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Worker Exposure Monitoring of Suspended Particles in a Thermal Spray Industry

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The purpose of the present work was the investigation and characterization of the quality of air in a thermal spray industry, in Greece. The activities that take place in the specific facility, as well as in most other similar industries, include thermal spraying and several mechanical and metallurgical tasks that generate airborne particles, such as grit-blasting, cutting and grinding of metallic components. Since the main focus of this work was the workers exposure to airborne particles and heavy metals, portable air samplers with quartz fiber filters, were used daily for 8 h. Three samplers, carried from different employees, were used for a period of 1 month. Results showed that both particles and heavy metals concentrations were low, even in the production site, which was the most susceptible area. The only exceptions were observed in the case of cleaning and maintenance activities in the thermal spray booth and in the case of spraying outside the booth. The main reason for the low concentrations is the fact that most of the activities that could produce high-particle concentrations are conducted in closed, well-ventilated systems. Statistical elaboration of results showed that particles are correlated with Ni, Cu, Co. The same conclusion is extracted for Fe, Mn. These correlations indicate possible common sources.

Keywords heavy metals, monitoring, quality of air, suspended particles, thermal spray, workers exposure

1. Introduction

Thermal spray is a generic term for a group of coating processes used to apply metallic or non-metallic coatings on various substrates and for several applications, such as wear and/or corrosion resistance, thermal insulation, and many others. These processes use the thermal energy generated by chemical (combustion) or electrical (plasma or arc) methods to heat the coating material (in powder, wire or rod form) to a molten or semi-molten state. The resultant heated particles are accelerated and propelled, by either process gases or atomization jets, toward a prepared surface. On the surface, the heated particles impact, flatten and solidify, thus forming thin layers or lamellae, which adhere to the substrate surface. Coating is built layer by layer and results from the relative movement of the "spraying gun" and the part to be coated. Spraying procedure takes place either manually (a trained sprayer moves the gun by hand) or, usually nowadays, automatically inside spray booths (Ref 1-3).

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In any case, even when thermal spraying is implemented in spray booths with automated manipulation, workers can be exposed to several potential and real risks, such as high-noise levels, radiation, thermal, and electrical risks. The major one concerns the workers' respiratory system and results from their activities with potentially harmful particulate materials. Particle sizes range from submicron (fumes after spraying) to 150 μm (large particles). There are many opportunities for an operator to be exposed to particles, such as handling powders for thermal spray, grit-blasting of the part to be coated, and exposure to the process effluent if the ventilation system (dust collector) is not adequate.

Small airborne particles have a high probability of deposition deep in the respiratory tract (Fig. 1) and are likely to trigger or exacerbate respiratory diseases. Epidemiologic studies that have examined particles concentrations in relation to health statistics conclude that elevated fine particulate matter is associated with increased morbidity, even mortality. Furthermore, chemical composition of particles can also induce health-related effects. Of particular concern is the fact that most of the toxic trace metals in air, such as Pb, Cr, Ni, Cu, etc., are in the form of fine particles (Ref 4-7). Studies have shown that trace metals distributed widely throughout the lung on fine particles could catalyze the formation of oxidants within the lung, which, in turn, produce tissue damage (Ref 7, 8).

Therefore, the current study aims at the investigation and characterization of the quality of the air inside a thermal spray industry. Suspended particles (TSP) and heavy metals concentrations were measured and an overview of the situation is given. To the authors' knowledge, only few specific studies have been published regarding potential risks in thermal spraying facilities and

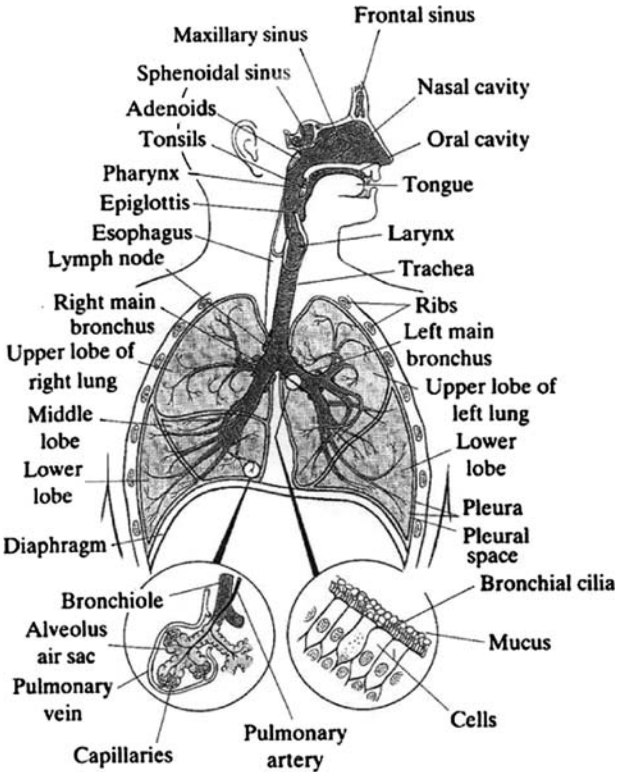

Fig. 1 The respiratory system (Ref 4)

even less regarding particle concentrations measurements, so this work could be used for comparative study with other relevant future efforts.

