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Effects of a water-retaining agent on the rheological behaviour of a single-coat render mortar

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Abstract

The effects of a water-retaining admixture on the rheological properties of a cement-based render mortar were studied. This agent, based on a cellulose ether compound, was introduced in contents up to 0.2 wt.%.

Rheological behaviour was studied with a rheometer for mortars using two different speed profiles. First, the step profile allowed observing the variation of *g* and *h* parameters with the water-retaining agent content, *g* and *h* being directly related to yield stress and plastic viscosity. Second, the dwell profile allowed the study of the rheological behaviour variation with time, particularly the study of structural breakdown and reconstruction phenomena. These phenomena could be followed through the evolution of the hysteresis area in the flow curves. It was also possible to conclude that this admixture has a thickening effect except for low amounts (≤0.08%) and that it promotes structural breakdown together with a secondary effect of retarding the setting time.

Keywords: Rheology; Admixture; Mortar

1. Introduction

Development or optimization of mortar formulations, relative to the nature and content of its particular components (binder, aggregates, water, admixtures, etc.), is normally made as a function of a particular application or performance. The application of mortars is very dependent of the material's characteristics in the fresh state and that, in turn, affects its final properties in the hardened state [1–3]. Hence, rheology becomes a major issue of study, since it is devoted to the analysis of the flow and deformation of materials under stress [4,5]. The rheological behaviour of mortars and cement pastes has been studied in the last years by several authors [5–9], that have attributed a typical Bingham behaviour ($\tau=\tau_0+\mu\gamma$), which is characterized by a yield stress and a plastic viscosity regarding the stress–strain rate relationship. The Bingham behaviour can also be expressed as a torque (T) to rotation speed (N) relation, $T=g+hN$, where g and h are coefficients directly proportional to yield stress and plastic viscosity, respectively, by constants of proportionality that must be determined by calibration [5,7,10].

Bingham fluids show a time-dependent behaviour characterized by a shear stress decrease at constant shear rate, particularly for higher shear rates [10]. Another interesting rheological feature is that these materials, especially cement pastes and mortars, present a structural breakdown phenomenon when submitted to a shear stress, as indicated by the decrease of torque with time in Fig. 1 [9]. When the equilibrium torque value (T_e) is attained, the structure is either completely destroyed or there exists an equilibrium between the structure breakdown and reconstruction rates. This structural breakdown phenomenon also causes a hysteresis behaviour in the flow curves (stress–strain), usually represented as torque (T) vs. rotation speed (N) [10]. Banfill and Saunders [11] showed that the shape of the hysteresis curve depends on the ascending and descending rate used during the test, which means, that at short cycle times only structural breakdown is observed, while as the

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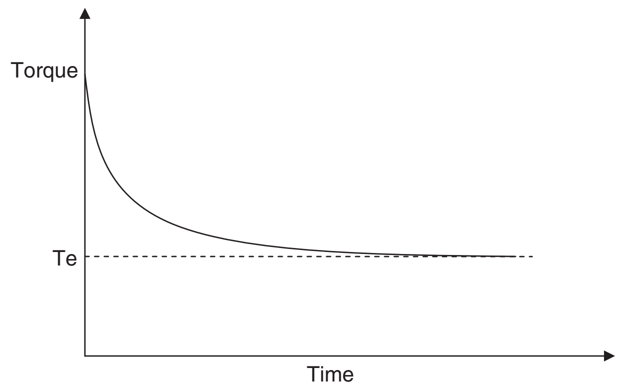

Fig. 1. Variation of torque with time at constant shear rate [9].

cycle time increases the structural reconstruction starts to show up. Other authors [12] called this phenomenon as coagulation and deflocculation processes but the overall described effect is the same.

The addition of admixtures is usually performed to improve a particular mortar's characteristics either in the fresh or hardened state. These admixtures have a direct or indirect effect over the workability and rheological behaviour of the mortars and so their introduction deserves careful study. One of the most commonly used admixtures are the water-retaining agents, precisely to retain water inside the mortar during the dehydration process caused by absorption into the support or by evaporation to the atmosphere. Because hydraulic binders, like cement, need water for the hardening process this type of admixtures are used on several mortars formulations [13,14].

