MINISTRY OF EDUCATION
National University for Science and Technology
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DOCTORAL THESIS

RESEARCH ON IMPROVING OCCUPATIONAL SAFETY AND HEALTH IN ORDER TO MINIMIZE THE EFFECTS OF POLLUTANTS WHEN WELDING IN PROTECTIVE GAS ENVIRONMENTS

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- 2023 –

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SUMMARY
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Author: Alina N. FĂTU (TRIFU)

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- 2023 -

Table of contents

Foreword

The current research and development in the field of welding engineering, which proposes a new economic vision, having as thematic priority the stimulation of a more effective economy from the point of view of the use of natural resources, more ecological and more competitive, as well as the community strategy regarding health and safety at work which aims at "the continuous, sustainable and unitary reduction of work accidents and occupational diseases" represents the basic argument and orientation of the doctoral studies, realized through this doctoral thesis.

The doctoral program included the preparation, presentation and support of exams and scientific reports, deepening the research, proposing and developing solutions and methods for assessing the risks of occupational injury and illness for welding operators, designing specific measures and means to warn of possible irregularities within the work system, the design and realization of an air ventilation system in a welding workshop corresponding to the requirements of occupational safety and health, the execution of activities related to research-development-innovation, the writing and publication of scientific articles, as well as the elaboration of this doctoral thesis regarding the improvement of safety and health at work in order to minimize the effects of noxes when welding in protective gas environments.

I express my full gratitude and deep appreciation to the scientific supervisor, Prof. Univ. Dr. Eng. Oana - Roxana CHIVU, renowned specialist and scientist with high moral standing, who, through permanent support and effective guidance, guided my conceptions and efforts, supporting me to complete this thesis.

I extend my warm thanks to the teaching staff of the ICTI Department for the guidance and valuable recommendations provided.

Thanks to my mother, sister and daughter Diana for their support.

Alina N. FĂTU (TRIFU)

Introduction

The modern development of all industrial fields, such as machine constructions, metal constructions, shipbuilding, electrotechnics, aeronautics, became possible thanks to the evolution of welding processes and welding-related procedures, with the help of which the joining of various machine parts and assemblies can be performed.
The elements that led to the application of welding processes on an increasingly large scale are: making welded joints with superior mechanical properties to the base metal; material economy; reducing the amount of work; superior tightness of welded seams in the case of installations, tanks and pipes for fluids; increased productivity, accompanied by a reduction in the respective construction costs, etc.
By welding, metal constructions can be easily transformed or improved even during execution, welded assemblies can be easily repaired. The increasing use of high-strength steels and alloys has made it possible to achieve, for the same operating conditions, or even more severe, lighter constructions at a lower price. Especially in the field of spacecraft, progress would not have been possible without the use of shielded gas welding, as high-strength metals and alloys can now be joined in very high or very low temperature environments. Constructions that work in corrosive or intensive wear environments, as well as constructions exposed to important variable demands, can also be made by welding.
The progress recorded in the last 10 years of welding, as a technological method of non-dismantling joining of metals, is inseparably linked to the evolution of welding techniques in a protective gas environment in general and to MIG-MAG welding in particular. The research carried out in intensively industrialized countries such as the USA, Japan or the European Community, regarding the rate of development of electric arc welding technologies in recent years and the importance of these processes, proves beyond a doubt that welding in a protective gas environment with MIG-MAG fusible electrode is the process with the most impressive evolution, respectively with the greatest extent of use at the present time (table 1).

Table 1. Dynamics of fusion welding processes worldwide

Country	Welding process			Year
	SE (%)	**MIG/MAG (%)**	SF (%)	
CE	58	32	10	2000
	21	**71**	8	**2020**
SUA	52	40	8	2000
	31	**62**	7	**2020**
Japan	67	18	15	2000
	19	**74**	7	**2020**

Considering the evolution of welding processes over the last 10 years in industrialized countries, as well as the information of the IIW (International Institute of Welding) and that of the European Profile Federation (EWF), welded joints are currently evolving at a high rate, which few industrial branches I can match. This development is also true for Romania, until the end of this decade, in our country the technological level in the field of welding engineering must increase to the equivalent of advanced countries. This determines the existence of several laser cutting installations, robotic systems for welding, but also high-performance materials for welding, cheaper and good quality shielding gases. Also, Romania is engaged in changing the image of welding engineering, from the current "3 D" (Dirty, Dusty and Dangerous = dirty, dusty, dangerous) to the future "3 C" (Cool, Clean and Clever =

pleasant, clean and smart), just as it is currently happening all over the world with the Welding Associations and Federations.

In the conditions of the continuous progress registered by the main technological fields of European research, which aim at the design and implementation of ecological manufacturing technologies, advanced materials, the reorganization and modernization of traditional industrial sectors, in order to comply with current community requirements regarding occupational safety and health, as well as environmental protection , the measurement of the noxes resulting from the welding processes is of great importance.

The obligation to reduce the concentration of certain harmful substances in the breathable air at the workplace, as well as in the section where the industrial activities of obtaining metal assemblies of welded structures, of various parts joined by welding, are carried out, raises the issue of analyzing toxic gas emissions in the actual conditions of use of certain welding technologies, in order to invent technical procedures to reduce these emissions, as well as the capabilities to introduce these measures in the execution of industrial production, in accordance with the requirements of the Occupational Safety and Health Law [L19].

Simultaneously with the measures to protect the health of welding operators, there should be environmental protection solutions, by reducing the release into the environment of harmful substances emitted during welding processes.

The Law on Occupational Safety and Health [L19], establishes the means by which the provisions for ensuring occupational safety and occupational health of workers are applied in all fields of activity, there being documentation drawn up by occupational health institutions, respectively by environmental protection agencies , in which the admissible thresholds of time-averaged exposure to the effect of these harmful substances are provided.

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In this situation, this doctoral thesis proposes to carry out assessments and determinations of noxious emissions, resulting from welding processes in a protective gas environment, the development of solutions and methods for assessing the risks of occupational injury and illness for welding operators, the design of specific measures and means to warn about possible inconsistencies within the labor system.

* * *

The doctoral thesis is configured in two parts, part I "The current stage of theoretical and experimental research on nox emissions during welding in protective gas environments" includes 3 chapters, and part II entitled "Contributions to improving safety and health in work in order to minimize the effects of noxes when welding in protective gas environments" includes 5 chapters, the content of which is briefly presented in the following.

Chapter 1 "The current state of theoretical and experimental research on occupational safety and health related to welding fume emissions" presents the PRISMA methodology, a standardized methodology that helps ensure that the review and meta-analysis process is rigorous and objective. The search strategy focused on three key areas: mode of formation and composition of noxes, adverse health effects of welders, methods of prevention and protection.

Chapter 2 "Study on the generation of noxes in welding processes in a protective gas environment and the effects on the safety and health of welders" presents general-introductory notions about welding in protective gas environments, the main gases resulting from welding

technologies, documentary research on training and the composition of the noxes, their effects on the safety and health of welders, as well as technical means of protection.
Chapter 3 presents the conclusions drawn from the analysis of the current state of research on welding noxious emissions and the effects on occupational safety and health.
Chapter 4 describes the guidelines, the main objective and the research and development methods for improving safety and health at work in order to minimize the effects of noxious welding in protective gas environments.
Chapter 5 "Contributions regarding the improvement of working conditions for the welding job" presents the injury and occupational disease risk assessment sheet for the welding job and the proposed prevention and protection measures.
Chapter 6 "Contributions regarding the measurement and reduction of noxious emissions generated in the welding process" presents the emission measurement systems and the measurements made for the welder's workplace. The design and construction of an air ventilation system necessary for the evacuation of emissions from a welding workshop is described and then the re-measurement of gas emissions from the metal fabrication workshop where the ventilation system designed and built for this purpose was installed.
In chapter 7 "Experimental research and development of the Occupational Safety and Health Decision Support System", the author creates a decision support system aimed at OSH managers and workers in SMEs where welding activities are carried out, to help them identify the risks, know what measures need to be taken, what the legislation requires and how to train their workers. The system was designed in a multi-layer structure, to adapt to the support requirements of the decision makers.
In the last chapter of the thesis, entitled "Final conclusions and main contributions regarding the improvement of safety and health at work in order to minimize the effects of noxious welding in protective gas environments" the final conclusions of the specific research are presented, personal contributions are summarized, the original elements brought through this thesis in the field of safety and health at work and the perspectives and directions of further development are presented.

Chapter 1. The current stage of theoretical and experimental research on occupational safety and health related to welding noxious emissions

1.1. PRISMA methodology – description

Examining the specialized bibliography is an important part of a scientific research study. A special attention, in the writing of an academic research, is placed on the development of a new idea that requires the study of specialized literature in the field, being the most thorough recording of the level of skill and coverage of the scientific sector treated in national and international articles. In the elaboration of my doctoral thesis I used the specialized literature both as a basis and as a support for the development of a new perspective. Thus, the basic objective of the bibliographic analysis was to recapitulate and synthesize the reasoning and observations of the other researchers, without introducing new considerations, but with the possibility of formulating own concepts for and against the information acquired through documentation [A05].

1.4. Data extraction and analysis

Studies were assessed by checking the title, abstract and full text against the inclusion and exclusion criteria. For articles excluded during full-text screening, reasons for exclusion were documented. As the research question was quite broad, all potentially relevant information was extracted and summarized. Studies were sorted by content based on implementation process and survey instruments. General information about the articles (eg authors, year, title, country) was documented and the authors' key conclusions were also extracted.

1.6. Conclusions

Following the bibliographic study, the following conclusions can be drawn/ the following aspects were noted:

- Occupational disease is a "pathological state of an organ that intervenes as a result of performing a job or an occupation and is caused by toxic, physical, chemical or biological factors, specific to the workplace, as well as by the overloading of various organs or devices of the human body in the performance of work activities". It is accepted as occupational diseases and diseases that can be acquired by pupils, students and apprentices during the performance of practical activities when the exposures to danger are insufficiently checked.
- Occupational exposure to various hazardous substances can also favor the occurrence of common diseases with increasing frequency: hypertension, ischemic heart disease, chronic bronchitis, musculoskeletal disorders and behavioral disorders. To differentiate them from occupational diseases, as suggested by the WHO expert group, the above-mentioned diseases have been referred to in a specific occupational context under the term "occupational diseases".
- The duality of pathological consequences, following exposure to a certain toxic substance, is related to the magnitude of the risk, which, in turn, depends on the concentration of the respective toxic substance or the degree of overwork and the exposure time. At strong or very strong concentrations, the dangerous substance manifests a specific and decisive effect, which will lead to the appearance of occupational diseases. At medium concentrations and a long-term exposure, the effects become undefined and are located in the sphere of diseases with a wide spread, the harmful agent being considered in the complex of etiological factors.

