

# The Effect of Using Lightweight Aggregate on Some Properties of Cement Mortar

Ziyad Majeed Abed <sup>1</sup>

(Received 12/12/2017 ; accepted 16/1/2018 )

## Abstract

The aim of this research is to produce lightweight cement mortar with properties better than reference ordinary cement mortar. Porcelanite stone were utilized as lightweight aggregate with a volumetric partial substitution of fine aggregate. The process includes using different percentages (5, 10, 15 and 20 %) of pre-wetted (24hr.) porcelanite to produce lightweight mortar with internal curing. Water curing was used for reference mortar mixture and air curing for the other mixtures of porcelanite substitution. Compressive strength, flexural strength, density and ultrasonic pulse velocity for different ages (7, 14 and 28 days) have been tested. The results show an improvement in the properties of cement mortar especially in replacement percentage of 10 %.

Key Words: Bulk density, cement mortar, internal curing, lightweight aggregate, porcelanite, strength, UPV.

تأثير استخدام الركام الخفيف الوزن على بعض خصائص مونة السمنت

زياد مجيد عبد

## الخلاصة

الهدف من هذا البحث هو إنتاج مونة سمنت خفيفة الوزن مع خصائص أفضل من مونة السمنت العادي المرجعية. تم استخدام حجر البورسلانيت كركام خفيف الوزن مع استبدال جزئي حجمي من الركام الناعم. تشمل العملية استخدام نسب مختلفة (5 ، 10 ، 15 ، 20) ٪ من البورسلانيت المسبق الترطيب (24 ساعة) لإنتاج مونة خفيف الوزن ذات انضاج داخلي. تم استخدام الانضاج بالماء خلطة المونة المرجعية واستخدام الانضاج بالهواء للخلطات الأخرى ذات الاستبدال بالبورسلانيت. تم اجراء فحوص مقاومة الانضغاط، ومقاومة الاثناء، والكثافة وسرعة الموجات فوق الصوتية لمختلف الأعمار (7 ، 14 ، 28) يوم. اظهرت النتائج تحسنا في خصائص مونة السمنت وخاصة في نسبة استبدال 10٪.

## 1. Introduction

Mortar is defined as a mixture of finely divided hydraulic cementitious material, fine aggregate, and water in either the unhardened or hardened state; hydraulic mortar (ASTM C219, 2014). Mortar utilized as binder building blocks (bricks, stones, and concrete masonry units) together, seal the gaps between them, and decoration. Another kinds of mortar includes pitch, asphalt, and clay, were used between bricks. Ordinary Portland cement (OPC) mortar, commonly known as OPC mortar or cement mortar, is created by mixing OPC, fine aggregate and water. The advantages of Portland cement are its hardness, quick setting and fewer skilled workers required in building structures. Cement mortar becomes harder as age increases with continuing of curing. Mortar must be weaker than building blocks, because mortar is easier and less expensive to repair. Porcelanite is one of the most important sedimentary rocks. It is a lightweight aggregate with a white colour, low density and high permeability.

Lightweight concrete (LWC) has been used for structural members of buildings and bridges because it is lighter in weight than normal concrete. LWC permits reducing dead loads and costs of

<sup>1</sup> Assistant lecturer at the Department of Building and Constructions, University of Technology.

superstructure and foundation. It has better properties of fire resistance, heat and sound insulation than of normal concrete (Slate, F. O., Nilson, A. H. and Martinez, 1986).

LWC have a density less than  $(1920) \text{ kg/m}^3$ , on the other side, normal concrete have a density ranging between  $(2240) \text{ kg/m}^3$  and  $(2480) \text{ kg/m}^3$  (ACI 213R-03, 2003).

