Rheological Approach for Recycling Returned Concrete

Fabio Curto[1], Giorgio Ferrari[1], Stefano Carrà[1]

[1]Mapei S.p.A., R&D Lab, Milan, Italy.

ABSTRACT

According to a recent survey, 10 billion m^3 of concrete is produced every year around the world. A non-negligible portion of produced concrete is not completely used and consumed in job-sites: it is sent to concrete production in mixer truck and it is called returned concrete.

The main reason for concrete to be returned to the plant is that contractors prefer buying a bigger quantity of concrete compared to the estimated amount required, to avoid the risk of interrupting casting due to shortage of material. The rate of returned concrete is about of 0.5% of the amount produced at the plant. Estimates say that more than 50 million m^3 of concrete is produced every year all around the world. The correct and efficient recovery of the 250,000 m^3 of returned concrete is therefore a problem of great interest, both from an environmental and economic point of view.

This study will present an additive that acts on the viscosity of the concrete by making this returned concrete easier to recycle. By increasing the viscosity of the cement it is possible to facilitate mixer truck cleaning operations. Rheological experiments on cement paste and proper additive allowed us to optimize the formulation of the additive. In this way we could identify the correct amount of admixture and maximize the viscosity increase effect. Stress controlled rheometer is not able to characterize a concrete system with its aggregates, for this reason the cement paste has been studied as a simplified system. With different measurement protocols by a continuous procedure or with an oscillatory one, we were able to define the window-time at which it is necessary to use the additive to optimize the release of the mixer truck. In the second part of this work we will show the results of the effect on the final behaviour of the additive in relation to the different cement classes and job site temperatures.

INTRODUCTION

A possible solution to the problem of returned concrete, has been recently devised by the development of a patented additive. It is capable of transforming returned concrete into a granular material, that can be used as aggregate to partially substitute natural aggregates in the production of new concrete [1], thereby allowing to obtain practical, economic and environmental advantages and helping the optimization of the mixer truck cleaning process.

Returned concrete is treated directly in the mixer with two additives, one based on a superabsorbent polymer (SAP) and a second based on a set accelerator (Set Acc). The dosage of both of these additives depends on the rheology and water to cement ratio of the concrete.

The addictive acts in a series of stages:

1. SAP swells right after it is added and dissolves in concrete during the rotation of the mixer truck;
2. SAP absorbs most of the free water and concrete gets transformed in a granular material;
3. grains are composed by a structure, the core of which is formed by a larger of composite made by hydrating cement paste;
4. set accelerator is then added to consolidate the material;
5. granular material is finally removed after 24 hours, and it can be reused to produce new concrete.

MATERIALS AND METHOD

Materials

This work was carried out using three types of Portland cement, and one type of SAP: an anionic polyacrylamide with a molecular weight of 10^6 (Uma).

The cement granulometric distribution, is shown in Table 1. The cement mineralogical characterizations obtained by XRF (X-ray Fluorescence) are reported in the Tables 2a, 2b, 2c.

Table 1. granulometry of cements

	Mean	d_{10}	d_{50}	d_{90}	*%*
A	18.8	2.4	13.67	39.51	µm
B	21	2.73	15.43	47.89	µm
C	20.11	2.69	14.48	46.7	µm

Table 2a.

CEM I 52,5 R as A	
SiO_2 %	21.5
Al_2O_3%	4.7
Fe_2O_3%	3.2
CaO%	64.2
MgO%	1.3
K_2O %	0.8
SO_3 %	3.2

Table 2b.

CEM II A-LL 42.5 R as B	
SiO_2 %	20.58
Al_2O_3%	4.56
Fe_2O_3%	2.45
CaO%	65.51
MgO%	1.68
K_2O %	0.74
SO_3 %	2.54

Table 2c.

CEM II A-LL 42.5 R as C	
SiO_2 %	21.05
Al_2O_3%	5.51
Fe_2O_3%	2.45
CaO%	63.13
MgO%	1.16
K_2O %	1.16
SO_3 %	3.4

Sample preparation

To better understand the mechanism of action of the additive, rheology experiments were performed on cements pastes. Cementitious suspensions were mixed using 0,8 water cement ratio. Water was mixed with cement using a laboratory mixer. A rotational speed of 7000 rpm was applied for 5 minutes and then, after SAP addition, the specimens were remixed for 20 seconds. The three cements were all tested at w/c ratio of 0.8 at a 0.17% addition rate of SAP.

Experimental setup

Rheological characterization was performed with a stress controlled rheometer mod. ARG2, by TA Instruments, using parallel hatched 40 mm diameter plate geometry to prevent the slip of the sample during the test.

