Investigation of the influence of electrode manufacturers 'recipes on the production and chemical composition of welding fume particles

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Abstract. The quality of the welded joint, production and chemical composition of welding fume particles in the MMAW process, in addition to the welding parameters, mostly depend on the quality of the coated electrode. As part of the preliminary experimental research of the optimal technological composition of the electrode coating, from the aspect of minimizing welding fume, an experimental research of one class of electrodes, E 42 4 B 32 H5, EN 499/94, standard production program of three manufacturers of welding consumables. The test was performed to examine the influence of the manufacturer's recipe on the production and chemical composition of welding fume particles.

1. Introduction
To test the production and chemical composition of welding fume particles, a basic coated electrode marked, E 42 4 B 32 H5, with controlled hydrogen content, was selected for welding in all positions, except vertically downwards, carbon and medium-stress steels and mild steels under the condition of high loads. The initial and re-establishment of the arch is very good, and the slag is easily separated. It can be used for all general purposes where control of the hydrogen content is necessary. The basic materials are, general construction steels, pipe steels, steels for pressure equipment, steels for shipbuilding and steel castings. The main goal of this research is to experimentally check some literature data and to narrow the research range to a certain type of electrode, for which, through the implementation of the main experiment, we would try to determine the optimal composition of the electrode coating, which will, in addition to satisfactory welding chemical composition of welding fume particles and have good welding characteristics in every respect. [1,2]

2. Performance of experiments
The amount and chemical composition of welding fumes is directly related to the composition of the coating and the electrode core. Each electrode manufacturer has its own recipe for a particular type of coating, which can result in the production of different amounts and different chemical composition of welding fume particles for the same type of electrode. On the way from the establishment of the electric arc to the bath, the coated electrode fulfills several functions, namely physical, electrical, metallurgical and economic function. The greatest role during welding with a coated electrode is played by the electrode coating, so the functions to be fulfilled by the coated electrode will also be listed as functions for electrode coating. [3,4,5]

Low-carbon steel was used as the base material in the experiment, and electrodes for welding low-carbon steels were used accordingly. No significant amounts of certain chemical elements are
expected in the particles of welding fume, such as e.g. Cr, Mn, Mo, Ni, etc., which are otherwise found in high-alloy CrNi electrodes or alloy steels as alloying elements. Other chemical elements detected in the tests are considered regular impurities and steel companions. They appear in insignificant quantities and do not have a great impact on health and the environment. [1]

2.1. Equipment and procedure for conducting tests for the collection of welding fume particles
Standard EN ISO 15011, in the first part, defines a method for taking evaporation samples and describes a laboratory procedure for determining the emission levels of corrections generated during arc welding and suggests possible analytical techniques or chemical analysis to determine the chemical composition of consumer-generated evaporation. The emission level and evaporation composition depend on the welding process, welding parameters, coating, work surface size, etc. In this case, the welding was performed by the MMAW process. Welding equipment consisting of a welding chamber, glass fiber filters, traction fan, welding apparatus, precision scales for measuring the weight of welding fume particles was used to collect samples of welding fume from these electrodes. Among the 2 models of the welding chamber containing the standard EN ISO 15011, model 1 was selected and made, shown in Figure 1. [6]

![Figure 1. Model 1 of the welding chamber standard EN ISO1511](image)

The test welding chamber for collecting welding fume should have a process chamber and a ventilation duct in which the filter is located. The process chamber should be suitable for the selected welding process, which means that it must enclose the entire MMAW process and be large enough to allow the collection of the complete emission of welding fumes. The flow of ventilation through the process chamber must enhance the thermal movement of air which means that the ventilation outlet should be above the welding process to enhance the natural flow of heated air, while the air inlet should be below the welding process. The air flow capacity of the pump or fan should be sufficient to capture the fully emitted gases from the chamber but should not affect the integrity of the process [6].

Sampling of welding fumes will be performed at the outlet of the evaporation chamber where the appropriate filter should be located. The filter should be placed at a distance from the welding process.
or air inlet, 5 × larger than the diameter of the air outlet from the chamber. All equipment that comes into contact with welding fumes must be made of inert metals to prevent absorption, accumulation or chemical reaction with fume components. PVC pipes are also suitable for use. It is not necessary to use heat-resistant materials or to use cooling devices. It is necessary to regularly clean the inside of the chamber. Also the ambient air in the room where the chamber is located should meet the quality requirements prescribed by ISO 8756. It is a procedure for adjusting the air quality with changes in temperature and humidity used in the report of results. The requirements of ISO 8756 should be taken into account in the measurement methods specified in this standard [6].