The fundamental conclusion that emerged from the bibliographic analysis carried out was that it has not yet been clearly proven that the gases released during welding operations are the reason for the production of lung cancer among welders, but the explanation of the risk of lung cancer is often complicated because there are significant doubts in most research.

Chapter 2. Study on the generation of noxes in welding processes in a protective gas environment and the effects on the safety and health of welders

2.1. Introduction

Among the fields with high rates of development, strongly involved in modern industry, welding occupies a leading place due to the advantages it offers in the creation of highly complex products.

In our country, as in the world, welding technologies occupy an increasingly high percentage in the industry, over 50% of the volume of rolled steel semi-finished products being intended to obtain welded structures and assemblies for different economic sectors. The achievements of high-capacity technological machines in fields such as the chemical, petroleum, metallurgical, shipbuilding, aeronautical and aerospace industries, fine mechanical elements and equipment, electronic and microelectronic products and many others are remarkable.

2.2. The current state of theoretical and experimental research on the formation and composition of noxes

Due to the high energy applied during the welding process, fumes are formed when the base and weld metals vaporize and condense into particles in the air. Welding fumes are a complex mixture that can contain a number of hazardous metals and other particulate species table 2.3.

Table 2.3. Noxes emitted during welding

The noxes emitted during welding consist of:	
Particles of metals, non-metals and certain substances with harmful or dangerous effects, potential or actual, contained in welding fumes	Toxic or dangerous gases emitted by the welding process, caused by the thermal effect and certain chemical reactions that take place in the welding process, as its side effects

Welding fumes are an important topic that has been studied extensively over many years, and public awareness of the dangers of fumes from arc welding processes has increased significantly recently. The basic mechanism of welding fume generation is believed to be the vaporization of elements and oxides in the weld zone where the electrode is consumed, with the vapor rapidly condensing to form particles [F04].

The rate of smoke formation and its chemical composition are influenced by specific parameters of the welding regime and the type of method. The most significant factors, whose existence has been demonstrated to have an impact on the fume formation rate, as well as on the chemical composition of the smoke, are presented in fig. 2.8.

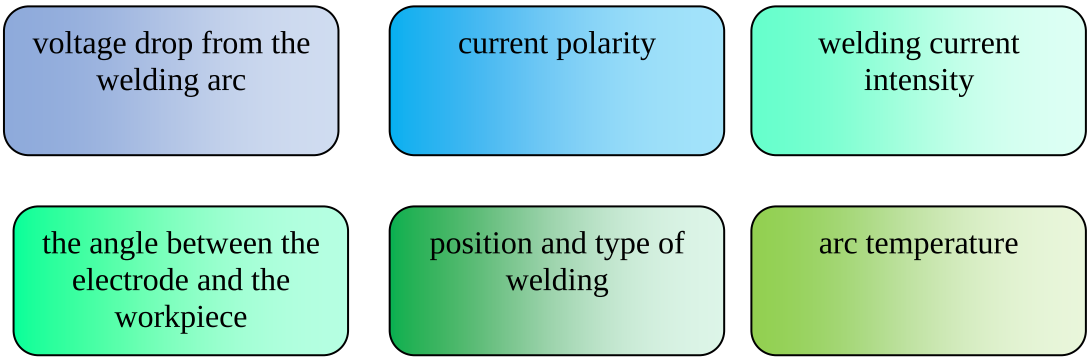


Fig. 2.8. Factors influencing the formation of fume

At higher voltages, the FFRs were slightly lower. In general, compared to the results for a 12% CO_2 argon shielding gas, the FFRs for 18% CO_2 argon were higher, as shown in Figure 2.13.

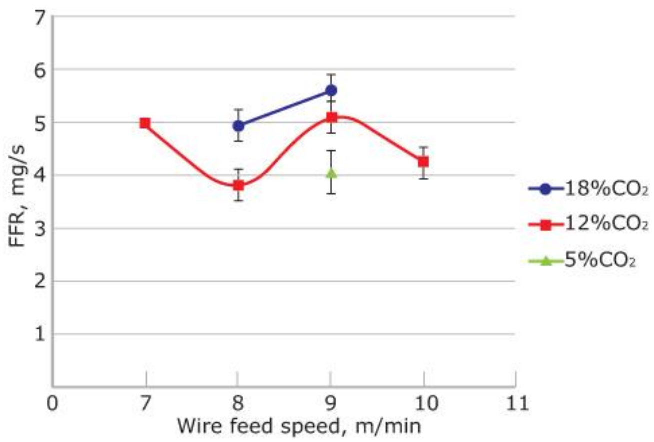


Fig. 2.13. Average fume formation rate (FFR) for various shielding gases [M03].

2.3 Current status regarding the effects of noxes on the safety and health of welders

Welding is an essential component in many industrial applications, but unfortunately welding has its negative effects in terms of health hazards for the working personnel. There are about 1 million welders worldwide [A01], these welders are exposed to harmful agents, generated by various welding processes, which can be carried into the inner parts of the lungs and other parts of the body and can lead to adverse effects on health, as can be seen in table 2.6.

Table 2.6. Source of welding gases and health effects [W05]

The type of gas	Source	Effects on health
Carbon monoxide	Formed in arc	It is easily absorbed into the bloodstream, causing headaches, dizziness or muscle weakness. High concentrations can lead to unconsciousness and death
Nitrogen oxides	Formed in arc	Eye, nose and throat irritation in low concentrations. Abnormal fluid in the lung and other serious effects at higher concentrations. Chronic effects include lung problems such as emphysema.
Oxygen deficiency	Welding in confined spaces and displacement of air by shielding gas	Dizziness, mental confusion, suffocation and death
Ozone	Formed in the welding arc, especially during plasma arc, MIG and TIG processes	Acute effects include fluid in the lungs and hemorrhage. Very low concentrations (eg one part per million) cause headaches and dry eyes. Chronic effects include significant changes in lung function.

2.4 The current status of measures to prevent and protect against welding noxes

To combat the large number of very different occupational risks, researchers, technicians and practitioners have developed an even greater number of preventive and control measures. This means that employers need guidance to choose the most effective measure. To facilitate this, the measures are classified, for example, as elimination measures, technical measures, organizational measures, and these types are put in hierarchical order figure 2.15. The highest level is seen as the most effective in terms of combating risks. Lower levels should only be applied if higher level measures are not available or if application would be disproportionate to the effort and achievable result. In most cases, a package of measures should be applied, whereby individual measures could be assigned to different hierarchical levels.

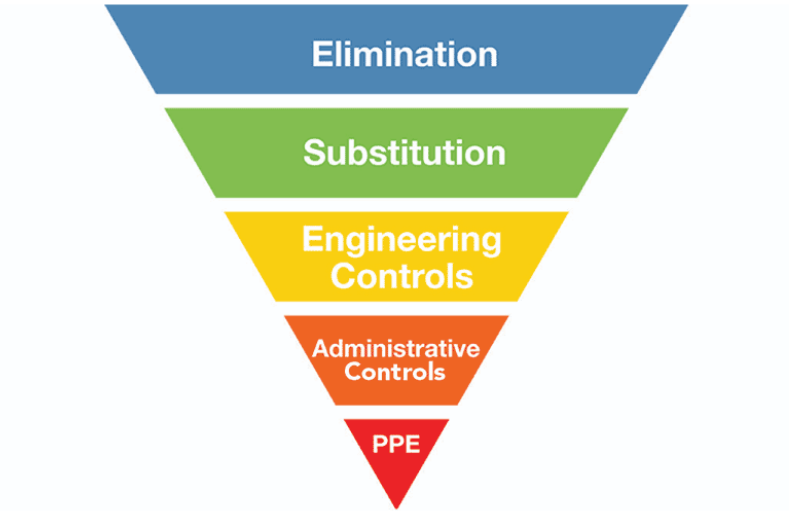


Fig. 2.15. The pyramid of prevention and control measures

2.4.2. Technical means of protection

Ventilation systems such as general ventilation, local exhaust ventilation (LEV) and mechanical ventilation could provide a significant reduction in exposure to noxious fumes when used correctly. Among these, the use of LEV as the primary engineering control for welding fume is well established. LEVs have the ability to not only remove the fraction of contaminants that reach the welder's breathing zone, but also provide a clean airflow when needed.

Ventilation can be divided into "natural" and "technical".

As can be seen in figure 2.17, natural ventilation allows the exchange of air between the indoor and outdoor atmosphere, for example through temperature variation. Any natural supply or exhaust ventilation of a production unit works by using the difference in temperature and air pressure in the workshop and on the street. This means that the driving force of natural traction is wind and thermal pressure.

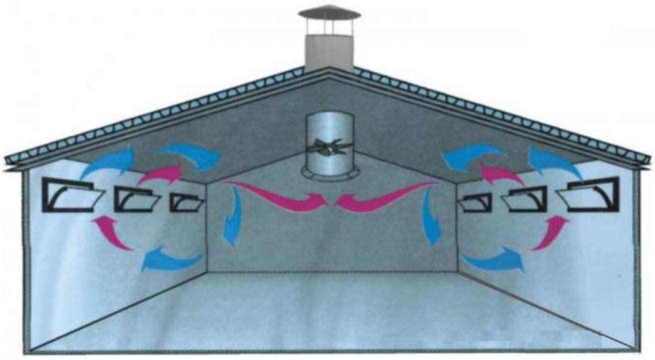


Fig. 2.17. Natural ventilation in industrial buildings [S05].

Hazardous substances as a by-product of welding processes, if unavoidable from a technical point of view, are recommended to be eliminated by: process modification, extraction at the point of origin, means of air conditioning [B03]. As explained in the previous sections, process modification appears to be technically feasible to some extent. However, since the complete suppression of smoke formation seems practically impossible, smoke extraction assumes the greatest importance.

Chapter 3. Conclusions regarding the current state of research on welding emissions and effects on occupational health and safety

Following the research-development study regarding the emissions of noxes when welding in a protective gas environment and the effects on the health and safety of workers, a series of important conclusions emerge, as follows.

