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New linear relationship between yield stress and plastic viscosity of an environmental cement paste

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Résumé:

Le présent papier est une contribution à proposer une nouvelle relation entre la contrainte de cisaillement (τ_y) et la viscosité plastique (μ) d'une pâte de ciment environnemental. La cendre obtenue par calcinations des boues issue des stations d'épuration (STEP) sous une température égale à 550°C. Trois échantillons de ciment écologique ont été développés par substitution de différents taux de cendre (5%, 10% et 15%) obtenue dans le clinker. La caractérisation de l'ouvrabilité de différentes pâtes cimentaires est effectuée en utilisant le mini-cône.

Mots clés : Contrainte de cisaillement ; Viscosité ; Boues ; Substitution ; Pâte

Abstract:

The present paper is a contribution to offer a new relationship between yield stress (τ_y)and plastic viscosity (μ) of environmental cement pastes. The ash obtained from calcinations of sludge from wastewater treatment plants (WWTPs) under a temperature less than 550°C. Three samples of eco-cement have been developed by substitution of different amount of ash (5%, 10% and 15%) obtained into the clinker. The characterization of the workability of different cement paste is carried out using mini slump cone.

Keywords: Shear stress; Viscosity; Sludge; Sustainable; Pastes

1. Introduction

Excess sludge treatment and disposal currently represent a rising challenge for wastewater treatment plants due to economic, environmental and regulation factors. Algeria has set targets for 2025 in the field of spatial planning in which it integrates the concept of sustainable development (Yuansong W. 2003). This new vision is based on economic growth, social equity and protection of the environment (Baudez J.C. 2001). The National office of Cleansing (ONA) in Algeria manages 154 WWTPs (ONA, 2020). Table 1 present most key figures from ONA for the month of January 2020. Several ways exist for the elimination of this sludge, but the choice remains often related to the cost of the installation, the origin of the sludge, the added value of the products which results from this and the impacts of the solution retained on the environment.

Among the solution retained to treat the sludge, we can cite the production of biogas as a source of heat and electricity on the one hand, and agricultural valorization in the production of fertilizer and compost on the other hand. Other fields of valorization of sludge from WWTPs are explored during the last two decades. Most of the recent works explore the heat treatment to reduce the volume of the sludge and to stabilize the mineral phases (Cusido, J. A. and al. 2011; Chiou, I.J. and al., 2006; Kaosol, T., 2010 and Montero, M.A.; 2009).

Table 1. Key figures from ONA for the month of January 2020 (ONA, 2020).

Number of municipals managed by ONA	1147 Municipalities
Total length of networks managed by the ONA	55281 Km
Number of sanitation centers	268 centers
Volume of wastewater discharged	105 Million m^3
Number of interventions carried out	32832 interventions
Linear network of priests	621081 ml of pipes
Number of connections made	71 connections
Linear of renewed pipes	971 ml
Number of manholes performed	80 manholes
Volume of solid waste evacuated	30904 m^3
Number of lifting stations managed by the ONA	499 lifting and drainage station
Number of WWTPs in operation by ONA	154
Installed capacity of WWTPs	10.390.779 Million inhabitant equivalents
Monthly volume of purified water	21 Million m^3
Average daily flow of treated wastewater	**668.386 million** m^3/day

2. Material and Methods

2.1. Origin of ash sludge used

The samples of the studied sludge drying bed were taken from the WWTPs in the Wilaya of Sidi Bel Abbes (a Wilaya in the west of Algeria, 400 km from Algiers (Algeria)). The samples were stored at a temperature of - 4 °C in order to eliminate any risk of fermentation. The volatile solids (VS), meanwhile, are measured by the loss on dried sample ignition at 550°C for 2 hours according to the standard NF EN 12879.

2.2. Physical properties

Physical parameters of the sludge such as: the amount of dry volatile matters (DVM), the amount of humidity, the amount of dry matter (DM), the organic matter content (OM), the amount of mineral matter (MM), dry apparent density and the Methylene blue value (MBV), are measured in accordance with French standards as shown in Table 2.

Table 2. Standards used to characterize the physical properties of the WWTPs sludge.

Property	Test standard
Loss on ignition of dry mass	NF EN 12879
Particle density and water absorption	NF EN 1097-6
Dry matter	NF U44-171
Loss on ignition in waste, sludge and sediments	NF EN 15169
Methylene blue of soil by means of the stain test	NF P94-068

2.3. Composition of different ecological cement produced

The preparation of the green-cement (mixtures of clinker; gypsum and ashes resulting by calcinations of sludge of WWTP) was made in the laboratory of the cement factory of Zahana (Wilaya of Mascara, west Algiers). From the components, to prepare the cement, the duration of crushing (in regard to blain specific area) was fixed to three minutes on the bases of standard cement preparation. The compositions of studied green-cements are given in Table 3.

