# Study on the Microstructure of Poly(Amide 6-Ether) Copolymers and Application in Elastic Fibers

**Yixiao Yu [1], Weicheng Yang [1], Yuhao Wu [1], Shengming Zhang [1*], Chengzhen Meng [1], Peng Ji [2*], Chaosheng Wang [1], Huaping Wang [3*]**

1 State Key Laboratory of Advanced Fiber Materials, College of Materials Science and Engineering, Donghua University, Shanghai 201620, China. lydiayyx@163.com; 2217389849@qq.com; wuyuhao0616@163.com; smzhang@dhu.edu.cn; 1222706@mail.dhu.edu.cn; cswang@dhu.edu.cn;

2 Innovation Center for Textile Science and Technology, Donghua University. Shanghai 201620, P. R. China. jipeng@dhu.edu.cn.

3 Key Laboratory of High Performance fibers & products, Ministry of Education, Donghua University, Shanghai, 201620, P. R. China. wanghp@dhu.edu.cn.

**Corresponding Authors**

Shengming Zhang* - State Key Laboratory of Advanced Fiber Materials, College of Materials Science and Engineering, Donghua University, Shanghai 201620, P. R. China. Email: smzhang@dhu.edu.cn.

Peng Ji* - Innovation Center for Textile Science and Technology, Donghua University. Shanghai 201620, P. R. China. Email: jipeng@dhu.edu.cn.

Huaping Wang* - Key Laboratory of High Performance fibers & products, Ministry of Education, Donghua University, Shanghai, 201620, P. R. China. Email: wanghp@dhu.edu.cn..

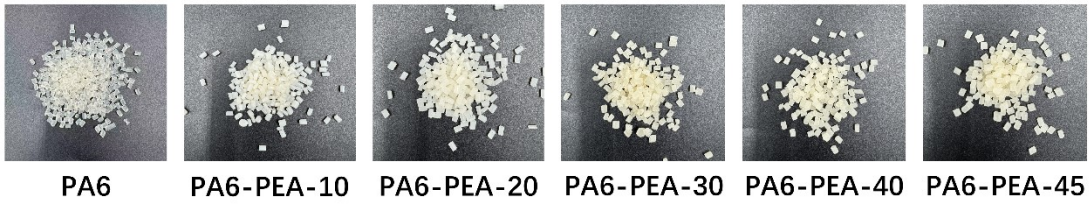


**Figure S1.** The pellets of PA6-PEA copolymers.

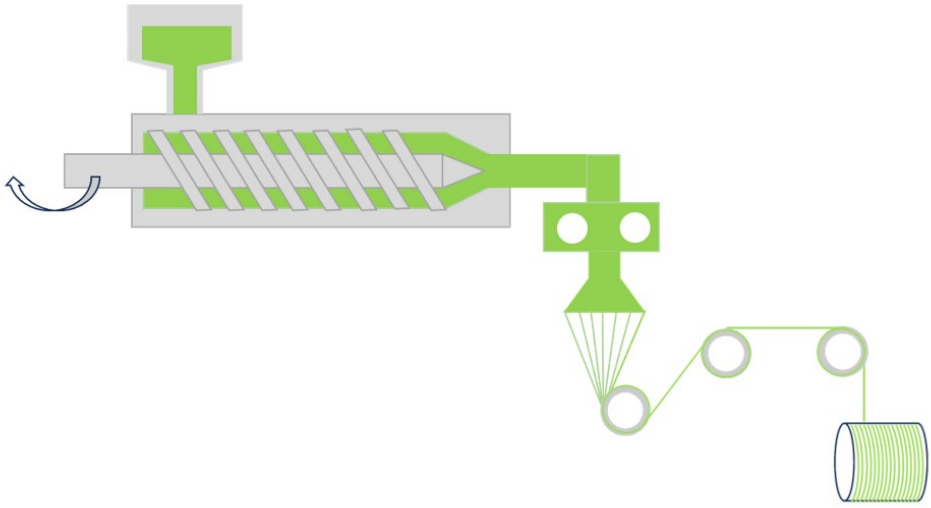

**Figure S2.** The schematic diagram of the melt spinning process.

**Table S1.** Spinning parameters of PA6-PEA elastic fibers.

| Item | Parameters | | | |
|---|---|---|---|---|
| Screw temperature (°C) | I | II | III | IV |
| | 255 | 270 | 265 | 265 |
| Metering pumps temperature (°C) | 265 | | | |
| Spinning components temperature (°C) | 265 | | | |
| Number of spinneret holes | 36 | | | |
| Spinneret aperture (mm) | 0.4 | | | |
| Spinning speed (m/min) | 800 | | | |


