Effect of Bentonite on the Rheological Behavior of Cement Grout in Presence of Superplasticizer

K. Benyounes, A. Benmounah

Abstract—Cement-based grouts has been used successfully to repair cracks in many concrete structures such as bridges, tunnels, buildings and to consolidate soils or rock foundations. In the present study the rheological characterization of cement grout with water/binder ratio (W/B) is fixed at 0.5. The effect of the replacement of cement by bentonite (2 to 10% wt) in presence of superplasticizer (0.5% wt) was investigated. Several rheological tests were carried out by using controlled-stress rheometer equipped with vane geometry in temperature of 20°C. To highlight the influence of bentonite and superplasticizer on the rheological behavior of grout cement, various flow tests in a range of shear rate from 0 to 200 s^{-1} were observed. Cement grout showed a non-Newtonian viscosity behavior at all concentrations of bentonite. Three parameter model Herschel-Bulkley was chosen for fitting of experimental data. Based on the values of correlation coefficients of the estimated parameters, The Herschel-Bulkley law model well described the rheological behavior of the grouts. Test results showed that the dosage of bentonite increases the viscosity and yield stress of the system and introduces more thixotropy. While the addition of both bentonite and superplasticizer with cement grout improve significantly the fluidity and reduced the yield stress due to the action of dispersion of SP.

***Keywords*—**Cement grout, bentonite, superplasticizer, viscosity, yield stress.

I. INTRODUCTION

BENTONITE powders are widely used in different branches of industry applications, such as in drilling fluids, dyes, pharmaceutical applications, paper, cement and ceramics, to change the rheology and control the stability of materials [1]. Bentonite is a natural clay material, composed mainly of montmorillonite, and secondary minerals such as quartz, calcite and micas feldspar, volcanic glass, organic matter, gypsum and pyrite are also present in bentonite [2].The structure of montmorillonites consists of two tetrahedral sheets (Si-O) separated by an octahedral sheet (Al-O-OH). However, sometimes, the tetravalent Si in the tetrahedral sheet is substituted by divalent Fe^{2+} or Mg^{2+} ions [3]. This substitution results in a deficit of positive charges, which are compensated by absorption of a layer of cations that are too large to be accommodated in the crystal. Bentonite is available commercially in the sodium and calcium forms. Sodium bentonite is readily absorbent and swells in the presence of water. Calcium bentonite does not expand in this way when water is added. Grouting technology is applied in civil engineering, and also in oil, gas and water wells to improve mechanical properties of rock formations by injecting slurries of high compressive strength, stability and permeability into open cavities, fissures and voids [4]. Cement-bentonite grouts are still the most commonly used grouts because they are easy and cheap to prepare [5]. Rheological studies of cement grout are essential for understanding flow properties and ensuring good flow performance. Increasingly, rheology can be used to tailor adequate profile of apparent viscosity that can take into account the various requirements, such as pumping pressure and distance. The measurement and control of rheological behavior of fresh mud grouts are very important on their injectability and on the quality of the grouting [6],[7]. Cement grouts are highly concentrated suspensions; their rheological behavior is generally very complex, it being dependent of several factors of different nature, including: physical factors, chemical and mineralogical, mixing conditions, measurement conditions, and presence of additives [8]. The rheology of cement-based grout is frequently investigated by means of viscometer measurement [9]. Many investigations on the rheological behavior of cement grouts have shown that these materials are viscoplastic fluids exhibiting a yield stress, which must be overcome by the shear stress so that the flow takes place [10],[11].

In this work an experimental study is conducted on the effect of the dosage of SP, water/binder ratio and the percentage of bentonite as partial replacements of cement on the rheological properties of cement grout.

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II. MATERIALS AND METHODS

A. Materials

The grouts investigated in this study were prepared using an ordinary Portland cement (CEM I). The water to binder ratio (W/B) was 0.5 and the dosage of superplasticizer was 0.5% by mass of cement.

Bentonite sample employed in this work was extracted from deposit in the Maghnia region, in west Algeria. A new generation of superplasticizer (SIKA VISCOCRETE TEMPO 12) on the basis of acrylic copolymer was used with a solid content of 30% and specific gravity of 1.11. The SP helps to the dispersal of cement particles that are exposed to aggregation due to colloidal interactions.

The used cement (CEM I) for the manufacture of cement slurry is composed of 95% of clinker and 5% of gypsum. The chemical and mineralogical compositions are shown in Tables I and II.

