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Dynamic Modulus of Elasticity of Some Mortars Prepared from Selected Jordanian Masonry Cements

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Abstract

In light of the highly demanding cement market in Jordan, comprehensive studies should be undertaken to investigate the properties of the different cement types. This paper studies the Dynamic modulus of elasticity (DME) at 2, 7 and 28 days in mortars using six cement Jordanian types with CaO contents less than that of the ordinary Portland cements. It was found that the DME has strong relation with compressive strength. At the age of 28 days the mortars had some different values of DME. One important result of our work is that DME at the age of 28 days can be derived from those of the two days mixes. To account for the differences in dynamic modulus of elasticity with time, it is highly recommended to study in detail the mortars petrography under the light microscope. Using the scanning electron microscope (SEM), usually with attachment for chemical analysis at the crystal scale, in addition to X-ray diffraction technique may help characterization of the cement phases qualitatively and quantitatively.

Keywords

Jordan, Masonry Cement, Mortars, Dynamic Modulus of Elasticity

1. Introduction

Mortars, used mostly in masonry construction, are similar to concrete mixes but without the coarse aggregate fraction with sand-cement ratio are usually around 3. Cements used for masonry purposes are being produced by partial replacement of OPC with pozzolan and/or lime materials as in [1] [2] [3] [4], and [5]. Reference [6] investigated the utilization of volcanic scoria from "Djoungo" (Cameroon) as cement and fine aggregate replacement in Portland cement masonry mortar. The study was carried out on two groups of mortars samples, mortars containing NPs as cement replacement by 25% and 45% by mass (OPC/NPs mortars) and mortars containing VSA as sand substitution at level of 25%, 50%, 75% and 100% by mass (VS mortars). Flow value, fresh and dry density, dynamic modulus and mechanical strengths of mortars at 28, 56 and 90 days were evaluated. Based on the results, they found that adding "Djoungo" volcanic scoria as cement replacement or by sand substitution in the appropriate ratio in mortar can be applicable for masonry. Reference [7] studied the prospect of recycling dredged sediments in self-compacting mortars (SCM) and their impact on the fresh and hardened properties of SCC pastes/mortars. Fifteen mortars/paste mixes were prepared using the response surface methodology. The responses were the workability and fluidity of the self-compacting pastes, and the mechanical properties of the self-compacting mortars (compressive, bending strength, and dynamic modulus of elasticity). A numerical optimization was used to select the optimal mixture with the maximum amount of treated sediments while maintaining self-compactibility properties. Thus, cement pastes or mortars made with such cements would have better strength and durability properties than those made with conventional cements. Very limited studies were performed to study the performance of these pastes in Jordan. Reference [8] has studied different aspects of a masonry cement produced by the Jordanian Cement Manufacturing Company (Lafarge). In a previous paper [9], we discussed the compressive strength of cements. Here, we are going to study the dynamic modulus of elasticity DME of the previously mentioned six cement brands.

2. Methodology

Two kg of each cement type were used by the senior author to prepare the different mixes and conduct the following tests: fineness, consistency or flow, and compressive strength (for details see [9]), according [10] to the European Standard EN 196, 2005 at the laboratories of University of Bologna, Italy during the summer of 2012. The proportions of the mix used were as follows: water 225 g, cement 450 g and 2 mm sand 1350 g.

Dynamic modulus of elasticity, was measured by using ultrasonic measurement device to measure the speed rate in the concrete specimen. The following formula was used to determine the modulus:

$$E_d = \rho\left\{(1+\mu)(1-\mu)V^2\right\}/(1-2\mu)$$

where:

E_d = Dynamic modulus of elasticity.

ρ = Mass density (g/cm^3).

μ = Poisson ratio of concrete, assumed 0.17.

V = Speed rate of wave in specimen m/micro sec.

Following is an example of Calculation of E_d for Thabet cement:

$$E_d\left(\text{Thabet}\right)=\left\{\left(1970\ \text{kg}/\text{m}^3\right)\times\left(\sec^2/9.81\ \text{m}\right)\times\left(1.17\right)\right.$$
$$\left.\times 0.66\left(\left(0.16/44.3\right)\times 10\text{E}6\right)^2\left(\text{m}^2/\sec^2\right)\left(9.81\ \text{N}/\text{kg}\right)\right\}\Big/\left(0.83\times 10\text{E}6\right)$$
$$=22773\ \text{MPa}$$

[9].

3. Results

Table 1 of [9] summarizes the results of the physical properties and compressive strength and **Table 2** measurements on propagation time of longitudinal ultrasonic waves from which values of the dynamic modulus of elasticity calculated.

