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Properties comparison of mortars with welan gum or cellulose ether

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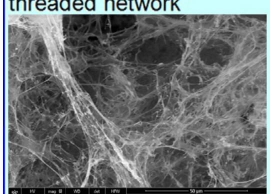
HIGHLIGHTS

- The effects of welan gum and HPMC on the mortar properties were analysed.
- The mechanism of mortar properties change by adding welan gum and HPMC was discussed.
- The application areas of mortar with welan gum and HPMC were suggested respectively.

GRAPHICAL ABSTRACT

Welan gum

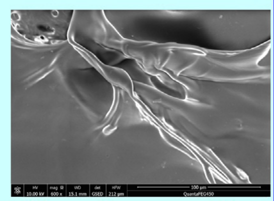
Forms a three-dimensional threaded network



Under shear conditions, the welan gum network instead crumples up and unfolds again when shear is removed

HPMC

Forms a film



Under shear conditions, the HPMC foil breaks up beyond recovery

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ABSTRACT

Welan gum is a type of microbial polysaccharide by fermentation, that could be used as thickener in cement and concrete because of its performance of thicken and anti-bleeding. At present, the most popular thicker in cement and concrete is cellulose ether, especially hydroxy-propyl-methyl cellulose – HPMC. This paper reports the different properties between mortars with welan gum or HPMC, as well as standing bleeding rate, mortar fluidity, compressive and adhesive strengths, microstructure by ESEM, rheological properties and electric properties by zeta potential.

It was shown that, both welan gum and HPMC are good thickener; however, welan gum has a clear benefit at higher W/C ratios as much less additive is needed. Both welan gum and HPMC meet adhesion requirements, but welan gum has negligible effect on compressive strength, whereas addition of HPMC results in a very substantial decrease of compressive strength. At high shear rates, mortar with welan gum has better stability than that with HPMC. In water, welan gum forms a three-dimensional threaded network whereas HPMC forms a foil. Under shear conditions, the HPMC foil breaks up beyond recovery, while the welan gum network instead crumples up and unfolds again when shear is removed. In addition, welan gum adsorbs better than HPMC, has greater influence on the zeta potential of cement clinker and changed its electric properties.

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1. Introduction

Welan gum is a recent type of microbial polysaccharide produced from fermentation by Alcaligenes [1–3], a very common and harmless bacterial species, which is inexhaustible and able to prevent mortar or concrete from bleeding and segregation, so it is potentially suitable for use as stabilizer or thickener in mortar and concrete [4–7]. The molecular structure of the saccharide unit [8,9] is shown in Fig. 1.

As welan gum is produced by bacterial fermentation, its quality is consistently high, and its quantity is hardly resource-limited. Welan gum is friendly to human health and the environment, and the manufacturing process is safe, cost-effective, and non-hazardous. Overall, the future looks bright for the wide application of welan gum.

By contrast, cellulose ether is normally extracted from cotton or wood in a chemical industrial process through a series of subsequent etherification steps [10,11]. It has good adhesive, thickening, and water retention properties, and is widely applied in construction as a concrete or mortar mix additive [12,13]. Currently, the most popular type is the non-ionic hydroxy-propyl-methyl cellulose – HPMC, with typical dosage of 0.1–0.6 wt% relative to cement, to achieve desired mortar or concrete mix properties. The molecular structure of HPMC unit is shown in Fig. 2.

However, production of high quality HPMC is strictly limited by the availability of high quality cotton, and quality varies between manufacturers as well as over time. Consequently, HPMC quality is slightly variable and less consistent compared to welan gum quality, while its bulk manufacture is substantially less environmentally friendly.

2. Materials and methods

2.1. Raw materials

2.1.1. Cement

The main binder used in this research is PO 42.5 cement from Hubei Province. The chemical composition of the cement was assessed by XRF on press tablets from cement powder mixed with standard Hoechst wax. Ignition loss LOI was determined gravimetrically at 1000 °C. The pressing plate was fed into a PANalytical Axios XRF instrument operated at 30–60 kV and 40–60 mA, and the signal was recorded on WDS detectors. Results were recalculated as main oxides and are given in Table 1.

Standard performance characteristics of the same PO42.5 cement are given in Table 2.

2.1.1. Welan gum and cellulose

Both pure welan gum and hydroxyl-propyl-methyl cellulose – HPMC come as fine off-white powders. A hydrous solution containing 0.12 wt% welan gum per liter has a viscosity up to 210 mPa·s at 20 °C and pH ~9. To obtain a similar viscosity (204 mPa·s at 20 °C, pH ~7), a hydrous solution demands 0.40 wt% HPMC, over three times as much. Hydrous solutions with both additives are subject to substantial shear thinning, as shown in Fig. 3.

