Effect of Chemical and Physical Cross-linking on Tensile Characteristics of Solution-Blown Soy Protein Nanofiber Mats

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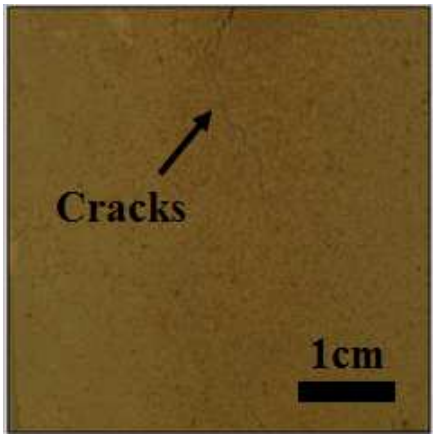

Figure S1. Soy protein/nylon 6 (50/50 wt/wt %) nanofiber mat cross-linked at 80 wt/wt% glyoxal/nanofiber mat ratio. Macroscopic cracks are visible in the sample.

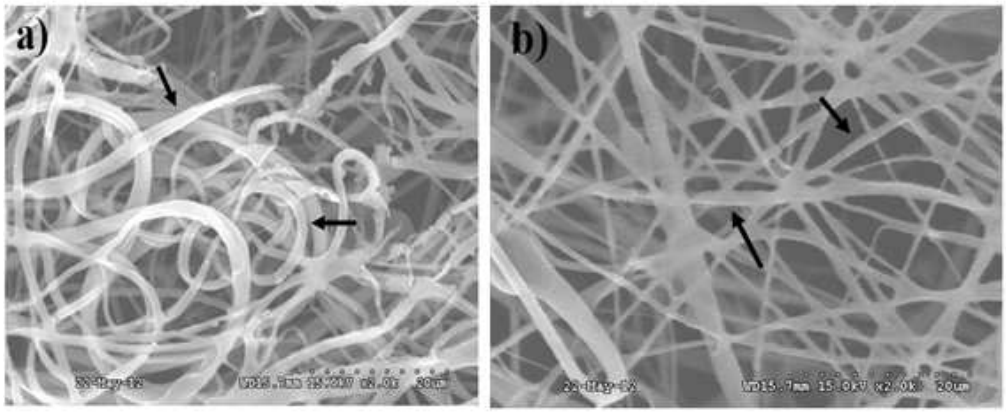

Figure S2. SEM images of soy protein/nylon 6 nanofibers after pre-wetting and wet conglutination under the load of 150 g. Nanofibers kept their individuality under 6 kPa pressure (as shown by arrows).

Table S1

Young's modulus, yield stress, and maximum strain and stress at rupture for soy protein/nylon 6 (50/50 wt/wt%) nanofiber mats cross-linked at different cross-linker (formaldehyde, glyoxal, zinc sulfate or sodium borohydride) to nanofiber mat mass ratios.

Cross-linking agent	Cross-linker/mat ratio (wt/wt %)	Average thickness of the samples (mm)	Average width of the samples (mm)	Average Young's modulus E (MPa)	Average yield stress Y (MPa)	Average specific strain energy U (MPa)	Average maximum strain at rupture $\varepsilon_{rupture}$(%)
Formaldehyde	0	0.2	7.04	16.51±2.39	0.29±0.11	9.63±2.88	0.38±0.08
	5	0.2	6.85	36.15±15.49	0.52±0.20	4.05±1.71	0.80±0.30
	10	0.2	7.66	57.55±14.25	0.80±0.21	4.79±2.11	1.28±0.35
	20	0.2	8.09	66.81±16.05	0.87±0.22	3.47±2.00	1.18±0.41
Glyoxal	0	0.2	8.36	13.87±6.36	0.37±0.13	7.65±3.26	0.56±0.17
	5	0.2	7.62	54.31±15.77	0.67±0.13	4.39±1.49	1.09±0.21
	10	0.2	7.38	66.95±17.48	0.70±0.15	3.24±1.23	1.14±0.22
	20	0.2	7.23	59.22±17.16	0.67±0.17	3.74±1.50	1.07±0.26
Zinc sulfate	0	0.2	8.84	13.56±5.44	0.53±0.17	4.32±1.54	0.54±0.14
	5	0.2	7.94	37.25±12.45	0.49±0.13	1.96±0.49	0.59±0.17
	10	0.2	6.58	48.82±13.37	0.56±0.16	1.31±0.48	0.62±0.16
	20	0.2	6.35	93.60±15.43	0.73±0.13	0.71±0.32	0.67±0.20
Sodium borohydride	0	0.2	7.12	16.43±4.09	0.39±0.20	3.63±0.61	0.46±0.08
	5	0.2	7.78	84.90±24.36	0.62±0.16	0.82±0.27	0.67±0.13
	10	0.2	8.21	90.88±20.24	0.52±0.14	0.53±0.16	0.53±0.07
	20	0.2	8.09	121.74±8.05	0.73±0.12	0.43±0.09	0.69±0.05

Table S2

Average mechanical properties for formaldehyde-cross-linked soy protein/nylon 6 (40/60 wt/wt %) nanofiber mats. One half of the samples were only cross-linked with formaldehyde. The other half was exposed to heating for 20 min at 80 °C on a glass slide on a hotplate after cross-linking with formaldehyde, glyoxal, or zinc sulfate.

