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Airborne Exposure to Heavy Metals and Total Particulate During Abrasive Blasting Using Copper Slag Abrasive

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This research investigates occupational exposure to metal and total particulate aerosols during abrasive blasting operations using one substitute abrasive, copper slag. Airborne exposures to metal (As, Be, Pb, Cr, Cd, V, and Ti) and total particulate aerosols from two copper slag sources are evaluated by the collection and analysis of personal breathing zone samples during abrasive blasting operations in both indoor and outdoor settings. Results from this research indicate that abrasive blasting operations using copper slag abrasive can generate, in a relatively short time, total particulate, lead, arsenic, and chromium exposures that exceed permissible exposure limits (PELs) set by the Occupational Safety and Health Administration (OSHA). Results also show statistically significant differences in exposure concentrations between slag sources. A correlation between total particulate concentrations and metal concentrations is indicated in both slag sources and in both indoor and outdoor settings. Results of this research allow occupational health and safety professionals to make a more informed determination of the degree of health risk posed to workers during abrasive blasting operations using commercially obtained copper slag abrasive.

Keywords Abrasive Blasting, Copper Slag, Total Particulate, Arsenic, Lead

Abrasive blasting is the use of high-pressure air to project abrasive particles at high velocity to clean metal and other surfaces. The common abrasives used to clean metal surfaces are silica sand, metal shot, metallurgic slags, and synthetic abrasives. Silica sand has traditionally been the most commonly used abrasive due to its availability, effectiveness, and low cost.

Occupational health studies performed by the National Institute for Occupational Safety and Health (NIOSH) and Burgess suggest a causal link between abrasive blasting with silica sand and the manifestation of silicosis.(1,2) In 1983, Shaman estimated that more than one million U.S. workers were at risk of developing silicosis and that more than 100,000 of these workers were employed as sandblasters.(3) Due to its potential health hazards, NIOSH has recommended that the use of silica sand (or substances containing more that 1% crystalline silica) be prohibited from use as a blasting abrasive and that less hazardous materials be used as substitutes.(1) As a part of this recommendation, NIOSH identified metallurgical slag abrasives, such as copper slag, as an acceptable substitute for silica sand. Although NIOSH reported metallurgic slags as being utilized in only 3.1 percent of the facilities conducting abrasive blasting, its increasing use has been acknowledged in other literature.(2)

Even though metallurgic slag abrasives are thought to be less toxic than silica sand, Stettler, Donaldson, and Grant reported their potential to contain high concentrations of heavy metals.(4) These finding led NIOSH to issue a warning in 1992 stating that no comprehensive studies have been conducted to evaluate the health effects of silica sand substitutes such as metallurgic slag abrasive.(5)

Occupational exposure to potential airborne contaminants during abrasive blasting is derived from aerosols generated as abrasive material is pulverized during impact with the desired target and from materials removed from the surface being cleaned. Copper slag abrasives can be commercially purchased under the trade names Apache, Green Diamond, Kleen Blast, Blast Off, Diamond K, Nevada Black, and Best Grit. Blair and Gesell have reported that these slags are being used as replacements for silica sand because of their reported low free silica content, availability, and desirable physical properties.(6,7) Even so, Mackay et al. have shown the potential for copper slag abrasive to contain hazardous elements such as beryllium, chromium, lead, and arsenic.(8) Also, in a recent evaluation of the use of copper slag abrasive, NIOSH identified large variability in chemical composition between commercially obtained copper slags as a result of the differences in source material.(9)

MATERIALS AND METHODS

Copper Slag Abrasive

The abrasive material used in this research was commercially obtained from companies that process this material from waste smelter furnace slag. Each company markets its copper slag as being a low free silica abrasive product. The slag sources used in this study are commercially known as Best Grit (Slag A) and Nevada Black (Slag B). The material safety data sheets (MSDSs) for these materials are similar and report that they contain a mixture of Fe_2O_3, SiO_2, Al_2O_3, CaO, HgO, or MgO in a tightly bound glassy matrix with other elements being present in concentrations less than 0.1 percent or 0.2 percent by volume. The MSDSs for these slags list an 8-hour OSHA PEL of 15 mg/m^3. The grit size chosen for both abrasive slag sources was 16/30, a medium grit size commonly used in abrasive blasting operations.

