

Metals in Dust Fractions Emitted at Mechanical Workstations

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Workers at metal machining workstations are exposed to airborne dust particles containing metals and their compounds. Their harmful impact on the workers' health depends on both their chemical composition and their distribution. The aim of this study was to determine the content of metals in dust fractions emitted in the process of mechanical machining of products made of brass, steel and cast iron. Samples taken during grinding, turning and drilling were tested. The concentration of metals in dust fractions was determined with atomic absorption spectrometry. The content of iron, manganese, chromium, zinc, lead, copper and nickel in the dust fractions was highly differentiated depending on the size of the particles, the material and the processes used.

workstation dust fractions metal atomic absorption spectrometry

1. INTRODUCTION

According to Poland's Central Statistical Office, over 382 000 workers in Poland are involved in the production of materials and products made of metals and their alloys [1]; those workers are often exposed to dusts. The most frequently processed materials are bronze, brass, steel, aluminium alloys, zamak (zinc and aluminium alloys) and cast iron. The adverse effects of inhaling dust depend on both the chemical composition and the size of the dust particles [2, 3, 4]. Operators of machines that process steel parts can be exposed to dusts containing iron, copper, nickel, manganese, magnesium and many other elements used in alloys. Processing parts made of brass can result in exposure to dusts containing copper, zinc, tin, lead, iron, manganese, etc. Special attention should be paid to the size of the inhaled particles that contain metals and their compounds. Fine dust particles released in processing metallic materials remain

airborne for an extended period. Chronic exposure to dusts containing metals and their compounds can cause respiratory disorders [5, 6, 7]. The size of the dust particles determines the location of their deposition in the respiratory system. In addition, the content of metals in individual particle size fractions of the dust can vary, and their bioavailability increases with the decreasing size of the dust particles they are contained in. For this reason, it is extremely important to know the content of metals in the dust fractions, which may be transferred to individual parts of the respiratory system, especially the gas exchange area in the lungs.

1.1. Air Sampling and Separation Into Fractions

To evaluate exposure to metals and their compounds contained in the dust fractions released in processing metallic materials, it is necessary to separate dust into specific size fractions when sampling workplace air, and then to perform a chemi-

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cal analysis to determine concentrations of individual metals in the samples. Standard No. PN-Z-04008-7:2012 defines the strategy and guidelines for sampling workplace air and interpreting measurement results [8].

Samples can be taken with stationary equipment or personal dosimeters. Personal dosimeters provide the most reliable results; a dosimeter (a pump and a sampler) worn by workers guarantees that the sample comes from where they actually breathe, regardless of the character of their work. Stationary sampling should be used only if workers, during their entire shift, work in the same place and the character of their work is relatively stable.

According to Standard No. PN-Z-04008-7:2012, air samples should be collected continuously, for a period equal to at least 75% of the work shift [8]. One to five air samples should be taken during that period.

To take a sample containing a specific fraction of dust, it is necessary to use an appropriate sampling device that allows separation of airborne dust into the required fractions. Sampling dust fractions consists in aspiration of contaminated air with a known flow for a specific period and separation of the required dust fraction in a filter, which is usually located in the top part of the cyclone separator or on appropriate steps of the impactor.

1.2. Preparation of Air Samples

When sampling air with a method that allows separation of particles of various sizes, it is also necessary to determine the content of various metals in individual fractions. However, to determine a metal, it is also necessary to consider an appropriate method of preparing a solution of the sample. It is good to use a method that can be used for many metals and that enables determining several metals in a single air sample.

The standardized methods used in Poland to determine metals and their compounds in workplace air usually work for single metals only. Methods for determining most metals that can be found in industrial processes, e.g., lead, cadmium, nickel, copper, aluminium, silver, antimony, chromium, zinc, iron, usually recommend

using nitrocellulose membrane filters with 0.8- μm (or possibly 1.5- μm) pore diameter to sample air. The air flow aspirated during sampling is generally up to 20 L/min (stationary sampling) or 2 L/min or less (sampling with personal dosimeters).