The substitution of normal weight aggregates (NWAs) by LWAs should be done on a volume basis, because of the notable differences in density (Bentz, Lura, & Roberts, 2005)

The impact of adding porcelanite was investigated, as an Internal Curing (IC) agent, on roller compacted concrete (RCC). Different percentages (5, 8, 12, 16, and 20%) of partial volumetric replacement of sand, was used. It was concluded that using (5) % porcelanite replacement of fine aggregate has a positive effect on RCC, when compared with conventional (reference) RCC (Abed & Abdulqader, 2014) (Abed & Abdulqader, 2016) (Abed & Abdulqader, 2017).

Lightweight masonry mortars with hollow glass microspheres and antifreeze admixtures were produced. It was found that at temperature of  $-10 \text{ }^\circ\text{C}$ , the following mixtures have best properties: lightweight masonry mortars with hollow glass microspheres and sodium nitrite (7) %, or sodium format (5) %, or potash (7) % with a setting retarder included (Semenov, Oreshkin, & T.A., 2012).

The acoustic relief in buildings was studied using polymer waste micronized poly (ethylene vinyl acetate) (EVA) in mortars for the sound insulation in sub-floor systems using different thicknesses (3, 5, and 7) cm and replacement percentages of aggregate by (10, 25, and 50) % of EVA. Specimens benefit from noise insulation of EVA polymer, increase in voids which reduce the weight of rendering of sub-floor (Brancher, Nunes, Grisa, Pagnussat, & Zeni, 2016)

Different parameters were used to study the effect of specimen dimensions on mortar such as: ultrasonic frequencies (54, 82, and 150) kHz, dimensions (4, 5, 7, 16, and 32) cm and water/cement ratios (0.4, 0.45, 0.5, 0.55, and 0.6). For span of (16 cm) and frequency 54 kHz, the values of UPV were between (4200 – 4450) m/s for ages between (2 – 28) days respectively (Gözde Özerkan & Özgür Yaman, 2007)

## 2. Experimental investigation

### 2.1 Materials

Portland cement (CEM I 42,5 N) (BS EN 197-1, 2011) was used for mortar mixture throughout present work. Also, the compounds of cement were calculated according to Bogue equations (ASTM C150, 2011). Natural sand was used as fine aggregate in all mixtures. The specific gravity for sand was (2.7), absorption was (1.2)%, and the grading was according to (BS EN 196-1, 2005). Porcelanite stone was used as a partial replacement of fine aggregate in all mixes (except for reference mix). The replacement percentages were (5, 10, 15 and 20) % as a volumetric replacement as same grading as fine aggregate. Porcelanite was pre-wetted with water in lab temperature for 24 hrs. to have saturation, as recommended in (ACI 211.2, 2011). Porcelanite specific gravity was 1.68, and absorption was (42) %. Dry rodded unit weight was  $[860 \text{ kg/m}^3]$  which within the limits ( $[1120 \text{ kg/m}^3]$  max. for fine aggregate) (ASTM C330, 2014). Table (1) showed the chemical analysis of fine porcelanite aggregate.

Table 1. Chemical analysis for porcelanite aggregate

Oxide composition	% by weight
SiO <sub>2</sub>	72
CaO	9.1
MgO	2.75
Fe <sub>2</sub> O <sub>3</sub>	0.97
Al <sub>2</sub> O <sub>3</sub>	3.23
SO <sub>3</sub>	1.1
Loss on ignition	9.6

## 2.2 Mixture proportion

Two types of mixtures were casted. First one was reference cement mortar. The second mixture was with adding different percentages of porcelanite (5, 10, 15 and 20)% instead of natural fine aggregate. Prisms and cubes with dimensions (16 cm \*4 cm \*4 cm) and (7.07 cm \*7.07 cm \*7.07 cm) respectively. Samples have been casted with mixing quantities of materials computed according to (ASTM C109, 2016) as in Tables (2) and (3).

