# The Effect of Different Portland Cements on Initial Hydration Reaction of a Self-Compacting Concrete Cement Paste

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## ABSTRACT

The hydration reaction of cement whether in paste, mortar or concrete is complex. Small amplitude oscillatory measurements in a rotational rheometer fitted with parallel plate attachment were used to evaluate the initial hydration kinetics of cement pastes. Four Portland cements of same strength manufactured at different factories and two new generation superplasticisers (SP) were used for the investigation. The effect of cyclone dust filler (Calcium Carbonate) was also evaluated. There was a considerable difference in the rate of hydration for the four cements and the influence of superplasticers and addition of cyclone significantly slowed down the microstructural development of cement.

## INTRODUCTION AND BACKGROUND

The hydration reaction of cement paste is complex and is effected by many factors. The effect of the same cement type manufactured at different factories on Self Compacting Concrete (SCC) paste mixes is not known. Nunes et al.[1] investigated the variation of cement quality produced on different days and the effect on SCC mortar/paste mixes. They concluded that each type of cement contains unique properties which interact with other constituents, resulting in a variety of interactions in the concrete mixture. Kirby and Lewis[2] investigated the rheological property evolution and hydration behaviour of cement suspensions. They show a rapid initial increase in G' with time to a plato of $10^5$ Pa and established a link between early stage hydration evolution and rheological property for Portland cement-superplasticiser suspensions. They infer that for the pure cement pastes at the onset of the acceleratory period the pastes, due to the hydration effects, stiffened irreversibly. Dynamic mode rheometry was used by Nachbaur et al.[3] to investigate the evolution of the structure of cement. They found that the main evolution of the structure of cement occurred during the first few minutes after the end of mixing. Bellotto[4] in 2013 also used small amplitude oscillation rheological measurements to study the evolution of cement paste during the dormant period. He observed an increase of more than 2 orders of magnitude in the value of the storage modulus G' up to the onset of the Portlandite precipitation and that in the acceleratory period G' continuous to steadily increase. The objective this study was to investigate the initial hydration of four cements manufactured in different factories with and without cyclone dust as filler and using two different superplasticisers.

Cyclone dust (Calcium Carbonate) is used as a filler in SCC to improve the packing density and to increase the viscosity. (Pederson[5]; Koehler[6]; Choulli et al.[7])

## METHODOLOGY and MATERIALS

An Anton Paar MC51 rheometer with parallel plate attachment was used and small amplitude oscillation measurements were performed to evaluate the initial hydration kinetics in terms of evolution of elastic modulus with time. This leads to the formation of an elastic gel of which the strength rapidly increases with time within the cement structure during the dormant period. Neat cement pastes as well as different SP concentrations were tested for each cement type with and without cyclone dust. The cements were from one company but manufactured at four factories. The chemical analysis of the 4 cements (C1-C4) is given in Table 1 and the physical parameters in Table 2.

Table 1. Chemical properties of the cements.

| Chemical properties | C1 | C2 | C3 | C4 |
|---|---|---|---|---|
| $SiO_2$ (%) | 20.15 | 20.7 | 19.4 | 21.7 |
| $Al_2O_3$ (%) | 3.82 | 4.37 | 3.59 | 4.95 |
| $Fe_2O_3$ (%) | 3.22 | 2.45 | 2.93 | 2.99 |
| $Mn_2O_3$ (%) | 0.09 | 0.81 | 0.75 | 0.49 |
| $TiO_2$ (%) | 0.22 | 0.33 | 0.32 | 0.42 |
| CaO (%) | 63.37 | 63.7 | 61.7 | 60.9 |
| MgO (%) | 1.13 | 3.58 | 4.26 | 2.17 |
| $P_2O_5$ (%) | 0.14 | 0.08 | 0.02 | 0.10 |
| Wet $SO_3$ (%) | 2.10 | 2.27 | 2.13 | 3.40 |
| Wet Cl (%) | 0.004 | 0.01 | 0.01 | 0.004 |
| $K_2O$ (%) | 0.62 | 0.52 | 0.29 | 0.34 |
| $Na_2O$ (%) | 0.99 | 0.16 | 0.14 | 0.18 |
| LOI (%) | 3.00 | 1.57 | 5.13 | 2.01 |
| Total (%) | 98.9 | 100.5 | 100.6 | 99.6 |
| FCaO (%) | 1.06 | 0.75 | 0.83 | 3.25 |
| IR (%) | - | 0.78 | 1.98 | - |
| Cl (ppm) | - | 106 | 106 | - |

