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Surface and colloidal properties of chalks: A novel approach using surfactants to convert normal chalks into dustless chalks

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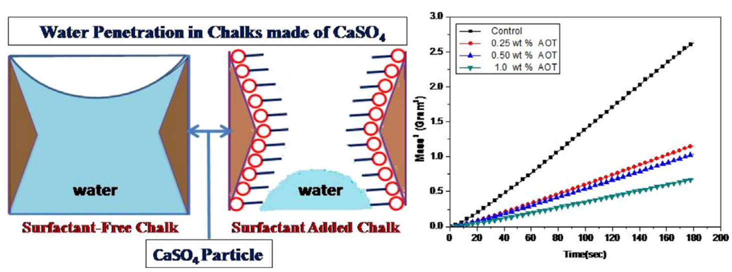
HIGHLIGHTS

- A quantitative investigation of normal and dust less chalk parameters are presented.
- Calcium sulphate based chalks are hydrophilic than calcium carbonate based chalks.
- The molecular mechanism explains the adsorption of surfactant in the chalk.
- Increasing AOT surfactant concentration decrease water penetration in the chalk.

GRAPHICAL ABSTRACT

Water penetration in porous structure of chalk (Mass^2 (Gram^2) vs. Time (Sec) graph of surfactant-free chalk and surfactant (AOT) treated chalk).



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ABSTRACT

Two classes of chalks, calcium sulfate (gypsum) based normal chalks and calcium carbonate based dustless chalks are used in teaching institutions globally. The cost of dustless chalks is almost 10 times higher than normal chalks. In many developing countries, chalk manufacturing is a home-based industry and supports the families. However, the fine dust produced by normal chalks has been of great concern for the health of teachers and students. In the present study, we have used XRD, water penetration, contact angle, particle size of dust generated, breaking strength of chalks, abrasion, weight/density, and surface morphology by SEM to delineate the differences in the properties and performance of these two classes of chalks. The results showed that the particle size of dustless chalks produced during writing/erasing process is significantly larger than that of normal chalks. The normal chalks are hydrophilic and absorb considerably more water than dustless chalks. This led to an approach to add a dewetting agent (surfactant) to normal chalk slurry to decrease water penetration in chalk. In addition, this improved mechanical strength and abrasion resistance of the normal chalks due to hydrophobic–hydrophobic interactions between particles. We were able to produce approximately similar quality chalks as the dustless chalks by addition of small concentration of surfactant (0.5 wt% AOT) in gypsum slurry. This approach will assist many small-scale manufacturers for making better quality chalks and diminish occupational health hazard to teachers and students.

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1. Introduction

In most developing countries of Asia and Africa, a large quantity of chalk-sticks are used for classroom teaching in schools, where it is almost impossible for students and teachers to avoid inhalation of the fine dust particles generated during writing/erasing process [1,2]. The nature of chalk dust and its effects on health problems related to lungs have been reported [3,4]. In India, more than fifteen million chalk-sticks are used every day resulting into dust particles. Globally the number of students and teachers exposed to chalk dust is in millions.

Two types of chalks have been used in this study, a lightweight and high dust generating normal chalk made from gypsum and a dustless calcium carbonate chalk. The imported chalk samples are 10 times costly than Indian gypsum based chalks. Hence majority of academic institution in India uses normal gypsum based chalks in the classrooms.

In the gypsum based chalk method main raw material is calcium sulfate or gypsum powder as slurry in water, which is poured into mould. Gypsum powder being hydrophilic can absorb water and can get solidified with time in form of chalk in a cylindrical mould. An easy process and cost effective raw material are advantages of this method. In contrast, dustless chalks are manufactured, using high-pressure extrusion process with polymeric binders, in developed countries like USA, UK, EU countries, and Korea [1]. Main raw materials for dustless chalk is mixture of calcium carbonate and calcium sulfate (gypsum) with addition of polymeric binder, e.g., PVA, PVP, starch, etc. The weight and density of these chalks are approximately twice than that of gypsum based chalk [1]. In addition the abrasion rate of dustless chalk was less compared to normal chalk [2].

