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Use of bacterial cell walls as a viscosity-modifying admixture of concrete

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ABSTRACT

This paper reports the rheological and other fresh properties of the cement paste amended with bacterial cell walls (BCW). The major component of BCW, peptidoglycan, resembles commonly used viscosity-modifying admixtures (VMAs) in chemical structures. Our results indicated that the apparent viscosities of the cement paste of W/C 0.36, 0.4, 0.44 and 0.5 amended with BCW of *Bacillus subtilis* were higher than those of the control cement without BCW. And the viscosities decreased with the increase of shear rates. BCW also increased the yield value of the cement paste. The VMA effects of BCW were comparable to that of diutan gum and dependent on the size of peptidoglycan, as lysozyme and sonication treatment decreased viscosities. BCW also demonstrated resistance to water dilution and resistance to bleeding and segregation. As an abundant material, BCW have the potential to be a new VMA in construction.

1. Introduction[1]

Viscosity-modifying admixtures (VMAs), also called anti-washout admixtures and free water control agents, are concrete admixtures with wide application in the construction industry and the petroleum industry [1]. Commonly used VMAs include synthetic polymers (e.g., acrylic copolymer CaAMPS®-co-NNDMA [2] and polyvinyl alcohol [3]) and biologically derived polysaccharides. The polysaccharides are natural or chemically modified biopolymers from diverse biological sources which include welan gum, diutan gum, cellulose ethers, starch, and chitosan. Both welan and diutan gum are the bacterial polysaccharides produced in fermentation [4,5]; cellulose ethers are derived from cell walls of higher plants [6]; chitosan is produced from the exoskeleton of crustaceans such as crabs and shrimps [7]. These VMAs enhance viscosity of cement paste, and viscosity decreases in response to increasing shear rate, which is known as shear thinning. The shear-thinning behavior of polysaccharides VMAs is attributed to their long-chain structures with three modes of action. (1) Adsorption. The hydrophilic groups such as hydroxyl groups in the chain bind water molecules via hydrogen bonding, which increases viscosity. (2) Association. The attractive forces between adjacent polysaccharide chains constrain motion of the water molecules between the chains, causing formation of a gel-like structure with high viscosity. (3) Intertwining. This refers to the association of the long chains causing them to intertwine and entangle at low shear rates to increase viscosity. As rates become higher, the intertwined chains break loose and align along the direction of liquid flow to decrease viscosity, thereby causing shear shinning [1,8]. The VMAs with anionic charges such as welan and diutan gum also bind the positively charged cement particles to enhance the attractions between cement particles and increase the viscosity [5]. The above action of VMAs enable fresh concrete to be stable and cohesive, resisting bleeding and sedimentation under rest condition and yet demonstrating high flowability under high shear conditions during pumping and vibration. Thus VMAs become necessary components of flowable cement-based systems such as self-compacting concrete [1].

Commonly used polysaccharide VMAs on the market are costly, which causes the concrete systems containing VMAs such as self-consolidating concrete to be costly [9]. According to a market research report, cellulose ethers, with even the minimal dosage, are responsible for more than 20% of the cost of the finished products [10]. Chitosan is 75% more costly than cellulose ethers [11]. Though highly effective, both welan gum and diutan gum are produced after aerobic fermentation of natural or genetically modified bacterium *Sphingomonas* sp. and are among the most expensive cement admixtures currently in use, at least two times as costly as cellulose ethers [11]. As a result, there have been continued efforts searching for new VMAs [9,12], e.g., a recent report of plant-derived polysaccharides as VMA [13].

While diverse biologically derived polysaccharides are VMAs, there is no knowledge of whether BCW, whose primary

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[1] VMA: viscosity-modifying admixture, SP: superplasticizer, BCW: bacterial cell walls.

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component, peptidoglycan, is a polysaccharide, have VMA functions. BCW are a natural material, as integral part of bacteria widely distributed and abundant on earth. Among the two major types of bacteria on earth, Gram-positive bacteria such as *Bacillus subtilis* and *Staphylococcus aureus* contain much more BCW than Gram-negative bacteria. In Gram-positive bacteria, about 20–70% of the cell mass is BCW [14,15]. The major component of BCW is peptidoglycan, which constitutes more than 50% BCW mass [16]. Peptidoglycan, along with the covalently attached secondary macromolecules including teichoic acids and proteins, forms a 15–30 nm thick layer to enclose the interior cell membrane and cell contents (called cytosol) [16] (Fig. 1) [17]. The chemical structure of peptidoglycan contains long polysaccharide backbones (also called glycan) and peptide side groups. The backbone is composed of repeating units of disaccharide, N-acetyl glucosamine-N-acetyl muramic acid. The side group contains a short peptide composed of four amino acids (Fig. 2a). The structure of peptidoglycan resembles the structures of VMAs including starch, welan gum, diutan gum, cellulose ethers, and chitosan (Fig. 2b–e), though the repeating sugar units of the backbone of peptidoglycan, starch, welan gum, diutan gum, cellulose ethers, and chitosan contain 2, 1, 4, 4, 1 and 1 monosaccharides. Also the side group of peptidoglycan is longer than those of other polysaccharides and can crosslink to form a three-dimensional peptidoglycan macromolecule. Additionally, peptidoglycan, being also anionic at alkaline pH [18], is more comparable to welan and diutan gum than to other polysaccharide VMAs. While previously studying the function of BCW of *B. subtilis* in increasing the mechanical performance of hardened concrete

