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## POLLUTION FACTORS IN ELECTRIC ARC WELDING

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**Abstract:** Electric arc welding is a manufacturing process that involves the existence of several factors with unfavorable effects on the environment. An analysis of the electric arc welding process allowed some clarification of the effects of polluting factors specific to this process. By using the systemic analysis method, the polluting effects generated by the electric arc welding process were highlighted. Considering the need for as much reasoned allocation of available financial resources to combat the polluting effects, the double-entry matrix method was used. In this way a somewhat justified ordering of the polluting effects became possible. It was found that the most intense polluting effect is determined by the number of harmful gases released, followed by visible radiation.

**Key words:** electric arc welding, pollution effects, systemic analysis, double entry matrix, financial resource allocation.

### 1. INTRODUCTION

In general, in machine manufacturing, non-removable joints can be obtained by some plastic deformation processes, such as riveting, welding, and soldering.

Welding is a process or operation of making a non-removable joint of two parts of metallic or, in general, thermoplastic materials, by using heat and/or pressure, with or without filler materials.

At the basis of welding processes, there are some interactions between the atomic structures of the materials involved in the process. If we take into account the materialization of the interatomic cohesion bonds in the contact areas between the parts to be welded, but also the nature of the energy used for heating and/or pressing, the temperature at which the joint is made, the method of forming the joint and the nature of the material addition, it is found that there are fusion welding and pressure welding processes, respectively. If the classification of welding methods is carried out considering the type of energy used, it is found that mechanical energy, thermal energy, electrical energy, and energy of particles included in a beam directed towards the welding area can be considered.

Among the welding processes that use electric energy to melt the materials of the two parts to be joined is also electric arc welding. This type of welding process uses an electric arc to generate the heat needed to melt and join the materials of the two parts involved in the process. An electric arc produced between the welding electrodes and the parts to be joined ensures conditions of melting and mixing of the materials of the two parts. Electric arc welding is one of the most used welding processes. On the other hand, electric arc welding is accompanied by effects that can produce some environmental pollution or negatively affect the operator's health. Aspects of this type have been and continue to be a concern for researchers in the field of machine manufacturing.

Thus, Mistodie and Rusu carried out research related to the evaluation and monitoring of risk factors that act at the level of workplaces corresponding to electric arc welding [1]. They concluded that it is necessary to identify and use appropriate ways to reduce the risks of affecting the health of welders or the environment in which welders work. The study [2] also researched the environmental impact of the shielded metal arc welding and gas metal arc welding processes [2]; [3] pursued the

identification of harmful substances that appear during the shielded metal arc welding. The influence exerted by the welding conditions on a size called *the pollution coefficient* was also emphasized. Results of some research on the effects exerted on the environment by polluting factors acting on the flame oxyacetylene welding processes were also published by a group coordinated by [4]. Further, [5] developed research on the effects of fumes in welding processes and the measures that could be put in place to protect welders in this regard. Another research of [6] addressed the issue of the existence of certain risks specific to electric arc welding from the point of view of the health of the human operator and the protection of the environment. Some aspects related to the minimization of the effects of welding processes on the environment, to ensure a better sustainability of these processes, were addressed in the paper [7].

The first objective of the research, the results of which were presented in this article, was to reveal the main factors specific to electric arc welding processes capable of exerting negative effects on the human operator (on the welder) and the environment in which the welding processes are carried out. It was also aimed at highlighting the factors or groups of factors capable of exerting influence on the parameters of interest in electric arc welding.

Another objective was to order, even if subjectively, the factors generating negative effects, using in this sense an appropriate method (the double entry matrix method). In the present work, the problem of the need to allocate an available financial resource to combat the polluting effects specific to the electric arc welding process was formulated.

By using the systemic analysis method, it was aimed to highlight the polluting effects in the case of the mentioned manufacturing process. Next, the double-entry matrix method was applied to assess the importance of different pollution effects.

## 2. POLLUTION FACTORS IN ELECTRIC ARC WELDING

*Pollution* means the presence of materials harmful to the environment. Such materials are

known under the generic name of *pollution*. It is considered that pollution can appear both because of some processes in nature (being cited, for example, ashes and gases generated by volcanic eruptions), as well as of activities initiated and promoted by human beings.