A sample taken onto a membrane filter is usually hot-mineralized with inorganic acids (usually by heating on a heating plate at $\sim 140\text{ }^{\circ}\text{C}$). Sample mineralization is done with nitric acid as well as sulfuric acid, hydrochloric acid, hydrofluoric acid or a mixture of those acids. Most methods recommend using concentrated nitric acid for mineralization, and then diluted nitric acid for preparing a solution of the analysed sample. However, in the case of determination of cobalt, mineralization requires using aqua regia; whereas samples containing tin are mineralized in a mixture of sulfuric acid and nitric acid. However, even if mineralization is done with nitric acid and the analyte solution is a diluted nitric acid solution, the procedure for preparing it is not identical in individual standardized methods. Therefore, when using methods provided by Polish standards (e.g., Standard No. PN-Z-04106-3: 2002 [9]), we cannot usually determine more than one metal in a single air sample. Individual metals are determined in a solution with atomic absorption spectrometry (AAS) with an acetylene-air flame or, occasionally, with an acetylene-dinitrogen monoxide flame, and also with AAS with a graphite tray.

There are, however, methods for determining many metals in a single air sample [10, 11].

2. METHODS

2.1. Workstations

The concentration of metals in dust fractions was measured in three factories that processed metallic materials. Factories A and B represented medium-size companies with under 250 workers. Factory C was a large company with over 250 workers. Table 1 briefly characterizes those factories.

The study covered 50 workstations where different metallic materials (brass, cast iron and steel) were processed with various techniques.

TABLE 1. Profiles of Factories

Factory	Type of Production	Processed Material	Type of Process
A	house plumbing systems, brass fittings for central heating, brass casting	brass	machining, thermal processing
B	medical instruments	steel	machining
C	lathe fixtures, machine and manual vices, milling/cutting tools, tool grips, sleeve/mandrel products	cast iron, steel	machining, thermal processing

The workstations included in the study performed cutting, milling, threading, forging, casting, trimming, sanding, polishing, turning and drilling of metal parts.

2.2. Air Sampling

Air samples were collected in accordance with the principles of personal dosimetry [8]. The samples from each workstation were used to determine selected metals in dust fractions of the following particle size ranges:

- <0.25 μm ;
- 0.25–0.5 μm ;
- 0.5–1 μm ;
- 1–2.5 μm ;
- 2.5–10 μm .

Samples were collected and dust was separated into size fractions with a Sioutas personal cascade impactor sampler (PCIS; SKC, USA). Collecting samples consisted in aspirating contaminated air at the flow of 9 dm³/min for a minimum of 6 h and separation of aspirated airborne particles into size fractions on individual collection plates of the PCIS. The air was aspirated to the PCIS with Leland Legacy sample pumps (SKC, USA). Following the manufacturer's guidelines, particles in the 0.25–10 μm range were collected with polytetrafluoroethylene (PTFE) filters with 0.5- μm pore diameter and disk diameter of 25 mm (SKC, USA). Particles under 0.25 μm were collected on PTFE filters with 2- μm pore diameter and disk diameter of 37 mm (SKC, USA).

The air flow aspirated with the sampling pumps was verified before each sampling with a Defender flow calibrator model 520 (SKC, USA).

2.3. Chemical Analysis

The PTFE filter, onto which the air sample was taken, was placed in a polypropylene vessel with closing. Then, 3 mL of a mixture of concentrated nitric acid and water were added at 1:2 of volume, followed by 3 μl of a Triton X-100 surfactant. The closed vessel was placed in an ultrasonic washer for 30 min. The solution above the filter was poured into a 25-ml flask. The operation was repeated with 3 ml of a nitric acid solution at a concentration of 1 mole/L. Then, 3 ml of the nitric acid solution at a concentration of 0.1 mole/L was added to the vessel, and subsequently transferred by quantity to a flask. The content of the flask was then made up to the 0.1-mole/L mark with nitric acid.

Chromium, zinc, manganese and iron were determined with AAS with an air-acetylene flame; copper, nickel and lead were determined with AAS with a graphite tray and Zeeman background correction.