**Figure S3.** PA6 fiber and PA6-PEA elastic fiber.

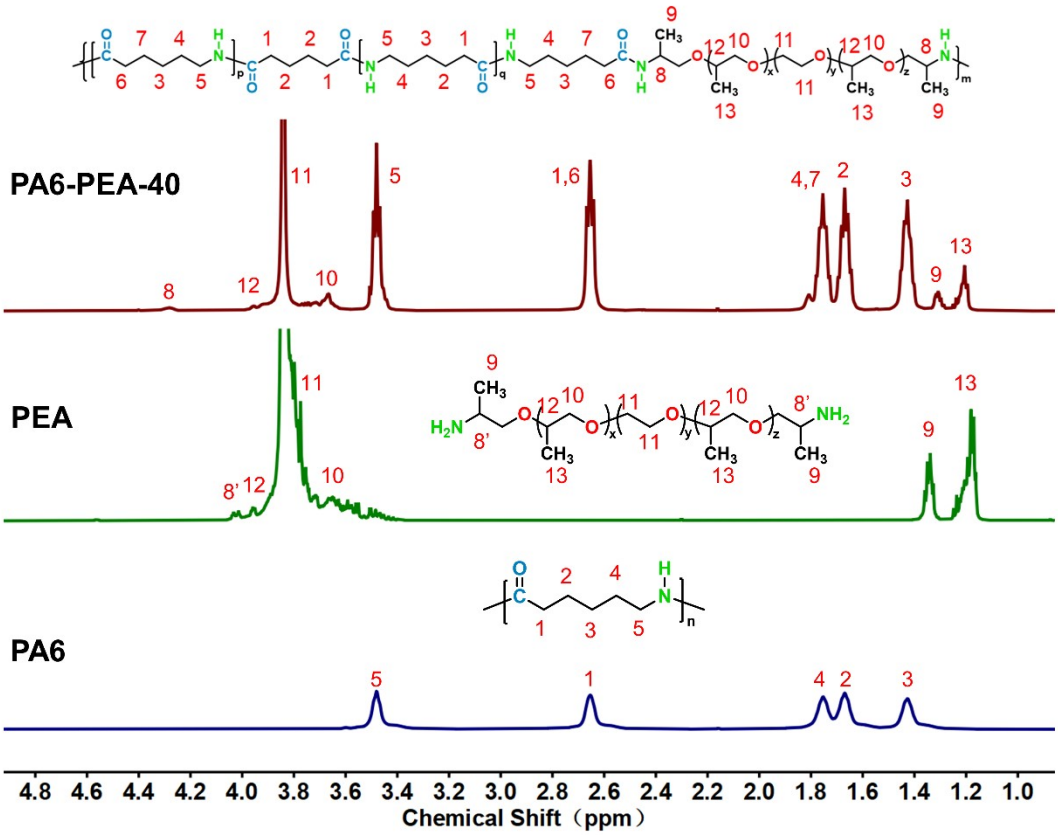


**Figure S4**. $^{1}$H NMR spectra of PA6-PEA-40, PEA and PA6.

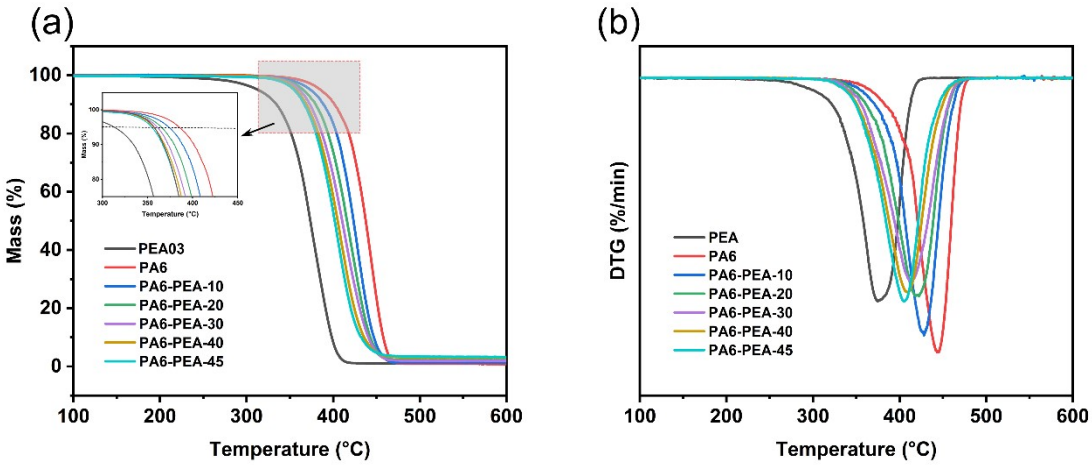


**Figure S5.** Thermal properties curves of PA6-PEA copolymers: (a) Thermal gravimetric curve and (b) DTG curve.

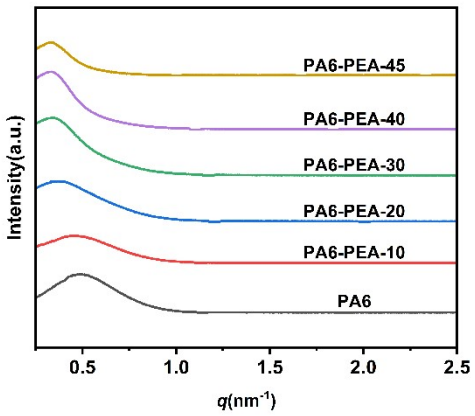


Figure S6. SAXS profiles of PA6-PEA copolymer.

Table S2. long period (*D*) of PA6-PEA copolymer

| Sample | PA6 | PA6-PEA-10 | PA6-PEA-20 | PA6-PEA-30 | PA6-PEA-40 | PA6-PEA-45 |
|---|---|---|---|---|---|---|
| *D* (nm) | 12.98 | 13.62 | 16.93 | 18.42 | 18.64 | 18.92 |

**Table S3.** The mechanical property parameters of PA6-PEA copolymers.

| Sample | Elastic Modulus (MPa) | Tensile Strength (MPa) | Elongation at Break (%) |
|---|---|---|---|
| PA6 | 1141.89±92.60 | 55.30±0.52 | 211.80±8.68 |
| PA6-PEA-10 | 1100.32±48.59 | 51.00±1.11 | 57.38±4.27 |
| PA6-PEA-20 | 692.64±54.26 | 43.49±2.35 | 259.91±15.54 |
| PA6-PEA-30 | 360.79±4.45 | 42.87±2.43 | 349.69±11.61 |
| PA6-PEA-40 | 174.99±4.60 | 37.08±1.17 | 460.45±18.59 |
| PA6-PEA-45 | 123.16±5.99 | 25.99±2.11 | 380.03±12.69 |

