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Nanocellulose based materials for the reinforcement of modern canvas-supported paintings

The aim of this work was to evaluate the use of novel nanocellulose-based consolidants for modern easel paintings as a possible alternative to lining and to the use of common adhesives. Two dispersions of consolidants were tested: nanofibrillated (CNF) and nanocrystalline cellulose (CNC). A model cotton canvas was used to evaluate the effect of these consolidants following treatment by the nanocellulose-based formulations. The surface appearance of the canvases was assessed before and after treatment using colorimetry and scanning electron microscopy (SEM). Additionally, the characterisation of the mechanical properties of the samples was performed using tensile testing and dynamic mechanical analysis (DMA-RH) at controlled relative humidity (RH) (3 RH cycles, 20-60-20% RH at 25 °C) before and after treatment. Finally, colour changes undergone by the samples upon accelerated ageing were measured by colorimetry. Taking into account the individual outcomes of each of these tests, it was possible to evaluate the merits and limitations of the use of nanocellulose treatments for the consolidation of modern painting canvases.

Nanocellulose, cotton canvas, nanocellulose, consolidation, SEM, DMA-RH, moisture response.

INTRODUCTION

The development and evaluation of alternative approaches to structural painting consolidation are of significant interest due to the risks associated with the poor reversibility and degradation of past and current adhesives in use (Bomford and Staniforth 1981; Ploeger et al. 2014). A recent survey carried out among conservators (Oriola 2016) has shown that there is currently a need for an alternative to the consolidants currently available which should demonstrate the following properties: reversibility, stability and compatibility as well as being user-friendly and non-hazardous. Thus, introducing nanocellulose in conservation has the distinct advantage of using a material being chemically similar and thus more compatible to the canvas unlike commonly used vinyl and acrylic-based resins. Nanocellulose consists of nano-sized clusters of cellulose chains. Beyond a similar chemical nature between the treatment and the treated material, it is this small particle size that ensures a higher physico-chemical interaction between nanocellulose and canvas substrates to be treated. More

recently, it has been widely studied for paper reinforcement owing to its mechanical (Lavoine, Bras, and Desloges 2014), optical, barrier properties and high tunability through functionalization (Nechyporchuk, Belgacem, and Bras 2016). Recent studies in paper and painting conservation showed evidence of their promising mechanical properties for reinforcement purposes (Volkel et al. 2017). As a biomaterial isolated from natural cellulose sources (eg. bacteria and algae) and in principle any cellulosic material (eg. wood), it is expected that the use of nanocellulose will grow significantly due to an increased demand for sustainability (Dufresne 2013).

The early and extensive works was done by Mecklenburg (1982), Hedley (1988) and finally Young and Ackroyd (2001) reveal the importance that relative humidity (RH) has on the properties of different constituents of a painting (canvas, glues, ground layer). The difference in mechanical behaviours of each of the layer, as a result of variable RH, is one of the main source of stress in these objects. These critical properties should therefore be assessed when choosing the appropriate material for conservation.

This research aims to provide preliminary results of the introduction to the use of nanocellulose materials as part of a consolidation strategy for modern easel paintings. Visual, mechanical and physicochemical testing of treated samples including assessment of their response to RH variations will help to define the suitability of these materials for canvas consolidation purposes.

MATERIALS AND METHODS

In the current study, nanofibrillated (CNF) and nanocrystalline cellulose (CNC) particles were used to take advantage of their different sizes (3-50 nm in diameter, 50 nm - 5 μ m in length), surface chemistry, and crystallinity. The prepared aqueous dispersions of nanocellulose were applied to the surface of a modern cotton unprimed canvas after it had been subjected to accelerated ageing and had reached a DP of 450 (Nechyporchuk et al. 2017). The model degraded cotton canvas was treated by blade-coating to achieve a mass coverage of 27g /m² and 83.1 g/m² in CNF and CNC respectively. The surface appearance of the canvas was assessed topologically by electron microscopy (SEM) (Philips XL30, FEI, Netherlands) before and after treatment. Mechanical assessment was performed by tensile testing at 30% RH and 25 °C (Instron5565A, Norwood, USA) and by assessing the mechanical response of the stretched samples to RH variations (20-60-20% RH, 25 °C) using a Tritec2000B DMA (Lacerta Technology, UK). The stability of the treatments was assessed by colourimetry (X-Rite 530 Colourimeter, USA) after accelerating ageing (90 °C, 65% RH, 3 weeks).