Blasting Location and Equipment

Abrasive blasting was performed in one outdoor and two indoor locations. Outdoor abrasive blasting was performed in an open area away from buildings and other structures. In one of the indoor locations, abrasive blasting was performed in a booth measuring 5.5 feet by 3.5 feet by 8 feet. In the other indoor location, abrasive blasting was performed in a room measuring 10 feet by 10 feet by 15 feet. Ventilation was provided to both indoor locations at an exhaust flow rate of 3,000 feet per minute. During abrasive blasting inside the room, all surfaces were covered with visqueen. Its removal and replacement between the use of different copper slag sources minimized the chance of cross contamination during sampling events. During sampling inside the booth, cross contamination of slag abrasive was minimized by vacuuming and wet-wiping all wall surfaces between each sampling run.

All abrasive blasting was performed using an A-BEC Industries portable blast cleaning machine. An abrasive air stream was delivered through a 7/16-inch orifice size venturi blast nozzle to a 1/4-inch industrial aluminum (99.7% pure) plate at an air pressure of 90 pounds per square inch gauge. This configuration is considered representative for most direct-pressure abrasive blasting. The industrial aluminum plate was chosen to eliminate sample interference with the chosen metals of interest in this study. Abrasive slag material was supplied to the portable blast machine via a 6 m^3 gravity-fed hopper and 100 feet of reinforced air hose. A 185-cfm Ingersoll-Rand air compressor provided pressurized air. The blast nozzle was held in a perpendicular orientation, 18 inches from the aluminum plate surface, to give maximum amount of abrasive ricochet and to simulate worst-case airborne dust conditions. Personal protective equipment worn by the abrasive blaster included a NIOSH-approved (type CE) supplied air abrasive blast helmet, abrasive-resistant suit, leather gloves, safety shoes, and hearing protection.

Sampling Protocol

This research was carried out in two phases. In phase one, only one copper slag source (Best Grit) was evaluated using 15 short-term personal samples taken at the booth and outdoor locations. These samples were analyzed for arsenic, lead, and total particulate. In phase two, 15 short-term personal samples were collected for each copper slag source (Best Grit and Nevada Black) during abrasive blasting in the larger room enclosure. These 30 samples were analyzed for arsenic, lead, beryllium, cadmium, chromium, titanium, vanadium, and total particulate. All collected samples were taken in the abrasive blaster's breathing zone, outside of the blasting hood.

Table I shows the number and type of aerosol samples collected for both slag sources at each abrasive blasting setting. All samples were collected using closed face 37-mm cassettes attached to Scientific Kit Corporation Aircheck 50 High Flow sampling pumps (model 22451) calibrated at a flow rate of 2.0 liters per minute. Filter media consisted of Zeflon, matched weight mixed cellulose ester membrane filters with 0.8 μm pore size. Between each sampling run, new sampling media were placed in the breathing zone of the abrasive blaster. Sampling times for the booth location ranged from 10 minutes to 21 minutes, with an average of 16 minutes. Sampling times for the outdoor

TABLE I
Sampling protocol

	Slag source A (Best Grit)			Slag source B (Nevada Black)[A]		
Abrasive blasting location	No. of sampling runs	Average sampling time	Sampling flow rate	No. of sampling runs	Average sampling time	Sampling flow rate
Room (10 ft. × 10 ft. × 8 ft.)	15	16 min	2 liters per min	15	15 min	2 liters per min
Booth (5.5 ft. × 3.5 ft. × 8 ft.)	15	16 min	2 liters per min			
Outdoor	15	22 min	2 liters per min			

[A] Slag source B was not sampled in the booth or outdoor abrasive blasting location.

