On the characterization of the generation rate and size-dependent crystalline silica content of the dust from cutting fiber cement siding

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European Standard EN 1093-3 and the experimental verification of representative sampling

The European Standard EN 1093-3 (CEN, 2006) specifies a test bench method for the measurement of the generation rate of a given airborne pollutant. The test bench includes a chamber, where the airborne pollutant is generated, a funnel, and a duct.

The standard requires the average flow velocity in the chamber to be larger than or equal to 0.1 m/sec for transporting respirable dust to the sampling section of the system. Under the operating air flow rate of the testing system used in this study, the flow velocity in the chamber was 0.44 m/sec. The Reynolds numbers for the chamber and duct are 34,000 and 170,000, respectively, indicating turbulent flow, maximizing mixing to obtain an appropriately representative sample at the sampling section.

To ensure representative samples being taken from the duct, the standard requires the sampling section to be 5-10 times of d_t (the square root of the area of the duct's cross section) downstream of the funnel and 3 times of d_t upstream of the other end of the duct. The sampling section of the testing system used in this study locates at 9 times of d_t downstream of the funnel and 4 times of d_t upstream of the blast gate valve. Other details of the requirement can be found in the standard document (CEN, 2006).

Analysis and comparison of the data from all the three instruments used in this study assumes that the particle size distribution is uniform along the two cross sections of the duct where the sampling probes locate. Using APS and its sampling probe, particle size distribution was measured at the two cross sections with a 10-point traverse in both horizontal and vertical planes of the duct at each cross section. The average particle size distributions during three repeated cuts measured from all the traverse points under the same testing condition result in a RSD of 4.1% for the total concentration, 0.9% for the geometric mean diameter, and 1.3% for the geometric standard deviation, demonstrating excellent uniformity of the particle size distribution throughout the two sampling cross sections in the testing system. The result also verified that samples taken by the three instruments were representative.

Testing materials

Fiber cement siding from four different manufacturers was evaluated in this study. Detailed specifications of these products are listed in Table S1. Because they may contain a different amount of silica in their respective formulations, which may also vary from time to time by the manufacturers, the manufacturing dates stamped on the siding boards, were recorded if available. The bulk density of the siding board was obtained by measuring the volume and mass of at least three boards from each manufacturer.

Table S1. Fiber cement siding evaluated in the study.

Manufacturer	Manufacturing Date	Measured Board Width, W (cm, inch)	Measured Board Thickness (cm, inch)	Measured Board Density (g/cm^3)
CertainTeed (Valley Forge, PA, USA)	05/27/2012	21.0, 8.25	0.76, 0.30	1.31±0.03
James Hardie (Mission Viejo, CA, USA)	08/21/2010	21.0, 8.25	0.76, 0.30	1.27±0.01
Maxitile (Houston, TX, USA)	09/30/2010	21.0, 8.25	0.79, 0.31	1.31±0.02
Nichiha (Norcross, GA, USA)	n/a	21.0, 8.25	0.79, 0.31	1.25±0.01

Note: cm — centimeter; g — gram; n/a — "not available".

Operating procedure for the cutting test

Before conducting a cutting test, the automatic tool testing chamber was programmed to perform a predetermined number of cuts. Each cut included the following steps: 1) the feed plate fed the board; 2) power was supplied to the tool; 3) the 2D actuator moved the tool and made a cut; 4) the tool was turned off; and 5) the 2D actuator moved the tool back to its original position. A waiting time about 5 seconds was programmed between steps 2) and 3) to ensure the blades of the power saws reached their designed rotating speed before making a cut.

For each cutting test, the air handling unit was turned on and the flow rate set to 0.64 m^3/sec by adjusting the blast gate valve. The flow rate was stable throughout each individual test of this study. Once the flow rate reached the desired value, the sampling instruments began sampling, and the automatic tool testing chamber was started. Upon finishing a test, the air handling unit was turned off, and the collected samples were removed from the instruments.

During each cut, a dust cloud was generated, and it was carried downstream by the air flow through the tool testing chamber and measured by the instruments through their respective sampling probes on the duct of the testing system. The APS collected size distribution measurements at 1-second intervals and its data indicated that no dust was detected when no cutting was conducted. The flow rate in the testing chamber (0.64 m^3/sec) was optimal so that the APS data with 1-second time resolution captured the entire profile of the dust cloud from each individual cut without overlapping the dust clouds between any two adjacent cuts.

LOD and LOQ for all the analyzed samples

Table S2. LOD and LOQ for all the analyzed samples.