Figure 1 shows the dynamic moduli of elasticity for the studied mortar types at 2, 7, and 28 day ages. At the age of 28 days the highest dynamic modulus of elasticity was recorded by Rasikh and the lowest by Shamaliyya cements.

Table 3 shows how the dynamic modulus increases with time. **Figure 2** shows that the 28 day modulus can be predicted from that of the 2 day modulus with a correlation coefficient exceeding 0.9.

Figure 3 shows an inverse linear relationship between the modulus of elasticity and water absorption. This relationship was referred to the decrease in the required stresses to obtain certain strains while increasing the water ratio. Despite a general weak positive relation between density and strength, it is evident in **Figure 4** that it is difficult to predict the dynamic modulus from density alone. **Figure 5** reveals that there is an inverse relation between consistency and dynamic modulus of elasticity with a ridge around the 50 consistency value separating high dynamic values to the right from low dynamic values to the left.

Plotting the less than 63 micron percentage against dynamic modulus (**Figures 6**), it is evidenced that there are inverse relations between the less than 63 microns size and dynamic modulus of elasticity, and positive relations with >63 microns size range (**Figure 7** and **Figure 8**), it is evidenced that the higher the percentage of the finer portion, the less the value of the modulus is.

Figure 9 shows that apart from 2 odd points there is almost perfect inverse relation with travel time of sonic waves. This is because dynamic modulus has been derived from travel time. The following polynomial equation can be used to derive dynamic modulus of elasticity (y) from the travel time (x) with r = 0.992

$$y=46.381x^2-5342.2x+169275$$

As seen in **Figure 10** there are strong positive relations between the dynamic modulus of elasticity and compressive strength.

4. Conclusions and Recommendations

The following conclusions can be drawn out from the present work:

1) There are some variations in the dynamic modulus of elasticity between the different brands of mortars prepared from the six Jordanian cements.

Table 1. Properties of the cements and their pastes [9].

Tests	Thabet	Bany	Shamaliyya	Mokawim	Rasikh	Ragihy
Fineness						
>125 µm	2.72	15.45	15.40	12.86	7.95	13.90
>63 µm	9.71	22.02	9.67	25.10	57.10	19.60
Pan < 63 µm	82.23	62.97	74.77	62.00	35.00	66.45
Consistency	50.00	60.00	47.50	72.50	50.00	37.50
Specific gravity **g/cm³**						
2-day	1.97	2.01	1.96	2.00	1.94	1.94
7-day	2.04	2.04	1.98	2.04	2.02	2.03
28-day	2.00	1.79	1.99	2.02	2.08	2.04
Water Absorption **%**						
2-day	9.81	9.44	10.39	9.73	7.89	9.88
7-day	8.83	8.76	8.90	8.80	7.52	9.43
8-day	8.28	8.81	9.51	8.72	8.86	8.80
			Compressive Strength			
2-day	15.53	20.04	5.00	11.10	32.64	47.10
7-day	36.65	39.94	24.41	36.86	48.52	29.27
8-day	46.90	47.5	41.00	58.50	58.50	47.10

Table 2. Sonic travel time and dynamic modulus of elasticity values.

Tests	Thabet	Bany	Shamaliyya	Mokawim	Rasikh	Ragihy
			Dyamic modulus of elasticity MPa			
2-day	22,773	26,256	15,682	22,878	29,376	20,435
7-day	30,977	33,114	27,055	28,895	34,395	30,676
28-day	33,515	34,998	31,975	34,212	37,741	34,495
			Sonic travel time (ms)			
2-day	44.30	42.70	54.56	45.63	47.50	47.53
7-day	39.60	38.30	41.75	39.30	47.40	39.70
28-day	37.60	36.80	38.50	37.50	36.23	37.52

Table 3. Increase of the modulus (in MPa) with mortars age.

Cement	2 day	7 days	28 days
Thabet	22,773	30,977	33,515
Bani	26,256	33,114	34,998
Shamal	15,682	27,055	31,975
Moqawem	22,878	28,895	34,212
Rasekh	29,376	34,395	37,741
Rajehy	20,435	30,676	34,495
Average	22,900	30,852	34,489

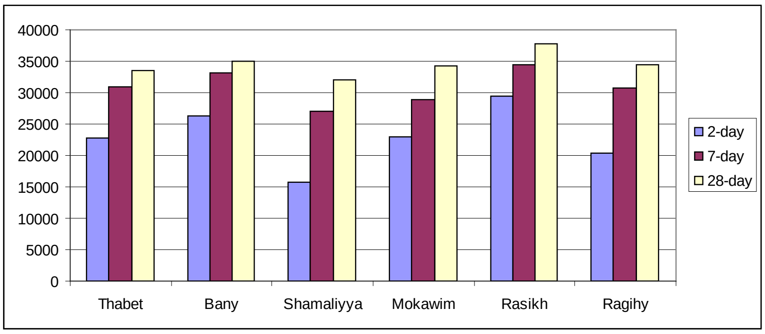

Figure 1. Changes in dynamic modulus of elasticity (in MPa) in mortars with time.