TABLE II

Summary statistics for total particulate and metal concentrations—Slag A and Slag B

Chemical agent	Summary statistic (n = 15)	Location: Room Slag A	Room Slag B	Booth slag A	Outdoor slag A
Arsenic	GM[A]	0.140	0.270	0.520	0.310
	GSD[B]	1.54	1.45	2.47	1.98
Lead	GM[A]	0.570	1.32	2.30	1.60
	GSD[B]	1.69	1.52	2.63	2.07
Titanium	GM[A]	0.440	0.880		
	GSD[B]	1.81	1.58		
Beryllium	GM[A]	< 0.001[C]	< 0.001[C]		
	GSD[B]				
Cadmium	GM[A]	< 0.001[C]	< 0.001[C]		
	GSD[B]				
Chromium	GM[A]	< 0.002[C]	0.240		
	GSD[B]		1.56		
Vanadium	GM[A]	< 0.002[C]	< 0.002[C]		
	GSD[B]				
Total particulate	GM[A]	668.0	781.0	3680.0	2140.0
	GSD[B]	1.73	1.53	2.62	2.10

[A] Geometric mean (mg/m^3).
[B] Geometric standard deviation.
[C] Below analytical detection limits.

location ranged from 12 minutes to 53 minutes, with an average of 22 minutes. Sampling times for the room location for Slag A ranged from 15 minutes to 27 minutes, with an average of 16 minutes. Sampling times for the room location for Slag B ranged from 13 minutes to 16 minutes, with an average of 15 minutes. All samples were analyzed by an American Industrial Hygiene Association (AIHA)-accredited laboratory using NIOSH Methods 0500 and 7300 for total particulate and metals, respectively.

Statistical Analysis

Using a standard chi-square goodness of fit and a Shapiro-Wilks W test, contaminant concentrations from both slag sources at all blasting locations were found to be adequately described by lognormal distributions. Summary statistics were tabulated separately for the contaminant concentrations resulting from the different slag sources used in all sampling locations. Using log-transformed means obtained from sampling in the room setting, differences in metal and total particulate concentrations between slag sources were evaluated using one-way analysis of variance (ANOVA) at the 0.05 alpha level. For Slag A, linear regression analysis, using the combined sample results from all locations, was performed to model the relationship between total particulate concentrations and metal dust concentrations. For Slag B, linear regression analysis was performed to model the relationship between total particulate concentrations and metal dust concentrations obtained in the room location.

RESULTS AND DISCUSSION

Log-transformed summary statistics of total particulate and metal concentrations for each slag source and at each sampling location are given in Table II. Airborne concentrations of arsenic, lead, and total particulate were found in all blasting location aerosols using Slag A. In addition to the above contaminants, airborne concentrations of titanium were also found in the room location aerosols. For Slag source B, which was only evaluated at the room location, airborne concentrations of arsenic, lead, chromium, titanium, and total particulate were found in the blasting aerosols. The ANOVA results given in Table III show statistically significant differences in arsenic, lead, chromium, and titanium aerosol concentrations between Slag sources A

TABLE III

ANOVA of log-transformed room aerosol concentrations by slag source

Agent	Log-mean Slag A (mg/m^3)	Log-mean Slag B (mg/m^3)	F-Statistic	p-value
TP[A]	6.50	6.66	0.760	0.392
As	−1.98	−1.33	19.5	< 0.001
Pb	−0.560	0.280	23.2	< 0.001
Ti	−0.820	−0.130	12.5	0.001

[A] TP = total particulate.

TABLE IV

Time required to reach OSHA PEL-TWA for Slag A and Slag B

Airborne contaminant	OSHA PEL-TWA (mg/m^3)	Room time (minutes)		Booth time (minutes) slag A	Outdoor time (minutes) slag A
		Slag A	Slag B		
TP[A]	15	15	15	22	40
As	0.01	15	28	37	60
Pb	0.05	63	44	37	60
Cr	0.5	LOD[B]	105		
Ti	10	< PEL-TWA	< PEL-TWA		

[A] TP = total particulate.
[B] Less than limit of detection.

and B sampled in the room setting. However, no statistically significant differences were found between these slag sources for total particulate aerosol concentrations.

For each sample run at all locations, 8-hour time-weighted-average (TWA) concentrations for metals and total particulate were calculated. The time required for total particulate and metal concentrations to reach the OSHA PEL-TWA was determined by adding each successive TWA and its associated sampling time until the occupational exposure limit was achieved. Results of this exposure evaluation are given in Table IV and show that for both slag sources sampled at the room location, total particulate and arsenic aerosol concentrations reached the PEL-TWA within 28 minutes, and lead aerosol concentrations within 63 minutes.