1. The search strategy focused on three key areas: formation mode and composition of fumes, adverse health effects of welders, methods of prevention and protection.
2. The systematic literature search was performed in March 2019 and updated in August 2020, 2021 and 2022 using the following international databases: Web of Science (ISI), Elsevier/Scopus (BDI), Elsevier/Science Direct, Google Scholar. Thus, the literature search covers a wide field of research: specialized publications in the field of welding, medical publications, publications in the field of safety and health at work and occupational health. [G04], [H05] (see § 1.2)
3. Current research shows that welding technologies in a protective gas environment represent an important percentage in making high-quality metal element joints. (see § 1.4)
4. As mentioned before, we decided to use Scopus, Web of Science Core Collection and Google scholar. I also consulted the websites of the most prestigious national and international institutions. The graphs over the years show the growing interest in the issue of noxes, as can be seen from the figures below (see § 1.5.2).

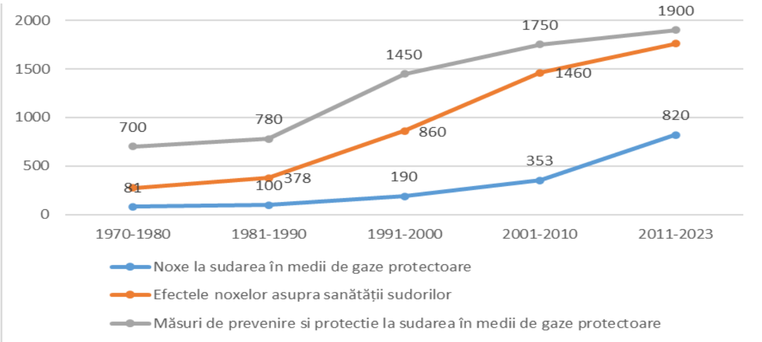


Fig. 3.1. Search results in the Google Scholar database

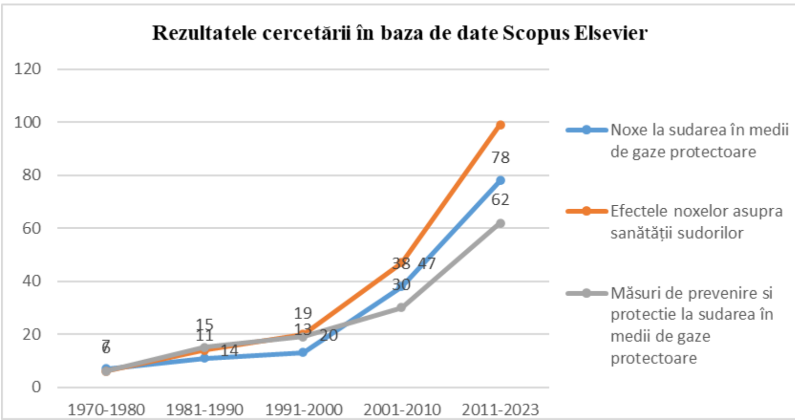


Fig. 3.2. Research results in the Scopus database.

5. The duality of the pathological effects associated with exposure to a certain nox is determined by the intensity of the risk, which depends on the concentration of the respective nox or the degree of overload, as well as the duration of exposure to work. At long-term exposure and at moderate concentrations, the effects become non-specific and

fall into the category of common conditions, nox being "numbered" among the many etiological factors (see § 1.5).

6. Little is currently known about the causes of lung inflammation caused by exposure to fumes from welding operations. Respiratory infections among welders have been shown to increase in severity, duration and frequency. The mortality rate from pneumonia was higher among welders, according to various studies (see § 1.6).
7. The welding operation in a protective gas environment can be classified as a dangerous job because:

Fig 3.3. The danger of the welding operation

8. Due to the high energy applied during the welding process, fumes are formed when the base and weld metals vaporize and condense into particles in the air. Welding fumes are a complex mixture that can contain a number of hazardous metals and other particulate species. (see § 2.2.).
9. The parameters of the welding regime and the type of application influence both the rate of smoke formation and its chemical composition. The most significant factors involved that influence the rate of smoke formation and its chemical composition are: arc temperature, current polarity, current intensity, angle between electrode and workpiece, position and type of welding (see § 2.2.).
10. It is generally accepted that FFR increases with welding current, but it has been confirmed that in the globular to spray transition range, a minimum occurs in FFR for an optimum voltage at a given wire feed speed. This minimum in FFR occurs for regular droplet transfer, without spatter and with the arc enveloping the droplets, resulting in low current density and relatively low droplet temperatures. (see § 2.2.).
11. Higher FFRs were observed for an increase or decrease in arc length with larger droplets and an increase in droplet transfer time or momentary contacts with the weld pool creating spatter, respectively.
12. A reduction in the carbon dioxide content of argon-based shielding gases results in a lower FFR, provided the optimum voltage is set. However, this reduction is quite small and will not be noticed unless the voltage is optimized. For argon shielding gas mixtures containing only 5% carbon dioxide, a low FFR is produced at high voltages from a wire-like vapor metal transfer condition. (see § 2.2.).
13. It was found that pulse welding produces the lowest FFR, by producing a droplet transfer condition similar to that obtained in the globular spray transfer region. (see § 2.2.).
14. Measuring and observing metal transfer modes provides insight into the causes of welding fume emission. Low smoke conditions are produced by a combination of parameters that can be understood by taking a full set of nox measurements. These measurements can be used to explain discrepancies in results obtained in other studies. (see § 2.2.).

15. Welding is an essential component in many industrial applications, but unfortunately welding has its negative effects in terms of health hazards for the working personnel. (see § 2.2.).
16. Exposure to welding fume (average PM2.5 concentration of 1.66 mg/m^3) was found to be responsible for inducing acute systemic inflammation in welders [K01]. In addition, chronic exposure to welding fumes is associated with a decline in lung function, and welders have an increased risk of chronic obstructive pulmonary disease (COPD), asthma, and chronic bronchitis [K02] [I01] [S02]. (see § 2.3.).
17. Toxic metals in welding fume particles are a problem for occupational safety and health. For example, Cr, the major component of stainless steel, will form hexavalent chromium (Cr6+) during the oxidation phase [M11], [M12]. Cr6+ is one of the most toxic and carcinogenic metals in welding fumes, with toxic effects manifested even at a minimal inhalation dose [G04], [B06], [U01], [H12]. Ni is a known human carcinogen, [14] and Mn can cause various neurological symptoms [E01], [C05], [D03], [W06]. (see § 2.3.).
18. A number of studies have measured the mass median aerodynamic diameter of most welding fumes to be in the fine particle size range of 0.20 to 0.50 µm [U01], [D03], [H13]. Most particles in this size range are deposited in the alveolar lung region, the deepest region of the lungs. (see § 2.3.).
19. The main hazard resulting from exposure to shielding gases is asphyxiation, which usually results from the accumulation of gases in confined spaces. The gases generated by the welding process in protective gas environments are: carbon monoxide, carbon dioxide, nitrogen monoxide, nitrogen dioxide, ozone, organic gases, solvent gases. (see § 2.3.).
20. After inhalation, nitrogen gases act more on the deeper respiratory tract than on the upper one (nose, trachea, large bronchi). The following symptoms are an indication of the primary stage of nitrogen gas poisoning: irritation of the eyes, nose and trachea, intensive coughing, shallow breathing, dizziness and headache, malaise and fatigue, exhaustion. (see § 2.3.).
21. There are numerous medical reports and case studies of upper respiratory tract symptoms, chronic bronchitis, asthma, hemoptysis, heart rate variability, basal cell carcinoma (BCC), etc., due to exposure to fumes and gases. welding. (see § 2.3.).
22. Hazardous substances as a by-product of welding processes, if unavoidable from a technical point of view, are recommended to be eliminated by: process modification, extraction at the point of origin, means of air conditioning [B03]. (see § 2.4.2.).
23. To combat the large number of very different occupational risks, researchers, technicians and practitioners have developed an even greater number of preventive and control measures. This means that employers need guidance to choose the most effective measure. To facilitate this, the measures are classified, for example, as elimination measures, technical measures, organizational measures, and these types are put in hierarchical order. The highest level is seen as the most effective in terms of combating risks. Lower levels should only be applied if higher level measures are not available or if application would be disproportionate to the effort and achievable result. In most cases, a package of measures should be applied, whereby individual measures could be assigned to different hierarchical levels.

24. The hierarchy of prevention and control measures, as presented both in the ISO 45001 standard [I02] and in the EU Framework Directive for health and safety at work 89/391 adopted in 1989 [E03] can be seen as a typical system:
- elimination of the danger;
- substitution with less dangerous materials, processes, operations or equipment;
- the use of technical prevention and control measures;
- the use of administrative prevention and control measures;

- providing and ensuring the use of appropriate personal protective equipment.

25. In Romania, in accordance with Law 319/2006 on safety and health at work, the employer must ensure that the risk due to exposure to welding noxes for the safety and health of workers is eliminated or reduced to a minimum. The following principles will apply, unless local regulations provide otherwise:
- Substitution/Replacement: the lowest emitting applicable process/feedstock combinations are selected whenever possible. Set the welding process with the lowest emission parameters (eg welding parameters/arc mode transfer, shielding gas composition).
- Technical prevention and control measures: apply the relevant collective protection measures (general ventilation, local exhaust ventilation).
- Organizational prevention and control measures: for example, limiting the time a worker is exposed to welding fumes. Welding procedure specifications are established and applied.
- Personal protective equipment: To protect the worker, personal protective equipment must be adequate, according to the work cycle.

26. For the application of the first principle, the development of protective materials and/or gases that lead to lower welding fume formation and emissions has been attempted. Both base metal and electrode composition were found to have a significant influence on the chemical composition of the smoke.

27. Another possible way to reduce smoke emissions is the correct choice of shielding gas mixtures. In 2006, Pires et al. [P01] reported that the shielding gas composition has a major influence on the mass and composition of the generated smoke. The authors found that the rate of smoke formation increased with increasing amount of CO2 in the shielding gas mixture and this was due to the higher oxidant content of the shielding gas mixture. In 2002, Dennis et al. demonstrated that a considerable reduction of hexavalent chromium in smoke was achieved by adding reducing agents such as NO or C2H4 as secondary shielding gas [DO2]. Thus, it was concluded that substantial smoke reduction can be achieved by lowering the percentage of CO2 and O2 in shielding gas mixtures or by using a suitable secondary shielding gas.

