41st Danubia-Adria Symposium Advances in Experimental Mechanics
September 23-26, 2025, Kragujevac, Serbia

DOI: 10.46793/41DAS2025.033S

COMPARATIVE EVALUATION OF THE ELASTIC MODULUS IN CEMENT PASTES USING ULTRASONIC AND 3-MIN-CREEP TESTING

Sophie SCHMID[1], Olaf LAHAYNE[2], Bernhard PICHLER[3]

[1] 0000-0003-4781-3976, TU Wien, Karlsplatz 13, 1040 Wien, Austria, E-mail: sophie.schmid@tuwien.ac.at
[2] 0000-0002-5252-1356, TU Wien, Karlsplatz 13, 1040 Wien, Austria, E-mail: olaf.lahayne@tuwien.ac.at
[3] 0000-0002-6468-1840, TU Wien, Karlsplatz 13, 1040 Wien, Austria, E-mail: bernhard.pichler@tuwien.ac.at

1. Introduction

The elastic modulus E is a suitable material property for quantifying the influence of sample preparation, material age, and ambient conditions on the mechanical behavior of cement pastes, because E can be characterized efficiently using non-destructive methods. A comparison of results obtained from different independent test methods sheds light on the reliability and precision of the methods used, as well as on potentially necessary improvements and limitations in characterization. A comparative study is performed on cement pastes prepared from composite binders made of Portland cement, limestone, and calcined clay.

2. Materials and methods

Three cementitious binders: an ordinary Portland cement (OPC), a binary blend called limestone Portland cement (LPC) containing, by mass, 70% OPC and 30% limestone, as well as a limestone calcined clay cement (LC3) containing, by mass, 70% OPC, 15% limestone, and 15% calcined clay, are used to prepare cement pastes at an initial water-to-solid mass ratio of 0.45 [1]. Two independent test methods are used to determine the elastic modulus from 1 to 7 days after paste production, namely (a) ultrasonic testing and (b) hourly 3-min creep testing, see Fig. 1.

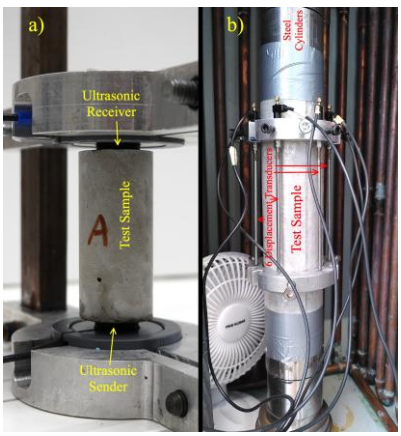

Fig. 1. Test setup for (a) ultrasonic and (b) creep testing.

Test repetitions are performed.

2.1 Ultrasonic tests

Non-destructive ultrasonic tests are conducted on cylindrical samples ($d = 3$ cm and $h = 6$ cm) once per day, from 1 to 7 days after paste production, approximately every 24 h. The test setup is shown in Fig. 1a). Longitudinal and transversal ultrasonic waves with a central frequency of 5 MHz are sent through the test setup. The times of flight of the ultrasound wave are measured. Preliminary tests showed that the results are independent of the frequency and the sample size.

2.2 Creep tests

Non-destructive 3-min creep tests [1,2] are conducted hourly on cylindrical samples ($d = 7$ cm and $h = 30$ cm), from 1 to 7 days after paste production. The test setup is shown in Fig. 1b). The cement paste samples are subjected to a compressive force corresponding to 15% of the material strength at the time of testing. The change of length of the sample is measured.

3. Data analysis

Ultrasonic tests are carried out four times for each sample and at each time instant of testing. The signal velocities v_L and v_T are computed by referring the measured times of flight of the ultrasonic pulses to the sample height. The theory of elastic wave propagation through isotropic media allows for calculating E based on the wave velocities and the mass density ρ [3]:

$$E = \rho \frac{v_T^2(3v_L^2 - 4v_T^2)}{v_L^2 - v_T^2}. \qquad (1)$$

Individual 3-min creep tests are evaluated based on the linear theory of viscoelasticity and Boltzmann's superposition principle, according to the evaluation strategy described in [1]. Values of the elastic modulus, the creep modulus, and the creep exponent are identified without making any constraining assumptions.

4. Results

The analysis of the results from ultrasonic testing allows for identifying two origins of fluctuations: variations between the samples and variations in the measurements of the times of flight, expressed in terms of wave velocities.