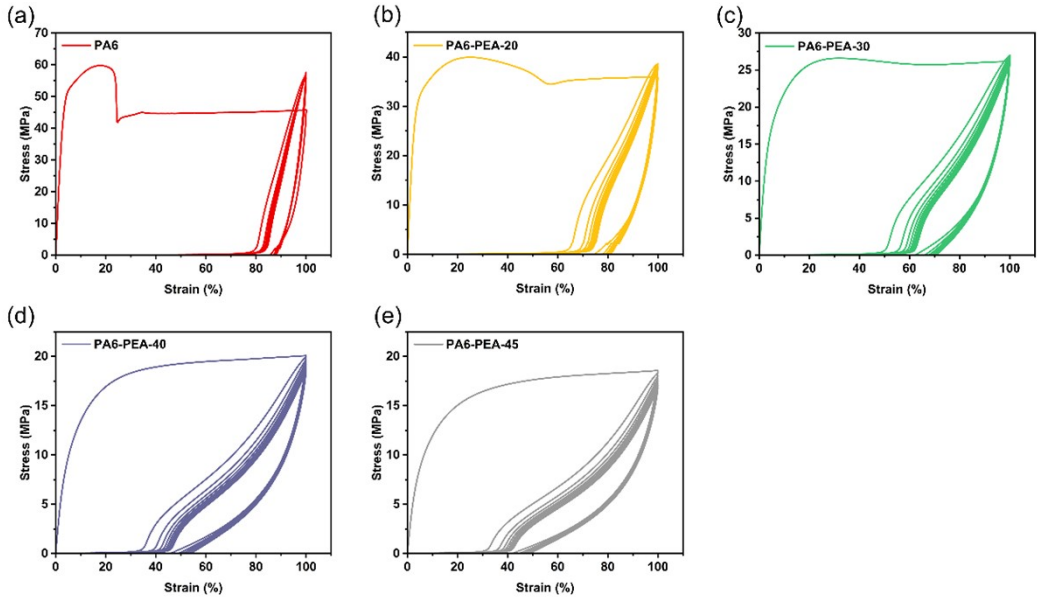


**Figure S7.** Cyclic tensile curves of PA6 and PA6-PEA copolymers after 10 cycles at 100% strain.

**Table S4.** Elastic recovery ratio of PA6-PEA copolymers after 10 cycles of stretching.

| Sample | Elastic recovery ratio (%) |
|---|---|
| PA6 | 14.81 |
| PA6-PEA-20 | 19.41 |
| PA6-PEA-30 | 29.92 |
| PA6-PEA-40 | 46.56 |
| PA6-PEA-45 | 51.45 |

**Table S5.** Dissipated energy data of PA6-PEA copolymers after 1st, 3rd, 5th, 7th, 9th and 10th cycles.

| Sample | Dissipated energy ($kJ/m^3$) | | | | | |
|---|---|---|---|---|---|---|
| | 1th | 3th | 5th | 7th | 9th | 10th |
| PA6 | 4500.35 | 331.96 | 294.27 | 278.86 | 269.74 | 266.00 |
| PA6-PEA-20 | 3363.39 | 425.91 | 355.86 | 327.27 | 310.07 | 303.71 |
| PA6-PEA -30 | 2224.86 | 377.47 | 314.60 | 287.35 | 270.51 | 264.01 |
| PA6-PEA -40 | 1497.72 | 296.37 | 246.41 | 223.87 | 209.51 | 204.04 |
| PA6-PEA -45 | 1343.23 | 253.56 | 211.13 | 191.90 | 179.75 | 175.11 |

**Table S6.** Hysteresis ratio data of PA6-PEA copolymers after 1st, 3rd, 5th, 7th, 9th and 10th cycles.

| Sample | Hysteresis ratio (%) | | | | | |
|---|---|---|---|---|---|---|
| | 1th | 3th | 5th | 7th | 9th | 10th |
| PA6 | 96.27 | 59.12 | 56.02 | 54.82 | 54.14 | 53.84 |
| PA6-PEA-20 | 93.42 | 64.42 | 60.83 | 59.34 | 58.41 | 58.06 |
| PA6-PEA -30 | 89.66 | 60.73 | 57.00 | 55.34 | 54.27 | 53.85 |
| PA6-PEA -40 | 84.07 | 52.08 | 48.28 | 46.42 | 45.17 | 44.68 |
| PA6-PEA -45 | 82.74 | 48.45 | 44.64 | 42.79 | 41.56 | 41.07 |

**Table S7.** Water absorption diffusion coefficient of PA6 and PA6-PEA copolymers.

| Sample | D ($mm^2/s$) |
|---|---|
| PA6 | $4.25\times10^{-7}$ |
| PA6-PEA-20 | $6.65\times10^{-6}$ |
| PA6-PEA-30 | $1.68\times10^{-5}$ |
| PA6-PEA-40 | $2.77\times10^{-5}$ |
| PA6-PEA-45 | $3.31\times10^{-5}$ |