Table 3. Composition in mass of the different green-cement studied in this research.

Cement	Gypsum (%)	Clinker (%)	Ash (%)
EC_0	5	95	0
EC_5	5	90	5
EC_{10}	5	85	10
EC_{15}	5	85	15
EC_{20}	5	90	20

2.4. Workability of cement pastes

Yield stress and plastic viscosity are considered as two main parameters that define paste rheology. Mini slump test is the commonly used technique to evaluate yield stress and plastic viscosity of fluid suspensions like cement paste, in terms of slump spread diameter (Dharmarathne, S.B.K.D et al., 2016). The first figure (fig. 1) showed the mini slump cone shape. The mini slump cone geometries are giving in Table 4. The mini slump cone used, and a typical slump spread are shown in fig.2 (a) and (b) respectively.

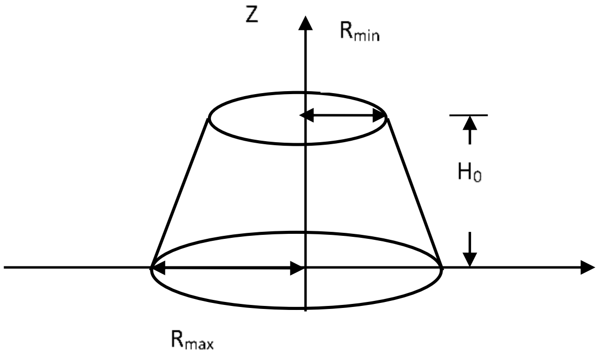

Fig.1. Mini slump cone shape.

Table 4. Mini slump cone geometries (NF EN 1961).

Rmin (m)	H_0 (m)	Rmax (m)
0.019	0.057	0.038

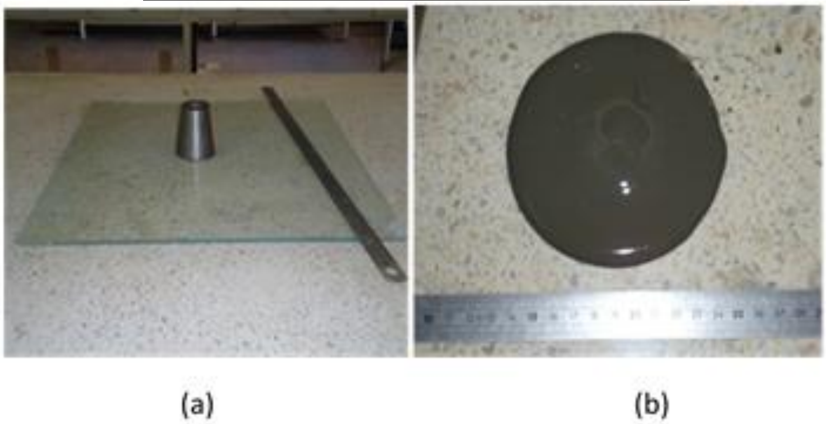

Fig.2. (a) Mini slump cone, (b) mini slump spread.

The yield shear stress can be calculated using the model developed by Russell as follows (Bouvet, A. et al. 2010):

$$\tau_y = \frac{225 * \rho * g * V^2}{128 * \pi * SD^5} \qquad (01)$$

Where ρ is density of the material, g ($m.s^{-1}$) is acceleration of gravity, V (m^3) is volume of mini cone and SD (m) is slump spread diameter.

An experimental relationship between the viscosity/yield shear stress and time to final spread is given as; (Tregger, N. et al., 2008):

$$\frac{\mu_p}{\tau_0} = 6{,}41.10^{-3} T_f - 1{,}94.10^{-3} \qquad (02)$$

Where T_f (s) is the time to final spread.

3. Results and Discussions

3.1. Physical properties

The physical characteristics of the studied sludge are shown in Table 5. From these results, it is to note the high-water content, the high OM (≈ DVM) levels and a relatively low value of methylene bleu value. Compared with the characteristics of other WWTPs sludge, these values are relatively comparable.

Table 5. Physical characteristics of the sludge from WWTPs.

Property	Value
Dry matter (%)	85,11
Dry volatile matter (% DVM)	39,87
Mineral matter (% DM)	60,13
Humidity (%)	14,88
Particle density	0,69
Methylene blue of à soil by means of the stain test	0,85

3.2. Physical properties

The Table 6 summaries different parameters carried out from test of all sample environmental cements developed.

Table 5. Different parameters defining the workability in this research.

Designation	PCR	PC5	PC10	PC15
Ash (%) = C	0	5	10	15
ρ	1,7	1,68	1,64	1,61
R (m)	0,104	0,09	0,089	0,085
τ_y (Pa)	13,42	27,34	28,22	34,87
μ (Pa.s)	5,12	10,44	10,78	13,32

PCR is the paste cement reference (0% Ash), C= Ash%.

