NANO-ENGINEERED CNC/FLAX/BIO-EPOXY HIERARCHICAL COMPOSITES

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Introduction

Nature always serves as a valuable source of inspiration for the development of high-performance materials, showcasing numerous finely tuned hierarchical structures and exceptional properties. Inspired by nature, a nano-engineered hierarchical natural fibre composite system has been developed in this work, consisting of cellulose nanocrystals (CNC) as nano-reinforcement in a flax/bio-epoxy composite, with the aim of solving some long-standing challenges in natural fibre composites. Localised nano-modifications on flax fibre surfaces have been achieved, while a comparison of dispersing CNC into epoxy resins has also been performed, with a systematic characterisation performed to examine the performance of the hierarchical natural fibre composites.

Manufacturing process

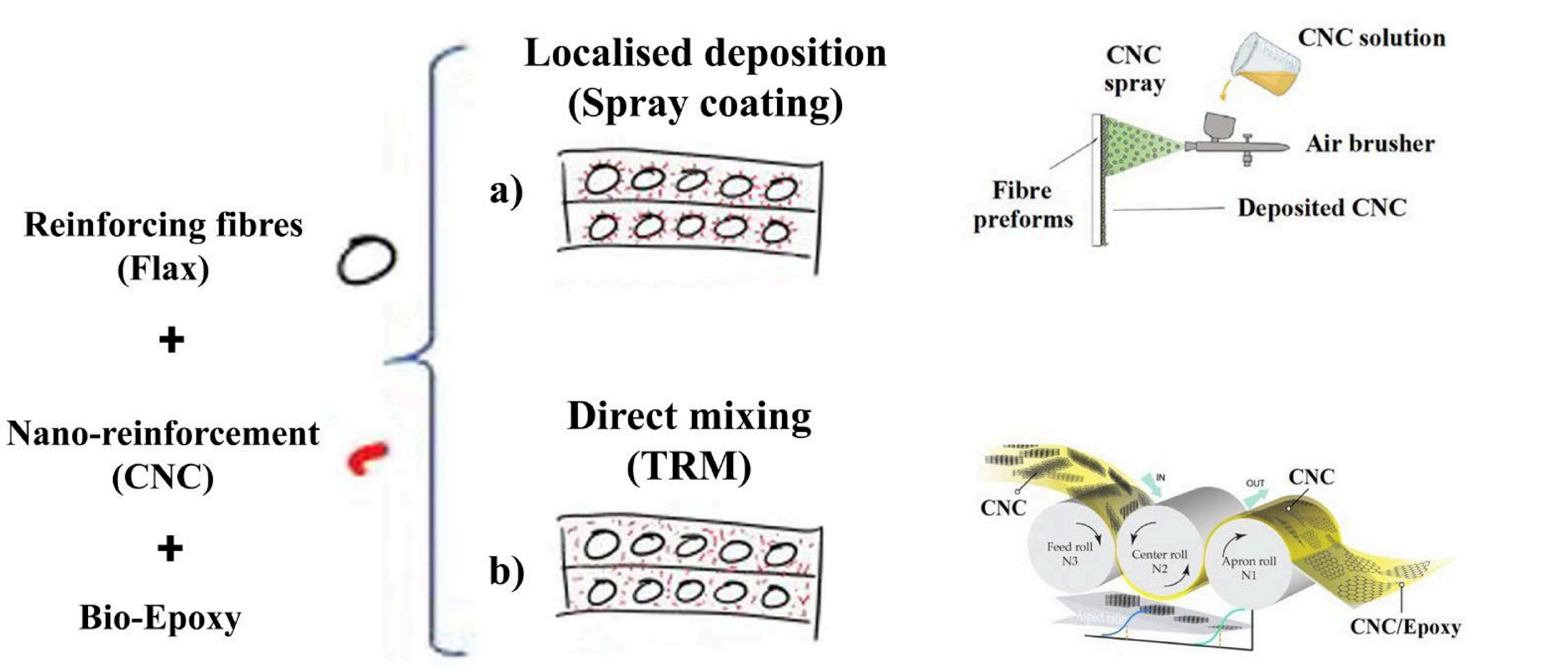

Fig. 1. Schematic illustrations of a) localised nano-modification onto fibre preforms via a simple spray coating method, and b) dispersing nanofillers into epoxy resins by three roll mill (TRM) prior to infusion.