The main purpose of this research was to evaluate the parameters, which are responsible for performance of normal gypsum based chalks and carbonate based dustless chalks using various scientific methods such as XRD, DLS, Contact angle, Water penetration, SEM, etc. The liquid penetration in chalk capillaries was analyzed using Washburn method [5], which provides information on wettability of packed powders as well as chalk sticks. For determination of contact angle, of powders or solid porous samples (e.g., chalk-sticks) several methods have been reported, e.g., Modified Washburn method [6], sessile drop technique [7], and Wilhelmy plate technique [8], thin layer wicking technique [9]. Some of these techniques were utilized in this study.

Several experiments were performed to improve the quality of existing normal chalks by addition of surfactants. Shah and co-workers [10–16] have earlier reported the use of surfactant to control various technological processes, e.g., foaming, wetting time of textiles, droplet size in emulsions, wetting of Teflon, solubilization rate of benzene in micellar solutions, and wettability of clays.

To the best of our knowledge, a systematic investigation on scientific parameters controlling dust generation from writing chalks has not been reported in literature. By comparing the properties of normal and dustless chalks, we have delineated the differences in their surface and bulk properties. We also propose a molecular mechanism in order to explain the increase in hydrophobicity of chalk leading to formation of large chalk particles that sediment much faster in air compared to dust of normal chalks. The current strategy involved the addition of a small amount of a surfactant (AOT) to gypsum slurry that can significantly improve chalk performance in a cost effective manner.

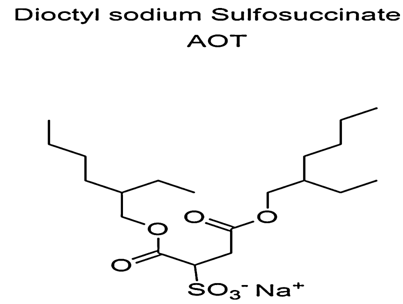

Fig. 1. Structure of a surfactant AOT.

2. Materials

2.1. Normal and dustless chalks

For comparative study, several blackboard chalk samples were collected from Indian market and some samples are imported from USA and Korea.

2.2. $CaCO_3$ and $CaSO_4$ powders

The main powder raw material for the writing chalks is $CaCO_3$ and $CaSO_4$. The chalk powders were procured from chalk manufacturer (Best Chalks Inc., Rajkot, India). The molecular weight of $CaCO_3$ is 100.1 g/mol, $CaSO_4$ is 172.1 g/mol, and particle size of raw powders was 200–300 μm.

2.3. Aqueous phase

De-ionized ultra pure distilled water from Millipore system was used as the aqueous phase for all the measurements. The surface tension of water was measured by Wilhelmy plate technique and force tensiometer sigma700 (KSV, Finland) at 25 ± 0.5 °C and it was found 72 mN/M.

2.4. Surfactants

Anionic surfactant Aerosol OT(AOT)-$C_{20}H_{37}NaO_7S$ (Dioctyl sodium sulfosuccinate) was used for modification of wettability of chalks. The surfactant was of high purity grade with molecular weight of 444.56 g/mol obtained from SDFCL (SD fine chem. Limited, India). Aqueous solutions of this surfactant 0.1–1 wt% were prepared in distilled water for the preparation of surfactant containing chalks. A chemical structure of surfactant is presented in Fig. 1.

3. Methods

3.1. Pour and tap density measurement of powders

The pour density is the uncompacted powder density where as the tap density is the density of compacted powder by 1250 taps generated by the instrument. These parameters were measured using a test apparatus supplied by Veego Instruments Corporation, TAP/MATIC-II model, India. In this method, the cylinder is raised by a height of 14 ± 2 mm and then allowed to drop under its own weight. The poured bulk density and tap density of $CaSO_4$ and $CaCO_3$ powders were measured. The powder sample was gently filled in a 100 ml glass cylinder kept in a slightly inclined position. The poured volume and mass of powder were noted.