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THE PARTICLE EMISSION DURING ARC WELDING, COMPARISON OF WELDING METHODS

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Abstract: The research focuses on measurement of particle emissions during arc welding. The methodology of measurement follows the legal requirements of governmental regulation 361/2007 and relevant norms for welder exposure measurement, also approach used to evaluate outdoor air quality and automotive emissions were used. The exposure of students during welding classes never exceed the PEL limit. It was found out that legislation limit for welders, PEL, is rather high and can be easily met. In continuation, the particles size categorization done by cascade impactor and environmental dust monitor was done. We noticed many small particles and much less large particles, majority in sizes 0,1-1 µm, which can be easily breathed in and can enter blood stream.
Keywords: welding, fumes, airborne particles, emissions, occupational safety, 361/2007

INTRODUCTION

During arc welding there are many risks that should be understood, counteracted. These are EM radiation, electric shock, risk of fire, particle emissions, gases etc. The welders exposed to fumes for long hours, many years, can experience health problems.

The airborne particles, fumes, are created by physical, metallurgical, chemical processes, and size of particles widely varies, generally 0,01 – 10 µm and can be easily breathed in. Though many welders, employers consider fumes natural, and as such tend to neglect the related risk, the clean working environment increases safety and quality of work, so much research is done in area of fumes reduction. E.g. welding source manufacturer EWM recommends pulse compared to short arc transfer stating it can reduce fume generation from 2,3 mg/s to 0,7 mg/s. [1] The filler wire manufacturers can also reduce fumes. Eg. Lincoln Electric presented 24% reduction of fume emission rate with new metal cored wire Outershield MC710RF-H. [2]

In this paper we focus on measurement of welding particle emissions in realistic conditions of welding school, welders exposure and we try to relatively evaluate welding methods. Aims of the research are:

- Measure level of student exposure to welding fumes during the class to assure safety.
- Evaluate welder exposure to fume using different techniques, fillers and compare them.
- Characterize welding emitted particles by size and weight for different methods.

METHODOLOGY

As the particles have influence on human health, the methods of measurement, legislative limits are given by occupational safety law and related standards. The Czech governmental regulation 361/2007 sets permissible exposure limit (PEL) of welders to particles, to certain gases etc. The PEL for welding dust in 8 hr shift is to be max 5 mg/m^3. For practical reasons, in this research the welding cycle was shorter, from 5-90 minutes.

— Personal exposure measurement

To measure welder exposure according to law, norms, personal sampling unit on figure 1 was borrowed from Academy of Sciences. The unit composes of sampling head with filter, placed into the welding helmet close to the mouth, figure 2, and the pump with flow approx.. 2 l/min. After a specified time of welding, work, the filter is weighted and exposure evaluated.

Figure 1: Personal sampling unit with pump

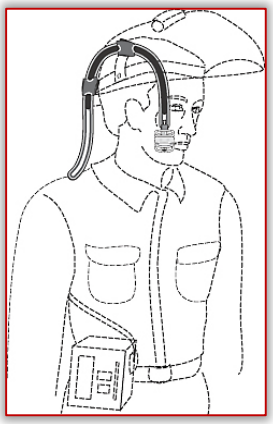


Figure 2: Placement of the sampling unit

— Characterization of emitted particles

Two devices with different principle of work were used to characterize the welding particles size. In this research these measurements are used for relative comparison of methods in term of number and size of particles, parameters, influence of time on particle evolution etc. **ELPI**, figure 3, from Dekati is 14-stage cascade impactor to measure airborne particle mass size distribution based on electric charge of particles. Particle size distribution is measured in 14 fractions, range of 16 nm – 10 µm. Environmental dust monitor **EDM** from Grimm, figure 4, uses light absorption, diffraction to classify particles into 31 size classes, from 0.25 to 32 µm.

Figure 3: Dekati ELPI – cascade impactor

Figure 4: Environmental dust monitor Grimm 1.109

— Welding methods, filler wires, parameters

Welding methods are SMAW (Shielded Metal Arc Welding), GMAW (Gas Metal Arc Welding), FCAW (Filler Cored Arc Welding). Filler material from Esab, Hyundai, Filarc and China OEM were used. Welding parameters were set according to recommendations of wire manufacturer and method as on the package. The parameters are not stated in detail in the research, because the high number of used wires and methods.

