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INVESTIGATION OF INHALABLE PARTICLES CHARACTERISTICS GENERATED DURING WELDING OF THE STAINLESS STEEL

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Abstract: Welding is one of the most dangerous industrial processes. Welding processes have potentially hazardous impact on human health, and on the environment as well. The health effects of this process on workers are numerous and very serious, like respiratory diseases, damage to skin, eyes, hearing, or can cause organ problems (stomach, kidneys), and also can be fatal like cancer. The degree of risk depends on the composition, concentration and time exposed to the harmful process/emissions and usage of different welding procedures, basic material and electrode. In this study we measure inhalable dust fraction with a personal sampler, during manual arc welding of stainless steel with and without the usage of ventilation device. The aim was to determine the difference in the amount and composition of the particles accumulated on the filter of personal sampler. The particle size and morphology characteristics was examined with scanning electron microscopy and elemental composition of samples was examined with energy dispersive spectrometry analysis. The results showed the difference in the composition of the particles that dominate in the samples and also different geometrical characteristics of inhalable dust in samples.
Keywords: welding, particles, SEM, image analysis

1. INTRODUCTION

Manual metal arc welding is a process of joining materials, where the arc is struck between an electrode fluxes coated metal rod and the work piece. There are several types of electrode coatings, such as basic, rutile, cellulose, acidic, etc., which can be used for alloy welding [1,2]. Occupational health and safety during welding very much depends on usage of different welding procedures, basic material and electrode.

In the welding process there are numerous factors that can be hazardous to human health like: heat, noise, infrared and ultraviolet radiation, body position of workers, fires and explosions, electrical hazards, compressed gases [3]. But the main problem in the welding process, regarding to occupational safety and health, is a welding smoke which is made of fine particles and gasses [3]. That mixture can contains nickel, manganese, chromium, silica, copper, arsenic, asbestos, beryllium, ozone, cadmium, compounds of fluorine, nitrogen oxides, carbon monoxide, cobalt, zinc, selenium and lead which are very toxic and can cause serious health issues for workers [4]. Consequences on health can be reversible (irritations, dermatitis), irreversible (asbestosis) or fatal (cancer) [5].

In addition to the fact that dust particles that workers can inhale during welding process are very dangerous by chemical composition, the degree of hazard to human health and level of penetration in the human body also dependent on particles size and shape. So, for the complete evaluation of exposure to welding smoke, it is necessary to have determine physical-chemical characteristics of particles [1]. The International Standard Organization for Standardization (ISO), the American Conference of Governmental Industrial Hygienists (ACGIH), and the European Standards Organization (CEN) have defined particle size fractions according to their aerodynamic diameter: inhalable, thoracic and respirable fractions [6,7].

In this study we sampled inhalable particle fraction, including all particles smaller than 100 micrometers. A qualitative analysis of chemical composition of particles on the surface of filters collected by personal sampler is possible with the use of energy dispersive spectrometry (EDS) analysis. Investigations of particle size and shape with scanning electron microscopy (SEM) enable a complex identification and evaluation of exposures.

The aim of this work was to determine the characteristic of dust particles generated during welding processes of stainless steels, and testing the differences in samples with used and without using ventilation system during welding process.

2. MATERIAL AND METHODS

The experimental part was performed at the welding laboratory at the Faculty of Mechanical Engineering, University of Ljubljana. With personal sampler from Department of Production Engineering, Faculty of Technical Sciences, University of Novi Sad, dust particles were sampled during the welding process of stainless steel with a rutile electrode.

Analysis of the geometry and composition of dust particles was examined with scanning electron microscope at the Department of Materials and Metallurgy, Faculty of Natural Science and Engineering, University of Ljubljana.

— Sampling

For the sampling of dust particles, a time-integrated method is often used in engineering practice to determine the concentration of aerosols. In this method, the sampler inhale air with a pump, simulating the level of breathing of workers. The particles, along with the air enter in to the device, and be collected in filter.