Cross-linking agent	Cross-linking ratio (wt/wt %)	Untreated samples				Thermally-treated samples			
		Average Young's modulus E (MPa)	Average yield stress Y (MPa)	Average maximum strain at rupture $\varepsilon_{rupture}$ (%)	Average maximum stress at rupture $\sigma_{xx,rupture}$ (MPa)	Average Young's modulus E (MPa)	Average yield stress Y (MPa)	Average maximum strain at rupture $\varepsilon_{rupture}$ (%)	Average maximum stress at rupture $\sigma_{xx,rupture}$ (MPa)
Formaldehyde	1	21.84±8.06	0.31±0.08	2.60±0.79	0.55±0.23	13.48±2.87	0.32±0.04	4.66±0.42	0.50±0.07
	5	20.59±5.28	0.30±0.07	2.43±0.68	0.39±0.07	17.58±4.63	0.33±0.04	3.35±0.84	0.42±0.07
	10	52.42±15.32	0.70±0.13	4.17±1.64	1.10±0.19	36.16±8.91	0.86±0.36	5.87±2.42	1.09±0.15
	50	36.95±10.83	0.39±0.10	2.08±0.66	0.55±0.10	24.92±7.55	0.46±0.11	4.24±1.41	0.69±0.14
Glyoxal	1	26.89±3.41	0.42±0.03	2.95±0.53	0.60±0.04	16.08±7.18	0.52±0.20	4.03±0.81	0.55±0.13
	5	29.86±13.68	0.37±0.07	1.81±0.54	0.43±0.07	19.12±3.65	0.41±0.03	3.88±1.37	0.58±0.07
	10	123.74±21.75	0.84±0.18	0.87±0.38	0.99±0.32	89.10±32.97	1.01±0.17	1.16±0.56	1.04±0.50
	50	173.50±28.12	1.50±0.05	0.30±0.08	0.67±0.21	118.43±36.17	1.17±0.33	0.35±0.16	0.54±0.22
Zinc sulfate	1	27.93±7.20	0.31±0.09	2.03±0.65	0.44±0.12	21.49±6.32	0.38±0.11	2.61±0.69	0.46±0.09
	5	18.28±7.46	0.29±0.09	2.50±0.93	0.36±0.06	14.75±4.00	0.33±0.03	3.52±0.85	0.43±0.07
	10	116.28±17.52	1.10±0.28	1.32±0.47	1.39±0.38	87.92±14.28	0.96±0.11	1.96±0.80	1.28±0.34
	50	63.27±24.46	0.32±0.09	0.57±0.18	0.36±0.13	55.56±17.00	1.39±0.48	1.15±0.42	0.61±0.23

Table S3

Overall mechanical properties of thermally bonded soy protein/nylon 6 (40/60 wt/wt %) nanofibers in comparison with those of the non-bonded ones.

Sample	Average thickness of the samples (mm)	Average width of the samples (mm)	Average Young's modulus E (MPa)	Average yield stress Y (MPa)	Average specific strain energy U (MPa)	Average maximum strain at rupture $\varepsilon_{rupture}$ (%)	Average maximum stress at rupture $\sigma_{xx,rupture}$ (MPa)
Thermally-bonded nanofibers	0.22	11.38	18.76±5.17	0.61±0.16	8.09±2.69	6.86±1.17	0.92±0.23

Non-bonded nanofibers	0.22	12.17	12.89±5.34	0.38±0.09	6.34±1.87	8.19±1.71	0.6±0.16

Table S4

Average mechanical properties of pre-wetted, wet-conglutinated soy protein/nylon 6 (40/60 wt/wt %) nanofibers in comparison with the corresponding untreated ones.

Sample	**Average thickness of the samples (mm)**	**Average width of the samples (mm)**	**Average Young's modulus E (MPa)**	**Average yield stress Y (MPa)**	**Average specific strain energy U (MPa)**	**Average maximum strain at rupture $\varepsilon_{rupture}$ (%)**	**Average maximum stress at rupture $\sigma_{xx,rupture}$ (MPa)**
Wet-conglutinated nanofibers	0.16	9.11	25.33±7.15	0.65±0.12	9.34±2.75	7.21±1.62	1.03±0.20
Untreated nanofibers	0.18	8.99	15.33±4.81	0.61±0.26	7.08±2.02	6.31±1.41	0.76±0.20

Table S5

Average mechanical parameters of soy protein/nylon 6 (40/60 wt/wt %) nanofiber mats aged in hot water (80 °C) for 1 h in comparison with the corresponding untreated samples.

Sample	**Average thickness of the samples (mm)**	**Average width of the samples (mm)**	**Average Young's modulus E (MPa)**	**Average yield stress Y (MPa)**	**Average specific strain energy U (MPa)**	**Average maximum strain at rupture $\varepsilon_{rupture}$(%)**	**Average maximum stress at rupture $\sigma_{xx,rupture}$ (MPa)**

Aged nanofibers	0.18	5.06	21.47±6.34	0.44±0.18	12.15±2.52	11.49±3.44	1.09±0.21
Untreated nanofibers	0.17	10.43	18.64±1.61	0.47±0.06	5.57±1.69	5.95±1.04	0.73±0.09