Water-retaining agents are also known as thickening or viscosity enhancing admixtures, which are found essential to reduce segregation amongst the components, improve homogeneity, workability and also the hardened product characteristics [14–17]. They are based on cellulose ethers and the most widespread ones are cellulose methyl-hydroxypropyl (MHPC) or cellulose methyl-hydroxyethyl (MHEC) and due to their hydrophilic nature they retain water physically adsorbed [17], which reduces the available water and increases the plastic viscosity and yield stress [14,15]. However, some authors [15,18] have also observed that small additions can cause a decrease in the yield stress of mortars.

The multiple effects of this admixture clearly justify further studies. Hence, this work aims to analyse the effect of a water reducing agent on the rheological behaviour of single-coat render mortars, monitoring its parameters (plastic viscosity and yield stress) as well as the relation between the flow curve hysteresis behaviour, the structural breakdown phenomenon and the presence and amount of this particular admixture.

2. Experimental

In this study, the base mortar (BM) is an outdoor white render applied as a single layer and for that purpose is also described as a single-coat render mortar. The mortar's basic constitution involves Portland white cement (type I, 52.5 N) as a binder and aggregates are basically constituted of siliceous sand with a particle size distribution below 1.25 mm. The binder/aggregate ratio is typically 1 : 5 and water content was set at 21% of the total weight of dry mortar. The water-retaining admixture was a cellulose methyl-hydroxypropyl (MHPC) compound and its content was varied until 0.2% of the total weight of dry mortar. The amounts used in this study were 0.05%, 0.08%, 0.10%, 0.15% and 0.20% of MHPC, being the formulation referred to as (BM + %MHPC). In some particular samples, setting times were measured with an automatic Vicat needle apparatus.

The rheological behaviour was studied with a specific rheometer (Viskomat PC) for mortars. All mortars were mixed by following the same procedure, that consists of an initial mixing period of 30 s at low speed (~ 60 rpm), followed by a resting period of 45 s and ending with a second mixing period of 60 s at the same speed as previously. Measurement was performed after 10 min resting from end of mixing. This

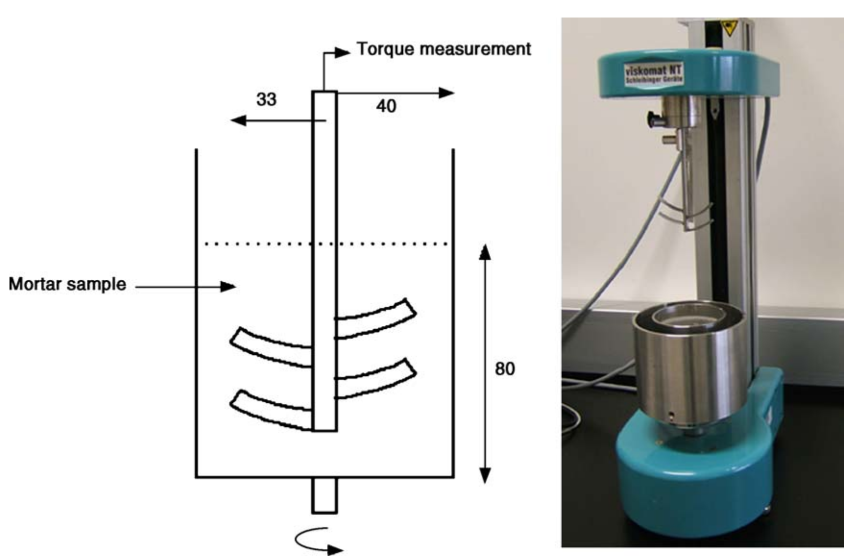

Fig. 2. Details of the specific rheometer for mortars (Viskomat PC).

