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Moisture sorption by cellulose powders of varying crystallinity

Albert Mihranyan [a], Assumpcio Piñas Llagostera [b], Richard Karmhag [c], Maria Strømme [c], Ragnar Ek [a,*]

[a] *Department of Pharmacy, BMC, Uppsala University, Box 580, 75123 Uppsala, Sweden*
[b] *Department of Pharmacy, Barcelona University, Joan XXIII s/n, 08028 Barcelona, Spain*
[c] *Department of Engineering Sciences, The Ångström Laboratory, Uppsala University, Box 534, 75121 Uppsala, Sweden*

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Abstract

Moisture in microcrystalline cellulose may cause stability problems for moisture sensitive drugs. The aim of this study was to investigate the influence of crystallinity and surface area on the uptake of moisture in cellulose powders. Powders of varying crystallinity were manufactured, and the uptake of moisture was investigated at different relative humidities. The structure of the cellulose powders was characterized by X-ray diffraction, BET surface area analysis, and scanning electron microscopy. Moisture uptake was directly related to the cellulose crystallinity and pore volume: Cellulose powders with higher crystallinity showed lower moisture uptake at relative humidities below 75%, while at higher humidities the moisture uptake could be associated with filling of the large pore volume of the cellulose powder of highest crystallinity. In conclusion, the structure of cellulose should be thoroughly considered when manufacturing low moisture grades of MCC.

Keywords: Microcrystalline cellulose; Algae cellulose; Moisture sorption; Cellulose structure

1. Introduction

Microcrystalline cellulose (MCC) is one of the most commonly used tabletting excipients (Bolhuis and Chowhan, 1995) and many of its properties depend on its moisture content (Ahlneck and Alderborn, 1988; Ahlneck and Zografi, 1990; Amidon and Houghton, 1995). However, moisture sorption by MCC has also been reported to cause stability problems for moisture sensitive drugs (Carstensen et al., 1969; Genton and Kesselelring, 1977; Carstensen and Lothari, 1983). Ordinary MCC is manufactured with 4–5% (w/w) moisture content (European Pharmacopoeia, 2002). For moisture sensitive drugs, low moisture grades of MCC are available (1.5%, w/w, moisture in Avicel PH 112 and 3%, w/w, moisture in Avicel PH 103, FMC Corp.); however, these appear hygroscopic (Doelker et al., 1995).

In general, vapor sorption can occur either on the surfaces or in the bulk of a material. Moisture uptake by cellulose powder is recognized as predominantly occurring in the bulk of disordered regions (Howsman, 1949). Absorption of moisture in the bulk of disordered regions of cellulose particles has been widely accepted as the reason for manifold differences between BET N_2 and BET H_2O surface area values

* Corresponding author. Tel.: +46-18-471-41-12; fax: +46-18-471-42-23.
E-mail address: Ragnar.Ek@farmaci.uu.se (R. Ek).

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(Zografi et al., 1984; Zografi and Kontny, 1986). One complication in understanding the mechanisms of moisture sorption and its dependence on the material's structure is the complexity of the cellulose structure. Therefore, the applicability of the term amorphous (or "liquid-like") in its original meaning is sometimes questionable. Whilst X-ray diffraction analysis clearly indicates various degrees of order in cellulose, many parameters (e.g. Tg, "glassy-rubbery" state transitions, etc.) directly associated with the amorphous state cannot be reliably reproduced (Stubberud et al., 1996). Verlhac et al. (1990) suggested that what appears to be "amorphous" cellulose consists mainly of surface chains. A clear relationship between availability of surface hydroxyl groups and cellulose crystallinity was established.

Varying the crystallinity of cellulose powder is expected to cause changes in the moisture content. In order to investigate the influence of the structural properties of cellulose on moisture sorption, it is necessary to select cellulose powders over a broad range of crystallinities. The crystallinity may be altered by various methods: The disordered state in cellulose can be induced either by addition of swelling agents (Patil et al., 1965) or by grinding (Suzuki and Nakagami, 1999), whereas extraction of cellulose from cell walls of certain algae is reported to produce highly crystalline cellulose (Ek et al., 1998).

The aim of this study is to, for the first time, show how structural properties, such as surface area, pore volume, and crystallinity, are interconnected when influencing the cellulose powder's ability to interact with moisture. The study is performed over a broad range of cellulose crystallinities and surface areas including, a.o., cellulose powders of algal origin. As a consequence of this, unique SEM pictures together with physical characteristics of the algal celluloses will also be presented.

