Performance standard: Are we testing the right performance?

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1. INTRODUCTION

Portland cement is made from common materials found almost everywhere, but they contain impurities that vary from one source to the next. The thermal process that transforms these natural materials into clinker is quite straightforward from a theoretical point of view for anyone who can read phase diagrams. But the process's end product, namely Portland cement clinker, is not simple at all. In fact, it is a complex mixture of 4 main minerals (C_3S, C_2S, C_3A, and C_4AF) and secondary minerals (free lime, periclase, uncombined silica, alkali sulfates, calcium sulfates, etc.).

C_3S and C_2S crystals can be well developed or small; the interstitial phase (C_3A and C_4AF) may be relatively crystallized or more or less amorphous or partially crystallized and partially amorphous . Belite nests and free-lime clusters can also be found. The nature of the atmosphere in the clinkering zone can pass from slightly oxidizing to slightly reducing and change the morphology of the clinker.

These differences and many others make it quite impossible to produce identical clinkers in two different cement plants. Of course, once the clinker has been produced, cement manufacturers can manipulate the calcium sulfate content and form and the fineness to control the final properties of their cements, but only to a certain extent.

Consequently, producing a Portland cement with controlled and predictable properties means homogenizing the clinker and the Portland cement, and checking some of its properties.

Quite early in the development of the cement industry, it became imperative to develop some acceptance tests to ensure a certain level of technical performance so that Portland cement could be used safely and securely.

With the development of blended cements that contain a certain fraction of various more or less cementitious materials (such as limestone filler, fly ash, slag, natural pozzolans, artificial pozzolans, silica fume, metakaolin and rice husk ash), these blended cements should show greater variation in technical characteristics than "pure" Portland cement. The reason is that these cementitious materials have chemical composition and morphological feature that vary far more than that of Portland cement clinker.

Moreover, in striving to reduce their energy costs, cement producers are increasingly turning to the so-called alternative fuels (used tires, animal flours, used paints and varnishes, PCBs, domestic wastes, recycled plastics, and so on). The variability of these alternative fuels also impacts clinker variability.

Finally, presently, many cement producers use calcium sulfates of different sources to control the setting of their cement, which affects the rheological and mechanical properties of the cement.

More than ever, it is absolutely necessary to be sure that current acceptance standards result in the production of a binder with predictable mechanical and rheological properties. This can be done with a performance standard, but what performances are to be tested? Are today's acceptance standards still valid? Should some be eliminated, others modified, and still others added?

2. WHICH PERFORMANCE STANDARDS?

Generally speaking, I believe that the standards developed over the years in North America to test “pure” Portland cement have well served the industry until recently. Radical changes are not needed, except perhaps in assessing the rheological behavior to resolve field problems with some cements when making concretes ranging from 0.35 to 0.40 in w/c.

If, until recently, it was safe to test cement pastes with a w/c of 0.48 to 0.50 because the w/c of most concretes was over 0.60. This no longer holds true. Indeed, high-performance concretes with w/c ranging from 0.35 to 0.45 are increasingly being used. While some cements evidence no workability problems during the first 90 min after the batching of such concretes, other cements meeting the same acceptance standards yield unacceptable slump losses.

Hydration conditions are considerably modified when cement particles are brought closer to each other by decreasing the w/c (Figure 1). In this situation, hydration is governed by a diffusion process rather than a dissolution-precipitation process. When the cement particles are in such close contact with one another, it is not necessary for ettringite crystals or C-S-H to grow very rapidly in creating the initial mechanical bonds. In fact, it can even be negative from a rheological standpoint. Less “glue” is needed and it has to be developed over shorter distances and has fewer spaces to fill.

Nevertheless, as stated before, current acceptance standards do not require drastic changes in response. We simply need to change some of them slightly and to modify the process for optimizing cement characteristics.

3. PRIORITIZING RESISTANCE OR RHEOLOGY

Until now, generally speaking, the approach has been to optimize the phase composition, “gypsum” content and form, and fineness to achieve higher cube strength. Too many cement producers still believe that concrete compressive strength depends exclusively on the cube strength of their cement. Although it is an important factor the influence of the w/c is as important. The short- and long-term resistance of a concrete depends on the w/c, as Féret , Abrams and Powers[1, 2,3] discovered it, not exclusively on the cube strength of the cement.