28. Rose emphasizes the importance of advanced MIG/MAG process variants to control droplet generation and detachment. A particularly accurate short-circuit treatment was found in the case of a bridge between the droplet and the weld pool, significantly reducing smoke formation and emission [R02]. This, in addition, can be improved by the application of shielding gases with low oxidation potential. Rose also points out that the mass-based approach to quantifying smoke emissions needs to be reconsidered because of nanoscale particle sizes, which are often not caught by smoke filters, yet lead to a greater potential health risk.

29. Regarding principle II, namely the application of technical measures of prevention and control, according to Spiegel-Ciobanu various technical measures and devices are applicable to reduce the operator's exposure to smoke [S05]. Ventilation systems such as general ventilation, local exhaust ventilation (LEV) and mechanical ventilation could provide a significant reduction in exposure to noxious fumes when used correctly. Among these, the use of LEV as the primary engineering control for welding fume is well established. LEVs have the ability to not only remove the fraction of contaminants that reach the welder's breathing zone, but also provide a clean airflow when needed.

30. Regardless of whether technical ventilation uses mechanical means such as fans or air blowers, both approaches are described as difficult to apply where consistency in reducing smoke exposure is required [S05]. Stationary exhaust equipment is stated to be the "most effective" way to capture hazardous substances directly after generation and emission [S05]. (see § 2.4.2.).

31. Technical ventilation systems are generally emphasized in regulatory requirements to protect welders and operators from fume exposure; in addition to these, personal protective equipment (PPE) is installed where technical ventilation fails or cannot be sufficiently supported in the work environment. (see § 2.4.3.).
32. A comprehensive review of local exhaust ventilation (LEV) based on experimental and field studies by Flynn and Susi shows that local exhaust ventilation is capable of reducing welding fume exposure rates by more than 40 -50% compared to natural ventilation given [F01]. (see § 2.4.3.). Stationary exhaust equipment is stated to be the "most effective" way to capture hazardous substances directly after generation and emission. In order to properly extract the noxes, the high efficiency of the device applied together with the transfer of the captured smoke to suitable filter materials is considered predominant [S05].
33. Hazardous substances as a by-product of welding processes, if unavoidable, are recommended to be eliminated by: process modification, extraction at the point of origin, means of air conditioning [B03]. As shown in previous chapters, process modification appears to be feasible to some extent. However, since the complete suppression of fume formation seems practically impossible, fume extraction assumes the greatest importance regarding the health and safety of welders.

Chapter 4. Directions, main objective and research-development methodology for improving safety and health at work in order to minimize the effects of noxious welding in protective gas environments

4.1. Research and development directions

Based on the results of the current analysis, it is considered that the following directions of research and development regarding the improvement of safety and health at work to reduce the impact of noxes when welding in protective gas environments are updated in fig.4.1.

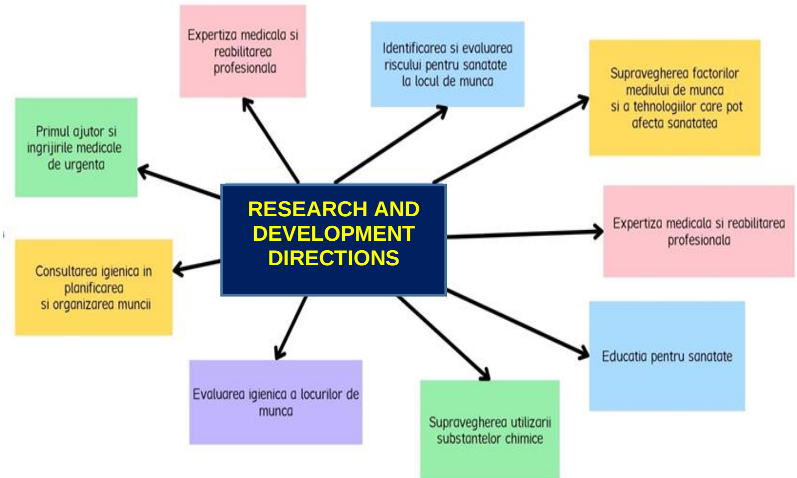


Fig. 4.1. The directions of research and development regarding the improvement of safety and health at work.

4.2. Obiectivul principal al activității de cercetare-dezvoltare

Taking into account the data, results and research-development directions regarding the improvement of safety and health at work in order to minimize the effects of noxes when welding in protective gas environments, it is established as the main objective of the doctoral activity: the assessment of the risks of occupational injury and illness for the welder

workplace in a protective gas environment and the implementation of measures to reduce the emissions of noxes generated in the welding process in order to improve safety and health at work.
The analysis of the research-development directions led to the establishment of the following specific objectives, in order to achieve the proposed main objective of the doctoral thesis:
- The use of the PRISMA methodology for the analysis of the current state of research on the emissions of noxes in the welding process in protective gas environments;
- Carrying out emission measurements for the welder's workplace;
- Designing and building an air ventilation system necessary to evacuate emissions from a welding workshop;
- Designing an IT system to assist the decision regarding safety and health at work SSAD-SSM;
- Applying the method of assessing the risks of occupational injury and illness for MEVARO-SUD welders;
- Application of the new method developed by MEVARO-SUD for hearing impaired welders.
- Establishing future directions for monitoring and reducing noxious emissions generated in the welding process in order to improve safety and health at work.

4.3. Research and development methodology

The main objective of the doctoral activity, as well as the future development, is achieved by respecting the research-development methodology specific to the field studied. The list of methodological elements used is presented below.

(1) Documentation

A thorough analysis of the current state of theoretical and experimental research on occupational safety and health related to welding noxious emissions was carried out, using the PRISMA methodology for systematic reviews [P03, P04]. It is a standardized methodology that helps to ensure that the review and meta-analysis process is rigorous and objective, it can be used not only to establish the current state in a given field but also to provide evidence-based recommendations for decision-making in all fields, for further policy development and research.
The search strategy focused on three key areas: mode of formation and composition of noxes, adverse health effects of welders, methods of prevention and protection [P03, P04].
The systematic literature search was performed in March 2019 and updated in August 2020, 2021 and 2022 using the following international databases: Web of Science (ISI), Elsevier/Scopus (BDI), Elsevier/Science Direct, Google Scholar. The literature analysis and search covered a wide field of research: specialized publications in the field of welding, medical publications, publications in the field of safety and health at work and occupational health.

(2) Establishment of the methodology

The research methodology is important to identify the way in which the chosen subject is to be treated, the use of the known theory and the achievement of the proposed objectives. It contains a set of techniques and methods by which the theoretical concepts are checked for the purpose of deepening, verifying the applicability, the development through new meanings, new utilities [B09].
Qualitative-quantitative research was used, necessary and essential for understanding the events, in order to highlight characteristics or behaviors specific to the analyzed field.

Quantitative research was conducted by collecting and processing data through experiments and observations. As a certain amount and volume of data is required for the processing and results to be relevant, this highlights some of the results of the data processing.
The research plan was drafted in such a way as to lead to the achievement of the objectives:

- Carrying out the bibliographic study
- Determination of the main factors in the generation of noxes in welding processes in a protective gas environment
- Determination of the factors that influence the formation and composition of welding smoke
- Analysis of the current state regarding the effects of noxes on the safety and health of welders
- Analysis of current measures for prevention and protection against welding noxes
- Assessing the risks of occupational injury and illness for the welder workplace
- Carrying out emission measurements for the welder's workplace
- Design and realization of an air ventilation system necessary for the evacuation of emissions
- Measurement of emissions from the welding workshop after installing the ventilation system designed and built
- Elaboration of the Support System for Decision Assistance regarding Safety and Health at Work
- Development and application of the method for assessing the risks of occupational injury and illness for welding activities in protected gas environments MEVARO-SUD
- Application of the MEVARO-SUD method for the hearing impaired welder
- Presentation of the conclusions resulting from the doctoral research activity, highlighting personal theoretical and practical contributions;
- Recommending some future research directions for improving safety and health at work in order to minimize the effects of noxious welding in protective gas environments

(3) Gathering and processing information obtained as a result of research

Data is collected from the following sources:

a) primary, collected by the doctoral student, using various techniques: experiment, interview, observations;
b) secondary, statistical data published by various bodies, which are processed to check the validity of the hypotheses.

Data collection, processing, analysis, presentation in the form of tables, diagrams, graphs, interpretation, gives more accuracy and rigor, helping to find the links between different variables of the studied processes.
The researches are based on theories, personal approaches of the author, interpretation, the formulation of some findings, the description of the case studies carried out, necessary when an extensive and in-depth analysis is desired of some situations encountered in the processes of emanating noxes during welding in protective gas environment.

(4) Interpretation of results

Through the analysis and interpretation of the collected data, the PhD student shows the relationships and processes that support the conclusions, looks for more extensive interpretations and formulates theoretical concepts regarding the improvement of safety and health at work in order to minimize the effects of noxious welding in protective gas environments.

The research carried out by the authors brings new elements, increasing knowledge regarding the current state of professional risk assessment methods in the field of welding processes, solving some problems related to the generation of noxes in welding processes in a protective gas environment and the effects on the safety and health of welders .

(5) Outline and communication of conclusions

In the last chapter of the thesis, the personal, theoretical and practical contributions are formulated, based on them, proposals are made for the practical use of the results in the field of occupational safety and health of welders, and the perspectives and directions for further development of research in the field are presented. The results of the scientific research resulting from this doctoral thesis were partially communicated within the framework of scientific events held in the country and abroad.

Chapter 5. Contributions regarding the improvement of working conditions for the welder workplace

In this chapter, the assessment of the risks of occupational injury and illness for the workplace "Welder" at the SUDEX SRL company was carried out, with the help of the INCDPM method, on which occasion we found that the method can be improved and we proposed a new method, called MEVARO-SUD .

For the workshop where the assessment was made and where an inefficiency of the ventilation system was found, we proposed, in order to improve the working conditions, the use of a hood. The technical documentation regarding the design, realization, installation of the hood and efficiency testing is detailed in the next chapter.