Carrying out an electric arc welding process (Fig. 1) involves connecting an electrode in the form of a thin rod and the workpieces to be welded in the circuit of an electric current source that allows the initiation and maintenance of an electric discharge in the arc between the electrode and the workpieces. From the point of view of what can be immediately observed in the case of an electric arc welding process, it is necessary to mention first *the light radiation*.

To evaluate the intensity of the light emitted by a source, it is possible to use two sizes, namely: a) *luminance*, with the help of which the intensity of light emitted or reflected by a surface is evaluated. Luminance is measured in candelas per square meter; b) *illumination*, highlighting the intensity of light radiation that reaches a surface, and it is measured in lux.

To be able to consider the negative effect of light radiation, the maximum intensity of this radiation must exceed certain values. Thus, it is considered that the human eye is not negatively affected if the luminance does not exceed  $10^4$ - $10^5$  candelas/m<sup>2</sup>. However, it is necessary to highlight the fact that the maximum intensity of light radiation that is considered not to exert a negative effect on the human eye is dependent on several factors. Such factors are the duration of exposure, the wavelength of the incident light radiation and individual sensitivity, which registers a variation between certain limits.

The maximum intensity of electric arc light radiation specific to electric arc welding processes is very high. It should be noted that this electric arc emits not only visible light radiation, but also *ultraviolet radiation* (harmful to the welder's skin and eyes) and *infrared radiation* (capable of producing burns and other effects of a thermal nature). The electric arc generated in welding processes is characterized by a luminance of  $10^6$ - $10^8$  candelas/m<sup>2</sup>, thus far exceeding the maximum value of light radiation that would not affect the human eye. To protect against light radiation, it is necessary to use welding masks, equipped with radiation

protection filters and respective protective clothing, designed to cover those areas of the body exposed to radiation, but also to the possible negative effects of contact with metallic material splashes melted.

Another important category of polluting factors are the toxic gases and vapors that are released from the arc welding process. Such gases are nitrogen oxides (represented by the formula  $\text{NO}_x$ , carbon monoxide (CO), ozone ( $\text{O}_3$ ), and phosgene ( $\text{COCl}_2$ ). It will find that the electric arc welding process not only produces gases but also contributes to the release and spread in the atmosphere of mixtures of metal particles and oxides in the form known as smoke, but also larger particles of metallic materials, which may contain toxic metals such as manganese, chromium, nickel, and lead.

The main effects of these polluting factors on the human being are eye and skin burns, severe lung damage and other various problems (difficulty breathing, bronchitis, asthma, chronic lung diseases), headaches, dizziness, irritations not only of eyes but also at the level of the nose and throat, poisoning, cancer, neurological conditions.

The intense noise generated by electric arc welding processes is also a polluting factor. As in the case of light radiation, the maximum value of the noise intensity, exceeding which exerts negative effects on humans, is influenced by the duration of exposure to the action of noise and, respectively, the frequency of the noise. In principle, it is considered that in the case of a noise intensity of up to 85 dB, the duration of exposure should not exceed 8 hours per day, while at a noise intensity of 100-110 dB, the

duration of exposure will not be greater than 15 minutes/day.

Sound intensity values of 120 - 140 dB may correspond to the pain threshold and may result in immediate hearing loss. At values above 130 dB, hearing loss can be instantaneous and permanent, and exceeding 140 dB can lead to eardrum rupture and severe damage to inner ear components. To combat the harmful effects of the noise generated during electric arc welding, it is recommended to use protective means such as earplugs and headphones, reduce the duration of exposure to intense noise, and monitor and implement noise control measures.

In Figure 1, the factors or groups of factors capable of leading to negative effects of the electric arc welding process on the human being or the environment can be observed.

Providing some means to combat the polluting effects of the electric arc welding process is not possible without costs which, in certain situations, can be quite high. This fact cannot, however, lead to not paying enough attention to the available possibilities to combat the action of polluting factors.

### 3. SYSTEMIC ANALYSIS OF THE POLLUTION PROCESS GENERATED DURING ELECTRIC ARC WELDING

Systemic analysis is an analysis method based on the consideration of the investigated process or assembly as a system, which therefore presents several input factors and, respectively, output parameters, whose values are affected by the values of the input factors and of the correlations that exist between the input factors and the output parameters [8, 9].

