SPANWISE MEASUREMENTS OF TURBULENCE STRUCTURE OVER PERMEABLE WALLS

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Abstract In order to understand the effects of the wall permeability on turbulence near permeable walls, spanwise flow field measurements are carried out for turbulent flows in channels with permeable bottom walls by a two-component particle velocimetry (PIV) system. The porous media used are three kinds of foamed ceramics which have almost the same porosity ($\sim$ 0.8) but different permeability. The turbulent flow fields in the *spanwise* planes are discussed using instantaneous and statistical measurement data. At a small permeability Re (Re_K), low speed and high speed regions, which form a similar streaky structure to that of solid-wall turbulence, are observed. In case of a large Re_K, although some large scale striped patterns are observed, they are confirmed to be different from those of the solid wall turbulence structure.

BACKGROUND AND EXPERIMENTAL METHODS

Porous materials are used for many industrially important devices such as catalytic converters, metal foam heat exchangers and the gas diffusion layers of fuel cells because of the large void space and the ratio of their surface area to their volume. Therefore, in the authors' group, to understand the turbulent flow physics over porous media, turbulent channel flows whose bottom walls are made of porous media were investigated in *x*-*y* planes and turbulence statistics and structures were discussed [3][4].

The streaky structure seemed to be weakened by the increase of the wall permeability in the DNS [2]. Although the permeability was assumed to be a function of the porosity and the mean particle diameter in [2], such a relation is not always valid. It is thus desirable to treat the permeability and the porosity as independent parameters. On the other hand, as far as the authors' knowledge, the spanwise turbulence structure over permeable walls has not been experimentally studied. Therefore, the present study attempts to investigate spanwise turbulent vortex structure over permeable walls using instantaneous and statistics of the PIV experimental data focusing on the effect of the wall permeability.

Figure 1 illustrates the test section of the present experimental setup. Tracer particles are capsules containing Rhodamine B and their mean diameter and specific gravity are respectively 10 μm and 1.50. Tap water is pumped up from a water tank, then the flow is fully developed in a driver channel (3000mm) and enters the test section. The channel consists of solid smooth acrylic top and side walls and a porous bottom wall. The thickness of the porous wall is about 0.06m which was twice the channel height *H*=0.03m for the clear fluid region whose width *W* is 0.3m. The porosity of the presently used porous media is φ=0.8 and the permeability is K=0.20, 0.33, and 0.87$\times 10^{-7}$m^2.

RESULTS AND DISCUSSIONS

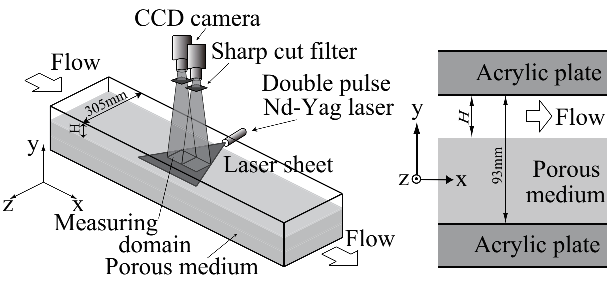

Figure 1. Experimental setup.

Figures 2 and 3 show the examples of the instantaneous velocity and vorticity contours at $\mathrm{Re}_K \simeq$0, 1, and 6, where the permeability Reynolds number Re_K(=$u^p_\tau\sqrt{K}/\nu$), is based on the wall permeability *K*, the wall friction velocity u^p_τ on the porous wall, and the kinematic viscosity ν. Figures 2 and 3 have the same areas of $z/H \times x/H$=2.7$\times$4.0. (Figures 2(a) and 3(a) correspond to $z^+ \times x^+$=890$\times$1340, Figs.2(b) and 3(b) correspond to $z^+ \times x^+$=480$\times$720, and Figs.2(c) and 3(c) correspond to $z^+ \times x^+$=2930$\times$4400 with the wall unit based on u^p_τ.) In Fig.2, black areas correspond to regions 10% below the local mean velocity (low speed regions), and white areas correspond to regions 10% above the local mean velocity (high speed regions). Figure 3 shows snapshots of the wall-normal vorticity ω^+_y which is normalized by $(u^p_\tau)^2/\nu$. In Figs.2(a) and 3(a), it is obvious that there are low speed and high speed regions near solid walls (Re_K=0). In Figs.2(b) and 3(b), it can be seen a similar structure at $\mathrm{Re}_K \simeq 1$. Although at $\mathrm{Re}_K \simeq 6$, some striped structure may be seen in the instantaneous velocity contours (Fig.2(c)), such a structure is not obvious in the vorticity contours (Fig.3(c)). It is thus confirmed that the structure at a small Re_K still keeps similarity to those near solid walls, though at a larger Re_K, such a streaky structure tends to vanish.

Figure 4 presents the spanwise autocorrelation of the streamwise velocity. The upper windows in the figures are enlarged views of z^+=100-450 and z^+=1000-3000. At $\mathrm{Re}_K \simeq 1$ the spanwise autocorrelation exhibits a local minimum at $z^+ \simeq 50$. This local minimum is usually associated with the average spanwise distance between low speed and neighboring high speed streaks. Generally, the spanwise distance between two neighboring low speed regions is $100\nu/u^p_\tau$ in buffer regions on solid walls [1]. This also confirms that there is a similar structure at a smaller Re_K to those near solid walls. In the upper window of Fig.4(a), the oscillations in the autocorrelation for larger spanwise spacings indicate the periodicity due to the presence of the streaks. In contrast, the local minimum becomes weak at $\mathrm{Re}_K \simeq 6$ in Fig.4(b) while such a spanwise correlation between the low speed and the high speed regions statistically confirms that there are stripes in the structure. Disappearance of the streak structure is confirmed by the larger correlation distance and the absence of oscillations in Fig.4(b). Although the autocorrelation on solid wall is not shown due to the page limitation, it is similar to that at $\mathrm{Re}_K \simeq 1$ (Fig.4(a)). In conclusion, the streaky structure tends to vanish with the increase of Re_K and at $\mathrm{Re}_K \simeq 6$ it totally vanishes. However, some large stripes still remain in the velocity field at a larger Re_K.

