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Correspondence

Response to discussion of the paper: "On the measurement of free deformation of early age cement paste and concrete" [Bjøntegaard Ø, Hammer TA, Sellevold EJ. Cement and Concrete Composites 2004;26:427–435]

We were a bit provoked by the discussion of our paper by P. Lura and O.M. Jensen (PL/OMJ), but hopefully this will only enliven the discussion on this important topic. On this importance we agree, as evidenced by the rather dubious compliment paid to us; that our paper "*has the merit of participating in this most necessary debate on measurement techniques*".

Of the many aspects in this debate PL/OMJ pick out two for detailed discussions: (1) the relationship between autogenous deformation (AD) of a concrete and its cement paste, and (2) the membrane permeability in volumetric method. Neither point is in our view central to the debate, but certainly useful to clarify.

The most important issues raised in our paper are:

(a) Lack of reproducibility in Round-Robin tests, and general lack of agreement between results in the literature.
(b) Choice of procedure to establish a zero-point for AD.
(c) Effects of bleeding.
(d) Contradictions between volumetric and linear measurements.
(e) Effects of temperature/temperature history.

We think it is vital that these points be clarified if we are to arrive at realistic test procedures as a basis for constructing models for AD. Such models are necessary as input in stress calculation programs, and is a severe limitation on the usefulness of such programs today. We hope PL/OMJ will contribute to this work.

PL/OMJ point (1): The simple volume fraction model used by us was of course not meant to be an appropriate composite model (we are aware of the vast literature in the area), but merely as a demonstration that the paste-to-concrete reduction factor of 0.28 did not even come close to make the two agree (our Fig. 10). PL/OMJ suggest Hobbs model which in the simplest form gives a constant reduction factor around 0.21 (their Fig. 1), thus really further demonstrating our point in Fig. 10 in that Hobbs model would not improve the agreement much either. They then apply the simple Hobbs model to their own data set—a model that is as "*conceptually wrong*" as our; it simply gives a different factor, 0.21 versus 0.28.

The problem is not primarily the composite model but the incompatibility of our paste and concrete data as discussed in our paper.

The fact that the PL/OMJ data (their Fig. 1) give consistent results using the simple Hobbs model is of course gratifying, but they do not discuss the crucial question of how the zero-points for the AD are chosen, nor do they discuss the water in their own aggregate. The former is a difficult question (see for instance Fig. 1 in our paper), and in addition we do not expect a pure paste to behave identically to the same paste in concrete in this respect, since the filler and fine aggregate in concrete do influence early hydration. Freiesleben Hansen [1] discusses the point in connection with early heat development and concludes that paste data should only be used when comparing cements; for heat calculations in concrete it is necessary to test concrete. We believe this heat argument is equally, or even more, valid for AD—since both properties are directly related to hydration rates. The zero procedure for free deformation results (autogenous- and thermal deformations) is discussed in some detail previously [2,3] introducing the practical concept of "stress-inducing deformations". The topic was later discussed in [4].

For paste the zero-question is often more difficult and much of the difference between curves found in the literature are caused by very early differences. Both Fig. 1 and 10 (our paper) and Fig. 1 (PL/OMJ) show how steep

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(or variable) the early slopes are for pastes—which of course is accompanied by strong influence of the chosen zero-procedure. Perhaps a good procedure for isothermal paste data would be to zero at 24 h in order to facilitate comparison in two time periods. We invite PL/OMJ's views on this question.

The PL/OMJ discussion on other factors influencing the paste/concrete-relationship leaves us with an "eerie" feeling. Each factor (water reducing admixtures, water in aggregates and the evolving ratio between the elastic moduli of paste and aggregate) are discussed quite similarly in our paper—did not PL/OMJ read it through? They refer to own work on these question; such as water in aggregate as a source (their Ref. [4] from 2001). We note that we discussed the possibility in 1997 [5].