For Slag source B, room aerosol chromium concentrations reached the PEL-TWA within 105 minutes. Room aerosol titanium concentrations in both slag sources did not reach the PEL-TWA at any time during the 15 short-term sampling runs. For Slag A, booth arsenic and lead concentrations reached their respective PEL-TWAs in 37 minutes, while the PEL-TWA for total particulate was reached in 22 minutes. For the outdoor blasting using Slag A, the PEL-TWAs for arsenic and lead were reached in 60 minutes and the PEL-TWA for total particulate was reached in 40 minutes.

Figures 1 through 4 show linear regression analysis of Slag sources A and B for total particulate aerosol concentrations versus arsenic and lead aerosol concentrations. Good regression

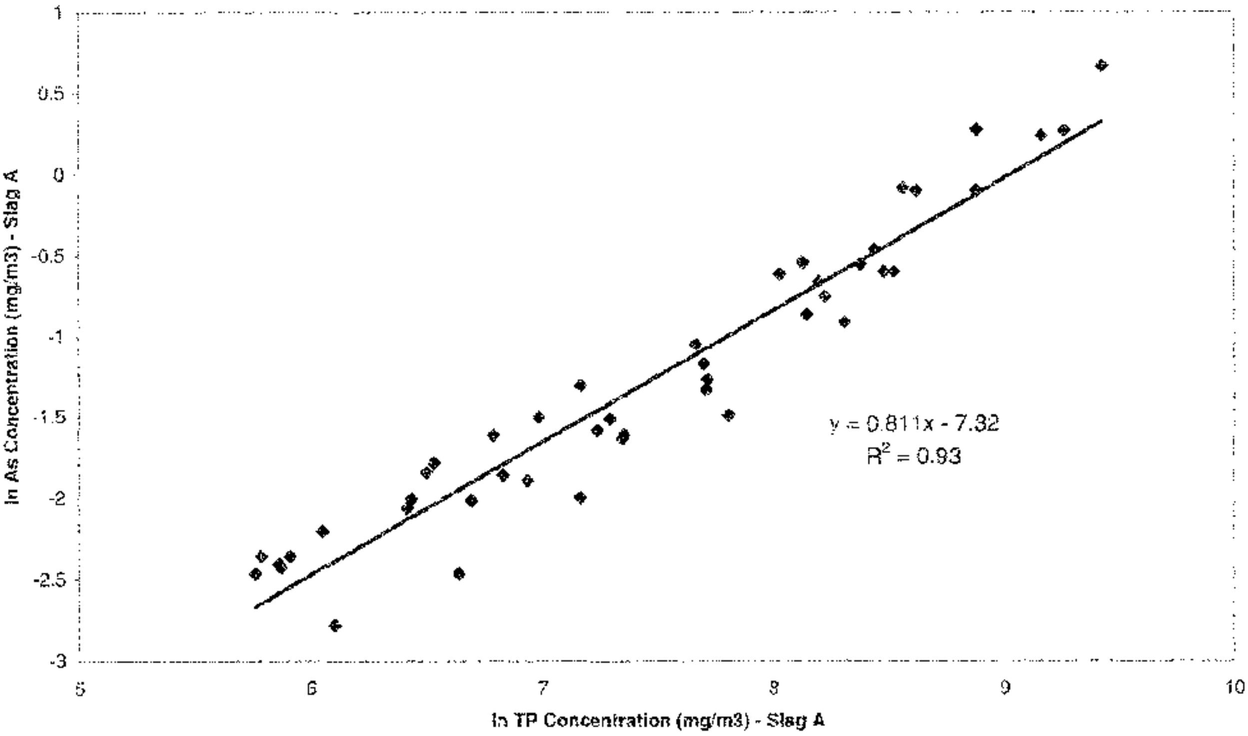

FIGURE 1

Regression plot for arsenic and total particulate aerosol concentrations—Slag A.

