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Mechanical and Biological Properties of Silk Fibroin/Carbon Nanotube Nanocomposite Films

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Abstract: Multi-walled carbon nanotubes (MWCNTs) were homogeneously dispersed in silk fibroin (SF) solutions at different compositions, and a simple solvent-casting method was used to fabricate SF/MWCNT films. Structure, viscosity, and mechanical properties of the SF/MWCNT nanocomposites were characterized by FTIR (Fourier Transform Infrared Spectroscopy), viscometry, and tensile testing. Fibroblast cells were used to examine cell viability and attachment to nanocomposite films. Compared to a pure SF film, adding just 0.5 % (w/w) of MWCNT to the SF matrix could enhance the Young's modulus and ultimate tensile strength by approximately 24 % and 39 %, respectively. In addition, with increasing -

atrix c%()-7(,)-6.e T0 Tc 48.524 0 Td(t)Tj-0.0132 Tc -0.0066 Tw -48.524 -1.111 Td[(c)-6.8(ells in)-6.6(the pr)-6.5(ese)-6.8(nce)-6.8(of)-6.8(M)-6.4

engineering. CNTs are one of the most useful nanoscale agents for material property reinforcement because of their extraordinary mechanical, electrical, and thermal properties [4-6]. CNTs have shown controversial and complex properties. Pristine CNTs have displayed cytotoxicity on certain cell lines, which can be attributed to the use of metal catalysts, such as nickel, during CNT fabrication [7]. Conversely, CNTs incorporated with biopolymers have shown great biocompatibility [8-10]. Despite the growing debate over the cytotoxicity of CNTs, these previous publications demonstrate why interest in this field has doubled in recent years [11].

Silk is a natural protein that has been widely used as a biomaterial for many years. Due to its flexible nature, biocompatibility, and

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Silk Fibroin Purification

q k r ck r r r
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r , h r c k r 9.
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r r . h c c r r
c r r
k r r r h r c . h c c -
r h q % (/). h
c c r r h h r
k r r .

SF/MWCNT Nanocomposite Film Fabrication

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r 0 , h c h. h
c r q ch r .
r ch r r
h h r k
r r . r c /
, h r c
r r r h r r r r
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. 0 - . r -

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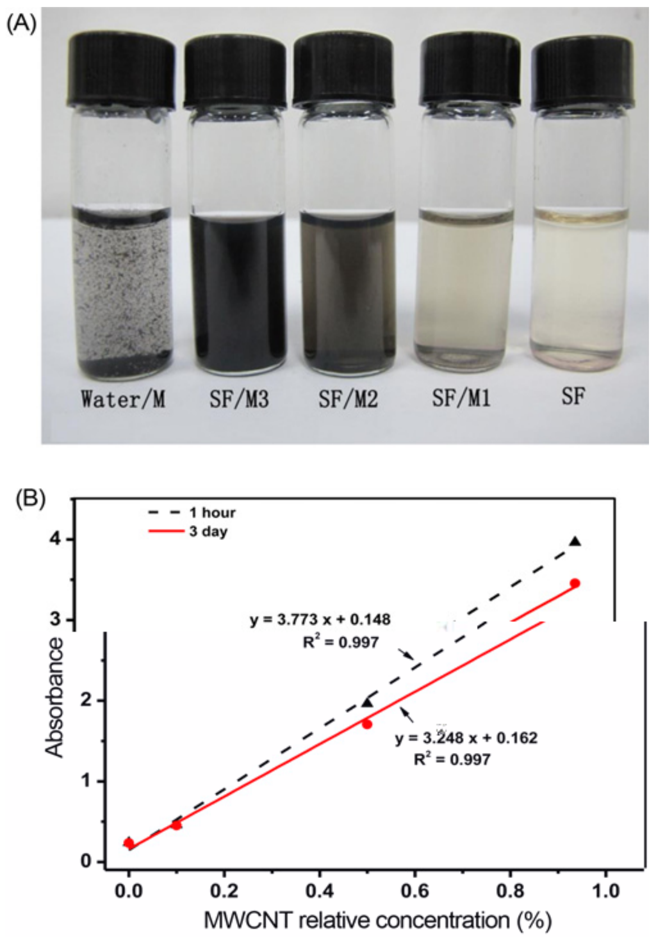


Figure 1. (A) SF/MWCNT nanocomposite solutions of different MWCNT compositions (M1, M2, M3 represent 0.1 % (w/w) MWCNT, 0.5 % (w/w) MWCNT, 1 % (w/w) MWCNT respectively.) after 3 days, and MWCNTs in water (Water/M) after only 1 h. (B) Absorbance of SF/MWCNT solutions as a function of relative MWCNT concentration of after 1 h and 3 days in a stationary position.

r r' h h r c . h r c q r r r r , h h r. h h r c , h r r ch q , ck c r. h c r c , r , r , r cc r r h r ck . h r ( ), r r h r r c r c r h r , h ch r h r rk , . r h r r , h r r c r h r ch r 9 . h c h r r r k r .