Two experiments were performed, measurement of welding fume production and chemical analysis of welding fume particles. For the needs of both experiments, it is necessary to collect welding fume particles. The collection of welding fume particles was performed in a welding chamber according to the procedure described in standard EN ISO 15011 [6,1].

2.2. Experiment and experimental results for determining the production of welding fumes

Standard ISO 15011, describes the problems of the laboratory method for collecting samples of evaporation and gases generated during electric arc welding processes, for estimating the rate of exhaust gases (production) stipulates that three tests are made and the mean value is calculated. [6]

For the purposes of this experiment, three basic electrodes, of the same class E 42 4 B 32 H5, from three different manufacturers, whose chemical composition of pure weld metal is shown in Table 1, were selected.

| Table 1. Chemical composition of pure weld metal |
|-----------------------------------------------|
|      %   | C   | Mn | Si | S  | P  |
|--------|-----|----|----|----|----|
| B1     | 0,07| 0,80| 0,50| 0,02| 0,02|
| B2     | 0,07| 1,00| 0,60|  -  |   - |
| B3     | 0,08| 1,00| 0,50|  -  |   - |

The data were taken from the catalog of three manufacturers. Electrodes from three manufacturers are marked B1, B2 and B3. Differences in the chemical composition of pure weld metal are minimal. The recommended welding current for the electrode diameter Ø 3.25 mm and this class of electrodes is \( I = (110 \div 140) \) A. [1]

During the experiment for measuring fume production, a total of nine tests were planned and performed, three tests for each type of electrode marked B1 (B11; B12; B13), B2 (B21; B22; B23) and B3 (B31; B32; B33). Standard electrodes with a diameter of 3.25 mm and a length of 350 mm were used. The welding current for all three electrodes was 120 A during the experiment. Fume production tests were performed by single electrode welding, recording the active duration of the arc burning. Filters were weighed before and after the test. [1]

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Table 2. Welding fume production

| Marking | Welding time t (s) | Particle weight M (mg) | Fume production P (mg/s) | Mean values productions P (mg/s) |
|---------|-------------------|-----------------------|-------------------------|---------------------------------|
| B11     | 93                | 610                   | 6.56                    | 6.37                            |
| B12     | 98                | 560                   | 5.71                    |                                 |
| B13     | 95                | 650                   | 6.84                    | 6.37                            |
| B21     | 91                | 580                   | 6.37                    |                                 |
| B22     | 88                | 590                   | 6.71                    | 6.69                            |
| B23     | 90                | 630                   | 7.00                    |                                 |
| B31     | 94                | 550                   | 5.85                    |                                 |
| B32     | 89                | 510                   | 5.73                    | 6.03                            |
| B33     | 86                | 560                   | 6.51                    |                                 |

A graphical representation of the results of welding fume production for three electrodes and three samples for each electrode, according to Table 2 is given in Figure 2 [1].

Figure 2. Production of welding fume for electrode E 42 4 B 32 H5 three manufacturers

The highest production of welding fume particles was generated by welding with electrodes of the manufacturer of electrodes B2 and amounts to 6.69 mg/s, then the manufacturer of electrodes B1 and amounts to 6.37 mg/s and the lowest production is generated by the manufacturer of electrodes B3 and amounts to 6.03 mg/s. Based on the values of the mean productions of welding fume particles, it can be concluded that there are differences in productions for different electrode manufacturers, but that in this case they are not so significant. However, when it comes to high consumption of coated electrodes in production, higher production of welding fume particles means both higher total emission and amount of particles in the workspace. [6,1]

2.3. Experiment and results of chemical analysis of welding fume particles

During the experiment, welding fume particles were collected to examine the effect of the manufacturer's recipe on the chemical composition of the particles. In each sample, a mass of fume particles generated from three electrodes (a total of 27 electrodes) was collected on one filter, which gives a sufficient amount of particles for chemical analysis. A total of nine tests were performed, three
tests for each type of electrode marked B1, B2 and B3. The results of chemical analysis of welding fume particles are shown in Table 3. [1]