Table 2. Quantities of materials used in the mixing mortar for a cube

Replacement of Porcelanite (%)	Sand [gm]	Porcelanite [gm]	Cement [gm]	Water [ml.]
0%	688	0.00	250	121
5%	654	14	250	121
10%	619	28	250	121
15%	585	42	250	121
20%	551	56	250	121

Table 3. Quantities of materials used in the mixing mortar for 3 prisms

Replacement of Porcelanite (%)	Sand [gm]	Porcelanite [gm]	Cement [gm]	Water [ml.]
0%	1493	0.00	542	263
5%	1419	30.5	542	263
10%	1343	61	542	263
15%	1269	91	542	263
20%	1196	121.5	542	263

## 2.3 Preparation, casting, compaction and curing

After the cleaning of steel moulds the internal faces were thoroughly oiled to avoid adhesion with mortar after hardening. The mixing procedure, Casting and compaction of cubes and prisms were according to (BS 4550-3.4, 1978) and (BS EN 196-1, 2005) respectively. After (24) hours from mixing, the samples were demoulded. Reference mixture specimens were kept in water curing tank until testing. All other mixtures with added porcelanite were cured in the air at lab temperature.

## 2.4 Testing

Compressive strength test was carried out according to (BS EN 196-1, 2005). Three cubic specimens of (7.07) cm were tested at ages 7, 14 and 28 days. Flexural strength test for prismatic specimens (16 cm \*4 cm \*4 cm) was carried out according to (BS EN 196-1, 2005). The ages of specimens were 7, 14, and 28 days. Density test was performed according to (BS EN 1015-10, 1999) at ages 7, 14 and 28 days. The ultrasonic pulse velocity test is one of the non-destructive tests. Ultrasonic Pulse transit times are measured by direct transmission method. This test is carried out according to (ASTM C597, 2009) on prisms of length [16cm] at ages 7, 14 and 28 days.

## 3. Results and discussion

Table (4) lists the results of compressive strength, flexural strength, density and UPV. The specimens were tested at ages 7, 14 and 28 days for all mixtures. The values of compressive strength, flexural strength, density and UPV for all specimens have increased with the progress of the age; this may be due to the fact of the continuous hydration process.

Table (4) Effect of Porcelanite Replacement on Cement Mortar

Property	Age (days)	Porcelanite Content %				
		0	5	10	15	20
Compressive strength MPa	7	27.8	26.2	27.2	24.9	22.5
	14	28.3	28.7	29.5	28.1	28
	28	40.1	41	42.1	40.5	39.2
Flexural strength MPa	7	5.32	6.9	7.98	7.56	7.2
	14	6.72	7.56	8.4	7.8	7.6
	28	7.1	7.9	8.7	8.2	8.1
Density kg/m <sup>3</sup>	7	2156	2150	2181	2144	2101
	14	2171	2180	2156	2163	2142
	28	2185	2196	2230	2200	2175
UPV km/s	7	3.9	3.96	3.99	3.8	3.69
	14	3.97	4.01	4.05	3.91	3.82
	28	4.03	4.06	4.08	4.01	3.91

Figure (1) shows that there was an increment in the compressive strength with an increase in the percentages of porcelanite replacement up to (10%) and thereafter, it decreased with increasing the percentage of the porcelanite in the mortar. In spite of the fact that the porcelanite aggregate is much weaker than the normal fine aggregate, the increasing in the compressive strength up to (10)% porcelanite replacement may be due to enhanced cement hydration because of using a saturated porcelanite which works as an IC agent, and this improves of the interfacial transition zone and reduces shrinkages that induced the micro cracking.