There is, on the other hand, the concept of a *systemic approach*, whereby: a) the components of the system are considered as subsystems that interact with each other; b) the investigated system is in an environment with which it can interact; c) there is information about the dynamics of processes or phenomena in the system. It can be observed, as it was otherwise and expected the existence of some common aspects between the systemic analysis method and the systemic approach of an object or a process.

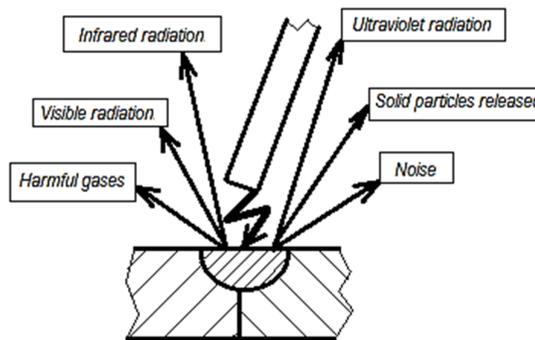


Fig. 1. Polluting factors in electric arc welding.

In essence, the steps to be followed in the case of applying the systemic analysis method of a process or object are the following: 1. Analysis of available information; 2. Grouping and systematization of information; 3. Analysis of interactions; 4. Building a graphic representation that highlights the input factors and output parameters of the investigated system; 5. Analysis of interactions and possibly the formulation of quantitative relationships corresponding to the identified interactions; 6. The use of information accumulated by using the systemic analysis method to ensure the conditions for the output parameters to have values appreciated as optimal by the user of the analysis results.

Resorting to the use of some of the principles of applying the systemic analysis method in the case of the need to investigate polluting factors specific to the electric arc welding process, it is considered that the following can be considered as *output parameters* of this process: 1. The quantities of pollutions resulting from the process (solid particles, gases, radiation, sound emission); 2. Health of the human operator (welder); 3. The possible impact of other factors characterizing the environment.

The main factors and groups of factors capable of affecting the values of the output parameters of the electric arc welding process could be the following: 1. The nature,

dimensions, and condition of the materials involved in the welding process; 2. The type of welding equipment used and the values of the parameters of the welding process; 3. The human operator, through the set of knowledge at his disposal and his level of conscientiousness; 4. The conditions in the space where the electric arc welding process takes place; 5. The existence of means to reduce or eliminate the polluting effects of the electric arc welding process.

It is necessary to note that, apart from the input factors in the electric arc welding process whose values can be set and tracked by the human operator, there may also be *disturbing factors*, which can exert influence on the values of the output parameters, but whose values cannot be controlled by the operator involved in the materialization of a welding process. It is thus considered that disturbing factors specific to the welding process could be the uncontrolled variation of the composition of the materials used in the process, some of the parameters of the welding process, the level of fatigue of the welder, etc. A graphical representation of the modeling of the pollution process when using electric arc welding using systemic analysis can be seen in Figure 2.