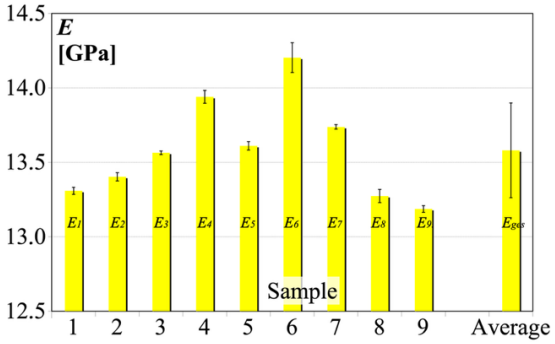

Fig. 2. Elastic modulus of OPC paste samples.

Up to nine cement paste samples are tested for each of the three materials. As for the OPC paste samples, the standard deviations ΔE_1 to ΔE_9 based on ρ and the four values of v_L and v_T are between 0.01 and 0.10 GPa corresponding to 0.09 and 0.70% of the mean values of E_i. For the mean value E_{ges} over all samples, the standard deviation ΔE_{ges} amounts to 0.32 GPa. This is equal to 2.3% of E_{ges}. For LPC and LC3 pastes, we get 2.4 and 2.7%. Therefore, variations between the samples are herein found to be the main source of deviations.

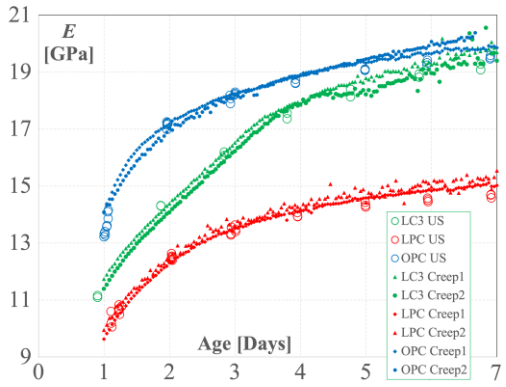

Fig. 3. Comparison of values of the elastic modulus, obtained from ultrasonic testing (large circles) and 3-min creep testing (small symbols).

Creep tests take much more time and effort than ultrasonic tests. Therefore, the number of investigated samples is smaller. Two creep test series are performed for each material, see Fig. 3. The mean difference between the two test-series of one material is about 1.9% for the LC3 paste, 1.6% for the LPC paste, and 1.4% for the OPC paste. These variations are slightly smaller than that of the ultrasonic tests.

The largest differences between ultrasonic test-related and creep test-related values of the elastic modulus amounts to 6%, see Fig. 3 for values of the elastic modulus obtained from ultrasound testing (large circles) and that obtained from 3-min creep testing (small symbols). The largest deviations are observed on the second day of the test series, when the microstructure of the cement paste is still undergoing significant changes due to cement hydration. From 2 days onward, the mean differences between the results of the two test methods are 1.6% for the LC3 and LPC pastes and 2.6% for the OPC paste.

5. Discussion and conclusion

The differences between the values of the elastic modulus from ultrasonic testing and 3-min creep testing are in the range of some 2%. This is the same order of magnitude as the variance between individual test samples. This variance is – to a certain extent – unavoidable. This indicates that a good test reproducibility is achieved for both test methods. The match between the two methods underlines the reproducibility of sample production, especially for the creep tests samples, which were prepared not concurrently, but with time lags of several weeks.

6. Outlook

The performance of ultrasonic tests on additional cement paste samples is recommended especially for future creep test series on cementitious materials, since it is little additional effort, but provides a reliable check of the results obtained in the analysis of the creep tests. The variance between individual samples can be minimized by using always the same sample preparation method. Test repetitions underscore the reliability of test results, because the variance between two samples will never be zero. The direct numerical comparison of ultrasonic and creep test results is recommended to be integrated into the test evaluation of ultrasonic and creep tests.

References

[1] Schmid, S. J., Zelaya-Lainez, L., Lahayne, O., Peyerl, M., & Pichler, B. (2025). Hourly three-minute creep testing of an LC3 paste at early ages: Advanced test evaluation and the effects of the pozzolanic reaction on shrinkage, elastic stiffness, and creep. *Cement and Concrete Research*, 187, 107705.

[2] Irfan-ul-Hassan, M., Pichler, B., Reihsner, R., & Hellmich, C. (2016). Elastic and creep properties of young cement paste, as determined from hourly repeated minute-long quasi-static tests. *Cement and Concrete Research*, *82*, 36-49.

[3] Kohlhauser, C. *Elasticity tensor determination by means of ultrasonic pulse transmission*, PhD thesis, TU Wien 2009.