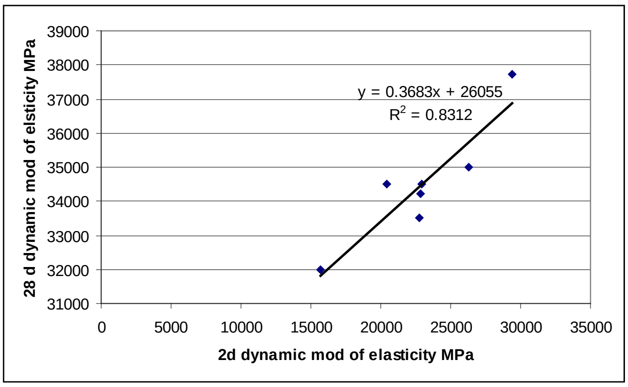

Figure 2. Deriving the 28 day dynamic modulus of elasticity from that of the 2 day.

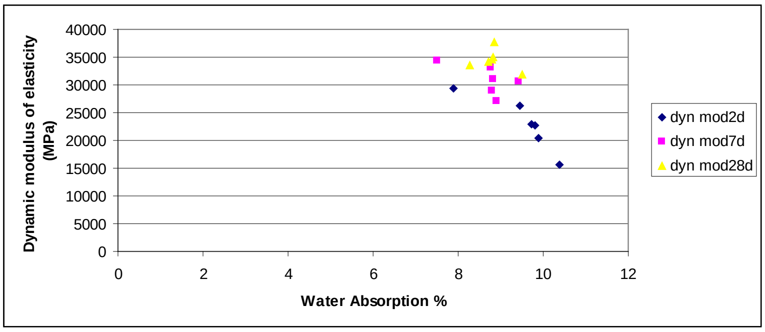

Figure 3. Inverse linear relationships between dynamic modulus of elasticity and water absorption.

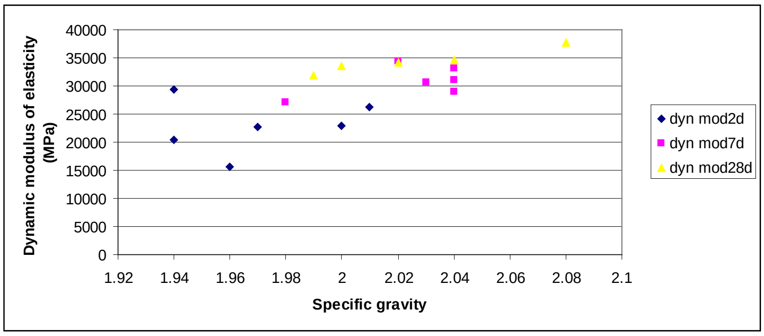

Figure 4. A positive weak linear relationship between dynamic modulus of elasticity and density.

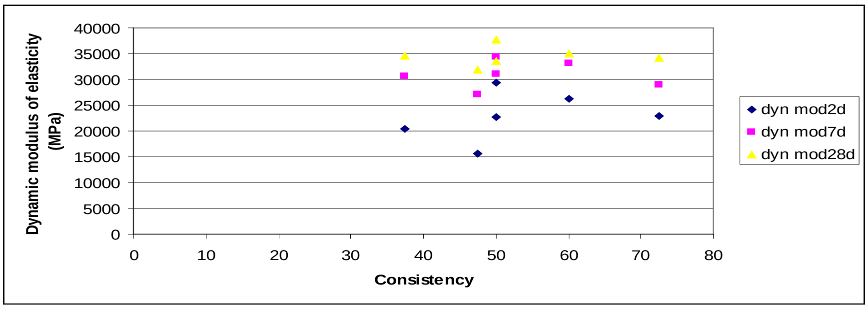

Figure 5. There is an inverse relation between consistency and dynamic modulus of elasticity with a ridge around the 50 consistency value separating high dynamic values to the right from low dynamic values to the left.