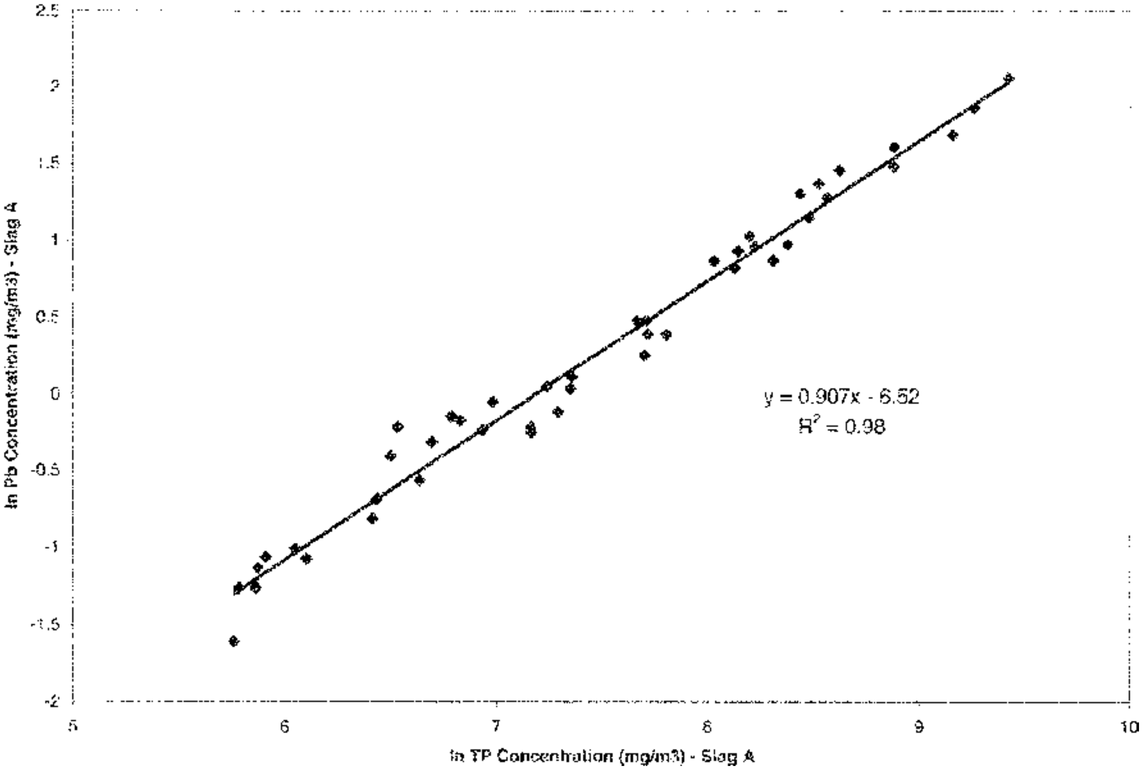

FIGURE 2
Regression plot for lead and total particulate aerosol concentrations—Slag A.

