Field comparison of two inhalable samplers used in Italy to measure the wood dust exposure

Antonella Campopiano¹, Fulvio Basili¹, Federica Angelosanto¹,
Annapaola Cannizzaro¹, Angelo Olori¹, Deborah Ramirez¹, Antonino Iannò²,
Laura Angelici³

¹Department of Medicine, Epidemiology, Occupational and Environmental Hygiene, Italian Workers' Compensation Authority, Monte Porzio Catone, Rome, Italy, ²Department of Medicine, Epidemiology, Occupational and Environmental Hygiene, Italian Workers' Compensation Authority, Lamezia Terme, Italy, ³Department of Occupational and Environmental Health, Epidemiology Unit, University of Milan, Milan, Italy

Background: Particle size affects the performance of personal air samplers used to measure dust exposure in the workplace. Few field studies have been conducted for comparing the performance of personal inhalable samplers. **Objective:** To compare wood dust sampling with two inhalable samplers: IOM (Institute of Occupational Medicine) and Italian cone.

Methods: 136 Italian cone/IOM paired samples and 136 passive IOM samples were collected in 30 Italian woodworking industries. The valid number of sample pairs was 114. Ultra-large particles were collected by passive IOM. The sampling membranes were weighed and the size particles were measured. Mass differences in active and passive IOM samples were calculated (IOM-Δ).

Results: Statistical analysis of all 114 Italian cone/active IOM paired results showed a significant mass difference ($P < 0.05$) and no significant mass difference for sanding and cutting woodworking processes. The Italian cone/IOM-Δ paired results consistently showed no statistically significant mass differences in any woodworking processes. Both samplers performed similarly when ultra-large particles mass contribution was not considered.

Conclusions: These findings confirm the presence of ultra-large particles in woodworking. The Italian cone and IOM samplers can be used interchangeably for personal wood dust exposure assessment, when the wood activities produce small-size particles.

Keywords: Wood dust, IOM sampler, Conical sampler, Aerodynamic diameters, Inhalable sampling, Ultra-large particles

Introduction

In 1999, the European Union (EU) set a hardwood dust exposure limit value of 5 mg/m³ weighted over an 8-h workday to be implemented by occupations involving any wood dust mixture containing hardwood. The EU Member States adopted this value and in compliance with European Directive 1999/38/EC of 29 April 1999 and in 2000, Italy issued Legislative Decree No. 66, specifying that the assessment of conformity with the 5 mg/m³ limit value be performed by means of personal inhalable fraction sampling.^{1,2} The European Commission is currently exploring the possibility of reducing the limit value for hardwood dust from 5 to either 3 or 1 mg/m³.³

The European standard EN 481 defines conventions for particle size fractions used to assess possible health effects resulting from inhalation of airborne particles in

the workplace.⁴ Conventions are defined for the inhalable, thoracic, and respirable fractions. The conventions are relationships between the aerodynamic diameter and the fractions to be collected or measured approximating the regions of the respiratory tract under average conditions. They are stated in terms of mass fraction and it is often used to specify instruments to sample airborne particles for the purpose of measuring concentrations corresponding to defined fractions. The inhalable convention is defined as the probability of particle collection by the nose and mouth for particle size up to 100-μm aerodynamic equivalent diameter.⁵ Particles with diameter larger than 100 μm are undefined by the convention.⁶

Samplers that meet the EN 481 requirements should be used to collect the different fractions.⁴ There are a variety of commercially available personal samplers used to measure dust exposure in the workplace, but their efficiency varies and depends on multiple factors including: wind velocity and direction, inlet size, geometry, orientation,

Correspondence to: Antonella Campopiano, INAIL Department of Medicine, Epidemiology, Occupational and Environmental Hygiene, Via Fontana Candida 1, Monte Porzio Catone, Rome 00040, Italy. Email: a.campopiano@inail.it

aerosol particle size, electrical charge, particle bounce properties, the conductive properties of sampler, and other factors.