#### 4. WEIGHTING THE OUTPUT PARAMETERS OF THE POLLUTION PROCESS IN ELECTRIC ARC WELDING

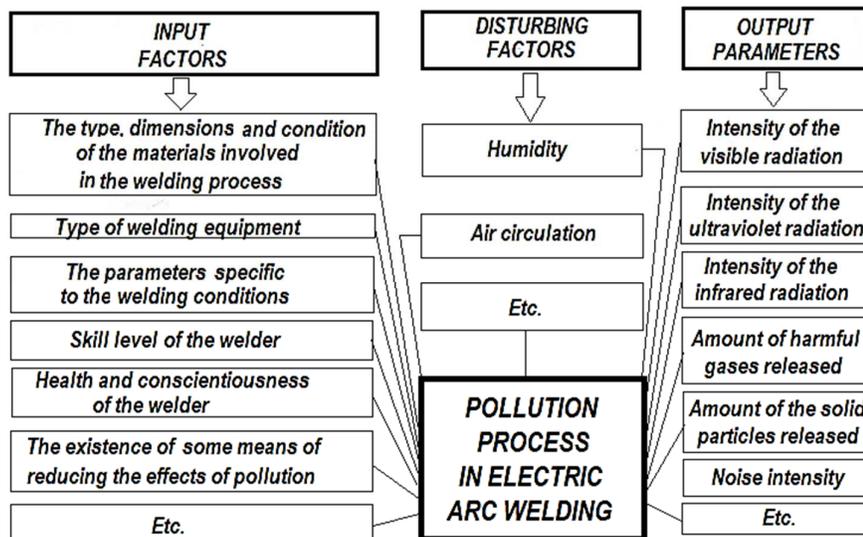


Fig. 2. Graphic representation of the use of the systemic analysis method in the case of the pollution process specific to electric arc welding.

It is considered necessary to apply measures to combat the effects of polluting agents in the case of a manufacturing process such as the electric arc welding process. The action of analyzing the effects of the polluting agents is necessary because it is considered that there is an accessible financial resource and it is desired that its allocation considers the importance of the results of the pollution. For ordering several quantities by considering their importance from one or more points of view, numerous methods are known, usually approached under the name of *decision methods*. A first classification of these methods can be carried out if the application of one or more criteria to evaluate the alternatives identified for solving a certain problem is considered. Monocriteria decision methods and multicriteria decision methods, respectively, appeared in this way. From the group of multicriteria decision methods, it can mention the imposed decision method (promoted by Professor Vitalie Belous and some of his collaborators), the analytic hierarchy process, the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), the data envelopment analysis (DEA) digraph-based approach, preference ranking organization method for enrichment evaluation (PROMETHEE), a group of methods from value analysis, etc.

Many of the mentioned methods and in fact, other methods of selecting a solution from several available solutions consider giving weights to the solutions identified by using criteria of interest for the investigated activities. The finding is valid for methods such as the imposed decision technique [10], the method of the analytic hierarchy process [11], and the rank correlation method [12]. Ordering the solutions involves going through several stages and sometimes even repeating some stages, as is the case with the rank correlation method [12].

For reasons related to the operativeness of the application, in the case addressed (the need to compare the effects of the polluting factors identified in the case of electric arc welding), the use of so-called *double-entry matrix method* will be preferred for this purpose. Compared to the previously mentioned ordering methods, the

double-entry matrix method involves a smaller number of steps and calculations. In principle, such a double-entry matrix can take the form of a table in which the quantities to be compared are written along the first line and the first column. In the case of the need to order the output parameters corresponding to the effects of the polluting factors of the electric arc welding processes, these parameters will be written along the first line and the first column of the double-entry matrix. In the next stage, the pollution parameters are compared two by two, giving marks of type 1-0, when the first of the parameters is appreciated as more important than the second, 0.5-0.5 when the two factors are of approximately equal importance and respectively 0-1 when the second parameter is considered more important than the first. A subsequent line of the table which, according to what has been shown so far, will comprise the same number of lines and columns (thus corresponding to a square matrix) will include a sum of the values given to each alternative along the vertical columns.

A value considered in the case of many of the methods of ordering several alternatives available to solve a problem is a *coefficient of relative importance*, determined by relating the sum of the marks given to each alternative to the number of comparisons made to complete the square matrix.

The values of the coefficient of importance of each alternative (in the present case, of each polluting effect) will be entered in the line following the one that includes the sums of marks awarded to each alternative mentioned in the table. The last line of the table could include the ranking places of each alternative, places established by analyzing the values of the importance coefficients. By applying the previous considerations for the set of polluting effects specific to the electric arc welding process, the information contained in Table 1 arrived at.

Some aspects likely to highlight the negative effects of the polluting factors considered in Table 1 are briefly mentioned next [1-6, 13]. Thus. If inhaled, the gases released in the welding process can cause lung disease and cancer to the human operator. Ultraviolet

radiation that occurs when applying electric arc welding procedures is also considered a carcinogenic source. Shielding gases are used to protect the weld material from the corrosive action of atmospheric oxygen and water vapor. At the same time, protective gazelles can cause breathing problems and even suffocation when inhaled in large quantities.