2. Materials and methods

2.1. Materials

Five different types of cellulose were used: microcrystalline cellulose (MCC, Avicel PH 102, FMC, Ireland), agglomerated micronized cellulose (AMC), low crystallinity cellulose (LCC), Algiflor brown algae cellulose (Algiflor, Danisco, France), and Cladophora green algae cellulose (*Cladophora glomerata* harvested from the Baltic Sea). The Algiflor brown algae were a blend of five species: *Laminaria digitata*, *Lessonia nigrescens*, *Macrocystis pyrifera*, *Ascophyllum nodosum*, and *Fucus serratus*.

2.1.1. Agglomerated micronized cellulose (AMC)

To produce AMC, MCC was ground in a mortar mill (Retsch KM 1, Germany) for 2 h with water (1 ml of water per 2 g of powder). A 10% suspension of the resultant powder (w/v) was then spray-dried (Minor Type 53, Niro Atomizer A.S., Denmark) at T_{in} = 205–210 °C and T_{out} = 95–100 °C with a feed-rate of 1.7 l/h.

2.1.2. Low crystallinity cellulose (LCC)

To produce LCC, 50 g of MCC was dispersed in 1 l of 70% $ZnCl_2$ solution and vigorously stirred. After allowing it to swell for 1 h, the cellulose was precipitated with additional water. The resultant powder was washed repeatedly until the conductivity of the washed water approximated that of deionised water (i.e. 10^{-6} S/cm) and, thereafter, spray-dried as described above.

2.1.3. Cladophora and Algiflor algae cellulose

Five hundred grams of algae (i.e. Cladophora green algae and Algiflor brown algae) were bleached with 180 g of $NaClO_2$ in 0.5 l acetic buffer. The mixture was diluted to 5 l, poured into a plastic bag and stored in a water-bath for 3 h at 60 °C. The product was washed until neutrality (pH ∼7) as indicated by coloration of a paper indicator (Universalindikator, Merck, Sweden) and filtered. Three liters of 0.5 M NaOH was added to the remainder, and the resultant product was stored at 60 °C in a water-bath overnight. The resultant pulp was washed till neutrality, filtered, and dried at room temperature. Dry, purified algae were ground prior to acidic hydrolysis (Fitz Mill type D6, Manesty Machines, UK). To 50 g of the product 1 l of 5% HCl was added, and the suspension was heated till boiling. Once boiling, it was removed from the heat, and the slurry was allowed to stand overnight. The remainder was washed till neutrality, filtered and spray-dried as described above.

2.2. Methods

2.2.1. Scanning electron microscopy

Micrographs of each sample were taken (Leo Gemini 1550 FEG SEM, UK) at a 100,000 magnification. The samples of each powder were mounted onto double-sided sticky tape over aluminium stubs and coated with gold under vacuum prior to the studies.

2.2.2. X-ray diffraction

An X-ray diffractometer with Bragg-Brentano geometry was used (Diffraktometer D5000, Siemens, Germany). The Cu Kα radiation was utilized ($\lambda = 1.54$ Å) and the angle 2θ was set between 10 and 45°. The crystallinity index was calculated as

$$\mathrm{CrI} = \frac{I_{002} - I_{\mathrm{am}}}{I_{002}} \quad (1)$$

where I_{002} is the overall intensity of the peak at 2θ about 22° and I_{am} is the intensity of the baseline at 2θ about 18° (Segal et al., 1959).

2.2.3. Moisture sorption

The moisture content was measured gravimetrically after samples had been stored at 25 °C over saturated salt solutions of LiCl, CH_3COOK, K_2CO_3, NaBr, NaCl, and KNO_3 corresponding to 11, 25, 40, 63, 75, and 96% relative humidity (RH), respectively (Nyqvist, 1983) for at least 48 h. Prior to the measurements, the samples were stored over P_2O_5 (0% RH) for 10 days.

2.2.4. Surface area and porosity

The specific surface area of the powders was obtained from a BET (Brunauer et al., 1938) analysis of N_2 adsorption isotherms (ASAP 2010, Micrometrics, USA). The total pore volume of the powders was obtained as the volume of adsorbed nitrogen at relative pressure approximating unity. The weight of the samples in these measurements was chosen so as to produce a total surface of 5–10 m^2. The surface area available for water adsorption was calculated based on the principles described by Brunauer et al. (1938) and the assumption that each water molecule occupies a surface area of 12.3 $Å^2$ (Wefers, 1964). The method is applicable for relative humidities below 40%.

3. Results

3.1. Scanning electron microscopy

Fig. 1 illustrates the texture of the cellulose samples as obtained by SEM. The surface of the LCC particles was smooth: a similar texture was visible in the MCC particles. The surface of the AMC particles was irregular, whereas the Algiflor cellulose particles appeared deeply grooved. In the Cladophora cellulose sample, a web-like structure composed of numerous filaments was visible.

