Novel Diesel Particulate Filters containing Fine Ceramic Fibres

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Introduction

Fine (carbon) particles in Diesel exhaust can adversely affect human respiratory health. *Diesel Particulate Filters* (DPFs) must remove at least most such particles, without unduly raising the *Exhaust Back-Pressure* (EBP). Current DPFs are made by sintering ceramic powders (such as SiC or Cordierite), but the pore structure is coarse, so that filtration is inefficient while the filter is clean (*regenerated*). A fibrous composite, with a multi-scale pore architecture, may allow high filtration efficiency, even soon after regeneration, while also raising the *Thermal Shock Resistance* (TSR).

Potential Benefits of (Fine) Fibres

The main problems with existing DPFs are:

- Low filtration efficiency immediately after regeneration, due to the uniformly coarse microstructure
- Sub-optimal TSR , limiting the life of the DPF
- Need for frequent regeneration, partly due to the low particle-carrying capacity associated with coarse pores.

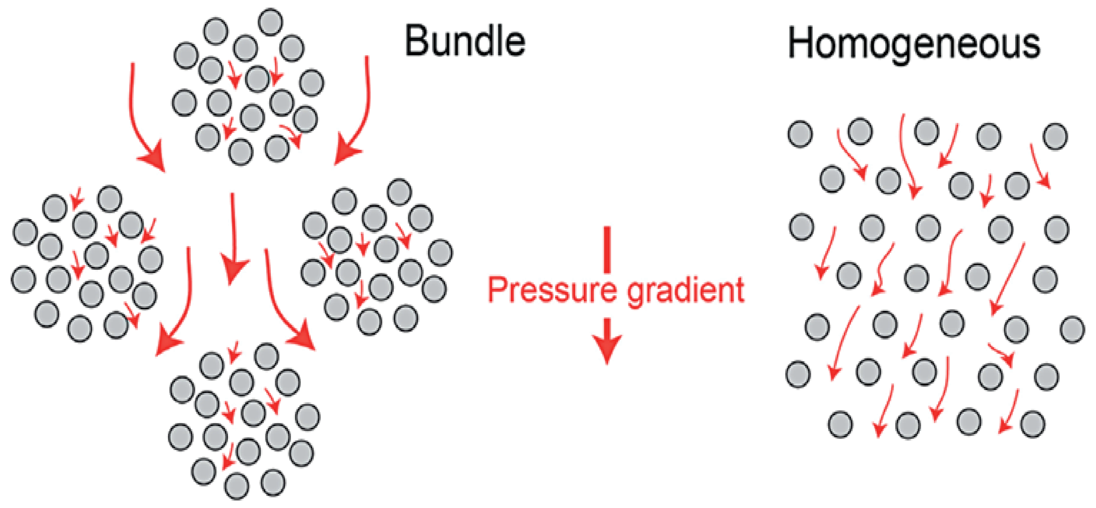

Fig. 1: Schematic depiction of how fluid flow takes place through fibre bundles, compared with a homogeneous dispersion of fibres.

Incorporation of (bundles of) fine fibres offers the following:

- A multi-scale pore architecture (Fig.1) should allow a combination of fine scale filtration and low EBP
- The presence of fibres is expected to raise both the toughness and the strain tolerance, enhancing the TSR
- Increased surface area will enhance particle retention capacity, increasing the intervals between regenerations and perhaps allowing the process to occur continuously.

Porosity and Permeability

Green compacts were made by milling and blending of a fine silica-based fibre with alumina powder and a PVA binder, followed by cold isostatic pressing. These compacts were then sintered in air at about 1100˚C. The porosity level and permeability were assessed by densitometry and flow rate measurements.

These measured values are shown in Fig.2. As expected, both porosity and permeability are raised by fibres, which create a more open structure. (It may be noted that the target permeability level for DPFs is typically about 10^{-12} m^2.)