The following measuring instruments were used to determine concentrations of selected metals in the solutions:

- a Solaar M atomic absorption spectrometer (Thermo Electron, UK) adapted to work with an air-acetylene flame, equipped with a hollow cathode lamp, for determination of chromium, zinc, manganese and iron; a computer with Solaar version 10.14 (Thermo Electron, UK);
- a SpectraAA 880 atomic absorption spectrometer (Varian, Australia) with a graphite tray and Zeeman background correction, equipped with hollow cathode lamps, for determination of copper, nickel and lead; pyrolytically coated graphite trays, an automatic sample feeder, a computer with SpectraAA 880Z version 2.10.

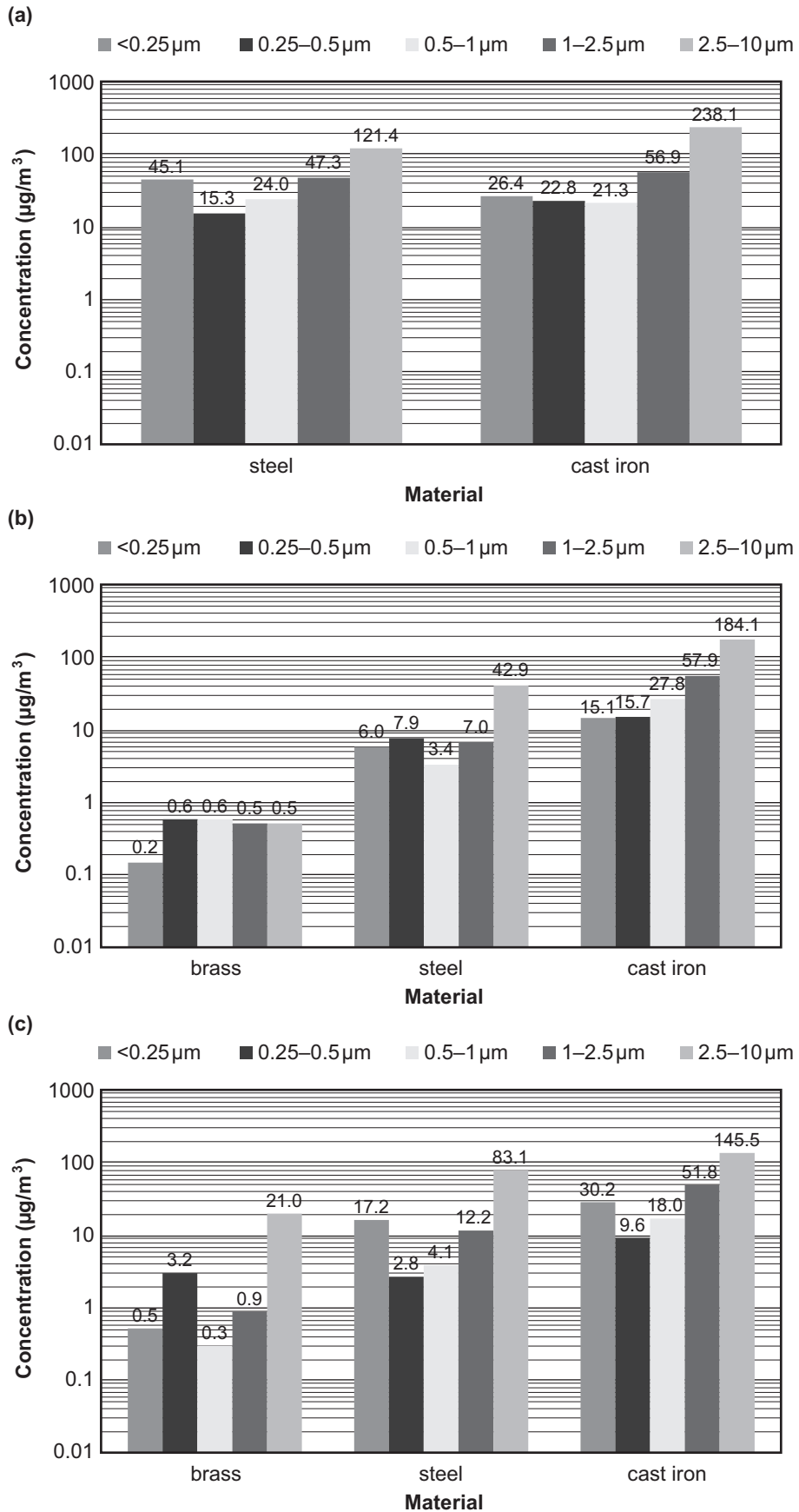


Figure 1. Concentration of iron in dust fractions emitted at mechanical working workstations: (a) grinding, (b) turning and (c) drilling.

3. RESULTS AND DISCUSSION

The results of measurements at 50 workstations where metallic material processing took place showed that concentrations of metals in dust particle fractions under 0.25 μm , 0.25–0.5 μm , 0.5–1 μm , 1–2.5 μm and 2.5–10 μm varied substantially. The highest concentrations of metals in the dust fractions released at the workstations where brass parts were processed were determined for the 2.5–10 μm fraction: zinc (36.8 $\mu\text{g}/\text{m}^3$, forging), copper (90.6 $\mu\text{g}/\text{m}^3$, turning), lead (48.4 $\mu\text{g}/\text{m}^3$, drilling) and iron (21.0 $\mu\text{g}/\text{m}^3$, drilling), whereas for nickel in fractions in the 0.5–1 μm range (1.7 $\mu\text{g}/\text{m}^3$, forging).

The highest concentrations of metals in the dust fractions released at the workstations where steel parts were processed were determined at the polishing workstation for the 2.5–10 μm fraction: manganese (12.5 $\mu\text{g}/\text{m}^3$), copper (26.1 $\mu\text{g}/\text{m}^3$), nickel (8.2 $\mu\text{g}/\text{m}^3$) and iron (151.3 $\mu\text{g}/\text{m}^3$). The highest concentrations of metals in the dust fractions released at the workstations where cast iron parts were processed were determined for the 2.5–10 μm fraction: manganese (29.6 $\mu\text{g}/\text{m}^3$, milling), nickel (4.0 $\mu\text{g}/\text{m}^3$, turning) and iron (287.0 $\mu\text{g}/\text{m}^3$, grinding), while for copper in the fraction with particle size under 0.25 μm (6.7 $\mu\text{g}/\text{m}^3$, grinding).

