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Needleless electrospinning of PEO nanofiber mats

T. Grothe[1], C. Großerhode[1], T. Hauser[1], P. Kern[1], K. Stute[1], A. Ehrmann[1, a]

[1]Faculty of Engineering and Mathematics, Bielefeld University of Applied Sciences, Bielefeld, 33619, Germany

[a]andrea.ehrmann@fh-bielefeld.de

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Abstract. Polyethylene glycol (PEG) is used in a variety of applications, from medicine and pharmaceutics to green wood stabilization to skin creams and toothpaste. PEG is often used as coating or supplement for fibres created from other materials or spun as composite fibre in combination with other materials, such as cellulose, collagen or PVDF. However, reports about spinning of pure PEG fibres are scarce. This is why in a recent project the possibilities of spinning nano fibres from PEG were examined. Using the needleless electrospinning machine "NanoSpider Lab" (Elmarco), we produced mats of different thicknesses from nano fibres with diameters between 200 and 800 nm. One of the most important parameters for the ability of the polymer to create nano fibres is the chain length, given by the molecular weight. Thus, our investigation included PEG with molecular weights between 40,000 daltons and 2,000,000 daltons, i.e. PEO 40,000 to PEO 2,000,000. It could be shown that high molecular weights did not necessarily result in the densest and most homogenous fiber mats, but the maximum possible polymer concentration influenced the results as well. The fiber mats resulting from different spinning solutions for maximum and minimum electrode distances were examined using a confocal laser scanning microscope, showing that a middle molecular weight combined with high polymer concentration and small electrode distance creates ideal nanofiber mats.

Introduction

Electrospinning, also known as nanospinning due to the small diameter of the created fibers, belongs to the primary spinning technologies. Opposite to other spinning processes, electrospinning necessitates only relatively small equipment and can thus also be used in usual textile laboratories to create either continuous fibers or homogenous fiber mats [1-5]. Additionally, nanospun mats have large surface areas, enabling their use as filter materials [6-8], catalyzers [9], or medical wound dressing [10].

Poly(ethylene oxide) (PEO) belongs to the materials which can be electrospun easily and which can be used in a broad range of applications. Additionally, it can be used as spinning agent for other materials which are not or not sufficiently spinnable [11-13]. Nevertheless, reports about nanospinning pure PEO are scarce [14] and mostly concentrate on needle-electrospinning [15].

After we examined the influence of different spinning parameters and the PEO concentration in the aqueous spinning solution in a previous project [16], this article concentrates on the effect of varying the molecular weight and the electrode distance, verifying that both parameters are crucial for the fiber creation.

Experimental

Electrospinning was performed using the electrospinning machine "Nanospider Lab" (Elmarco, Czech Republic). PEO with different molecular weights between 40,000 daltons and 2,000,000 daltons, purchased from S3 Chemicals, was used.

Table 1 gives an overview of the PEO concentrations in aqueous solution for different molecular weights. The concentrations chosen were adapted to the desired static viscosity for electrospinning

with a nozzle with diameter 0.9 mm (~ 10^4 mPa·s, this is similar to honey).

Table 1. Concentrations chosen for PEO with different molecular weights.

Molecular weight / kD	PEO concentration / wt%
40	55
100	20
300	12
600	8
1,000	6
2,000	4

The spinning parameters were as follows: temperature 21.4 °C, relative humidity 44 %, electrode-substrate distance 50 mm, nozzle diameter 0.9 mm. The high relative humidity – which is slightly higher than the usually defined upper border for nanospinning, i.e. 40 % – ensures that differences between the spinning solutions are well visible, while for better suited humidity between approx. 20 % and 35 %, small deviations between the performances of different spinning solutions can be expected to show less influence on the resulting fiber mats.

The electrode distance was chosen as maximum and minimum values, i.e. 240 mm and 120 mm, respectively. For the higher electrode distance, a voltage of 80 kV was chosen, resulting in currents of approximately 0.1 mA, while for the lower electrode distance, a voltage of 50 kV was used, leading to similar current values.

The produced nanofiber mats were optically investigated using a confocal laser scanning microscope (CLSM) VK-9000 by Keyence.

Results and Discussion

The results of the spinning experiments with the maximum electrode distance are depicted in Fig. 1, while Fig. 2 shows the CLSM images of the nanofiber mats spun with the minimum electrode distance.

As can be seen in Fig. 1, the PEO with the lowest molecular weight results in thicker fibers than the other molecular weights. This relation could not be found explicitly in the literature since most papers concentrate on spinning with one PEO molecular weight. While for 100 kD, a denser fiber mat was produced, only singular fibers were created using the 300 kD PEO. This can be attributed to a better fitting of the polymer solution to the spinning process in case of 100 kD – previous experiments have shown the strong dependence of fiber creation on PEO concentration for needle electrospinning [15] and needleless electrospinning [16]. For 600 kD, a relatively even fiber mat is created, as expected from former experiments [16]. The mat resulting from nanospinning with 1,000 kD, however, is significantly less dense and ordered. For the PEO with 2,000 kD, no fibers are created.