The optical radiation specific to the arc welding workplace is very intense and this makes it necessary to use some means to reduce its effects on the human operator and the surrounding environment. Since the intense optical radiation is specific to the electric arc welding process, screens, and welding masks are used to protect the human operator, the glasses are chosen so that the intensity of the light radiation reaching the retina has values at most equal to the allowed values of radiation intensity. Regarding the protection of the environment and therefore also of some people who would be near a workplace where an electric arc welding process takes place, it is necessary, of course, when the available space allows, the placement of some panels' protection. It is also necessary to place some panels to notify people in the vicinity of the workplace about the need to protect against the effects of very intense optical radiation specific to electric arc welding.

Optical radiation is also responsible for the possible appearance of some negative effects, such as eye injuries, ocular melanoma, etc.

An additional risk can be represented by the presence of solid or liquid materials at high temperatures in the work area. Contact with such materials can cause skin burns to the human operator and to avoid such situations, the welder must have appropriate professional knowledge and be equipped with appropriate protective equipment. The noise generated by electric arc welding processes and some operations related to them (cutting blanks, polishing or other methods intended to reduce the heights of surface asperities or burs, drilling, etc.) can adversely affect the hearing status of the human operator. Examination of the information included in Table 1 shows that the proposed order for the effects of the polluting factors is as follows: 1. Amount of the harmful gases; 2. Intensity of the visible radiation; 3. Intensity of the infrared radiation; 4-6. Intensity of the ultraviolet radiation; 4-6. The quantity of solid particles released; 4-6. Noise intensity.

It is necessary to underline the fact that even in the case of the double-entry matrix, but also in the case of using other methods of ordering several alternatives, there is the assumption of a certain subjectivity in the assignment of marks (appreciations) when comparing the alternatives two by two. Overall, however, the use of the

*Table 1*

**The use of the double-entry matrix for ordering the polluting factors in the case of electric arc welding.**

<b>Output parameters</b>	<b>Intensity of the visible radiation</b>	<b>Intensity of the ultraviolet radiation</b>	<b>Intensity of the infrared radiation</b>	<b>Amount of the harmful gases</b>	<b>Amount of the solid particles released</b>	<b>Noise intensity</b>
The intensity of the visible radiation	X	0	0	1	0.5	0
The intensity of the ultraviolet radiation	1.0	X	0.5	1	0.5	0.5
The intensity of the infrared radiation	1.0	0.5	X	1	0	0.5
Amount of harmful gases released	0	0	0	X	0	0
Amount of the solid particles released	0.5	0.5	1	1	X	0.5
Noise intensity	1.0	0.5	0.5	1	0.5	X
Sum of marks	3.5	1.5	2.0	5	1.5	1.5
Coefficient of importance	0.23	0.1	0.13	0.33	0.1	0.1
Order	2	4-6	3	1	4-6	4-6

double-entry matrix method allows the reasoned identification of a certain order of the alternatives considered.

It may be considered, therefore, that when the financial resource is allocated to combat the action of each of the polluting effects, to allocate, following the values of the importance coefficients and the analysis carried out, 33 % to combat the effects of the harmful gases released, 23 % for combating the effects of visible radiation, 13 % for combating the effects of infrared radiation and 10% each for combating the effects of ultraviolet radiation, the effects due to released solid particles and, respectively, combating the noise generated during electric arc welding.

A problem following the completed stage will be the actual identification of solutions offered by different manufacturers, solutions that fit within the predetermined financial allocation. It is an important responsibility of the coordinators of spaces where electric arc welding processes are carried out to take all possible measures to protect the human operator and the environment against the negative effects of electric arc welding processes or to find other technological solutions to obtain results like those of electric arc welding, but with smaller or even non-existent negative effects.

## 5. CONCLUSIONS

The problem of combating the polluting effects generated by the application of certain manufacturing processes is part of the environmental protection concerns. In the research whose results are presented in this paper, the need for a reasonable allocation of an available financial resource to counteract the specific pollution effects of electric arc welding was considered. The study of specialized literature confirmed the interest given by some researchers in combating the polluting effects in the case of electric arc welding. A preliminary analysis of such a manufacturing process highlighted the existence of several factors generating polluting effects. The use of the systemic analysis method led to some clarifications regarding the polluting effects of some factors that act during electric arc welding

processes. To order these polluting effects, the double-entry matrix method was used. In this way, it was found that the most important polluting effect is the quantity of harmful gases released, followed by the intensity of visible radiation. The allocation of an available financial resource to combat the polluting effects generated by the electric arc welding process could be done by considering the percentage weights established for each effect based on the results obtained by applying the double-entry matrix method. Next, an even more detailed analysis of the factors likely to generate polluting effects during electric arc welding is planned, as well as the identification of proper solutions to counteract these effects.