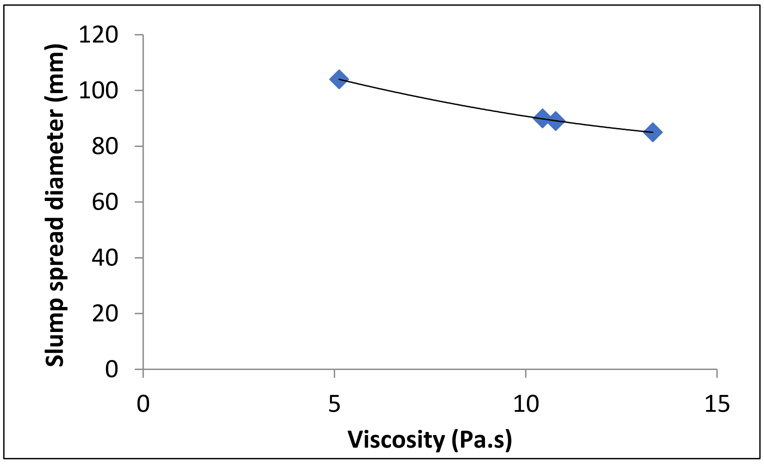

Fig.3. Correlation between slump spread diameter and viscosity

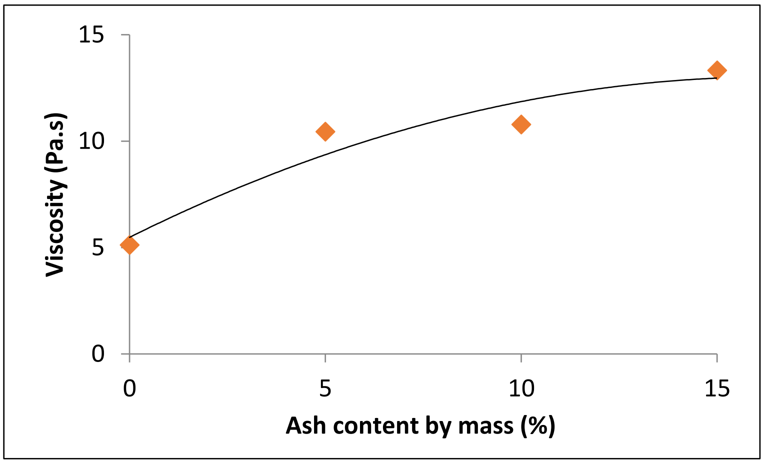

Fig.4. Correlation between viscosity and rate of ash content

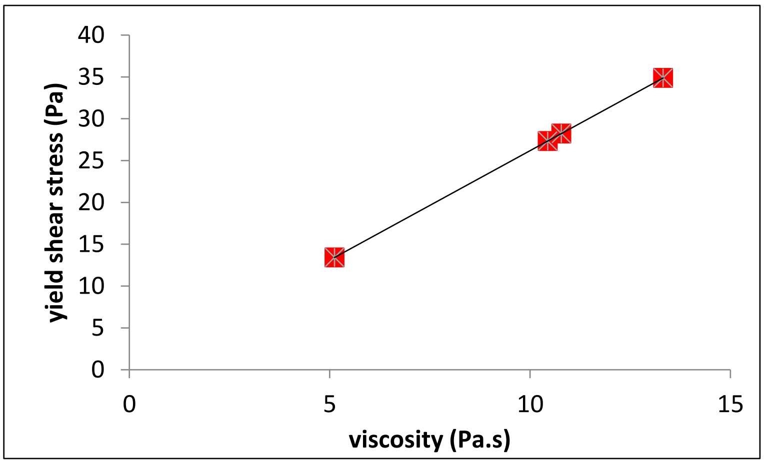

Fig.5. Correlation between yield shear stress and viscosity

Figures 3, 4 and 5 present correlation between different parameters carried out (slump spread diameter and viscosity, viscosity and rate of ash content and yield shear stress and viscosity). From different figures of correlations, we can give the new relationships between workability parameters cited above.

Table 7. The relationships characterizing the rheological phenomenon of the cement pastes studied.

$SD = 0{,}1189\mu^2 - 4{,}5123\mu + 123{,}99$	$R^2 = 0{,}997$
$\mu = -0{,}0278.C^2 + 0{,}9158.C + 5{,}479$	$R^2 = 0{,}9276$
$\tau_0 = 2{,}6158.\mu + 0{,}0272$	$R^2 = 1$

4. Conclusion

The study mainly focuses on mathematical relationship between different parameters characterizing environmental cements pastes in their fresh states. The relationships obtained given an easy new way to calculate yield shear stress using only the simple test of mini slump cone for the laboratory which they haven't Rheometer.

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