At the identical temperature condition, welan gum is a much better thickener than HPMC, at much lower concentrations. At 0.12 wt%, viscosity of welan gum solution may reach 210 mPa·s, whereas the effect is essentially negligible for HPMC solution of the same concentration. The same effect is observed at the lower concentrations of both additives, where it is however less pronounced.

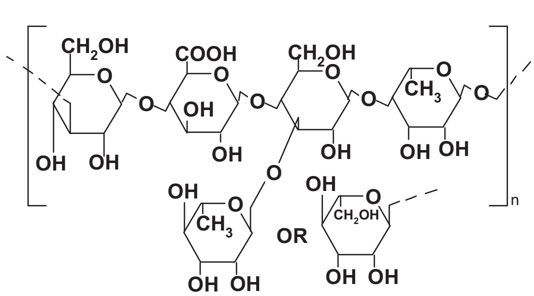

Fig. 1. Molecular structure of welan gum.

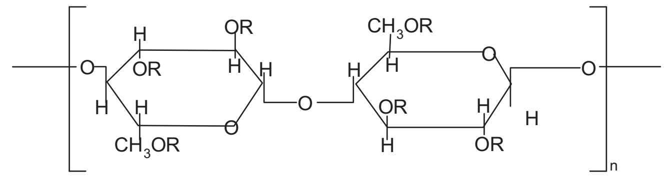

Fig. 2. Molecular structure of HPMC.

Table 1
Chemical composition of PO 42.5 cement in main oxides and ignition loss LOI, by XRF in wt%.

Oxide	LLD	Unit (wt%)
Na_2O	0.01	0.19
K_2O	0.01	0.57
MgO	0.01	2.20
CaO	0.1	60.90
SrO	0.01	0.06
BaO	0.01	0.06
MnO	0.01	0.16
Fe_2O_3-total	0.01	2.65
Cr_2O_3	0.01	0.06
Al_2O_3	0.01	5.04
TiO_2	0.01	0.38
ZrO_2	0.01	0.01
SiO_2	0.1	22.10
P_2O_5	0.01	0.12
SO_3	0.01	2.44
LOI	0.01	2.93
Cl	0.01	0.05
SUM total	100.00	99.93

2.2. Experimental

2.2.1. Standing bleeding rate of slurry and mortar fluidity

To assess anti-bleeding capacity, the effect of a designed proportion of welan gum or HPMC to cement was studied for water-cement ratios of 0.5, 0.6, 0.8, 1.0, 1.2 and 1.5. Cement slurries (without sand, only cement, water and additive) were prepared according to the designed proportions, mixed at about 1000 rpm. After mixing, slurries were poured into 250 mL measuring cylinders and sealed with fresh-keeping foil to avoid evaporation, and kept still for 1 h to observe bleeding. Then the minimum amounts of welan gum or HPMC in wt% per cement needed to completely prevent bleeding at different W/Cs were determined.

Mortar fluidity was measured according to Chinese Standard GB/T 2419-2005. Mix proportions are shown in Table 3. Mortar mixes were prepared by adding water and additive to PO42.5 cement and stirring at 200 rpm for 30 s, next gradually add sand over the course of 30 s, and conclude with stirring at 1000 rpm for 90 s. After completed mixing, mortar fluidity was tested.

2.2.2. Mechanical properties

Standard cement mortar mixes of Chinese Standard GB/T 17671-1999 were added 0.1 wt% welan gum or 0.3 wt% HPMC (Table 3), conform respective manufacturer's recommendations, mixed at ~1000 rpm. Compressive strength of cement mortar was assessed after 3d and 28d according to GB/T 176771-1999, and adhesive strength after 7d and 14d according to JGJ/T 70-2009 (Chinese Standard, ISO compliant). In addition, mortar was plastered horizontally on a tile and then vertically onto a wall. After keeping still for 1 h, water was flushed over the mortar surfaces so as to imitate rain conditions, and anti-scouring and anti-drooping properties were observed.

2.2.3. Rheological properties

Rheological properties were assessed for slurries with constant W/C ratio of 0.5, containing 0.1 wt% welan gum and 0.3 wt% HPMC relative to cement, enabling direct comparison. The test procedure was commenced with pre-shear at constant rate 30 s^{-1} for 15 s. Next, shear rate was linearly increased from 0 to 200 s^{-1} over 180 s, and finally decreased from 200 to 0 s^{-1} also in 180 s. The shear profile is given below in Fig. 4.

2.2.4. Observation of additive morphology by ESEM

Welan gum water solution was prepared at 0.2 wt%, and HPMC water solution at 0.6 wt%. Samples were prepared for microscopy by putting solution in dimpled aluminum holders. The Quanta 450 FEG-ESEM instrument was operated at 10 kV with a beam current of 20 nA and probe diameter of 500 nm at point of incidence, working distance 15.1 mm. To minimize decomposition of welan gum and HPMC upon exposure to an electron beam in vacuum, temperature in the ESEM instrument was kept at ~3 °C and pressure at ~0.1 kPa.