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Method for Shape Evaluation of Exhaust Particles by Machine Learning-Based Image Analysis

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Particles in automotive exhausts are well known to be formed not only chemically during fuel combustion, but also by physical aggregation process. Since mechanisms and formation processes are related to particle size (particle diameter) and shape, it is important to understand physical shape of particles. In this study, a machine-learning based method for analyzing images acquired by transmission electron microscope (TEM) was investigated in attempt to establish a technique for simultaneously measuring the number distribution of particle size and shape of particles in automotive exhausts.

Exhaust particles were collected and measured during an emission test on a chassis dynamometer (Fig.1). The test vehicle was a 1.0 L PFI-equipped gasoline passenger vehicle which complies with Japanese emission standards enforced in 2018. The test cycle was 3 phase-WLTC, a soak condition of which was a hot start. Exhaust particles were collected on TEM grids installed on each stage of the Electrical Low Pressure Impactor (ELPI+, Dekati). Particle number (PN) was measured by a PMP-compliant PN measurement system (MEXA-2000SPCS, Horiba) and a condensation particle counter (model 3750, TSI). Particles collected on the TEM grids were observed with a 200 kV TEM (JEM-2100, JEOL).

TEM images were analyzed with an open-source image analysis software Fiji and its plugins. Firstly, by applying a Non-local Means filter, all images were pre-processed to smooth background noise. Secondly, a machine-leaning based segmentation plugin Trainable Weka Segmentation was used to detect particles in the images (Fig.2). Finally, the number, size and shape of the detected particles were analyzed by the software.

Fig.3 shows the result of particle shape evaluation. In this study, particle shape was evaluated by Roundness in order to quantify the elongation of particles. Here, Roundness is a ratio of minor axis to major axis of a particle. Referring to JIS A 1481-4 for quantitative asbestos analysis, when defining particles with a Roundness of 0.33 or less as rod-like particles, only 4.1% of particles collected on the ELPI+ stage 2 (cutoff diameter D_{50}=16 ~ 30 nm) were rod-like particles.

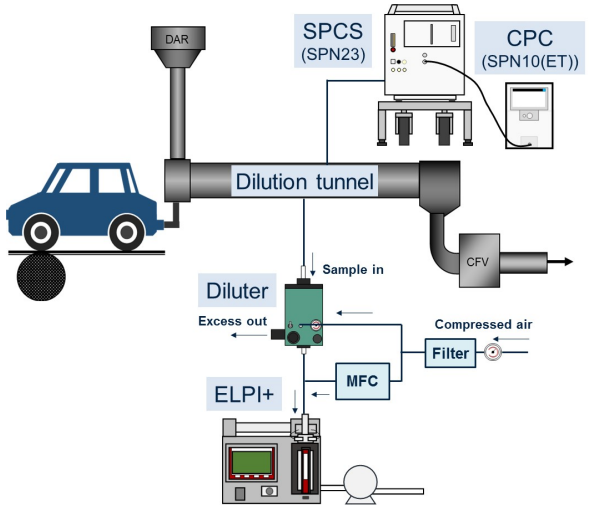

Fig.1 C/D Test and Measurement Equipment

Fig.2 Example of Training Procedure in TWS

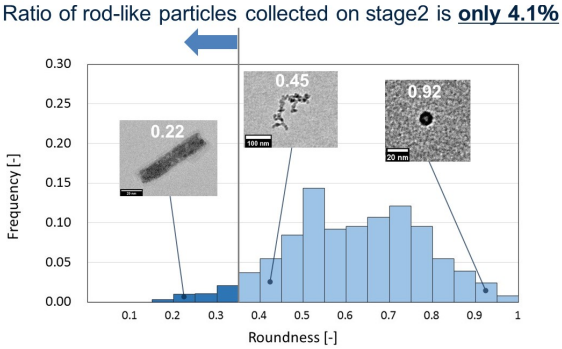

Fig.3 Roundness Distribution of Particles Collected on ELPI+ Stage2 at Hot Start WLTC 3 Phase