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Fatigue loading enhances the strength of nylon nanofiber yarns

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The application of tensile fatigue to nylon-66 nanofiber yarns improves the nanofiber alignment and crystallinity of their structure, thereby increasing tensile strength.

In the field of nanofibrous materials, nanofiber yarns have high potential for use in applications such as tissue engineering and artificial blood vessels, due to their high aspect ratio and high porosity. The tensile mechanical properties of this new generation of yarns has therefore received considerable attention in recent years.[1–3] However, little is known regarding fatigue behavior and the effect of fatigue loading on the tensile properties of these yarns.

Fatigue is defined as the fracture of a material after the application of repeated stress at a level less than is required to cause failure in a single application of stress.[3,4] Because the failure of fibrous materials is most often due to fatigue loading, their fatigue behavior is particularly important. Accordingly, we have investigated the tensile fatigue behavior of nylon-66 (PA66) nanofiber yarns. We chose PA66 due both to its biocompatibility and its position as a representative of polymeric nanofiber yarns in general.

To produce continuous nanofiber yarns, we carried out electrospinning—see Figure 1(a)—between the neutral cylinder and two syringe nozzles. Our method employs high-voltage DC electricity (18.5kV) to charge a suspended droplet of a polymer solution, subsequently converting it to an electrospun nanofiber yarn at room temperature. To increase mechanical performance, the strands are rotated around their axis, resulting in twisted yarn.[1,3] Twisting increases the interface traction between the nanofibers, leading to greater cohesion. The nanofibers are kept together in this yarn structure by a radial force, making it more compact. Figure 1(b) shows a scanning electron microscopy image of the nanofiber yarn.

We employed a Zwick/Roell Z2.5 mechanical tester to perform the tensile mechanical tests. To examine the influence of the fatigue loads on the tensile strength of the yarns, we performed monotonic

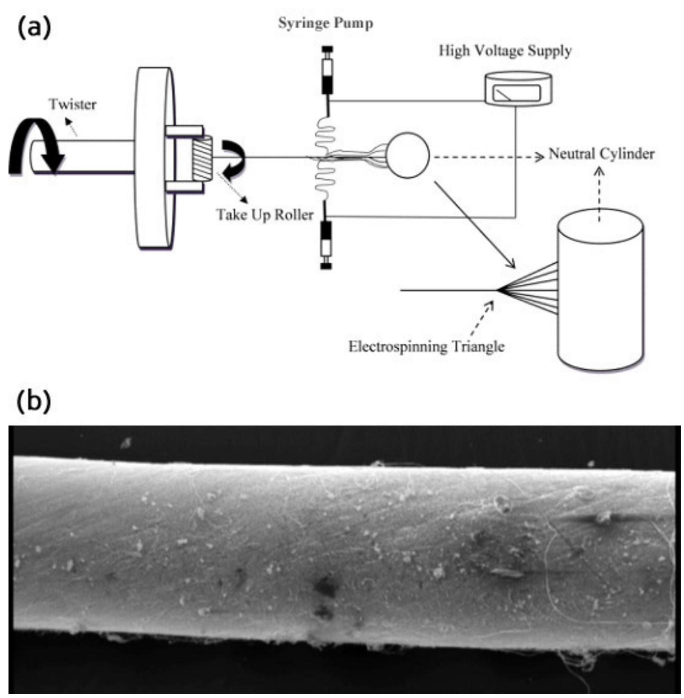

Figure 1. *(a) The experimental electrospinning setup for the fabrication of nanofiber yarns. It consists of a DC high-voltage power supply, two syringe nozzles with flat-tipped needles, two digitally controlled positive displacement syringe pumps, a neutral cylinder, and a take-up twister unit.[1,3] (b) Scanning electron microscopy (SEM) image of the fabricated nanofiber yarn (100× magnification).*

tensile tests before and after the fatigue loads were applied, at a speed of 50mm/min. The fatigue tests were load controlled at a speed of 300mm/min with a loading amplitude of 78% of the average ultimate tensile load. All the samples experienced 2000 cycles and remained unbroken. One generally expects degradation after fatigue, resulting in

