Twenty-Third International Conference on Composite Materials (ICCM23)

Improvement of mechanical properties of 3D-printed continuous flax fibre/poly(lactic) acid composites by impregnated filament with surface treatment

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Keywords: *Additive manufacturing; 3D printing; Continuous flax fibre reinforced composites (CFFRCs); Surface treatment*

Introduction

Compared with traditional composite manufacturing techniques, the low moulding pressure, the short moulding time, and the twist structure and continuity of plant yarns are the characteristics of 3D printed continuous plant fibre reinforced composites. These make the impregnation even more difficult and thus led to low mechanical properties of 3D printed composites. We choose a silane coupling agent, which can eliminate the hydroxyl group through chemical reaction with the fibre surface, and establish a chemical bond with the matrix. To improve the wettability of the fibre and the interface performance of the composites, thereby improving the mechanical properties. Then, poly(lactic) acid (PLA) and surface-treated yarns are prepared into pre-impregnated filaments for 3D printing using a customed continuous fiber impregnation equipment. The mechanical properties of the continuous flax fibre/PLA composites (CFFRCs) prepared by 3D printing in the present work are comparable to those manufactured by compression moulding in literature.

Methods

1. Hydrolyzed silane coupling agent was used to spray onto the surface of the flax yarns, then they dried at 80℃ for 6h and reacted at 120℃ for1h.
2. An in-nozzle impregnated 3D printer was modified to manufacture CFFRCs using surface treated flax yarns, the fibre volume fraction of CFFRCs was 25%.
3. An impregnation equipment was modified to fabricate CFFRCs using surface treated flax yarns and PLA, the fibre volume fraction of CFFRCs was 40-50%.
4. The mechanical properties of the CFFRCs, namely Mode I interlaminar fracture toughness, tensile properties and flexural properties were tested.
5. The SEM images of fracture surfaces of these CFFRCs specimens were obtained to analyze the mechanism of improved mechanical properties.

