21st ETH-Conference on Combustion Generated Nanoparticles

Soot nanostructure analysis from a modern turbocharged direct-injection gasoline engine

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Introduction

Gasoline Direct Injection (GDI) engines are a rapidly growing technology, promising significant improvements in fuel economy. As a result there is increasing demand from health organisations and manufacturers to understand GDI emissions. High Resolution Transmission Electron Microscopy (HRTEM) can image soot particles at the atomic level, and with the use of an image processing program, analysis of nanostructure parameters can determine the reactivity of the particle and hence its effect on engine components, particulate filters and public health.

Aims

Using HRTEM images of GDI soot collected from passenger cars used in a city/urban environment, analyse the soot nanostructure and compare the reactivity of GDI soot with a selection of other soot samples by measuring the fringe lengths, tortuosity (curvature) and layer separation.

Objectives

- Measure primary particle size distributions of carbon black, diesel and gasoline soot.
- Compare the nanostructure parameters, crystallinity and reactivity of three forms of carbon nanoparticles: carbon black, diesel and GDI soot.

Methodology

Image Processing

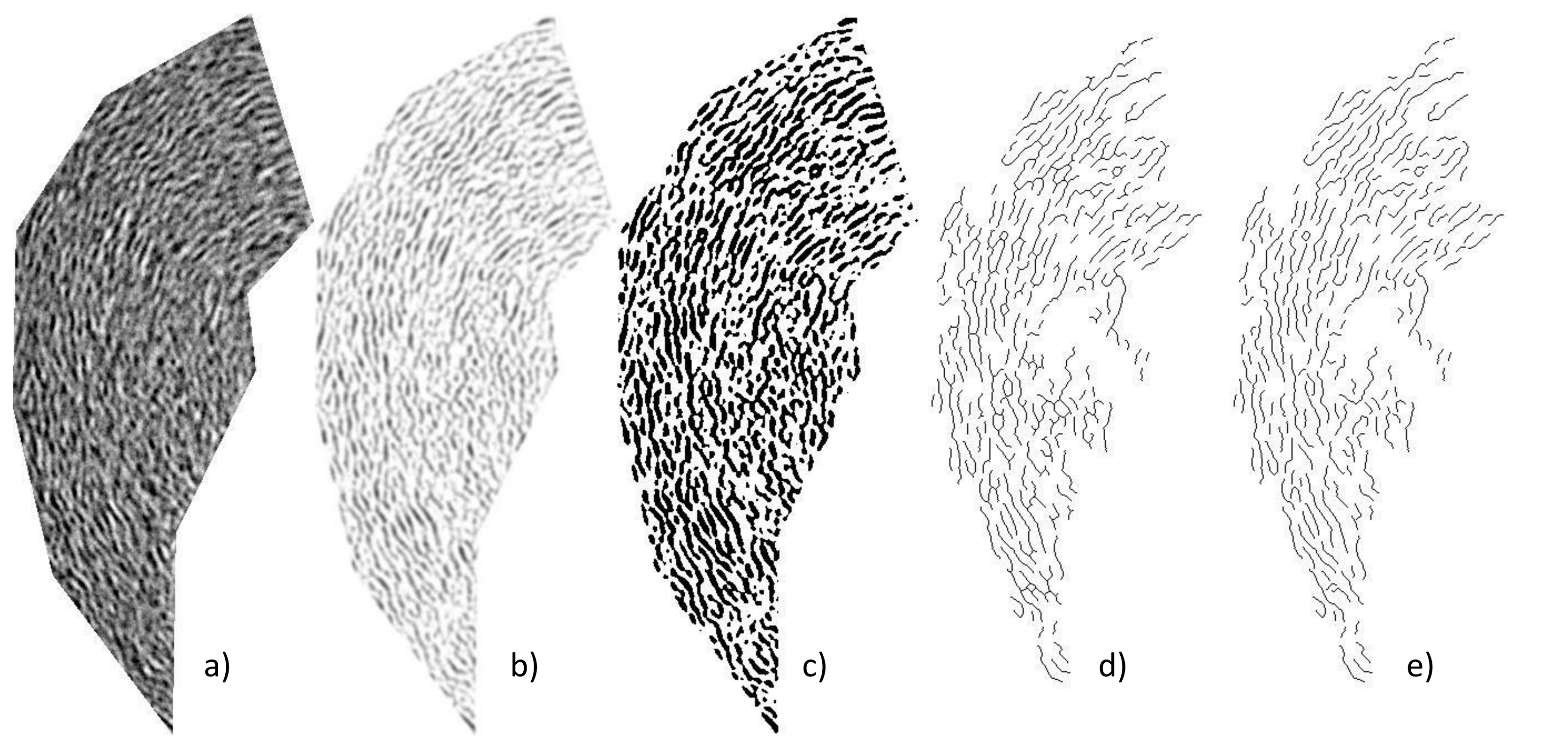

Figure 1. Inverted image at various stages of processing. a) Original HRTEM image. b) After contrast enhancement, Gaussian blur and white top hat transformation. c) After binarization. d) After skeletonization with border fringes and artefacts removed. e) Final image after fringe cleaning algorithm.

Image Analysis

$$\text{Fringe length} = \text{Geodesic length}$$

$$\text{Tortuosity} = \frac{\text{Geodesic length}}{\text{Euclidean length}}$$

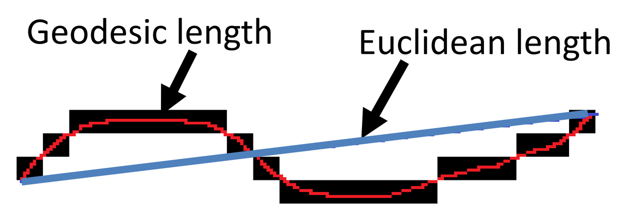

Figure 2. Representation of measures for fringe length and tortuosity.

The image analysis program calculates the fringe length and tortuosity for each fringe in the processed image.

The fringe separation is averaged from the separation at every pixel between pairs of manually selected fringes.

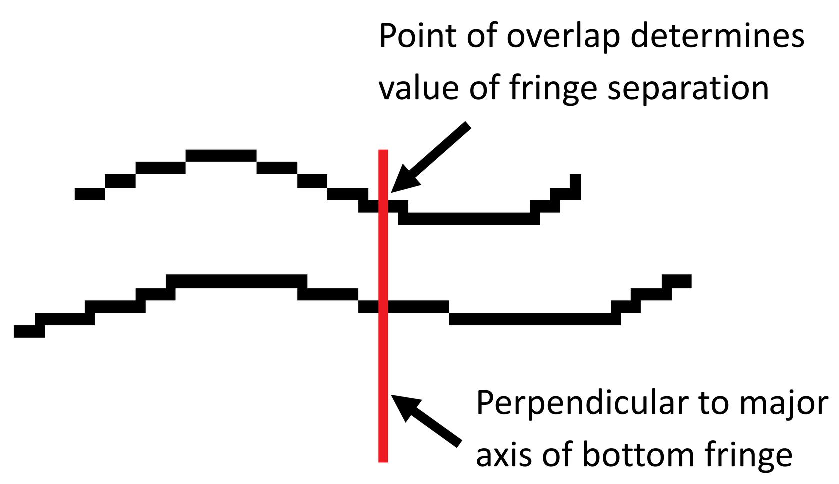

Figure 3. Representation of fringe separation measurement method.

