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Introduction

Poly(vinyl alcohol) (PVA) is a water-soluble, fully biodegradable, non-toxic and non-sensitizing polymer. It can be processed into fibres with high crystallinity and crystal fibrillation resulting in excellent tensile strengths in the range of 1.0–1.5 GPa and initial moduli of 110–115 GPa.^{1–3} PVA fibres have been widely utilized in commercial products, such as wetting clothes, shampoos, fish nets, and ropes.⁴ Furthermore, PVA-based fibres have been considered to be an attractive choice in various applications including young scaffolding, filtration materials, membranes, optics, protective clothing, and drug release.⁵ The high strength, high modulus, relatively low density, high alkali resistance and good adhesive properties of PVA suggest potential applications by advanced techniques such as fibre-reinforced thermoplastic (FRT). PVA fibres were successfully incorporated into conventional materials to not only reduce the weight of structural materials, but also to enhance their ductility, toughness, and crack resistance.⁶

High-strength and high-modulus PVA fibres can be produced by wet spinning, dry-jet wet spinning, dry spinning and gel spinning.⁷ Among these methods, gel

spinning with subsequent stretching is well-suited for producing high-modulus PVA fibres.⁸ The concept of gel spinning is based on increasing the polymer orientation and increasing chain folding, which allows the fibres to be drawn to a high degree of chain alignment.⁹ For PVA fibres, full extension of the molecular chains is hindered by steric hindrances to chain slippage by the presence of OH groups as well as intra- and inter-chain hydrogen bonding. Therefore, PVA fibres have been drawn to near or even above the normal melting temperature in order to achieve high mechanical drawability, which is key for obtaining very high chain orientations.¹⁰ The high molecular orientation causes the PVA fibres to achieve high

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