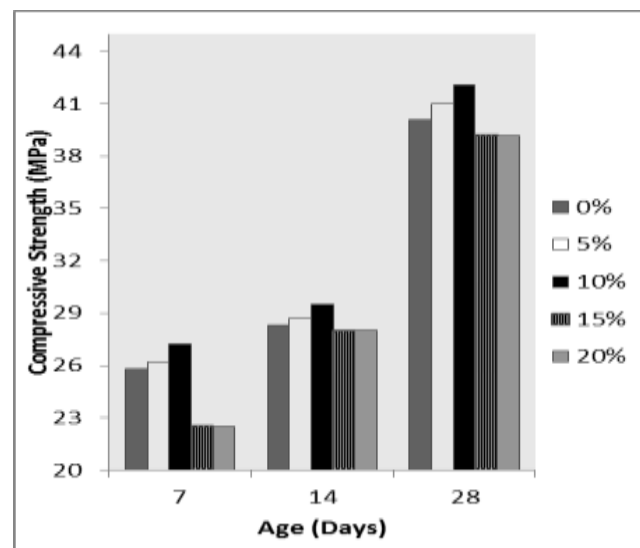


Figure 1. Effect of Porcelanite on Compressive Strength of Mortar Cement

Figure (2) explains the increment of flexural strength with the increase of percentages of replacement compared to reference mixture (0% porcelanite). In the cases of using percentage of replacement more than (10) %, the flexural strength decreased but still more than reference. Such behaviour is probably due to; firstly, the increase of percentage of lightweight aggregate which it weaker than normal aggregate and secondly, because of the increasing of reserved water in mixture. For all specimens, the results indicated that with the progress of curing age all mortar specimens show a continuous gain in flexural strength.

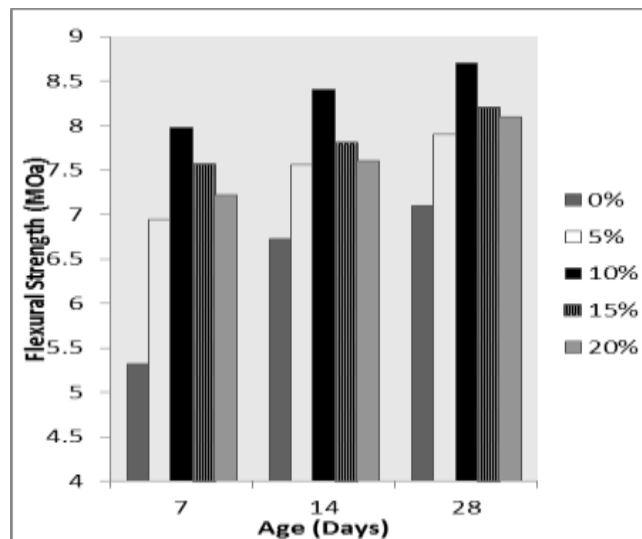


Figure 2. Effect of Porcelanite on Flexural Strength of Mortar Cement

Figure (3) shows that the density of mixtures with porcelanite replacement percentages of (5 and 10) % were more than reference mixes (except for 5% at age 7 days). The densities of percentages (15 and 20) % were less than other percentage of replacement. At age of 28 days, there was an increase in density with (15)% porcelanite, more than reference and (5)%, which occurs because of the continuity of IC by using the additional water supplied by saturated porcelanite and un-hydrated particles of cement. For specimens which using air curing, the additional water promotes higher degree of hydration which fills the pores with hydration products (Gel) and increases the density.

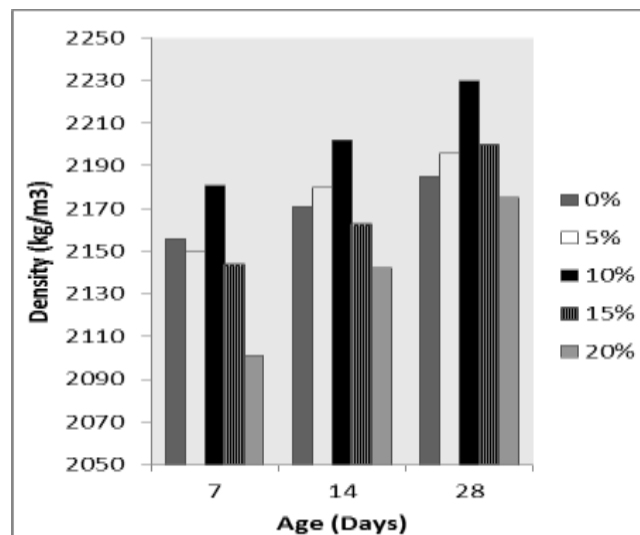


Figure 3. Effect of Porcelanite on Density of Mortar Cement

Figure (4) shows that using porcelanite aggregate as partial replacement with percentages more than (15) % decreases UPV of mortar compared with reference mortar. The decreasing in UPV can be attributed to; firstly, high moisture content within the mortar containing saturated porcelanite aggregate as internal curing materials. Secondly, UPV decreased due to increase the voids within the mortar which have a negative effect on UPV. The percentage of (10) % replacement gave better results than (5) % and reference mixture. The increasing in UPV may be