Designing experiments that permit objective comparison of samplers is challenging. The Institute of Occupational Medicine (IOM) sampler showed high agreement with inhalable convention under controlled conditions, but IOM samples collected more mass than expected when evaluated under woodworking conditions. Sampling performance is strongly dependent on particle size. Kenny et al. noted that the IOM sampler may over-sample for particles greater than 100 μm .⁷ This could be a problem in the wood industry due to the presence of large particles in the air. Although they normally settle rapidly, they can remain airborne over significant distances if projected with sufficient velocity, leading to an overestimation of the exposure level. Other studies have found that the IOM sampler over-samples airborne dust concentration compared to the Conical Inhalable Sampler (CIS), with greater differences for larger particles in laboratory studies and field studies.^{8–10}

The samplers described above work similarly, with particulate matter aspirated through an orifice on the face of the sampler and deposited on a filter in the body of the sampler. The main difference between the samplers is in the size and shape of the orifice.

In Italy, the cone sampler which resembles the CIS and is referred to as the “Italian cone” sampler, is used widely given its wide availability at all Italian Prevention Services. The CIS sampler has an orifice diameter of 8 mm, slightly larger than the Italian cone sampler with a diameter of 7.8 mm; both operate at a flow rate of 3.5 l/min and the sample is collected on a 25-mm filter supported by a metal grid. The IOM sampler is also commonly used in Italy. It has a molded conductive plastic body with a single 15-mm orifice, a 25-mm filter contained in a cassette inside the sampler body and operates at a flow rate of 2 l/min. The cassette system allows the particles to collect on the filter and the cassette walls, simulating the function of the nasal septum.

Previous field studies in woodworking companies showed that IOM and Italian cone samplers resulted in different values of dust collected. The difference appeared to be roughly corrected by the dust deposited on the filter in the IOM sampler not connected to a personal sampling pump (in other words – dust deposited by forces other than air suction).¹¹ The difference could be attributed to the different inlet geometry of two samplers. The IOM sampler is set to collect the projectile particles greater than 100 μm produced during woodworking operations.

The aim of this paper was to compare two wood dust personal sampling devices carried commonly used in Italy: the IOM and Italian cone sampler. We also studied the size of the wood particles collected to verify the presence of ultra-large particles.

Methods

Thirty secondary woodworking industries were investigated in Lazio Region of Italy. The industries produced window and doorframes, door skins, shutters, plywood, chipboard, and medium-density fiberboard. Each company averaged five workers. The surveyed establishments used a mixture of hard and soft woods, although a significant proportion of manufactures of joinery and furniture also used composite woods.

The two most commonly used samplers in Italy were considered: IOM and Italian cone sampler. The IOM sampler was purchased from SKC, Inc. (Eighty Four, PA), the Italian cone sampler was purchased from Zambelli s.r.l. (Bareggio, Milano). Another IOM sampler not connected to a personal sampling pump was also used to determine the amount of dust deposited on the collection surface of the sampler by forces other than air suction, in other words by their own momentum or by turbulent deposition.¹² Thus, each worker wore three samplers: an IOM sampler connected to a personal sampling pump (Aircheck 2000, SKC Inc., Eighty Four, PA, U.S.A.) operating at a flow rate of 2 l/min (active IOM sampler); another IOM sampler not connected to a personal sampling pump operating as a passive sampler capable of collecting projectile particles produced during processing (passive IOM sampler), and a 25-mm diameter stainless steel conical sampler (Italian cone sampler), connected to a personal sample pump (224 PCXR8, SKC Inc., Eighty Four, PA, U.S.A.) to guarantee a higher flow rate of 3.5 l/min.

Two IOM samplers were located on the same shoulder of worker and Italian cone sampler was located on the other shoulder of worker. The shoulders used (left and right) were randomized.^{13,14} There were a total of 408 samples as 136 of co-located active and passive samples. Of these, 22 pairs of IOM samples and 22 Italian cone samples were excluded due to the pump failure and mis-handling samples. Total valid sample number was 342 as 114 pairs and 114 passive samples.