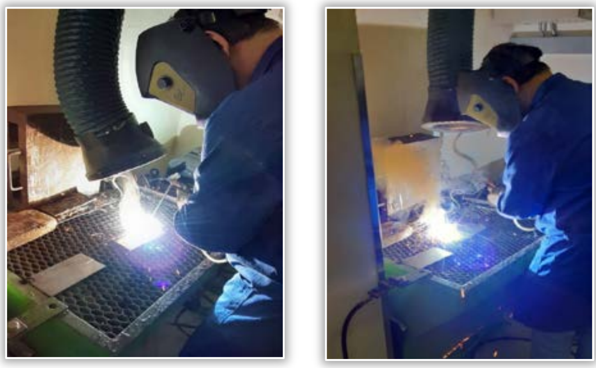
In the case of personal sampling, the sampler is located at the operator (worker) near his breathing zone (approximately 20 - 30 cm from the nose and mouth) (Figure 1), for the evaluation of workers exposure to particles [8,9]. Personal sampler operator carries with him and allow him to make any movement during the job.

Figure 1. Position of a personal sampler

Sampling was performed using the personal sampler EGO PLUS TT (Zambelli), with conical nozzle and filter with 25 mm diameter. Filters are made of mixed esters of cellulose that are suitable for use in microscopic analysis. The air flow rate was 3.5 l/min, in accordance with the manufacturer's recommendation (Zambelli). Sampling time was 1 min. The room temperature was 25 ° C, without air movement. A personal sampler was placed at the top of the chest, near the collarbone in the respiratory area of the worker/technician.

Sampling was performed in two cases, in case welding process with use air suction device (Figure 2a) and in the case of welding process without the using of a air suction device (Figure 2b).

We welded AISI 316 stainless steel (Table 1) using a manual arc welding process and rutile electrode INOX R 18/8/6 Fe (Table 2). Time of sampling was only one minute because of the amount of particles that are generated on filter and image analysis that are more difficult with particle overlapping.



a) b)

Figure 2. Sampling in case of welding process with use a suction device (a), and without use a suction device (b)

Table 1. Composition of AISI 316 stainless steel

	C	Mn	Si	Cr	Ni	P	Mo	N
%	0.07	2.0	1.0	16.5-18.5	8-13	0.04	2-2.25	0.11

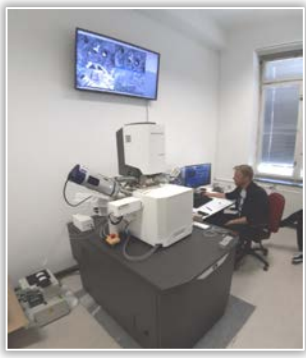
Table 2. Composition of INOX R 18/8/6 Fe electrode

	C	Si	Mo	Cr	Ni
%	0,12	< 1,2	7	19	9

— Scanning electron microscopy

For the analysis of dust particles (their shape, size, composition, etc.), we used a ThermoFischer Quattro S with a field emission gun (FEG). It allows operation in three vacuum modes, namely high vacuum (<6 10^{-4} Pa), low vacuum (up to 200 Pa) and ESEM mode (up to 4000 Pa).

For sample imaging, the FEG SEM Quattro S is equipped with detectors of secondary (SEI), backscattered (BEI) and transverse electron (STEM) detectors. It combines the principles used in transmission electron microscopes (TEM) and scanning electron microscopes (SEM). Resolution in high vacuum mode is 0.8 nm (STEM), 1.0 nm (SEI) and 2.5 nm (BEI), and 1.3 nm in ESEM mode 10 (SEI) and 2.5 nm (BEI) respectively. A new generation UltimMax detector is built in to analyze the chemical composition.


a)


b)

Figure 3. Scanning electron microscopy (a); Sputter Coater Balzers SCD 050 (b)

The sample was first carbonized to determine the composition of the dust particles. Sputter Coater Balzers SCD 050 was used for the vaporization process (Figure 3b).

After evaporation, samples were analyzed using a scanning electron microscope (SEM) (Figure 3a).

— **Image analysis**

Particle analysis is characterized by the acquisition of parameters that describe particle geometry using the image processing method. These parameters often represent interdependent variables. We use JMicroVison software. To determined particle size we use descriptors that 2D SEM image of particles convert to a circle of equivalent area. The diameter of this circle is then reported as the equivalent circle diameter (ECD) of the particle [10,11].

To determined particles shape we used descriptor which defines the textural roughness of a particle – convexity, a one to define the form of particles – elongation.

3. RESULTS AND DISCUSSION

— **EDS analysis**

EDS analysis of chemical composition of inhalable particles in welding process with using air suction, are shown in Figure 4. Elemental composition of particles trapped on a filter (EDS mapping) show that the particles contain oxygen, carbon, chromium, silicon, aluminum, potassium, iron and manganese. The results indicate that the particles have been oxidized.

