Effects of Hydroxyethyl Methylcellulose on the Shrinkage Cracking of Cement Mortars

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Abstract

The effects of hydroxyethyl methylcellulose (HEMC) on the shrinkage cracking of cement mortars during plastic and hardened stage were investigated. Time to cracking and crack extent were assessed by plastic and drying shrinkage cracking test respectively. The results indicated that adding HEMC into cement mortars could obviously improve their anti-cracking properties during either plastic stage or hardened stage. Cement mortar will have no plastic shrinkage cracking when modified with HEMC in amount of 0.2% by weight of cement and fly ash; and will have no drying shrinkage cracking with HEMC in amount of 0.12%. Furthermore, the effect of HEMC on microstructure of cement mortars were also discussed to illustrate the mechanism of HEMC modified cement mortars.
Keywords: Hydroxyethyl methylcellulose; Cement mortar; Plastic shrinkage cracking; Drying shrinkage cracking; Mechanism

1. Introduction

Shrinkage is the dimensional change that occurs in all cement-based materials, which mainly include plastic shrinkage and drying shrinkage according to its occurring time. The shrinkage is not unacceptable in itself but it is sometimes accompanied by development of slots that are unsightly and objectionable. These slots may develop into macroscopical cracks even when taking standard precautions. Cracks can impair the serviceability, durability, or esthetics of cement-based materials, and are therefore of economic significance in construction industry. There are many methods used for reducing the shrinkage and improving anti-cracking of cement-based materials, such as adding fiber, adding polymer, innovating curing methods, and so on. Polymers have been used to modify properties of cement-based materials for nearly 100 years [1-2], among which latex are used most commonly. As a kind of polymer, latex can modify the mechanical properties, anti-permeability property, anti-freeze property, and so on, of cement-based materials [3-6], even their self-leveling property [7]. Although latex is effective for modifying many properties of cement mortar, its high content makes the latex addition very costly. Such a high latex content (10-20% by weight of cement) is typical for latex-modified cement in order to maximize the flexural strength. Comparably, polymer powder is much less used in cement than latex, but

it is also valuable for improving the toughness of cement-based materials. Hydroxyethyl methylcellulose is a polymer powder that can be used in cement-based materials, and usually used in small amounts (such as 0.4% by weight of cement) [8]. According to the report [9-11], hydroxyethyl methylcellulose has the function of water reduction and retention on cement mortar, and can obviously improve the flexural strength of cement mortar. However, the effect of hydroxyethyl methylcellulose on the anti-cracking property of fresh and hardened cement mortar had not been investigated before, so it is studied in this paper.
Two types of cracking are tested in this paper. One is cracking of fresh cement mortar, which is characterized by plastic shrinkage cracking (within 24 hours) and tested using a wooden mold; the other is cracking of hardened cement mortar, which is characterized by drying shrinkage cracking (1-21 days) and tested using a steel ring. Furthermore, the effects of hydroxyethyl methylcellulose on microstructure of cement mortars are also discussed to illustrate the mechanism of Hydroxyethyl methylcellulose modified cement mortars.

2. Experimental

2.1 Materials

Table 1 and Table 2 presents the physical and chemical properties of the ordinary Portland cement, CEM 32.5R, used in this study. The sand used is natured sand (100% passing 1.75mm sieve, 99.9% SiO_2). Fly ash (chemical properties are shown in Tab.3) was used in the amount of 10% by weight of cement. A white polymer powder, hydroxyethyl methylcellulose MH10007 P4 (HEMC for short), produced by Clariant Ltd. Co., German, is also used. No coarse aggregate is used.

Table1 Physical properties of cement

Density (g/cm^3)	Specific area (m^2/kg)	Setting time (min)		Flexural resistance (Mpa)		Compressive strength (Mpa)	
		Initial	Final	3d	28d	3d	28d
2.85	334	90	270	4.03	7.48	16.99	45.13

Table 2 Chemical properties of cement w%

SiO_2	CaO	Al_2O_3	Fe_2O_3	SO_3	MgO	K_2O	TiO_2
28.8	50.2	11.5	3.3	3.6	1.0	0.9	0.5

Table 3 Chemical properties of fly ash w%

CaO	SiO_2	Al_2O_3	MgO	Fe_2O_3	K_2O	TiO_2	Na_2O	P_2O_5	SrO	BaO	ZrO_2
6.38	52.7	30.5	1.46	4.32	0.96	1.26	0.56	0.30	0.16	0.13	0.06