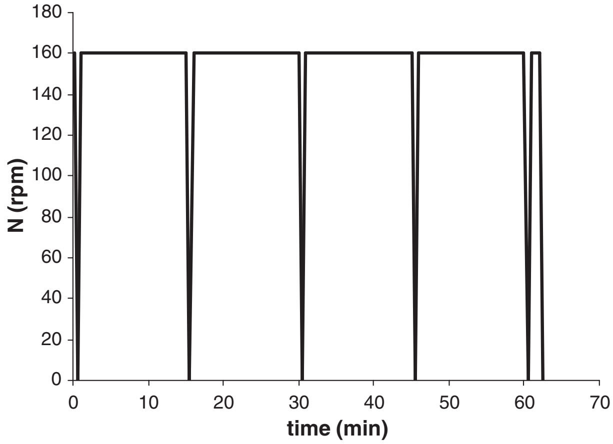

Fig. 3. Dwell speed profile for rheometer measurements.

rheometer consists of a cylindrical vessel, where the same amount of sample is placed ready to rotate at several programmable speeds. A fixed blade is automatically inserted in the centre of the vessel and measures continuously the torque during the test (Fig. 2). Data on sample temperature, torque and speed are registered and sent to an associated computer.

The rotation speed of the vessel can be programmed and, in this study, two types of speed profiles were used. In the first profile, named dwell, the speed is set at a constant value (160 rpm) for a long period of time (150 min). Each 15 min the speed is brought to zero and then back to 160 rpm (see Fig. 3). In these variable speed zones, flow curves (*T* vs. *N*) can be constructed. This dwell profile is specially designed to evaluate the changing rheological behaviour with time. In the second profile, named step, the rotation speed is set to vary with time, decreasing from an initial value of 200 rpm until zero. At each speed, it waits around 1 min before descending 20 rpm each time (Fig. 4). This allows reaching equilibrium values of torque for each speed and to build equilibrium flow curves for a better determination of plastic viscosity and yield stress-related coefficients (*h* and *g*, respectively). The effect of the water-retaining agent (MHPC) on these mortar rheological parameters was evaluated using this step speed profile.

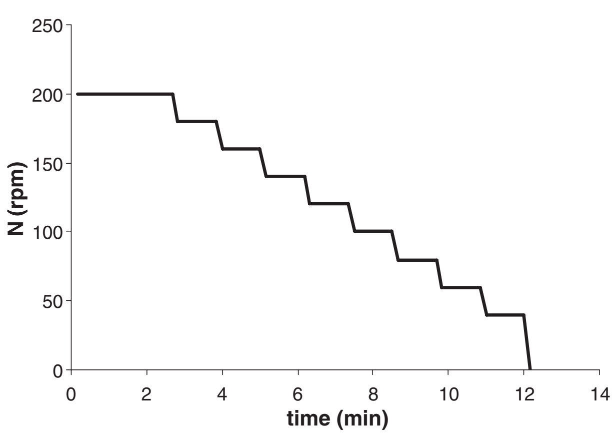

Fig. 4. Step speed profile for rheometer measurements.

3. Results and discussion

Fig. 5 presents the results concerning the effect of water-retaining agent on the plastic viscosity (*h*) and yield stress (*g*) coefficients, taken with the step speed profile. It is possible to observe a clear minimum in the yield stress and plastic viscosity for mortars with contents up to 0.08% of MHPC, increasing afterwards and showing the thickening nature of this admixture.

These cellulose-based materials are high molar-mass polymers that act in the mix by fixing water molecules, reducing the free water in the system and therefore increasing the viscosity. The polymer chains can also suffer an intertwining process which further increases the viscosity. Such entanglement can be disaggregated by mixing and the polymer chains aligned with the flow direction causing a decrease in the viscosity [14]. Some authors [14,15,18] have also reported this effect including the existence of a small content responsible for the minimum. Although this alignment with the flow could eventually promote the movement in the same direction of the particles in the suspension and cause that thinning behaviour, it is possible that other factors could contribute to that minimum in the presence of small amounts of MHPC. One of such factors could be related to the fact that the water-retaining agent (MHPC) could introduce air in the mixture, causing this thinning behaviour. Measurements of the included air in this base mortar and in the one containing 0.08% MHPC gave values of 18% and 22%, respectively, proving the inclusion of air by the MHPC agent. Nevertheless, more extended data is needed on this particular subject to be able to setup the aforementioned correlation. For larger amounts of MHPC, the polymer chains intertwining dominates and the typical thickening behaviour is observed.

