

Rheology of silk solutions and short fibre formation

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INTRODUCTION

High surface area to volume ratio gives fibres in the micron or submicron range with a finite length up to 5 mm desirable properties for a wide range of applications in fields including textile, filtration and tissue engineering [1]. Recently a new method, using shear dispersion, has been identified to produce short fibres, where a polymer solution is injected coaxially in a fast flowing coagulant liquid [2]. The complexity of the process of formalising the fibre formation mechanism results from the many factors influencing the process, one of those being the viscoelastic properties of the polymer solution investigated in this work.

CONCEPT

The fibre formation process is typically investigated as a function of viscosity. The viscosity of polymer solutions, however, is strongly affected by concentration and molecular weight of the polymer and has been observed to not be a complete predicting tool for short fibre formation. The predictability of fibre production, function of these factors combined or on their own, is yet to be explored in depth.

To this point, high and low molecular weight silk solutions were produced following two separate methods, respectively based on LiBr and CaCl₂. The solutions were then concentrated, mixed together at different ratios and diluted to different end concentrations for characterisation and fibre production. Fibre properties were assessed relative to concentration, molecular weight and viscoelastic properties of the used polymer solution.

RESULTS

The average molecular weight has been shown to be much higher in LiBr-dissolved silk solutions compared to CaCl₂-dissolved silk solutions by performing SDS-PAGE electrophoresis. Critical entanglement concentrations were calculated by analysing the viscosity/concentration relationship of the solutions, and yielded ~6.52 wt% for high- and ~8.62 wt% for low molecular weight silk. Generally, concentration, MW and shear forces were found to affect the length and appearance of the produced fibres. Fibres produced with the high-shear mixer were generally less entangled and, by proxy, shorter. This is consistent with the shear forces in the shear mixer being ~30 times higher than in the laminar flow device. The entanglement of the produced fibres was found to increase with concentration and molecular weight of the dope solutions. As shown by figure 1, fibres produced with polymer solutions of similar viscosities, but different molecular weights and concentrations were found to be very different. Fibre thickness was measured to be around 200 nm (SEM), increasing with concentration but not with molecular weight of the polymer solutions. Spheres present in the fibre samples where more dilute polymer solutions were used as shown in figure 2, could be explained by slight change from jetting to dripping of the polymer jet breakup. Solidification time was calculated to be between 2.23x10⁻³ ms and 12.7 ms using a simple diffusion model.

