Rheology and stability of self-compacting concrete cement pastes

T. H. Phan, M. Chaouche*

Laboratoire de Mécanique et Technologie, CNRS/ENS Cachan/Université Paris 6,
61 Avenue du Président, 94235 Cachan, France

* Email: chaouche @lmt.ens-cachan.fr

Received: 18.7.2005, Final version: 23.9.2005

Abstract:
The rheological behaviour of a cement paste used in Self-Compacting Concretes (SCC) formulations is compared to that of an "ordinary" cement paste (OC) devoid of organic admixtures. In order to mimic the flow conditions experienced by the cement paste in the inter granular space of concretes, the rheological behaviour is investigated in a squeeze flow geometry. By considering the evolution of the squeeze force for different velocities as a function of the instantaneous distance between the discs, it is found that the behaviors of the two cement pastes are qualitatively different. For the OC pastes, the force decreases with increasing squeeze velocity for any given discs separation, indicating that the material is undergoing fluid-solid separation due to filtration of the fluid phase through the porous media made up by the grains. Such behaviour reflects the very poor flowability of the OC paste. The behaviour of the SCC paste is qualitatively different. Above a certain critical value of the speed U_c, the force is an increasing function of the speed for any given disc separation. Under these flow conditions the rheological behaviour of the material is that of a viscous, although highly non-Newtonian, fluid which corresponds to the flowability conditions of the material. For squeeze speeds smaller than U_c, the rheological behaviour of the SCC paste is similar that of OC, indicating that below this critical velocity the material undergoes solid-fluid separation corresponding then to its non-flowability zone.

Zusammenfassung:
Das rheologische Verhalten einer Zementpaste, die in selbstverfestigenden Betonformulierungen (SCC) verwendet werden, wird mit dem Verhalten einer „gewöhnlichen" Zementpaste (OC) ohne organische Beimischungen verglichen. Um die Fliessbedingungen, die von einer Zementpaste im Zwischenraum zwischen den Betonkörnern herrschen, nachzuahmen, wird das rheologische Verhalten in einer Quetschflussströmung untersucht. Bei der Analyse der Entwicklung der Quetschkraft für verschiedene Geschwindigkeiten als Funktion des momentanen Abstands zwischen den Scheiben wurde gefunden, dass sich das Verhalten der beiden Zementpasten qualitativ unterscheidet. Für die OC-Paste nimmt die Kraft mit zunehmender Quetschgeschwindigkeit für einen gegebenen Scheibenabstand ab. Dies deutet darauf hin, dass in dem Material ein Flüssig-Fest-Übergang stattfindet aufgrund der Filtration der flüssigen Phase durch das poröse Medium, das aus den Körnern besteht. Dieses Verhalten reflektiert die sehr geringe Fliesseigenschaft der OC-Paste. Das Verhalten der SCC-Paste ist qualitativ verschieden. Oberhalb einer kritischen Geschwindigkeit U_c ist die Kraft eine steigende Funktion der Geschwindigkeit für einen gegebenen Plattenabstand. Unter diesen Fliessbedingungen entspricht das rheologische Verhalten des Materials dem einer viskosen, obwohl sehr nicht-newtonschen, Flüssigkeit, was dem Fliessverhalten des Materials entspricht. Für Quetschgeschwindigkeiten, die kleiner als U_c sind, ähnelt das rheologische Verhalten der SCC-Paste dem der OC-Paste. Dies deutet daraufhin, dass das Material unterhalb dieser kritischen Geschwindigkeit eine Fest-Flüssig-Trennung durchführt entsprechend seiner Nichtfliesszone.

Key words: self-compacting concrete, rheological behaviour, squeeze flow, filtration

1 INTRODUCTION

Self-Compacting Concretes (SCC) are characterized by their high fluidity so that they can be processed without vibration, fill easily small interstices of formworks and be pumped through long distances. On the other hand, the SCC cement paste has to be viscous enough to avoid gravitational or flow-induced segregation. Since these two types of required properties are apparently contradictory, the formulation of SCC turns out to be critical and is not well-controlled. The link between the flow (rheological) properties and the formulation is actually one of the key-issues for the design of SCC. If we consider the rheological properties that characterize SCC, the yield stress must be zero or very low and the behaviour of its effective viscosity as a function of the flow field must be controlled. The range of

This is an extract of the complete reprint-pdf, available at the Applied Rheology website
http://www.appliedrheology.org

4 CONCLUSION

We have presented an experimental investigation into the behaviour of a SCC paste compared to that of an OC paste in squeeze flow geometry. The OC paste was suspected to undergo flow-induced heterogeneity due to the phase separation between the fluid and the particles. This gave rise to a velocity dependence of the squeeze force opposite to that usually expected for a concentrated suspension under these flow conditions. This reflects the very poor workability of the OC paste as formulated here. In contrast, the SCC paste was found to show a more complex squeeze behavior. At high squeeze speeds and/or large paste thicknesses, the normal force is an increasing function of the speed, as expected in the case of purely viscous flow of the paste. Under these circumstances, the paste is suspected to remain more or less homogeneous. At small speeds and/or small paste thicknesses, the squeeze behaviourof SCC paste is similar to that of OC paste. We then determined a qualitative diagram of the flowability of the SCC paste. From scaling analysis, we argued that the consistency of the fluid phase (polymer solution here) was the key parameter to obtain a stable suspension under squeeze flow conditions (and/or at rest). However, in practice we need the shear-thinning aspect of the fluid phase (small shear-thinning index) to increase the fluidity of the paste under processing conditions (such as pumping). Then, similarly to other types of industrial fluids (such as drilling mud), the SCC would be stable relative to fluid-solid separation at small solicitation rates (mechanical or gravitational), but flowable enough at high solicitation rates.