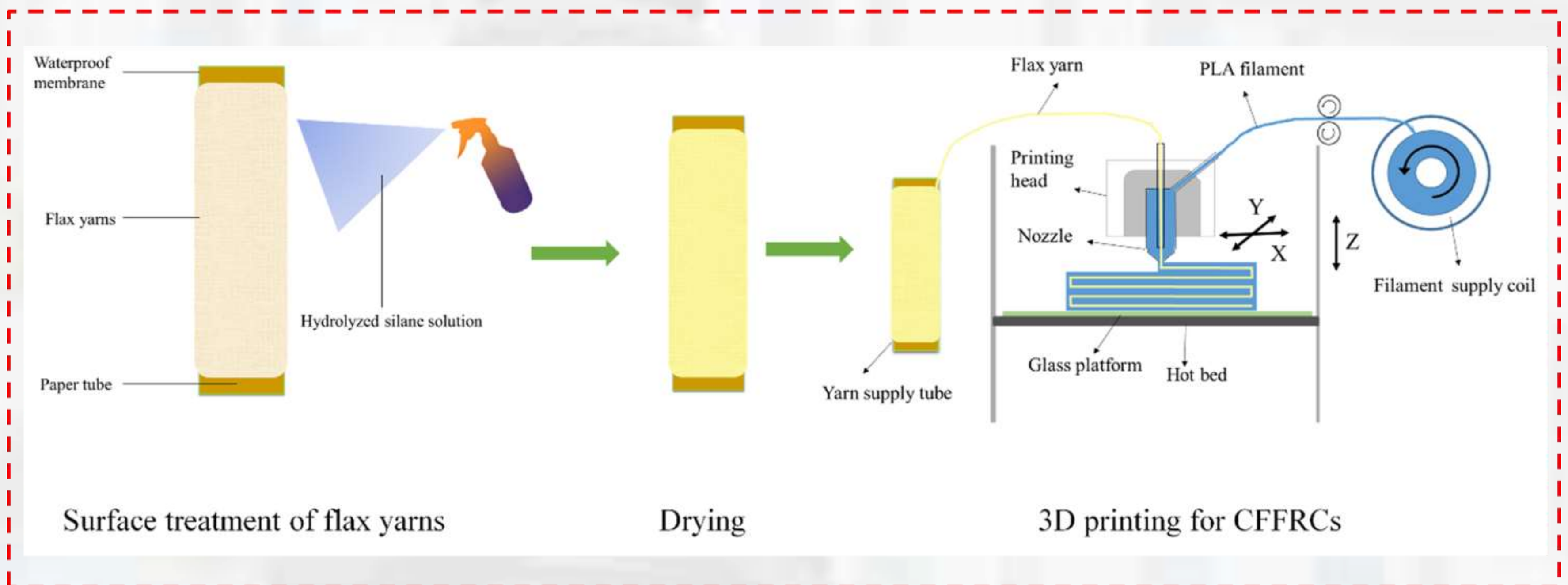

Fig.1 Schematic of fabrication process of 3D printing of CFFRCs.

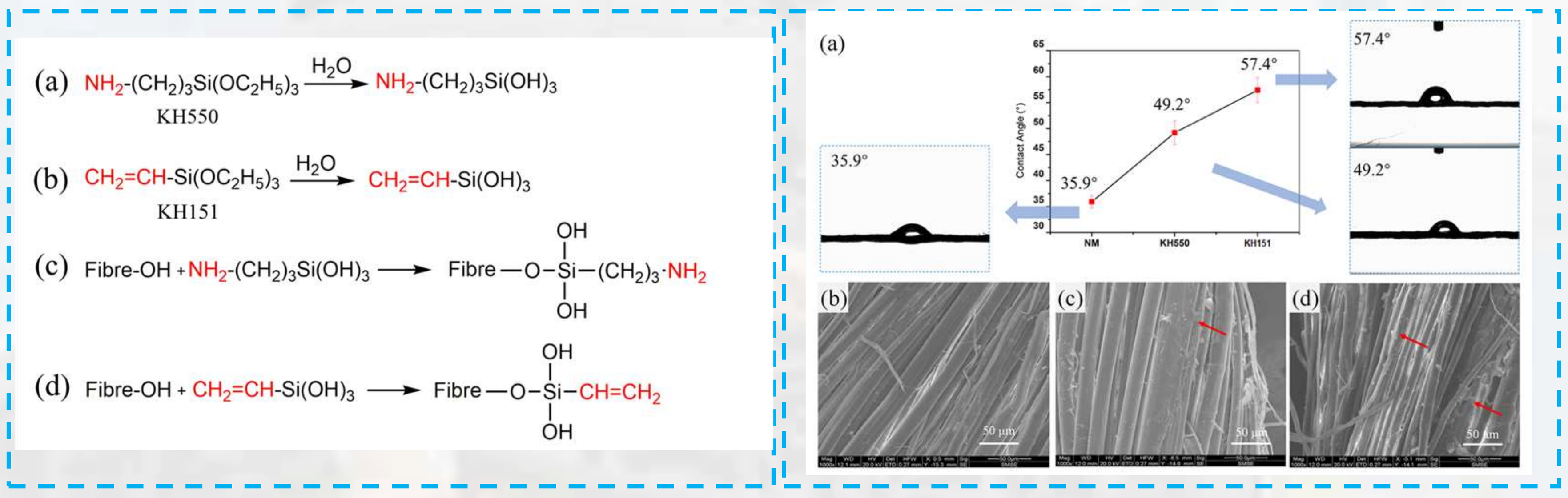

Fig.2 Left: Hydrolytic process of (a) silane KH550 and (b) silane KH151, and (c, d) condensation reaction between flax fibre and silanol. Right: (a) Measured contact angle and (b) surface morphologies of untreated, (c) KH550 treated and (d) KH151 treated flax yarns. The red arrows indicate the attached silane.

