al₂O₃                   | II/B-M      | Dry content   | 99.1%     |
| Fe₂O₃                   | IV/B (P-W)  | Kjeldahl Nitrogen | 0.57 %    |
| CaO                     |             | Ca (as Ca₃O₅) | 97.1 %    |
| MgO                     |             | K             | 148.8 mg/kg |
| K₂O                     |             | Mg            | 1600.2 mg/kg |
| Na₂O                    |             | Cd            | 0.1 mg/kg  |
| Na₂Oeq                  |             | Cr            | 1.1 mg/kg  |
| SO₃                     |             | Cu            | 37.4 mg/kg |
| LOI                     |             | Pb            | 0.6 mg/kg  |
| Clinker                 |             | Zn            | 2.8 mg/kg  |
| Limestone               | 4.7         | Ni            | 0.2 mg/kg  |
| Pozzolan                | 0           | P             | 152.8 mg/kg |
| Fly ash                 | 0           |               |           |
| Gypsum                  | 5           |               |           |

### Table 2
Mix proportions and notations.

| Notation | Water/Cement ratio | Water (kg/m³) | Water (kg/m³) | Coarse gravel aggregates (kg/m³) | Coarse gravel aggregates (kg/m³) | Sand aggregates (kg/m³) | Type of cement |
|----------|--------------------|---------------|---------------|-------------------------------|-------------------------------|------------------------|----------------|
| S1       | 0.5                | 249           | 498           | 1451                          | -                             | -                      | CEM I 52.5 N   |
| S2       | 0.5                | 259           | 518           | -                             | 1475                          | -                      | CEM I 52.5 N   |
| S3       | 0.5                | 298           | 596           | -                             | 1475                          | -                      | CEM I 52.5 N   |
| S4       | 0.5                | 249           | 498           | 1451                          | -                             | 1414                   | CEM II/B-M 42.5 N |
| S5       | 0.5                | 259           | 518           | -                             | 1475                          | -                      | CEM II/B-M 42.5 N |
| S6       | 0.5                | 298           | 596           | -                             | 1475                          | -                      | CEM II/B-M 42.5 N |
| S7       | 0.5                | 249           | 498           | 1451                          | -                             | 1414                   | CEM IV/B (P-W) 32.5 N |
| S8       | 0.5                | 259           | 518           | -                             | 1475                          | -                      | CEM IV/B (P-W) 32.5 N |
| S9       | 0.5                | 298           | 596           | -                             | 1475                          | -                      | CEM IV/B (P-W) 32.5 N |
| M1       | 0.5                | 405           | 810           | 760                           | -                             | -                      | CEM I 52.5 N   |
| M2       | 0.5                | 285           | 570           | -                             | 1129                          | -                      | CEM I 52.5 N   |
| M3       | 0.5                | 285           | 570           | -                             | 1129                          | -                      | CEM I 52.5 N   |
| M4       | 0.5                | 405           | 810           | 760                           | -                             | -                      | CEM II/B-M 42.5 N |
| M5       | 0.5                | 285           | 570           | -                             | 1129                          | -                      | CEM II/B-M 42.5 N |
| M6       | 0.5                | 285           | 570           | -                             | 1129                          | -                      | CEM II/B-M 42.5 N |
| M7       | 0.5                | 405           | 810           | 760                           | -                             | -                      | CEM IV/B (P-W) 32.5 N |
| M8       | 0.5                | 285           | 570           | -                             | 1129                          | -                      | CEM IV/B (P-W) 32.5 N |
| M9       | 0.5                | 285           | 570           | -                             | 1114                          | -                      | CEM IV/B (P-W) 32.5 N |

### Table 3
Porosity of different concretes.

| Notation | Porosity (%) | Notation | Porosity (%) |
|----------|--------------|----------|--------------|
| S1       | 9.6          | M1       | 11.8         |
| S2       | 9.7          | M2       | 12.1         |
| S3       | 9.4          | M3       | 12.7         |
| S4       | 8.25         | M4       | 8.8          |
| S5       | 8.5          | M5       | 8.76         |
| S6       | 8            | M6       | 8.5          |
| S7       | 10.7         | M7       | 13.1         |
| S8       | 10.6         | M8       | 12.7         |
| S9       | 12.5         | M9       | 14.2         |
Table 4
Mechanical parameters of the reference and mussel shell concretes.

| Notation | Compressive strength (MPa) | Elastic modulus(GPa) | Notation | Compressive strength (MPa) | Elastic modulus(GPa) |
|----------|---------------------------|----------------------|----------|---------------------------|----------------------|
| S_1      | 14.87                     | 7.1                  | M_1      | 10.13                     | 5.05                 |
| S_2      | 14.34                     | 7.3                  | M_2      | 10.56                     | 5.13                 |
| S_3      | 14.52                     | 6.93                 | M_3      | 10.8                      | 5.33                 |
| S_4      | 14.27                     | 7.05                 | M_4      | 9.84                      | 5.5                  |
| S_5      | 13.46                     | 7.4                  | M_5      | 10.57                     | 5.8                  |
| S_6      | 12.43                     | 7.2                  | M_6      | 10.43                     | 5.95                 |
| S_7      | 12.5                      | 6.96                 | M_7      | 8.82                      | 4.46                 |
| S_8      | 12.03                     | 6.02                 | M_8      | 7.47                      | 4.15                 |
| S_9      | 11.97                     | 5.91                 | M_9      | 7.2                       | 3.6                  |