As this result shows, the optimal molecular weight for electrospinning is not necessarily the highest possible value. Instead, the necessary reduction of the PEO concentration for high molecular weights diminishes or completely prohibits the fiber creation. Thus, the optimal combination of molecular weight and concentration must be found.

Comparing Fig. 2 with Fig. 1, all fiber mats are denser and more regular than the respective results for an electrode distance of 240 mm. For the highest molecular weight of 2,000 kD, an open, irregular mat is created, while no fibers were spun at all for the higher electrode distance.

This comparison shows more significant differences than a former examination at a usual relative humidity of 35 % in which only the fiber mat densities were varied by a modified electrode distance [b]. As expected, exceeding the ideal value range of humidity (or other parameters) helps finding more meaningful results for a variation of other spinning or material parameters.

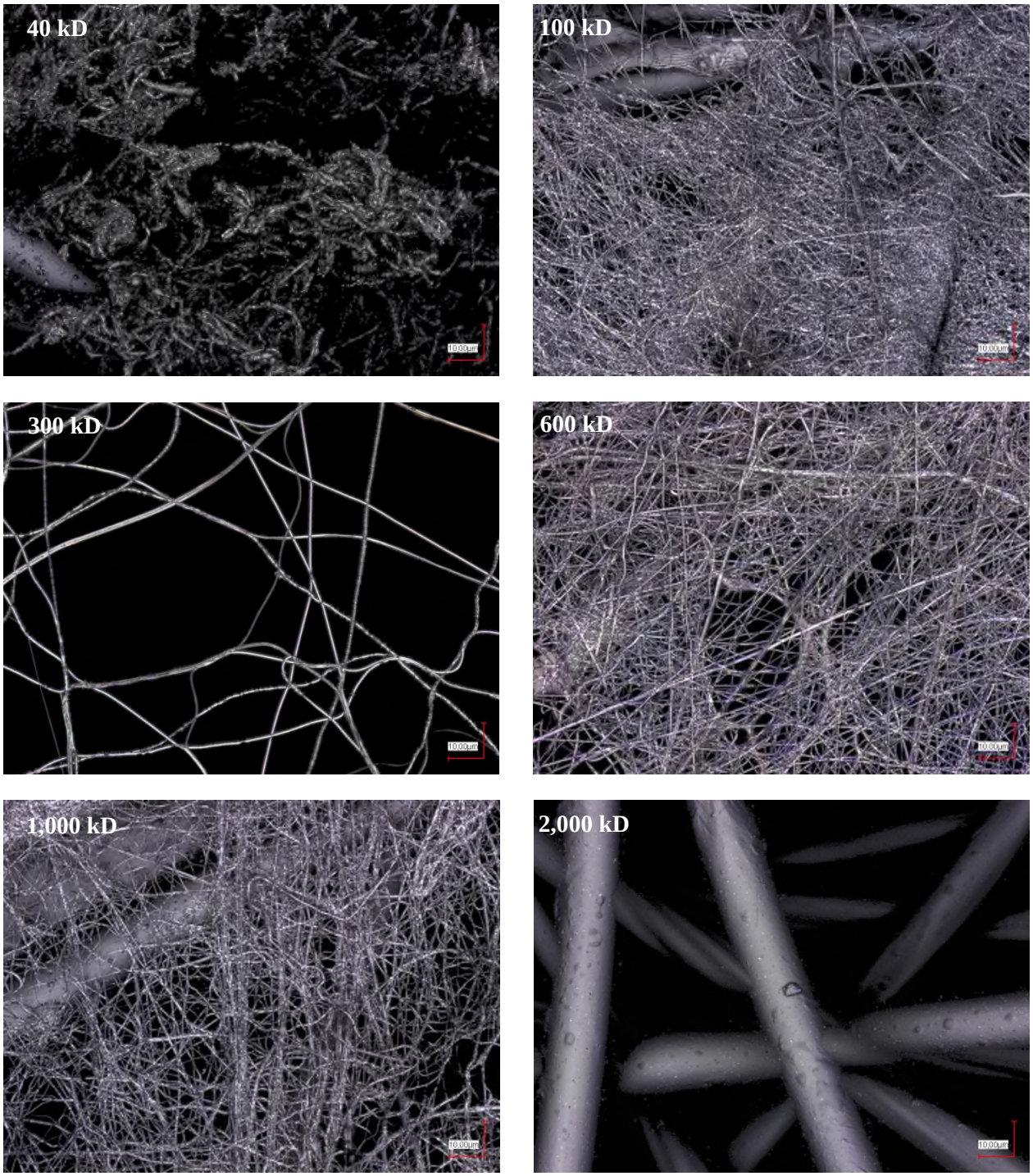

Fig. 1 Nanofiber mats, spun from PEO with different molecular weights, using an electrode distance of 240 mm.