5.1. Assessment of occupational injury and disease risks for the welder workplace using the INCDPM method

The INCDPM method for risk assessment involves identifying all risk factors in the analyzed system and quantifying their dimensions using a combination of two parameters: severity and frequency of the maximum possible impact on the human body. Thus, the partial risk levels for each risk factor are established, and the global risk levels for the analyzed system as a whole are established. (job). The method was approved by the Ministry of Labor and Social Solidarity in 1996 and has been tested until now in most economic fields. The method provides an economic and social justification for managerial decisions regarding the order of taking preventive measures. This allows both an x-ray of the current situation at each workplace, highlighting acceptable and unacceptable risks, and the measures that need to be taken. The welder performs the work process of non-removable joining of metal parts by electric arc welding both in the workshop and in various places in the building.

The overall risk level of the workplace is calculated with the relation (5.1.), and the graphic representation of the partial risk levels is shown in figure 5.1.:

$$N_{rg1} = \frac{\sum_{i=1}^{41} R_i r_i}{\sum_{i=1}^{41} r_i} = \frac{0(7x7) + 0(6x6) + 1(5x5) + 10(4x4) + 30(3x3) + 0(2x2) + 0(1x1)}{0x7 + 0x6 + 1x5 + 10x4 + 30x3 + 0x2 + 0x1} = \frac{455}{135} = 3{,}37$$

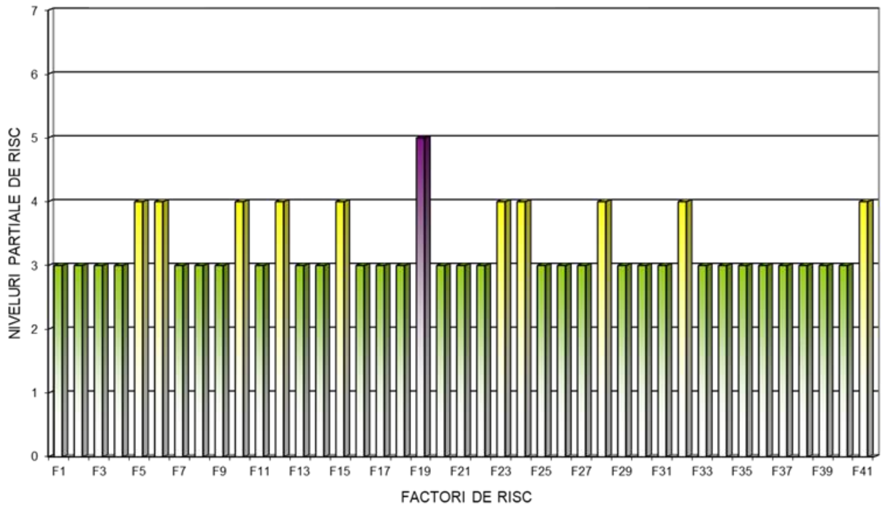


Fig. 5.1. The partial levels of risk

5.1.4. Interpretation of assessment results

In order to reduce/eliminate the 11 risk factors, located in the unacceptable group, the measures presented in the "Proposed measures sheet" for the welding workplace are formulated.

The dispersion of risk factors according to the elements of the work system is presented as follows (fig. 5.2.):

- 39.02%, factors specific to the means of production;
- 19.51%, factors specific to the work environment;
- 7.32%, factors specific to the workload;
- 34.15%, factors specific to the worker.

The analysis of the Evaluation Sheet indicates that 60.98% of the risk factors can have irreversible consequences on the worker (death or disability).

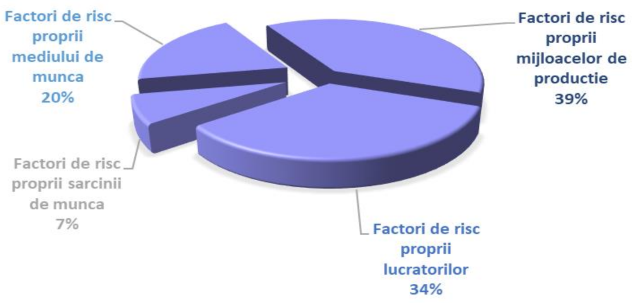


Fig. 5.2. The share of risk factors identified by the elements of the work system

5.2. The method of assessing the risks of occupational injury and illness for MEVARO-SUD welding activities

Description of the method

The proposed method aims at the quantitative calculation of the level of risk for a job/work station, section according to the assessment of the risks of occupational injury and illness. The job assessment sheet is a centralizing document that contains the overall job risk levels after the method is completed. The job sheet that was created in this way serves as the basis for the prevention program in occupational accidents and occupational diseases for the job, the workplace, the sector, the department.

The principle of the method

The method consists in identifying all the risk factors in the analyzed system (work station/job) using predefined checklists and calculating the risk based on the combination of the severity and the probability of the occurrence of the risk.

Potential users

This method can be used both in the design and construction phase and in the capitalization phase. However, its application requires mixed formations of people specialized both in workplace safety and in the analyzed processes (assessors and technologists).

In its early stages, the methodology is a useful and necessary tool to enable designers to integrate workplace safety principles and measures into the design and engineering of work systems. During the operation phase, this method is useful for the personnel of the company's occupational safety service to perform the following tasks: scientific analysis of the occupational safety situation in each workplace and rigorous justification of prevention programs

Work tools used

The necessary stages for the evaluation of work security in a system are described in fig 5.3.

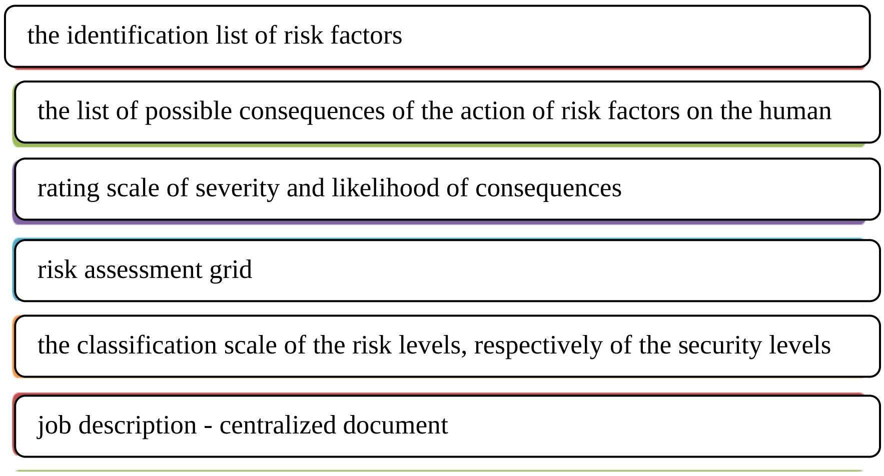


Fig. 5.3. Stages of performing the risk assessment

The logical scheme of the stages of the new designed method is presented in fig 5.5.

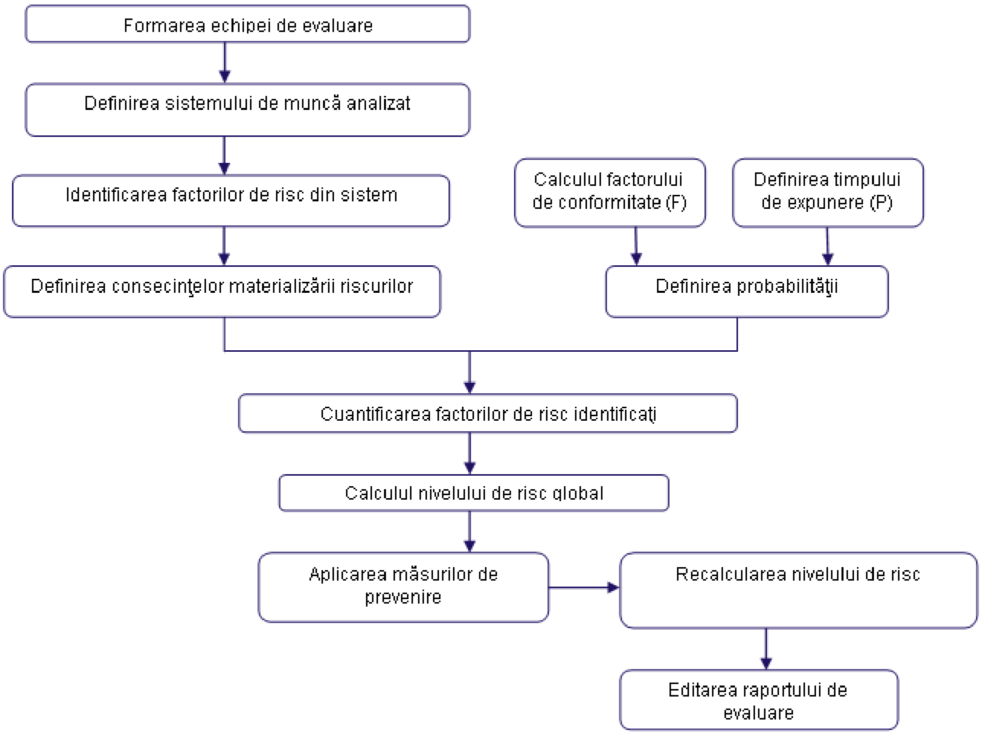


Fig. 5.5. The stages of the MEVARO-SUD method

5.2.3. Application conditions

In order for the application of the method to give the most suitable results, the first condition is that the analyzed system is a workplace, clearly defined in terms of its purpose and components. In this way, the number and types of potential interconnections studied are limited, as are the risk factors that must be implicitly considered.
The advantage of the proposed method is that its application is not limited by the physical existence conditions of the evaluated system. It can be used in all stages related to the life cycle of a work system or part of it: research and design, implementation, installation and commissioning, performance of the work process. Since there are many specific manifestations of risk factors, even for a relatively simple system, the workflow in this method is relatively laborious. Identifying and managing workplace risks based on the data obtained requires specialized personnel. The use of information technology is possible due to some characteristics of the method, such as:

- clear phasing of the work procedure;
- the presence of an algorithm for calculating the risk level;
- the type of association between variables that are taken into account to determine the level of risk

$$Nrg = \frac{\sum_{i=1}^{22} R_i r_i}{\sum_{i=1}^{22} r_i} = \frac{0(5x5) + 0(4x4) + 5(3x3) + 11(2x2) + 6(1x1)}{0x5 + 0x4 + 5x3 + 11x2 + 6x1} = \frac{95}{43} = 2{,}21$$

$$Nrgr = \frac{\sum_{i=1}^{22} R_i r_i}{\sum_{i=1}^{22} r_i} = \frac{0(5x5) + 0(4x4) + 0(3x3) + 16(2x2) + 6(1x1)}{0x5 + 0x4 + 0x3 + 16x2 + 6x1} = \frac{70}{38} = 1{,}84$$

NPR – Partial risk level
NPRR – Partial residual risk level
Nrg – global risk level
Nrgr – remaining global risk level

After applying the prevention and control measures presented in the assessment sheet, the risk level is recalculated, obtaining the global residual risk level (Nrgr). This is a residual risk. The risk remaining after implementing appropriate control measures is known as residual risk.
After the control is implemented, the hazard must be reassessed according to the new situation. These measures reduce the likelihood that an accident will occur. Because if an accident happens, the severity remains the same. It should be emphasized that it is impossible to eliminate all hazards, but they can be controlled.

