Slump flow of autoclaved aerated concrete slurries

Citation for published version (APA):
Straub, C., Quercia Bianchi, G., Florea, M. V. A., & Brouwers, H. J. H. (2014). Slump flow of autoclaved aerated concrete slurries. In *Proceedings of the 5th International Conference Non-Traditional Cement and Concrete (NTCC2014), June 16-19, 2014, Brno, Czech Republic* (pp. 237-241)

Document status and date:
Published: 01/01/2014

Document Version:
Publisher's PDF, also known as Version of Record (includes final page, issue and volume numbers)

Please check the document version of this publication:

• A submitted manuscript is the version of the article upon submission and before peer-review. There can be important differences between the submitted version and the official published version of record. People interested in the research are advised to contact the author for the final version of the publication, or visit the DOI to the publisher's website.
• The final author version and the galley proof are versions of the publication after peer review.
• The final published version features the final layout of the paper including the volume, issue and page numbers.

Link to publication

General rights
Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

- Users may download and print one copy of any publication from the public portal for the purpose of private study or research.
- You may not further distribute the material or use it for any profit-making activity or commercial gain
- You may freely distribute the URL identifying the publication in the public portal.

If the publication is distributed under the terms of Article 25fa of the Dutch Copyright Act, indicated by the "Taverne" license above, please follow below link for the End User Agreement:

www.tue.nl/taverne

Take down policy
If you believe that this document breaches copyright please contact us at:

openaccess@tue.nl

providing details and we will investigate your claim.

Download date: 04. Oct. 2023

Slump flow of Autoclaved Aerated Concrete slurries

C. Straub[1], G. Quercia[2], M.V.A. Florea[3], H.J.H. Brouwers[4]

[1] *Dipl.-Min., Materials innovation institute (M2i), Noord-Brabant, The Netherlands,* ***c.straub@m2i.nl***
[1] *Built Environment, Building Physics and services, Noord-Brabant, The Netherlands,* ***c.straub@tue.nl***
[2] *MSc., Materials innovation institute (M2i), Noord-Brabant, The Netherlands,* ***g.quercia@m2i.nl***
[2] *Built Environment, Building Physics and services, Noord-Brabant, The Netherlands,* ***g.quercia@tue.nl***
[3] *Dr. Dipl.-Eng., Built Environment, Building Physics and services, Noord-Brabant, The Netherlands,* ***m.v.a.florea@tue.nl***
[4] *Prof.dr.ir, Built Environment, Building Physics and services, Noord-Brabant, The Netherlands,* ***jos.brouwers@tue.nl***

Abstract

Autoclaved Aerated Concrete (AAC) is already well known in Central Europe for decades. In traditional cement and concrete research a huge increase of knowledge has improved the material behaviour and efficiency. The understanding of the mineral reactions and properties in AAC has also improved, but several relations are still unknown. In this research a closer look is taken on the influence of the water amount and the mixing procedure on the viscosity determined by the slump flow test. Three different cones were evaluated and two possible evaluation methods presented.

Key Words: *AAC, Autoclaved Aerated Concrete, slurry, spread flow, Vicat, Hägermann*

---

1. INTRODUCTION

For Autoclaved Aerated Concrete (AAC) the green body is an important link between the raw materials and the final product. Unfortunately very few studies take this part of the production process into account [1-9], and there are no standards available.

For the AAC process the flow behavior of the mixture is very important: on one hand the mix has to fill the mould completely in a timely manner, on the other hand a too high water content limits the strength of the AAC product and can affect the stability of the rising of the cake.

For cement and concrete the spread flow test [10] is an easy, fast and appropriate method to evaluate the flow behavior of the mixture.

2. MATERIAL AND METHODS

All experiments are based on a reference recipe (provided by HESS AAC Systems B.V.) shown in Table 1. The raw materials have been analyzed using a number of techniques (PSD, XRF, XRD, density). All materials fulfill the condition $d_{90} < 90$ µm.

Table 1: AAC mix composition

Material	**Proportion [Mass%]**
Quartz powder	66.7
Lime	8.3
Cement	20.0
Portlandite	2.5
Anhydrite	2.7

The quartz powder (SF300 from Quarzwerke GmbH) has a purity of >98 %, and contains quartz as single mineral phase. Cement (CEM I 42.5 R from Cemex) fulfils the requirements of the standard (EN 197-1), in terms of chemical composition and phase content. Lime (11/6 from Fels-Werke GmbH) consists of 96 % CaO (all given percentages by mass), with < 10 % $Ca(OH)_2$ (determined by density measurement). The MgO content is <0.6 %. The slaking curve (DIN EN 459-2) is described by the following parameters: t_{60} = 10 min; T_u= 64.6 °C; t_u= 12 min; T'_{max}= 75.8 °C; T_{max}= 81.4° C. Portlandite (WKH 2/4 CL90 from Fels-Werke GmbH) consists of 70.1 % CaO with a LOI of 27.4 %. The calcite content is less than 15 % (determined by density measurement). Anhydrite powder (Anhydritstaub from Knauf) originates from a natural anhydrite rock and contains also dolomite and gypsum in minor amounts.