2.2 Methods

2.2.1 Test for plastic shrinkage cracking

The test specimens cast into a wooden molds with dimensions of 914×610 ×19 mm. Steel wires (8mm in diameter) were welded into a 874×570 mm frame and installed along the perimeter of the wooden mold and at its half height (as shown in Fig. 1[12]). The frame was used to restrain the movement of cement mortars caused by drying shrinkage, which is the direct reason for shrinkage cracking. A polyethylene film was placed into the mold before casting the mortar specimens to prevent absorption of water by the bottom surface of the wooden mold. Mortar specimens were mixed in a normal mixer for 3 minutes, with mix proportions of (cement and fly ash): sand: water=1:1:0.4, adding HEMC in the required amount if needed. In this study, the amount of HEMC is by weight of cement and fly ash. As soon as the mixture was placed into the wooden mold, it was troweled to produce a smooth surface. Immediately after casting, the panels were exposed to a wind of about 5 m/s induced by a fan, and were heated by 1000 watt lamps placed 1.5 m above the samples. The test set-up was illustrated in Fig. 2 [12]. The heating was continued for 4 hours, while the wind continued for 24 hours.

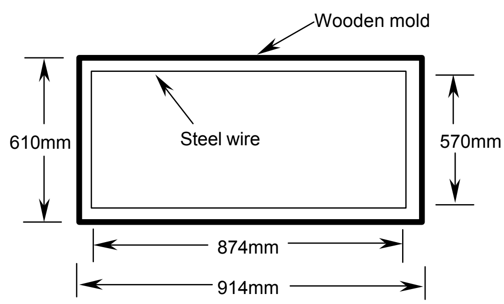

Fig. 1 Schematic of the plastic shrinkage cracking mold [12]

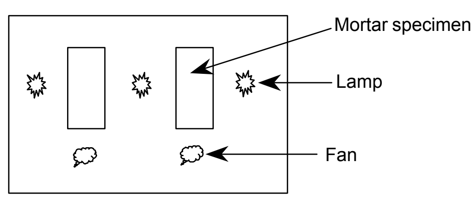

Fig.2 Set-up for the plastic shrinkage cracking test [12]

During the test, temperature and relative humidity of the environment were kept constantly at 20 and 50% respectively. Time to the first cracking was recorded through observation. Cracking lengths and average cracking widths were measured 24 hours after casting mortar specimen. Cracking widths were divided into 4 categories, each of which was assigned a weighted value (A_i) as shown in Table 4. For each category of cracking, the weighted value was multiplied by the cracking length in centimeters (l_i) to get the weighted cracking value (W_i). The sum of the weighted values of all cracks in a specimen was called the “ total weighted cracking value (W)”, which represented the cracking potential of the specimen.

Table 4 Weighted values of cracking widths

Crack width d /mm	Weighted value (A_i)
Large ($d \geq 3$)	3
Medium ($3 > d \geq 2$)	2
Small ($2 > d \geq 1$)	1
Hairline ($d < 1$)	0.5

2.2.2 Test for drying shrinkage cracking

A steel ring was used to test the restrained drying shrinkage cracking in this study, whose dimensions were shown in Fig.3 [13]. The inner steel ring was obtained by cutting a round mechanical tube. An iron board tube was used as an outer mold. Both these rings were placed concentrically on a wooden base so that the free space between them could be filled with the mortar specimens. Mortar specimens were mixed in a normal mixer for 3 minutes, with mix proportions of (cement and fly ash): sand: water=1:1:0.4, adding HEMC in the required amount if needed. The outer mold was stripped off 1 day after casting. Then the mortar specimen will be cured for 4 days at 20 , 100% relative humidity. After that, the upper side of the mortar ring was sealed off using silicone rubber seal, so that drying could be allowed only from the outer circumferential surface, and the mortar specimen was exposed to drying at constant temperature of 20 and relative humidity of 50% respectively. Record the time occurring drying shrinkage cracking, and then record its width every day until 21 day after casting using JC4-10 reading microscope. The crack width reported here was an average of three measurements: one at the center of the ring and the other two at the centers of the top and bottom halves of the ring.