Table 3 summarizes the results of EDS analyzes of dust particles composition generated during welding with using a suction device at four locations (1 - 4) in wt. %.

Table 3. EDS results of particles during welding with using a suction device (% by weight)

	C	N	O	Na	Al	Si	K	Ti	Cr	Mn	Fe	Ni
Spectrum 1	-	-	28.98	0.72	0.60	2.79	2.47	0.33	0.80	25.48	36.51	1.33
Spectrum 2	-	-	27.92	1.14	0.44	2.61	6.71	-	5.98	17.25	35.89	2.05
Spectrum 3	-	-	16.89	-	0.17	-	-	-	-	-	82.93	-
Spectrum 4	68.88	16.26	13.86	-	-	-	-	-	-	-	1.0	-

The results of the EDS analyzes collected in table 3 confirm that these are oxidized particles. The particle at site 1 mainly contains Fe, Mn, and O and smaller amounts of Na, Al, Si, K, Ti, Cr, Ni. The particle at site 2 has a similar composition to the particle at site 1. The larger spherical particle at site 3 represents iron oxide with a smaller amount of Al. The analysis of site 4 shows, in particular, the composition of the filter.

EDS analysis of chemical composition of inhalable particles in welding process without using air suction, are shown in Figure 5. The figures clearly show that the particles contain oxygen, carbon, chromium, silicon, aluminum, potassium, iron, nickel and manganese. The results indicate that these particles were also oxidized.

Table 4 summarizes the results of EDS analyzes of dust particles during welding without the use of a suction device at three locations (5 - 7) in wt. %.

Table 4. EDS results of particles during welding without using a suction device (% by weight)

	O	Al	Si	K	Cr	Mn	Fe	Ni
Spectrum 5	28.32	0.44	0.76	-	8.36	6.00	52.70	3.42
Spectrum 6	32.33	0.46	5.31	0.46	4.64	29.20	27.59	-
Spectrum 7	52.90	0.73	0.47	-	1.49	1.10	36.13	7.17

The results of the EDS analyzes given in table 4 confirm that these are oxidized metal dust particles. The particle at site 5 contains mainly Fe and O, but smaller amounts of Mn, Al, Si, Cr and Ni. The particle at site 6 mainly contains Fe, Mn, and O, but smaller amounts of Al, Si, K, and Cr. And the particle at site 7 contains mainly Fe and O, but smaller amounts of Al, Si, Cr, Mn and Ni.