due to improve the density and homogeneity of cement mortar because of the IC which effects on hydration of cement. This hydration filled more micro pores with hydrates.

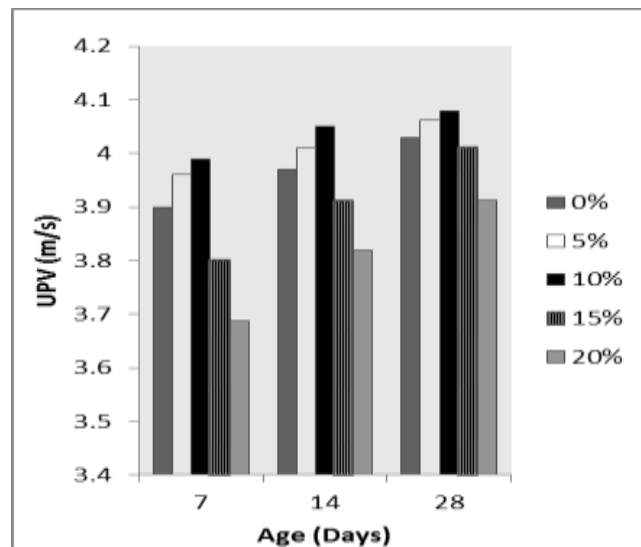
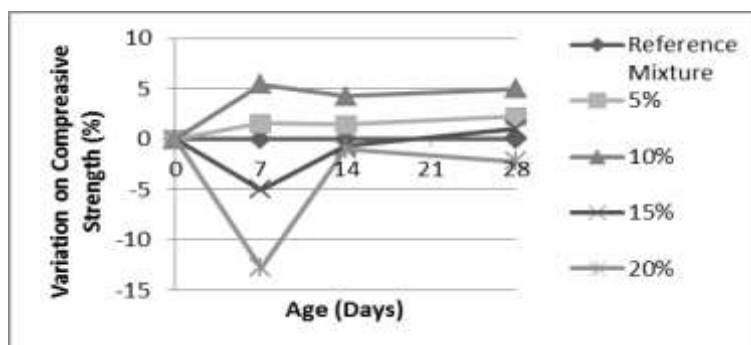
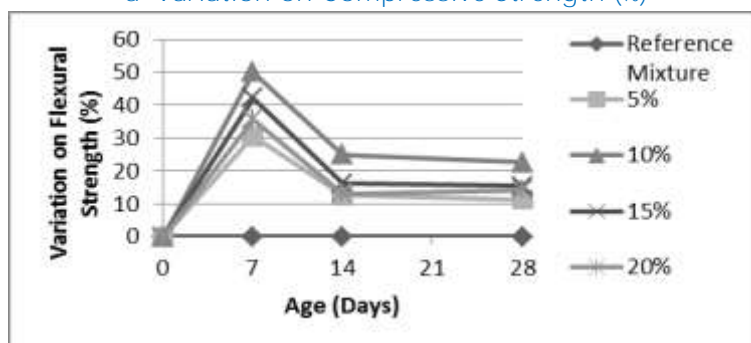