Table 2. Physical properties of the cements.

| Physical properties | C1 | C2 | C3 | C4 |
|---|---|---|---|---|
| Relative Density Pyc | 3.05 | 3.03 | 3.04 | 2.99 |
| Reported S/Surface, $cm^2/g$ | 3750 | 3650 | 4250 | 3850 |
| Std Consistence, % | 25.0 | 31.0 | 25.0 | 33.0 |
| Initial Set, min | 170 | 180 | 190 | 315 |
| Final Set, h | 3.25 | 3.75 | 3.75 | 6.00 |
| 45 μm Residue, % | 11.7 | 0.6 | 3.9 | 1.8 |
| 90 μm Residue % | 1.1 | 0.0 | 0.5 | 0.1 |
| 212 μm Residue, % | 0.2 | 0.0 | 0.0 | 0.0 |

The Chemical properties of the limestone cyclone dust is presented in Table 3 and the physical properties in Table 4.

Table 3. Chemical properties of Cyclone dust

| Chemical properties | Cyclone dust |
|---|---|
| $SiO_2$ (%) | 8.45 |
| $Al_2O_3$ (%) | 0.32 |
| $Fe_2O_3$ (%) | 0.57 |
| $Mn_2O_3$ (%) | 0.01 |
| $TiO_2$ (%) | 0.05 |
| CaO (%) | 49.23 |
| MgO (%) | 0.65 |
| $P_2O_5$ (%) | 0.16 |
| Wet $SO_3$ (%) | 0.20 |
| Wet Cl (%) | 0.04 |
| $K_2O$ (%) | 0.30 |
| $Na_2O$ (%) | 0.28 |
| LOI (%) | 39.76 |
| Total (%) | 100 |

Table 4. Physical properties of cyclone dust

| Physical properties | Cyclone dust |
|---|---|
| Relative Density Pyc | 2.62 |
| Reported S/Surface, $cm^2/g$ | 1850 |
| 32 μm Residue, % | 49.0 |
| 45 μm Residue, % | 28.9 |
| 90 μm Residue % | 1.5 |

Two superplasticisers from different suppliers were used. SP1 is a modified vinyl polymer-based super-plasticising admixture whereas SP2 is a new generation superplasticiser based on a modified polycarboxylate polymer. The charateristics of the two superplasticers are given in Table 5.

Table 5. Superplasticiser characteristics

| Characteristics | SP1 | SP2 |
|---|---|---|
| Consistency | Liquid | Liquid |
| Colour | Amber | Brown-green |
| Density according to ISO 758 (g/cm$^3$) | 1.07 ± 0.02 | 1.05 ± 0.02 |
| Dry content according to EN 480-8 (%) | 26 ± 1.3 | 20.3 ± 1 |
| Chlorides soluble in water according to EN 480-10 (%) | <0.1 | ≤ 0.1 |
| Alkali content ($Na_2O$ equivalent) according to EN 480-12 (%) | <2.5 | ≤ 1.0 |

RESULTS AND DISCUSSION

The variation in evolution of the initial reaction for four cements is shown by the growth in G' with time in Fig.1. There is a significant difference between the maximum value of G' reached for the four cements.