**Table S8.** Mechanical properties of PA6 fiber and PA6-PEA elastic fibers.

| Sample | | Strength (cN/dtex) | Elongation at Break (%) | Modulus (cN/dtex) |
|---|---|---|---|---|
| fPA6 | DR=1.5 | 1.73±0.19 | 172.57±12.95 | 9.85±0.69 |
| | DR=2.0 | 2.33±0.04 | 114.62±6.75 | 15.83±0.75 |
| | DR=2.5 | 3.01±0.14 | 79.88±4.73 | 22.13±2.04 |
| | DR=3.0 | 3.86±0.10 | 38.76±4.14 | 40.57±1.65 |
| fPA6-PEA-10 | DR=1.5 | 1.97±0.08 | 143.50±6.74 | 7.80±0.23 |
| | DR=2.0 | 2.55±0.09 | 75.93±3.30 | 12.61±1.64 |
| | DR=2.5 | 3.34±0.08 | 44.45±2.89 | 22.56±1.01 |
| | DR=3.0 | 3.98±0.11 | 18.85±1.23 | 29.87±3.31 |
| fPA6-PEA-20 | DR=1.5 | 1.80±0.05 | 116.80±5.03 | 7.12±0.64 |
| | DR=2.0 | 2.33±0.08 | 58.86±3.76 | 9.69±1.30 |
| | DR=2.5 | 3.23±0.10 | 28.59±2.29 | 15.88±1.46 |
| fPA6-PEA-30 | DR=1.5 | 1.57±0.02 | 79.41±2.47 | 4.32±0.31 |
| | DR=2.0 | 2.18±0.10 | 38.47±2.23 | 5.35±0.85 |

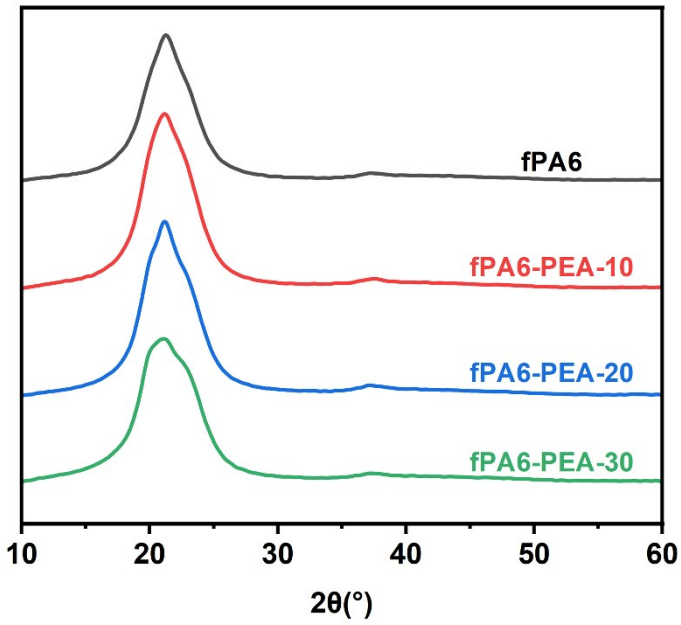


**Figure S8.** XRD spectrum of PA6 fiber and PA6-PEA elastic fibers at 2.0 times draft.

**Table S9.** Crystallinity of PA6 fiber and PA6-PEA elastic fibers at 2.0 times draft.

| Sample | Crystallinity (%) |
|---|---|
| fPA6 | 53.12 |
| fPA6-PEA-10 | 51.02 |
| fPA6-PEA-20 | 48.79 |
| fPA6-PEA-30 | 46.57 |

**Table S10.** Moisture regain data of PA6 fiber and PA6-PEA elastic fibers

| Sample | fPA6 | fPA6-PEA-10 | fPA6-PEA-20 | fPA6-PEA-30 |
|---|---|---|---|---|
| Moisture regain (%) | 4.98±0.19 | 5.91±0.21 | 6.62±0.12 | 7.23±0.56 |