RESULTS

— Exposure of students, SMAW welding class

The exposure of students to welding fumes during practical welding class was evaluated. The students were welding fillet welds with SMAW basic electrodes for 90 min (class duration). The measured weight concentration is at Figure 5. The PEL limit value 5 mg/m^3 (regulation 361/2007 Sb.) was not reached by any student. It can be noted, that 3 main groups of results exist.

The students 1-6 the students welded standing, students 7-11 welded sitting with fume extraction switched on, while measurement, 12-14 was done without fume extraction. Sitting students are closer to the fume generation place, so they have higher exposures. Standing students have lower exposure as their head is further away from arc, source of fume. The exposition of students to fumes is highest in case without use of fume extraction. As SMAW has small productivity, especially in hands of students in the class, the exposure to welding fumes is low and even in the case without fume extraction. The safety and legal standards are met in the classes taught at CTU in Prague.

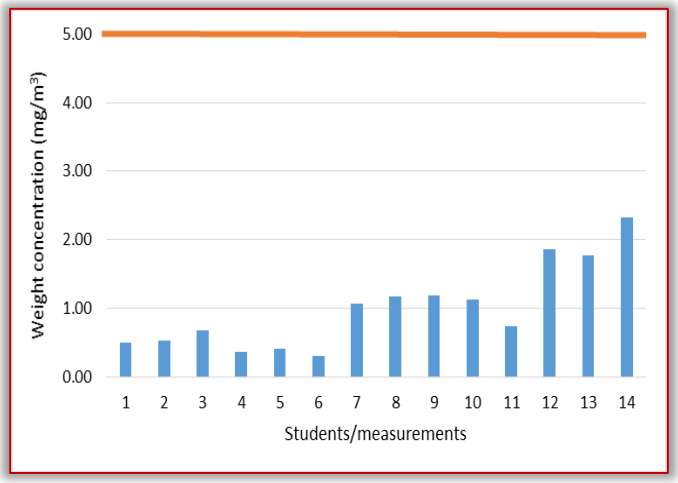


Figure 5: Results of measurement of personal exposure of 14 students during welding class

Note: The personal exposure limit (PEL) 5 mg/m^3 was not exceeded in any case. 1-6 – students welding standing with fume extraction on; 7-11 – students welding sitting with fume extraction on; 12-14 – students welding without fume extraction

— Personal exposure, different welding methods

Short time gravimetric measurement using different welding methods was done with purpose to compare methods. From tab. 1 it is clear that particle emissions, i.e. welder exposure, are closely related to welding method, its productivity and most importantly the fume extraction.

Table 1: Exposure of welder using different welding methods (welding 5-15 min) [3]

Welding method (repetitions-with and without fume extractions)	Weight concetrations without fume extraction [mg m^{-3}]	Weight concetrations with fume extraction [mg m^{-3}]
GMAW-Cu uncoated wire (3)	10,0	-
GMAW-Cu coated wire (3, 1)	10,6	0,8
GMAW-stainless steel (2, 1)	6,2	0,4
FCAW – different cores (7)	27,2	-
SMAW – Rutile electrode (3, 1)	2,0	0,5
SMAW – Bazic electrode (5, 2)	1,1	0,5
Oxyfuel cutting	5,8	Outdoor rail cutting
Grinding	1,4	-
Casting – induction furnace	3,7	-

Note: The typical length of measurement was 5-15 min of straight welding, with just technological breaks if need, i.e. SMAW - electrode exchange, GMAW, FCAW – change of weld sample. In this measurement not the whole shift is considered.

The FCAW method, most productive, creates high amount of emissions, SMAW on the other hand the lowest. We can notice that all GMAW, FCAW methods would exceed 5 mg/m^3 limit several times without fume extraction.

High exposure to welding fumes can be noted also for oxyfuel cutting, casting and grinding. In the right column, we can notice that fume extraction is very effective to reduce welder exposure and must be switched on every time.

— Particle classification

The need of particle classification is related to discrepancy of personal exposure (particle weight) measurement and probable interaction of particles with human body. As is known the large diameter particles create the mass, while smaller particles (under 1 µm) can enter the blood stream and harm the body.

