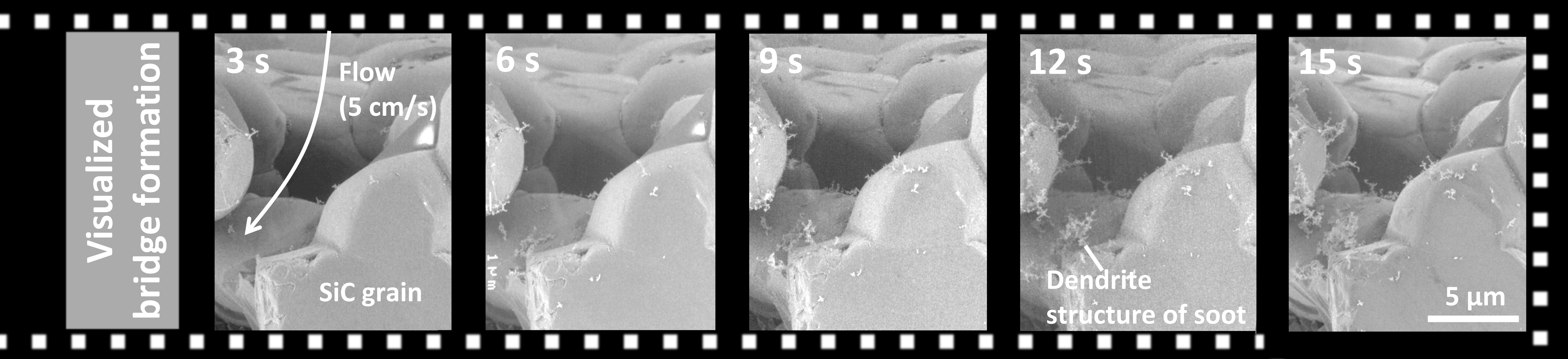

Electron Microscopic Visualization of Soot Bridge Formation and Configuration Analysis of Diesel Particulate Filter

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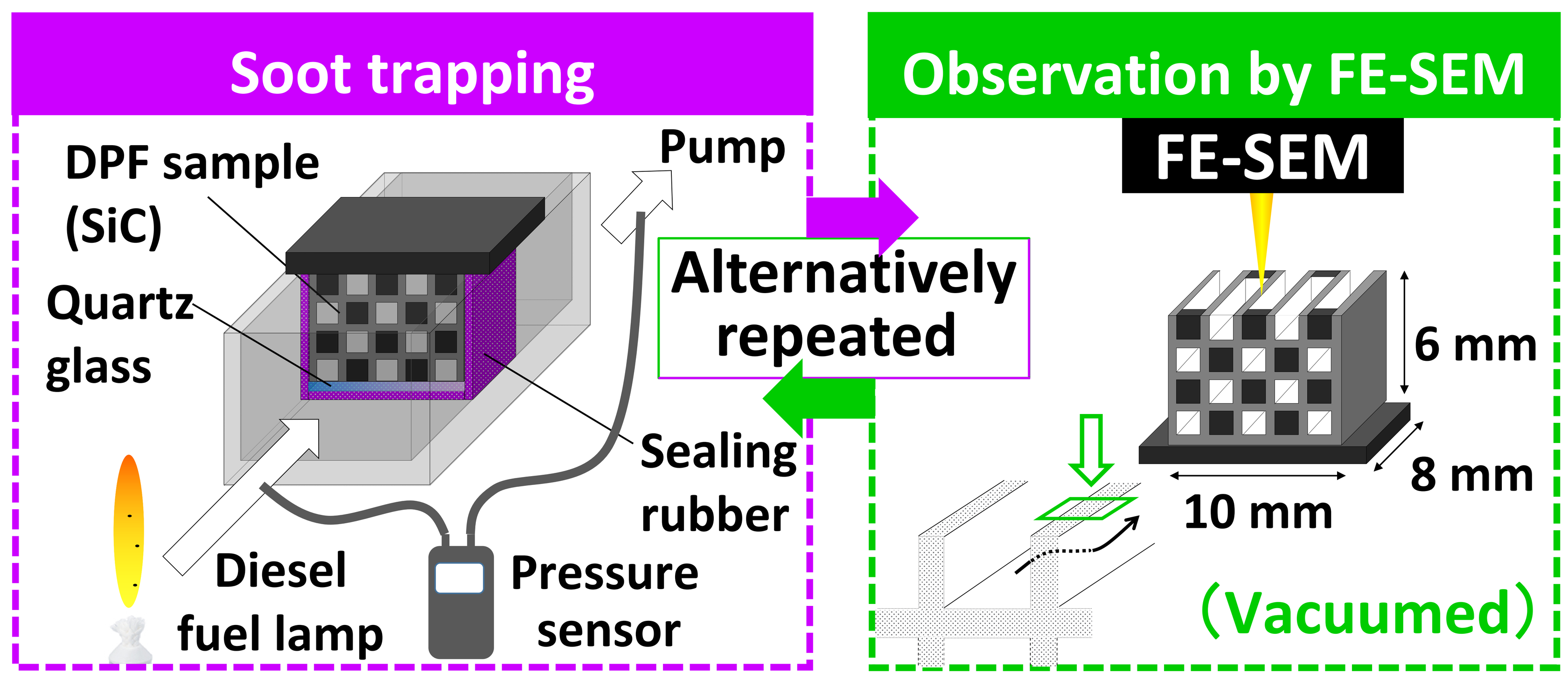
Introduction