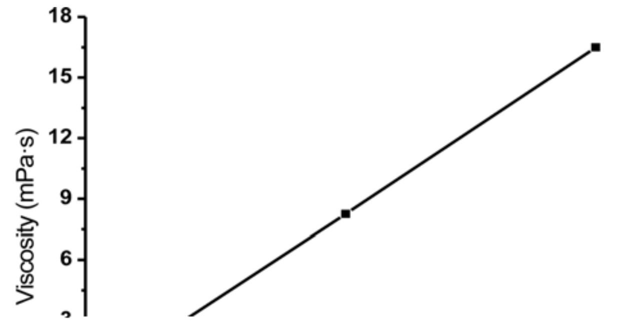


Figure 2. The relationship between viscosity and MWCNT concentration.

Viscosity

k r / c h r c c r r 0 . r r r r c r , h c ch r r r c r. r r h c c h c . h 0. % h r rk c h c . r, cr h c , c c cr . % h cr h c . h h c h r c h / h r r . - c r r c c r r r ch h r r r rc .

Secondary Structure of SF/MWCNT Films

r r k h c k r r c r , h c r r c r h r - c r c . cc r h r . r , h r r c r r c k c r h r (9 - 0 c $^{-1}$) r r r (r ( )-( )). k r c r c r r c r c , α-h c , β- h , β- r . h q h r c r r r r h ch c r r . h r (, , ,), h h c c cr r 0 0. % (/), h rc β- h cr h β- r r c r cr c (<0.0). h h cr c c 0. % (/), h rc β- h β- r c ch , h , h rc α-h c r c cr c (<0.0). h h c c r ch 0. % (/), h β- h r c r cr r . %