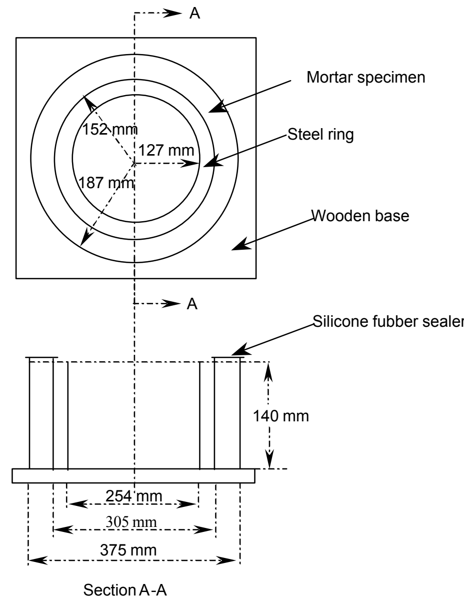

Fig. 3 Test specimen dimensions [13]

3. Results and discussion

3.1 Effect of HEMC on plastic shrinkage cracking of cement mortars

Table 5 shows time to the first cracking, number of cracks and total weighted value of cracking of cement mortars modified with HEMC in different amount by weight of cement and fly ash.

Table 5 Plastic-shrinkage cracking of cement mortars with HEMC

HEMC	Time to the first cracking/min	Number of cracks	Weighted value of cracking/cm
0	53	9	178.6
0.02%	80	6	115.7
0.04%	90	4	91.3
0.08%	95	2	53.9
0.012%	98	1	26.2
0.016%	104	1	7.9
0.20%	-	0	0

The results in Table 5 show that, addition of HEMC into cement mortars can obviously improve their anti plastic shrinkage cracking property, and with the increase of HEMC, the cement mortars will have better anti-cracking property. As shown in Table 5, time to the first cracking of cement mortars modified with HEMC is longer than blank mortar. When the amount of HEMC reaches to 0.16%, the time is 51 minutes longer than that of blank mortars, and only has one plastic shrinkage cracking, the total weighted value of cracking decrease by 95.6% than blank mortar.

And when the amount of HEMC reaches to 0.20%, the cement mortar will have no plastic shrinkage cracking.

These differences in times and crack extent are probably related to the development of tensile strength on the one hand and increasing capillary pressures on the other [14]. It must be noted that the increase of time to the first cracking will reduce capillary pore sizes due to hydration; this will increase both vacuum pressures as well as tensile strength — two opposing effects where plastic shrinkage cracking is concerned [14]. The results in Tab.5 show that with the increase of HEMC, the tensile strength increase arising from the reduction of capillary pore sizes could predominate over the vacuum pressure effect, resulting in progressively less plastic shrinkage cracking.

3.2 Effect of HEMC on drying shrinkage cracking of cement mortars

Fig. 4 shows the experimental results of drying shrinkage cracking width of cement mortars modified with HEMC.

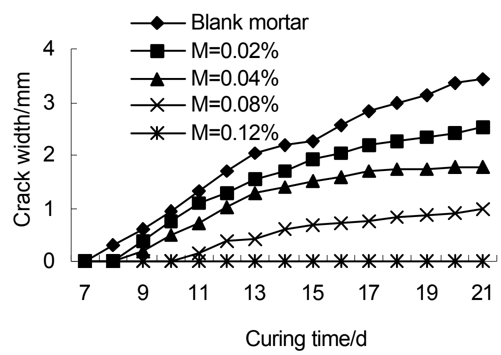

Fig.4 Drying shrinkage cracking width of cement mortars with M

As shown in Fig. 4, addition of HEMC into cement mortars can delay the time to occur drying shrinkage cracking and reduce the crack width. Blank mortar occurs drying shrinkage cracking 8 d after casting, while cement mortars with HEMC in the amount of 0.02% and 0.04% will occur 9 d after casting, cement mortar with HEMC in the amount of 0.08% occurs 11 d after casting, and cement mortar with HEMC in the amount of 0.12% occurs no cracks. As for the expanding speed of drying shrinkage cracking width, the cement mortars with HEMC are slower than blank mortar. At the curing time of 21 d, the drying shrinkage cracking width of cement mortar with HEMC in the amount of 0.02%, 0.04% and 0.08% reduce by 26.8%, 48.6% and 71.4% than blank mortar respectively.