The sampling lines were calibrated with a primary flow-meter (Dry Cal DC-Lite, BIOS International Corporation, Butler, NJ, U.S.A.). The samples were collected through PVC filters as described by the NIOSH method 0500, with a diameter of 25 mm and porosity of 5 μm .¹⁵

Gravimetric analysis

The mass captured on the membranes was determined by weighing the filters before and after sampling with a Sartorius balance (capacity: 210 g, precision: 0.01 mg, Sartorius AG, Gottingen, Germany) equipped with a device to neutralize electrostatic charges. Before each weighing, the filters were conditioned in the weighing room for two hours (temperature and humidity controlled environment). The IOM cassette system is designed to be weighed as a single unit so that all particles entering the

sampler orifice are weighed. The cassette was weighed twice, before and after sampling.

A calibration check on the balance was performed each day at the start of working day.

Sampling time was adjusted in order to obtain a satisfactory particle deposition on the filters but at least three or four hours were sampled.

Three main woodworking activities were considered: “sanding,” “planing and shaping,” and “cutting.”

SEM analysis

Some passive IOM cassettes were opened after weighing and the membranes were chosen based on the quantity of dust collected on the filter: A, B, C, D, and E were the filters of “sanding” activity; F, G, H, I, and L, the filters of “planing and shaping,” and M, N, O, P, and Q the filters of “cutting.” Besides, two sets of three filters (active IOM, Italian cone and passive IOM) were chosen from personal sampling during sanding and shaping processes.

The 21 selected filters were prepared with gold coating under vacuum and observed by scanning electron microscope analysis (SEM, LEO 440, LEO Electron Microscopy Ltd, Cambridge, U.K.) coupled with energy dispersive X-ray spectrometry (EDAX, INCA ENERGY 400, Oxford Instruments, Abington, U.K.) to determine particle aerodynamic diameters.

Wood particles were irregularly shaped, most of them had an elongated shape and could be classified as non-spherical. A shape factor was calculated for each particle. The shape factor is defined as the ratio of the drag force of the non-spherical particle and the drag force of a sphere having the same volume and velocity. Shape factors were calculated using the following equation

$$K_D = 0.8624(1/3 + 2/3(d_s/d_n)) + 0.0739(d_{\max}/d_n) + 0.0108(AR)$$

where K_D is the dynamic shape factor, d_s is the diameter of a sphere with surface area equal to that of the object, d_n is the diameter of a sphere with projected area equal to that of the object, $d_{\max}$ is the maximum dimension of the object measured in the direction of motion, AR is the aspect ratio, the ratio of the longest to the shortest dimension of the object in the area projected normal to the direction of motion.^{14,16}

The equivalent volume diameters (D_s) were converted to aerodynamic equivalent diameters, or simply aerodynamic diameter, (D_a) by correcting for density and average shape factor using equation:

$$D_a = D_s \sqrt{(\rho K)}$$

an average density ρ was chosen as 0.7 g/cm³.^{14,17}

Shape factor and D_s were obtained from SEM measurements. The two dimensions x and y of 300 wood particles (minimum and maximum value) were measured by SEM on each filter. Average K_D estimate was obtained by

averaging the two dimensions of the particle. The diameter distribution was tested for normality.

Statistical analysis

Statistical parameters such as: arithmetic and geometric mean, arithmetic and geometric standard deviation were calculated to describe the size distribution of experimental data.

Statistical analyses were performed on matched pairs after calculation of air concentrations. All variables were tested to ensure that they met statistical assumptions.

Normal distribution assumption was checked by graphical check (histogram, q-q plot) and formal test (Shapiro–Wilks). Since concentration values measured by the three samplers were not normally distributed, a log-transformation was performed. Log-transformed data were used.

Pearson’s correlation coefficients and their corresponding P-values were calculated to show how well-paired samples correlated with each other.

Mixed linear models were used to look for statistically significant differences between the paired samples controlling for and testing variation between the different sampling activities.