Figure 1 shows average values of iron concentration in the dust fractions emitted in the process of mechanical working (grinding, turning and drilling) of brass, steel and cast iron parts.

An analysis of the percentage content of metals in individual fractions showed that it varied significantly for all sizes of particles. At the workstations for processing metallic materials, the highest percentage of zinc, manganese and iron was usually found in the 2.5–10 μm range. Higher percentage was found only in the fraction under 0.25 μm in the case of chromium at the workstation for steel part cutting and cast iron turning, and manganese at the workstations for steel part cutting and milling. The highest percentage of copper in the dust fractions released at the workstations for processing steel and cast iron, were usually found in the fraction under 0.25 μm . The

workstations for sanding and polishing steel parts, where a higher percentage of copper was found in the fractions of 2.5–10 μm , were an exception. The percentage of nickel in the fractions released at the workstations for processing brass and steel parts varied to such a high degree that no general conclusions could be drawn. The percentage of individual metals in fractions under 0.25 μm , 0.25–0.5 μm , 0.5–1 μm and 1–2.5 μm was usually lower than their percentage in the 2.5–10 μm fraction. Nevertheless, the percentage of individual metals expressed as total values for fractions under 2.5 μm was significant for all metals.

Figure 2 shows sample test results. It shows the highest values of percentages of iron, manganese, chromium, copper and nickel content in the dust fractions emitted during drilling metallic items made of brass, steel and cast iron.

4. CONCLUSIONS

The content of iron, manganese, chromium, zinc, lead, copper and nickel in dust fractions differed greatly depending on the size ranges of particles, the material machined and the processes of mechanical working.