3.2. X-ray diffraction

The X-ray diffraction patterns of the samples are presented in Fig. 2. As a result of the chemical treatment, a smeared out diffractogram was observed in LCC indicating a high degree of disorder. From the AMC panel, we observe that grinding MCC was less efficient in reducing crystallinity than was the chemical treatment. The MCC diffractogram revealed a relatively ordered structure with a narrow peak at 22° and a diffuse peak between 13 and 18°. Two peaks of low intensity at 14 and 16° were identified in the Algiflor cellulose sample; however, these were diffused in pattern, indicating lower degree of order than seen in Cladophora cellulose powder. Sharp, distinct peaks at around 14, 16, and 22° as well as a small peak at 20° featured the Cladophora cellulose sample, characterizing this material as highly crystalline. The corresponding crystallinity indices are summarized in Table 1.

3.3. Moisture sorption

The moisture sorption isotherms are presented in Fig. 3. Below 75% RH, the moisture sorption was higher for materials with a lower crystallinity index. At very high relative humidities, the moisture content of the Cladophora cellulose powder increased sharply. The level of hysteresis between the sorption and desorption curves was broader for materials with a lower crystallinity index. In Fig. 4, the moisture content of the samples is plotted as a function of their crystallinity index at different relative humidities. The moisture content of the materials decreased steadily at RHs between 11 and 75%. At higher RHs, the

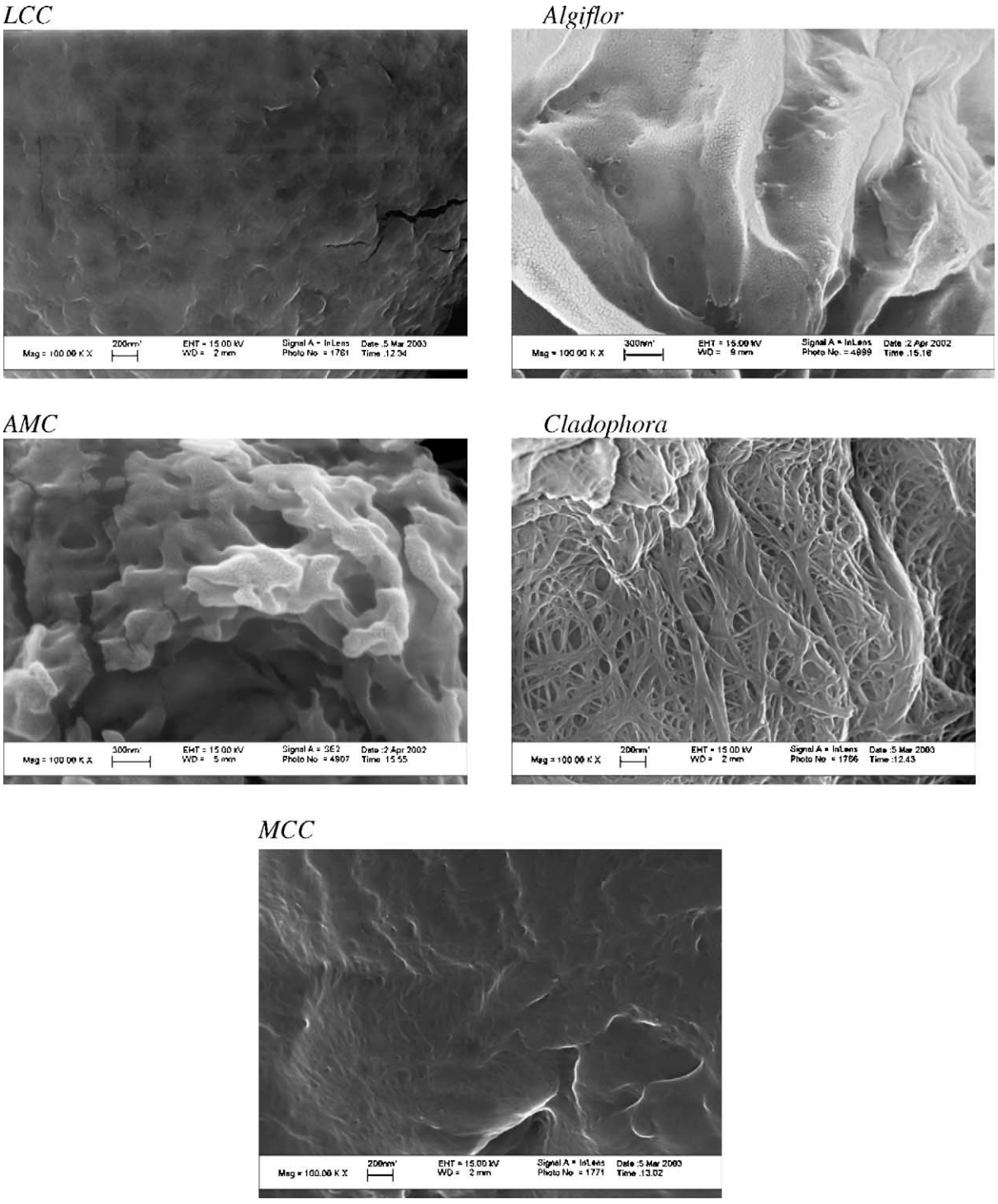

Fig. 1. SEM micrographs of cellulose powders at 100,000× magnification.

