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Study of nopal mucilage and marine brown algae extract as viscosity-enhancing admixtures for cement based materials

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HIGHLIGHTS

- Two new bio-polymers are proposed as alternative viscosity-enhancing admixtures for cement-based materials.
- Nopal mucilage and marine brown algae extract dispersions showed a shear-thinning behavior.
- The Herschel–Bulkley yield-stress increased with increasing brown algae extract concentration in cement based materials.
- Stable, cohesive and homogeneous SCC mixtures can be produced using both new VEAs.

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ABSTRACT

Viscosity-enhancing admixtures (VEAs) are required in the production of self-consolidating concrete (SCC). This paper presents the rheological properties in rotational and oscillatory shear tests of cement pastes and mortars with a w/c ratio of 0.50, containing nopal mucilage and marine brown algae extract, which are proposed as two new VEAs. For comparison purposes, a commercial VEA based on welan gum was used. In addition, preliminary SCC mixtures were prepared using the proposed and the commercial VEA. The slump flow, J-ring, L-box, V-funnel and static segregation column were used to evaluate the SCC fresh state properties. The results indicated that the new VEAs produced a significant increase on the shear viscosity and the yield-stress of pastes, mortars and SCC, which increased with increasing concentration and depending on their molecular nature. This was more noticeable in the mixes containing brown algae extract, which may be related to chains' entanglement and gel-network formation. Cement pastes and mortars containing the proposed VEAs exhibited a solid-like behavior at short values of strain amplitude (<1%). The proposed VEAs produced some stable and homogeneous SCC mixtures in comparison with the commercial VEA based in welan gum.

1. Introduction

Concrete based on Portland cement is the most widely used construction material in the world, and its production follows a trend of growth. In 2011, the world production of Portland cement reached 2.8×10^9 tonnes and is expected to increase around 4×10^9 tonnes for the 2050 [1]. About 15% of the total concrete production contains chemical admixtures [2], which are chemicals added to concrete, mortar or grout at the time of mixing to modify their properties, either in fresh or hardened state [3].

Self-consolidating concrete (SCC) is a highly flowable and stable concrete that flows under its own weight, and can be compacted without any external consolidation [4,5]. SCC allows increased productivity levels as it shortens construction time and reduces construction costs. It also improves the working environment, the quality of concrete under difficult casting conditions, and the surface quality [6].

Modern production of SCC requires the use of chemical admixtures such as superplasticizers (SPs) and viscosity-enhancing admixtures (VEAs) used to achieve high flowability and high resistance to segregation of concrete, respectively [7]. SPs are linear

Abbreviations: ALG, marine brown algae extract; ALGD, marine brown algae extract dispersion; ATR, attenuated total reflection; BMS, ball-measuring system; C, Portland cement; CAgg, coarse aggregate; CM_0, control cement mortar; CP_0, control cement paste; CSH, calcium-silicate hydrate; FAgg, fine aggregate; FTIR, Fourier transform infrared spectroscopy; LVE, linear viscoelastic; M, cement mortar; MUC, nopal mucilage; MUCD, nopal mucilage dispersion; Na-alginate, sodium alginate; Na-AlginateD, sodium alginate dispersion; P, cement paste; PVC, poly (vinyl-chloride); RM, reference mortar; RP, reference paste; RSCC, reference self-consolidating concrete; SCC, self-consolidating concrete; SP, superplasticizer; VEA, viscosity-enhancing admixture; W, water.

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polymers containing sulfonic groups attached at regular intervals to the polymer backbone. Most formulations belong to one of the following groups: sulfonated melamine–formaldehyde condensates, sulfonated naphthalene-formaldehyde condensates, modified ligno sulfonates and polycarboxylate derivates [8].

While resistance to segregation can be achieved by using a large amount of fine materials, the preferred approach is to use VEAs [5]. These are water-soluble polymers that increase the viscosity and cohesion of cement-based materials [6,9]. The common viscosity-enhancing admixtures used in concrete production include microbial polysaccharides such as welan gum, cellusose derivates (methyl cellusose and cellulose ethers), alginates, acrylic-based polymers, polyethylene oxides and mineral materials such as colloidal silica and fine carbonate fillers, among others [5–10]. The main disadvantage of the commercial VEAs is their high cost, which increases the overall cost of the SCC and makes it non-competitive with respect to ordinary concrete.

The use of admixtures in the concrete industry is increasing, especially the use of bio-admixtures, which are functional molecules used to modify material properties. The global expenditure of bio-admixtures in the year 2000 was estimated at US \$ 2×10^9 [2]. It is evident that the cost of SCC will be reduced if admixtures are cheaper and more readily available. Some alternatives to the commercial VEAs are polysaccharides from nopal mucilage and marine brown algae.

Nopal mucilage, from the *Opuntia* gender, has been used as an additive to improve the durability of lime-based mortars [11] and to improve the Portland cement concrete [12]. It also inhibits aluminum and steel corrosion [13–15] and increases the plasticity of mortars and reduces their permeability [16]. A preliminary study using the mini cone test [12] has demonstrated the potential use of nopal mucilage as VEA for SCC. On the other hand, alginates from brown algae have been used as a bonding agent in composites, increasing compressive strength without any effect on flexural strength [17] and they have been suggested as potential VEA for concrete [6].