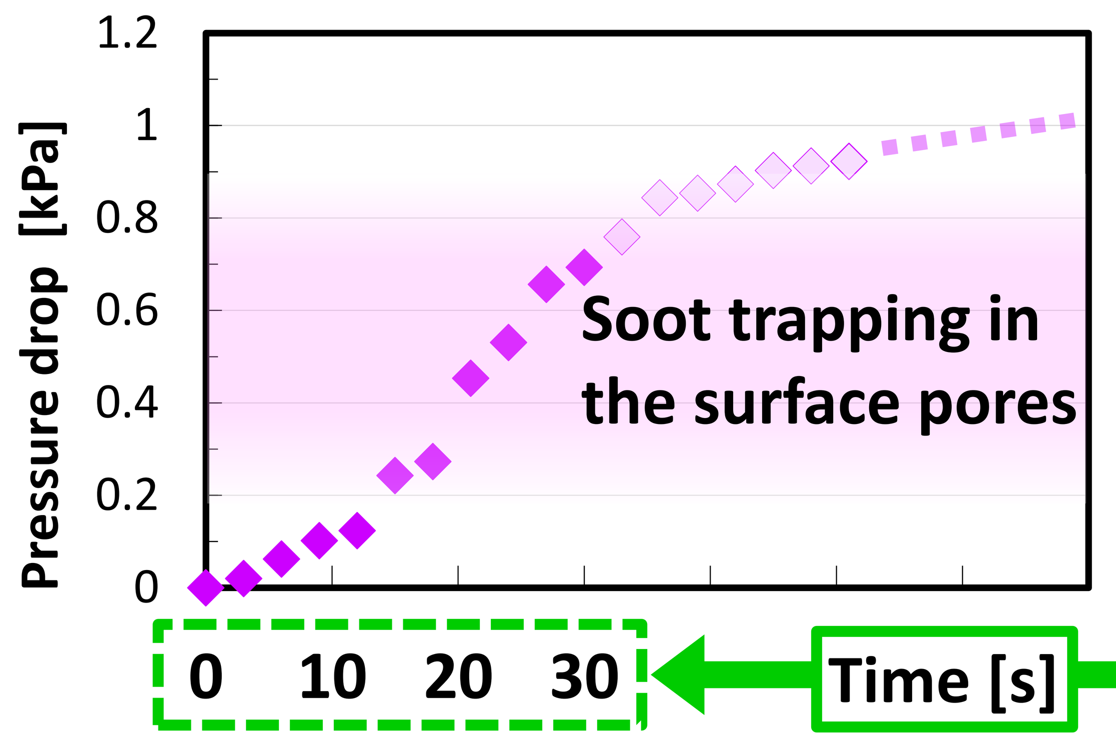
The particle-scale understanding of the soot trapping phenomena inside diesel particulate filter (DPF) is important not only for improving its pressure drop and filtration efficiency but also for achieving a perfect soot oxidation strongly affected by the geometry of the soot. In this study, taking the results of particle-scale visualization of soot trapping process, the effect of the porosity distribution near the wall surface on the bridging depth was investigated.