Table 3. Results of chemical analysis of welding fume particles

| Ordinal number | Chemical element | Chemical composition of welding fume particles for the electrode E 42 4 B 32 H5 Electrode designation and sample designation | Electrode B1 | Electrode B2 | Electrode B3 |
|----------------|------------------|-----------------------------------------------|-------------|-------------|-------------|
| 1. Ca           | 1.99             | 1.94                                    | 1.96         | 1.969       | 1.963       |
| 2. Mg           | 0.30             | 0.30                                    | 0.31         | 0.31        | 0.31        |
| 3. K            | 1.35             | 0.14                                    | 0.16         | 0.16        | 0.15        |
| 4. Na           | 3.50             | 3.76                                    | 3.51         | 3.59        | 3.50        |
| 5. Fe           | 16.76            | 15.60                                   | 18.96        | 17.11       | 19.55       |
| 6. Cu           | 0.01             | 0.01                                    | 0.01         | 0.01        | 0.01        |
| 7. Mn           | 3.16             | 3.06                                    | 3.30         | 3.173       | 3.104       |
| 8. Zn           | 0.01             | 0.01                                    | 0.01         | 0.01        | 0.01        |
| 9. Cr           | 0.001            | 0.001                                   | 0.001        | 0.001       | 0.001       |
| 10. Cd          | 0.001            | 0.001                                   | 0.001        | 0.001       | 0.001       |
| 11. Pb          | 0.032            | 0.029                                   | 0.030        | 0.030       | 0.030       |
| 12. Ni          | 0.001            | 0.001                                   | 0.001        | 0.001       | 0.001       |
| 13. Co          | 0.001            | 0.001                                   | 0.001        | 0.001       | 0.001       |

According to the procedure prescribed by the ISO 15011 standard, chemical analysis of fume particles was performed according to the AAS method (atomic absorption spectrometry) in the Laboratory for Chemical Analysis of the University "Džemal Bijedić" in Mostar. Chemical analysis of fume particles was performed for 13 chemical elements. The table also gives the mean values of the content of chemical elements for three samples of one electrode and are marked with: B1, B2, B3. All conditions of the experiments of this experiment were the same, so that the results were mutually comparable. [1]

Higher Mn content in fume particles can be found when basic electrodes are used because they contain ferrous manganese in the coating which serves as a deoxidizer. Manganese is prone to oxidation states so that its content in pure weld metal is 0.8%, table 1, and in fume particles its content ranges from 3.17% to 5.13%, for electrode B1 it is 3.17%, for electrode B2 is 4.08% and for electrode B3 the Mn content is 5.13%. [1]

From the aspect of Fe content in fume particles, electrode B2 contains the most Fe and is 22.71%, electrode B3 contains 19.55% Fe and electrode B1 has the lowest Fe content and is 17.11% [1].

From the aspect of Pb content in fume particles, electrode B3 contains the least Pb and is 0.02%, electrode B2 has 0.016% and electrode B3 has the highest Cu content and is 0.04% [1].

Other extremely harmful components, Cr, Ni, Co, are present in much smaller quantities and their contents are approximately the same for all three electrodes. As these are electrodes for welding general structural steels that do not contain alloying elements, such chemical elements are not expected in large quantities in fume particles and welding fumes generated from electrodes for welding general structural steels are much less dangerous, so the health of welders and environment.

The difference in the content of individual chemical elements for the three tested electrodes of different manufacturers exists, but analyzing the mean values of the percentages of 13 analyzed chemical elements, it can be concluded that these differences are not significant. [7,1]
3. Conclusion

The coated base electrode E 42 4 B 32 H5 for MMAW process from three different manufacturers of additional material of the same class, from the aspect of production and chemical composition of welding fume particles, was tested. The production of welding fume particles is different for each coated electrode from different manufacturers. The lowest production of welding fume particles was obtained by welding with electrode B3 and is 6.03 mg/s, and electrode B3 is the best in terms of production of welding fume. It was also found that the chemical composition of welding fume particles is different for each manufacturer of welding consumables. As it is welding of general structural steel with the mentioned coated basic electrode, in the particles of welding fume, as expected, there are no large amounts of the most harmful chemical elements, such as Cr, Mn, Ni, Mo, etc., which cause severe diseases. From the aspect of Mn content, which is very harmful to health, electrode B1 is the most favorable because it contains the least Mn in particles and amounts to 3.173%. From the aspect of Fe content in welding fume particles, because Fe causes long-term harmful effects on health but much less in relation to Cr, Mn, Ni, Mo, etc., the most favorable electrode is B1 because it has the lowest Fe content in particles and is 17.11%. Which electrode the consumer will choose depends on the set requirements that must be met. In any case, it is necessary to apply personal protective equipment and space protection with adequate ventilation equipment.

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