European Polymer Journal 68 (2015) 585–591

Contents lists available at ScienceDirect

European Polymer Journal

journal homepage: www.elsevier.com/locate/europolj

Consolidation and dewatering of a microfibrillated cellulose fiber composite paper in wet pressing

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ARTICLE INFO

Article history:
Received 31 October 2014
Received in revised form 25 February 2015
Accepted 7 March 2015
Available online 30 March 2015

Keywords:
Nanocellulose
Wet pressing
Paper making
Dewatering
Consolidation
Calcium carbonate

ABSTRACT

The emerging research field of bio-based nanomaterials has gained a lot of interest recently. One of the most promising new range of materials are the micro and nanofibrillated celluloses, or nanocelluloses that are based on wood or other natural cellulose sources. While the strength increasing potential of nanocelluloses is evident in light of the current knowledge, the related challenges in dewatering are inevitable due to the hydrophilic nature and the large relative surface area of the material. The target of this work was to characterize the dewatering and structural changes of a high filler content (70 wt% precipitated calcium carbonate) biocomposite containing microfibrillated cellulose in a wet pressing process. Softwood bleached kraft pulp fibers were used as a reinforcement in the composite. Press dewatering performance together with dynamic density measurements were made with a press simulator, and scanning electron microscopy and mercury intrusion porosimetry were used in the structural analysis of the samples. The dewatering of a new type of MFC based composite was shown to be better than traditional softwood based fibers. The high amount of filler in the structure does not contribute to the binding of water and helps to provide channels for water removal. Mercury porosimetry data was able to partially explain the good press dewatering of the composite paper compared to a SBKP reference paper. Based on the results, it can be concluded that the dewatering of the MFC composite is not limited by the wet pressing operation commonly used in the paper manufacturing industry. Excellent optical properties together with potential cost savings supports the use of this type of novel composite in future applications.

1. Introduction

Cellulose is a polysaccharide consisting of β(1 → 4) linked D-glucose units with a large range of industrial uses. Natural cellulosic fibers form the back-bone of the paper and packaging industry and, thus, are an extremely important source of sustainable raw material. Cellulosic fibers are built in a hierarchical fashion from cellulose fibrils, with a width range of 3–5 nm. Therefore, cellulose pulp fibers are an excellent source of renewable nanomaterials. In the current generation of natural fiber products, fibers with cross-dimensions of roughly 10–100 μm dominate. However, a growing consensus believes that in the next generation of fiber products cellulose nanofibers in the size range of 3–100 nm cross-section will have a very important role. Cellulose nanofibers, commonly known as micro and nanofibrillated celluloses (MFC and NFC) are fibrils or fibril aggregates producible by several different mechanical or chemi-mechanical processes. The first method to produce MFC by mechanically disintegrating pulp fibers was published 30 years ago by Turbak et al. [1]. Since then, various mechanical and chemical treatments have been

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http://dx.doi.org/10.1016/j.eurpolymj.2015.03.045
0014-3057/

proposed to produce nanocellulose. These treatments, along with various nanocellulose applications, have been described in the recent review papers [2–4].

One of the most important uses of cellulose pulp fibers is in paper and board products. Paper is produced by mixing pulp fibers together with other additives, such as pigments, then forming and dewatering a web on a paper machine. Paper machines have evolved over hundreds of years to reach a high level of sophistication. A typical modern paper machine today may have a width over 10 m, speeds approach 2000 m/min and a production of several hundred thousand tons per year.

Web based products, where nanocellulose composes the major structural component, have many potential advantages over traditional paper products. Because nanofibers are notably smaller than typical pulp fibers, excellent surface- and optical properties can be achieved [5,6]. Since the surface area is large, the bonding efficiency of the nanofibers leads to good strength properties [7–13]. While numerous laboratory studies have explored the properties of nanocellulose papers and composite materials, comparatively little attention has been focused on feasible, large scale manufacturing routes.