Two fabrication routes are employed to manufacture the hierarchical flax/epoxy nanocellulose composite, a top-down method based on three roll mill (TRM) process to disperse CNCs within the matrix, and a bottom-up method with spray coating to locally deposit nanofillers onto flax fibre preforms, followed by vacuum assisted resin transfer moulding (VARI).

Wetting properties

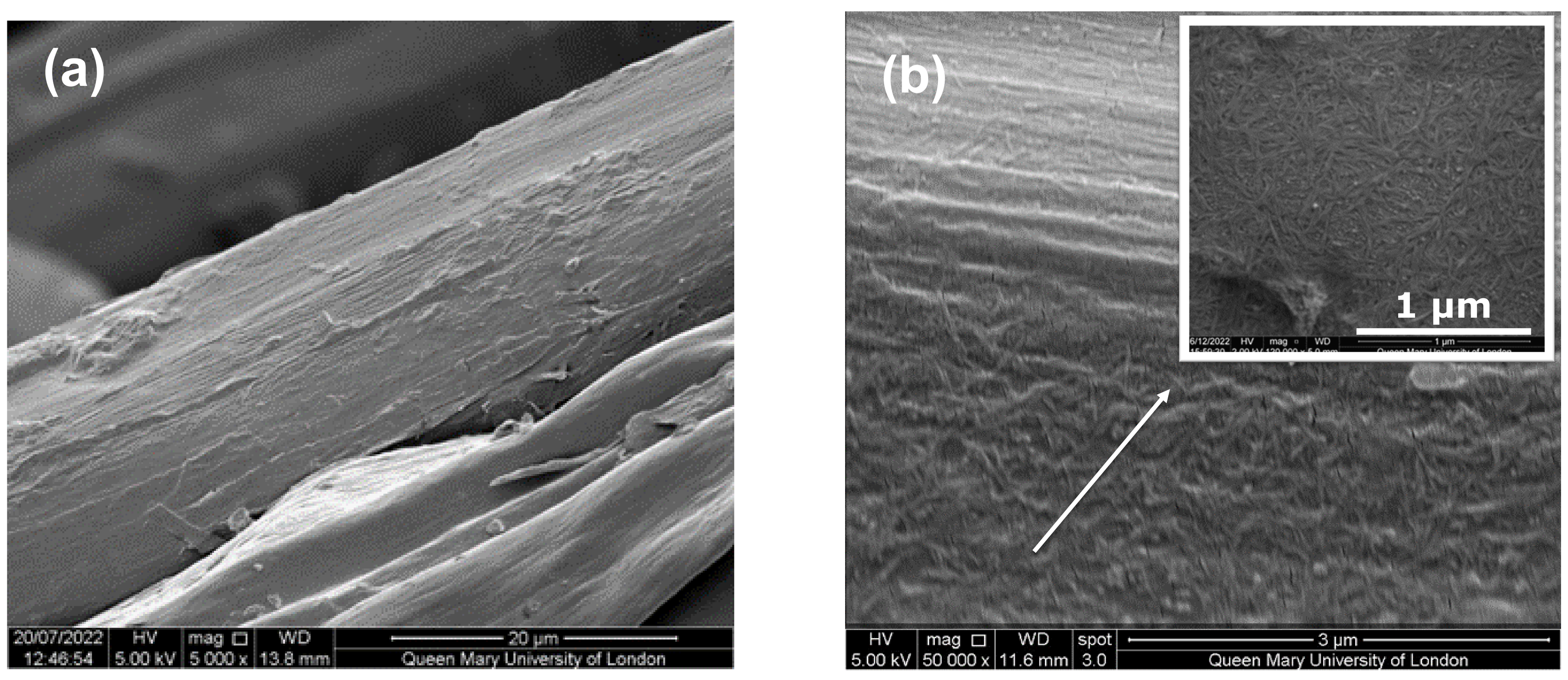

Fig. 2. SEM images of (a) neat flax, and (b) flax with CNC spray coated.