Table 1 shows that it was possible to manufacture a concrete reaching 57.9 MPa at 18 h, 63.4 MPa at 20 h, and 65.3 MPa at 22 h using a cement with a Blaine fineness of 340 m^2/kg, a C_3S content of 52%, and a C_3A content of 0.5% (Table 2). The secret of this ultra-resistant concrete is its very low w/c of 0.20.

The time has come for cement producers to stop optimizing the characteristics of their cements to achieve higher cube strengths, because the only result is often to complicate the task of those trying to make more durable concretes out of it.

We now need to focus on optimizing cement composition and characteristics in terms of rheological performance: this is the construction industry’s most urgent need. Repeated rheological problems in the field can cost millions of dollars. Moreover, durability problems requiring early repair, rehabilitation, or premature destruction of structures can result from the cement characteristics not being optimized according to the right criteria. Concrete users do not need cements with high cube strengths; they need cements that make it easy to control rheology. This is the challenge facing the cement industry at the beginning of this century.

4. PRIORITIZING THE RHEOLOGICAL PERFORMANCE OF A CEMENT

4.1 Current situation

At things stand, controlling cement rheology is the weak link in acceptation standards. The flow of a standard paste with a w/c of 0.48 or 0.50 is measured about 10 min after the first contact between the water and cement and then at the initial setting time 2 to 3 h later. Nothing is checked in between, as shown in Figure 2. The concrete is transported and placed during this time frame, which is a crucial part in the life of concrete for those who are concerned about the durability of concrete structures and the economics of placing concrete.

4.2 The ideal cement

The ideal cement from the contractor's standpoint has the rheological characteristics represented in Figure 3. While it is impossible to make this ideal cement, there is still room for improvement in the current situation presented in Figure 2.

4.3 Continuing to test cements at w/c ranging from 0.48 to 0.50

In my opinion, the time has come to change the w/c at which cement pastes are tested. A w/c of 0.48 or 0.50 is too high for testing the rheology of a cement paste: the cement particles are too far apart and the water essentially controls the rheology. The large distance between the cement particles can hide strong interactions when they are closer together.

Powers [3] taught us that a minimum w/c of 0.42 is needed for a cement to reach full hydration, at least theoretically in the absence of curing and 0.36 under water curing. Above these values, the paste contains water that will never participate directly in hydration or be part of the gel water that adheres to cement particles. Therefore, it could be logical to test cement paste in the 0.35 to 0.40 range for those who like round numbers.

Of course, this value is so low that a water reducer or a superplasticizer must be used to disperse cement particles in order to counteract the flocculation of cement particles [4]. Introducing such dispersants in the paste prevents flocculation of cement particles (Figure 4), so that the water trapped within the flocks is liberated, making the cement paste more fluid.

Performance standards allow cement producers complete latitude in selecting the most efficient dispersant to improve the rheology of their cement pastes as long as customers are informed of the brand and dosage of the dispersant used.

It is my opinion and that of those who are concerned about the future of the cement and concrete industries from a sustainable-development viewpoint that all cements should be tested in the w/c range of 0.35 to 0.40. The rheological interaction of the cement particles at this level can be seen, because water alone no longer controls paste rheology.

Those who are apprehensive making flow tests with a dispersant will nonetheless be forced to do so because, in the near future, all commercial cements will contain a dispersant introduced during final grinding. Ignoring the beneficial effect of water reducers significantly decreases the sustainability of today's commercial cements.

Moreover, decreasing the w/c of standard cement pastes will increase the cube strength, which will please the inveterate proponents of cube strength.

4.4 Monitoring rheology until initial setting

The two most critical periods in the life of a concrete are the first 90 min following the start of mixing and initial curing. Consequently, paste rheology should be given all necessary attention during this critical period. The more the rheology of the paste resembles that given in Figure 3, the better the cement will be. Therefore, the focus should be on optimizing rheologicap properties rather than on mechanical strength.