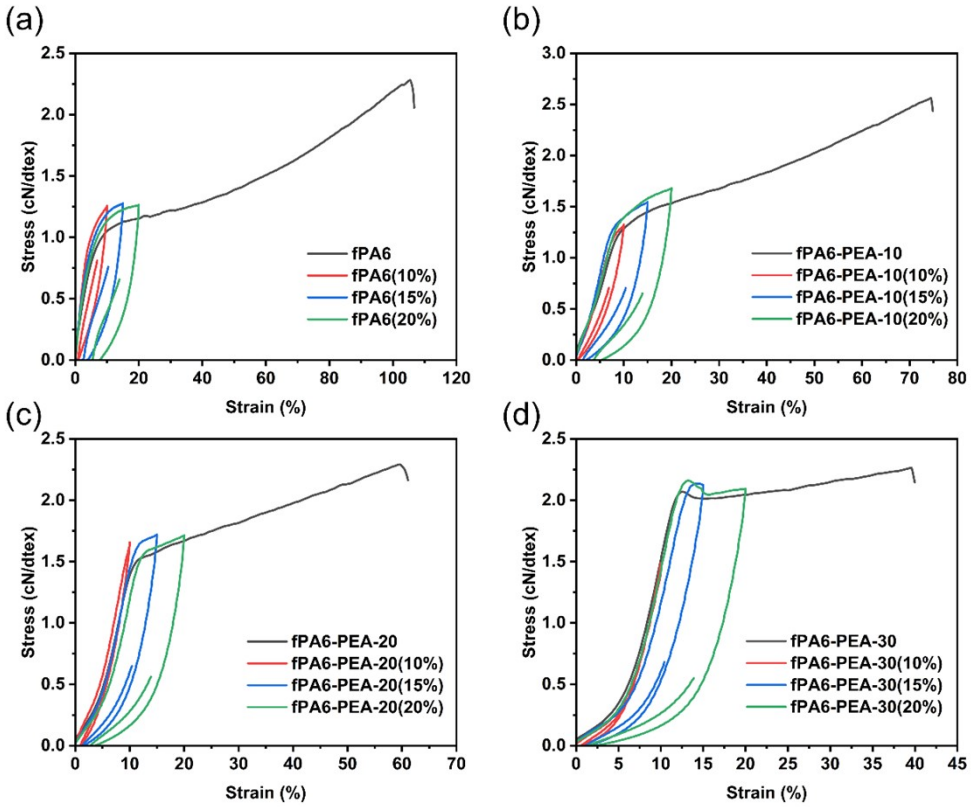


**Figure S9.** Stress-strain curves and Elastic recovery curves: (a) fPA6, (b) fPA6-PEA-10, (c) fPA6-PEA-20 and (d) fPA6-PEA-30.

**Table S11.** Elastic recovery rate of PA6 fiber and PA6-PEA elastic fibers.

| Sample | | 10% | 15% | 20% |
|---|---|---|---|---|
| fPA6 | DR=1.5 | 90.00±1.00 | 82.89±0.38 | 76.67±1.15 |
| | DR=2.0 | 92.33±0.58 | 83.33±1.15 | 74.33±1.89 |
| | DR=2.5 | 91.33±0.58 | 81.11±1.02 | 69.68±0.28 |
| | DR=3.0 | 94.67±0.58 | 80.44±0.77 | 71.75±0.35 |
| fPA6-PEA-10 | DR=1.5 | 91.67±0.58 | 90.89±0.38 | 85.50±1.80 |
| | DR=2.0 | 96.00±1.00 | 90.89±1.39 | 81.83±0.29 |
| | DR=2.5 | 96.00±2.00 | 89.56±1.54 | 81.33±1.26 |
| | DR=3.0 | 97.33±0.58 | 90.89±1.39 | / |
| fPA6-PEA-20 | DR=1.5 | 94.03±1.70 | 91.78±1.02 | 86.67±0.76 |
| | DR=2.0 | 92.67±2.08 | 92.22±0.39 | 87.30±1.82 |
| | DR=2.5 | 95.33±0.58 | 89.78±1.39 | 85.17±0.58 |
| fPA6-PEA-30 | DR=1.5 | 94.13±2.32 | 93.87±0.87 | 91.88±1.04 |
| | DR=2.0 | 93.84±0.79 | 94.00±1.95 | 93.00±1.00 |