The procedure was as follows:

- (1) an ANOVA model for repeated measures was fitted in order to check Equality of Variance across groups (type of samplers) using the Levene’s test (either with absolute or squared deviations from the group means), which is generally the recommended method to examine whether the variances of data defined by two or more groups are equal. It can end up with an inflated Type I error rate. It essentially calculates the absolute value or squared value of each observation residual from its group mean and then performs an analysis of variance on the positive deviations. Levene’s test is less sensitive than other tests to departures from normality (e.g. which is required for Bartlett’s test);
- (2) in order to take into account for multiple comparison, adjusted P-values and confidence limits were calculated from the simulated distribution of the maximum or maximum absolute value of a multivariate t random vector. All covariance parameters except the residual variance were fixed at their estimated values throughout the simulation.

Non-significant P-values ($P > 0.05$) indicate that the samplers were not statistically different, with mean values close to one indicating similar readings. The P-value from Lavene’s test indicated sufficient evidence to indicate the variances across the three groups are unequal, so we decide to use mixed models using PROC MIXED in SAS. PROC MIXED provides the capability to work directly with unequal variances, as it is able to apply different estimates of the variances for levels of a grouping factor specified as one of the CLASS variables. As a result, all observations having the same level of the variable entered on the GROUP = option of the REPEATED statement as shown below will have the same estimated variance.

Figure 1 Geometric mean concentration of airborne dust collected using the Italian cone and active IOM samplers during studied woodworking processes. IOM-Δ is the mass collected using active IOM sampler without the mass deposited on passive IOM sampler.

Analysis was performed using SAS 9.2 (SAS Institute, Cary, NC, USA) a significant level of 0.05 was used (SAS V.9.2, SAS Institute Inc., Cary, North Carolina, USA).

Results

The data from the personal samplings were grouped in three main woodworking processes: “sanding,” “planing and shaping,” and “cutting.” Figure 1 shows the geometric mean concentration of dust generated during studied working processes and collected by the Italian cone and active IOM sampler. Figure 1 also shows IOM-Δ. It represents the mass collected by active IOM sampler minus the mass collected by the co-located passive IOM sampler.

The arithmetic and geometric mean concentration of airborne wood dust is shown in Table 1 for each working

process with standard deviation and minimum and maximum values.

Using active IOM, 26% of samples exceeded 10 mg/m³, 53% exceeded 5 mg/m³, and 85% exceeded 2 mg/m³ during sanding process; IOM-Δ gave the same percentages; using the Italian cone, the percentages were, respectively, 12, 38, and 82%.

In “planing and shaping” process, 16% of samples exceeded 5 mg/m³ using active IOM, 10% using IOM-Δ, and 5% using the Italian cone. In cutting process, 13% of samples exceeded 5 mg/m³ using active IOM, 13% using IOM-Δ, and no samples exceeded 5 mg/m³ using the Italian cone.

Table 2 shows the Pearson correlation coefficients between Italian cone/active IOM and Italian cone/IOM-Δ sampler pairs with the corresponding P-value for woodworking processes and for total measurements. High positive correlation was found for both sampler pairs and the Pearson correlation coefficient is always statistical significant.

Table 3 shows the geometric mean concentration (C_g) of airborne wood dust measurements with the Italian cone, active IOM and IOM-Δ samplers, and geometric mean ratios of Italian cone/active IOM and Italian cone/IOM-Δ (R_g) with adjusted P-value for multiple comparisons obtained by ANOVA model for repeated measures.

Figures 2, 3, and 4 show aerodynamic diameter distributions measured by SEM of the wood particles collected using passive IOM with their some statistical parameters shown in Tables 4, 5, and 6. Figure 5 shows an example of wood dust deposited on filter of passive IOM and the

Table 1 Arithmetic (C_a) and geometric (C_g) mean concentration of wood particles (mg/m³) with arithmetic (SD_a) and geometric (SD_g) standard deviation for each working process as a function of the sampler used