4. Mechanism

4.1 Effects of HEMC on the structure of cement mortars

Cement-based materials are undergoing shrinkage due to the loss of water. Mortars may be sufficiently fluid to comply with the volume change and, thus, develop relatively low tensile stresses. Alternately, mortars may be so stiff as to resist the volume changes and thus develop relatively high tensile stresses as compared with the tensile capacity of the material at that time. If the tensile stresses are not strong enough to resist the volume changes, especially when cement-based materials are restrained, there will occur slots between cement paste and sand. When the slots suffer to stresses caused from free water evaporation, external force and some others, they will expand and link with each other to form macroscopical cracks. As shown in Fig. 5, there are deep grooves between sand and cement paste in blank mortar, which are obviously separate. While added HEMC into cement mortars, they will turn into polymer latex with the function of water during mixing, and distribute uniformly in cement mortar. With the evaporation of free water in cement mortar, the polymer latex will turn into polymer film. At last, polymer film connects with each other to form continuous polymer net structure, and interlace with cement hydration production to become compact structure [15]. The polymer film has the function of interface modifier between sand and cement paste, and connect them tightly, so there are no clear boundary between sand and cement paste, as shown in Fig. 5, and the interface structure in cement mortar is improved effectively when adding HEMC into cement mortars. With the increase of amount of HEMC, the interface boundaries are more and more blurry. When the amount of HEMC reaches to 0.12%, there is nearly no observed boundary. Polymer film has better toughness, and function as bridge in cement mortar to disperse and transfer the stress suffered by cement mortar, thus the forming and expanding of slots in cement mortars are restrained. So the cement mortars modified with HEMC will occur cracks later and have smaller cracks width than blank mortars. When the amount of HEMC is increased, the polymer films then formed are more uniformity and closer, so can have better effect on dispersing and transferring cement mortars stress, so the cement mortars will have better anti-shrinkage cracking property during either plastic stage or hardened stage.

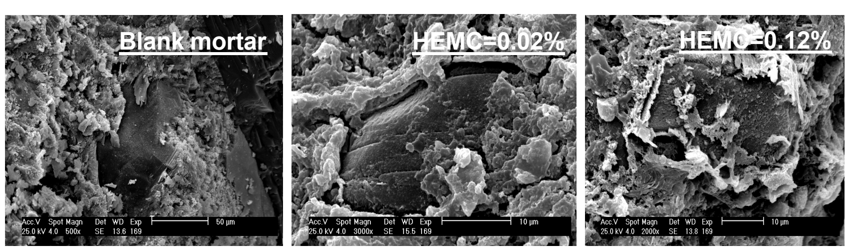

Fig. 5 Structure of cement mortars with HEMC

4.2 Effects of HEMC on the slot structure of cement mortar

The slots structures in cement mortars are observed by Scanning Electron Microscope (SEM), as shown in Fig. 6. Wider and longer slots can be easily found in blank mortar in Fig. 6; however, slots are getting smaller after addition of HEMC into cement mortars. With the increase of amount of HEMC, slots are more and more slender and shorter, and hardly connect with each other. When the amount of HEMC reaches to 0.20%, there nearly have no slots at the same amplification multiple of SEM. The results in Fig. 6 show again that the addition of HEMC can prevent the forming and expanding of slots in cement mortars, obviously reduce the size of slots, and effectively improve the anti-cracking property of cement mortars.

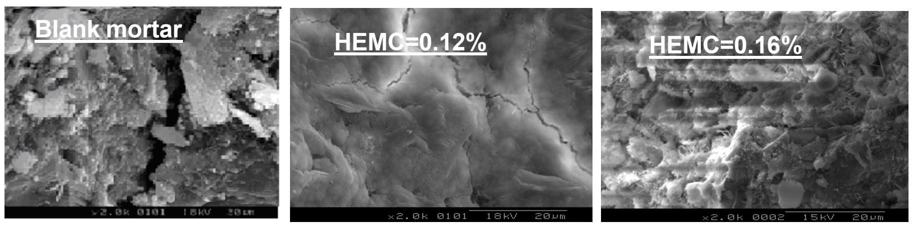

Fig. 6 Slots structure of cement mortars with HEMC

5. Conclusion

The addition of HEMC into cement mortars has obviously effects on the plastic shrinkage cracking and drying shrinkage cracking of cement mortars. As for plastic shrinkage cracking, with the increase of HEMC, cement mortars will occur plastic shrinkage cracking later; the number and total weighted value of plastic shrinkage cracking are reduced too. And when the amount of HEMC reaches to 0.20%, the cement mortar will have no plastic shrinkage cracking. As for drying shrinkage cracking, with the increase of amount of HEMC, cement mortars will occur drying shrinkage cracking later, the expanding speed of slots are getting slower, and the width of slots getting slenderer. Cement mortar with HEMC in the amount of 0.12% will occur no drying shrinkage cracks. The mechanism of HEMC modified cement mortar lies in that the addition of HEMC can influence the interface structure between sand and cement paste and improve the toughness of cement mortars, so can evidently increase their anti-cracking property.

Continuing research is needed to draw a more specific conclusion on the effect mechanism of cement mortars modified with HEMC.

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