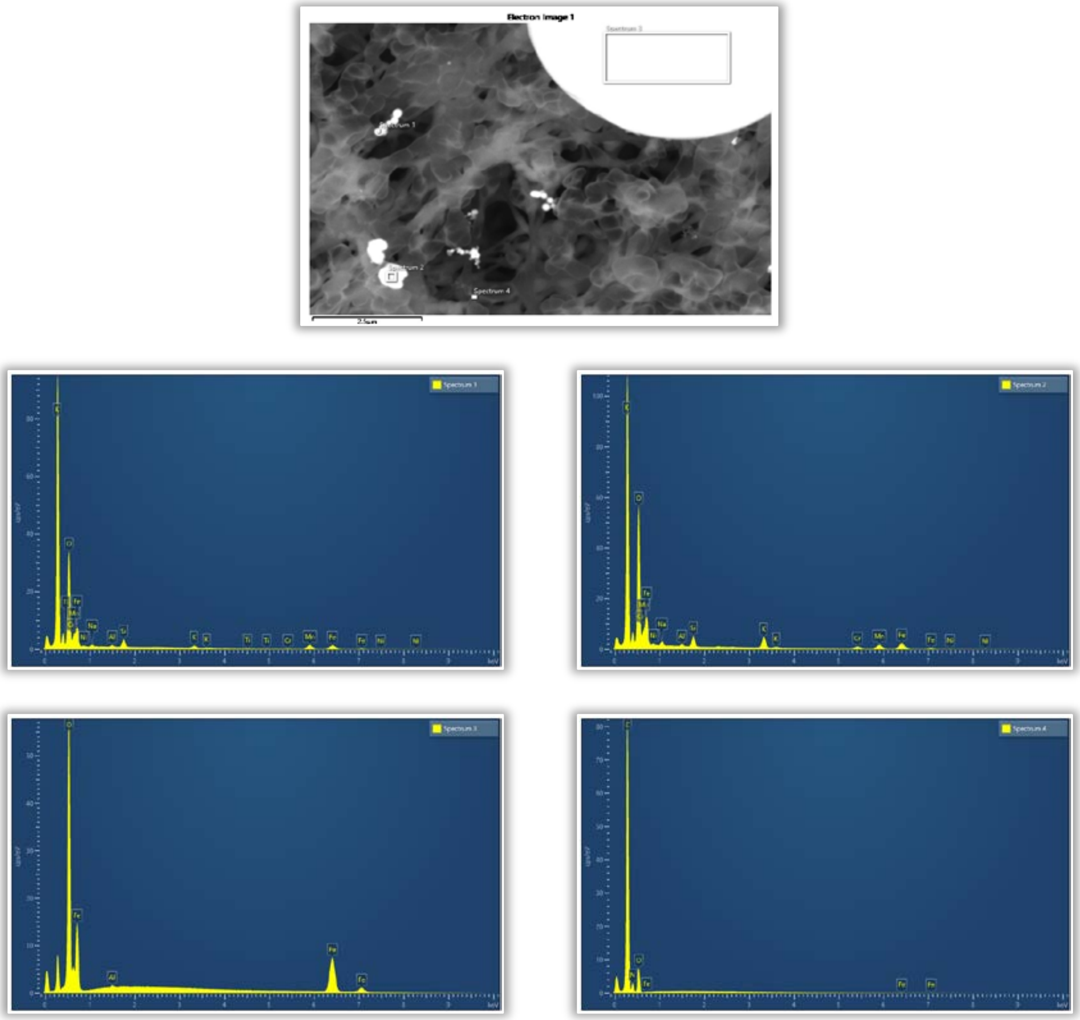


Figure 4. EDS analysis in four spectrum of chemical composition of inhalable particles in welding process with using air suction

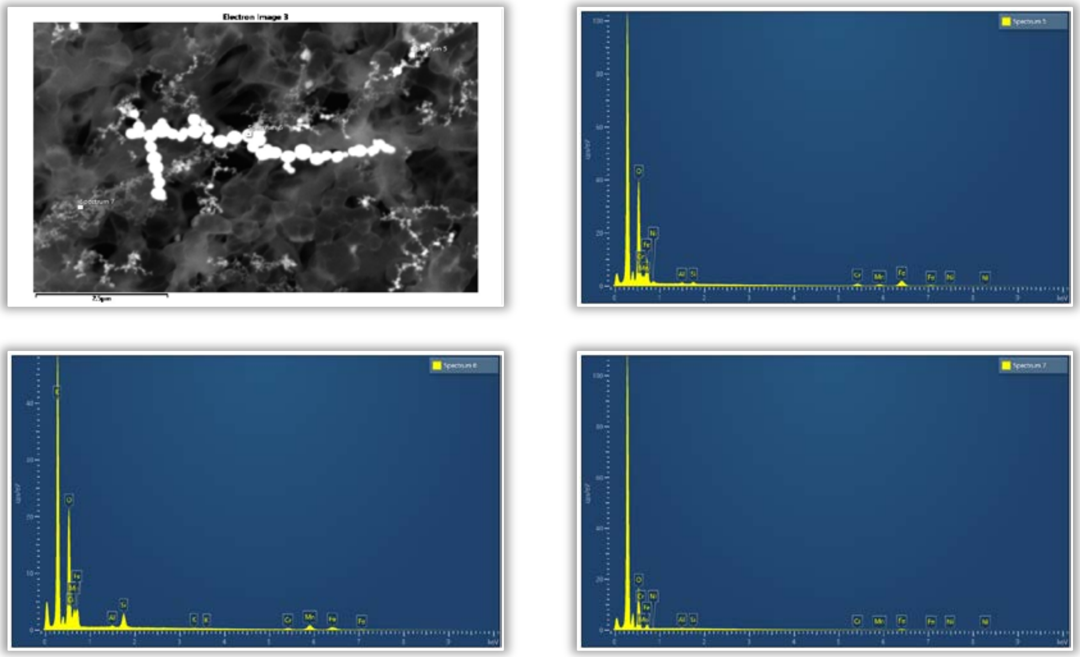
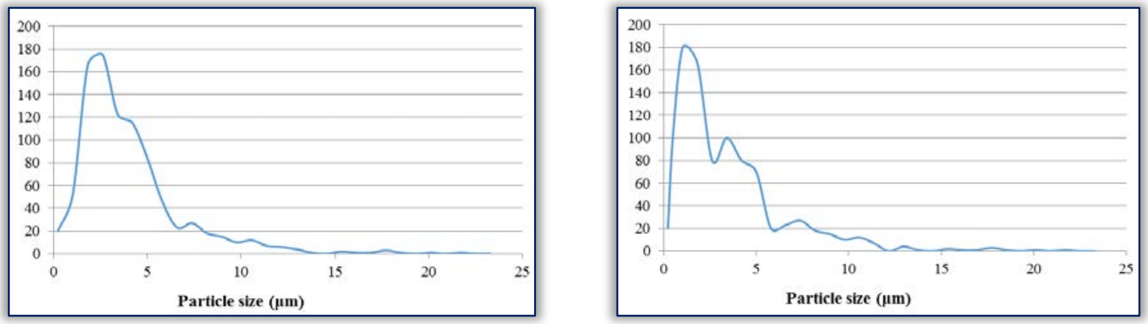