2. Experimental Procedure

2.1 The Thermal Spray Facility

The company where this study took place is located at the suburbs of Athens, Greece. The building where the company is situated is separated in five levels (Fig. 2). In the ground floor there is the thermal spray workshop (production site), where thermal spraying and several mechanical and metallurgical activities, such as grit-blasting, cutting, and grinding of metallic components take place. Because of the nature of the work being done there, this was the most susceptible site. It should be noted that thermal spraying is carried out in a sound-proof thermal spray booth, equipped with a dust collector. However, according to the company, there are very few exceptions during a year when the dimensions of the component to be coated are bigger than the booth. In these cases, spraying takes place out of the booth. Moreover, before thermal spray, each component is most commonly grit-blasted. Grit-blasting is also performed in a closed system which protects the operator from exposure to dust. In the second floor there is the quality control laboratory, which covers half the area over the production site. Therefore, the laboratory has a direct view of the production site and it could potentially be influenced by emissions from the production. In the rest of the building there are offices (third and fourth floor) and a smoking area (fifth floor). Smoking is not allowed anywhere else in the building for safety reasons, so it is not considered as a factor that could have any affects.

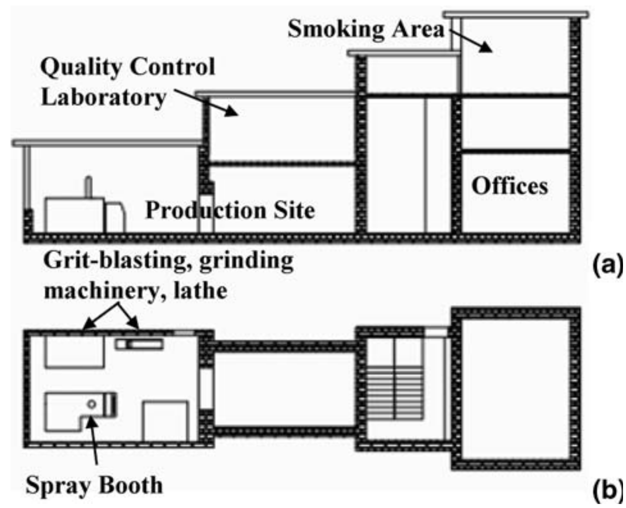

Fig. 2 Schematic representation of (a) cross section and (b) top view of the facility

2.2 Sampling and Chemical Analysis

Sampling and investigation of samples were carried out according to Greek legislation and EU regulations (Ref 9). Measurements took place daily (February to March 2004), for 30 working days (weekends were not included), for 8 h, time equal to the workers' shifts, so as to cover a broad range of the company's activities. Quartz fiber filters in portable air samplers (Casella Ltd.) were utilized for sampling (Fig. 3a), at a flow rate of 2 L/min. Three samplers were used daily, two in the production site since it was the main point of interest and one in the laboratory. Few samplings were also carried out in the offices. Each worker carried the sampler during the 8 h shift (Fig. 3b). Before installation, filters were pre-weighed in the laboratory with an accuracy of 0.01 mg. After sampling, they were transported to the laboratory for re-weighing. Samplers were tested daily for malfunctions and pump rate absorption calibration. Every worker carrying a sampler filled a form, where the main activities during the shift were reported. This was done with the aim to identify activities that could potentially contribute to suspended particles generation. It should be mentioned that every worker in the production is equipped with disposable and full-face masks and with uniforms that cover the whole body in cases of extreme situations, such as cleaning and maintaining the booth or filters.