The percentage of iron was significantly higher in the dust fractions emitted in the process of grinding items made of steel and cast iron.

The concentration of iron, manganese, chromium, copper and nickel in the dust fractions in the range of the respirable fraction was relatively high. It may affect the development of occupational diseases of the respiratory system.

It is necessary to reduce emissions of air pollutants at workstations by improving technological processes and proper operation of general and local ventilation systems.

The obtained results can be used to verify the criteria for assessing occupational exposure including the content of metals found in the working environment in dust fractions.

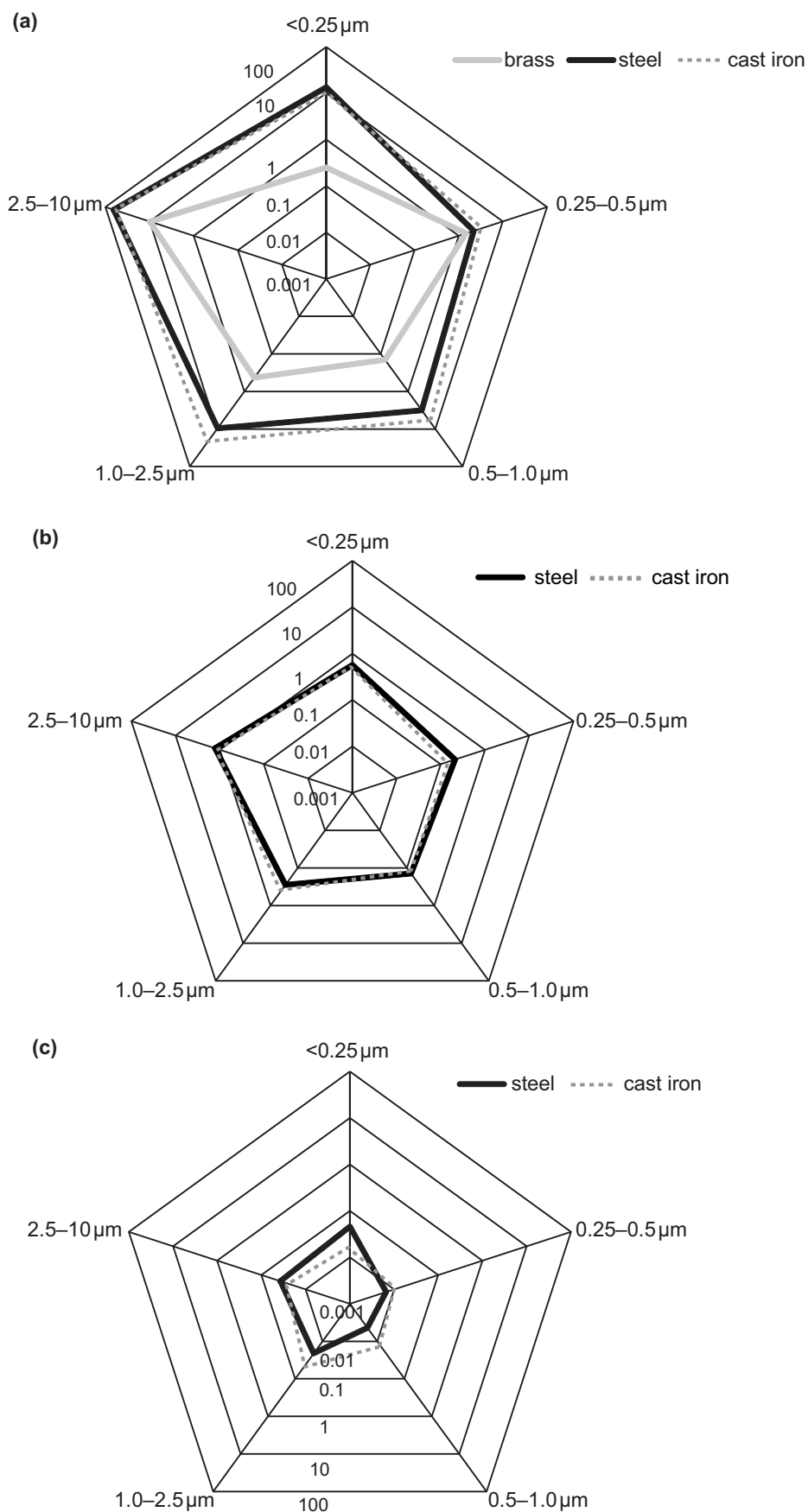


Figure 2. Percentage of metals in dust fractions emitted at workstations for drilling metallic items: (a) iron, (b) manganese, (c) chromium, (d) copper and (e) nickel.