	Dust on air samples (µg/sample)	Quartz on air samples (µg/sample)	Cristobalite on air samples (µg/sample)	Tridymite on air samples (µg/sample)	Quartz on bulk samples (%)
LOD	90	5	5	10	0.3
LOQ	300	17	17	33	0.89

Note: µg — microgram.

All the respirable dust samples had dust masses above the LOQ (300 µg/sample); except for the samples from cutting Nichiha board, they also had quartz masses above the LOQ (17 µg/sample). For the samples from cutting Nichiha board, the quartz mass is between the LOQ and LOD (5 µg/sample).

All the MOUDI samples with an aerodynamic diameter larger than 0.42 µm had dust masses above the LOQ (300 µg/sample); the other MOUDI samples had dust masses between the LOQ and LOD (90 µg/sample). Among the MOUDI samples from cutting Nichiha board, the quartz mass exceeded the LOQ (17 µg/sample) for the size channels above 4.2 µm; it was between the LOQ and LOD (5 µg/sample) for the size channels between 0.75 and 4.2 µm; and it was below the LOD for the other size channels. Among the MOUDI samples from cutting of the other three brands, the quartz mass was above the LOQ (17 µg/sample) for size channels above 0.75 µm; it was between the LOQ and LOD (5 µg/sample) for the size channels between 0.24 and 0.75 µm; and it was below the LOD for the three size channels below 0.24 µm. The non-detect samples are not included in Figure 5. Conducting MOUDI tests with more than 30 repeated cuts could have quartz mass in all the channels above the LOD. However, this would overload the first few channels and could result in more particles bouncing off the substrates and likely entering the subsequent channels, reducing the overall measurement accuracy.

Grease was not applied to the MOUDI's substrates for reducing particle bounce as this may introduce unknown interference to the silica analysis.

Adjusted silica distribution in the dusts of different sizes from cutting fiber cement siding

