[0036] FIG. 1 is a schematic diagram of a concrete monitoring system 100 for monitoring a concrete structure 80, according to various embodiments of the disclosure. As illustrated in FIG. 1, the concrete monitoring system 100 may include one or more sensor device (each hereinafter referred to as a "smart aggregate") 110. The piezoelectric aggregate 110 may also be referred to as an electromechanical impedance measurement-based smart aggregate (EIM-SMA). Various numbers of the smart aggregate 110 may be distributed and embeddable at different parts of a concrete structure 80. In some embodiments where the concrete structure 80 is relatively small, one smart aggregate 110 may suffice for monitoring the entire concrete structure 80. In the example illustrated, three smart aggregates 110 are embedded spaced apart from one another in the concrete structure 80 at approximately the same depth from the surface of the concrete structure 80. In other examples, a plurality of the smart aggregate 110 may be embedded at different depths from the same surface of the concrete structure 80. In some examples, each of a plurality of the smart aggregate 110 may be used to determine a state of a localized volume or a localized zone of the concrete structure 80.

[0037] Collectively, a plurality of the smart aggregate 110 may be used to determine a state of a relatively large volume of concrete. In some examples, data collected by the controller 120 from a distribution of the smart aggregate 110 may be used to show different parts of the concrete structure in each of their respective states. Use of the smart aggregate 110 allows for a choice of one or more targeted zones / volumes for monitoring. For example, to monitor the state of the concrete structure 80 closer to the surface, the smart aggregates may be embedded near to the surface of the concrete structure 80. Alternatively, to monitor the state of the concrete structure 80 deep under the surface, the smart aggregates 110 may be embedded deeper in the concrete structure 80.

[0038] In some embodiments, the concrete monitoring system 100 may further include a controller 120. In operation, the controller 120 is in signal communication with one or more of

CLAIMS

1. A concrete monitoring system, comprising:

   at least one piezoelectric aggregate embeddable in a concrete structure; and

   a controller, the controller being configured to:

      perform a plurality of frequency sweeps of the at least one piezoelectric aggregate to obtain a plurality of phase angles; and

      determine a state of the concrete structure based on a change in phase angle between ones of the plurality of phase angles.

2. The system as recited in claim 1, wherein the state of the concrete structure corresponds to a hydration state of the concrete structure.

3. The system as recited in claim 1 or claim 2, wherein the state of the concrete structure includes a finishing ready state of the concrete structure, wherein in the finishing ready state, the concrete structure is suitable for concrete surface finishing.

4. The system as recited in any one of claims 1 to 3, wherein the change in phase angle between ones of the plurality of phase angles includes the change in phase angle between the ones of the plurality of phase angles of the same piezoelectric aggregate.

5. The system as recited in any one of claims 1 to 4, wherein the change in phase angle includes a shift in a peak phase frequency between the ones of the plurality of phase angles.

6. The system as recited in claim 5, wherein the shift in the peak phase frequency is determined between an initial frequency sweep and a subsequent frequency sweep.

7. The system as recited in claim 5 or claim 6, wherein the shift in the peak phase frequency is in a range of 2kHz to 10 kHz.

8. The system as recited in any one of claim 1 to 7, wherein the change in phase angle includes a change in a peak phase amplitude between the ones of the plurality of phase angles.

9. The system as recited in claim 8, wherein the change in the peak phase amplitude is determined between respective ones of the plurality of phase angles of two consecutive frequency sweeps.

10. The system as recited in claim 8 or claim 9, wherein the change in the peak phase amplitude corresponds to a decrease in the peak phase amplitude in a range of 3 degrees to 8 degrees.

11. The system as recited in any one of claims 1 to 10, wherein the plurality of frequency sweeps are sequentially performed based on a measurement schedule.

12. The system as recited in any one of claims 1 to 11, wherein the plurality of frequency sweeps are iteratively performed based on a measurement cycle rate.

13. The system as recited in claim 12, wherein the measurement cycle rate is one frequency sweep per 30 minutes or shorter.

14. The system as recited in any one of claims 1 to 13, wherein each of the plurality of frequency sweep is performed over a sweeping frequency range, the sweeping frequency range is between 30kHz to 100kHz.

15. The system as recited in any one of claims 1 to 14, wherein each of the at least one piezoelectric aggregate comprises:
a piezoelectric member sandwiched between two concrete members.

16. The system as recited in claim 15, wherein a thickness ratio between the piezoelectric member and each of the concrete members is 2:5 or lower.

17. The system as recited in claim 15 or 16, wherein the piezoelectric member is a piezoelectric thin plate with respective surfaces coated with a metal paint.

18. The system as recited in claim 17, wherein the respective surfaces of the piezoelectric member are coated with a thin waterproof layer.

19. The system as recited in any one of claims 1 to 18, wherein the at least one piezoelectric aggregate includes two piezoelectric aggregates spaced apart by a minimum spacing, wherein the minimum spacing corresponds to minimal interference between the two piezoelectric aggregates.

20. The system as recited in any one of claims 1 to 19, wherein the controller is further configured to determine the state of the concrete structure during a maturing process of the concrete structure.

21. A concrete monitoring method, comprising:

performing a plurality of frequency sweeps of at least one piezoelectric-based aggregate embedded in a concrete structure to obtain a plurality of phase angles; and

determining a state of the concrete structure based on a change in phase angle between ones of the plurality of phase angles.

22. The method as recited in claim 21, further comprising:

determining a targeted state of the concrete structure based on the change in phase angle, wherein in the targeted state, the concrete structure is suitable for concrete surface finishing.

23. The method as recited in any one of claims 21 to 22, further comprising determining the state of the concrete structure during a maturing process of the concrete structure.