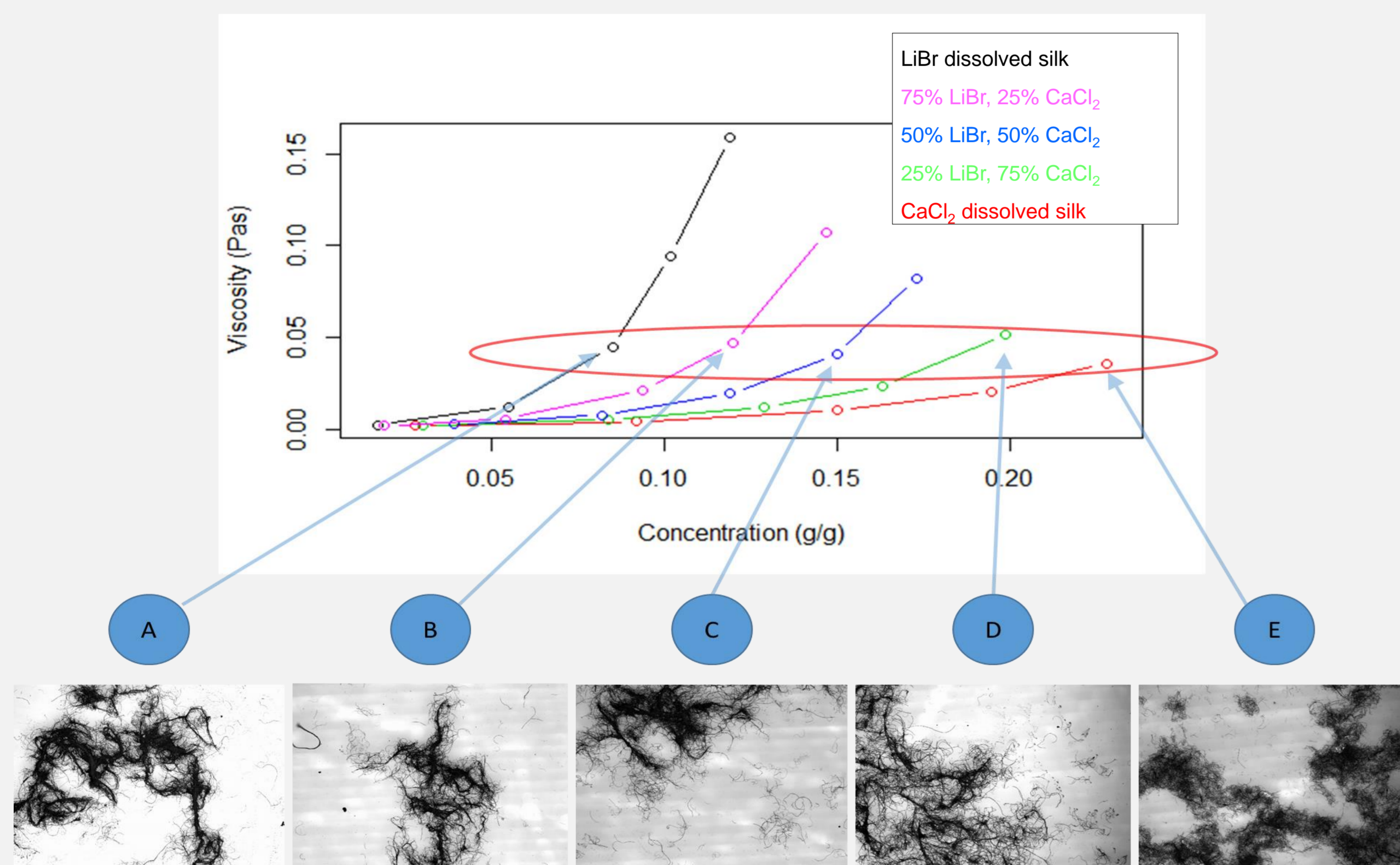


Figure 1. Fibres produced in the laminar flow device with polymer solutions of similar viscosities, but containing different polymer molecular weights and concentrations.

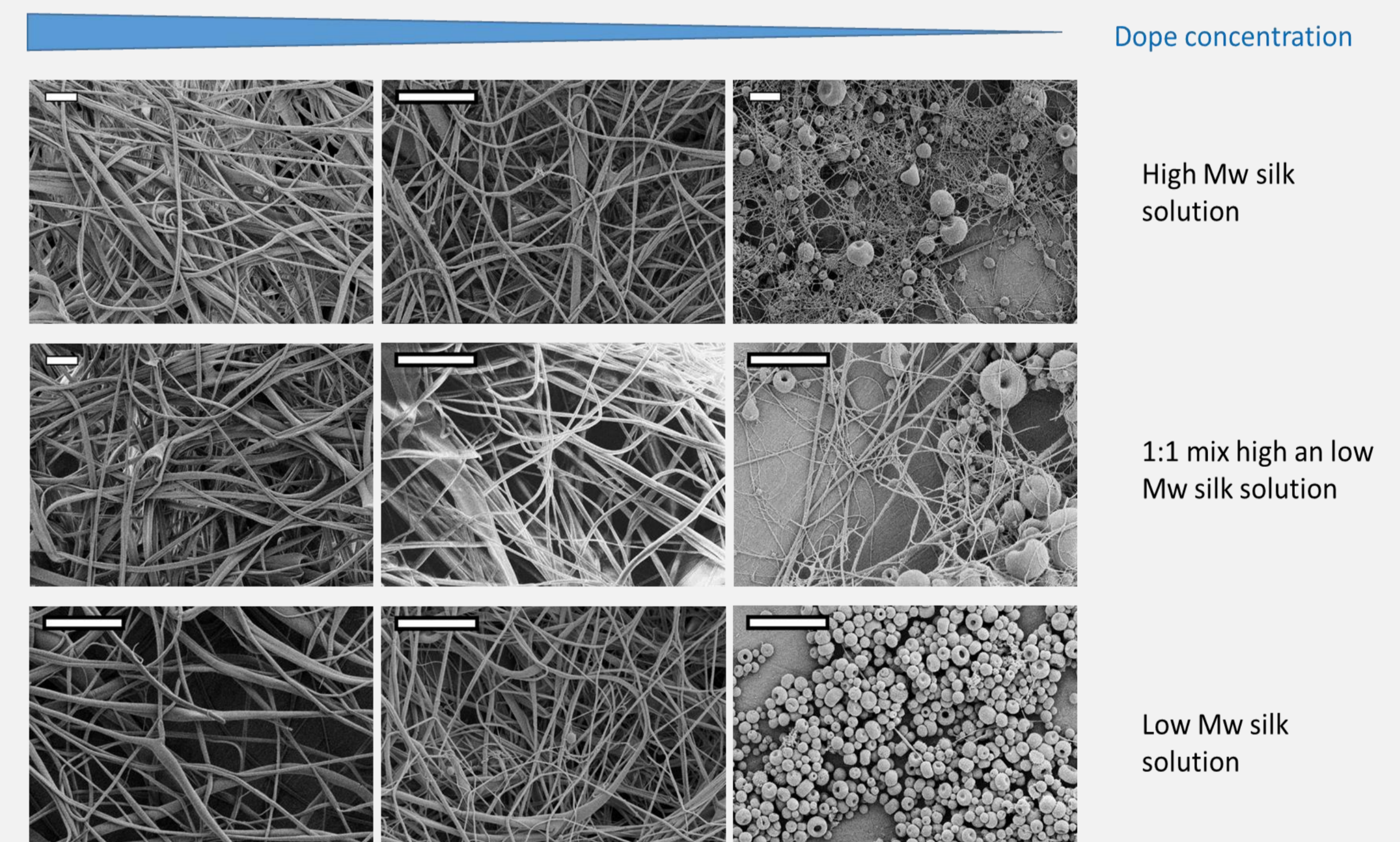


Figure 2. SEM images of fibres produced with different polymer solutions in the laminar flow device. Scale represents 10 µm.

CONCLUSION

It has been shown that the viscoelastic behavior of polymer solutions as a critical influencing parameter on the fibre formation process. However it has also been shown that viscosity cannot be considered on its own to predict characteristics of to produce fibre samples. Thus the understanding of the influencing factors on tensile strength of filaments produced with silk solutions has been significantly improved by this work.

REFERENCES

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