After collection and weighing, filters underwent chemical analysis in the form of acid digestion, in order to determine trace metals concentrations in the surrounding atmosphere (Ref 10). Filters were dissolved in an acid mixture (HNO_3 and HCl), and the resultant solution was

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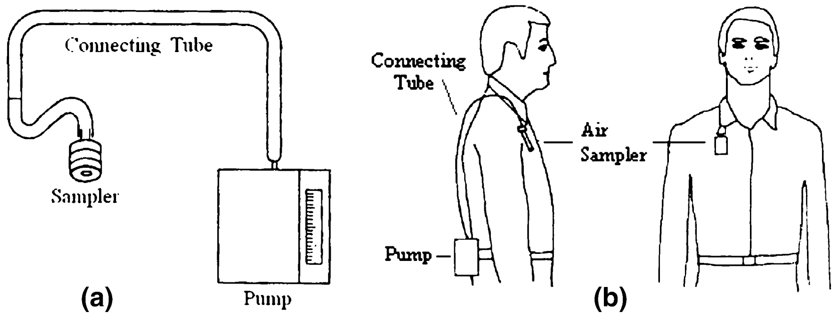

Fig. 3 (a) Portable air sampler and (b) schematic representation of sampling procedure

Table 1 Limit values for the presence of particles and heavy metals concentrations for an 8-h workday exposure (Ref 11, 12)

	Greek-EU Legislation, mg/m^3	OSHA exposure limits, mg/m^3
TSP	10	15
Ni	1	1
Cu	1	1
Cd	0.025	0.005
Mn	5	5
Co	0.1	0.1
Pb	0.15	0.05

analyzed for trace metals using a Perkin-Elmer 3300 Atomic Absorption Spectrometer. Each measurement was replicated twice and the difference between the two measurements was less than 5%. Nine elements were investigated: Fe, Cr, Ni, Cu, Cd, Mn, Zn, Co, and Pb. Exposure limits for some of these elements for an 8-h workday, according to Greek-European and U.S. legislation, are shown in Table 1 (Ref 11, 12).

3. Results and Discussion

3.1 Particles and Heavy Metals Concentrations

Figure 4(a) and (b) shows the daily variation of suspended particles' concentration in the production site for both samplers, while in Tables 2 and 3 the average, minimum, and maximum values of particles and heavy metals concentrations in the production site for both samplers are given.

Regarding the first sampler, the average value of particles concentration (4.363 mg/m^3) is almost 2.5 times lower than the limit set by Greek legislation for an 8 h exposure (10 mg/m^3). However, there is one significant transgression (96.1 mg/m^3), as it is clearly shown in Fig. 4a (sampling day No. 7). This is observed because during that day, cleaning and maintenance activities in the thermal spray booth took place and, consequently, workers were exposed to high levels of dust. In fact, this particular value raises the average value. Without this transgression, average particles concentration would be near 1 mg/m^3. Average values of heavy metals concentrations are lower

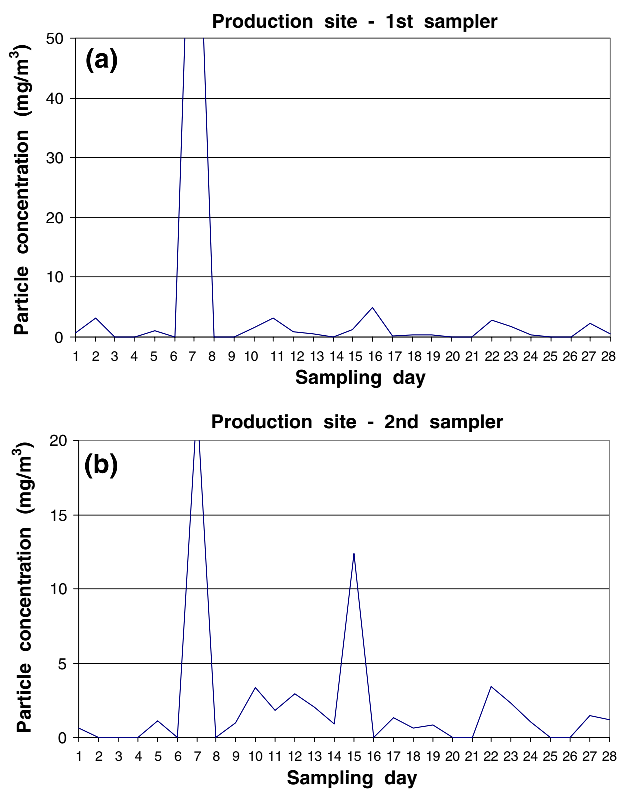

Fig. 4 Variation of particles' concentration in the production site (a) 1st sampler; (b) 2nd sampler

Table 2 Particles and heavy metals concentrations in the production site (1st sampler)