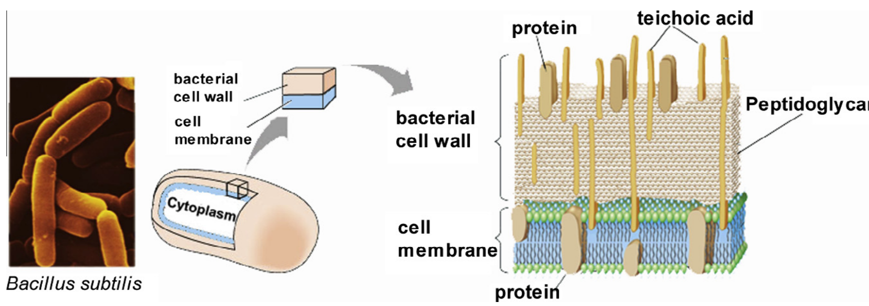

Fig. 1. The cell walls of the Gram-positive bacterium *B. subtilis*. Cytoplasm which contains the majority of cell content is enclosed by a cell membrane, which is enclosed by a cell wall containing peptidoglycan as the major component.

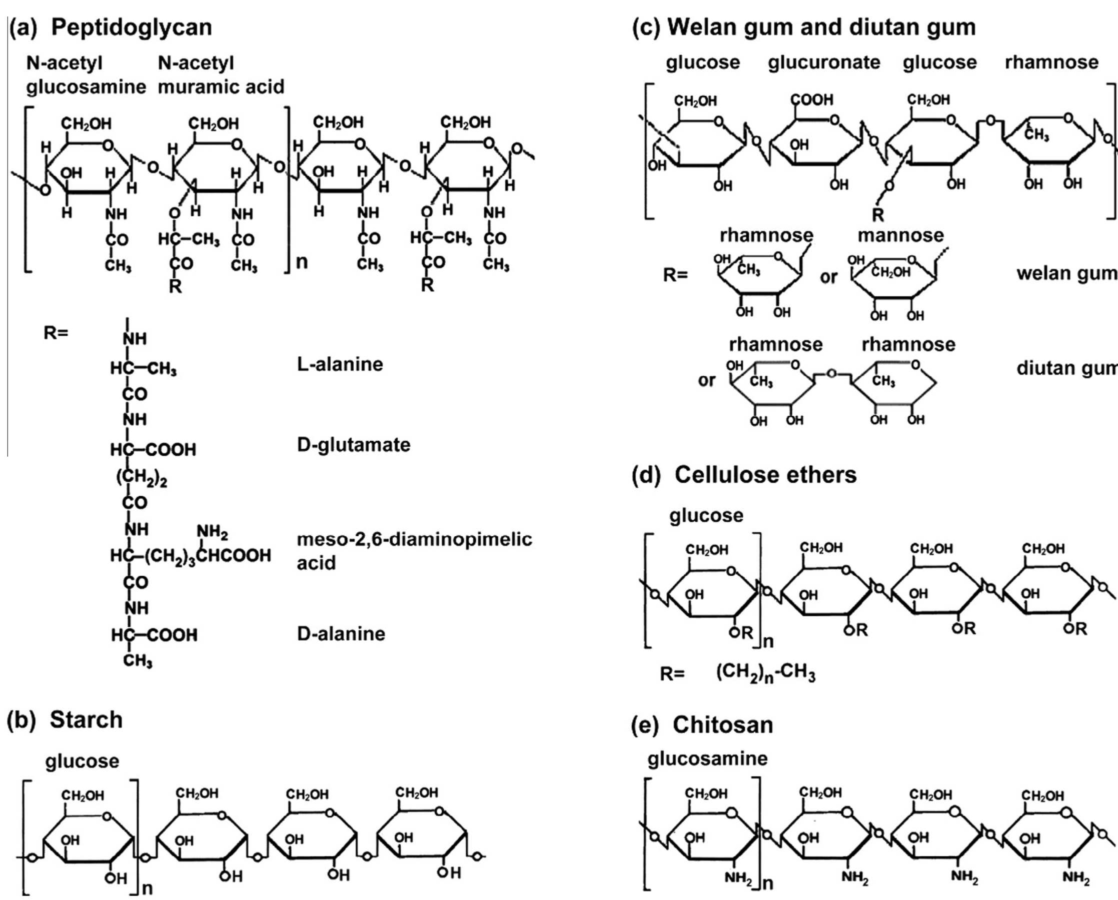

Fig. 2. The chemical structures of (a) peptidoglycan, (b) starch, (c) welan or diutan gum, (d) cellulose ethers, and (e) chitosan. The structures are composed of the long-chain polysaccharide backbones and the short side groups, indicated as R.