TABLE I
CHEMICAL COMPOSITION OF CEMENT

component	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	Na_2O	SO_3	CaO(free)	Cl^-	LOI	I
Content %	20.63	4.84	2.16	63.18	1.16	0.51	0.10	1.55	0.10	0.0092	7.23	5.04

TABLE II
MINERALOGICAL COMPOSITION

Phase	Mineral constituents of clinker	Content %
Clinker	C_3S	56
	C_2S	20
	C_3A	05
	C_4AF	13
	CaO	01
Setting regulator	Gypse	05

B. Preparation of Samples and Procedure Test

The pastes were mixed by hand for 2 min using 100 g of the powders (cement plus bentonite) and the appropriate quantity of water (predissolved superplasticizer) to give 0.5 water/binder ratio, and immediately transferred to the outer measuring cylinder and mounted on the rheometer. When the Navigator program started the impeller was automatically inserted and shear measurements started. An initial 2 min preshear at 100 s^{-1} was followed by the test. The shear rate during mixing is one of the most important variables affecting the rheological properties of fresh Portland cement pastes [12]. According to Yang [13], the pastes prepared with a high energy blender or by hand mixing sieved materials had a fine and creamy appearance. This suggests that a well mixed paste was obtained by these two methods, in which the size and quantity of clusters were reduced significantly.

III. RHEOLOGICAL MEASUREMENTS

The influence of bentonite dosage on the rheological properties of grouts can be studied in plots of the variation of shear rate as a function of shear stress applied to the grouts. Flow curves of the examined grouts containing superplasticizer are depicted in Fig. 1. Grouts with bentonite exhibit high apparent viscosities at low shear rates and significantly lower viscosities at greater shear rates. The effect of the increase in the concentration of bentonite on viscosity depends on the shear rate. For a given concentration of bentonite, the increase in the dosage of bentonite is more effective in increasing viscosity at low shear rate than that at high shear rate. The apparent viscosity is then decreased with an obvious improvement in flowability at high shear rate regimes. Fig. 2 shows a typical descending part of a conventional flow curve for cement paste in presence of bentonite (10%) and SP (0.5%).

It is well established that cement paste reasonably follows a yield stress fluid behavior, and therefore the flow curve in Fig. 2 shows the yield stress (the parameter of concern in this study) is determined by extrapolation of the shear stress–shear rate curve corresponding to a zero shear rate.

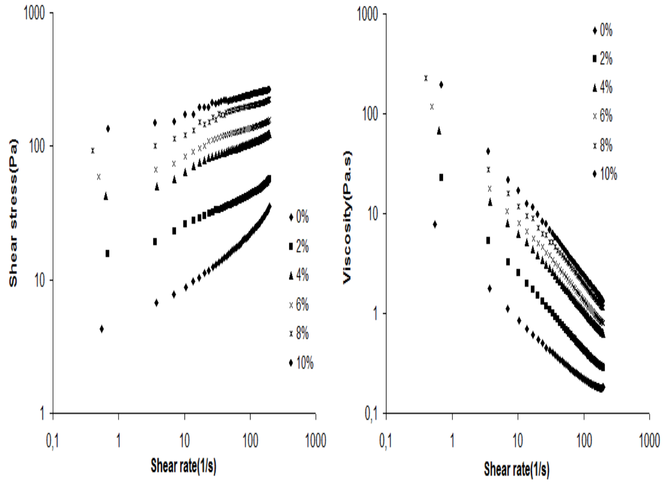

Fig. 1 Flow curves for blended cement pastes with different dosage of bentonite at w/b ratio of 0.5

The substitution of cement by the bentonite allows the shear thinning at high shear rates and increased viscosity at low shear rates. The apparent viscosity of all mixtures decreases with increasing shear rate. This is due to disentanglement network accompanied by a partial alignment of clay particles and cement coated polymeric chains of SP in the direction of flow. Under these conditions, the systems are characterized by a non-Newtonian shear thinning behavior. The shear stress–shear rate data is well represented by Herschel–Bulkley model (1). This model is given by:

$$\tau = \tau_0 + k.\dot{\gamma}^n \quad (1)$$

where τ_0 is the yield stress, k is the consistency, and n is the pseudoplastic index. The mixture is shear-thinning when n < 1 and shear-thickening when n > 1. The mixture behaves as Bingham material when n = 1. The flow curves for various mixtures made with different cement-bentonite-SP combinations were determined at a maximum shear rate of 200s-[1]. When the concentration of bentonite increases for constant superplasticizer (SP) content, it will it induce a drastic increase on yield stress and consistency values (fig.3, 4). As highlighted by test results, and as can be observed in Fig. 5, the flow index response can be affected by various mixture parameters, such as w/b, superplasticizer type, and chemical composition of cement. An increase in bentonite dosage in presence of superplasticizer (SP=0.5%), decreases the shear–thinning behavior of grouts (Fig. 5). The rheological behavior of these groups is very shear-thinning, this is already reported in the literature [9], [11], [14]. A correlation between viscosity and yield stress is achieved as shown in Fig. 6.

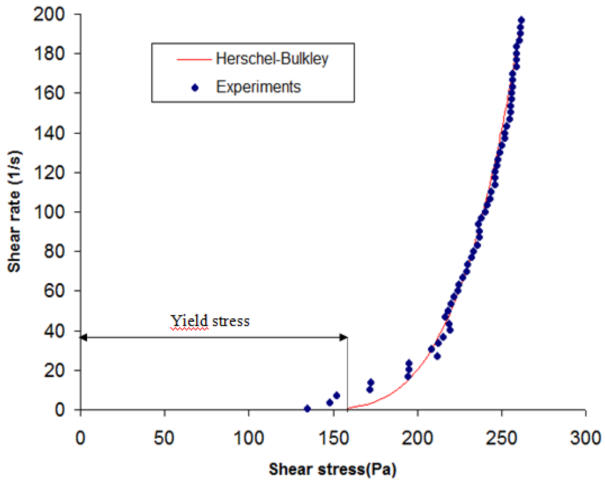

Fig. 2 Shear rate-shear stress flow curve (only down curve shown)

The trend shows a decrease in flow index with the increase in consistency. The experimental points in this empirical relation were derived from pastes with 0.5% SP and having bentonite at different amount (2-10%).