Example of results of ELPI particle classification of GMA welding is at figure 6. Manual GMA welding without fume extraction with solid wire G3Si1 Cu coated. Parameters are 19 V, wire feed 7 m/min (164 A). Visible is the fact that majority of emitted particles is of size 0,01-1 µm and as such can be breathed in. Small number of large particles, which cannot enter the alveoli and blood stream on the other hand creates weight, but actually are safer. To reflect this discrepancy certain change of welders exposure measurement should be done.

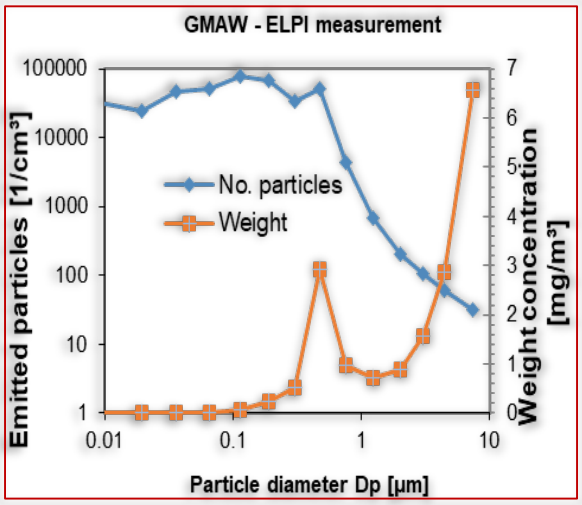


Figure 6: Result ELPI measurement – GMAW

— Time evolution of the particle presence at the workplace

The fumes created by welding are not influencing the welder only, but everyone on the job floor as the particles are easily driven by air stream and are for long time suspended in the air even after welding is finished The results of measuring GMAW at time of welding and after the welding termination are at figure 7. Parameters: without fume extraction, solid wire G3Si1, Ø1 mm, 19 V, wire feed 7 m/min (164 A).

The principle of particle reduction in time are several:

dilution with surrounding air,
aggregation of small particles to larger clusters and
the particles settle down due to gravity force.

From the graph it can be noted, that all particles, especially those under 1 µm, tend to decrease their presence slowly, it takes up to 2 hours until the background environment has same conditions as before welding.