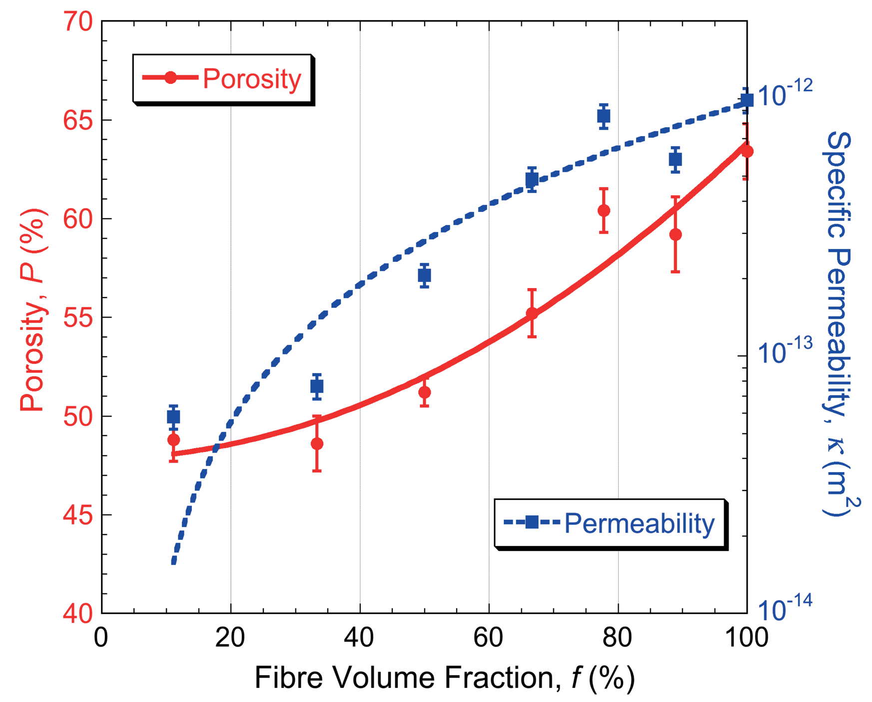

Fig.2: Dependence of porosity and permeability on fibre content.

Stiffness

Low stiffness is beneficial in DPFs, since it raises the strain tolerance and TSR (by reducing the stresses associated with thermal gradients). The effect of fibres on stiffness is not easy to predict; higher porosity favours low stiffness, but fibres have high axial stiffness.

The net effect will depend on packing & orientation distribution. Fig.3 indicates a dependence on fibre content, although all of these stiffness levels are low.

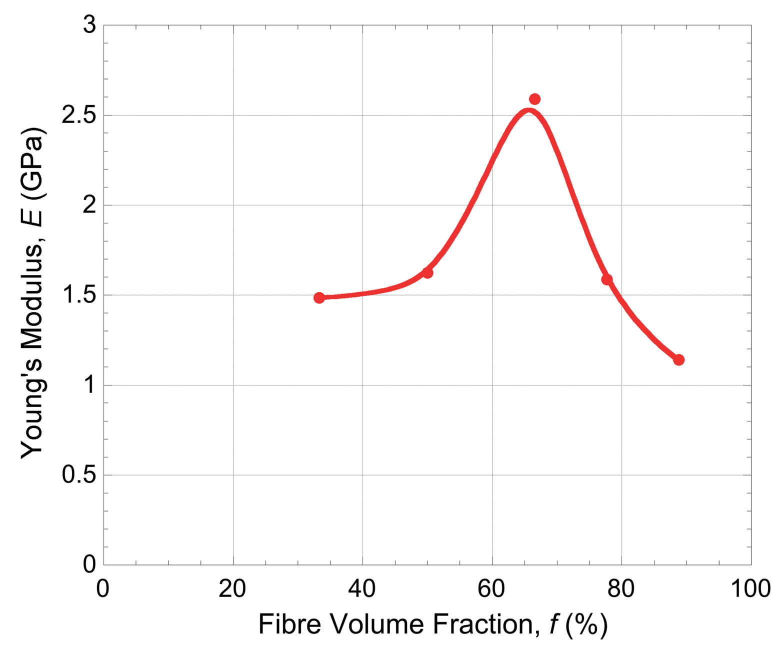

Fig.3: Dependence of stiffness on fibre content.

Prospects

In general, the mechanical and permeation properties of exploratory DPF material incorporating fine fibres have conformed to expectations. In addition to stiffness and permeability data, the fracture energy has been found to rise substantially as the fibre content is increased. Assessments will shortly be made of the TSR.

In parallel with these thermo-mechanical characteristics, it will be important to check on the filtration efficiency for very fine particulate. Experimentally, this is best done using real Diesel exhaust, requiring actual DPFs to be manufactured. However, the performance of candidate materials will first be explored using numerical simulation (see below).