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reduced material strength.[3] However, the average tensile strength of the nanofiber yarns before and after fatigue was 88.4 and 116.1MPa, respectively. We can therefore conclude that the application of cyclic loading on the samples increases the tensile strength of the nanofiber yarns considerably, in exact contradiction to general expectations.[3,4]

Figure 2 shows the typical stress-strain curves obtained from the monotonic tensile tests, before and after the application of oscillating loads. Before fatigue, the curves indicate almost linear behavior in the elastic and plastic regions. However, after cyclic loading is applied, there are considerable differences, especially in the plastic deformation regions. After fatigue loading, the rupture of the yarns is dominated by yield. The tensile strength of the material lies close to the yield point. Moreover, the yarns exhibited nonlinear elastic behavior.[3]

As can be seen in Figure 3, cyclic loading increases the nanofiber alignment in the tensile direction, which contributes to improvement of tensile strength. Moreover, differential scanning calorimetry tests show that fatigue loading considerably increases the crystallinity of the material, which changed from 17 to 26% after the application of fatigue. We conclude that the increased nanofiber alignment and crystallinity within the yarn structure were the main factors behind the enhanced tensile strength.[3]

In summary, we have shown that applying fatigue to nanofiber yarns results in positive changes to their stress-strain behavior. Our study reveals the importance of fatigue loading effects on the performance of nanofiber yarns for applications such as artificial blood vessels, suture yarns, and tissue scaffolds.[3] In future work, we aim to investigate the fracture modes of continuous PA66 nanofiber yarns with different twist levels after monotonic, low-cycle fatigue, and post-cyclic monotonic tensile tests. We are also exploring the interactions between fatigue loading and wicking.

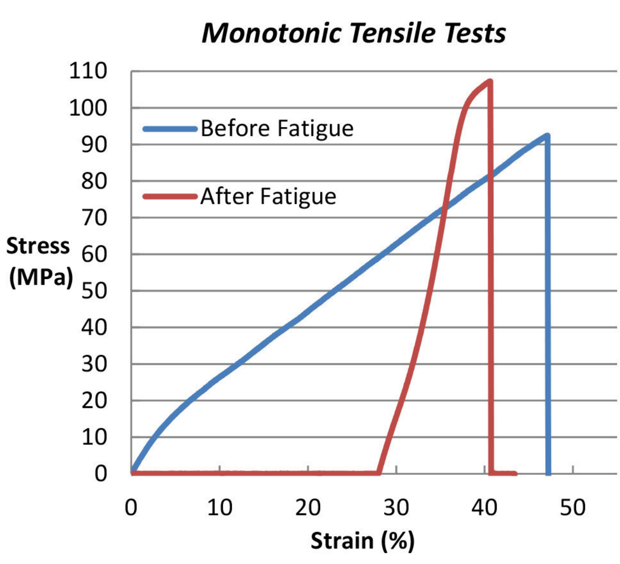

Figure 2. *Typical stress-strain curves obtained from monotonic tensile tests before and after application of fatigue loading.*

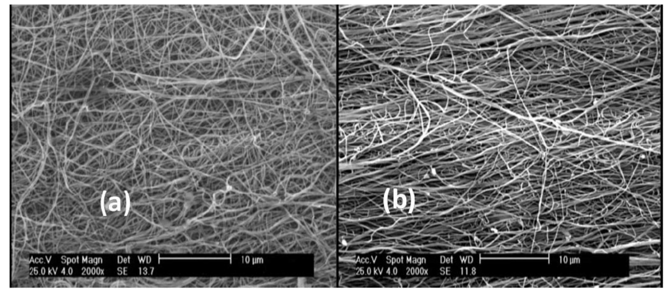

Figure 3. *SEM images of nanofiber yarn (a) before fatigue loading and (b) after fatigue loading.*

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