The sample was placed between the geometry and the Peltier plate having used a

1000 μm gap, immediately after mixing, to evaluate the samples' rheological properties. Two measurement protocols were employed: continuous and oscillatory. By continuous flow test the viscosity profile of the cement pastes with the three cements was measured. Mortar samples are a concentrated suspensions of solid particles grains in a continuous high viscous system as water thickened by SAP. Polymer is able to retain a large amount of water in comparison with its initial weight, as the water molecules diffuse into the hollow sphere inside the polymer network, hydrating the polymer chains. The flow curve was measured from 0 to 100 s^{-1} and then back from 100 to 0 s^{-1}. This test allows to measure viscosity, the hysteresis characteristics of the samples and the yield stress, parameters that uniquely identify the rheological behaviour of the sample.

Oscillatory measurements allow to study the structural rearrangement of the material. These were performed at constant stress and frequency (1 Hz), as a time sweep, at a low shear stress, in the range of materials' linear viscoelasticity domain (LVR) to reflect the time evolution of the system structure.

Otherwise oscillatory measurements performed at increasing stress allow one to estimate the structuring of the material, the consistency of the material and the efficiency of SAP.

RHEOLOGICAL CHARACTERIZATION

<u>Tests on different mortars</u>

The first evaluation was on pastes with different cements, having added the SAP.

During measurements, in order to minimize the border effect by water evaporation, a trap was used on the upper plate, Fig. 1 shows the flow curves of the samples.

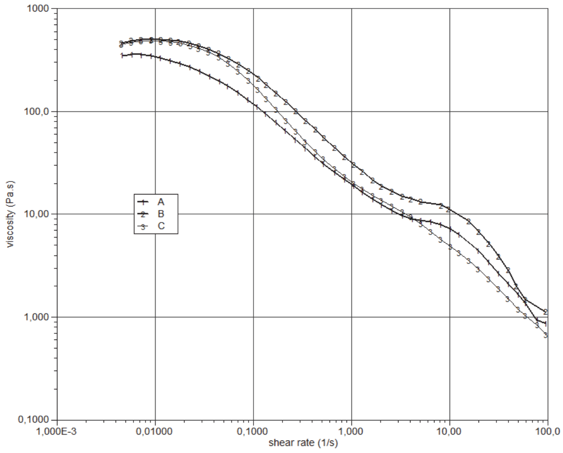

Figure 1. Flow curves at 23°C.

Yield values, at zero-shear, of the three samples are comparable; only at 10s^{-1} a shear thickening behaviour in mortar produced with A and B cement show up.

The second rheological test was performed to monitor viscosity evolution occurring as the polymer is swelling.

In order to evaluate this phenomenon viscosity at a constant rate (10 s^{-1}) for 10 minutes (Fig. 2) was measured.

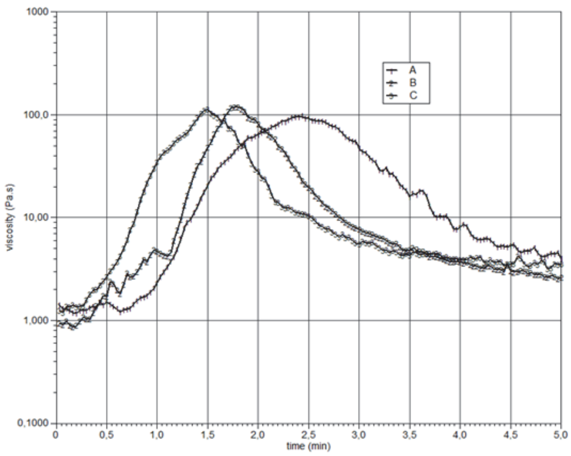

Figure 2. Viscosity evolution at 10 s^{-1}.

Throughout this test it is possible to measure a viscosity trend, at stationary condition, of the samples, at a shear comparable to the one applied in the concrete mixer-truck.

The maximum viscosity value occurs as the SAP is acting to increase the viscosity of the cement paste.

In Fig. 3 results of the stress sweep experiments are shown, the elastic modulus (G’) is plotted vs. shear stress (σ) [2]. This is a well-known procedure, to verify the cement paste consistency.

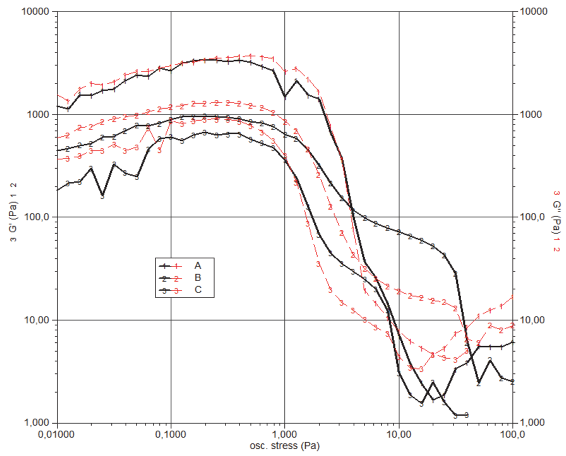

Figure 3. Stress sweep curves.

The graph shows a maximum value of G’ around 10^3 Pa, that could be an indication of a probable homogeneous structure, of cement grains [3, 4]; more over maximum G’ value it is comparable with G”.