Conclusion

Electrospinning PEO with different molecular weight showed that the ideal molecular weight is approximately between 300 kD and 600 kD, allowing for concentrations between 6 % and 12 % in aqueous solution for needleless nanospinning. Fiber mats were spun more regularly and denser if the minimum electrode distance was used instead of the maximum value. Exceeding the ideal humidity range for electrospinning intensifies problems with less suitable spinning solutions and thus allows for distinguishing between them with high reliability.

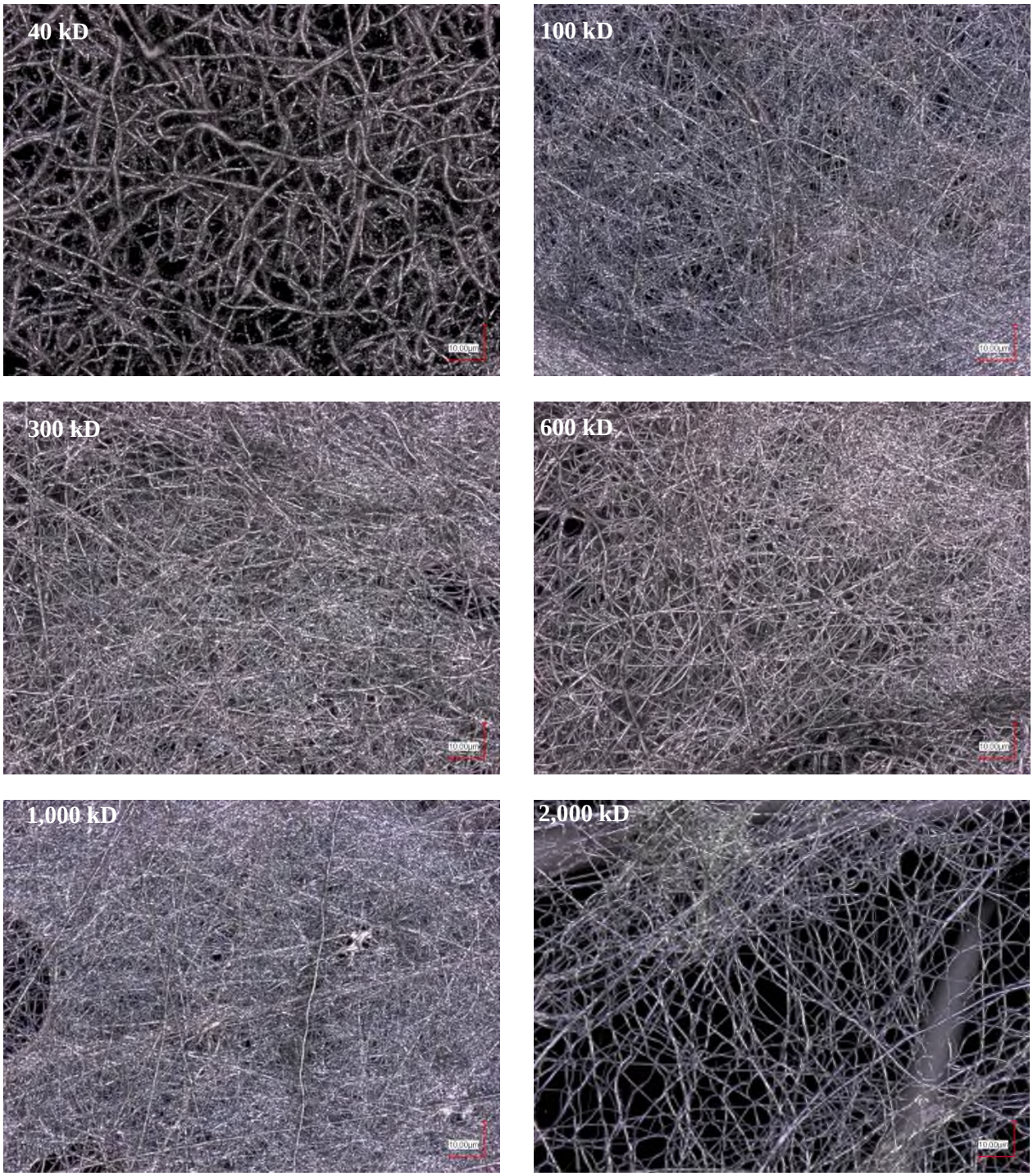

Fig. 2. Nanofiber mats, spun from PEO with different molecular weights, using an electrode distance of 120 mm.

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