Figure 5. EDS analysis in four spectrum of chemical composition of inhalable particles in welding process without using air suction

— Size and shape descriptors

In both cases, with or without using of air suction device during the welding process, analysis of particle size over the ECD parameter showed that particles below 5 µm was dominated. The results are shown over the frequency in Figure 6.

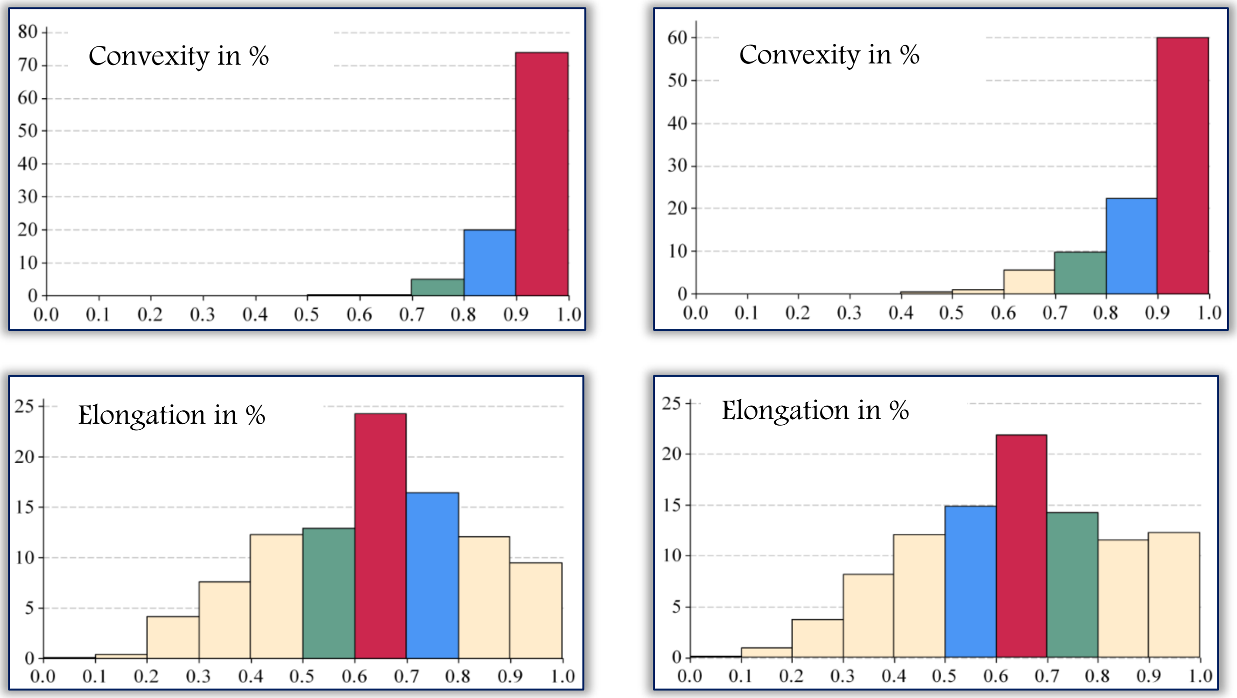


(a) (b)

Figure 6. The frequency of occurrence of a certain particle sizes: a) sample with particles collected during the welding with usage a suction device; b) sample with particles collected during the welding without usage a suction device;

In the case of sample with particles that was collected during the welding process with using a suction device, we can see the presence of slightly larger particles, and the reason is because in the case of sample with particles collected during the welding process without using air suction, the dominant are the smaller smoke particles.