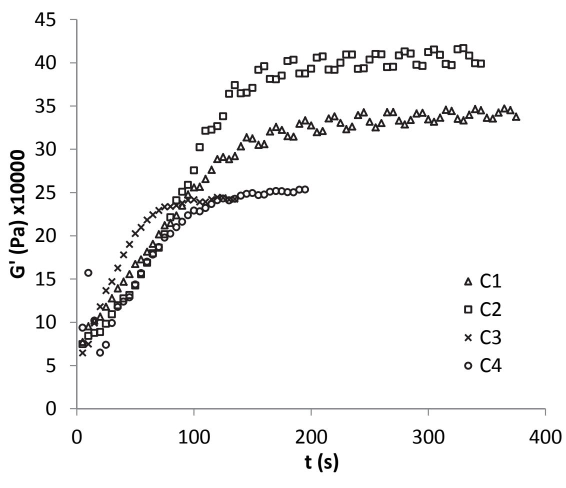


Figure 1. Effect of different cements on evolution of G' with time

The effect of SP1 for 2 concentrations namely 0.2% and 0.5% is shown in Fig 2 and Fig.3 respectively.

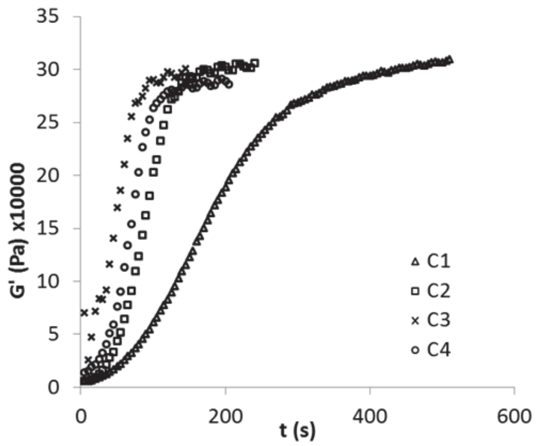


Figure 2. Effect of SP1 (0.2%) with different cements on G' with time

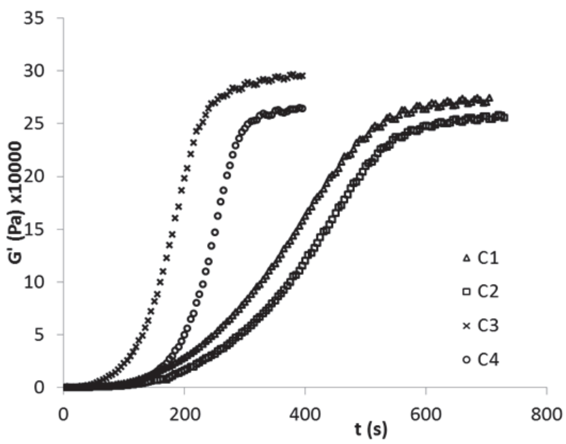


Figure 3. Effect of SP1 (0.5%) with different cements on G' with time

As can be expected the addition of SP with increasing concentration has a retarding effect on the hydration of cements. The effect however varies with cement type.

The effect for the four cements with SP2 for concentrations of 0.2 and 0.5% SP2 is shown in Fig.3 and Fig.4.