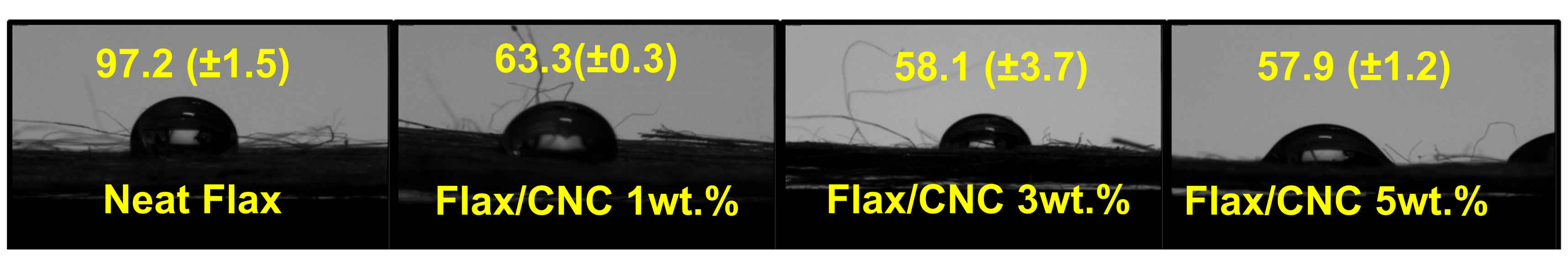

Fig. 3. Effect of flax fibre surface modification on wetting behaviour: a reducing trend of contact angle between epoxy and flax-CNC preforms, indicating an improved wettability with localised CNC deposition.