Results

Primary Particle Size

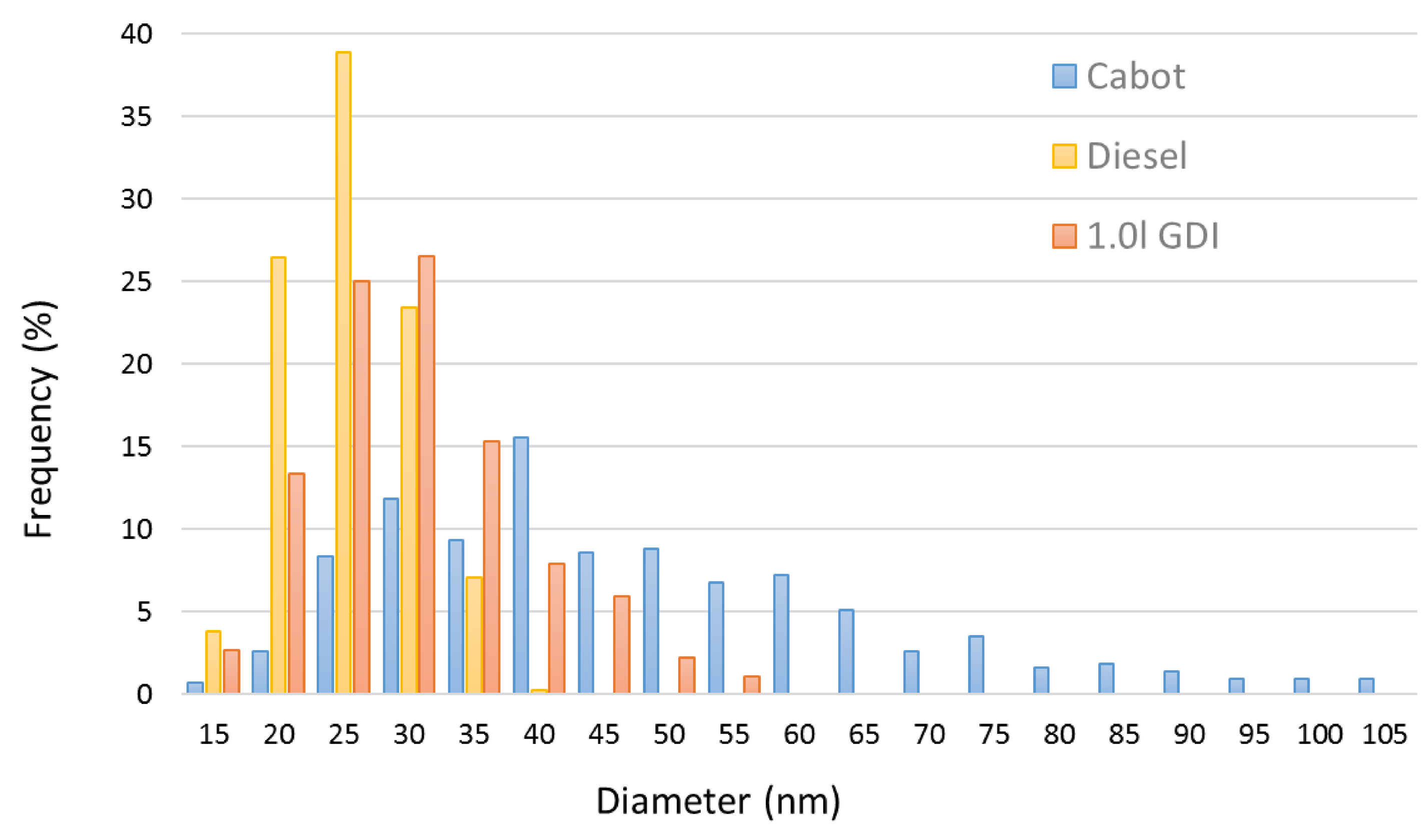

Figure 4. Primary particle size comparison between carbon black (Cabot), diesel and 1.0l GDI soot.