Sampler	Working process	Sample number	C_a	SD_a	C_g	SD_g	Min	Max
Italian cone	Sanding	34	5.07	3.98	3.71	2.32	0.56	17.39
	Planing and shaping	49	1.91	2.43	1.31	2.33	0.12	4.00
	Cutting	31	1.27	0.96	0.98	2.07	0.27	4.00
Active IOM	Sanding	34	6.60	4.51	5.05	2.20	0.84	16.80
	Planing and shaping	49	3.17	3.06	2.19	2.51	0.23	8.18
	Cutting	31	2.30	2.18	1.46	2.80	0.20	7.73
IOM-Δ	Sanding	34	6.26	4.42	4.72	2.25	0.73	15.1
	Planing and shaping	49	2.94	3.00	1.95	2.60	0.23	4.31
	Cutting	31	2.16	2.11	1.35	2.79	0.20	7.38

Notes: IOM-Δ is the mass collected by active IOM sampler without the mass deposited on passive IOM sampler.

Table 2 Pearson’s correlation coefficients between sampler pairs and working process

Sampler pairs	Sample number	Correlation coefficient	P value
Italian cone/active IOM			
Total	114	0.909	<0.001
Sanding	34	0.959	<0.001
Planing and Shaping	49	0.837	<0.001
Cutting	31	0.794	<0.001
Italian cone/IOM-Δ			
Total	114	0.907	<0.001
Sanding	34	0.930	<0.001
Planing and shaping	49	0.851	<0.001
Cutting	31	0.780	<0.001

Table 3 Geometric mean (C_g) concentration and geometric standard deviation (SD_g) of airborne wood dust (mg/m^3) collected by the Italian cone, active IOM and IOM- Δ samplers

Working process	Sample number	C_g (SD_g)						Geometric mean ratio								
		Italian cone		Active IOM		IOM- Δ		(Italian cone/active IOM)			(Italian cone/IOM- Δ)			R_g	CI 95%	P value
		R_g	CI 95%	R_g	CI 95%	R_g	CI 95%	R_g	CI 95%	P value	R_g	CI 95%	P value			
Sanding	34	3.71	(2.32)	5.05	(2.20)	4.72	(2.25)	0.73	0.44	1.24	0.409	0.79	0.46	1.34	0.631	
Planing and shaping	49	1.31	(2.33)	2.19	(2.51)	1.95	(2.60)	0.63	0.39	1.02	0.063	0.70	0.43	1.14	0.233	
Cutting	31	0.98	(2.07)	1.46	(2.80)	1.35	(2.79)	0.70	0.38	1.29	0.412	0.75	0.41	1.38	0.603	
Total	114	1.65	(2.64)	2.51	(2.80)	2.30	(2.86)	0.68	0.52	0.88	0.020	0.74	0.57	0.96	0.111	

Notes: R_g : geometric mean sampler ratio. CI: Confidence interval. Adjusted P-value for multiple comparisons obtained by mixed models.

Figure 2 Aerodynamic diameter distributions of dusts collected using passive IOM sampler during wood sanding. **Figure 3** Aerodynamic diameter distributions of dusts collected using passive IOM sampler during wood planing and shaping.

two dimension x and y of the particle. Particle aerodynamic diameter distributions of the dusts generated by shaping and by sanding processes are shown in Figs. 6 and 7, respectively.

The Kolmogorov–Smirnov test was applied to test the normality of distributions of the aerodynamic equivalent diameters related to all filters observed by the SEM and log-transformed data were used. The test provided the values of the distance (K–S distance) between the observed distribution and the ideal distribution, at 0.05 significance level P. The test applied to the size distribution of 15

passive IOM filters (from A to Q) was failed (K–S distance ranged between 0.07 and 0.12 with $P < 0.001$) indicating that the data varied significantly from normal distribution. On the contrary, the test applied to size distribution of four personal sampling filters carried out with the Italian cone and active IOM (Figs. 6 and 7) was passed (K–S distance ranged between 0.03 and 0.05 with $P > 0.2$) indicating that the data matched the pattern expected.

Discussion

The geometric mean of airborne wood dust mass concentrations obtained using active IOM sampler was always larger than those obtained using the Italian cone sampler (Table 1). The largest geometric mean concentration of dust was measured using active IOM during sanding. For this process, more than 50% of samples exceeded $5 mg/m^3$. The geometric mean concentrations of dust measured for other woodworking processes were both less than $5 mg/m^3$.