- Then, it will make easier to place concrete in the field, since it will not be necessary to add a water reducer, superplasticizer, or, even worse, water to restore the workability needed to place the concrete.
- Then, it will make it easier to build durable structures, since the concrete be properly cured after placement in the forms.
- Then, less concrete will be wasted.
- Then, sustainable development will no longer be an empty shell in the concrete industry at that time.
- Then, the economical performance of cement and concrete companies will be significantly improved because concrete structure's worst enemy is not steel, wood, bricks, glass, or aluminum, but rather bad concrete.
- A structure built with bad concrete will have to be repaired, rehabilitated, or demolished before completing its projected life cycle and the repair or demolition of bad concrete results in large manpower costs and a few material costs. Any money spent on repair or demolition is no longer available for building new infrastructure, where the amount of cement and concrete are 10 to 100 times higher than when repairing.

4.5 Monitoring of slump loss

As a consequence of the research work done on the rheology of low w/c concrete under the Industrial Chair on Concrete at the University of Sherbrooke, the 3 cements producers in Quebec daily monitor the slump loss of a reference concrete (Class C2 under Canadian standard CSA A 23.1). It is essentially an air-entrained concrete with a w/c of 0.43 to 0.45 that contains a water reducer. Since this monitoring was initiated, no catastrophic slump losses have been observed in the field from a practical point of view. Generally speaking, a significant improvement in the rheology of the delivered concrete has been noted, which results in a significant increase in the durability of concrete structures in Quebec's harsh environment.

5. CONCLUSION

Current acceptance standards have served the industry well for many years. Recent technological progress in the use of superplasticizers to disperse cement particles has made a few acceptance tests somewhat outdated, so that they are not as safe as they once were. In order to take the next step, it will be good to decrease the w/c at which cement pastes are tested to the 0.35 to 0.40 range, instead of the current 0.48 to 0.50. This decrease necessitates the selection of a water reducer or a superplasticizer to meet the currently recommended initial flow. This low w/c emphasizes the rheological interaction of the cement particles in low w/c concretes.

Cement composition, fineness, and calcium sulfate content and form should be optimized in the future to improve cement rheology, rather than to increase cube strength. It could be requested, for example, that the standard paste does not lose more 30% of its initial flow during the first 90 min after the first contact between the cement and water as shown in Figure 5. Afterwards, initial and final setting times and cube strength could be determined as is now the case.

In order to improve the rheological behavior of concrete delivered in the field, the slump loss of a reference concrete should be monitored during the first 90 min after the end of mixing, as is currently practised in Quebec's three cement plants and perhaps elsewhere.

This is not a great revolution, but rather a small step forward that should result in concrete structures of higher quality and, consequently, of greater durability. I am pretty sure that the future competitiveness of the cement and concrete industries will be positively influenced by such a small change.

6. REFERENCES

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[2] D.A. Abrams, Design of concrete mixtures, Structural Research Lab. Lewis Inst. Bull, Chicago, 1 (1918).

[3] T.C. Powers, Structure and physical properties of hardened Portland cement paste, Journal of the American Ceramic Society, 4 (1) (1958) 1-6.

[4] P.C. Kreijger, Plasticizers and dispersing admixtures, Admixture Concrete International, The Construction Press, London, UK, 1-16

Table 1. Compressive strength of 0.20 reactive powder concrete

f'c*	Individual values			Average
18 h	56.9	59.7	56.9	57.9
20 h	58.3	59.5	63.4	63.4
22 h	66.3	63.9	65.7	65.3

* curing at 35°C

Table 2. Characteristics of the cement used to make the 0.20 concrete

	SiO_2	CaO	Al_2O_3	Fe_2O_3	MgO	Na_2O	K_2O	Na_2O equiv.	SO_3	L.O.I.
%	23.1	62.9	3.2	4.7	1.8	0.12	0.40	0.38	2.4	0.63