Nanostructure Parameters

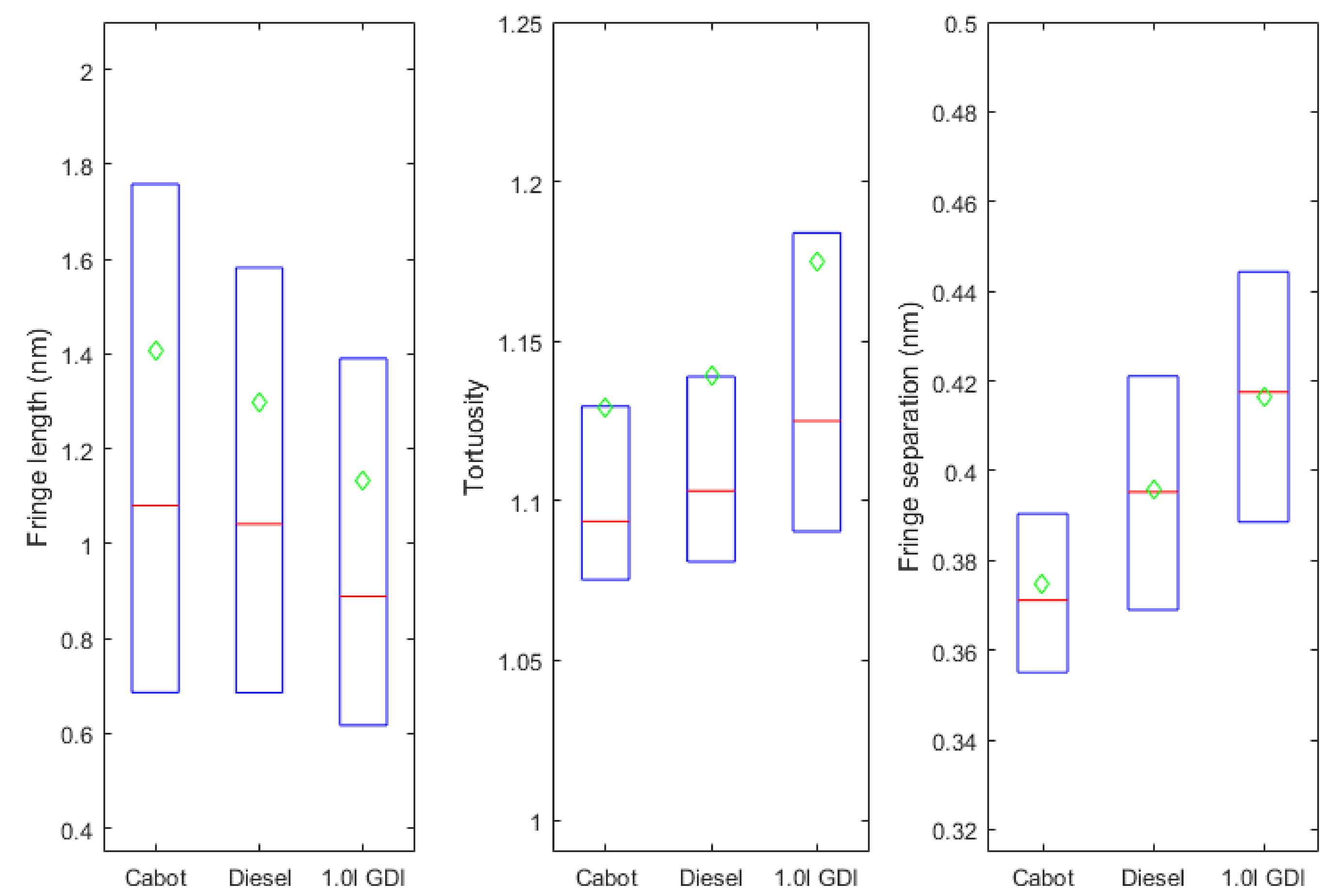

Figure 5. Comparison of nanostructure parameters between the three types of soot. Green marks indicate the mean value, red the median and blue the interquartile range.

Conclusions

- GDI soot has smaller primary particles (mean 30nm) than carbon black (mean 48nm) but larger than diesel soot (mean 20nm).
- GDI soot has shorter fringe lengths, higher fringe tortuosity and larger fringe separations than carbon black and diesel soot.
- GDI soot consequently will have increased oxidation rates relative to diesel soot and carbon black, and so will be more reactive.
- Fringe separation shows the most significant change when comparing carbon black with GDI soot.

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