References

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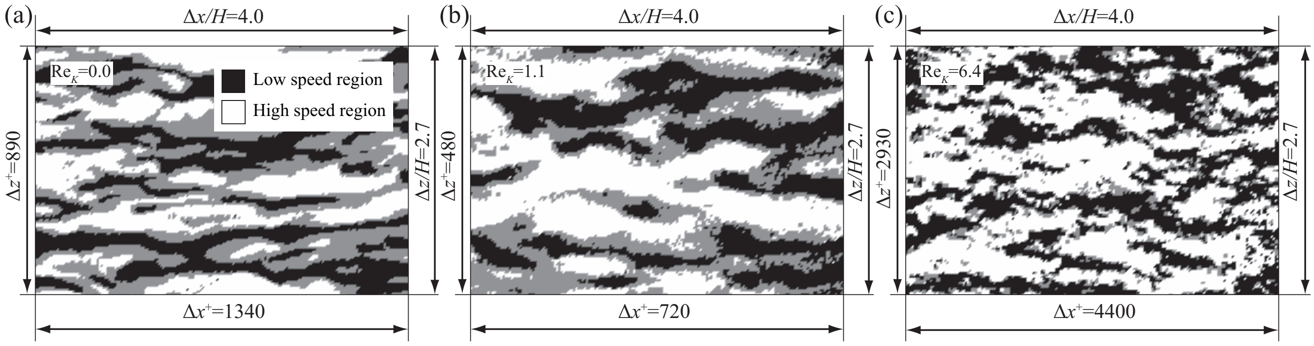

Figure 2. Instantaneous velocity contours;(a)at Re_K=0.0, y^+=22.3, (b)at Re_K=1.1, y^+=17.6, (c)at Re_K=6.4, y^+=17.7.

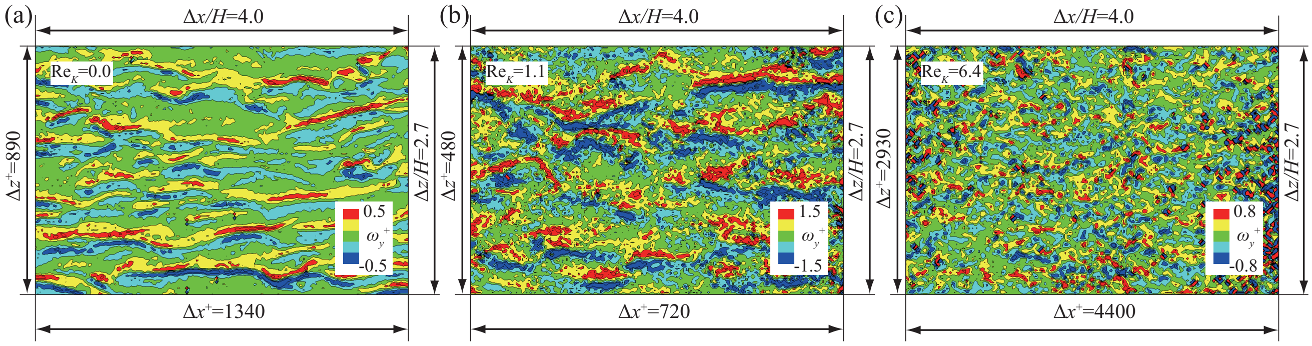

Figure 3. Instantaneous vorticity contours;(a)at Re_K=0.0, y^+=22.3, (b)at Re_K=1.1, y^+=17.6, (c)at Re_K=6.4, y^+=17.7.

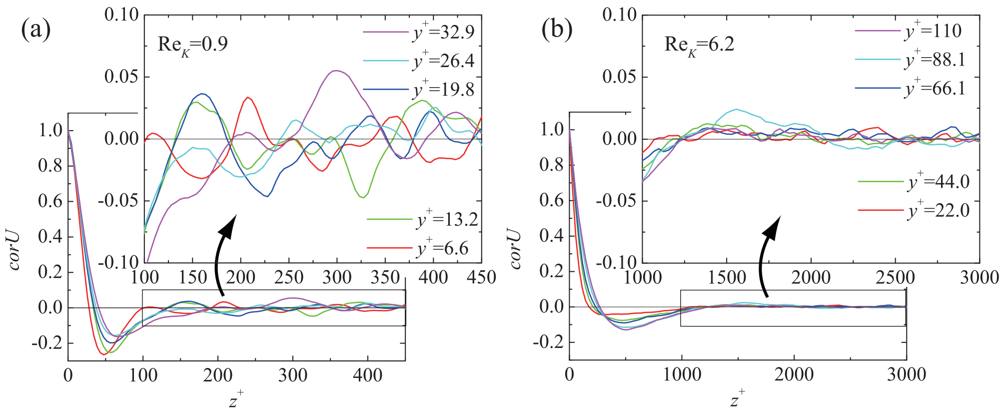

Figure 4. Spanwise autocorrelation of the streamwise velocity.