Mechanical and thermomechanical properties

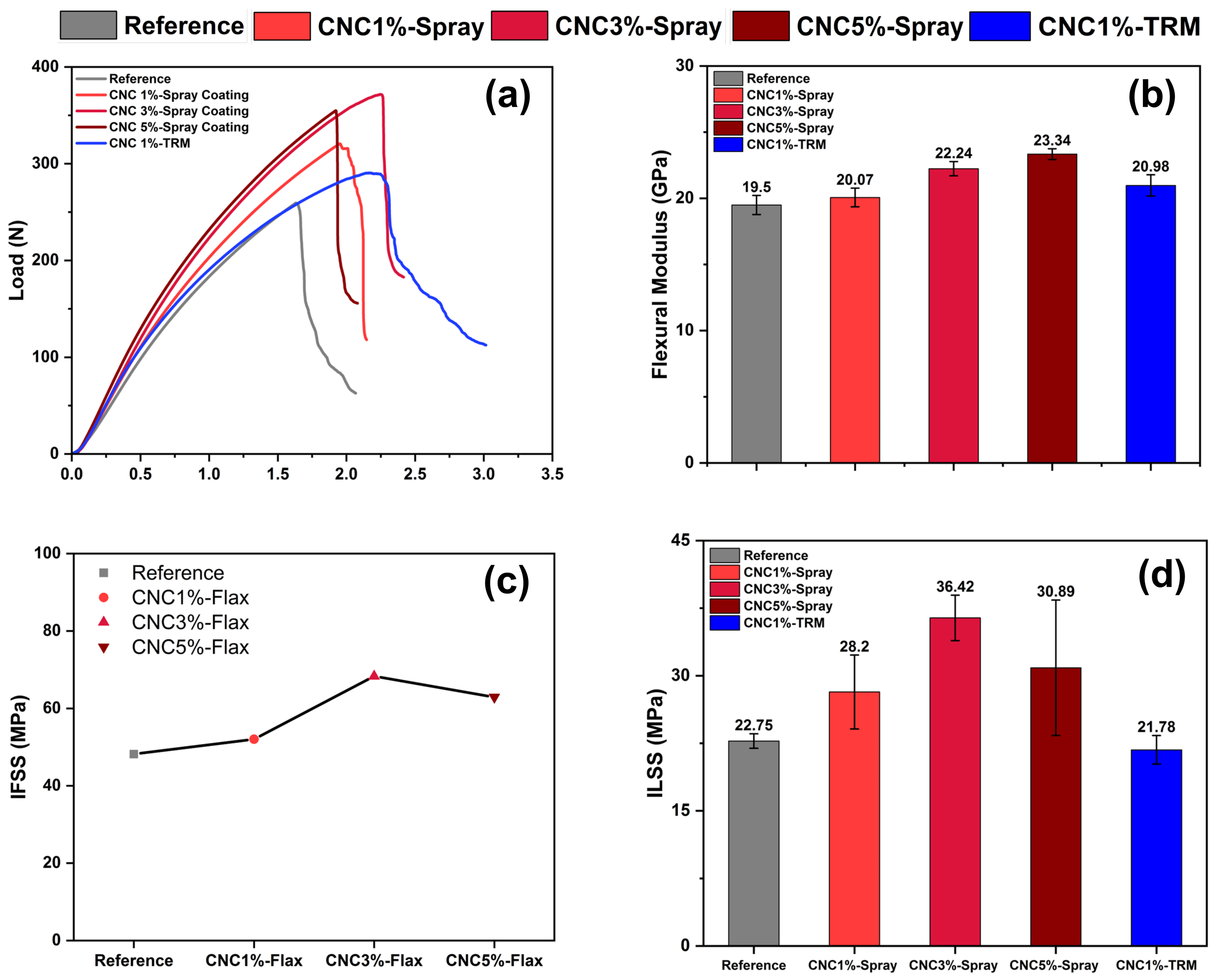

Fig. 4. Mechanical properties of nano-engineered composites, showing improved performance with the introduction of CNC: (a) load-displacement curves and (b) modulus of flexural tests, (c) interfacial shear strength, and (d) interlaminar shear strength.

By testing contact angles of CNC-Flax with different concentrations, it was observed that the contact angle decreased with increasing amount of CNC (Fig. 3.), indicating an improvement in wettability of epoxy resin hence an increased interfacial adhesion between the fibre and resin. With 3 wt.% CNC deposited, the contact angle of epoxy resin has been reduced from 97.2° (of neat flax) to 58.1° (40% reduction). This can be attributed to the increased roughness resulting from the surface areas of CNC nanofillers.

While all spray coated CNC loadings examined in this work have led to improved mechanical properties, the incorporation of 3.0 wt.% CNCs resulted in a significant enhanced modulus (14%) and interlaminar shear strength (60%). The introduction of CNCs in both systems has also led to an increased glass transition temperature (Tg), as shown in Table 1 below.

Table. 1. Glass transition temperatures (Tg) of nano-engineered composites by DMA.

Samples	Control	CNC1%-Spray	CNC3%-Spray	CNC5%-Spray	CNC1%-TRM
Tg (°C)	74.7 ± 0.4	77.6 ± 0.6	79.5 ± 0.5	81.1 ± 0.1	79.1 ± 1.3

Conclusions

A nano-engineered natural fibre composite has been developed, with tailored flax surfaces via locally deposited cellulose nanocrystals. A significantly enhanced wettability of flax to epoxy resins has been achieved, thanks to the surface areas of nanofillers hence an increased surface roughness. As expected, the mechanical properties of CNC-coated flax-reinforced composites have been improved, with flexural modulus, interfacial shear strength and interlaminar shear strength evaluated for different nanofiller loadings. The simplicity and versatility of the spray coating method employed in this work, demonstrates a feasible route to develop natural fibre composites with tailored functions and improved performance.