	C_3S	C_2S	C_3A	C_4AF	Blaine fineness
%	52	27	0.5	14.3	340 m^2/kg

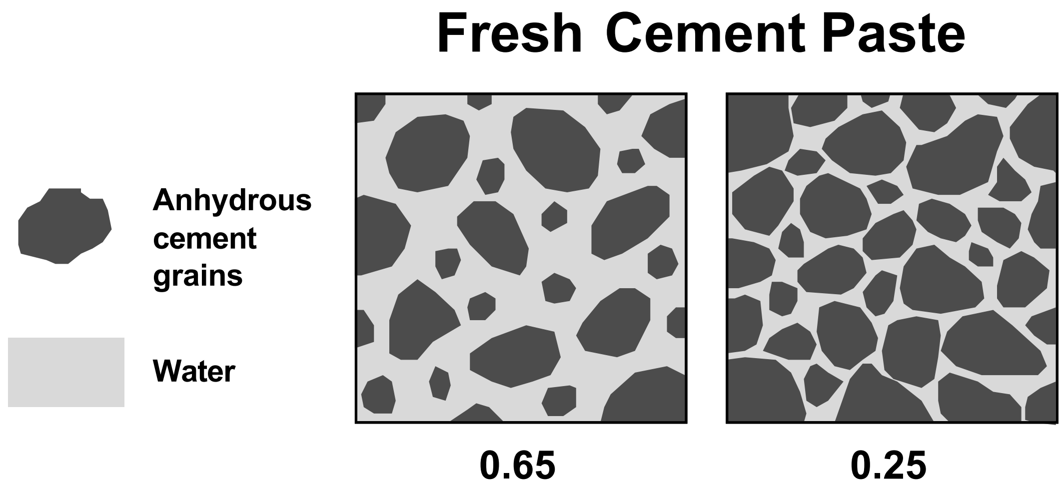

Figure 1. Influence of the water/cement ratio on the distance between cement particles in a fresh paste

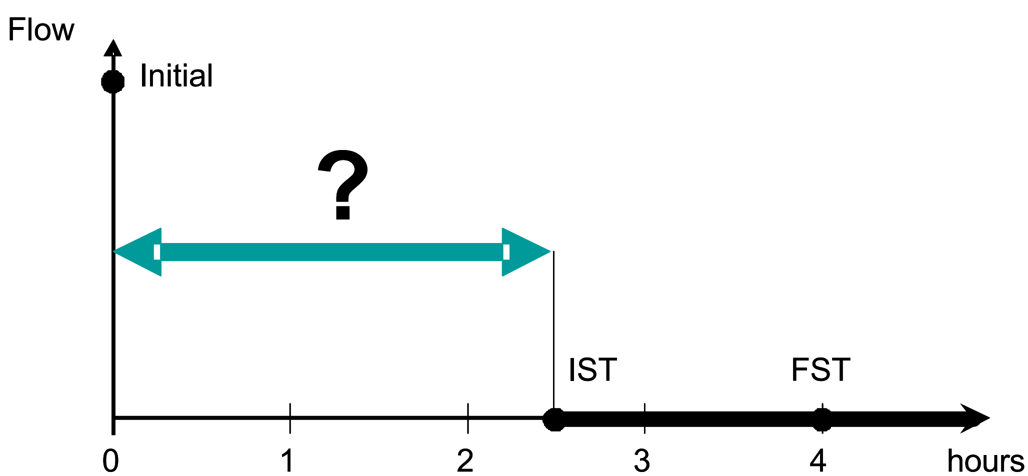

Figure 2. Testing the rheology of present Portland cement paste
(IST = Initial setting time, FST = Final setting time)