The addition of a foaming agent (Al-powder) was not performed, in order to elongate the opening time of the slurry for more comparable results (the reaction of Al-powder starts already during the mixing and is very time sensitive).

The investigated water-to-powder mass ratios (W/P) were 0.525, 0.625 (reference), 0.725 and 0.825. The W/P ratios of 0.425 and 0.925 were performed as a single measurement to validate the fit.

The experiments were performed as follows: after preheating the specific water amount (depending on the aimed W/P ratio) to 45 °C, the mixer (Silverson L5M) was started at slow speed. Quartz and portlandite were successively added and mixed properly. The addition of lime, cement and anhydrite was performed within 30 seconds and then mixed further for 90 seconds. Within 5 minutes after the beginning of the addition of lime and cement all flow experiments were finished.

During the addition of the materials the speed of the mixer was continuously increased. This was necessary to provide a good homogenization, while avoiding splashing or an increased incorporation of air bubbles.

The spread flow test itself was performed by placing the clean and dry cone on a horizontal and plane glass plate. While manually holding the cone steady on the plate, the slurry is filled in. The slurry is added till the cone is completely full (in the case of the Hägermann cone even more and cut off with a glass rod). Directly afterwards the cone is lifted and the next cone is filled. With one slurry-mix all three cones were filled in random order (to equalize the effect of time). For each W/P ratio five independent measurements were performed.

3. MIXING PROCEDURE

The slurry properties are also dependent on the mixing procedure. Therefore, a comparison between a normal laboratory overhead stirrer (IKA RW20.n with normal stirring staff) and a high energy mixer (Silverson L5M with special stirring staff) on the spread flow test was performed. The reference mix (W/P = 0.625) was applied and the spread flows of the different cones were measured (Fig. 1). It appears that the high energy mixer lead to a spread flow increased with approximately 2 cm compared to the normal mixer. Also the range of the specific spread is narrower.

This stems from the better homogenization of the mix. For example the agglomerates of material found after the mixing occurred in a higher amount and size when the normal mixer was used.

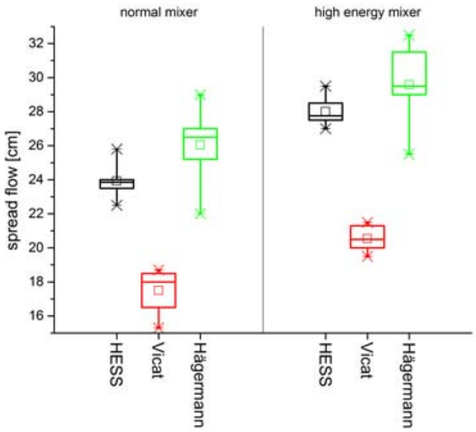


Fig. 1: Comparison of the influence of different mixers on the spread flow measured by different cones

4. SPREAD FLOW TEST

The reason for applying the spread flow test to AAC slurries is that it is a fast measurement, and no additional equipment is required. Especially the latter was taken into account when selecting the cones. The Hägermann cone (EN 1015-3) is used widely in cement and concrete laboratories, as well as the Vicat cone (EN 196-3). The Hägermann cone has the advantage of its design: the intended equality of shear stress at every point of horizontal layer. The Vicat cone was not intentionally created for the spread flow measurement, but because it is a standardized cone it is often used in quality control. The third cone is a self-developed cone used at HESS AAC systems B.V. (further referred to as the HESS cone) and at several AAC plants for controlling the viscosity and subsequently adjusting the W/P ratio.

For comparing the cones their main parameters were displayed in Table 2.