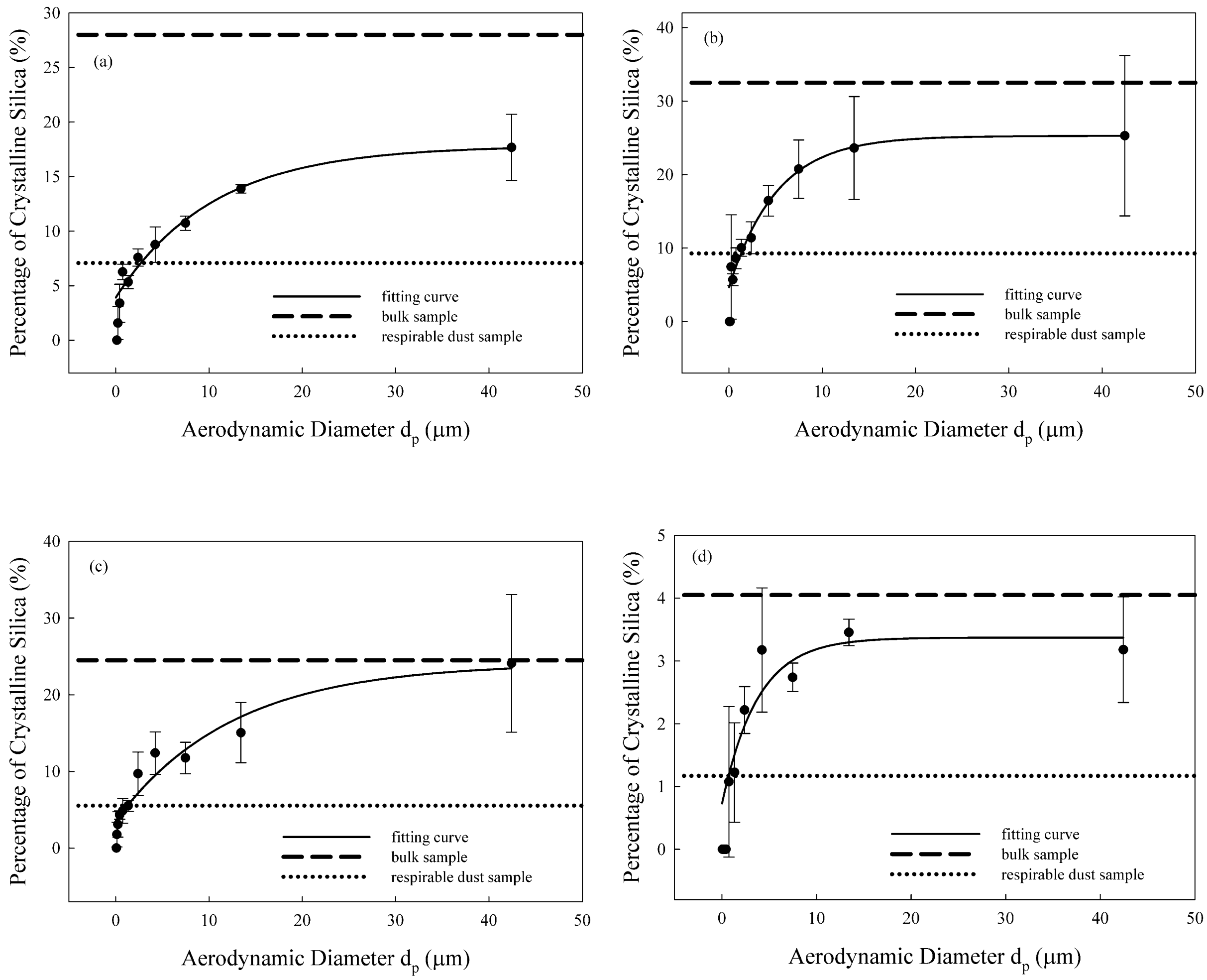

Figure S1. Silica distribution in the dusts of different sizes from cutting fiber cement siding board of (a) CertainTeed; (b) James Hardie; (c) Maxitile; (d) Nichiha. Adjusted for the measured XRD intensity.

Comparison of the silica content in respirable dust from respirable dust samples and derived from the MOUDI samples.

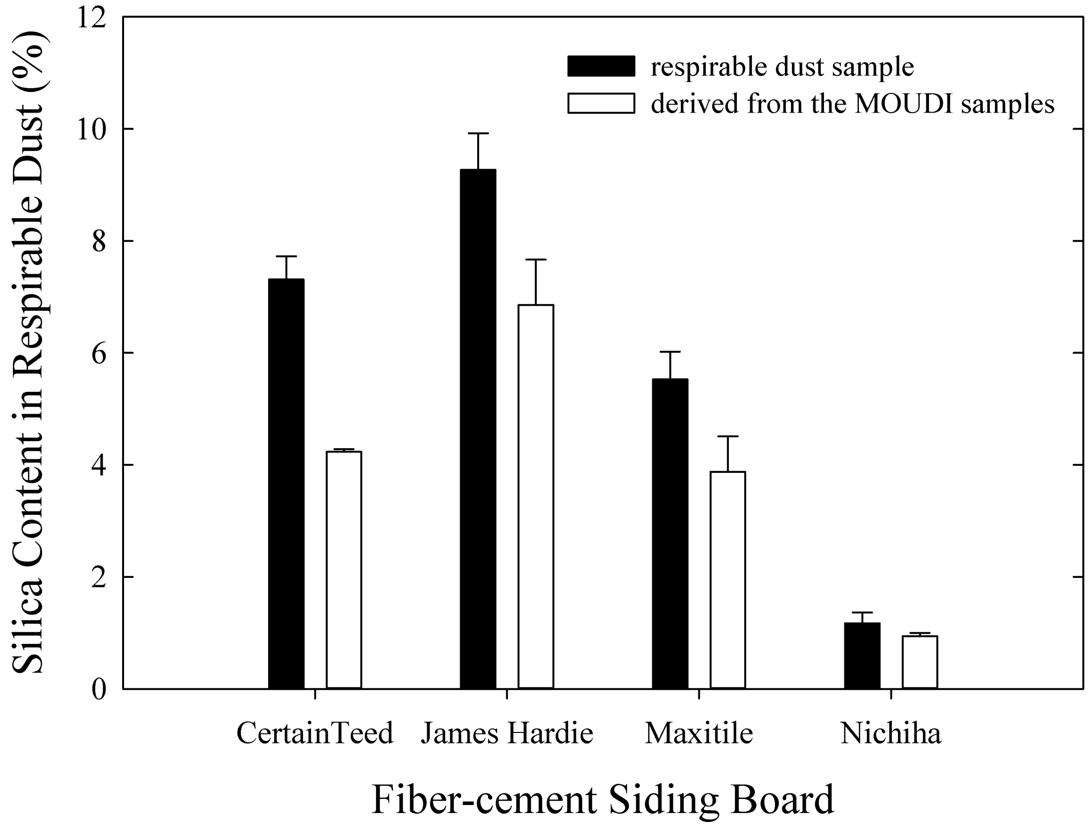

Figure S2. Comparison of the silica content in respirable dust from respirable dust samples and derived from the MOUDI samples.