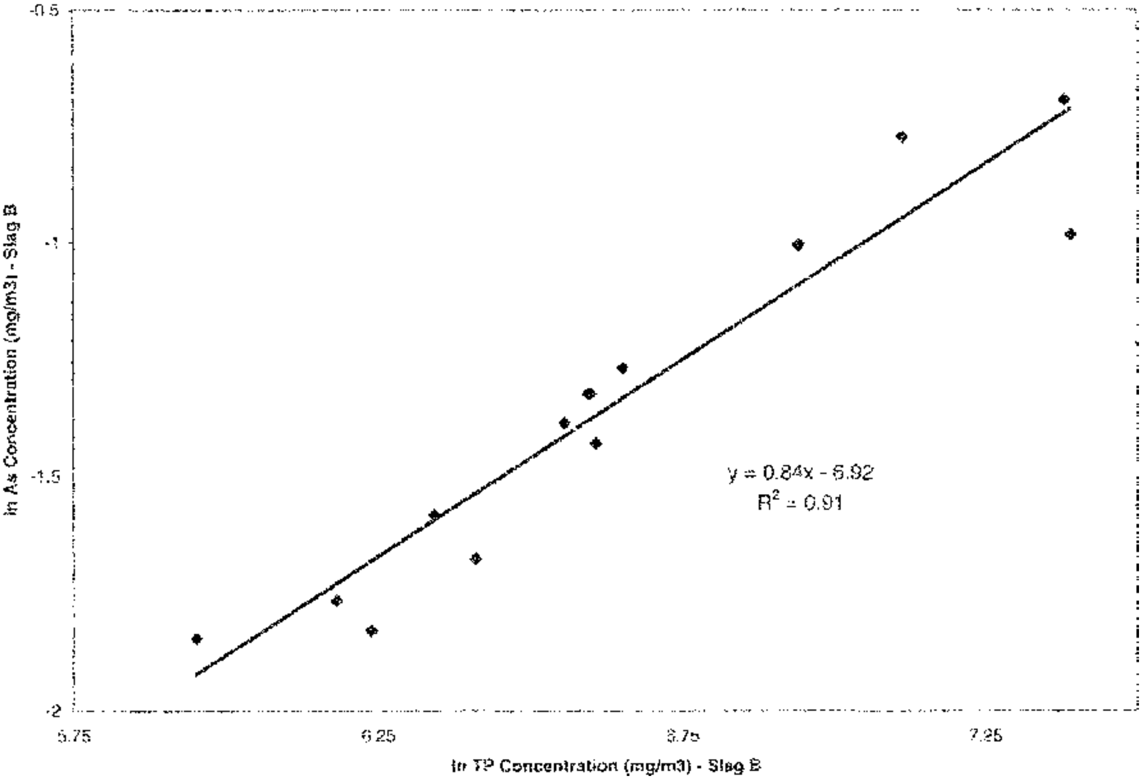

FIGURE 3
Regression plot for arsenic and total particulate aerosol concentrations—Slag B.