RESULTS

First, the assessment by colorimetry of the colour change occurring upon treatment of the canvas samples indicates that the two nanocellulosic treatments do not visibly modify the canvas colour

($\Delta E < 1$). Comparison of the surface topography of untreated with treated degraded samples (i.e. Figure 1) confirms that a continuous surface deposition was achieved preserving the fabric topology. For the CNF-treated sample in particular, a natural web-like network is formed across the cotton fibres. The penetration of the treatments within the canvas is however limited for both CNF and CNC treatments which act as surface coatings. This provides a first qualitative assessment of the impact and effectiveness of nanocellulose treatments for woven structures.

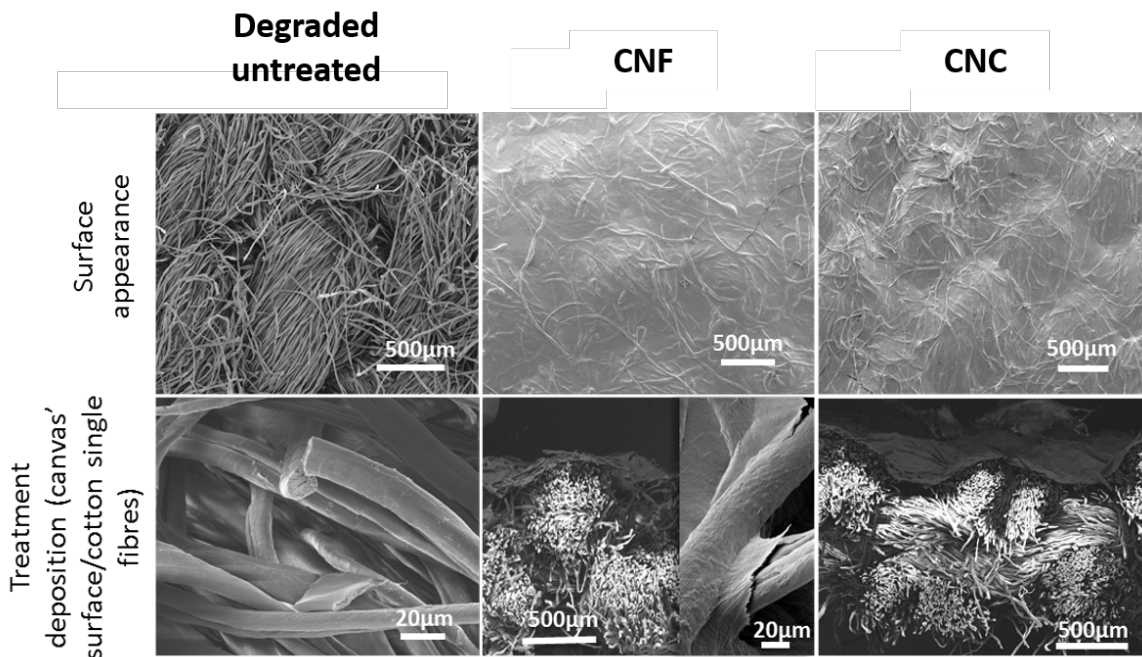


Figure 1. SEM images showing the canvas surface topography before and after treatment.

To further understand the impact of the treatments in terms of mechanical properties the samples were tested using tensile testing. Figure 2 indicates an increase in the Young's modulus for treated degraded sample in the 0-2% strain range at which a painting is usually tensioned (Mecklenburg 1982). This reveals the stiffening effect provided by the treatments which is favourable for canvas consolidation. The results also indicate the better performance achieved with the CNC treatment, which might result from the higher mass coverage measured for the CNC-treated canvas. Also, at higher strain the CNF- and CNC-treated canvas undergo several tension drops which could account for localized rupture of the nanocellulose coating. It could be the results of both the low penetration of the treatments mentioned previously and the brittleness of the nanocellulose films (Mäkelä et al. 2016).