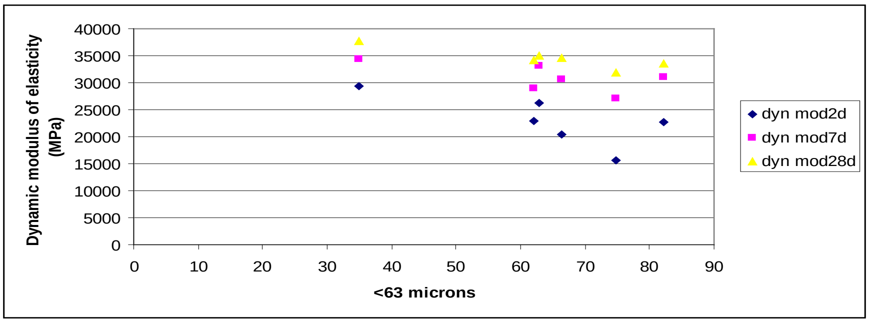

Figure 6. Inverse linear relations between less than 63 microns and dynamic modulus of elasticity.

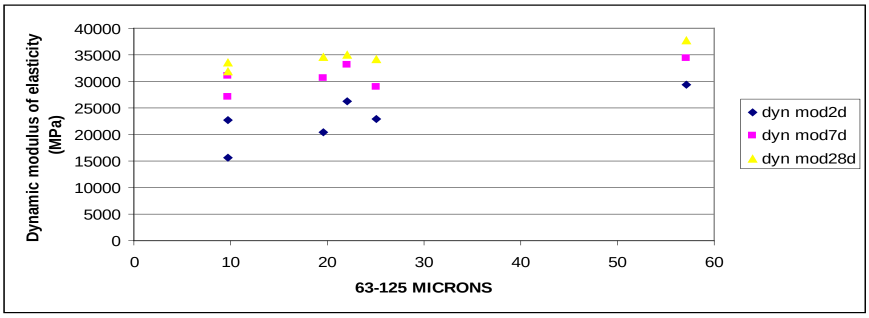

Figure 7. Positive relations between dynamic modulus of elasticity and 63 - 125 size portion.

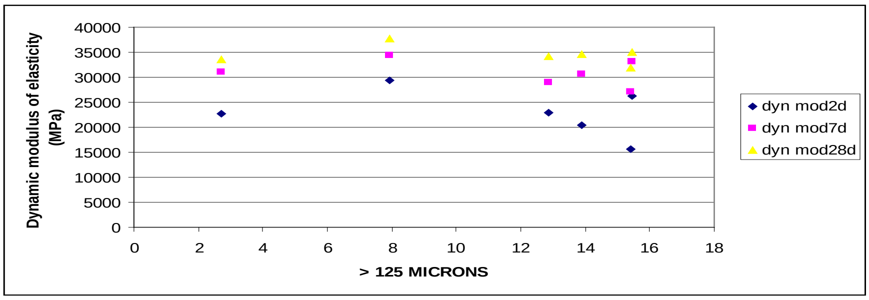

Figure 8. Some curvilinear relations between dynamic modulus of elasticity and coarse cement size portion. Maximum values of elasticity modulus correspond with 8% coarse size.

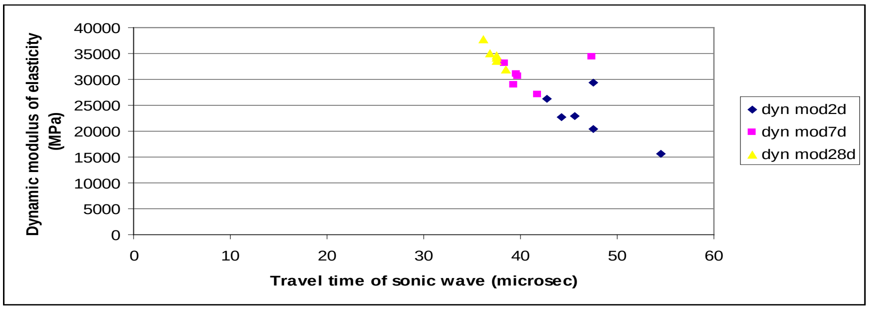

Figure 9. If the two odd points are excluded, it can be clearly seen that there is a perfect negative relationship between travel time of longitudinal sonic waves and dynamic modulus of elasticity. See text for fitting equation.

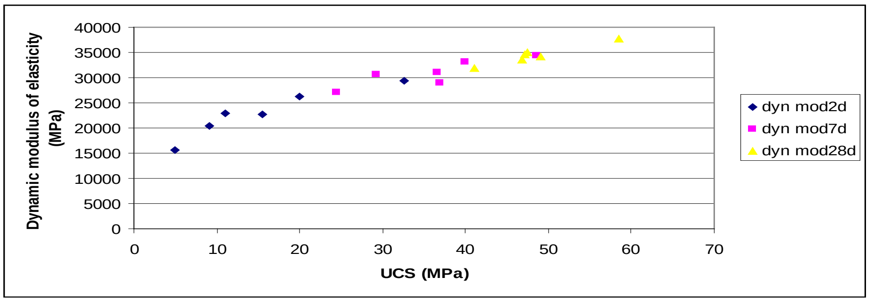

Figure 10. A curvilinear positive relation between UCS and dynamic modulus of elasticity. See conclusions for fitting equation.

