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Response of self-compacting paste (SCP) systems containing Acacia Modesta gum

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HIGHLIGHTS

- It became clear that different types of Acacia gums when incorporated in SCPs gave different responses and should be used with complete understanding.
- Therefore, AM gum in cementitious systems offers many potential areas for application and further future research work.
- The AM gum powder may be used for reducing shrinkage in SCP systems, establishing internal curing inside the SCCS, for enhancing the viscosity of the cementitious systems and for producing slightly porous energy efficient cementitious systems.

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ABSTRACT

This paper shows the response of self-compacting paste systems (SCPs) containing botanical Acacia Modesta (AM) gum, a natural organic ooze-out of an indigenous tree called *Phulai*, as an admixture. The gum being different in its nature and origin, exhibited different results from Acacia Nilotica gum powder when used in SCPs. AM gum powder was characterized by X-ray Diffraction (XRD), Scanning Electron Microscopy (SEM), Nuclear Magnetic Resonance (NMR) and Fourier Transform Infrared Spectroscopy (FTIR). The self-compacting paste systems (SCPs) containing 0.25%, 0.5%, 0.75% and 1% AM gum powder were tested for super-plasticizer (SP) demand, flow, viscosity, air content (in fresh state), density, total linear early shrinkage, calorimetry and both short-term (28-day) and long-term (90-day) compressive strengths. SCPs with AM gum powder showed a considerable decrease in total shrinkage, a reduction in density values, an increase in fresh state viscosity. AM gum powder also had a retarding effect on setting times of the respective gum modified SCPs. Moreover, the electrical resistivity of samples containing AM increased tremendously indicating change in the microstructure of the gum modified SCP systems. It became clear that different types of Acacia gums when incorporated in SCPs gave different responses and should be used with complete understanding. Therefore, AM gum in cementitious systems offers many potential areas for application and further future research work. The AM gum powder may be used for reducing shrinkage in SCP systems, establishing internal curing inside the SCCS, for enhancing the viscosity of the cementitious systems and for producing slightly porous energy efficient cementitious systems.

1. Introduction

Self-compacting concrete (SCC) is defined by ACI 237R-07 as “a highly flow-able, non-segregating concrete that can spread into place, fill the formwork, and encapsulate the reinforcement without any mechanical consolidation” [1] by virtue of possessing high deformation and resistance to bleeding and segregation, the two contrasting characteristics of SCC which are difficult to achieve . The study on paste systems is essential as this phase acts as a vehicle for the transport of aggregate phase. Self-compatibility of cementitious systems is achieved by using high range water reducing agents (HRWRA) also known as “super-plasticizers (SPs)” while resistance to bleeding and segregation is achieved by incorporating mineral and chemical admixtures and/or by using low water-powder ratio [2]. Various species of Acacia gum are found throughout the world; its different types have been discussed in literature

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[3–5]. The characterization tests showed that AM gum is composed largely of hydrophilic components and therefore it behaves as a *nearly* inert material in SCPs. Acacia gum's benefits in industry date back to the second millennium BC when the Egyptians used it as an ink and adhesive. Today the gum has found many applications in different fields but here its effect on cementitious systems is explored.

The gum of Acacia Modesta, a species of genus Acacia, has been used for current study due to its universal availability and to show that the use of various types of Acacia gums in cementitious systems as a dry powder or in solution form yields different responses [4] and therefore this fact must be known to researchers and practitioners. The gum emanates from the mature trees of Acacia Modesta (AM) indigenously known as *Phulai*. It exists in the form of viscous liquid, rich in fibers and composed mainly of polysaccharides and proteins [3,4]. The characterization tests show that it consists of macromolecules of carbohydrates (∼97%) and a small proportion of proteins (<3%) [5]. Upon soaking under sun it assumes shape of granules which can be milled to a powder form. Contrary to already published work on Acacia Nilotica gum in conventional and SCP systems [4], it has been observed that the water demand remains almost the same with the addition of AM up to 1% by weight of cement and is also independent of the size of AM gum particles, a fact contrary to Acacia Nolitica gum. Differences in botanical types, regions, tree characteristics and curing regime all affect the response of extracted gums in cementitious systems.

2. Research significance

Little published work exists on the characterization, response differences and potential applications shown by various types of Acacia gum modified self-compacting cementitious systems. This paper certainly addresses these aspects and adds to already existing knowledge on Acacia gum modified cementitious systems having many potential applications.