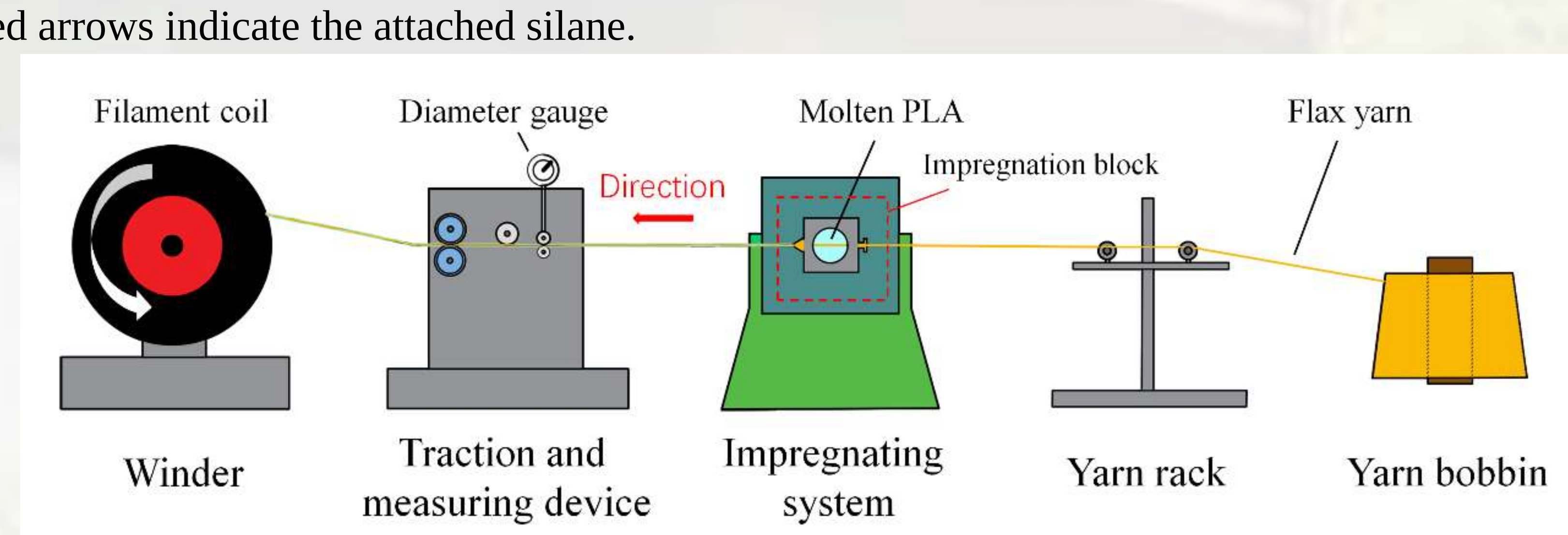

Fig.3 Schematic diagram of the fabrication process for pre-impregnated filaments.

Results/Discussion

Table.1 The delamination initiation $G_{Ic(I)}$ and propagation $G_{Ic(P)}$ values of 3DP CFFRCs with 25 vol%.

Specimens	$G_{Ic(I)}$	$G_{Ic(P)}$
untreated	1.33±0.15	1.83±0.30
KH550 treated	1.47±0.14	2.44±0.15
KH151 treated	1.64±0.30	2.91±0.36