All these variations have a clear effect on the mortars workability as is obvious from the variation of torque values with time (Fig. 6). Curves in this figure were obtained by using the dwell speed profile, which enables us to evaluate the variation of the rheological behaviour of mortars, with different amounts of MHPC, over long times. The chosen amounts were the extreme admixture content values (0% and 0.2% MHPC) and the one corresponding to the sample with the minimum *g* value (0.08% MHPC). Indeed, the torque values are lower for

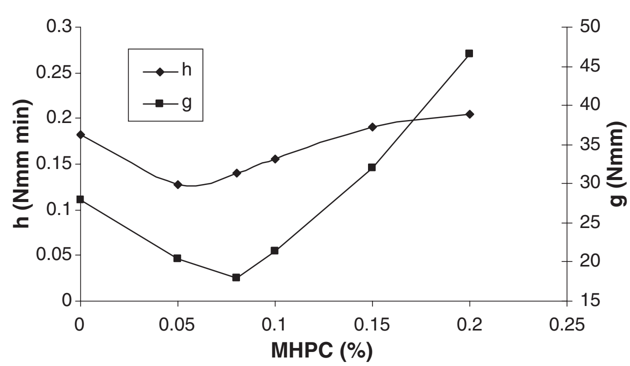

Fig. 5. Effect of water-retaining agent (MHPC) over the rheological parameters (*g*, *e*, and *h*) determined form tests carried out with the step speed profile (mortars prepared with 21% of kneading water).

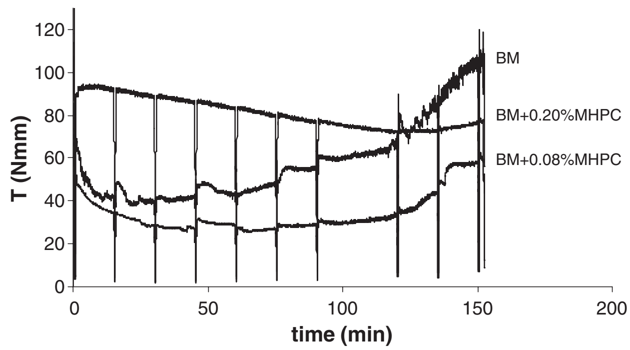

Fig. 6. Torque variation with time of mortars with and without water-retaining agent (MHPC) (mortars prepared with 21% of kneading water).

the 0.08% MHPC containing mortar, resulting in thinning or fluid behaviour characterized by that minimum on *g* and *h* values. The higher content of MHPC (0.2%) gave even higher values of *g* and *h* than the base mortar (BM) showing its clear thickening behaviour.

It is also possible to observe in Fig. 6 that the base mortar (BM), without admixture, shows breakdown of its structure, obvious from the decrease of the torque values up to 15 min after stirring has started. This holds until 45 min of test. The phenomenon of structural breakdown can be confirmed by the variation of the hysteresis area as a function of time in the flow curves. Indeed, Fig. 7 shows a significant decrease in the hysteresis area, between the ascending and descending flow curves (dwell speed profile), from 0 to 15 min. Breakdown is not fully completed for the BM mortar at 15 min although the reconstruction rate approaches the breakdown one after this time. The balance between these two rates corresponds to the flat area in Fig. 6 (torque vs. time curves).

In the MHPC-containing samples, the structural breakdown occurs before, mainly during the mixing process of the mortar. When the rheological measurement is made there is already practically no hysteresis area (Fig. 7; time = 0 min). The 0.08% MHPC mortar achieves the equilibrium in torque values (Fig. 6) after 15 min of test, in a condition of complete structural breakdown as indicated by the absence of hysteresis area (Fig. 7; time = 15 min). On the other hand, the mortar with higher contents of MHPC (0.2%) presents a slower process with time, achieving the equilibrium dwell only for higher testing times (≈ 120 min), as evidenced in Fig. 6.