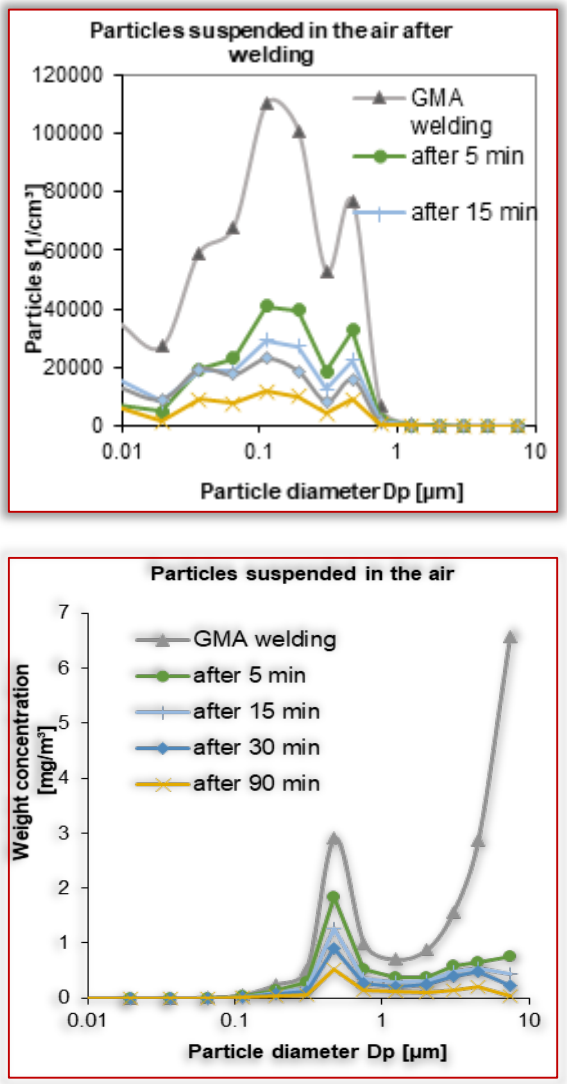


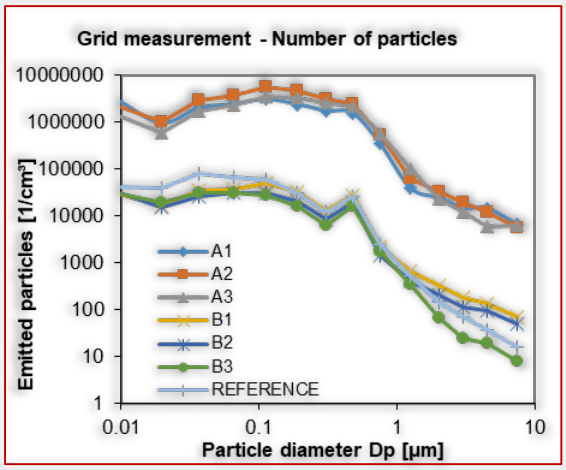
Figure 7: Result ELPI measurement – Particles in the air after finishing welding

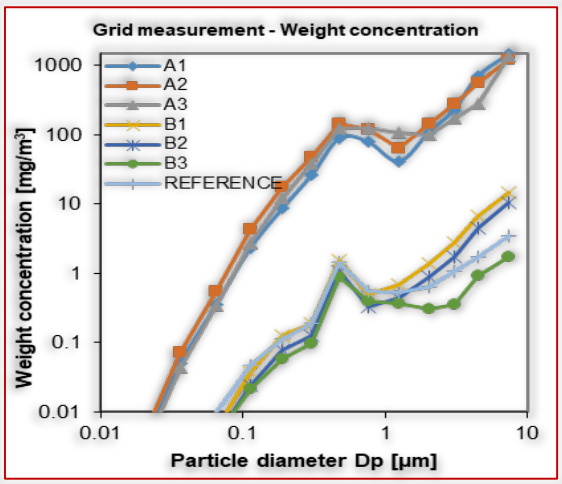
— Particle measurement according to position relatively to arc

The particles are emitted from the area of the arc and are driven by arc heated air upwards, where typically is the head of welder. By placing the inlet of ELPI machine to different positions, we mapped volume and size of particles. The positions of measurement and results are shown at Figure 8.

The graphs are using logarithmic scales. As can be seen on the logarithmic graphs, the measured curves can be divided into 2 groups with similar results:

central column, measurement above the arc (A1, A2, A3), number of particles 10E6-10E7 /cm^3, total particle weight 500-600 mg/m^3
the rest B1, B2, B3, REFERENCE – particles 10E4-10E5 /cm^3, total weight up to 10 mg/m^3





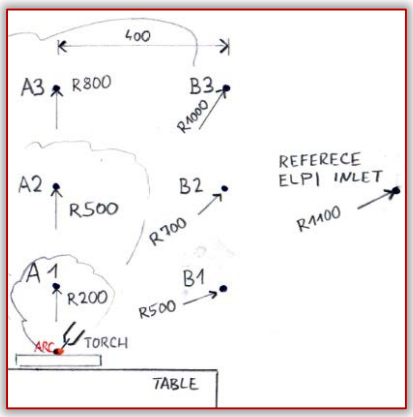


Figure 8. Result ELPI measurement – Particles no., weight measured in the grid, position

CONCLUSIONS

— Aim 1. Level of student exposure to welding fumes during SMA welding class

It was proven that law exposure limit was not exceeded by any of the students. On the other hand, from this experiment it can be understood that the PEL limit is rather high, as even in the case of non-functioning fume extraction it was not exceeded.

— Aim 2. Evaluate welder exposure to fume using different welding techniques, fillers etc..

Particle emissions, i.e. welder exposure, are closely related to welding method, its productivity and work load of the welder. The higher the productivity of the method, the higher exposure of welder can be expected. The highest values were noted for metal cored wires FCAW. It was also noted that the fume extraction is extremely important and should be switched on. With fume extraction the 5 mg/m^3 limit was never exceeded.

— Aim 3. Characterize welding particles by size and weight for different methods.

In the welding fume the vast majority of particles are in the size range under 1 µm and as such can enter the blood stream and harm the body more than larger, heavy particles. Based on results the authors consider that legal welder exposure limit, or the method of measurement should be reconsidered based on size of created particles etc.

It must be stated that welding fumes increase the risk of lung cancer etc., so setting rather strict limits is in the interest of welders, their employers. During welding, also non-welding personnel is exposed to welding fumes. This exposure is of similar level as the welder in case the fume extraction is not used. Thus efficient air filtration or fume extraction is a must.

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Note:

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