REFERENCES

[1] Domone PL, Chai HW: Design and testing of self-compacting concrete, Proceedings of RILEM International Conference on Production Methods and Workability of Concrete, Edited by PJM Bartos, DL Marrs, and DJ Cleland, Scotland (1996).

[2] Sakata S, Maruyama K, Minami M: Basic properties and effects of welan gum on self-compacting concrete, Proceedings of RILEM International Conference on Production Methods and Workability of Concrete, Edited by PJM Bartos, DL Marrs, and DJ Cleland, Scotland (1996).

[3] Nagataki S: Present state of superplasticizers in Japan, Inter. Symposium on Mineral and Chemical Admixtures in Concrete, Toronto (1998).

[4] Lachemi M, Hossain KMA, Lambros V, Nkinamubanzi PC, Bouzoubaâ N: Performance of new viscosity modifying admixtures in enhancing the rheological properties of cement paste, Cem. Concr. Res. 34 (2004) 185-193.

[5] Sari M, Prat E, Labastire JF: High strength self-compacting concrete: original solutions associating organic and inorganic admixtures, Cem. Concr. Res. 29 (1999) 813–818.

[6] Ferraris F., Karthik OH, Hill R: The influence of mineral admixtures on the rheology of cement paste and concrete, Cem. Concr. Res. 31 (2001) 245–255.

[7] Leighton DT, Acrivos A: The shear-induced migration of particles in concentrated suspensions, J. Fluid Mech. 181 (1987) 415-439.

[8] Cunha FR, Hinch EJ: Shear induced dispersion in a dilute suspension of rough spheres". J. Fluid Mech. 309 (1996) 211-223.

[9] Roussel N, Lanos C: Plastic fluid flow identification using a simple squeezing test, Appl. Rheol. 13 (2003) 132.

[10] Min BH, Erwin L, Jennings HM: Rheological behaviourof fresh cement paste as measured by squeeze flow, J. Material Science 29 (1994) 1374-1381.

[11] Chan TW, Baird DG: An evaluation of a squeeze flow rheometer for the rheological characterization of a filled polymer with a yield stress, Rheol. Acta 41 (2002) 245-256.

[12] Ozkan N, Oysu C, Briscoe BJ, Aydin I: Rheological analysis of ceramic pastes, J. European Ceramic Society 19 (1999) 2883-2891

[13] Bird RB, Armstrong RC, Hassager O: Dynamics of Polymeric Liquids, Wiley, New York (1987).

[14] Adams MJ, Aydin I, Briscoe BJ, Sinha SK: A finite element analysis of the squeeze flow of an elasto-viscoplastic paste material, J. Non-Newtonian Fluid Mech. 71 (1997) 41-57.

[15] Sherwood JD, Durban D: Squeeze-flow of a Herschel-Bulkley fluid, J. Non-Newtonian Fluid Mech. 77 (1998) 115-121.

[16] Sherwood JD: Liquid-solid relative motion during squeeze flow of pastes, J. Non-Newtonian Fluid Mech. 104 (2002) 1-32.

[17] Poitou A, Racineux G: A squeezing experiment showing binder migration in concentrated suspensions, J. Rheol. 45 (2001) 609.

[18] Chaari F, Racineux G, Poitou A, Chaouche M: Rheological Behaviourof Sewage Sludge and Strain-Induced Dewatering." Rheol. Acta 42 (2003) 273-279.

This is an extract of the complete reprint-pdf, available at the Applied Rheology website
http://www.appliedrheology.org

[19] Delhaye N, Poitou A, Chaouche M: Squeeze flow of highly concentrated suspensions of spheres. J. Non-Newtonian Fluid Mech. 94 (2000) 67-74.
[20] Collomb J, Chaari F, Chaouche M: Squeeze flow of concentrated suspensions of spheres in Newtonian and shear-thinning fluids, J. Rheol. 48 (2004) 405.
[21] Chhabra R, Comiti J, Machac I: Flow of non-Newtonian fluids in fixed and fluidised beds: A review, Chem. Eng. Sci. 56 (2001) 1-27.
[22] Fadili A, Tardy PMJ, Pearson JRA: A 3D filtration law for power-law fluids in heterogeneous porous media, J. Non-Newtonian Fluid Mech. 106 (2002) 121-146.
[23] Bonneau O: Etude des effets physico-chimiques des superplastifiants en vue d'optimiser le comportement rhéologique des bétons ultra haute performances. Ph.D thesis, ENS-Cachan/Sherbrooke University (1997).

This is an extract of the complete reprint-pdf, available at the Applied Rheology website
http://www.appliedrheology.org