5.3. Conclusions

From both risk assessments carried out with the two methods, it emerged that the workplace "Sudor" within the company SUDEX SRL is a workplace with a medium to high level of risk.
In the case of the INCDPM evaluation method, all the risk factors at the analyzed workplace were identified based on a predefined checklist and the level of risk was quantified according to the combination of two parameters, the severity and the frequency of the maximum consequence on the human body. All the mandatory stages were completed: defining the workplace, identifying risk factors, assessing risks, ranking risks and proposing preventive measures.
A detailed analysis of the workplace was carried out, highlighting the stages of the technological process, the devices and machines used, the clear specification of the welder's task; the existing environmental conditions in the welding workshop were described and the work safety requirements were specified. The identification of risk factors was made for each component of the workplace analyzed, establishing the possible dysfunctions that may occur, generating accidents or illnesses.
The working method used was direct observation of workers and logical deduction. To the extent possible, all predictable and probable mistakes of the executor related to work assignments, in the form of omissions and erroneous actions, were analyzed, as well as their impact on their own security and the other elements of the system.
The job evaluation sheet was completed with the identified risk factors; table 5.14. it contains details of the factors and the size of the parameters by which it is evaluated. Of the 41 risk factors identified, 11 exceeded the value of 3 as a partial risk level, which places them in the unacceptable range. The Nrg calculated for the job "Welder" with the value of 3.37 falls into the class of jobs with a medium to high risk level.
The improvement of the security level of the analyzed work system requires the proposal of measures established according to the hierarchy of assessed risks, these being presented in table 5.14., "Fiche of proposed preventive measures", grouped into organizational and technical measures. The chapter ends with the enumeration of collective and individual prevention and protection measures specific to welding processes in a protective gas environment.
The conceptual framework to guide the MEVARO-SUD method was identified following the analysis of the existing methods in the specialized literature and the experience accumulated in the field, based on the risk management paradigm. The conceptual framework involves a series of steps, including: assessing occupational risks, translating risk information into specific actions, introducing and managing risk reduction interventions, evaluating interventions and providing feedback for existing interventions as well as future action plans .
The MEVARO-SUD method calculates the probability of an event occurring as a combination of frequency and exposure time, offering, in addition to the INCDPM method, the possibility to see how, after the application of prevention and protection methods, the global risk level decreases (remaining a so-called residual risk) by calculating a global residual risk level (Nrgr).
It should be emphasized that the risk assessment process requires continuous monitoring and review. Workers change, facilities improve, machines and equipment are replaced, machine

accessories are added, and technology develops. As a result, the risk assessment will need to be constantly updated. If their source is removed (for example, by replacing an old machine with a newer one), some hazards automatically disappear, while new ones may appear.

Chapter 6. Contributions regarding the improvement of health and safety conditions at work in a metal fabrication workshop

6.1. Research methodology undertaken to improve working conditions for the welder job

In order to improve the conditions of health and safety at work in the workshops of metal fabrications where welding is used with predilection, we followed a research methodology as follows:

1. measurement of emissions during manual welding operations with a covered electrode and welding in a protective gas environment;
2. in the (proven) case of exceeding the maximum admissible values, the design of an additional ventilation system to help reduce the noxes in the workshop;
3. restoring the meters on gas emissions from the metal fabrication workshop where we installed the additional ventilation system designed and made for this purpose.

6.2 Presentation of emission meters for the welder workstation

Emissions were measured in a metal workshop. In this workshop, several mechanical processing operations are carried out by cutting, such as: welding, milling, drilling, grinding. In order to obtain the landmarks that will later be welded, operations such as: cutting, grinding, bending, polishing, shaping of metals are carried out in this workshop.

For the non-demountable joint by welding of the landmarks obtained through the previous operations, the procedures of manual welding with a covered electrode and manual welding in a protective gas environment are used.

To measure the emissions in the welding workshop, an auto-laboratory of the company SC Eneeco Consulting SRL was used, it is qualified by the Ministry of Health for industrial toxicology.

The measurement of emissions from the welding workshop was carried out using a mobile equipment installed on the special vehicle shown in figure 6.2. which is provided with a pipe, for capturing emissions, located in the upper part of the vehicle.

6.3 Emission measurement systems at the workplace

A system of measuring devices mounted on a van was used to evaluate the emissions at the welder's workplace. In this way several types of emissions were measured as shown below:

- for the ambient sulfur dioxide, SO_2, an APSA-370 type monitor was used. This is a device for continuous monitoring of atmospheric SO_2 using UV fluorescence. The APSA-370 uses an internal dry sampling device to achieve the highest levels of sensitivity and accuracy. The dry method, due to its minimal maintenance requirements, continuous monitoring capability, and instantaneous analysis of unaltered gas, has been a preferred method for air pollution monitoring.

- for nitrogen oxides, NO, NO_2, NO_x, at the ambient level, the HORIBA APNA-370 device was used. It continuously monitors atmospheric concentrations of NO, NO_2 and NO_x using a chemiluminescence cross-flow modulated semi-decompression method. The APNA-370 uses an internal independent dry sampling device to achieve the highest levels of sensitivity and accuracy.

- for carbon monoxide, CO, the APMA-370 monitor was used, which is a device for continuous monitoring of CO concentrations using a non-dispersive cross-modulation infrared

analysis method. The APMA-370 uses an internal independent dry sampling device to achieve the highest levels of sensitivity and accuracy.
In table 6.1. the results of measuring the emissions of noxes released during the various operations for the welder job are presented - the job description.

Table. 6.1. The results of CO, NO, NO_2, and SO_2 emissions

No	Workplace	Professional nox	Maximum admissible concentration [mg/m^3]		Pollutant concentration measured over the period [mg/m^3]	
			8 h	15 min	8 h	15 min
1	Sample no. 120	CO	20	30		33,44
		NO	30	40		1,19
		NO2	5	8	-	0,011
		SO2	5	10		0,34
2	Sample no. 121	CO	20	30		35.81
		NO	30	40		1,23
		NO2	5	8		0,013
		SO2	5	10		0,41
3	Sample no. 122	CO	20	30		37.20
		NO	30	40		1,17
		NO2	5	8	-	0,09
		SO2	5	10		0,30
4	Sample no. 123	CO	20	30		39.60
		NO	30	40		1.3
		NO2	5	8		0,017
		SO2	5	10		0,51

From the point of view of the emissions generated by manual welding, there is a constant significant excess of carbon monoxide emissions.
In these conditions, when the meters indicated important values of the emissions, in order to improve the working conditions, we considered it necessary to design a ventilation system that would help to quickly evacuate the noxes from the premises of the welding workshop.

6.4 Design and construction of an air ventilation system necessary to evacuate emissions from a welding workshop

For the evacuation of gas emissions from the welding workshop, we designed and executed a forced ventilation system that is mounted in the upper part of the workshop. The main element of this ventilation system is a bladed rotor driven by a motor.

6.5 Measurement of emissions from the welding shop after installation of the ventilation system designed and built

As a result of the commissioning of the forced air ventilation system in the welding workshop, the noxes meters were restored, resulting in the values shown in table 6.2. As can be seen from figures 6.10. - 6.13., the commissioning of this forced ventilation system led to the drastic decrease of emissions, especially of carbon monoxide, CO, from the value of 39.6 to 9.21 mg/m^3, which represents a value far below the maximum permissible concentration.

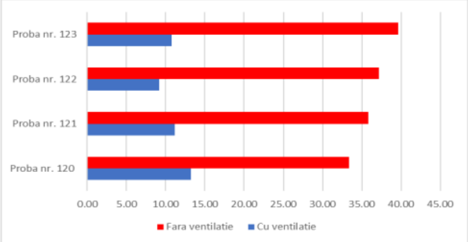


Fig.6.10. Comparison of CO emission values before and after installation of the ventilation system.

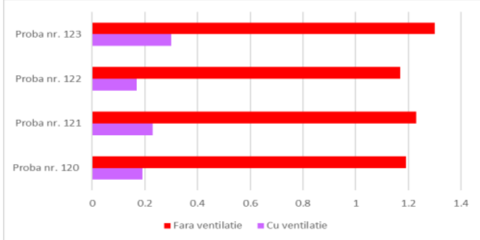


Fig.6.11. Comparison of NO emission values before and after installation of the ventilation system.

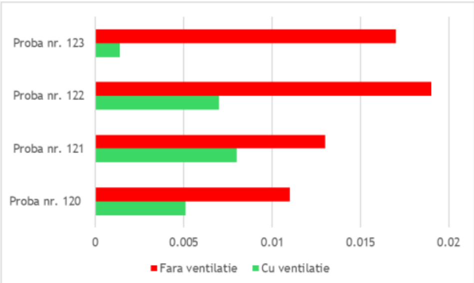


Fig.6.12. Comparison of NO_2 emission values before and after installation of the ventilation system

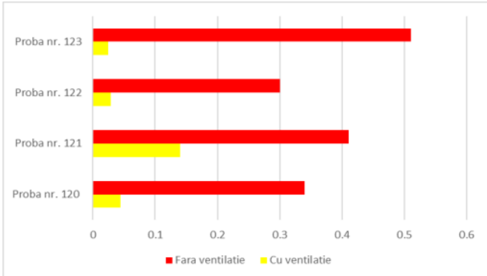


Fig.6.13. Comparison of SO_2 emission values before and after installation of the ventilation system

6.6 Conclusions

Welding, as a non-dismantling technological process, represents an important source of atmospheric pollutants whose influence on the human body is significant. To highlight them, as part of the research, we measured the emissions resulting from the welding in the protective gas environment of several samples before and after the installation of the designed ventilation system. It was found that the emissions have significant values and in the case of carbon monoxide, CO, the values exceed the maximum permissible limits. As a result, for the presented section, but as for any other welding section, we designed and made a forced industrial air ventilation system that proved its effectiveness in the sense of extracting polluted air from the welding section and its forced evacuation outside. For this system, we presented the execution drawings of its housing and rotor, which represent the most important elements of the assembly.