For “planing and shaping” processes, 16% of samples exceeded $5 mg/m^3$ using active IOM, 10% using IOM- Δ , and 5% using the Italian cone. For cutting processes, the percentages exceeding $5 mg/m^3$ were: 13% using active IOM, 13% using IOM- Δ , and 0% using the Italian cone.

High positive correlation was found for the Italian cone/active IOM and Italian cone/IOM- Δ sampler pairs and the Pearson correlation coefficient was consistently statistically significant (Table 2). Pearson correlation coefficients showed a positive and significant correlation between the two samplers in each working process. The performance comparison between the Italian cone and active IOM showed a larger geometric mean concentration of dust when active IOM was used. This finding held also when the total measurements were considered (Table 3). R_g was always less than one for both sampler pairs. Statistical analysis showed that the Italian cone/active IOM pair had a mass difference, no statistically significant for sanding and cutting processes ($P > 0.05$). In “planing and shaping” processes, R_g almost approached significance ($P = 0.06$) and appeared to be significant ($P < 0.05$) when total measurements were considered (Table 3).

This finding is attributed to the different inlet geometry of the IOM sampler with respect to inlet orifice of the

Figure 4 Aerodynamic diameter distributions of dusts collected using passive IOM sampler during wood cutting.

Italian cone sampler.^{11,18,19} Due to its larger inlet orifice, the IOM sampler can collect large projectile particles greater than 100 µm, or so-called ultra-large particles, produced during woodworking processes.^{6,9,13,20} Aitken et al. showed that ultra-large particles have a low probability for inhalation and do not need to be considered when taking air sample measurements.²¹

In our study, we observed that when the passive IOM sampler was placed within the breathing zone of worker and disconnected from the vacuum pump, it was able to collect particles, mainly large projectile particles. By subtracting ultra-large particle mass contribution from the mass collected by active IOM sampler, the wood dust concentrations (shown here with IOM-Δ) approached to the values obtained by the Italian cone sampler.

Figure 5 SEM image of a wood particle collected by passive IOM sampler.

The comparison between the Italian cone/IOM-Δ pair showed a larger geometric mean concentration of dust collected by IOM-Δ for the three working processes and for the total measurements; however, the difference was not statistically significant ($P > 0.05$). The Italian cone/IOM-Δ pair was found to be exchangeable ($P > 0.05$) (Table 3).

SEM analysis of the membranes of passive IOM samplers confirmed that ultra-large particles were present. During wood processing, projectile particles and ultra-large particles are relatively common, probably due to their aerodynamic properties.¹² These particles are undefined by inhalable convention. Figure 6 shows that IOM collected a greater number of particles with aerodynamic diameter greater than 100 µm compared to the Italian cone sampler during shaping process.

Table 4 Statistical parameters of aerodynamic diameter distributions of the particles collected by passive IOM sampler during wood sanding

Statistical parameters	A	B	C	D	E
Arithmetic mean (µm)	5.8	3.7	5.5	0.9	6.3
Geometric mean (µm)	2.4	1.3	4.0	0.6	3.6
Arithmetic standard deviation (µm)	9.0	8.5	5.3	1.1	7.3
Geometric standard deviation (µm)	1.5	1.4	2.2	2.5	3.1
Maximum value (µm)	50.5	75.6	39.9	8.0	49.6

Table 5 Statistical parameters of aerodynamic diameter distributions of the particles collected by passive IOM sampler during wood planing and shaping

Statistical parameters	F	G	H	I	L
Arithmetic mean (µm)	21.9	16.2	19.7	22.3	18.3
Geometric mean (µm)	11.7	4.6	5.7	9.8	6.9
Arithmetic standard deviation (µm)	52.0	66.7	38.8	36.3	38.2
Geometric standard deviation (µm)	2.5	3.1	2.8	3.7	2.8
Maximum value (µm)	581.0	746.0	450.4	340.5	434.6

Table 6 Statistical parameters of aerodynamic diameter distributions of the particles collected by passive IOM sampler during wood cutting

Statistical parameters	M	N	O	P	Q
Arithmetic mean (µm)	8.6	7.2	9.8	8.0	5.5
Geometric mean (µm)	4.9	2.5	5.7	5.2	3.2
Arithmetic standard deviation (µm)	11.9	17.8	14.9	10.7	8.4
Geometric standard deviation (µm)	2.8	3.6	2.8	2.6	0.9
Maximum value (µm)	131.2	201.2	173.1	102.5	79.1

Figure 6 Aerodynamic diameter distributions of dusts collected using the samplers worn by the worker during wood shaping.