Experiment & Results

Time-lapse Visualization

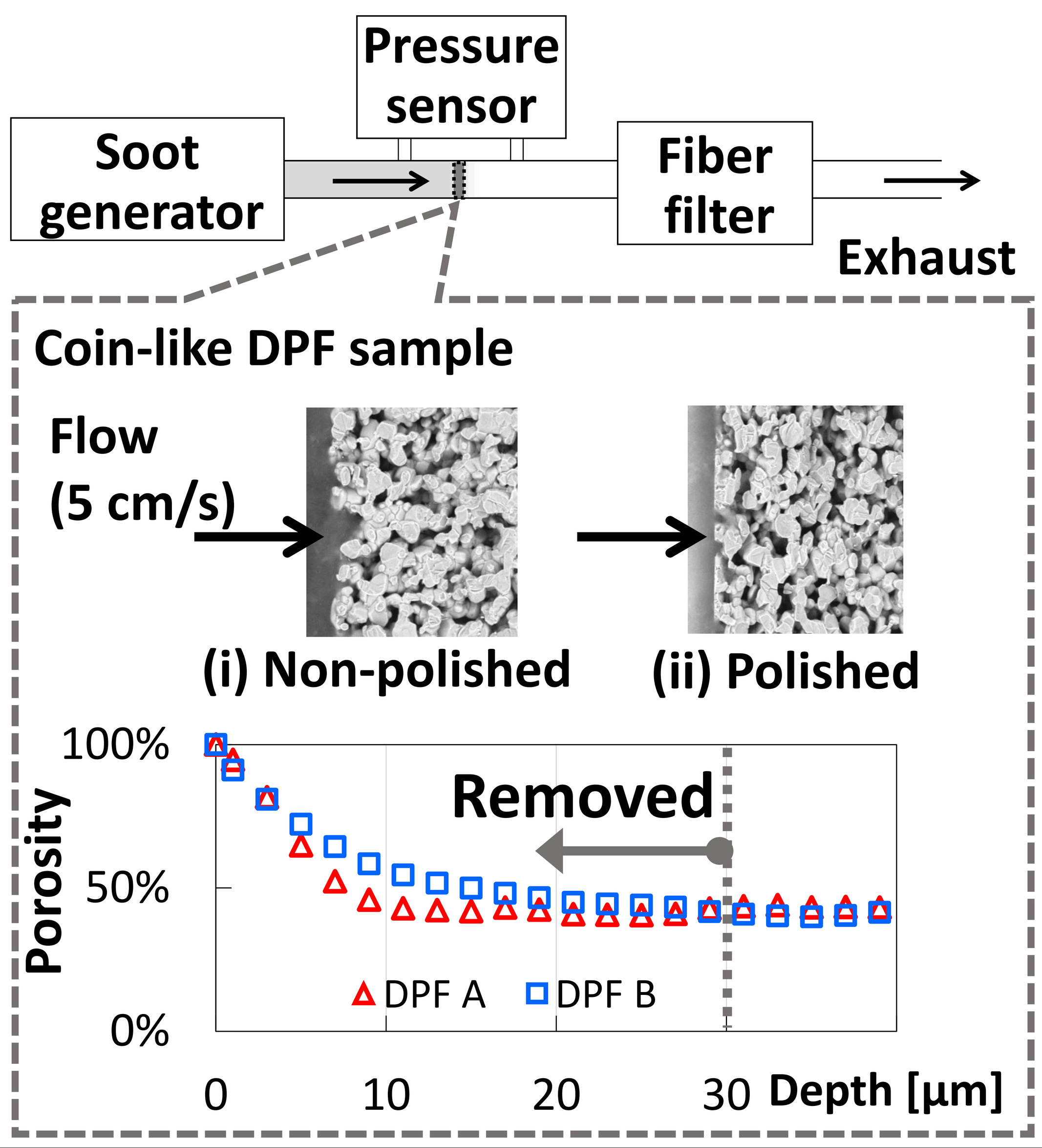
The dendrite structures were locally grown at the contracted flow area between the SiC grains, ultimately constructing a bridge and closing the porous channel. After bridging, soot filled with the upstream pore (surface pore) and the pressure drop drastically increased.