Table 2: Dimensions of the investigated cones

Cone	**Lower diameter [cm]**	**Height [cm]**	**Volume [cm³]**
Vicat	7.5	4.0	154
HESS	7.0	6.0	244
Hägermann	10.0	6.0	348

The results of the spread flow tests plotted against the W/P ratio can be visualized in Fig. 2. The Vicat and HESS cones result in diameters of a quite narrow range and also appear to have a linear relation. However, the Hägermann cone does not. For a comparison of the cones it was suggested that the height of each cake prepared under the same conditions shall be constant independently from the cone. With respect to the W/P ratio, the high of the cake should show an inversely proportional behavior. Therefore the inverse height (calculated using the measured diameter and the volume of the cone assuming a cylindrical shape) was plotted against the W/P ratio (Fig. 3). The fit for all cones revealed quite similar results, the quality of the fit being in all three cases better than R² = 0.960. Finally the equation to describe the diameter of the spread flow (d) as a function of the W/P ratio is:

$$d = \sqrt{4V * \frac{\left(a * \left(\frac{W}{P}\right) + b\right)}{\pi}}$$

Where V is the volume of the cone and a and b are fit parameters (Fig. 3, lines). An interesting point of this function is the point of slope = zero, when the diameter of the cake is kept as the lower diameter of the cone. For better visualization the diameter of the flow is corrected in Fig. 4 for this initial diameter. Both the Vicat and the HESS cones meet the zero flow both at W/P = 0.425, while the Hägermann cone has a shift to higher W/P ratios, which can be explained by the intended equality of shear stress in the design.

In order to validate these fit parameters, single point experiments at W/P = 0.425 and 0.925 were performed (Fig. 4). As predicted by the fit, no slump flow could be observed at W/P = 0.425, while at 0.925 the flow corresponded to the predicted values.

Another possibility to link the values is the original spread flow equation [11].

$$\Gamma = \left(\frac{d}{d_0}\right)^2 - 1$$

Where Γ is the relative slump, d is the measured mean diameter of the cake and d_0 is the lower diameter of the cone.

In contrast to the previously described method, the volume ratios of water and powder were inserted, and only the Hägermann cone can be evaluated using this equation. This has been visualized in Fig. 5. Nevertheless also here a linear fit of a good quality is possible ($R^2 = 0.960$). The evaluation of the Hägermann cone gives $E_p = 0.061$ (slope) and $\beta = 1.24$ (point of origin). Again the Vicat and HESS cones are intersecting at the same V_W/V_P-ratio for zero spread, and the Hägermann cone requires a slightly higher water amount. Concerning the initial values, the fit function is express by:

$$d = d_0 * \sqrt{\frac{\left(\frac{W}{P}\right) * \left(\frac{\rho_{Powder}}{\rho_{Water}}\right) - \beta}{E_p} + 1}$$

and is graphically displayed in Figure 6.

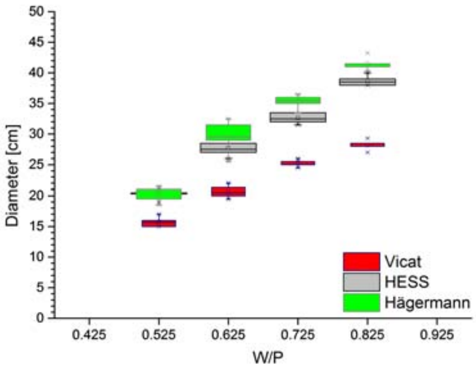


Fig. 2: Spread flow experiments of the reference mix against the water-to-powder mass ratio

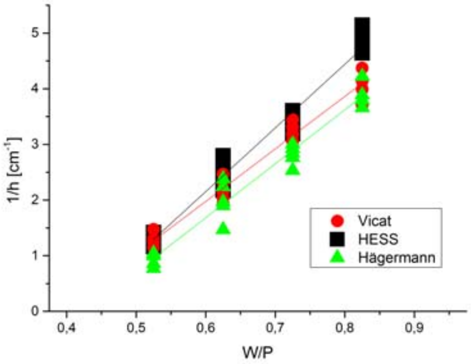


Fig. 3: Spread flow test expressed as (calculated) inverse height against the water-to-powder ratio.

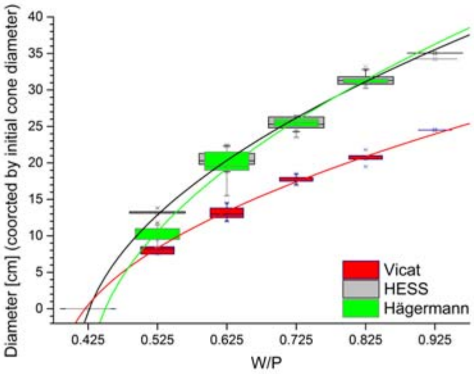


Fig. 4: Fit functions (inverse height approach) of the corrected spread diameter with validation points.