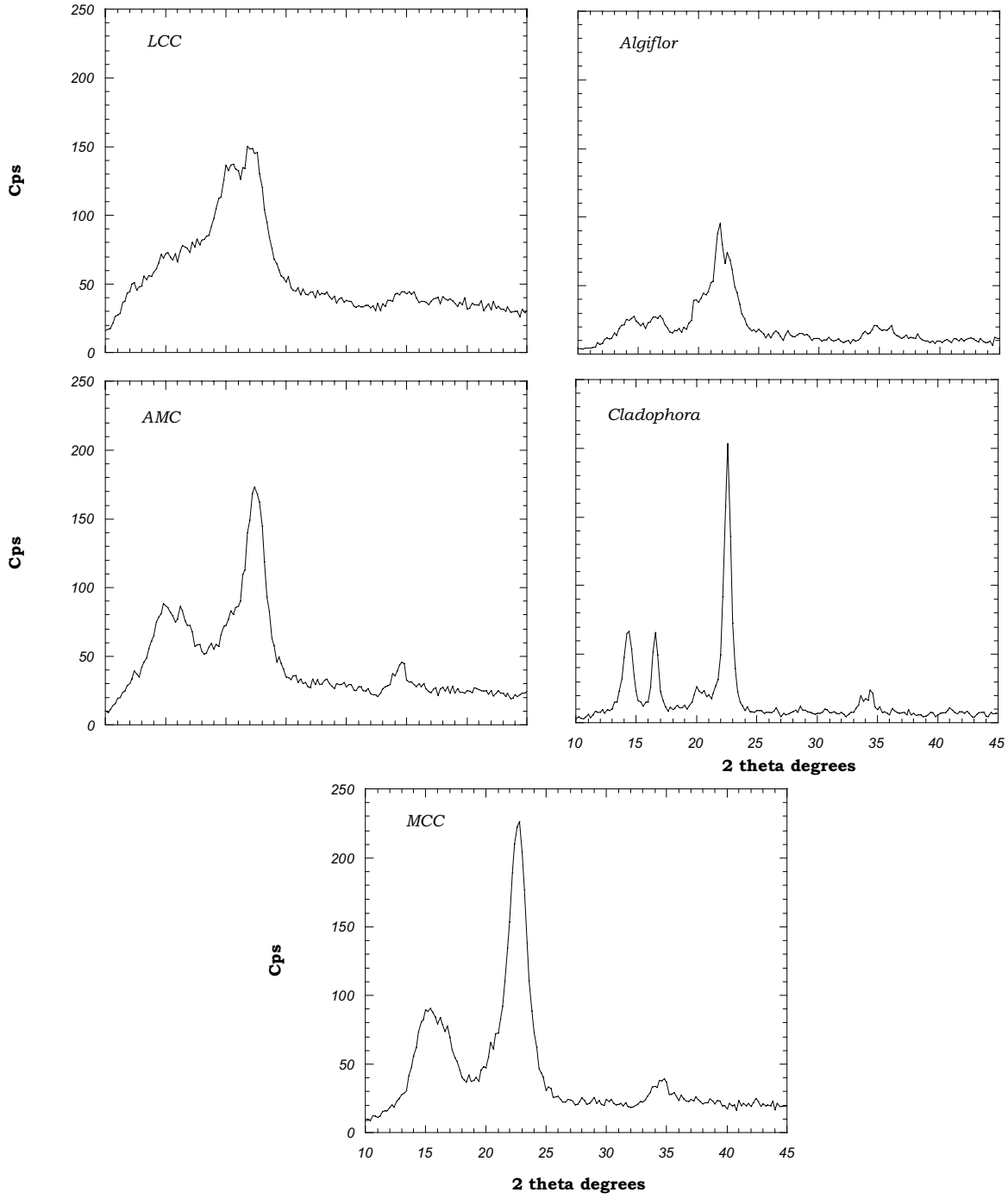

Fig. 2. X-ray diffraction patterns of cellulose powders of varying crystallinity.

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