PL/OMJ point (2): PL/OMJ demonstrate that water transport through the rubber membrane takes place from the very start of the test due to osmotic effects—and not as we stated only after self-desiccation becomes significant. We of course accept this data which, together with our data on later water penetration, should eliminate the use of condoms for AD-measurements in the future. However, we believe their finding has no practical significance in the early fluid phase. The water moving through the membrane would not be recorded as a volume change, since the increased weight inside the condom would be exactly compensated by increased buoyancy. Therefore, data up to setting are valid, as evidenced by our experience that chemical shrinkage and condom method data agree quite well in this period.

When a solid skeleton is formed and empty pores develop, then of course the extra water taken up early due to the osmotic effect (plus bleeding water, if present) combines with the water driven through the membrane by relative humidity and pressure gradients to disturb the autogenous condition, as pointed out by PL/OMJ. This means of course that AD data after the departure point between chemical shrinkage and condom data (often in the range 4–10 h at 20 °C [6]) are not valid. Our formulation "beyond some days" is clearly erroneous.

In conclusion we would like again to emphasize the problem that published reports on AD are often in conflict, but this is often ignored by the authors who then proceed to explain/interpret their own results in isolation. One example may be the occurrence of early expansions often found by some techniques/materials combinations, but not with others. Do expansions exist (apart from bleeding/reabsorption effects)? Another example is the effects of the entire temperature history from water meets cement. Very few comprehensive reports exist on this most important question (very few concrete structures are cured isothermally!)—and it is discussed to a surprisingly small extent. A literature study giving the status on the field was reported in 1999 and 2001 [1,7] and a more condensed version of this study was published in a RILEM State-of-the-Art Report in 2003 [8].

We hope our paper will promote discussion and more work in these areas that are basic both to our fundamental understanding and to practical use of Advanced Curing Technology Programs.

References

[1] Freiesleben Hansen P. Hærdeteknologi-1, Portlandcement (in Danish). Aalborg Portland, Denmark, 1978, pp. 50.
[2] Bjøntegaard Ø, Kanstad T, Sellevold EJ, Hammer TA. Stress inducing deformations and mechanical properties of high performance concrete at very early ages, 5th Int. Symp. on Utilization of High Strength/High Performance Concrete, Sandefjord, Norway, 1999.
[3] Bjøntegaard Ø. Thermal dilation and autogenous deformation as driving forces to self-induced stresses in high performance concrete. Doctoral thesis, NTNU, Dept. of Structural Eng., December 1999, ISBN 82-7984-002-8, 1999.
[4] Weiss J. Experimental determination of the "Time Zero" t_0 (maturity-zero M_0). In: Bentur A, editor. State-of-the-art report: RILEM report 25. Early age cracking in cementitious systems. Sarl: RILEM Publications; 2003. ISBN 2-912143-33-0 [chapter 6.1].
[5] Bjøntegaard Ø, Sellevold EJ, Hammer TA. High performance concrete at early ages: Selfgenerated stresses due to autogenous shrinkage and temperature, Supplementary paper at the Third CANMET/ACI International Symposium on Advances in Concrete Technology, Auckland, New Zealand, 1997.
[6] Justnes H, Clemmens F, Depuydt P, van Gemert D, Sellevold EJ. Correlating the deviating point between external and total chemical shrinkage with setting time and other characteristics of hydrating cement paste. In: Proc. of the Int. RILEM Workshop: Shrinkage of Concrete—Shrinkage 2000, Paris 16–17 October 2000, 2002.
[7] Bjøntegaard Ø, Sellevold EJ. Autogenous and thermal deformations, IPACS-report, TU Luleå, Sweden, ISBN 91-89580-20-6, 2001.
[8] Bjøntegaard Ø, Sellevold EJ. Autogenous and thermal deformations. In: Bentur A, editor. State-of-the-Art report: RILEM report 25 Early Age Cracking in Cementitious Systems. Sarl: RILEM Publications; 2003. ISBN 2-912143-33-0 [chapter 4.1].

Erik J. Sellevold
Ø. Bjøntegaard
T.A. Hammer
The Norwegian University of Science and Technology
Trondheim, Norway
Tel.: +47 73 59 50 72; fax: +47 73 59 47 01
E-mail address: oyvind.bjontegaard@bygg.ntnu.no