Using these execution drawings we moved on to its physical realization as can be seen in the images presented.

After putting it into operation, I repeated the measurements and obtained values far below the maximum admissible ones (fig. 6.10. – 6.13.)

Thus, we achieved one of the objectives of the thesis, the ventilation system proved its effectiveness in ensuring a normal working environment for workers in this field, with nox values below the admissible ones.

Chapter 7. Experimental research and development of the Occupational Safety and Health Decision Support System for hearing impaired workers

7.1. Introduction. System description

The metalwork welding industry is dominated by small and medium-sized enterprises (SMEs) that do not have full-time staff for occupational health and safety. In addition, as is well known, industry-wide accident and occupational disease rates are twice as high among SMEs as compared to large enterprises.

It is therefore good health and safety practice to create a supportive environment without (pre)judgment and to communicate this to all employees. Considerable research has been conducted on the relationship between employee well-being at work and their work environment. Workers with disabilities face the same risks as non-disabled workers doing the same work but may face additional risks or be more susceptible to the same risks because of their condition.

People who, due to physical, mental or sensory conditions, are not able to carry out their daily activities normally and require protective measures to help them recover, integrate into society In general, there are several methods to reduce this deficiency, devices (compensatory hearing loss) and/or the use of sign language.

Aspecte analizate în evaluarea riscurilor pentru lucrătorii cu dizabilități

- conceperea sarcinilor și activităților profesionale
- cerinta specifică legată de handicapul său
- echipamentul tehnic
- adaptate nevoilor individuale
- mediul de muncă
- amenajarea locurilor de muncă
- căile de acces/evacuare
- organizarea muncii
- tehnologiile auxiliare
- riscuri fizice
- riscurile psihosociale

Considering the complex aspects listed above, the author of the paper responds to the needs of such small and medium-sized enterprises by proposing a decision support system (SSAD-SSM) that is addressed to managers and staff with attributions regarding occupational safety and health of disabled workers in SMEs where welding activities are carried out.

Also the decision support system has been developed in a way that can be understood by managers, welders, occupational health and safety experts, managers, students, casual welders, professional welders and their supervisors, at all levels of experience.

7.2 Components (tutorial component, assessment component, protective measures component)

The designed system offers the decision maker, in the field of professional risks, full support so that this decision leads to the reduction or even elimination of some of the identified risks.

The system is designed in a multi-layered architecture, meeting the support needs of decision makers. SSAD-SSM has 3 components. The basic layer of the system includes the informational guidance system, followed by the intermediate layer, namely the expert system for evaluating professional risks, based on which decisions must be made. The final layer, the upper layer of the system, is a set of procedures and means of information processing and transmission, which includes preventive processes and risk control measures.

The tutorial, informative component contains national legislation on occupational safety and health, general occupational safety regulations, specific instructions, specific occupational safety regulations for metal welding.

The risk assessment component contains the description of the specific elements of the new occupational risk assessment method for hearing impaired welders, called MEROSUD-DIZAB.

In this stage, the risk factors of occupational injury and illness will be assessed for the job "welder in protective gas environments", analyzing only the specific risk factors of disability (hearing impairment) for each component of the work system (Table 7.1. Sheet A - "means of production"; Table 7.8. Sheet B - "work environment"; Table 7.9. Sheet C - "work load"; Table 7.10. Sheet D - "worker"). A hearing-impaired person is employed in this position. the working hours are 4 hours a day and they work at the company headquarters.

7.3. Elaboration of the IT application in Excel for the "protection measures" component of the Decision Support System on Safety and Health at Work for workers with hearing disabilities

The software application for the "protective measures" component of the Occupational Safety and Health Decision Support System for hearing impaired workers was designed as a series of Microsoft Excel® 2013 worksheets to record the user's responses to checklist items. verification, to automatically calculate the risk level R, the frequency of occurrence of the risk factor F and to generate a series of preventive measures based on the previously calculated risk level.

One of the most important features of the software application is its portability to different devices with different operating systems, such as personal computers, tablets and smartphones. Also, the operation of the software tool is very simple, requiring basic knowledge of Microsoft Excel®.

7.3.2.2 Description of the operation of the computer application

The purpose of this program is to obtain an R risk level, based on which a series of prevention and control measures will be generated.

The risk level R will be calculated as a combination of G (severity of the maximum foreseeable consequence) and P (probability), R=(G,P)

The steps of the program aim to obtain G and P.

The program has 6 steps/pages (Excell sheets) contains the Forward (green) and Back (red) buttons.

Step 1 The user will answer a set of questions. Based on the number of positive responses, the program will calculate a factor N (non-conformity factor).

Step 2 Based on N from the previous page the program calculates an F. Also here the user chooses a time T (based on a preset table).

Step 3 The program calculates P (probability).

Step 4 The user chooses G (Gravity) from a predefined table.

Step 5 The program calculates R (risk level)

Step 6 Preventive measures are given based on the previously obtained risk level R

7.4. Conclusions

Assessing the risks of occupational injury and disease for a disabled worker (a hearing impaired welder in this case) is a process of identifying risk factors and quantifying them taking into account the 4 components of the work system (means of production, environment of work, work load, worker). The evaluation method used in this software is both a qualitative and quantitative method.

The qualitative component also constitutes the principle of the method and consists in identifying the non-conformities of the work system, taking into account the legislative requirements and the European recommendations regarding jobs for people with disabilities. Non-conformities are identified on each component of the work system on the basis of checklists developed taking into account the legislative requirements and the European recommendations regarding workplaces for people with disabilities. The method is also quantitative because it allows us to quantify the level of risk for each component of the work system separately, depending on the Severity and Probability of manifestation of the respective risk factor.

The software application for the "protective measures" component of the Occupational Safety and Health Decision Support System for hearing impaired workers was designed as a series of Microsoft Excel® 2013 worksheets to record the user's responses to checklist items. verification, to automatically calculate the risk level R, the frequency of occurrence of the risk

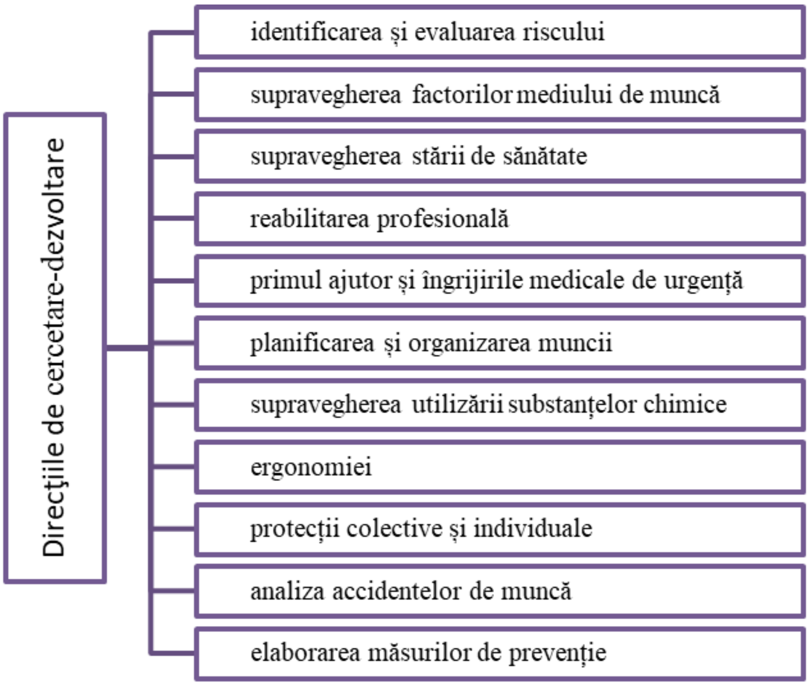
factor F and to generate a series of preventive measures based on the previously calculated risk level.
Microsoft Excel was chosen because it is one of the most popular and powerful spreadsheet and data analysis applications with multiple advantages: it is relatively easy to learn and use, making it accessible to a large number of users, from beginners to professionals; allows data to be organized into spreadsheets, cells and tables, which makes managing and manipulating information easier and more organized; provides a wide range of mathematical and statistical functions to perform complex calculations, from simple addition and multiplication operations to advanced statistical analysis; graphs and visualizations can be created to represent data visually, which helps to understand and interpret information more easily; provides powerful data analysis tools such as pivot tables, filters, sorting, and analysis functions (such as Vlookup and Hlookup); allows the automation of repeated tasks with the help of macros and the VBA (Visual Basic for Applications) programming language; allows multiple users to simultaneously work on the same spreadsheet and share files for collaboration; its appearance and functionality can be customized through macros, overlays, custom formulas, and conditional formatting; provides compatibility with a variety of file formats, including CSV, TXT, PDF and other data formats, allowing data to be shared and imported/exported with other applications; provides security options such as password protecting files and managing access rights to protect sensitive data; it is part of the Microsoft Office suite and benefits from regular updates from Microsoft as well as technical support.

Chapter 8. Final conclusions and main contributions regarding the improvement of safety and health at work in order to minimize the effects of noxes when welding in protective gas environments

(1) From the analysis of the current state regarding the emissions of noxes when welding in a protective gas environment and the effects on the health and safety of workers, important conclusions emerged, which are presented in detail in chapter 3, such as:

- welding is an essential component in many industrial applications, but unfortunately welding has its negative effects in terms of health hazards for working personnel;
- chronic exposure to welding fumes is associated with a decrease in lung function, and welders have an increased risk of chronic obstructive pulmonary disease (COPD), asthma and chronic bronchitis;
- the main hazard resulting from exposure to welding gases is asphyxiation, which usually results from the accumulation of gases in confined spaces. The gases generated by the welding process in protective gas environments are: carbon monoxide, carbon dioxide, nitrogen monoxide, nitrogen dioxide, ozone;
- există numeroase rapoarte medicale și studii de caz care se referă la simptome ale căilor respiratorii superioare din cauza expunerii la vapori și gaze de sudură.