Figure 4. Effect of Porcelanite on UPV of Mortar Cement

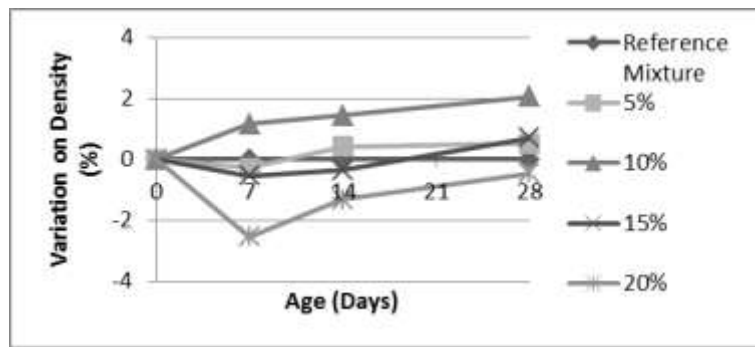
Figure (5) showed that the greatest increase (variation) in the progress of properties of mortar was at first week. The zero value at Y- axis represents the reference cement mortar. This variation was due to the replacement percentage of porcelanite aggregate in mortar. The percentages of replacement (5 and 10) % have a positive effect on all properties. On the other side, generally, the percentages (15 and 20) % have a negative effect on all properties except for flexural strength. The reason of increasing in flexural strength was due to the effect of reserved water in mixture used air curing (ASTM C348, 2008).



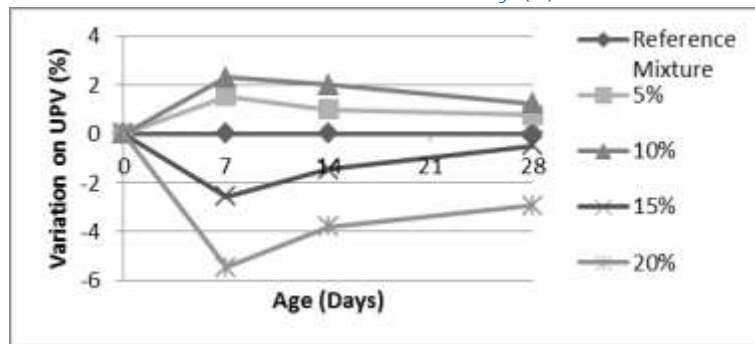
a-Variation on Compressive Strength (%)



b-Variation on Flexural Strength (%)



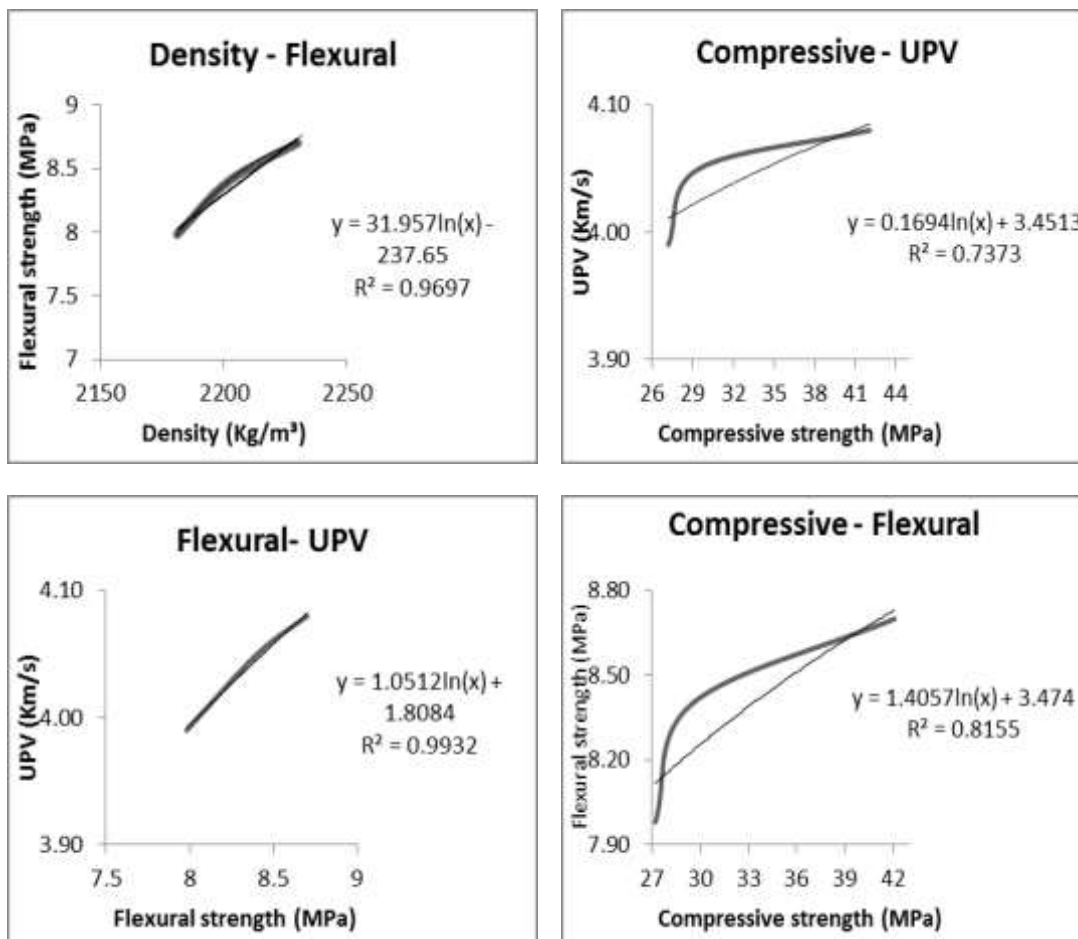
c-Variation on Density (%)