Figure 7 Aerodynamic diameter distributions of dusts collected using the samplers worn by the worker during wood sanding.

On average the particles with smaller aerodynamic equivalent diameter were found on the five filters of sanding processes, (wood dust with geometric mean of aerodynamic equivalent diameter around 2 µm and arithmetic mean around 4 µm) (Table 4) while larger particles were generated from planing and shaping processes (particles with geometric mean of aerodynamic equivalent diameter around 8 µm and arithmetic mean around 20 µm) (Table 5). In some cases, SEM observation of the entire surface of the passive IOM filters from planing and shaping processes showed particles with aerodynamic equivalent diameters that exceeded 900 µm.

The percentage of particles having a diameter larger than 100 µm was more than 1% and it reached 3% on some filters. An intermediate size situation occurred for cutting processes (wood dust with geometric mean of aerodynamic equivalent diameter around 4 µm and arithmetic mean around 8 µm) (Table 6).

Although the estimate percentage of ultra-large particles found on the filter of passive IOM during planing and

shaping processes was low, their gravimetric contribution was not negligible; their mass heavily affects the total mass collected. The ultra-large particle mass could reach around 40% of the total mass.

The Kolmogorov–Smirnov test showed that all size distributions of particles collected by passive filters significantly differ from Gaussian distribution indicating that the distributions of particles deposited on these filters cannot be described by log-normal distributions. On the contrary, the particles collected during sampling showed a log-normal distribution.

The influence of particle size seems to have a key role in our findings. When the airborne particles were small in size (as in the sanding process), the amount of wood dust collected by active IOM and the Italian cone were comparable and both samplers can be used interchangeably for personal wood dust exposure assessment.

In field sampling in the carbon black manufactory industry, Kerr et al. found that when particle size was small the CIS (which resembles the Italian cone) and IOM samplers were comparable.²² Other studies showed that CIS under-samples airborne dust concentration compared to the IOM sampler, with greater differences for larger particles.^{8–10} Our sampling carried from planing and shaping processes confirmed this finding.

Gravimetric analysis defines occupational wood dust exposure and the presence of large and ultra-large particles influences mass measurements leading to an overestimation on the exposure level. Our data showed that the percentage of samples exceeding 5 mg/m³ was reduced from 16 to 10% in planing and shaping processes, if the ultra-large particles deposited on passive IOM were not considered.

Note that the results reported here are underestimated because only the particles collected on the sampling filters were calculated, ignoring the contribution of the particle fraction deposited to wall of the IOM cassette. According to Demange et al., the particles deposited on the walls should be the largest and the percentages of mass deposited on the walls seem to be very variable when large-size particles are involved.²³

Disclosure statement

No potential conflict of interest was reported by the authors.

References

- 1 Council Directive 1999/38/EC of 29 April 1999 amending for the second time Directive 90/394/EEC on the protection of workers from the risks related to exposure to carcinogens at work and extending it to mutagens. Available from: <http://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX:31999L0038>
- 2 Decree law of government n° 66, 25 February 2000 Implementation of the directives 97/42/CE and 1999/38/CE, that modify directive 90/394/CEE, on the subject of the protection of workers against the risks stemming from exposure to cancerous or mutating agents during work. Available from: <http://www.nonsoloaria.com/Leggi%20aria/DL66.pdf>