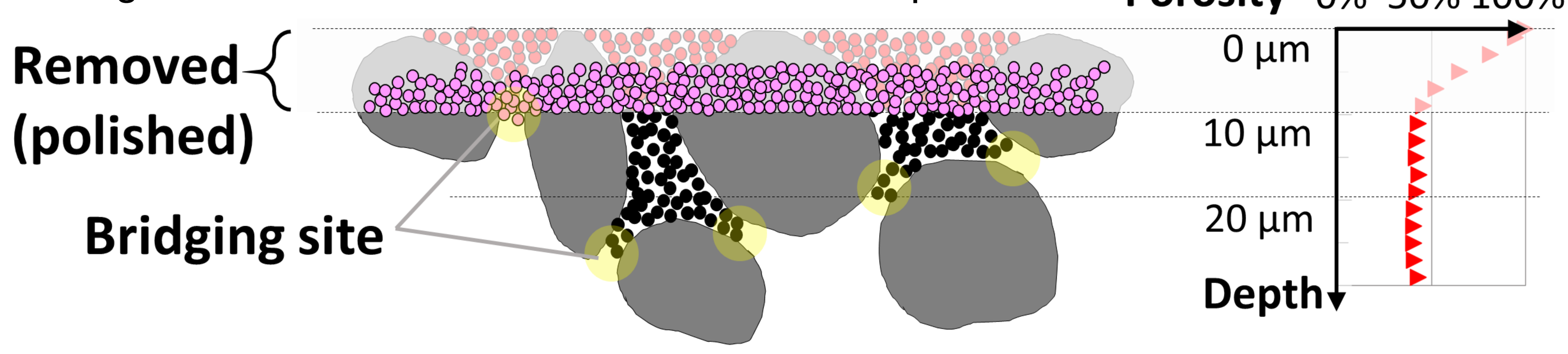


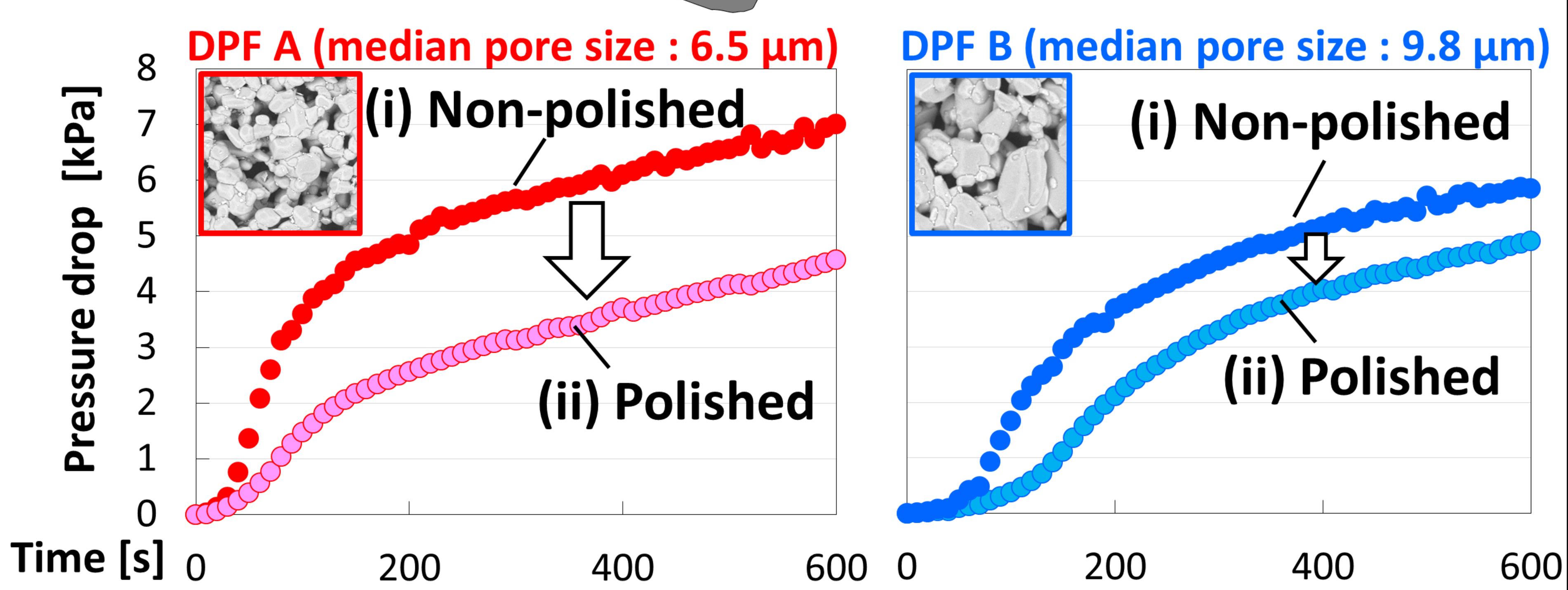


DPF with uniform porosity

With the DPF of which the porosity distribution was eliminated by polishing, the pressure drop across the soot in the surface pore was decreased because of reducing the soot accumulated inside the surface pore.