Modelling of Gas Flow in DPFs

A useful tool for exploring the effect of pore architecture in DPF materials is *Computational Fluid Dynamics* (CFD) modelling of the flow of gas (and heat) within them. Realistic capture of the structure is essential, but this is readily done via *Computed X-Ray Tomography* (CRT). An example is shown in Fig.4, relating to a commercial DPF.

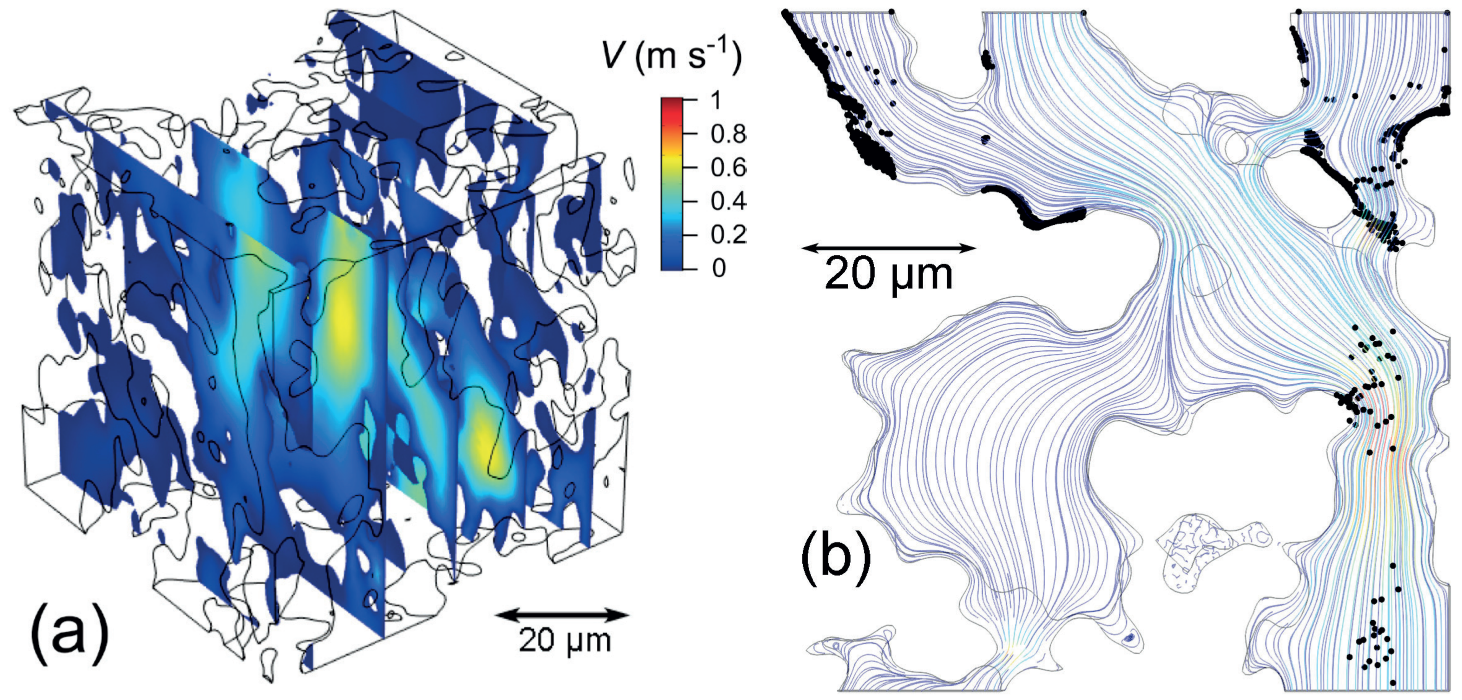

Fig.4: CFD (COMSOL) outcomes for gas flow through the structure of a DPF, captured by CRT, under a pressure gradient of 2 MPa m^{-1} (20 mbar across 1 mm thick wall): (a) perspective view of velocity contours in parallel sections & (b) flow streamlines, & accumulating deposition of (20 nm) carbon particles, within a section.

Tomography of fibrous candidate DPF materials has also been performed, giving good agreement with experimentally determined values of porosity and permeability.