During the oscillatory deformation the elastic and viscous modulus (G’ and G”) are controlled by the rates of spontaneous particles rearrangement. It must be underlined that in particular curve nr. 2 (of cement B) shows at high stress values (around 10 Pa) an increase of the G’- G’’. That high stress value has probable structure reorganization effect.

Fig. 4 shows time sweep characterization curves.

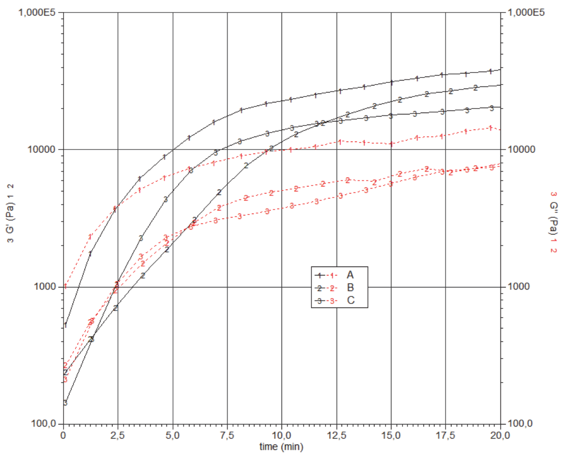

Figure 4. Time sweep curves.

This test performed at constant stress, in the Linear Viscoelasticity Region, to give an indication on the variation of the elastic and the viscous modulus over time. It reflects “gel-sol” transition as SAP is swelling [5]. The crossover of the different pastes shows the admixture effect at quasi-stationary condition with different cements.

The results are summarized in the table below.

Table 3. 0.17% SAP and w/c = 0.8.

	$\eta_{10\ s^{-1}}$ [Pa*s]	**flow curve** [Pa*s]		**stress sweep**		**time sweep**	
		η at 4 s^{-1}		Max [Pa]		cross over t_{gel} (min)	G’ after 15 min [Pa]
	t_{max} (min)	forth	back	G'	G"		
A	2,4	9	16	3320	3670	2,5	31200
B	1,7	15	27	970	1310	6	22700
C	1,5	10	18	890	650	2,5	17800

<u>Temperature effect</u>

In order to evaluate temperature effect over SAP action, a stress sweep, was performed. It was investigated only the cement paste obtained the cement 42,5 II class (see Fig.5).

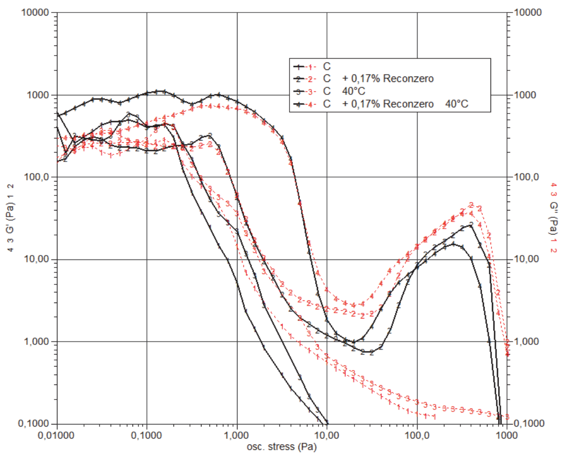

Figure 5. Stress sweep curves at 23° vs. 40°C.

The graph shows a not-Newtonian behaviour with the temperature: increasing the temperature G' increases.

<u>Tests with different SAP's particles size</u>

The same set of tests was performed on a cement paste, prepared only using cement B and mixed with SAP at different particles size:

① > 500 μm
② 250 – 500 μm
③ < 250 μm

These rheological measurements allow to conclude that the SAP performances are influenced by their own particle size distribution. In fact tests give the following results (Table 4).

Table 4. G' and G" in Pa.

	Max G'	***Max G"***	***G' after 15 min***
① > 500 μm	520	730	15000
② 250 – 500 μm	830	1100	22500
③ < 250 μm	87000	11000	65800

Slowing small SAP particles with a diameter less than 250 μm display better structure formation efficiency.

RESULTS AND DISCUSSION

Rheological characterization represents a fine and powerful tool to describe physical-chemical interactions, between cements and admixtures.

The measurements allowed to demonstrate that SAP in cement acts as follows: polymer swelling causes an increase of the viscosity, which together with the accelerator, determines the new aggregates formation.

The accelerator has to be added as the SAP increases the viscosity, for this purpose Rheology measurements can further more simulate the shear stress of the concrete mixer truck. This information could be achieved with the viscosity measurement at 10 s^{-1} of shear.

Flow curves demonstrated that the different cement could have different effects on the final performance of the rheological admixture [6]. Also mixing temperature is a parameter that might significantly affect SAP performance. Time sweep test, in fact, through the different G' demonstrated structure evolution with the different cements. The stress sweep tests show probable homogeneous structures due to gel formation in the presence of the polymer (SAP). As we increase the temperature the consistency increases, possibly due to the structure of the polymer. Finally there is another very important effect, determined by the SAP different particle size: efficiency will be more evident, as they increase the viscosity and modulus as showed at Tab. 5.

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