Measurement of welding fume production in welding with high-alloy electrodes

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Abstract. Due to their good structural properties, stainless Cr-Ni steels have a very wide application in various branches of technology. During the welding of stainless Cr-Ni steels with high-alloy coated electrodes, welding fumes of complex chemical composition are generated, which is very harmful for welders and the environment. For the purposes of this experiment, two variants of one rutile Cr-Ni commercial electrode, designated E 23 12 2 LR 12, were designed and fabricated. Higher production of welding fume particles also means greater danger to humans and the environment. In order to show the influence of the base material on the production of welding fume particles, an experiment for measuring the production of welding fume particles was performed in which two different steels were used as the base material, general structural steel S235JRG2 and stainless steel X6CrNiTi18.10.

1. Introduction
Welding fumes, which are a complex mixture of fumes and gases, are an inevitable harmful emission in most electric arc welding processes. The largest amount of welding fumes is generated from the electrode coating and it also represents the place where the reduction of the amount of welding fumes can be most influenced. For these reasons, the assessment of electrode quality, from the aspect of health protection, can be performed by measuring the production of welding fume particles. Measurement of the production of welding fume particles, in addition to the stated reasons, is performed in order to determine the influence of the coating character (rutile, basic, cellulose, oxide), the influence of current change, the influence of base material and other parameters on welding fumeproduction. The production of welding fumes, their chemical composition, as well as the quantities of harmful ingredients in the particles, are subject to adherence to the permitted exposure limits and norms prescribed by legal norms. Public health institutes periodically perform measurements for all economic entities, whose production results in harmful emissions into the environment. [1]

Additional materials, in this case coated electrodes for MMAW process, can be competitive on the market only if their harmful emissions in terms of quantity and chemical composition meet the regulations. Only when the set environmental requirements are met, it is possible to move on to the welding characteristics of the additional material. [1]

The experiment for measuring fume production can be reported in several ways, and the results can be expressed using the weight of welding fume particles per unit time, the weight of welding particles
per unit mass of deposit and the weight of welding fume particles per unit mass of electrode.
measurements of welding fume particle production per unit time (mg/s) [1,2].

2. Description of an experiment to measure the production of welding fume particles
The prerequisite for performing this experiment was to create a functional welding chamber for
collecting welding fume particles in which welding will be performed and welding fume particles will
be collected, which was done according to EN ISO 15011 and described in the preliminary
experimental part of the doctoral thesis [2,3 ].

For the purposes of this experiment, two electrodes of the Cr-Ni type were used, made in the
laboratory of the factory for the production of additional welding material "ELEKTRODA ZAGREB",
according to a predetermined composition of the lining and the core. The electrodes marked A and B
represent two variants of one commercial electrode, marked E 23 12 2 LR 12 in which, within the
allowed limits from the aspect of weld quality, the contents of the most harmful chemical elements
Mn, Mo, Cr and Ni are varied. [2]

Electrode E 23 12 2 LR 12 is a rutile coated electrode intended for welding identical and similar
stainless steels, as well as for mutual welding of dissimilar steels in the REL welding process. It is
suitable for plating non-alloy and low-alloy steels. The low-carbon Cr – Ni – Mo steel weld is stable at
temperatures up to 350 °C. The weld metal structure is austenite with delta ferrite. The chemical
composition of pure weld metal is given in Table 1. [4]

| Chemical composition of pure weldmetal of a commercial electrode E 23 12 2 LR 12 |
|---------------------------------|------|-----|-----|-----|-----|
| Chemical element            | C    | Mn  | Si  | Cr  | Ni  | Mo  |
| %                            | 0,03 | 0,9 | 0,8 | 22,5| 12,5| 2,7 |

The recipe of the chemical composition of the electrode coating (internal name of the electrode
manufacturer, the so-called formula), raw materials and their origin used for electrode coating differ
from manufacturer to manufacturer and are known only to the electrode manufacturer, Table 2. [2]

| Orientation composition of the electrode coating |
|-----------------------------------------------|-----|
| Material type                  | Weight share % |
| Rutile                          | 25  |
| Silicates (feldspar, quartz…)    | 25  |
| Fe alloys (FeCr, FeMn, FeSi…)   | 8   |
| Metal powder (Ni, Cr…)          | 25  |
| Carbonates (limestone)          | 10  |
| Other (binder, liquid silicates) | 7   |
| Σ                               | 100 % |