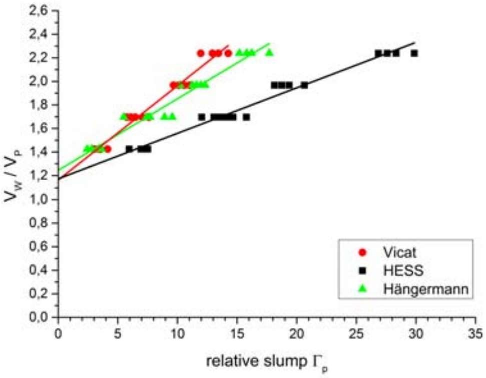


Fig. 5: Evaluation of the slump flow test as described in [10, 11] applied to the different cones

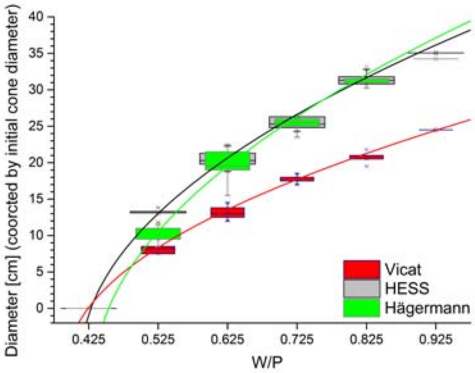


Fig. 6: Fit functions (Spread flow approach) of the corrected spread diameter with validation points

5. CONCLUSIONS

It is possible to use the spread flow as a valid technique to describe the AAC slurries. The use of different available cones can be described by a mathematical function and can be directly related. From the two mathematical models to describe the spread flow experiments, the inverse-height-approach can be recommended, because its application is easier. The influence of the mixing procedure is also considered as well as the material-related parameters.

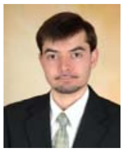
ACKNOWLEDGEMENT

This research is carried out under Project Number M81.1.12478 in the framework of the Research Program of the Materials innovation institute M2i (www.m2i.nl), together with the industrial partner HESS AAC systems B.V. and the sponsors of the Building Materials research group at TU Eindhoven

REFERENCES

[1] Gundlach, H. (1973). *Dampfgehätete Baustoffe*. Wiesbaden und Berlin, Germany: Bauverlag GmbH.
[2] Reinsdorf, S. (1963). *Leichtbeton Band II Porenbetone*. Berlin, GDR: VEB Verlag für Bauwesen.
[3] Röbert, S., et al. (1969/1987) *Silikatbeton Herstellung Bewertung Anwendung.* Berlin, GDR: VEB Verlag für Bauwesen.
[4] Oates, J.A.H. (1998). *Lime and Limestone Chemistry and Technology, Production and Uses*. Weinheim, Germany: WILEY-VCH.
[5] Zürn, S.G. (1997). *Einfluß der Sandminerale auf die Bildung von Calciumsilikathydraten (CSH-Phasen), das gefüge und die mechanischen Eigenschaften von Porenbeton* (doctoral dissertation). Berlin, Germany: Logos-Verlag
[6] Taylor, H.F.W. (1997). *Cement chemistry 2nd edition*. London, UK: Thomas Telford.
[7] Kikuma, J., et al. (2010). *In Situ Time-Resolved X-Ray Diffraction of Tobermorite Formation Process Under Autoclave Condition*. J. Am. Ceram. Soc., 93, 2667–2674.
[8] Connan, H., et al., (2006). *Thermal characterisation of autoclaved cement made with alumina-silica rich industrialwaste.* Journal of Thermal Analysis and Calorimetry, 84, 521–525.
[9] Kikuma, J., et al., (2011). *Effects of quartz particle size and water-to-solid ratio on hydrothermal synthesis of tobermorite studied by in-situ time-resolved X-ray diffraction*. Journal of Solid State Chemistry, 184, 2066–2074.
[10] Hunger, M. (2010). An integral Design Concept for Ecological Self-Compacting Concrete (doctoral dissertation). Technische Universieit Eindhoven, Eindhoven, The Netherlands
[11] Skarendahl, A. & Petersson, O. (eds) (1999). *1st International RILEM Symposium on Self-Compacting Concrete*. France, Stockholm, Sweden: RILEM Publications S.A.R.L.

BIOGRAPHIES



Chris Straub is working at M2i, the Netherlands, and PhD student in the group of Prof. H.J.H. Brouwers at the Eindhoven University of Technology, the Netherlands.

George Quercia Bianchi, has received his bachelor and master degree from the Simon Bolivar University (MSc) Caracas, Venezuela. He is a Guest PhD researcher in the department of the Build Environment, Einhoven University of Technology (TU/e) and he is currently working as Senior Research Advisor-Cement at Trican Well Services Ltd, R&D Centre, Calgary, AB, Canada.

M.V.A. Florea is a postdoctoral researcher at the Eindhoven University of Technology, after finishing a PhD thesis on secondary materials for cement-based products in 2014.

H.J.H. Brouwers is professor Building Materials and head of the unit Building Physics & Services at Eindhoven University of Technology.