2) The 28 day dynamic modulus of elasticity of mortars can be derived from 2 day modulus.
3) An inverse linear relationship exists between dynamic modulus of elasticity and water absorption.
4) There is an inverse relation between consistency and dynamic modulus of elasticity with a ridge around the 50 consistency value separating high dynamic values to the right from low dynamic values to the left.
5) Positive weak linear relationship exists between dynamic modulus of elasticity and density.
6) Dynamic modulus of elasticity has inverse relation with the fine cement size portion (<63 microns), positive relation with the intermediate size (63 - 125), and curvilinear relation with the >125 microns (with maximum values of the modulus corresponding to 8% of the coarse portion).
7) There is almost a perfect power relation with compressive strength for all ages. Thus compressive strength can be easily derived from dynamic modulus of elasticity using the following equation:

$$\text{Compressive strength} = 2/10^{12} \times \text{dynamic modulus of elasticity}^{2.9618} \left(r = 0.9816\right)$$

From a practical point of view, dynamic modulus of elasticity, can be estimated from sonic time of propagation using the equation mentioned in the text. Consequently, uniaxial compressive strength can be derived using the equation in 7 above.

As the cements used here have less CaO content than standard OPC cements, their cement mineral phases cannot be derived by Bogue equation. Microscopy (SEM) and X-ray diffraction may be used to identify the type and amount of cement mineral phases. Poisson ratio was assumed to be 0.17 in the present work. It is highly recommended to measure the actual Poisson ratio and repeat this work including more cement types and mixes with different water cement ratios.

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

References

[1] Lanas, J., Bernal, J., Bello, M. and Galindo, J. (2004) Mechanical Properties of Natural Lime-Based Mortars. *Cement and Concrete Research*, **34**, 2191-2201. https://doi.org/10.1016/j.cemconres.2004.02.005

[2] Fortes-Revilla, C., Martinex, S. and Blanci-Varela, M. (2006) Modelling of Slaked Lime Metakaolin Mortar Engineering Characteristicsin Terms of Process Variables, *Cement and Concrete Composites*, **28**, 458-467. https://doi.org/10.1016/j.cemconcomp.2005.12.006

[3] Lanas, J., Sirera, R. and Alvarez, J. (2006) Study of the Mechanical Behavior of Masonry Lime-Based Mortars Cured and Exposed under Different Conditions. *Cement and Concrete Research*, **36**, 961-970. https://doi.org/10.1016/j.cemconres.2005.12.003

[4] Lanas, J. and Alvarez, J. (2003) Masonry Repair Lime-Based Mortars: Factors Affecting the Mechanical Behavior, *Cement and Concrete Research*, **33**, 1867-1876. https://doi.org/10.1016/S0008-8846(03)00210-2

[5] Gleize, P., Müller, A. and Roman, R. (2003) Microstructural Investigation of a Silica Fume-Cement-Lime Mortar. *Cement and Concrete Composites*, **25**, 171-175. https://doi.org/10.1016/S0958-9465(02)00006-9

[6] Tchamdjou, W.H.J. Cherradi, T., Abidi, M.L. and Pereira-de-Oliveira, L.A. (2017) The Use of Volcanic Scoria from "Djoungo" (Cameroon) as Cement Replacement and Fine Aggregate by Sand Substitution in Mortar for Masonry. *European Journal of Environmental and Civil Engineering*, 1-19. https://doi.org/10.1080/19648189.2017.1364298

[7] el Mahdi Safhi, A., *et al.* (2019) Development of Self-Compacting Mortars Based on Treated Marine Sediments. *Journal of Building Engineering*, **22**, 252-261. https://doi.org/10.1016/j.jobe.2018.12.024

[8] Haddad, R. and Shannag, M., (2008) Performance of Jordanian Masonry Cement for Construction Purposes. *Jordan Journal of Civil Engineering*, **2**, 19-31

[9] Al-Beijat, H., Bignozzi, M. and Moh'd, B. (2013) Compressive Strength of Jordanian cement Mortars. *Open Journal of Civil Engineering*, **3**, 6 p.

[10] BE EN-196-1 (2005) Methods of Testing Cement, European Standards. European Committee for Standardization (CEN), Brussels.