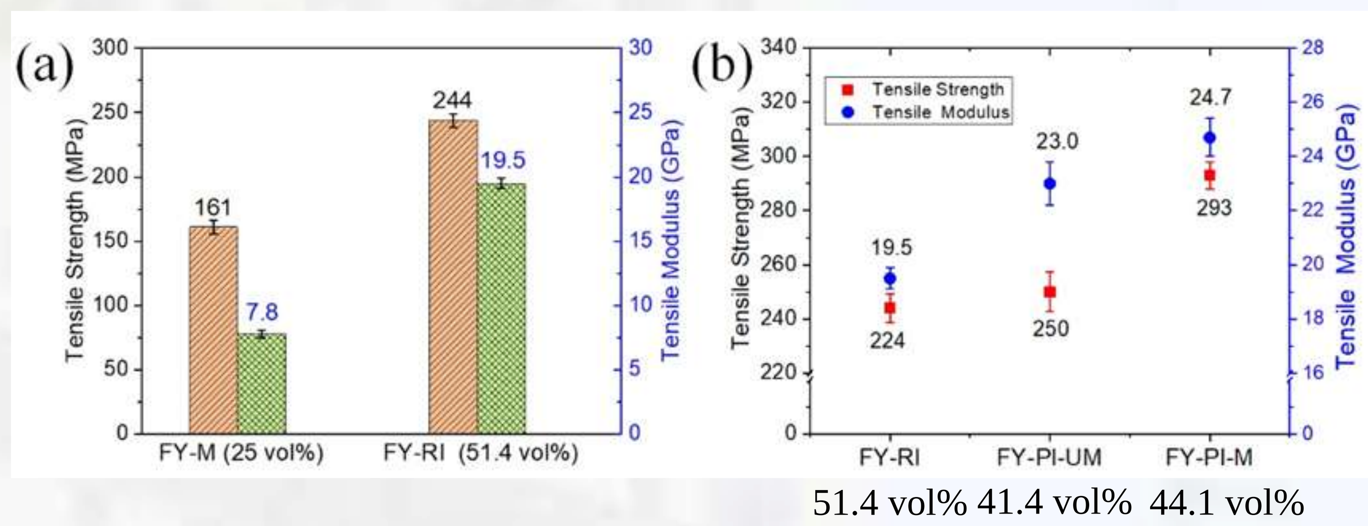

Fig.4 Tensile properties of (a) CFFRCs with different fibre volume fractions and (b) three types of CFFRCs

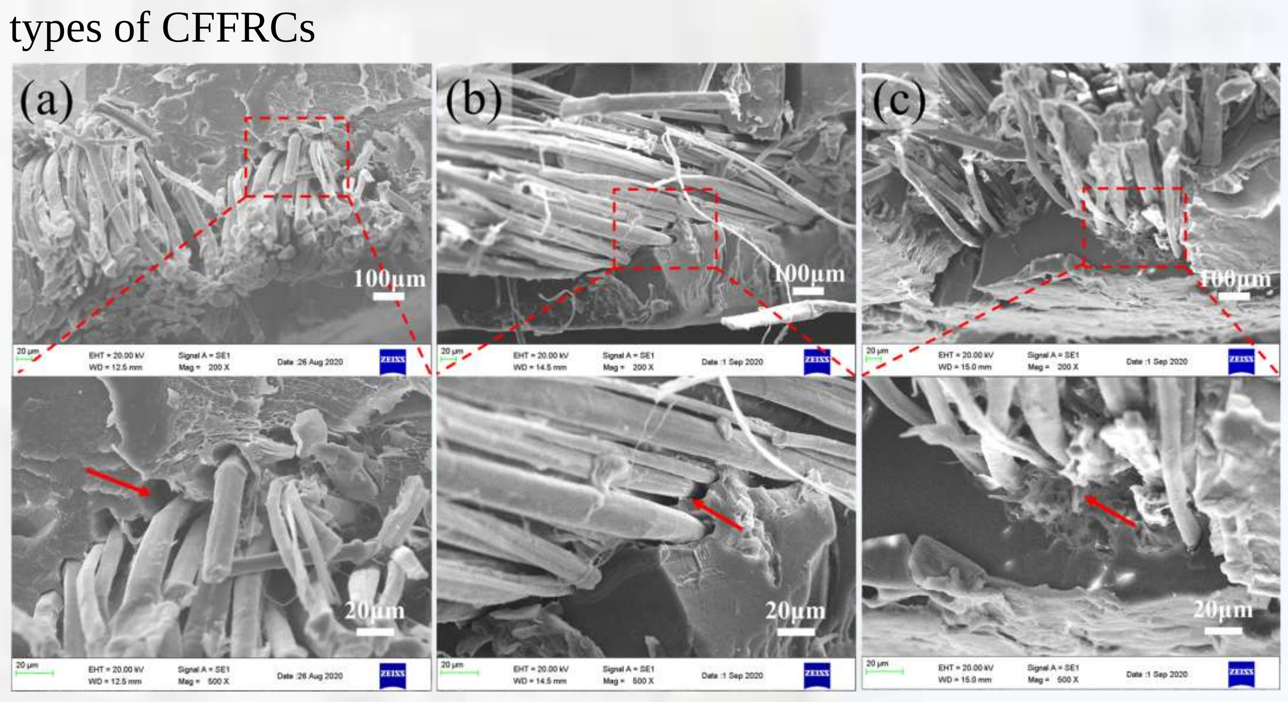

Fig. 5 Tensile fracture surface morphologies of (a) FY-RI, (b) FY-PI-UM, and (c) FY-PI-M. Red arrows indicate the interface between flax fibre yarn and PLA matrix.