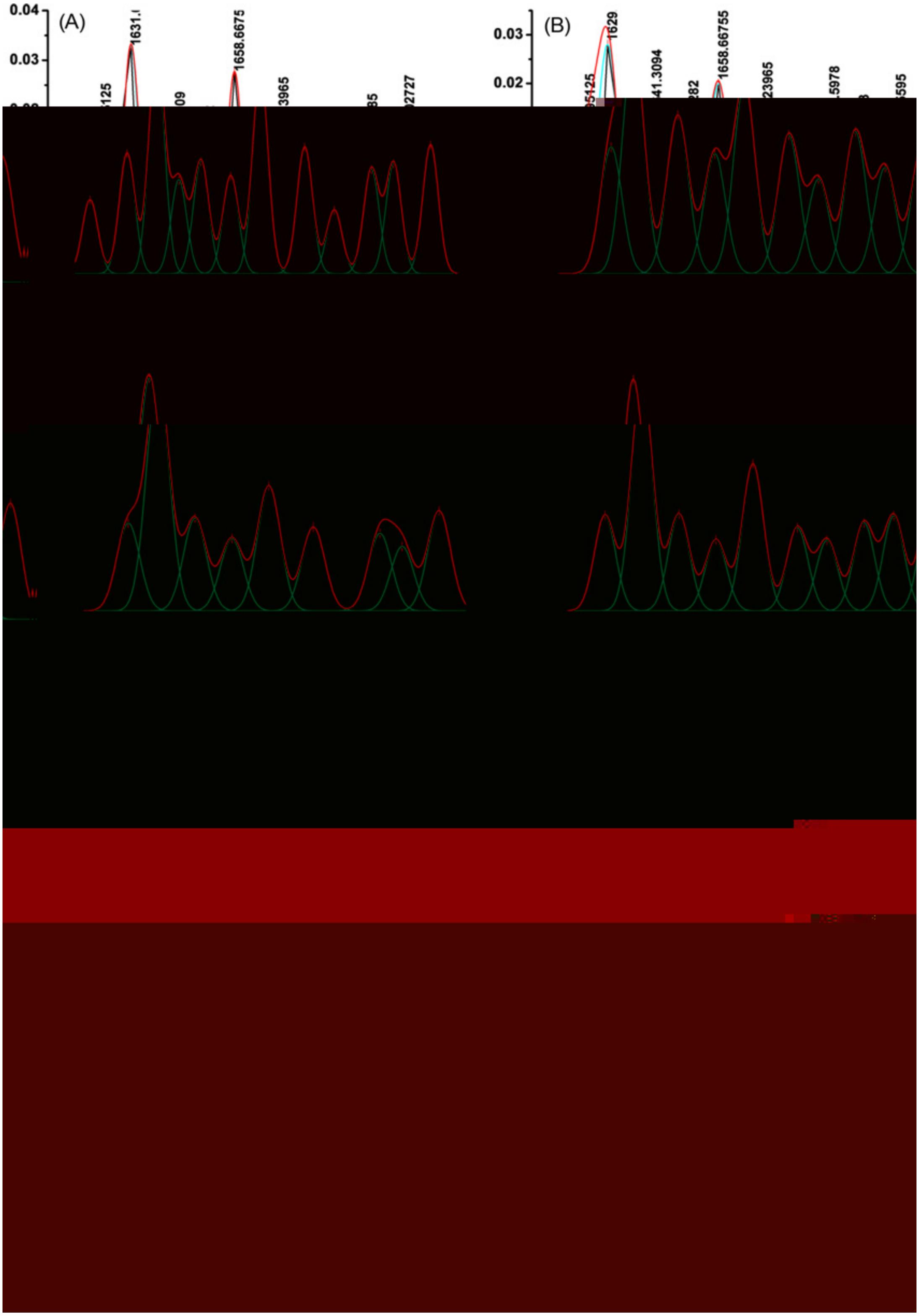
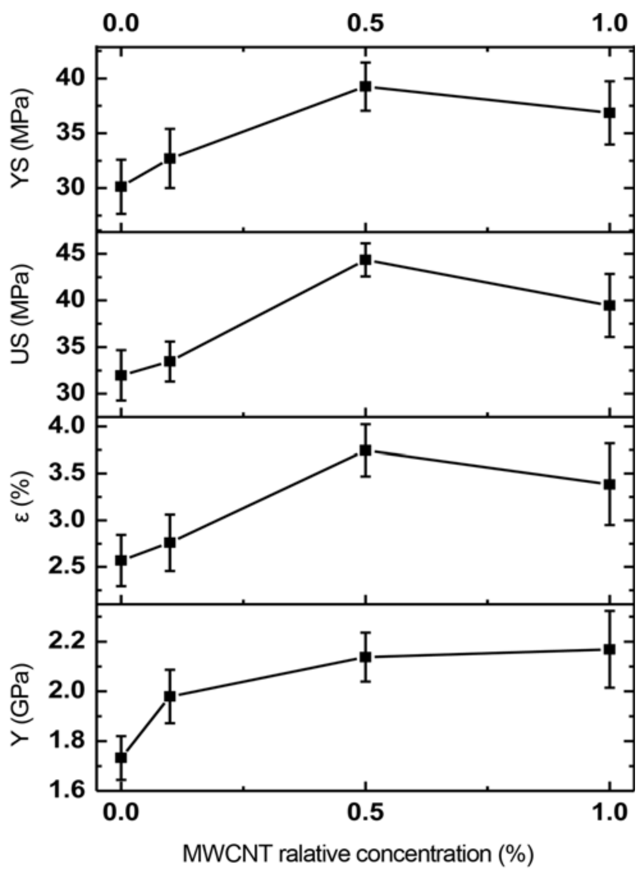


Figure 3. FT-IR spectra and secondary structure contents of silk films fabricated at various MWCNT concentration; (A) FT-IR spectra of SF (pure silk film), (B) FT-IR spectra of SF/M1 (SF/0.1 % (w/w) MWCNT film), (C) FT-IR spectra of SF/M2 (SF/0.5 % (w/w) MWCNT film), (D) FT-IR spectra of SF/M3 (SF/1 % (w/w) MWCNT film), (E) α-helices structure content, (F) β-sheets structure content, (G) random coils structure content, and (H) turns structure content. *Significant difference between groups (* <0.01). The data represent mean±SD (=4).