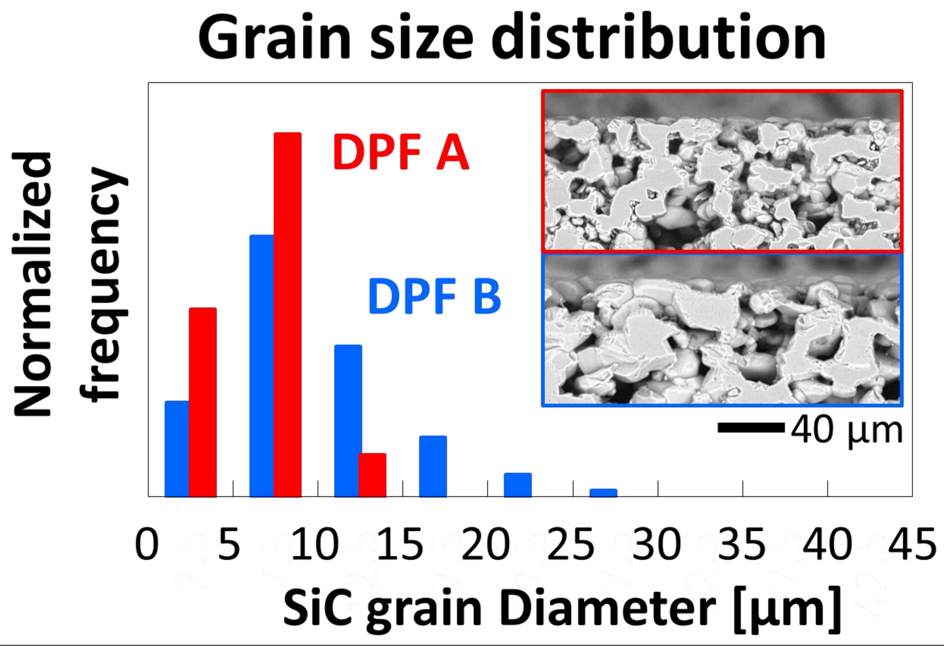




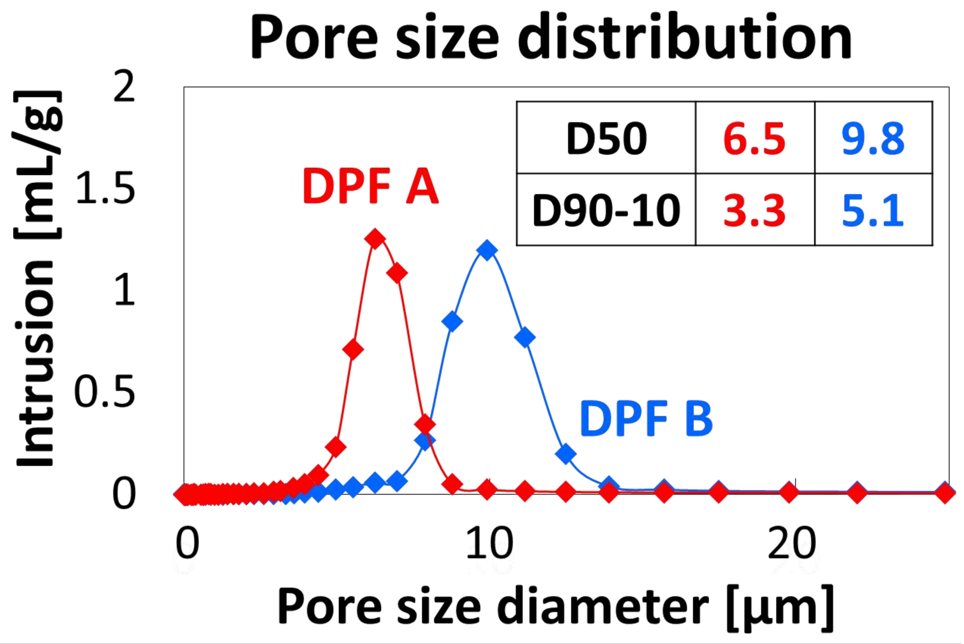
Effect of SiC grain size

Polishing surface was more effective to decrease the pressure drop when the SiC grains had a more uniform size. Since the DPF B had a broad size distribution of SiC grains and larger pore, the bridging sites randomly existed and were not always in accordance with the porosity distribution.

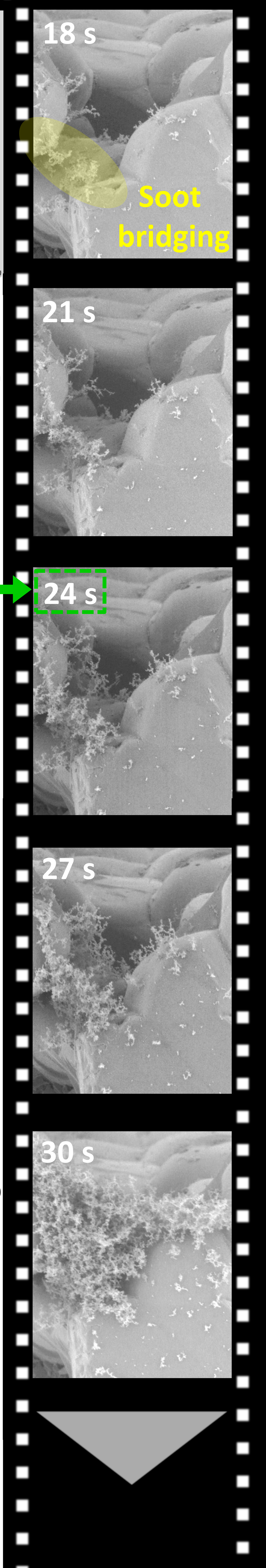
Grain size distribution



Pore size distribution



D50	6.5	9.8
D90-10	3.3	5.1



Conclusions

Particle-scale visualization of the soot trapping showed that the soot accumulation in the surface pores initiated by the bridge formation played a principal role for the drastic increase in pressure drop. The depth of bridging strongly depends on the porosity distribution and the uniformity of the SiC grain size composing the DPF.