- 3 Institute of Medicine (IOM): A review of monitoring methods for inhalable hardwood dust. IOM Research Project: P937/1A, 2011.
- 4 European Standard UNI EN-481, Workplace atmospheres – Size fraction definitions for measurement of airborne particles, 1994.
- 5 Vincent JH, Armbruster L. On the quantitative definition of the inhalability of airborne dust. *Ann Occup Hyg.* 1981;24:245–248.
- 6 Liden G, Kenny LC. Errors in inhalable dust sampling for particles exceeding 100 µm. *Ann Occup Hyg.* 1994;38:373–384.
- 7 Kenny LC, Aitken RJ, Chalmers C, Fabries JF, Gonzalez-Fernandez E, Kromhout H, et al. A collaborative European study of personal inhalable aerosol sampler performance. *Ann Occup Hyg.* 1997;41:135–153.
- 8 Kenny LC, Aitken RJ, Baldwin PEJ, Beaumont GC, Maynard AD. The sampling efficiency of personal inhalable aerosol samplers in low air movement environments. *J Aerosol Sci.* 1999;30:627–638.
- 9 Aizenberg V, Choe K, Grinshpun SA, Willeke K, Baron PA. Evaluation of personal aerosol samplers challenged with large particles. *J Aerosol Sci.* 2001;32:779–793.
- 10 Thorpe A. Assessment of personal direct-reading dust monitors for the measurement of airborne inhalable dust. *Ann Occup Hyg.* 2007;51(1):97–112.
- 11 Campopiano A, Ramires D, Spagnoli G, Arcaro F, Bosco MG, Pandolfi P, et al. Primi risultati del confronto tra due selettori utilizzati per la captazione di polveri di legno [Comparison between two wood dust samplers, preliminary findings]. *Giornale degli Igienisti Industriali.* 2006;31:86–97.
- 12 Kenny LC. Developments in workplace aerosol sampling – a review. *Analyst.* 1996;121(9):1233–1239.
- 13 Lee T, Harper M, Slaven JE, Lee K, Rando RJ, Maples EH. Wood dust sampling: field evaluation of personal samplers when large particles are present. *Ann Occup. Hyg.* 2011;55:180–191.
- 14 Harper H, Muller BS, Bartolucci AL. Determining particle size distributions in the inhalable size range for wood dust collected by air samplers. *J Environ Monit.* 2002;4:642–647.
- 15 National Institute for Occupational Safety and Health (NIOSH): Manual of Analytical Methods, 4rd ed., Particulates Not Otherwise Regulated, Total: Method 0500, Issue 2, 1994.
- 16 Lee CT, Leith D. Drag force on agglomerated spheres in creeping flow. *J Aerosol Sci.* 1989;20:503–513.
- 17 Jhonson DL, Leith D, Reist CP. Drag on non-spheres in creeping flow. *J Aerosol Sci.* 1987;20:503–513.
- 18 Marconi A. Campionamento delle frazioni dimensionali di rilevanza sanitaria per le polveri di legno [Sampling of size fractions for wood dust]. *Giornale degli Igienisti Industriali.* 2002;27:110–121.
- 19 Belosi F, Prodi F, Santachiara G. Real time wood dust sampling with particle size classification. European Aerosol Conference, Salzburg, Abstract T17A005, 2007. Available from: <http://www.gaef.de/eac2007/eac2007abstracts/T17Abstractpdf/T17A005.pdf>
- 20 Harper M, Zayed Akbar M, Andrew ME. Comparison of wood-dust aerosol size-distribution collected by air samplers. *J Environ Monit.* 2004;6:18–22.
- 21 Health and Safety Executive (HSE): Large particle and wall deposition effects in inhalable samplers, by R.J. Aitken, R. Donaldson. (HSE Contract Research Report No.117/1996). Sudbury, Suffolk, UK: Health and Safety Executive Books, 1996.
- 22 Kerr SM, Muranko HJ, Vincent JH. Personal sampling for inhalable aerosol exposures of carbon black manufacturing industry workers. *Appl Occup Environ Hyg.* 2002;17:681–692.
- 23 Demange M, Görner P, Elcabache JM, Wrobel R. Field comparison of 37-mm closed-face cassettes and IOM samplers. *Appl Occup Environ Hyg.* 2002;17:200–208.