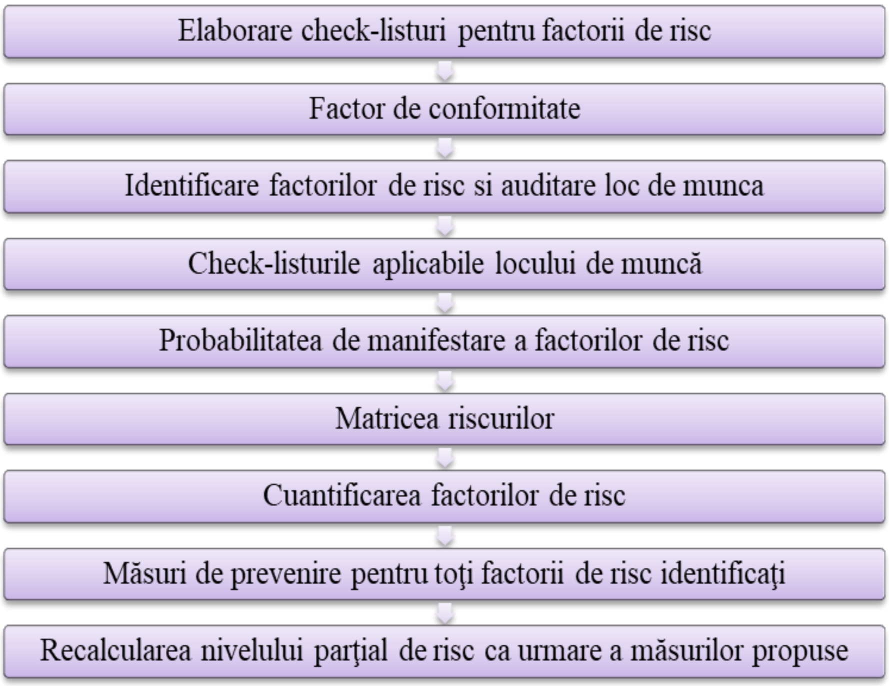
(2) Taking into account the conclusions of the current stage regarding the emissions of noxes when welding in a protective gas environment and the effects on the health and safety of workers, the following directions of research and development have been established



(3) Knowing the current state and deepening the directions of research and development regarding the emissions of noxes when welding in a protective gas environment and the effects on the health and safety of workers, it was established as the main objective of the thematic activity of the doctorate (see and § 4.2): the assessment of the risks of occupational injury and illness for the welder workplace in a protective gas environment and the implementation of measures to reduce the noxious emissions generated in the welding process in order to improve safety and health at work.
(4) As follows, the relevant conclusions are presented regarding the doctoral research and development activity to achieve its main objective, in relation to the methodological reference elements (see § 4.3).

○ Adaptation to the occupational safety and health literature of the PRISMA method, a method used by medical researchers to obtain systematic reviews of studies evaluating the effects of health interventions, regardless of the design of the included studies. Using the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) method to determine the current state of theoretical and experimental research on occupational safety and health related to welding nox emissions provides a high-quality approach and standardized that brings multiple advantages in the systematic literature review process and provides a comprehensive picture of the topic of interest.

○ A method for assessing the risks of occupational injury and illness was designed for MEVARO-SUD welding activities, which aims to reduce the subjective elements in the analysis of the probability of occurrence of risk factors.
The proposed method tracks the level of work risk/security for a job/work station, department or enterprise, based on the assessment of occupational injury and disease risks.
The essence of this method is the identification of the risk factors in the work system evaluated based on predefined checklists and the quantification of the risk based on the combination of the severity and the probability of the risk manifestation. (see § 5.1).



○ A series of own occupational safety and health instructions specific to the welding profession have been developed in the form of procedures. The instructions include the measures to prevent work accidents and occupational diseases specific to the SUDOR profession and aim to reduce or eliminate existing risk factors in the work system, specific to each of its component elements (see § 5.1).

○ An air ventilation system for exhausting emissions from a welding workshop was designed and built. For the evacuation of gas emissions from the welding workshop, we designed and implemented a forced ventilation system that is mounted in the upper part of workshops or industrial halls. The main element of this ventilation system is a bladed rotor driven by a motor. (see § 6.4)

In order to improve the conditions of health and safety at work in the workshops of metal fabrications where welding is used with predilection, we followed a research methodology as follows:

1. measurement of emissions during welding operations in a protective gas environment;
2. in the (proven) case of exceeding the maximum admissible values, the design of an additional ventilation system to help eliminate the noxes in the workshop;
3. restoring the meters on gas emissions from the metal fabrication workshop where we installed the additional ventilation system designed and made for this purpose. (see § 6.1)

○ **Development of the OSH Decision Support System for hearing impaired workers.**

The decision support system is addressed to managers and staff with attributions regarding occupational safety and health of disabled workers in SMEs where welding activities are carried out. The system has a multilayered architecture of 3 components, satisfying the support needs of decision makers. The basic layer of the system includes the informational guidance system, followed by the intermediate layer, the expert system for assessing professional risks, based on which decisions must be made. The final layer of the system is procedural which contains the prevention procedures and control measures. (see § 7.1).

The tutorial, informative component contains the national legislation on safety and health at work, the general rules of safety at work, specific instructions for welding and cutting metals.
The risk assessment component consists of the "MEROSUD-DIZAB occupational risk assessment method for hearing impaired welders" - Disability risk assessment (see § 7.2.2).
The protective measures component is found in the excell soft application for the disabled welder) and was designed as an open system with evolutionary implementation using the prototype method. The prototype is a first variant of the intended system, i.e. a core of it with the essential features in an initial form. During the realization/development, it will be adapted to the requirements of the user/beneficiary according to the conclusions of the successive-progressive specific experiments and will be extended with new functions.
(5) To achieve the main objective of the doctoral research-development activity, this doctoral thesis brings a series of contributions, the most important of which are as follows.

- the adaptation of the Prisma method to the specialized literature in the field of safety and health at work, to determine the current state of theoretical and experimental research on safety and health at work related to welding noxious emissions and which offers a high-quality, standardized approach, with multiple advantages in the process of systematic literature review and provides a comprehensive picture of the topic of interest.
- the development of a method for assessing the risks of occupational injury and illness for MEVARO-SUD welding activities, after applying the method it results in a document called "Evaluation form of the workplace/workplace", where we find NRG at the workplace . The resulting job sheet represents the foundation of the occupational accident and occupational disease prevention program for the job, workplace, sector, section or enterprise analyzed.
- application of the new method in a case study of risk assessment for the workplace "welder in gas protective environment"
- measuring the emissions of noxes generated in the welding process in a protective gas environment, from a metal fabrication workshop, using a mobile self-laboratory authorized by the Ministry of Health for industrial toxicology. From the point of view of the generated emissions, an important excess was found in carbon monoxide emissions
- design and implementation of an air ventilation system necessary to evacuate emissions from a welding workshop.
- as a result of the commissioning of the forced air ventilation system in the welding workshop, the noxes meters were redone, resulting in the values shown in table 6.2. As can be seen from figures 6.10. - 6.13., the commissioning of this forced ventilation system led to the drastic decrease of emissions, especially of carbon monoxide, CO, from the value of 39.6 to 9.21 mg/m3, which represents a value far below the maximum permissible concentration.
- redoing the measurements of noxious emissions after testing and putting the ventilation system into operation. A drastic decrease in emissions, especially of carbon monoxide, was observed, from the value of 39.6 to 9.21 mg/m3, which represents a value far below the maximum admissible concentration.
- development of a method for assessing the risks of injury and occupational disease in the case of disabilities for welders with hearing disabilities MEROSUD-DIZAB. The evaluation method used is both qualitative and quantitative. The qualitative component also constitutes the principle of the method and consists in identifying the non-conformities of the work system, taking into account the legislative requirements and the European recommendations

regarding jobs for people with disabilities. Non-conformities are identified on each component of the work system on the basis of checklists developed taking into account the legislative requirements and the European recommendations regarding workplaces for people with disabilities. The method is also quantitative because it allows us to quantify the level of risk for each component of the work system separately, depending on the Severity and Probability of manifestation of the respective risk factor.

- the development of the Decision Support System regarding Safety and Health at Work for hearing impaired workers. The system was designed in architecture and has 3 components.
- developing the prototype of an excel software application that performs the automated assessment and offers a set of individualized prevention and protection measures for the existing risk factors in a welding workshop. The prototype is a first variant of the intended system, i.e. a core of it with the essential features in an initial form. During the realization/development, it will be adapted to the requirements of the user/beneficiary according to the conclusions of the successive-progressive specific experiments and will be extended with new functions.

*** * ***

The present doctoral thesis, through the issue, approach and results, contributes to stimulating the design and implementation of ecological manufacturing technologies, to the modernization of traditional industrial sectors, in order to comply with current community requirements regarding occupational health and safety, as well as environmental protection, measurement of the noxes resulting in the welding processes being of great relevance.

The contributions to addressing issues that have not been sufficiently covered in occupational risk assessment methods so far demonstrate the scientific importance of this PhD thesis. (e.g. addressing the problem of risk assessment for disabled workers, obtaining individualized prevention and protection measures with the help of easy-to-use and highly accessible informatics).

The practical importance of this PhD thesis is that the SSAD-SSM decision support system has been developed in a way that can be easily understood and used by managers, welders, occupational health and safety experts, managers, students, casual welders, professional welders and their supervisors, at all experience levels. The system provides the decision-maker (related to occupational risks) with sufficient support for that decision to minimize certain risks that have been identified. Also of practical importance is the design and realization of the ventilation system necessary to evacuate emissions from a welding workshop.

The problem of noxes present in the process of welding in a shielding gas environment requires a research activity - continuous and analytical development, to determine new methods of evaluation and reduction of noxes emissions, resulting from welding processes in a shielding gas environment, the development of solutions and methods for assessing the risks of occupational injury and disease for welding operators, the design of specific measures and means to warn about possible inconsistencies within the work system.

The research carried out by the authors brings new elements, increasing knowledge regarding the current state of professional risk assessment methods in the field of welding processes, solving some problems related to the generation of noxes in welding processes in a protective gas environment and the effects on the safety and health of welders. The results of the scientific research resulting from this doctoral thesis were partially communicated in the framework of scientific events held in the country and abroad, and were capitalized in 10 articles, 8 as the first author.

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