d-Variation on UPV (%)

Figure 5. The Percentages of Variation due to Using Porcelanite in Mortar

Figure (6) shows the mathematical relationships between the different properties of mortar cement using 10% of porcelanite at Age (28) Days.



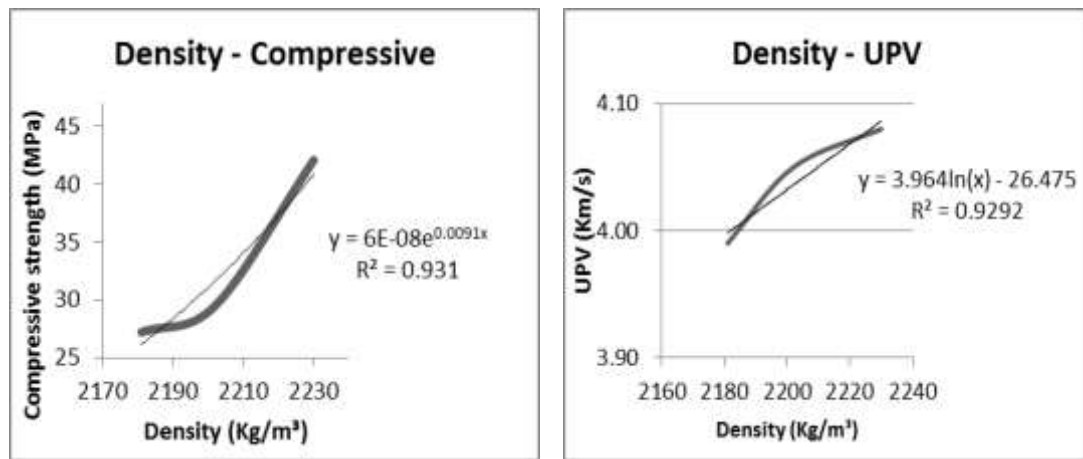


Figure 6. The Relationships between the Properties of Mortar Cement Using 10% of Porcelanite at Age (28) Days

## 4. Conclusions

Based on the results presented in this paper it can be concluded that:

- The results of adding porcelanite show an improvement in the properties of cement mortar especially in replacement percentage of 10 % with (4.2-5.4) %, (22-50) %, (1.2-2.4) % and (1.2-2.3) % for compressive strength, flexural strength, density and ultrasonic pulse velocity respectively in spite of using air curing.
- The behaviour of mortar cement with replacement a partial volume of fine aggregate with porcelanite can be used in the fabrications of lightweight boards and thin sections in construction sector without using water curing.