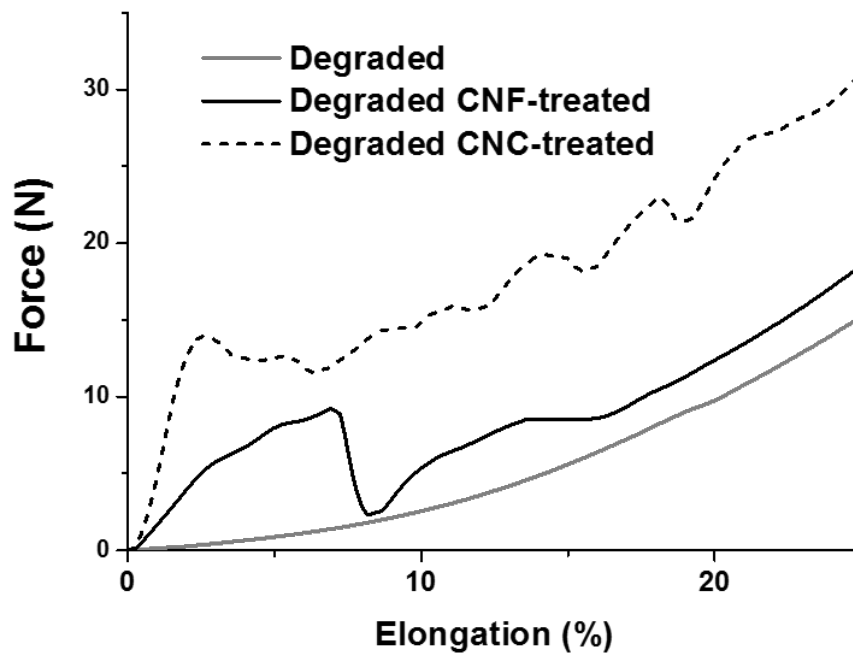


Figure 2. Tensile strength curves of the untreated and treated canvases.

The treatments might also induce variations in hydrophilicity of the treated canvases. This was quantified by contact angle measurements and dielectric measurements. More importantly, its impact on the samples' mechanical properties was assessed using controlled relative humidity dynamic mechanical analysis (DMA-RH). For these experiments, the samples were exposed to cycles of programmed RH (20-60-20% RH, 25°C) and changes in sample storage modulus (i.e. stiffness) following the RH-cycling was measured. An increase in response of the storage modulus to RH variations could be measured for CNF treated canvases while the stiffer CNC treated canvas showed lower variations in canvas stiffness between the two RH levels.

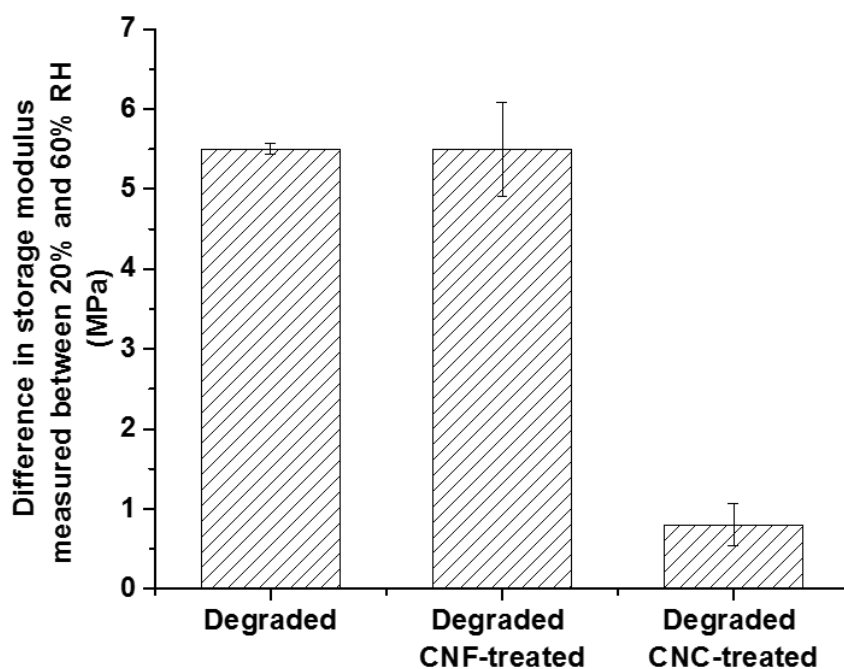


Figure 3: Difference in storage modulus measured between the 20% RH and 60% RH plateaux.

The long-term stability of the treatment was also investigated. Preliminary results indicate that no visible colour changes ($\Delta E < 3$) could be measured by colourimetry for CNC-coated degraded canvas in comparison with the aged degraded control sample. The darkening of the CNF-treated sample was however observed after ageing ($\Delta E > 5$). Further investigations will assess whether the consolidation conferred by the treatments is maintained despite the colour changes previously mentioned.

CONCLUSIONS

This study has so far indicated the merits of the two different nanocellulose treatments for canvas reinforcement and provides a basis for the use of nanocellulose for the reinforcement of modern painting canvases. At this stage the CNC treatment appears to perform better in term of reinforcement and long-term stability than CNF treatment. Further studies will include the assessment of the mechanical stability of the treatments and their comparison with common canvas consolidants.

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