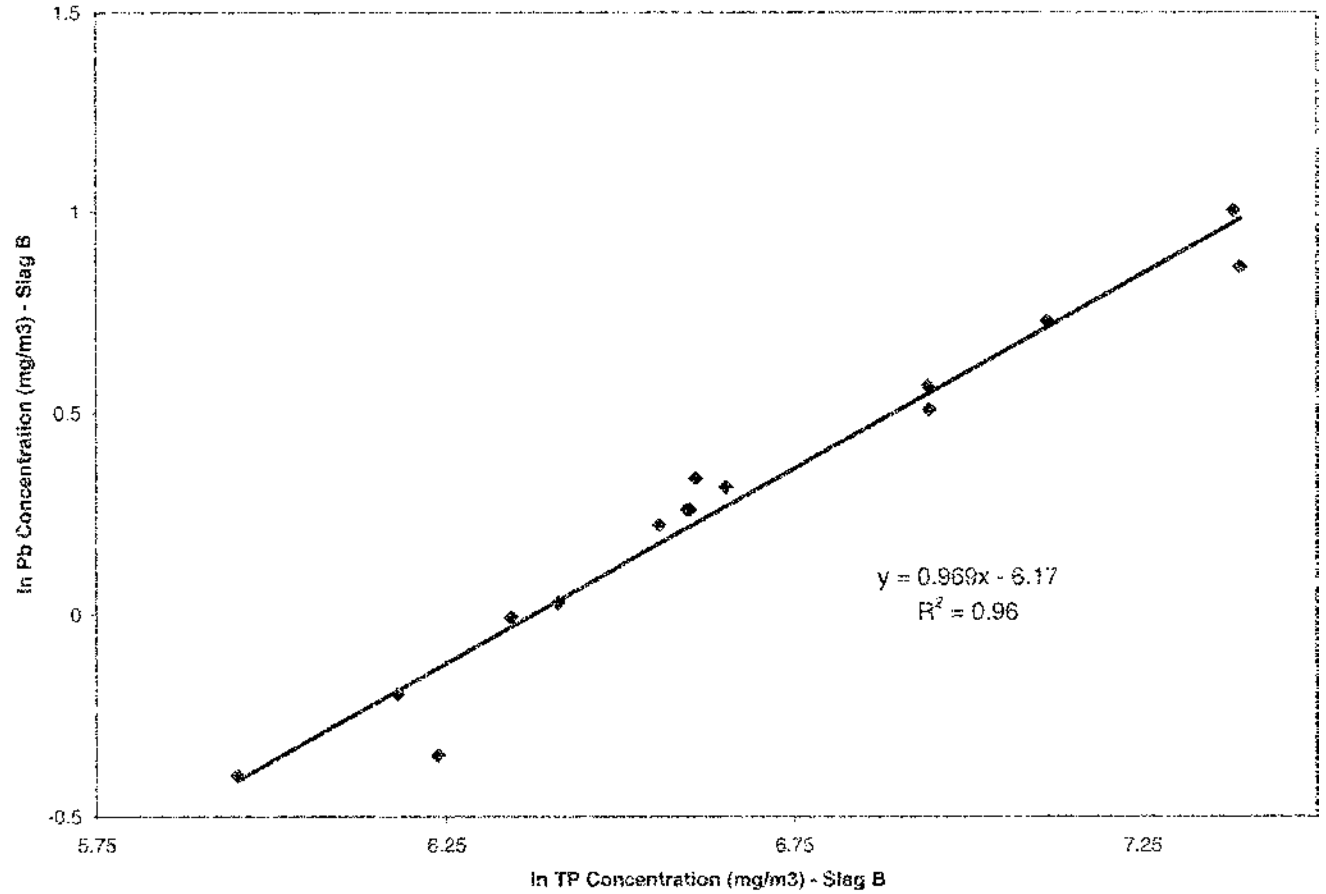

FIGURE 4

Regression plot for lead and total particulate aerosol concentrations—Slag B.

results are obtained for both slag sources. Figures 1 and 2 depict the Slag A relationships using all sample locations combined (booth, room, outdoor). Obtained R^2 values of 0.93 and 0.98 indicate that these metals are predicted reasonably well from total particulate measurements of Slag A at different abrasive blasting locations. Figures 3 and 4 depict the Slag B relationships between total particulate and arsenic and lead aerosol concentrations collected at the room location. Although based on fewer samples, obtained R^2 values of 0.91 and 0.96 reinforce the predictability of metal concentration using measurements of total particulate.

The abrasive blasting performed in this study did not use recycled abrasive material. Some discussion must be given to the use of recycled copper slag abrasive as its use could result in a size shift toward the aerosolization of smaller particles. In addition, since the metals in the copper slag are bound in a glassy matrix, the potential for an increase in their bulk percentage is likely as the matrix degrades with each usage of recycled slag. As such, it is recognized that a particle size shift and an increase in bulk metal percentage would impact the correlations between total particulate and metals concentrations seen in this study.

CONCLUSIONS

The following bulleted items summarize the results obtained from this research project:

- Use of either source A or B copper slag abrasive generates total particulate aerosols that exceed the OSHA PEL-TWA within 15 minutes of blasting;
- Use of either source A or B copper slag abrasive generates arsenic and lead metal aerosols that exceed OSHA PEL-TWAs within 63 minutes of blasting;
- Use of copper slag abrasive from Slag B generates chromium metal aerosols that exceed the OSHA PEL-TWA within 105 minutes of minutes of blasting;
- Use of either source A or B copper slag abrasive generates titanium metal aerosols that do not reach the OSHA PEL-TWA after 225 minutes of blasting;
- Use of copper slag abrasive from source B generates higher concentrations of airborne metals and total particulate than from source A, and;
- There exists an apparent correlation between total particulate aerosol concentration and metal aerosol

concentration using copper slag abrasive from both source A and source B.

The results listed above indicate that abrasive blasting using copper slag abrasive as a substitute for silica sand can generate total particulate and metal aerosols above the OSHA PEL-TWA in a relatively short period of time. This is of particular concern to not only the individual performing the abrasive blasting, but also to support workers in the immediate area. It has also been shown that use of copper slag abrasive marketed from different sources can generate different types of aerosols in terms of contaminant types and levels.

The regression results seen with both slag sources are a potential benefit to industrial hygienists monitoring these types of abrasive blasting operations. If a true correlation exists between total particulate concentration and metal concentration, then sample analysis becomes less costly. Gravimetric analysis of a total dust sample to predict potential concentration levels of a particular metal constituent is much less expensive than the typical evaluation of metal aerosol mass using inductively coupled plasma analysis.

As is evidenced by this study, more research must be done on the use of metallurgic slag abrasive as a substitute for silica sand. The health effects of total particulate dusts and heavy metals such as arsenic and lead are well documented. Long-term exposure to aerosols containing these contaminants at levels similar to those shown in this study warrants concern to an inadequately protected worker.

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