	Average, mg/m^3	Minimum, mg/m^3	Maximum, mg/m^3
TSP	4.363	0.192	96.129
Fe	0.132	0.016	0.440
Cr	0.010	0.001	0.095
Ni	0.117	0.001	2.783
Cu	0.011	0.001	0.103
Cd	0.002	0.001	0.004
Mn	0.004	0.001	0.020
Zn	0.131	0.038	0.207
Co	0.016	0.006	0.081
Pb	0.038	0.004	0.105

Table 3 Particles and heavy metals concentrations in the production site (2nd sampler)

	Average, mg/m^3	Minimum, mg/m^3	Maximum, mg/m^3
TSP	2.175	0.176	22.447
Fe	0.151	0.016	0.501
Cr	0.007	0.002	0.044
Ni	0.101	0.001	2.443
Cu	0.006	0.001	0.025
Cd	0.002	0.001	0.004
Mn	0.003	0.001	0.008
Zn	0.128	0.036	0.174
Co	0.014	0.006	0.022
Pb	0.033	0.005	0.098

than the limits set by legislation. Even the maximum values do not exceed the limits, with one exception for Ni (2.783 mg/m^3—Greek legislation: 1 mg/m^3), which was observed during the maintenance day. Fe, Ni, and Zn were the most common metals, with 83% of the total metals measured, which is considered normal because of the nature of the activities and the materials that are being used in the industry. Heavy metals were 11% of the particles concentration.

The situation is similar for the second sampler in the production site. The average particles concentration (2.175 mg/m^2) is 4.5 times lower than the limit. However, there were two transgressions of the limit (Fig. 4b). The first (22.447 mg/m^3) was observed during the maintenance and cleaning activities of the spray booth, while the second one (12.405 mg/m^3) was observed during a day when spraying out of the booth took place, despite the efforts for effective ventilation. Heavy metals concentrations were again low. In any case, there was one transgression for Ni (2.443 mg/m^3), linked with the maintenance activities. Fe, Ni, and Zn were the most common metals, with 85% of the total metals measured, while heavy metals were 20% of the particles concentration.

Figure 5 and Table 4 show the variation and the average values of particles and heavy metals concentrations in the quality control laboratory, above the production site. Despite the fact that there is a direct connection of the laboratory with the production site, low values are observed for particles and heavy metals. The average particles concentration (0.905 mg/m^3) is 11 times lower than the limit. It should be noted that particles and heavy metals concentrations did not exceed the limits at any time. The comparatively higher particles values observed during sampling days 15-21 are attributed to grinding and cleaning operations of thermally sprayed components that was carried out at the laboratory. In any case, even these concentrations are low (<3 mg/m^3). The same stand for heavy metals, as well, since no transgressions are observed. Fe, Ni, and Zn were 80% of the total metals measured, while heavy metals were 28% of the particles concentration.

Finally, a few samplings, held in the offices, did not give notable results, since all the measurements were very low, in the range of 0.01-0.1 mg/m^3. From the above results regarding the production and the laboratory, it seems that

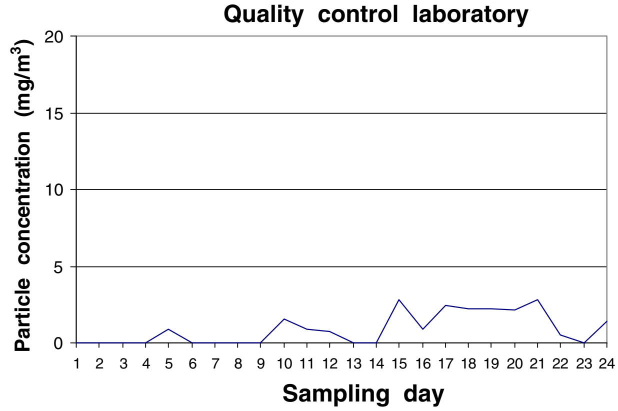

Fig. 5 Variation of particles' concentration in the quality control laboratory

Table 4 Particles and heavy metals concentrations in the laboratory

	Average, mg/m^3	Minimum, mg/m^3	Maximum, mg/m^3
TSP	0.905	0.152	2.840
Fe	0.063	0.020	0.246
Cr	0.004	0.001	0.010
Ni	0.013	0.001	0.153
Cu	0.003	0.001	0.012
Cd	0.001	0.001	0.003
Mn	0.003	0.001	0.007
Zn	0.127	0.038	0.201
Co	0.014	0.008	0.022
Pb	0.027	0.009	0.094

a significant proportion of the particles in the production site do not affect the rest of the building, on the contrary they have only a local effect. Probably, most of the particles belong to the coarse fraction, therefore rendering suspension weak. This fact also explains the difference in the particles concentrations between the production site (4.363 and 2.175 mg/m^3) and the laboratory (0.905 mg/m^3).