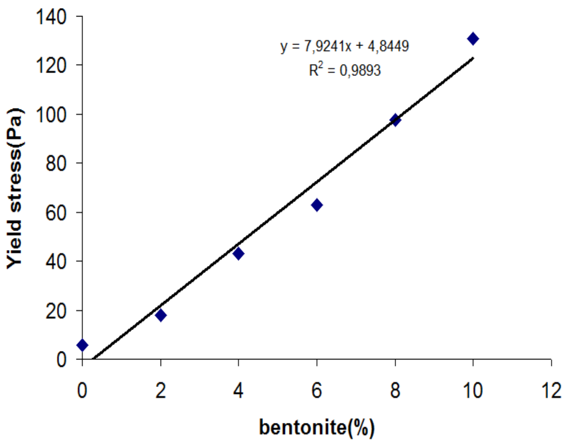

Fig.3 Influence of the bentonite dosage on yield stress, τ_0

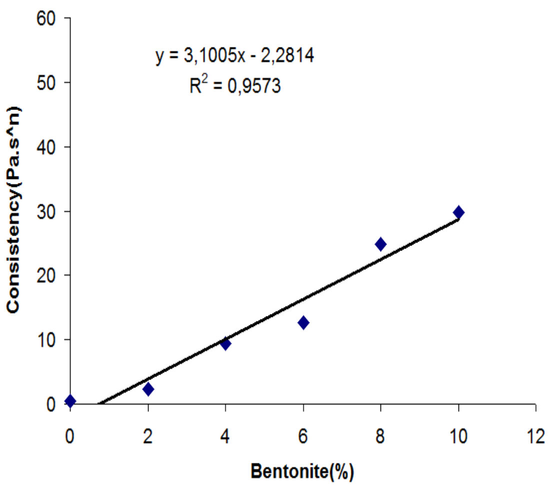

Fig. 4 Influence of the bentonite dosage on consistency index, *k*.

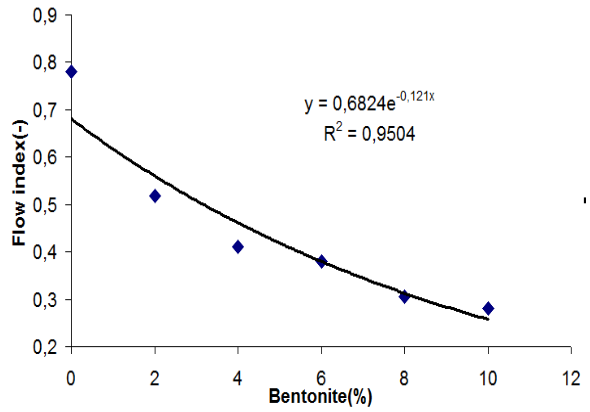

Fig. 5 Influence of the bentonite dosage on flow index, n

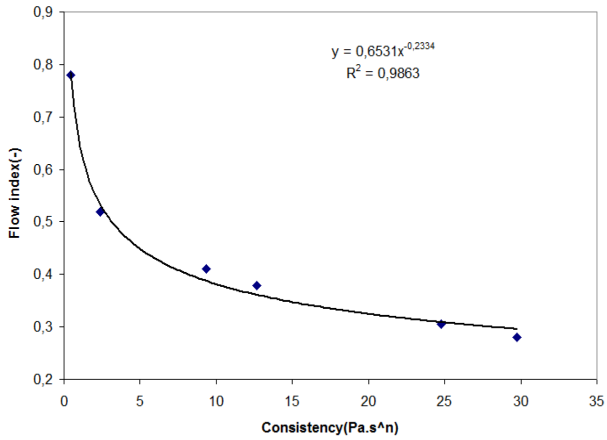

Fig. 6 Relation between flow index and consistency

IV. Conclusion

In this work we have carried out experiments, which have analyzed the effect produced by the dosage of the bentonite employed in this study on the rheological properties of cement grout. The results have allowed characterizing the rheological behavior of cement-bentonite based grout by the Herschel-Bulkley rheological model. The experimental results allow concluding that the cement grout used exhibit shear thinning non Newtonian flow behavior when the bentonite concentration increase. When the bentonite is present in the mixture for a constant superplasticizer (SP) content, it will cause a drastic increase on apparent viscosity, yield stress and consistency values. This characteristic is very interesting to use the bentonite as viscosity modifying agent, it is possible to obtain grouts that have satisfactory rheological properties, especially if bentonite is employed in combination with a superplasticizer.

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