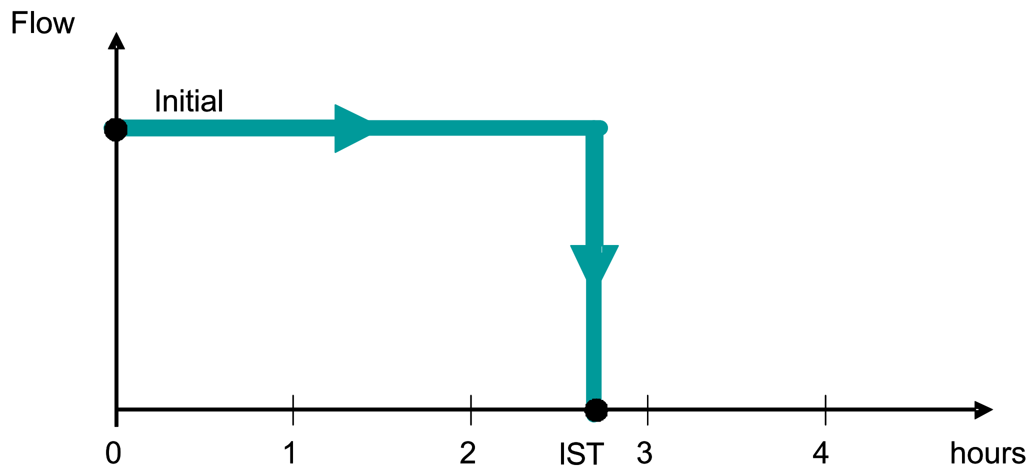

Figure 3. The ideal Portland cement paste from a rheological point of view
(IST = Initial setting time)

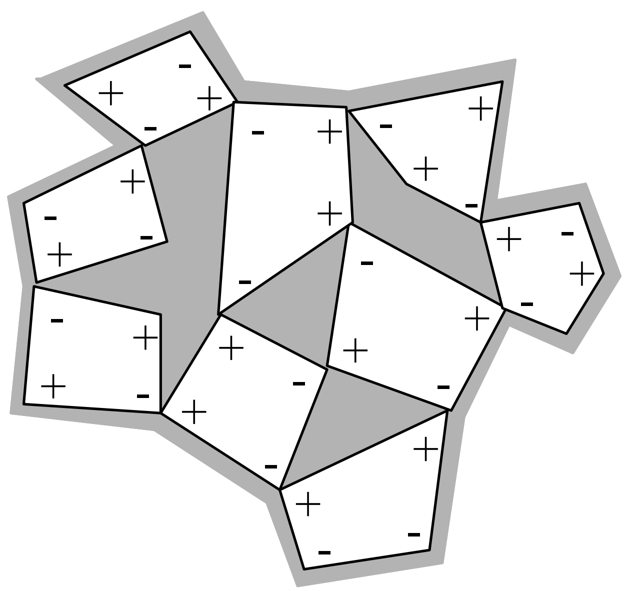

Figure 4. Flocculation of cement particles

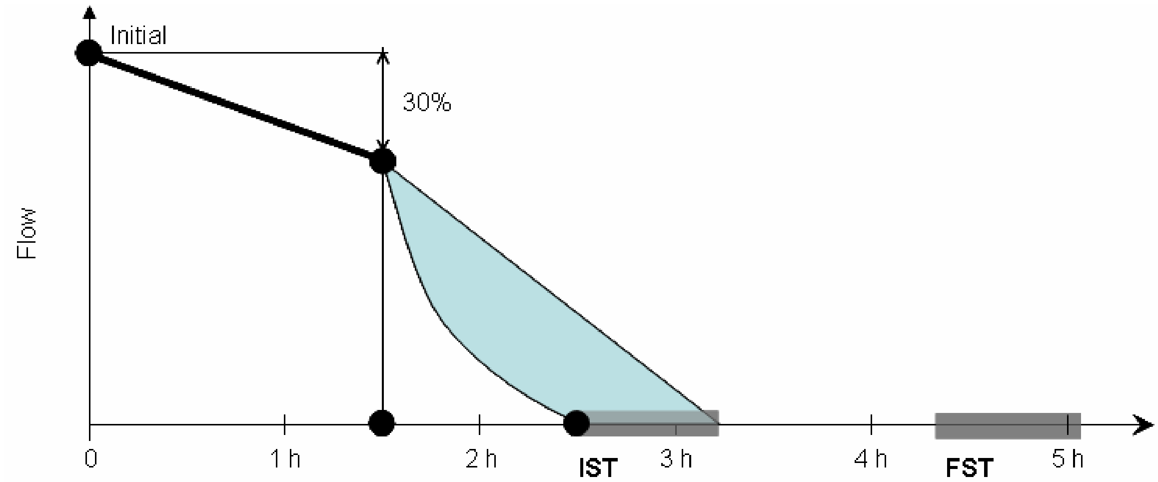

Figure 5. Flow loss during the first hour and half following the first contact between cement and water in a paste having a W/C of 0.40 to 0.42

(IST = Initial setting time, FST = Final setting time)