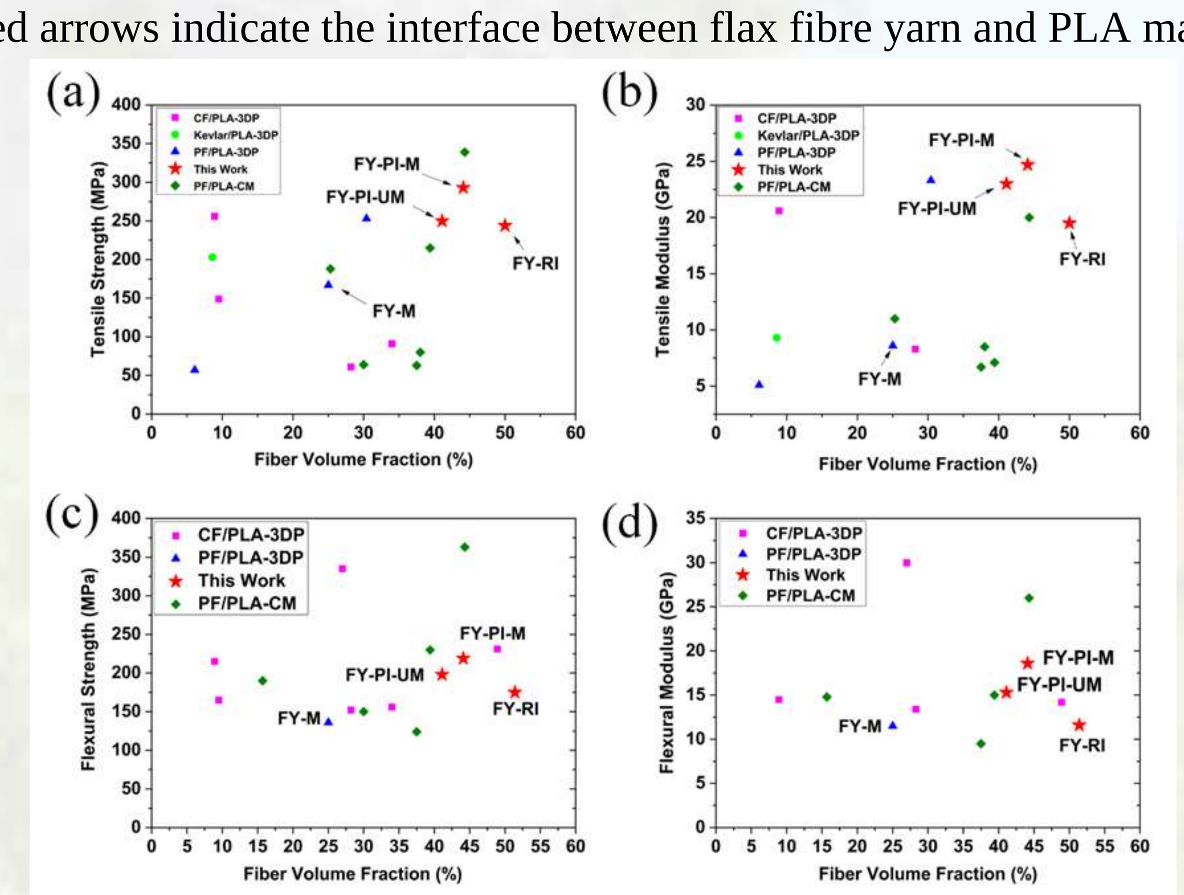

Fig.6 Comparison of mechanical properties of continuous fibre-reinforced PLA composites fabricated by 3D printing (3DP) and compression moulding (CM): (a-b) tensile properties, (c-d) flexural properties. PF represents plant fibre.

Conclusions

1. An efficient 3D printed plant yarn surface treatment process is proposed to improve mechanical properties of CFFRCs.
2. Improved fibre wettability helps to reduce voids and increase interfacial properties in CFFRCs arisen from low printing pressure and twisted structure of yarns.
3. The high fiber volume fraction and interfacial properties are beneficial to improve the mechanical properties of 3D printed CFFRCs.
4. The mechanical properties of the CFFRCs prepared by 3D printing in this work are comparable to those manufactured by compression moulding in literature.

Yu Long *et al.*, *Composites Part B: Engineering*. 2021
Yu Long *et al.*, Journal of Manufacturing Processes. 2023