## References

- Abed, Z. M., & Abdulqader, A. S. (2014). Assessing the Effect of Using Porcelanite on Compressive Strength of Roller Compacted Concrete. *Journal of Engineering*, 20(10), 16–28.
- Abed, Z. M., & Abdulqader, A. S. (2016). Effect of Using Porcelanite as Partial Replacement of Fine Aggregate on Roller Compacted Concrete with Different Curing Methods. *Journal of Engineering*, 22(9), 21–35.
- Abed, Z. M., & Abdulqader, A. S. (2017). Effect of Using Lightweight Aggregate on Properties of Roller-Compacted Concrete. *ACI Materials Journal*, 114(4), 517–526. <https://doi.org/10.14359/51689775>
- ACI 211.2. (2011). Standard Practice for Selecting Proportions for Structural Lightweight Concrete. *Materials Journal*, 87(6). <https://doi.org/10.14359/1919>
- ACI 213R-03. (2003). Guide for Structural Lightweight-Aggregate Concrete. *American Concrete Institute*.
- ASTM C109. (2016). Standard Test Method for Compressive Strength of Hydraulic Cement Mortars (Using 2-in. or [50-mm] Cube Specimens).
- ASTM C150. (2011). Standard Specification for Portland Cement. *ASTM International, West Conshohocken, PA*. <https://doi.org/10.1520/C0150-11>
- ASTM C219. (2014). Standard Terminology Relating to Hydraulic Cement. *ASTM International, West Conshohocken, PA*. <https://doi.org/10.1520/C0219-14A>
- ASTM C330. (2014). Standard Specification for Lightweight Aggregates for Structural Concrete. *ASTM International, West Conshohocken, PA*. [https://doi.org/10.1520/C0330\\_C0330M](https://doi.org/10.1520/C0330_C0330M)
- ASTM C348. (2008). Standard Test Method for Flexural Strength of Hydraulic-Cement Mortars. *ASTM International, West Conshohocken, PA*.
- ASTM C597. (2009). Standard Test Method for Pulse Velocity Through Concrete. *ASTM International, West Conshohocken, PA*. <https://doi.org/10.1520/C0597-09>
- Bentz, D. P., Lura, P., & Roberts, J. W. (2005). Mixture proportioning for internal curing. *Concrete International*, 27(2), 35–40.
- Brancher, L. R., Nunes, M. F. de O., Grisa, A. M. C., Pagnussat, D. T., & Zeni, M. (2016). Acoustic behavior of subfloor lightweight mortars containing micronized poly (ethylene vinyl acetate) (EVA). *Materials*, 9(1), 1–9. <https://doi.org/10.3390/ma9010051>
- BS 4550-3.4. (1978, June). Methods of testing cement. Physical tests. Strength tests. *British Standards Institution*.
- BS EN 1015-10. (1999, November). Methods of test for mortar for masonry. Determination of dry bulk density of hardened mortar. *British Standards Institution*.



- BS EN 196-1. (2005). Methods of testing cement. Determination of strength. *British Standards Institution*.
- BS EN 197-1. (2011, September). Cement. Composition, specifications and conformity criteria for common cements. *British Standards Institution*.
- Gözde Özerkan, N., & Özgür Yaman, İ. (2007). Evaluation of Cement Mortars By Ultrasound. *4th Middle East NDT Conference and Exhibition, Kingdom of Bahrain, Dec 2007*, 1–11.
- Semenov, V. S., Oreshkin, D. V., & T.A., R. (2012). Properties of Lightweight Masonry Mortars with Hollow Glass Microspheres for Winter Conditions. *Vestnik , Moscow State University of Civil Engineering (MGSU)*, (10), 182–190.
- Slate, F. O., Nilson, A. H. and Martinez, S. (1986). Mechanical Properties of High-Strength Lightweight Concrete. *Journal of American Concrete Institute*, 83(4), 606–613.