2.1. Characterization of Acacia gum

The compounds present in different types of Acacia gums are of similar nature in terms of sugars such as rhamnose, arabinose and galactose [5] but vary in percentages [6] to produce response differences. Acacia Modesta gum also consists of polyhydroxy aldehydes [7] and is not able to react with silicates [8]. Therefore its grains remain almost unreacted particles within cement matrix. The detailed mechanism was mentioned by Lambert and his co-researchers who examined sugar silicates in detail and reported how a few monosaccharides such as arabinose, glucose, mannose and galactose could not form sugar silicate complexes [8]. Therefore, AM gum is likely to behave as a nearly inert material in cementitious systems. This behavior of gum in cementitious systems may be one of the reasons for increase in setting times confirmed by a progressive delay in Calorimetry peaks and a progressive increase in shrinkage-reducing capacity for gum based SCP formulations.

3. Experimental program

3.1. Materials

Bestway Type I Ordinary Portland Cement (OPC) of grade 53 conforming to ASTM standard C150-04, Powder Melflux 2651F by BASF Germany as a super-plasticizer and Acacia Modesta gum powder as a potential admixture were used for this study. The Acacia Modesta gum was obtained from a local market. The dry materials were stored in sealed containers before use to avoid contact with moisture.

3.2. Formulations and mixing regime

Five SCP formulations containing 0%, 0.25%, 0.5%, 0.75% and 1% gum content with respect to dry cement weight were prepared at constant mixing water cement ratio of 0.27. The formulations were prepared for constant target flow of 30 ± 1 cm measured by Hagerman's cone measuring $6 \times 7 \times 10\,cm^3$ achieved by adjusting superplastizer content. The formulations tested were as follows.

1. C1-SP0.175-AM0.0-27
2. C1-SP0.28-AM0.25-27
3. C1-SP0.35-AM0.50-27
4. C1-SP0.42-AM0.75-27
5. C1-SP0.52-AM1.00-27

A typical formulation of, for instance C1-SP0.28-AG0.25-27, consists of CEM I type cement, 0.28% super plasticizer (SP) dose needed for target flow, 0.25% Acacia Modesta (AM) gum and 27% mixing water content at 25 °C and 55% relative humidity (RH) in the laboratory. All other formulations can be understood accordingly. Also all percentages in formulation nomenclature are with respect to the weight of cement.

The mixing was done in the Hobart mixer as per DIN-196. The dry contents were first mixed manually and then fed into the mixer bowl containing the mixing water. Slow mixing at 145 rpm was done for 30 s. Thereafter the interior of bowl was cleaned followed by fast mixing at 285 rpm for 150 s. Total mixing time was 180 s. Following this procedure, twenty-seven $4 \times 4 \times 16\,cm^3$ specimens were cast. The samples were covered with plastic sheet and de-molded after 5 days. The samples of neat cement paste were cured in water whereas samples containing AM gum were both air-cured as well as water-cured. Finally, these samples were tested as per DIN 196 standards and different curing regimes produced different results.

3.3. The testing procedures

3.3.1. Flow measurements and setting times

The flow of SCP systems incorporating AM was determined through Hagerman's mini-slump cone of $6 \times 7 \times 10\,cm^3$ dimensions. The target flow was 30 ± 1 cm. The super-plasticizer demand for each SCP formulation was achieved through trials by varying SP content. The mixing was done in the Hobart mixer. The initial and final setting times were determined as per the DIN-196-1.

3.3.2. Calorimetric response

All five formulations were placed in F-CAL 8000 Calorimeter to study their hydration kinetics for 180 h and the response is shown in Fig. 10.

3.3.3. Density and viscosity measurement

Actual dimensions of the cast samples were measured using Vernier calipers and volume of hardened SCP samples was calculated along with their weights at the age of 7th, 14th and 28th day of casting. Thereafter, the densities of water-cured control samples and air-cured AM gum based samples were calculated.

3.3.4. Rheometric investigation

Brookfield DV-III Ultra Programmable Rheometer with SC4-27 spindle was used to measure viscosity of the SCP control sample and those containing 0.25%, 0.5%, 0.75% and 1.0% gum at 50 rpm ($17\,s^{-1}$), 62 rpm ($21\,s^{-1}$), 80 rpm ($27\,s^{-1}$) and 100 rpm ($34\,s^{-1}$) respectively at a w/c ratio of 0.40 at respective SP demands for comparative response study.