Moreover, Fig. 7 confirms the structural breakdown effect where it is also clear, for the 0.2% MHPC sample, that the hysteresis area is smaller than for the base mortar (BM) sample. As a matter of fact, one could say that for the mortars containing MHPC, the structural breakdown phenomenon is promoted when compared to the base mortar.

Looking still at Fig. 6, it is also possible to verify that with the BM sample for times longer than 45 min the structure reconstruction rate increases and it is specially so above 120 min. At the same time, from the analysis of the hysteresis curves for the longer times (Fig. 8), it is possible to observe an increase in hysteresis area with the increase in the reconstruction process, also reflected in the torque increase with time. In the 0.08% MHPC containing mortar, the torque values are steady until much later, around 120 min and, for longer times, there is also the observed increase in reconstruction rate. The 0.2% MHPC containing mortar slowly attains the equilibrium in torque values only after 120 min, keeping it until 135 min, above

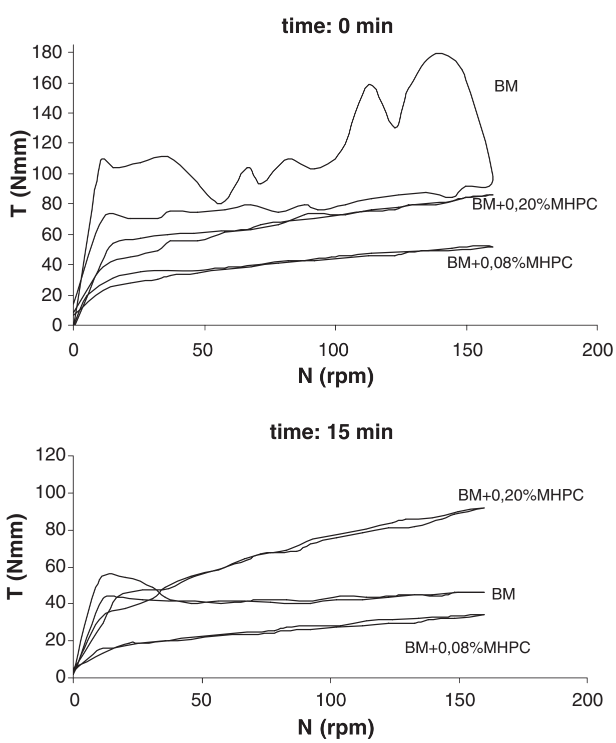

Fig. 7. Flow curves of base mortar (BM) and mortars containing 0.08% and 0.2% MHPC at different testing times (0 and 15 min; dwell speed profile).

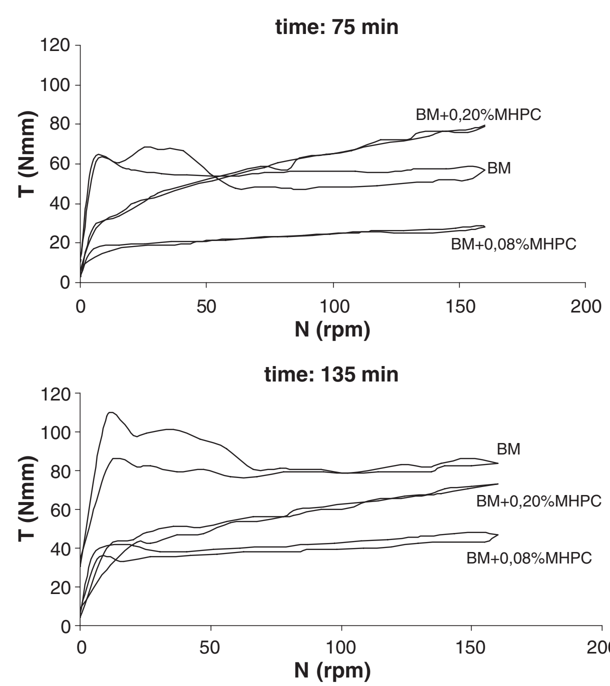

Fig. 8. Flow curves of base mortar (BM) and mortars containing 0.08% and 0.2% MHPC at different testing times (75 and 135 min; dwell speed profile).