## 6. REFERENCES

- [1] Mistodie, L.R., Rusu, C.C., *Arc welding workspace risk factors evaluation and monitoring*, The Annals of "Dunărea de Jos" University of Galați, Fascicle V, Technologies in Mechanical Engineering, ISSN 1221-4566, pp. 85- 92, 2007.
- [2] Amza, G., Cicic, D.-T., Rontescu, C., Apostolescu, Z., Pică, D., *Theoretical and experimental research on the environmental impact of certain welding processes*, Proceedings of the 4th IASME/WSEAS international conference on Energy & environment, 60-65, 2009.
- [3] Amza, G., Rontescu, C., Cicic, D.-T., Apostolescu, Z., Pică, D., *Research on environmental pollution when using shielded metal arc welding (SMAW)*, U.P.B. Scientific Bulletin, Series D, ISSN 1454-2358 72(3), pp. 73-88, 2010.
- [4] Amza G., Dobrotă D., Groza Dragomir M., Paise S., Apostolescu Z., *Research on environmental impact assessment of flame oxyacetylene welding processes*, Metalurgija, ISSN 0543-5846, 52, 4, pp. 457-460, 2013.
- [5] Kumar, P., Mistry, J. *Impact of welding processes on environment and health*, International Journal of Advanced Research in Mechanical Engineering & Technology, ISSN 0976-6340, 1(1), pp. 17-20, 2015.
- [6] Mgonja, C.T., *The effects of arc welding hazards to welders and people surrounding*

- the welding area*, International Journal of Mechanical Engineering and Technology (IJMET), ISSN 0976-6340, 8, 3, pp. 433-431, 2017.
- [7] Red-D-Arc, *The environmental impact: sustainable welding practices in industry*, <https://blog.red-d-arc.com/welding/environmental-sustainable-welding-practices/>, accessed: 12.07.2024.
- [8] Băloiu, L.M., Frăsineanu, I., *Management of innovation* (in Romanian), Economical Publishing House, Bucharest, 2001.
- [9] Slătineanu, L., *Fundamentals of scientific research*, PIM Publishing House, ISBN 978-606-13-4903-6, Iași – Romania, 2020.
- [10] Belous, V., *The technical creation in machine manufacturing. Inventics* (in Romanian), Technical Publishing House, Iași, 1986.
- [11] Teknomo, K., *Revoledu, Analytic Hierarchy Process*, 2016, <http://people.revoledu.com/kardi/tutorial/AHP/AHP.htm>, accessed: 17.04.2017.
- [12] Nichici, Al., Cicală, E., Mee, R., *Prelucrarea datelor experimentale. Curs și aplicații*. Timișoara: Universitatea „Politehnica”, Centrul de multiplicare, 1996.
- [13] *What are the welding hazards and what are the requirements for protection?* (in Romanian) 2021, <https://ro.geaglesafety.com/news/news-50680448.html>, accessed: 9.09.2024.

### Factori poluanți la sudarea cu arc electric

Sudarea cu arc electric este un proces de fabricație care implică existența mai multor factori cu efecte nefavorabile asupra mediului înconjurător. O analiză a procesului de sudare cu arc electric a permis o anumită clarificare a efectelor factorilor poluanți specifici acestui proces. Prin utilizarea metodei analizei sistemice, au fost evidențiate efectele poluante generate de procesul de sudare cu arc electric. Luând în considerare necesitatea unei alocări pe cât posibil argumentate a unei resurse financiare disponibile pentru combaterea efectelor poluante, a fost utilizată metoda matricei cu dublă intrare. În acest fel, a devenit posibilă o ordonare justificată a efectelor poluante. S-a constatat că efectul poluant cel mai intens este determinat de către cantitatea de gaze eliberate, urmat de radiația vizibilă.

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