Therefore, in this research the rheological behavior of cement pastes and mortars containing nopal mucilage or brown algae extract was studied and compared to a commercial VEA. These viscosity-enhancing admixtures were also used in trial mixtures to demonstrate their suitability to produce stable SCC.

2. Materials and method

2.1. Materials

2.1.1. Cement aggregates and water

Ordinary Portland cement 30 R RS BRA with a Blaine fineness of 318.2 $m^2\,kg^{-1}$ was used in all the mixtures. Table 1 presents its chemical properties. Silica sand with specific gravity of 2.61, water absorption of 0.30% and fineness modulus of 2.91 was used to prepare the mortars for the rheological tests.

Table 1
Chemical analysis of ordinary Portland cement 30 R RS BRA, by mass percent.

Composition	%
Al_2O_3	3.69
CaO	58.77
Fe_2O_3	3.97
K_2O	0.31
MgO	1.58
MnO	0.10
Na_2O	0.18
P_2O_5	0.10
SiO_2	18.77
TiO_2	0.17
Loss on ignition	5.39

For the SCC mixtures, river gravel with 9.5 mm maximum size was used as coarse aggregate, having water absorption of 1.90% and a specific gravity of 2.48. The fine aggregate was river sand having a fineness modulus of 2.96, water absorption of 2.80% and a specific gravity of 2.68. The particle size distributions of both sands are presented in Table 2.

Distilled water was used to prepare the VEAs dispersions, cement pastes and mortars. Tap water was used in the SCCs mixtures.

2.1.2. Viscosity enhancing admixtures (VEAs)

2.1.2.1. Nopal mucilage. *Opuntia ficus-indica* cladodes were used to extract the mucilage (MUC). These cladodes had a moisture content of 93% (wet basis). An aqueous extraction with heating was used (Fig. 1-A). The cladodes were diced into thin slices with a thickness of 2 ± 0.2 mm. Then the slices were weighed and put into an aluminum container and distilled water was added to obtain a mix with a water-to-raw material ratio by weight of 2. The mucilage was extracted at a temperature of 60 ± 5 °C for a period of 3 h with manual agitation approximately every 10 min. The extracted mucilage was then separated from large particles by decantation and then filtered using a sieve No. 100 (150 μm). It was kept refrigerated until use (Fig. 1-C). A refractometer (Westover, model RHB-32ATC) was used to determine its concentration in degrees Brix. The solid content in the extract used for cement pastes and mortars was 8.70 ± 0.30 $g\,L^{-1}$, whereas the extract used for the SCC mixtures had a solid content of 7.33 ± 0.23 $g\,L^{-1}$.

2.1.2.2. Marine brown algae extract. A concentrated extract of marine brown algae (*Macrocystis pyrifera*) used in the industry as a binder in the production of pellets and extruded foods was used in our experiments as raw material (ALG). This ALG is a semi-pasty dispersion with a high content of polysaccharides, minerals and proteins. It was used in this study because of its lower cost compared to that of high purity alginate salts (Fig. 1-B and 1-C). In addition, sodium alginate (ACS grade) was used to prepare aqueous dispersions at concentrations of 5 $g\,L^{-1}$, 10 $g\,L^{-1}$ and 20 $g\,L^{-1}$ in order to compare its viscous behavior with the ALG.

Table 2
Particle size distributions of silica sand and river sand.

Sieve size (mm)	Silica sand (F.M. = 2.92) (% passing)	River sand (F.M. = 2.96) (% passing)
4.75	100	97.90
2.38	100	82.90
1.20	92.60	63.05
0.599	15.28	40.01
0.297	0.34	16.66
0.152	0.11	3.38
0.075	0.05	1.01
Pan	0	0

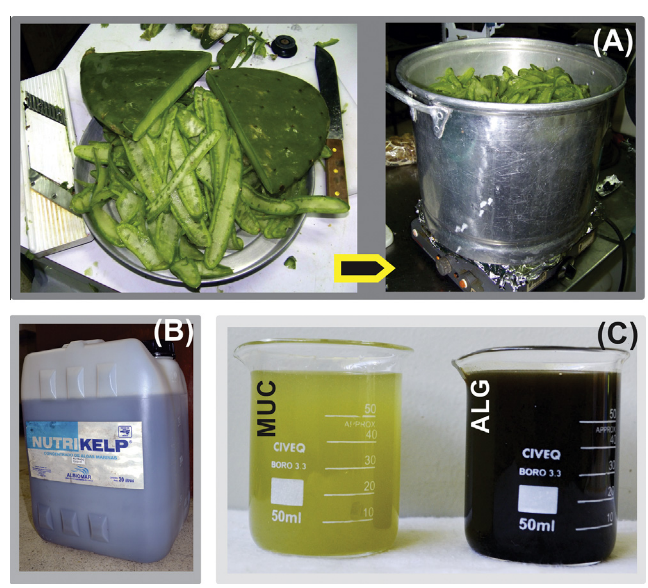

Fig. 1. Nopal mucilage extraction process (A); concentrated ALG (B); MUC and ALG dispersions (C).