Two types of wire, marked 316 L and 308 L, were used to make the core of the laboratory
electrodes. Standard EN ISO 14343 prescribes the quality of the chemical composition of the drawn
wire from which the electrode core is made. The chemical composition of the wire for the electrode
core by the wire manufacturer "Rodacciai" Italy, is shown in Table 3 [5].
Table 3. Chemical composition of core wire according to the manufacturer

| r.br. | Chemical element | 316L   | 308L   |
|-------|------------------|--------|--------|
| 1.    | C                | 0,011  | 0,012  |
| 2.    | Mn               | 1,680  | 1,630  |
| 3.    | Si               | 0,080  | 0,080  |
| 4.    | S                | 0,011  | 0,012  |
| 5.    | P                | 0,012  | 0,011  |
| 6.    | Cr               | 18,240 | 20,160 |
| 7.    | Ni               | 11,280 | 10,100 |
| 8.    | Mo               | 2,590  | 0,040  |
| 9.    | Al               | 0,003  | 0,004  |
| 10.   | Cu               | 0,080  | 0,040  |
| 11.   | Co               | 0,027  | 0,024  |
| 12.   | N                | 0,048  | 0,044  |
| 13.   | Ti               | 0,005  | 0,005  |
| 14.   | Nb               | 0,010  | 0,010  |
| 15.   | B                | 0,001  | 0,001  |
| 16.   | W                | -      | 0,010  |
| 17.   | V                | 0,039  | 0,037  |

The most influential alloying chemical elements in electrodes A and B are: Mn, Mo, Cr and Ni. The percentages of chemical elements Mn, Mo, Cr and Ni in wire, coatings and electrodes A and B, as well as the percentages of chemical elements Mo, Cr and Ni in pure weld metal for electrodes A and B are given in Table 4.

Table 4. Contents of main alloying chemical elements in electrodes A and B

|                      | electrode A    | electrode B    |
|----------------------|----------------|----------------|
| mass fraction (w) of | wire 316 L     | wire 308 L     |
| the chemical element |                |                |
| Mn                   | 1.49           | 1.40           |
| Mo                   | 1.04           | 4.31           |
| Cr                   | 20.82          | 18.14          |
| Ni                   | 4.97           | 6.44           |
| mass fraction (w) of |                |                |
| the chemical element |                |                |
| Mn                   | 1.68           | 1.63           |
| Mo                   | 2.59           | 0.04           |
| Cr                   | 18.24          | 20.160         |
| Ni                   | 11.28          | 10.100         |
| mass fraction (w) of |                |                |
| the chemical element |                |                |
| Mn                   | 1.62           | 1.69           |
| Mo                   | 1.96           | 1.62           |
| Cr                   | 19.29          | 18.99          |
| Ni                   | 8.71           | 8.49           |

mass fraction (w) of chemical element in the weld%

| Mn       | 1.62 |
| Mo       | 1.62 |
| Cr       | 22.5 |
| Ni       | 11.5 |

Mo ≈ 2.6
Cr ≈ 22.5
Ni ≈ 11.5
As part of the research of welding fumes in the welding of high-alloy steels, experiments were performed to measure the production of welding fume particles depending on the change in current and base material, as well as experiments to determine the chemical composition of welding fume particles [2].

2.1. Results of measurements of welding fume particle production of high-alloy electrodes

According to the literature, the basic material participates in the formation of welding fume particles with about 10 to 20% in relation to the electrode, which participates in the formation of welding fume particles with about 80 to 90% [6]. In order to show the influence of the base material on the production and chemical composition of welding fume particles, an experiment for measuring the production of welding fume particles was planned and performed. Carbon steel, S235JRG2, of non-guaranteed chemical composition with limited impurity content and partially prescribed content of C, Si and Mn, is used for welded and riveted structures in cases where there is no danger of brittle fracture as well as at temperatures up to 100 °C. Stainless steels are characterized by high resistance to corrosion, which is achieved by the formation of a thin, hard and compact surface layer, which protects the metal from further corrosion. In addition to high corrosion resistance, these steels are also fireproof, so they are used to work at temperatures above 550 °C, instead of low-alloy steels. Stainless steels are high-alloy, and in addition to at least 10.5% chromium, they also contain nickel, molybdenum, copper, titanium, silicon, manganese and niobium. The chemical composition of steel X6CrNiTi18.10 is given in Table 5.

Table 5. Chemical composition of steel X6CrNiTi18.

| Chemical element | C | Si | P+S | Cr     | Mo    | Ni     | Mn | The others |
|------------------|---|----|-----|--------|-------|--------|----|-----------|
| content %        | 0,06 | 2,0 max | 0,045 % P | 17÷19 | 9÷11,5 | 2,0 max | Ti | 5÷C min   |

The production of welding fume particles was measured depending on the change in current and the change in the base material. The recommended welding current for electrode E 23 12 2 LR 12, diameter 3.20 mm is (80 ÷ 110) A. The test was performed for three different current values, 80, 95 and 110 A. [4] The plan of the experiment according to which twelve tests were performed, the measured values during the experiment and the obtained values of the production of welding fume particles are shown in Table 6. [2]