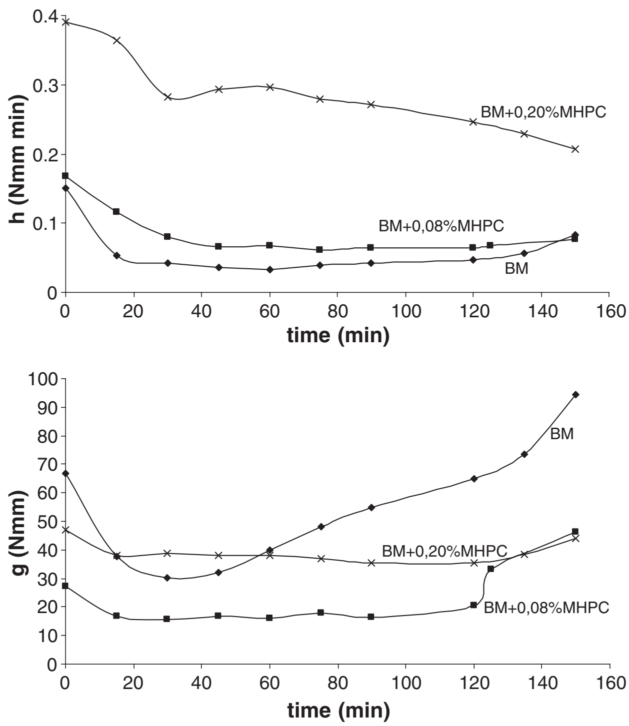

Fig. 9. Variation of *h* and *g* parameters as a function of testing time for mortars with different contents of MHPC agent (0%, 0.08% and 0.2%), taken with a dwell speed profile.

which a slow increase in reconstruction rate is noted. As before, this can be observed also from the hysteresis area evolution and, in Fig. 8, it is possible to verify that, at 75 min, the base mortar already presents an increase on hysteresis area while other compositions, including MHPC, still have practically no hysteresis. At 135 min, the flow curves start to open even for the 0.08% MHPC mortar.

Taking into account Figs. 6–8, one could say that there is a retarding effect of the water-retaining agent (MHPC) on the structure reconstruction rate, which could also indicate a setting retarding effect of this type of admixture. In this context, setting time measurements on mortars were made using the Vicat-needle method. Indeed, the base mortar (BM) presents an initial setting time of 150 min, while the 0.08% and 0.2% MHPC mortars present an initial setting times of 300 and 450 min, respectively. By retaining the water, the MHPC delays the hydration process of the cement particles leading to higher setting times.

Fig. 9 shows the variation of *h* and *g* coefficients with time, taken from the flow curves obtained with the dwell speed profile. Firstly, it is possible to observe the increase of the thickening effect with the increase in the MHPC content. Secondly, the base mortar and the one containing 0.08% MHPC show a rapid descent of plastic viscosity (*h*) until the equilibrium value which is then maintained throughout the test. The 0.2% MHPC containing mortar shows a continuous decrease of *h* during testing time. At last, Fig. 9 also permits to confirm that *g* values are also a good indicator for the breakdown–reconstruction phenomena since it follows quite well the modifications with time reflected in Figs. 6–8. The *g* value behaviour of the three sample compositions in Fig. 9 confirms that it diminishes when structure breakdown is occurring but, it is kept steady while at equilibrium and increases when the reconstruction rate becomes higher.

These rheological observations can also be very important in terms of the practical application of this kind of mortars. For instance, it helps to choose the best admixture content if one considers that the existence of a yield stress and viscosity minimum is important for the application by projection of the mortar, since it guarantees good flow ability and less wear in the projection equipment.

4. Conclusions

It is clearly demonstrated in this study that water-retaining admixtures can also have strong effects in the rheological behaviour of mortars in which formulations they are added. This reflects not only the main rheological parameters but also the structural breakdown and reconstruction phenomena, affecting the workability and application performance of this kind of mortar.