**Table S12.** Elastic recovery data of PA6 fiber and PA6-PEA elastic fibers after 5 cycles at 10% constant elongation.

| Sample | Rapid elastic recovery rate (%) | Slow elastic recovery rate (%) | Elastic recovery rate (%) | Stress relaxation (%) |
|---|---|---|---|---|
| fPA6 | 74.00±2.00 | 24.33±1.53 | 98.33±0.58 | 23.02 |
| fPA6-PEA-10 | 88.67±1.53 | 10.50±1.32 | 99.17±0.29 | 16.86 |
| fPA6-PEA-20 | 90.00±1.73 | 8.83±1.61 | 98.83±0.29 | 14.62 |
| fPA6-PEA-30 | 90.33±3.21 | 8.83±3.33 | 99.16±0.29 | 1.89 |

$$E_R = (L_1 - L_2)/L_1 \times 100\% \quad (S1)$$

$$E_S = (L_1 - L_3)/L_1 \times 100\% \quad (S2)$$

Where $L_1$ is the maximum tensile strain during the fiber cyclic stretching process, $L_2$ is the strain corresponding to when the stress reaches zero for the first time during the last recovery process, and $L_3$ is the strain corresponding to when stress begins to appear during the stretching process after 30s of recovery.

**Table S13.** Elastic recovery data of PA6 fiber and PA6-PEA elastic fibers after 5 cycles at 15% constant elongation.

| Sample | Rapid elastic recovery rate (%) | Slow elastic recovery rate (%) | Elastic recovery rate (%) | Stress relaxation (%) |
|---|---|---|---|---|
| fPA6 | 57.33±0.67 | 21.78±1.39 | 79.11±1.02 | 24.27 |
| fPA6-PEA-10 | 74.00±0.67 | 16.00±1.16 | 90.00±0.67 | 19.95 |
| fPA6-PEA-20 | 85.55±0.39 | 11.56±0.38 | 97.11±0.77 | 17.03 |
| fPA6-PEA-30 | 88.22±2.34 | 10.22±1.39 | 98.44±1.02 | 12.41 |

**Table S14.** Elastic recovery data of PA6 fiber and PA6-PEA elastic fibers after 5 cycles at 20% constant elongation.

| Sample | Rapid elastic recovery rate (%) | Slow elastic recovery rate (%) | Elastic recovery rate (%) | Stress relaxation (%) |
|---|---|---|---|---|
| fPA6 | 46.50±0.50 | 18.17±0.29 | 64.67±0.76 | 25.06 |
| fPA6-PEA-10 | 61.33±0.58 | 14.00±5.00 | 75.33±0.29 | 20.55 |
| fPA6-PEA-20 | 75.00±1.50 | 11.17±0.58 | 86.17±1.04 | 17.17 |
| fPA6-PEA-30 | 84.17±2.25 | 10.33±1.04 | 92.50±1.32 | 13.24 |

Table S15. Sound velocity orientation data for PA6 fibers and PA6-PEA elastic fibers.

| Sample | Drawing ratio | $f_a$ |
|---|---|---|
| fPA6 | 1.5 | 0.50 |
| | 2.0 | 0.59 |
| | 2.5 | 0.66 |
| | 3.0 | 0.70 |
| fPA6-PEA-10 | 1.5 | 0.34 |
| | 2.0 | 0.49 |
| | 2.5 | 0.59 |
| | 3.0 | 0.63 |
| fPA6-PEA-20 | 1.5 | 0.11 |
| | 2.0 | 0.27 |
| | 2.5 | 0.41 |
| fPA6-PEA-30 | 1.5 | 0.09 |
| | 2.0 | 0.21 |