Table 5
Mechanical parameters of the unmodified and AR-modified mussel shell concretes.

| Notation | 0% AR | 0.5% AR | 1% AR | 1.5% AR |
|----------|-------|---------|-------|---------|
| Notation | Compressive strength (MPa) | Elastic modulus(GPa) | Compressive strength (MPa) | Elastic modulus(GPa) | Compressive strength (MPa) | Elastic modulus(GPa) | Compressive strength (MPa) | Elastic modulus(GPa) |
| M_2      | 10.56 | 5.13    | 13.83 | 6.13    | 12.13  | 5.91    | 10.11  | 5.24    |
| M_3      | 10.8  | 5.33    | 12.25 | 5.98    | 12.74  | 5.56    | 9.92   | 5.24    |
| M_4      | 10.57 | 5.8     | 12.18 | 6.83    | 10.65  | 6.7     | 10.2   | 6.41    |
| M_5      | 10.43 | 5.95    | 13.28 | 7       | 12.84  | 6.82    | 12.21  | 6.53    |
| M_6      | 7.47  | 4.15    | 10.24 | 5.32    | 8.52   | 5.2     | 7.4    | 4.45    |
| M_7      | 7.2   | 3.6     | 8.28  | 5.07    | 7.68   | 4.49    | 6.88   | 4.09    |

Table 6
Mechanical parameters of the unmodified and AR-modified mussel shell concretes containing superplasticiser.

| Notation | 0% AR | 0.5% AR + 0.2% PCE | 1% AR + 0.2% PCE | 1.5% AR + 0.2% PCE |
|----------|-------|---------------------|-------------------|---------------------|
| Notation | Compressive strength (MPa) | Elastic modulus(GPa) | Compressive strength (MPa) | Elastic modulus(GPa) | Compressive strength (MPa) | Elastic modulus(GPa) | Compressive strength (MPa) | Elastic modulus(GPa) |
| M_2      | 10.56 | 5.13 | 16.88 | 6.5 | 17.33 | 6.65 | 15.81 | 6.3 |
| M_3      | 10.8  | 5.33 | 15.78 | 6.3 | 16.2  | 6.45 | 14.64 | 6.15 |
| M_4      | 10.57 | 5.8  | 13.88 | 7.2 | 12.2  | 6.95 | 11.55 | 6.8 |
| M_5      | 10.43 | 5.95 | 14.81 | 7.1 | 13.37 | 6.84 | 12.82 | 6.71 |
| M_6      | 7.47  | 4.15 | 10.76 | 5.66 | 9.9   | 5.35 | 9.5   | 5 |
| M_7      | 7.2   | 3.6  | 10.81 | 5.57 | 9.46  | 5.22 | 9.17  | 4.8 |

Table 7
Index properties of soils.

| Soil  | D_{max} (mm) | D_{min} (mm) | D_{50} (mm) | Uniformity coefficient C_u | Curvature coefficient C_v |
|-------|--------------|--------------|-------------|---------------------------|--------------------------|
| Soil 1| 12.7         | 4.76         | 8           | 0.88                      | 1.7                      |
| Soil 2| 4.76         | 2.38         | 3.4         | 0.86                      | 1.41                     |
| Soil 3| 2.38         | 1.19         | 1.8         | 1.04                      | 1.25                     |
| Soil 4| 1.19         | 0.42         | 0.8         | 0.89                      | 1.62                     |
| Soil 5| 12.7         | 0.42         | 3.1         | 1.6                       | 5.33                     |

Table 7 lists the index properties of the soils utilised for the laboratory injection tests. A schematic representation of the experimental arrangement for the grouting of soil columns is shown in Fig. 2. Figs. 3–7 present the experimental and predicted values of compressive strength in relation to the diameter of the specimens, the values of characteristic parameters f_t and l_{ch}
Fig. 2. Setup for the grouting of soil specimens.

Fig. 3. Experimental and theoretical data of compressive strength of $S_1$ grouted soil specimens.

Fig. 4. Experimental and theoretical data of compressive strength of $S_2$ grouted soil specimens.
Fig. 5. Experimental and theoretical data of compressive strength of $S_3$ grouted soil specimens.

Fig. 6. Experimental and theoretical data of compressive strength of $S_4$ grouted soil specimens.

Fig. 7. Experimental and theoretical data of compressive strength of $S_5$ grouted soil specimens.
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Fig. 8. Relationship between \( l_{ch} \) and \( D_{\text{max}} \) for the different soils.

Fig. 9. Relationship between \( l_{ch} \) and \( D_{60} \) for the different soils.

of Carpinteri’s model and the correlation coefficient \( R^2 \). Figs. 8 and 9 show the relation between soil’s \( D_{\text{max}} \) and \( l_{ch} \), and soil’s \( D_{60} \) and \( l_{ch} \), respectively.