Regarding yield stress and plastic viscosity of the fresh mortars, the increase of MHPC content has a thickening behaviour contributing for an increase on *g* and *h* parameters, except for low contents ($\leq 0.08\%$), where a decrease is noted with a corresponding lowering of torque values which is important in terms of application.

The structure breakdown and reconstruction phenomena can be followed by the variation in the hysteresis area of the flow curves as a function of time (dwell speed profile). A decrease in the hysteresis area is noted during the breakdown process, while the opposite happens when the reconstruction rate becomes higher in the competitive phenomena. The *g* value behaviour with time also follows quite well this process, constituting an alternative indicator.

The presence of MHPC also promotes a faster structural breakdown and a longer period of equilibrium between breakdown and reconstruction due to a certain inhibition of the hydration process, hence, causing a retarding action on setting as confirmed by the specific measurements.

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References

[1] J.F. Young, S. Mindess, R.J. Gray, A. Bentur, The Science and Technology of Civil Engineering Materials, Prentice Hall Inc., New Jersey, 1998.

[2] A.M. Neville, Properties of Concrete, Pitman Publishing, London, 1975.

[3] P.C. Hewlett, Lea's Chemistry of Cement and Concrete, Butterworth-Heinemann, Oxford, 2001.

[4] P.C. Hiemenz, Principles of Colloid and Surface Chemistry, Marcel Dekker Inc., New York, 1977.

[5] C.F. Ferraris, Measurement of rheological properties of cement paste: a new approach, Journal of Research of the National Institute of Standards and Technology 104 (1999) 461–478.

[6] P.F.G. Banfill, The rheology of fresh cement and concrete – a review, Proc. of 11th International Congress on the Chemistry of Cement, 2003, pp. 50–62.
[7] P.F.G. Banfill, Structure and rheology of cement based systems, Materials Research society Symposium Proceedings 289 (1993) 149–160.
[8] G.H. Tattersall, P.F.G. Banfill, The Rheology of Fresh Concrete, Pitman Publ., London, 1983.
[9] J.I. Bhatty, P.F.G. Banfill, A viscometric method of monitoring the effect of retarding admixtures on the setting of cement pastes, Cement and Concrete Research 14 (1984) 64–72.
[10] P.F.G. Banfill, Rheological methods for assessing the flow properties of mortar and related materials, Construction & Building Materials 8 (1994) 43–50.
[11] P.F.G. Banfill, D.C. Saunders, On viscometric examination of cement pastes, Cement and Concrete Research 11 (1981) 363–370.
[12] K. Hattori, K. Izumi, A new viscosity equation for non-Newtonian suspensions and its applications, in: P.F.G. Banfill (Ed.), Rheology of Fresh Cement and Concrete, Spon, London, 1991, pp. 83–92.
[13] DIN 18555 standards: Testing of mortars with mineral binders: Part 7. Determination of water retention value, (November 1987).
[14] K.H. Khayat, Viscosity-enhancing admixtures for cement-based materials – an overview, Cement & Concrete Composites 20 (1998) 171–188.
[15] M. Lachemi, K.M.A. Hossain, P.C. Nkinamubanzi, N. Bouzoubaâ, Performance of new viscosity modifying admixtures in enhancing the rheological properties of cement past, Cement and Concrete Research 34 (2004) 185–193.
[16] K.H. Khayat, M.S. Coric, I.F. Liotta, Influence of thixotropy on stability characteristics of cement grout and concretes, ACI Materials Journal 99 (3) (2002) 234–241.
[17] N.B. Eden, J.E. Bailey, Effect of polymer modification on the mechanical properties of calcium silicate and calcium aluminate cements, Proc. International Congress of the Chemistry of Cement, 1986, pp. 163–169.
[18] K.M. Green, M.A. Carter, W.D. Hoff, M.A. Wilson, The effects of lime and admixtures on the water-retaining properties of cement mortars, Cement and Concrete Research 29 (1999) 1743–1747.