Shape factors of particles in both cases showed that in the samples the dominant particles were with very low roughness and not elongated particles.



a) b)

Figure 7. Convexity and elongation of particles: a) sample with particles collected during the welding with usage a suction device; b) sample with particles collected during the welding without usage a suction device;

4. CONCLUSIONS

The investigation of the chemical composition of welding inhalable particles is very important factor for evaluation the risk of process. But in the case that we need comprehensive picture of hazardous effects of welding process, we also need to determine not only by chemical but also by physical characteristic of particles in welding fumes.

The studies demonstrate that welders are exposed to cancerogenic and neurotoxic metals, but showed also that particles of smaller sizes have potentially stronger toxic effects [12]. With increasing opportunities for investigating the size and morphological characteristic of welding fumes significantly extend the knowledge about their hazardous effects [1].

The results of the study showed the presence of toxic metals in the case of both samples. In the case of the sample with particles collected during the welding with usage a suction device, slightly larger particles are present, relative to the sample with particles collected during the welding without usage a suction device. However in both cases, the most particles are in the range of the respirable fraction. (<10μm), with low roughness and more round shape.

Note: This paper is based on the paper presented at IIZS 2019 – The 9th International Conference on Industrial Engineering and Environmental Protection, organized by Technical Faculty "Mihajlo Pupin" Zrenjanin, University of Novi Sad, in Zrenjanin, SERBIA, in 03–04 October, 2019.

References

[1] Stanislawska, M., Halatek, T., Cieslak, T., Kaminsk, I., Kuras, R., Janasik, B., Wasowicz, W, Coarse, fine and ultrafine particles arising during welding - Analysis of occupational exposure, Microchemical Journal, Vol. 135, pp. 1-9, 2017.

[2] Persoons, R., Arnoux, D., Monssu, T., Culié, O., Roche, G., Duffaud, B. Chalaye, D., Maitre, A., Determinants of occupational exposure to metals by gas metal arc welding and risk management measures: A biomonitoring study, Toxicology Letters, Vol. 231, No. 2, pp. 135-141, 2014.

[3] Bailey, L., Kerper, L., Goodman, J., Derivation of an occupational exposure level for manganese in welding fumes, NeuroToxicology, Vol. 64, pp. 166-176, 2018.

[4] Michalek I.M., Martinsen, I.J., Weiderpass, E., Hansenf, J., Sparene, P., Tryggvadottir, L., Pukkala, E., Heavy metals, welding fumes, and other occupational exposures, and the risk of kidney cancer: A population-based nested case-control study in three Nordic countries, Environmental Research,Vol. 173, pp. 117-123, 2019,

[5] Stanislawska, M., Cieslak, I., Kaminska, B., Janasik, R., Kuras, T., Halatek, W., Wasowicz, W., Assessment of occupational exposure to metals, fine and ultrafine particles arising during welding, Toxicology Letters, Vol. 258, pp. S222-S223, 2016.

[6] ISO 7708:1995 Air quality — Particle size fraction definitions for health-related sampling

[7] TLVs and BEIs, Threshold Limit Values for Chemical Substances and Physical Agents, Biological Exposure Indices, American Conference of Governmental Industrial Hygienists (ACGIH), 1330 Kemper Meadow Drive, Cincinnati, OH, 45240-1634, 1996

[8] MDHS: General methods for samplinh and gravimetric analysis of respirable and inhalable dust, Health and Safety Executive, UK 2014.

[9] Vincent J.H.: Aerosol Sampling: Sciencem Standards, Insrtrumentation and Applications, Wiley & Sons, Chichester, U.K 2007.

[10] Ilić Mićunović, M., Model za evaluaciju rezultata merenja karakteristika praškastih meterija zasnovan na elektronskoj mikroskopiji, doktorska disertacija, Novi Sad, 2018.

[11] Ilić Mićunović, M., Budak, I., Vučinić Vasić, M., Nagode, A., Kozmidis-Luburića, A., Hodolič, J., Puškar, T., Size and shape particle analysis by applying image analysis and laser diffraction – Inhalable dust in a dental laboratory, Measurement, Vol. 66, pp. 109-117, 2015.

[12] Xia, X.R., Monteiro-Riviere, N.A., Riviere, J.E., An index for characterization of nanomaterials in biological systems, Nat. Nanotechnol., Vol. 5, pp. 671-667, 2010.

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