3.2 Statistical Elaboration of Results

A first step in this direction is statistical correlation using the Pearson coefficient. A correlation coefficient close to 1 indicates significant positive correlation. With respect to particles and trace metals, significant correlation indicates that these have a common origin (Ref 5, 13, 14,). The respective values are shown in Tables 5 and 6 for production site and laboratory, respectively. It should be noted that for the production site, the average values of both samplers were taken.

For the production site, statistical elaboration shows that there is a significant correlation between particles and Ni, Cu, Co. Furthermore, correlation is observed between Fe and Mn. This is an indication of common sources; however, it was not feasible to identify them. The main reason was the fact that the workers, during their shift, did not do the same work all the time. Instead, regarding on

Table 5 Statistical correlation between suspended particles and heavy metals concentrations in the production site

	TSP	Fe	Cr	Ni	Cu	Cd	Mn	Zn	Co	Pb
TSP	...	0.133	−0.043	**0.991**	**0.857**	0.069	0.159	−0.515	**0.919**	−0.164
Fe	0.133	...	0.165	0.140	0.409	0.384	**0.745**	0.406	0.022	0.226
Cr	−0.043	0.165	...	−0.038	0.144	−0.148	−0.051	0.036	−0.119	0.138
Ni	**0.991**	0.140	−0.038	...	**0.870**	0.046	0.147	−0.541	**0.913**	−0.174
Cu	**0.857**	0.409	0.144	**0.870**	...	0.022	0.316	−0.320	**0.752**	−0.144
Cd	0.069	0.384	−0.148	0.046	0.022	...	0.021	0.331	0.144	0.092
Mn	0.159	**0.745**	−0.051	0.147	0.316	0.021	...	0.209	0.046	0.193
Zn	−0.515	0.406	0.036	−0.541	−0.320	0.331	0.209	...	−0.557	0.308
Co	**0.919**	0.022	−0.119	**0.913**	**0.752**	0.144	0.046	−0.557	...	−0.113
Pb	−0.164	0.226	0.138	−0.174	−0.144	0.092	0.193	0.308	−0.113	...

Table 6 Statistical correlation between suspended particles and heavy metals concentrations in the laboratory

	TSP	Fe	Cr	Ni	Cu	Cd	Mn	Zn	Co	Pb
TSP	...	0.153	0.086	0.035	−0.002	0.148	−0.015	0.049	0.592	0.070
Fe	0.153	...	−0.209	−0.120	0.616	0.224	0.524	0.324	−0.118	0.203
Cr	0.086	−0.209	...	0.178	−0.321	0.074	0.042	−0.440	0.043	−0.135
Ni	0.035	−0.120	0.178	...	−0.035	0.159	−0.061	−0.244	−0.235	−0.029
Cu	−0.002	0.616	−0.321	−0.035	...	0.123	0.256	0.468	−0.185	0.459
Cd	0.148	0.224	0.074	0.159	0.123	...	0.206	−0.132	−0.148	−0.250
Mn	−0.015	0.524	0.042	−0.061	0.256	0.206	...	0.134	−0.343	0.056
Zn	0.049	0.324	−0.440	−0.244	0.468	−0.132	0.134	...	0.150	0.293
Co	0.592	−0.118	0.043	−0.235	−0.185	−0.148	−0.343	0.150	...	−0.088
Pb	0.070	0.203	−0.135	−0.029	0.459	−0.250	0.056	0.293	−0.088	...

the needs, they did various activities, such as grit-blasting, cutting of metals, grinding, and polishing. On the other hand, no correlation is observed for particles and heavy metals in the laboratory, indicating that there was not a common source.

4. Conclusions

Particles and heavy metals concentrations were low and well below the limits, even in the production site, which was the most susceptible area, since most of the activities were conducted in closed, well-ventilated systems. The only exceptions were observed in the case of cleaning and maintenance activities in the thermal spray booth and in the case of spraying outside the booth. In such cases, the use of full-face masks and body uniforms is necessary for all workers involved in these processes, as well as a more effective ventilation system. Statistical elaboration of the results showed that particles are correlated with Ni, Cu, Co. The same stands for Fe, Mn. These correlations indicate possible common sources. Based on the results of this work, it was evident that no additional safety issues (apart from the ones already existing, such as face masks and uniforms) were urgent within the company. Finally, it seems that there is no pressing need for a new or wider survey, since the results do not impose such actions. However, in the case of a significant increase of production volume in the future, a more thorough investigation, including also stationary samplers, would be essential.

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