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<u>SUMMARY</u>

The initiation of soot accumulation inside a diesel particulate filter (DPF) is one of the important study topics for achieving not only lower filter pressure drop and good filtration efficiency during soot trapping but also improved soot oxidation, which is strongly affected by the geometry of soot inside the filter. This study focuses on the initiation of the soot trapping process, where a soot bridge structure forms at a certain depth in the porous channel of the DPF. We investigated the effects of porous structure on the site of bridge formation, which, in turn, determines the soot penetration depth.

In the first part of this study, time-lapse images of soot deposition in a DPF were taken on a soot-particle scale by using a field-emission scanning electron microscope (FE-SEM). As an experimental sample, a small DPF sample—cut out from an actual DPF was used. The top horizontal wall was removed to open channels. The top surface of each vertical wall was then polished to create a mirror-like cross-sectional surface and to make them flush. These opened channels were covered and sealed with a quartz glass plate having a smooth surface before introducing the soot into the DPF. This allowed visualization of the phenomenon of soot trapping along the cross section of the wall. Alternation of soot deposition and observation was repeated, using the same sample. By focusing on the same microscopic field for each time of observation, the soot bridge formation process inside the DPF wall could be compiled into a “time-lapse” image. The increasing amount of pressure drop was also measured before and after soot was introduced into the DPF. Through this FE-SEM time-lapse visualization of the cross-sectional views of the DPF wall, a dendrite soot structure was observed on the surface of the SiC grains that constitute the DPF. With the lapse of time, these dendrite structures locally grew in the contracted flow area between the SiC grains, thus obstructing the porous flow channel, and then finally bridged the porous channel at a certain depth. Once the porous channel was obstructed by the bridge, which performed like a filter made of soot, all the soot introduced into the pore was trapped on the bridge and filled the upstream pore; we call this the surface pore. As soot accumulated in the surface pores, the pressure drop increased drastically; ultimately, cake filtration started on the DPF wall surface.

The visualization indicated that the soot bridge formation tends to occur at the contracted flow area between SiC grains composing the DPF. Therefore in the second part of the study, the penetration depth of soot on the DPFs with various configurations was examined. First, we focused on the porosity distribution near the wall surface, where the porosity distribution changed from 100% open to the bulk porosity. This porosity distribution is as a result of the ceramic extrusion process during DPF manufacture, where the surface grains of the wall come into contact with the plane surface of the extruding die. To investigate its effect, one side of a coin-like DPF sample was polished by 100 μm eliminating the area with the porosity distribution and the pressure drop increase along with the soot trapping was measured. For the surface-polished DPF, the drastic increase in pressure drop during the soot accumulation in the surface pore was restrained. It is because in the surface-polished DPF, which had the uniform porosity, soot penetrated to a shallower depth than that in the non-polished DPF. Since in the area with the porosity distribution, there were fewer contracted flow areas for the bridge formation, the elimination of this area led to make the bridge formation at the shallower area from the top surface.

The same experiment was carried out by using another DPF composed of larger grains of SiC (here, we call the DPF composed by smaller SiC as DPF A and that composed larger grains as DPF B) expecting the more reduction of pressure drop by polishing surface. However, eliminating the porosity distribution was less effective, contrary to expectations. It is because of the uniformity of SiC grains of the DPF B. The pore size distribution measured using a mercury porosity meter and SiC grain size distribution measured from SEM images of wall top surface indicated that the DPF B had a broad size distribution of SiC grains and pores. Because of the broad distribution, the abundance ratio of the bridging site was not necessarily in accordance with the porosity distribution. Since the DPF A and B had a different configuration and thus the time taken for the bridge formation was different, we did not compare the absolute value of the pressure drop.

Particle-scale visualization of the soot trapping process and configuration analysis led to the conclusion; the bridge formation is the key process and of which depth is responsible for the drastic increase in pressure drop at the beginning of soot trapping process. Since the abundance ratio of this contracted flow area is strongly dependent on the porosity distribution near the wall surface and the grain size of the SiC constituting the DPF, the elimination of the surface pore is one possibility to make the bridge formation shallower, which results in a smaller increase in pressure drop compared to the actual DPF.