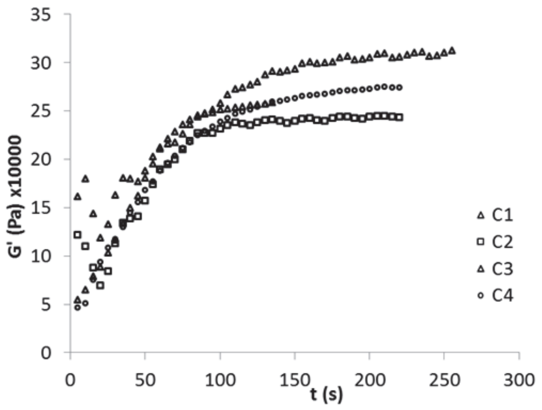


Figure 4. Effect of SP2 (0.2%) with different cements on of G’ with time

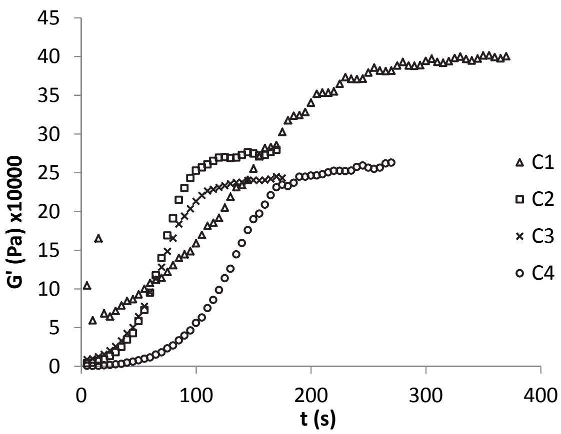


Figure 5. Effect of SP2 (0.5%) with different cements on G’ with time

A similar trend can be observed for SP2 however when comparing the two superplasticisers SP2 seems to be more effective in delaying the hydration process.

To show the effect of cyclone dust (CD), one concentration SP1 and SP2 namely 0.5% is shown in Fig. 6 and Fig.7 respectively. When compared with Fig. 3 and Fig. 5 it can be clearly seen how significantly the hydration process is slowed down by the addition of cyclone dust.

The effect of cyclone dust on SP2 is much more significant than on SP1.

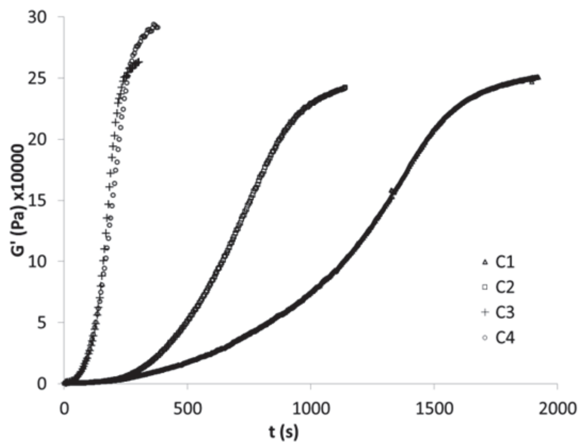


Figure 6. Effect of SP1 (0.5%) and CD with different cements on G’ with time

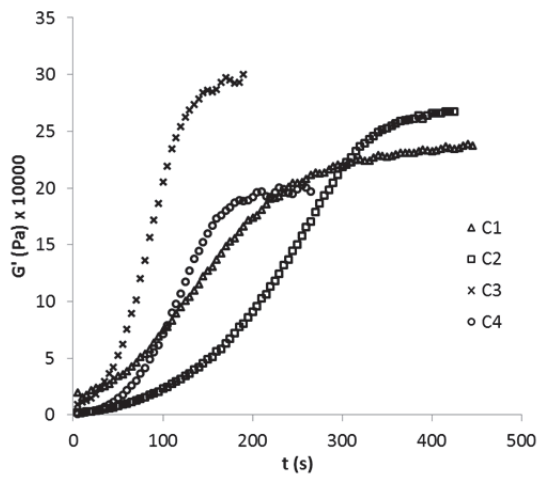


Figure 7. Effect of SP2 (0.5%) and CD with different cements on G’ with time

CONCLUSIONS

The main evolution of the initial reaction occurs within the first minutes after the end of mixing and the rate of hydration varied considerably for the different cements and also for the two superplasticisers used. It is shown for all four cements that the storage modulus increases more than two 2 orders of magnitude and in the acceleratory period G′(t) steadily increases. The addition of superplasticiser causes delay in the microstructural development followed by rapid accelerative process of structure formation. The effect is more significant for higher superplasticiser content. This shows very clearly in the evolution of storage modulus in time for all formulations. SP2 is more efficient in delaying the hydration process. The effect of the addition of the cyclone dust is that it slows down the rate of microstructural development for all the cements.

From the chemical and physical characteristics given for the different cements it can be seen that there is not much difference between them. It is not clear at this stage what causes the variation in initial hydration reaction. The similar superplasticers also have different effect on the hydration reaction.

ACKNOWLEDGMENTS

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