Table 6. Experimental plan and values of welding fume particle

| s.n test | Label electrode wire | Basic material | Test mark | Current A | The duration of the arc s | Particle weight M (mg) | Production particle P (mg/s) |
|----------|----------------------|----------------|-----------|-----------|---------------------------|------------------------|-----------------------------|
| 1. A1    | 316 L                | S235JRG2       | A1        | 80        | 85                        | 290                    | 3,41                        |
| 2. A2    | 316 L                | S235JRG2       | A2        | 95        | 69                        | 252                    | 3,65                        |
| 3. A3    | 316 L                | S235JRG2       | A3        | 110       | 59                        | 228                    | 3,86                        |
| 4. A4    | 316 L                | X6CrNiTi18.10  | A4        | 80        | 84                        | 228                    | 2,71                        |
| 5. A5    | 316 L                | X6CrNiTi18.10  | A5        | 95        | 71                        | 253                    | 3,56                        |
| 6. A6    | 316 L                | X6CrNiTi18.10  | A6        | 110       | 61                        | 291                    | 4,77                        |
| 7. B1    | 316 L                | X6CrNiTi18.10  | B1        | 80        | 85                        | 256                    | 3,01                        |
| 8. B2    | 316 L                | X6CrNiTi18.10  | B2        | 95        | 70                        | 244                    | 3,48                        |
| 9. B3    | 316 L                | X6CrNiTi18.10  | B3        | 110       | 60                        | 288                    | 4,85                        |
| 10. B4   | 316 L                | X6CrNiTi18.10  | B4        | 80        | 81                        | 237                    | 2,95                        |
| 11. B5   | 316 L                | X6CrNiTi18.10  | B5        | 95        | 69                        | 284                    | 4,12                        |
| 12. B6   | 316 L                | X6CrNiTi18.10  | B6        | 110       | 59                        | 292                    | 4,95                        |
The calculated values of welding fume particle production, for three values of welding current, 80, 95 and 110 A, two basic materials S235JRG2 and X6CrNiTi18.10 and for electrodes A and B, are shown in the diagram, Figure no. 1. On the diagram, certain laws of change in the value of production of welding fume particles can be observed.

![PRODUCTION OF WELDING FUME PARTICLES](image)

**Figure 1.** Welding fume particle production

All values of welding fume production show a growth trend with increasing current strength. The highest production of welding fume particles is generated when welding X6CrNiTi18.10 alloy steel with electrode B at a current strength of 95A in the value of 4.09 mg/s and 110A in the value of 4.95 mg/s. The values of fume production for current 80A are higher for both electrodes when welding carbon steel, while the values of production of welding fume for current of 110A are higher when welding stainless steel. This result can be explained by the presence of alloying elements in high-alloy steel, which evaporate at higher temperatures and generate welding fume particles. Alloying chemical elements from the base material evaporate harder and less because the temperature of the welding bath is significantly lower than the temperature of the electric arc. The alloying elements in the electrode (coating and wire core of the electrode) at the moment of transmission through the electric arc, where the highest temperature is, evaporate intensively and the influence of the electrode on the production and chemical composition of welding fume is much greater.

### 3. Conclusion

The obtained results defined the influence of variables on the obtained results. It was found that the production of welding fume does not depend significantly on the type of base material, in welding with lower currents. All values of welding fume production show a growth trend with increasing current strength. The fume production values for current 80 A are higher for both electrodes, A and B, when welding carbon steel, while the values of welding fume production for current 110 A are higher when welding stainless steel. Higher temperatures that develop when welded with higher currents cause evaporation of alloying chemical elements that are known to have higher evaporation points. From this aspect, it is recommended to work with lower welding currents within the limits recommended by the manufacturer of the welding consumable. The production of welding fume particles in the value of 4.95 mg/s, when welding steel X6CrNiTi18.10 with electrode B, represents the third degree of harmful emission of a total of 4 degrees, which requires the use of a certain type of
ventilation. The production of welding fume particles acquires the right meaning when expressed in mg/m³ of closed working space. Higher production of welding fume particles does not mean a greater danger to the health of welders. The real danger is posed by harmful ingredients in welding fume particles that can be determined by various methods of chemical analysis. The electrode has the greatest influence on the production and chemical composition of welding fume particles, namely the electrode coating, which participates in the generation of welding fume with (80 to 90)%.

From this aspect, the activities on the development of the electrode coating are always present, significant and interesting for reducing the production and harmful components in the welding fume particles.

References

[1] Razija B, Azra I 2015 Dubrovnik Methods for measuring the production of welding fume particles, 10th International Scientific Conference on Production Engineering, Development and modernization production
[2] Razija B 2011 Bihać Doctoral thesis Faculty of Mechanical Engineering, University of Bihać, Investigation of the optimal technological composition of the electrode coating from the aspect of minimizing welding fume
[3] EN ISO 15011-1, april 2002 Health and safety in welding and allied processes-Laboratory method for sampling fume and gases generated by arc welding-Part 1: Determination of emission rate and sampling for analysis of particulate fume
[4] Catalog of additional factory material 2018 „ELEKTRODA ZAGREB“
[5] Rodacciai 05.2008 Italia Certificato di collaudo
[6] Manual Metal Arc welding 2005 Aachen ISF