The manufacture of nanocellulose-based papers faces certain challenges compared to the manufacture of traditional papers. One of the main issues is that the water removal from a web containing nanocellulose is hindered by the relatively large surface area and swelling of the material. While studies have shown water retention values for kraft pulp fibers to be approximately 2 g/g, the water retention value of NFC/MFC produced from the same pulp can be as high as 30 g/g [14]. In order to develop a sensible dewatering strategy, both the furnish composition and chemistry as well as the dewatering processes must be examined.

In ordinary papermaking operations, water is first removed from between the fibers by vacuum, then squeezed out mechanically in wet pressing, and the final water is removed with heat. Since drying is an energy intensive and expensive unit operation, it is important to remove as much of the water as possible by mechanical means. This is also the case for nanocellulose based papers. Large scale, cost effective manufacturing demands that a significant amount of water can be removed from the web by mechanical means. Taipale et al. [15] have shown that selecting optimal retention system would enable the use of nanocelluloses without a significant decrease in drainage. Low amounts of nanocelluloses could also be used in the furnish for low grammage sheets without impairing the dewatering in wet pressing [16]. Furthermore, Hii et al. [17] have concluded that the optimal use of microfibrillated cellulose and filler could enhance both strength and optical properties without reducing the solids content after wet pressing.

In the present study, the removal of water from a nanocellulose web is examined. The furnish consists of 20% microfibrillated cellulose (MFC), 70% precipitated calcium carbonate (PCC) and 10% reinforcement fiber. In an earlier study, we found that this type of furnish yields desirable physical properties [5], and due to the relatively low price of the PCC, could lead to cost savings in the furnish raw material base. In the present study, our target was to determine whether it is possible to efficiently remove water in wet pressing and to examine the consolidation of the composite paper web compared to the traditional fiber furnish.

2. Materials and methods

2.1. Raw materials

The pulp fibers in the composite furnish were commercially produced softwood bleached kraft pulp (SBKP) which was delivered in the dry form. The SBKP was lightly refined in a conical refiner to a SR° = 18. The length weighted average fiber length of the pulp was 2.24 mm. MFC was a commercial grade Daicel Celish KY-100G delivered at 10 wt% solids. Its viscosity at 1.5 wt% and 10 RPM was $16.1 \cdot 10^{-3}$ Pa s measured with Brookfield RVDV-II viscometer using a vane spindle V73. PCC (grade FS240) was delivered by Omya AG at 35 wt%. It was of scalenohedral shape and its weighted mean particle size was 3.97 μm measured with particle size analyzer (Malvern Mastersizer 2000) using a general purpose model. The particle swelling of the raw materials was measured with a solute exclusion method [18,19].

2.2. Sample preparation

2.2.1. Mixing of components

SBPK fibers and MFC were diluted with deionized water to 1 wt% prior to mixing. A laboratory mixer (Diaf) was used in the dilution of pulp and a high shear disintegrator in the dilution of MFC in order to achieve a homogeneous suspension. SBPK fibers and MFC were then mixed together, and after adding the PCC, the suspension was mixed and diluted to 0.26 wt% for sample preparation.

2.2.2. Preparation of SBKP and MFC composite samples

The proportion of the materials in the MFC composite sheets based on dry weight was 10% SBPK, 20% MFC and 70% PCC. Pure SBPK fiber sheets were formed according to standard SCAN-CM 64:00. A modified laboratory sheet forming device was used in the MFC composite preparation. A 50 kPa overpressure was applied for 210 s and a nylon membrane (Sefar Nitex 03-10/2, Sefar AG, Switzerland) was used on top of the standard wire for retaining fine MFC and PCC particles [5]. All samples were adjusted to a moisture ratio of 4 g water/g dry after forming, and 4 circular samples were cut from each sheet for further experiments. For structural analysis before and after pressing, samples were freeze dried at −50 °C and 2.4 Pa. The time span from pressing to sample freezing was 15 s for all samples. Other samples were dried between blotting papers in 570 kPa pressure at 130 °C temperature for 2 min.

2.3. Wet pressing experiments

2.3.1. Press simulator

A universal material testing system (MTS 810) modified for press dewatering studies was used in the experiments. This system consisted of a smooth stainless steel top plate