Streak formation and fibre orientation in near wall turbulent fibre suspension flow

K. Håkansson*, M. Kvick*, F. Lundell†, L. Prahl Wittberg†, and L. D. Söderberg*

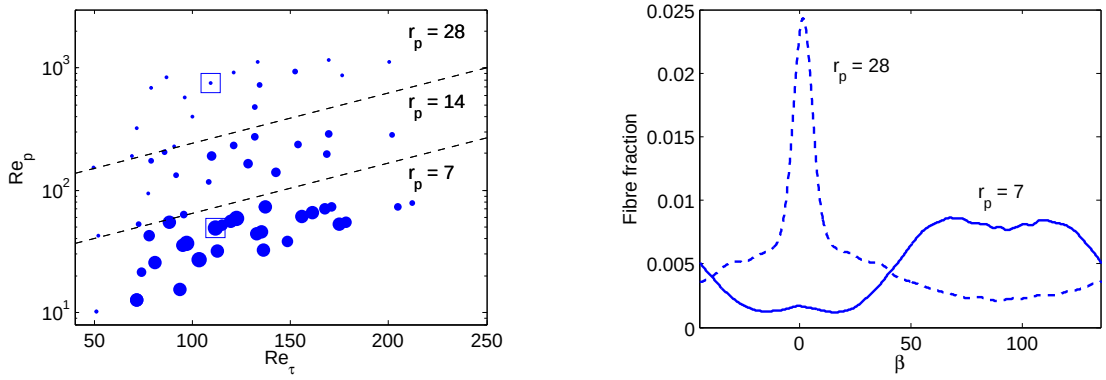
* Wallenberg Wood Science Center, KTH Mechanics, Royal Institute of Technology, SE-100 44 Stockholm, Sweden

† Linné FLOW Centre, KTH Mechanics, Royal Institute of Technology, SE-100 44 Stockholm, Sweden

karlh@mech.kth.se, kvick@mech.kth.se, fredrik@mech.kth.se

Keywords: Fibre suspension flows, Fibre streaks, Wall bounded turbulent flow, Fibre orientation

The shear flow in the headbox of a paper former plays an important roll for the structure and properties of the final paper. The headbox accelerates the pulp by transforming it from a pipe flow to a wide sheet that is jetted out onto the dewatering wires, where the paper is formed. In order to investigate phenomena present in a headbox, a turbulent fibre suspension flow near a wall is investigated in this study. The experimental setup consists of a slightly inclined open rectangular channel made of glass with reservoirs upstream and downstream. A pump is used to transfer the suspension from the downstream to the upstream reservoir. The suspension flows down the inclined channel driven by gravity. LDV measurements show that the flow is turbulent and fully developed. Cellulose acetate fibres with a density $\rho_f = 1300$ kg/m^3 and an aspect ratio of $r_p = 7, 14$ and 28 are used. Due to sedimentation most of the fibres are located close to the wall. The friction Reynolds number Re_τ is varied between 50 and 230 and the rotational particle Reynolds number Re_p between 10 and 1000. Re_p is based on the wall shear stress and the fibre length. By analyzing images taken from beneath, through the glass bottom of the channel, fibres are detected using a steerable filter. The position and orientation of the fibres in the wall parallel plane are obtained. The fibres form streamwise oriented streaks for some values of Re_τ and Re_p. Streakiness and streak widths are obtained through correlation analysis. The streakiness is shown for different Re_τ and Re_p in figure 1(a). Bigger dots represent more apparent streaky structures. The widths of the fibre-streaks are compared with the empirical value of $\sim 50l^+$ for low velocity streaks in turbulent boundary layers, where l^+ is the viscous length scale. The results show that the fibre-streaks scale in the same manner as the viscous sublayer streaks in a turbulent wall bounded flow. The orientation distributions of the fibres is highly dependent on the aspect ratio of the fibres. Furthermore, fibres with aspect ratio $r_p = 28$ are mostly aligned in the flow direction and fibres with $r_p = 7$ are mostly aligned perpendicular to the flow direction, see figure 1(b). The fibres with aspect ratio $r_p = 14$ are oriented more homogeneously, i.e. this might be an intermediate state.



(a) (b)

Figure 1: (a) Streakiness, bigger dots represent a lower value of the minimum of the spanwise correlation and thus a higher degree of streakiness. The orientation distributions for the measurements indicated by the squares are shown in (b). (b) Orientation distributions for $r_p = 28$ at $Re_p \approx 750$, $Re_\tau \approx 110$ (dashed line) and $r_p = 7$ at $Re_p \approx 50$, $Re_\tau \approx 110$ (solid line). $\beta = 0$ is the streamwise direction.