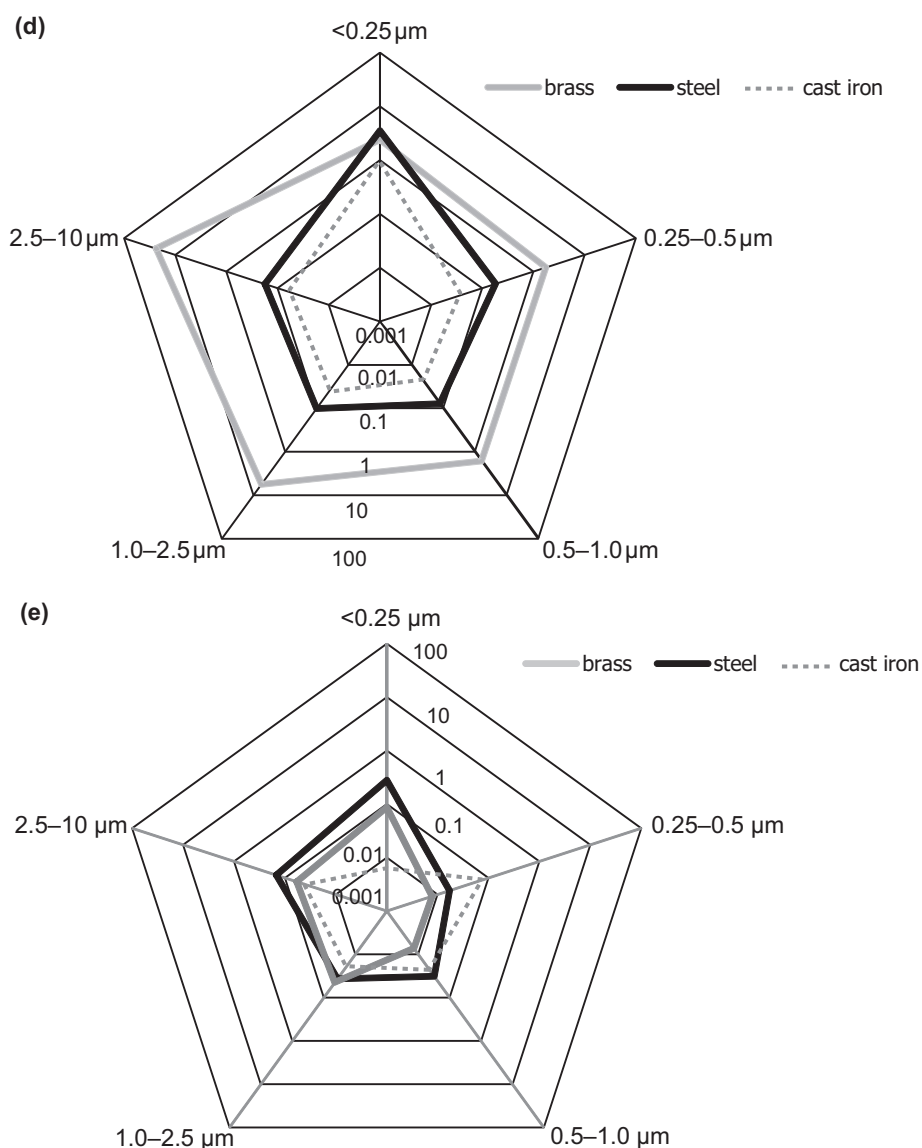


Figure 2. (continued)

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