More detailed information concerning the strength parameters of the tested materials can be found in the supplementary Excel files (https://data.mendeley.com/drafts/hcxk298h2h/1).

2. Experimental Design, Materials and Methods

For the purpose of this study, three types of Portland cement (code-named CEM I 52.5 N, CEM II/B-M 42.5 N and CEM IV/B (P-W) 32.5 N according to EN 197-1) were selected. The substances of these cements are presented in Table 1 both in terms of oxides and raw materials utilized for their production. For the preparation of natural aggregate concretes (reference concretes) and mussel shell concretes, natural and waste mussel shell aggregates were used. Natural aggregates came from crushed limestone. Mussel shell aggregates were produced by hydration of waste mussel shells in an oven at 110 °C for 24 h, and afterwards by crushing and sieving the dry material. The size fractions used for both natural or mussel shell aggregates were a sand fraction of 1.19-2.38 mm, and two gravels, with a 2.38-4.76 mm fraction, and a 4.76-12.7 mm fraction (Fig. 1). The composition of mussel shells is presented in Table 1. All the studied concretes were composed with a constant water to cement mass ratio equal to 0.5. The details of the compositions of the different concretes are given in Table 2.

A new generation polycarboxylate ether-type (PCE) dispersant was chosen as superplasticiser [1]. The dosage of PCE was kept constant and equal to 0.2% by cement mass for all concrete
mixes. An acrylic resin polymer latex (AR), a commercial product of methyl methacrylate–acrylic acid copolymer was utilized as a polymer additive in M_2, M_3, M_5, M_6, M_8 and M_9 concretes [2]. Its dosage varied from 0 to 1.5% by cement mass.

The preparation of concrete specimens, curing and storage followed the instructions of ASTM C 192-18. The assessment of the unconfined compressive strength and elastic modulus of the different concrete mixes was performed at 28 days of curing on cubic specimens (150mm x150mm x150mm) under a constant displacement rate of 0.16 %/min. A servohydraulic compression device was used for all the unconfined compression tests. It incorporates an axial deformation transducer (LVDT) and a load measuring apparatus connected to a data logger interfaced with a computer and data acquisition software for the automatic recording of stress-strain during the test. The elastic modulus was calculated from the linear part of the compressive stress-strain curve according to the suggestions of ASTM C 469-10. Porosity of concrete specimens was estimated with the use of vacuum saturation technique conforming to ASTM C 1202-19.

For the injection experiments, five poorly graded limestone soils with a relative density of 95% were used in the injection experiments. The cement used for the preparation of grouts was CEM I 52.5 N. A polycarboxylate ether-type superplasticiser was selected as additive.

Injections were carried out on reconstituted soil columns with diameters of 3.6, 4.5, 5.9, 7, 9.6, 11.9, 15.5 and 20cm, and constant length-to-diameter ratio of 2. The experimental set-up used for the grouting of soil specimens was constructed as described in ASTM D 4320-04 for the adequate laboratory simulation of the grouting process (Fig. 2). The preparation of soil columns was made as suggested by Anagnostopoulos et al. [3]. A total of 140 injections were performed using grouts with water to cement mass ratio of 0.4, superplasticised with 1% PCE by weight of cement. During the injection, the grouting pressure was kept constant and equal to 0.5 atm. Injection process ended when no further flow of the grout from the upper outlet hose of soil column occurred. The grouted specimens were left in the moulds for 3 days in a vertical position to harden and then demoulded. Afterwards, they were stored in a moist cabinet with a temperature of 23 °C and relative humidity of 95% until the day of testing. These cylindrical specimens were tested under compression at an axial displacement rate of 0.1%/min in order to estimate the compressive strength and elastic modulus at 28 days of curing (Figs. 3-7). The multifractal scaling law (MFSL), proposed by Carpinteri [4], was used to fit the experimental compressive strength values and it has the following form:

\[
\sigma_u = \sigma_0 \left(1 + \frac{l_{ch}}{d}\right)^{1/2}
\]

where \(\sigma_u\) is the laboratory measured compressive strength, \(d\) is the specimen diameter, \(\sigma_0\) is the asymptotic value of compressive strength and \(l_{ch}\) is the characteristic internal length of the material. The microstructural characteristic length \(l_{ch}\) is considered to be proportional to the maximum aggregate size \(D_{max}\). \(l_{ch} = a\ D_{max}\), as proposed by Carpinteri [5]. In order to determine the two constants, \(\sigma_0\) and \(l_{ch}\), and to achieve the best fitting of the experimental values, a non linear regression analysis was conducted. The values of the two constants and the correlation coefficients \(R^2\) for each grouted soil are shown in Figs. 3-7. The experimental values of elastic modulus are presented in the supplementary Excel file (https://data.mendeley.com/drafts/hcxc298h2h/1).

Each of the reported strength values correspond to the average value of triplicates with standard deviation less than 5% from the average value of all tested specimens manufactured from the same concrete mixture or grouted sand.

**Ethics Statement**

Not applicable.
Data Accessibility

https://data.mendeley.com/drafts/hcxk298h2h/1

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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