Mechanical Properties of SF/MWCNT Films



Biocompatibility of SF/MWCNT Films

Conclusion

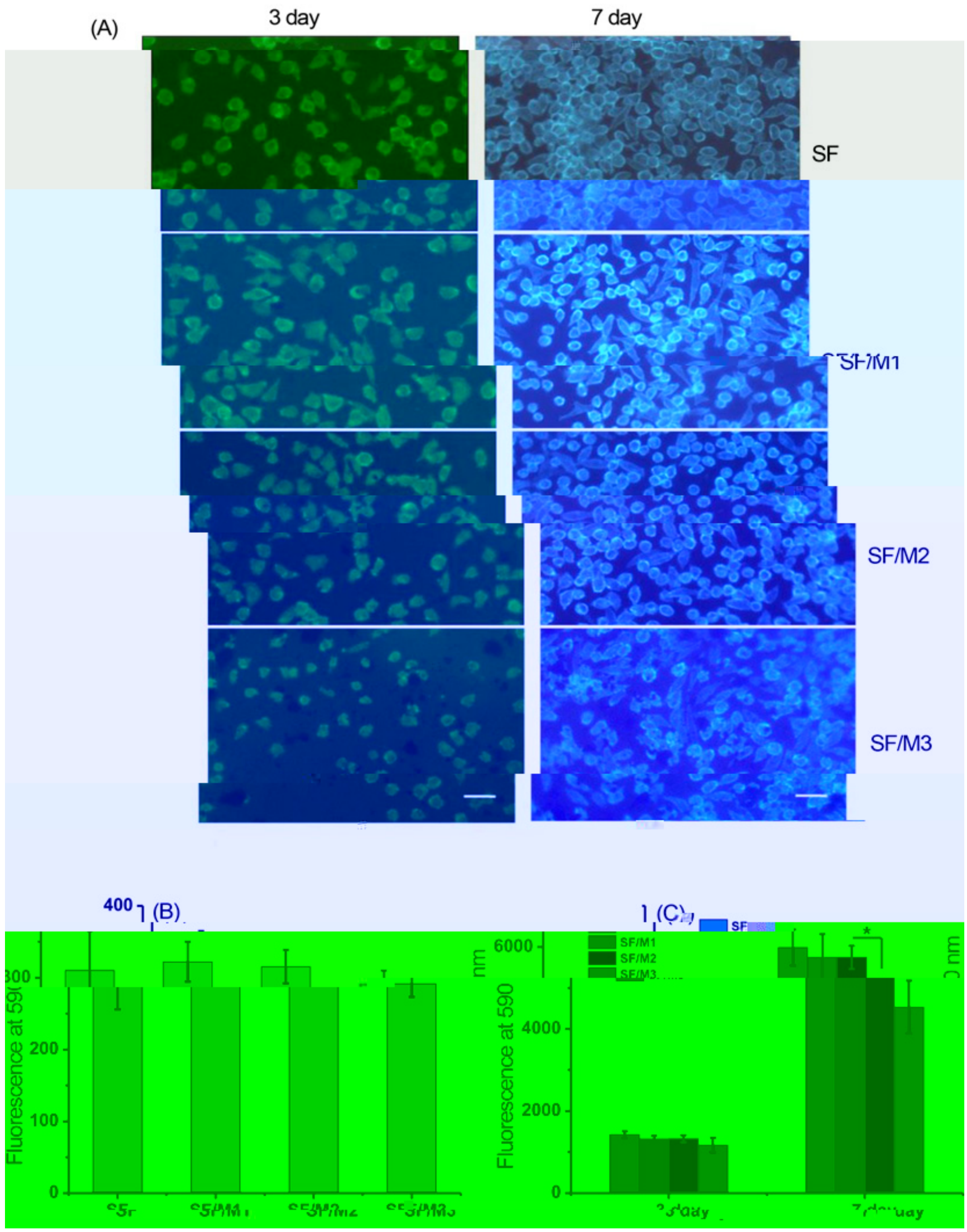


Figure 5. Attachment and proliferation of fibroblast cells on nanocomposite surfaces; (A) microscopic images of cultured fibroblast cells on SF (pure silk film), SF/M1 (SF/0.1 % (w/w) MWCNT film), SF/M2 (SF/0.5 % (w/w) MWCNT film) and SF/M3 (SF/1 % (w/w) MWCNT film) after 3 days and 7 days, (B) 3 h attachment of fibroblast cells on nanocomposite films, and (C) 3 day and 7 day proliferation of fibroblast cells on nanocomposite films. *Significant difference between groups (* <0.05). The data represent mean±SD (=4).

c , c r r / - r r . 0. % (/) h r
c . r c h , h c h ’ r h
h r r % 9 %, r c . h cr
r . c c r h c c c r r 0 % (/), h rc
c c r r c r , c , ch c β- h r c r cr c r . %

. %. r c ’ ch r r c r c r . c c c r r . r , h h /\ c h h c ch c c r - r .

Acknowledgements

h r h r rk (- - 0 0) r h r c r rch ( ) r c c h (9).

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