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THE INFLUENCE OF TECHNOLOGICAL CONDITIONS ON THE EMISSION OF WELDING FUME DUE TO WELDING OF STAINLESS STEELS

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Welding of stainless steel is very popular, which consequently is the reason for growing concern for the working environment at welding stations. Chromium is the basic alloying element of all groups of stainless steels. Majority of those steel grades contains nickel. Compositions of the elements occurring in welding fume have a probable or confirmed carcinogenic effect. The article shows the results of research of the relations between selected groups of stainless steels as well as technology parameters of arc welding processes and the welding fume emission, total chromium, chromium (VI) and nickiel contents in the fume.

Key words: stainless steels, arc welding, welding fume, carcinogenic substances

Utjecaj tehnoloških uvjeta zavarivanja nehrđajućih čelika na emisiju zavarivačkih prašina. Velika popularnost ovih materijala jedan je od razloga da povezano sa zavarivanjem stanje radnog mjesta budi veliko zanimanje. U nehrđajućim čelicima svih grupa, osnovni sastojak je krom. Većina ovih čelika sadržava također nikal. Spojevi ovih elemenata koji se nalaze u zavarivačkoj prašini, ubrajaiju se u tvari s opravdanim ili vjerojatnim kancerogenim djelovanjem. U ovom članku prikazani su rezultati ispitivanja odnosa između izabranih grupa nehrđajućeg čelika, tehnoloških parametra lučnog zavarivanja i veličine emisije prašine, sadržaja potpunog kroma, kroma (VI) i nikla u prašini.

Ključne riječi: nehrđajući čelici, lučno zavarivanje, zavarivačka prašina, kancerogene tvari

INTRODUCTION

While welding, parent metals and welding consumables as well as physical and chemical processes involving temperature change and UV radiation is the sources of welding fume, which contains solid particles (welding fume) and gases. Numerous tests conducted by the research centres all over the world have revealed that welding fume and gases emitted during welding contain hazardous substances, which pose a threat to human health while welding. Toxic and carcinogenic character of the welding fume and the level of the threat result from fume emission, its concentration at the workplace as well as fraction and chemical constitution. Welding fume emitted while welding of stainless steels contains significant quantities of elements, characteristic for those steels: in particular chromium and nickel. Some forms of chromium and nickel as well as chemical compounds of those metals have been recognised as leading chemical features for the estimation of health hazard, which accompanies welding of stainless materials. This means that those substances being emitted in large quantities are highly toxic. Some chromium and nickel compounds occurring in the welding fume have carcinogenic action stated by the International Agency for Research on Cancer. Epidemiological research carried for welders' population in many countries has revealed that the exposition to those substances, especially for long-term exposure, cause serious cancer diseases of various organs and systems of the human body [1-3]. At Instytut Spawalnictwa research into the reduction of health hazards occurring in welding by selection of the proper material and technological conditions for the process have been conducted for many years. Welding fume quantitative and qualitative emission result from the applied process, technological conditions as well as parent metal and welding consumables composition. Parameters of arc welding significantly influence the quantity of the emitted pollutants [4-5]. Majority of the arc welding parameters are modifiable without any influence on the correct welding performance.

THE MATERIAL AND TECHNOLOGY SCOPE OF RESEARCH

Austenitic chromium – nickel steels are the majority of the whole corrosion resistant steels used for welded structures. The most popular, widely known and applied is X5CrNi18-10 steel. It is weldable with all arc welding

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processes and welding conditions for this steel are representative for the whole austenitic steel group. Above mentioned factors were taken into consideration while selection of X5CrNi18-10 steel as the basic material for research. X6Cr17 steel was selected from the large group of chromium steels as it was relatively often used material for welded structures. Stainless steel group is continually developing and new materials are being created. Such relatively new group are Duplex steels of austenitic – ferritic structure, whose alloying constituents are chromium, nickel, molybdenum and nitrogen. Duplex steels are used for welded structures, however this group is not very well known in industrial practice. In order to select good representation of tested materials as the third grade of steel – Duplex steel 2205 - X2CrNiMoN22-5-3, which is produced by all important steelworks companies, was chosen.

Aiming at the practical application of research results, the relation between fume emission, total chromium, chromium (VI) and nickel content in welding fume as well as technological conditions of three arc welding processes, which are the most frequently used for stainless steels: i.e. MIG/MAG, TIG and MMA processes were investigated. In accordance with general recommendations, welding consumables used while welding of ferritic, austenitic and Duplex steels should be as a principle similar to the parent metals. This rule has numerous advantages connected with the characteristics of the deposited metal of those materials. The deposited metal is similar to the parent metal in respect of mechanical properties, appearance (colour), flexibility and results of heat treatment and corrosion resistance [4]. An alternative for filler metals similar to the parent metals are (especially for ferritic steels) materials of austenitic structures, which have good plasticity of deposited metal as well as crack and corrosion resistance, but are dissimilar in the respect of a structure, colour, heat treatment workability and are definitely more expensive.

THE INFLUENCE OF THE MATERIAL AND TECHNOLOGY CONDITIONS ON THE FUME EMISSION

Total fume emission during arc welding of stainless steels is closely connected with applied welding consumables and welding current of the selected welding process. While welding of stainless steels, i.e. X5CrNi18-10 (Figure 1), X6Cr17 (Figure 2) as well as X2CrNiMoN22-5-3 with MIG/MAG and TIG processes, research has revealed that fume emission results from the welding current intensity. The emission of total fume increases along with the increase of current intensity. While investigating the fume emission during MIG/MAG welding process, three values of the welding current were applied: 150, 200 and 250 A. For the current of 150 and 200 A short circuit metal transfer in the arc was observed. The emission of total fume was smaller in comparison to that determined during globular metal transfer. For 250 A and mixed metal transfer, significant increase in the fume emission has been found. The influence of the current and current dependent method of metal transfer on the fume emission has been stated for all gas shields applied in the tests. For TIG process three current values have been set: 80, 100 and 140 A. The increase of the fume emission along with current increase has been stated (Figure 3). Current intensity for TIG process influences heat generation when arc is burning between non-consumable electrode and welded material, thus current determines thermal power of the arc. The increase of the current intensity causes the increase of arc plasma temperature as well as intensifies vaporisation of liquid metal and oxidation reaction.

The tests have confirmed the influence of the current applied during stainless steels welding with MIG/MAG processes (Figures 4, 5) and TIG process on the chromium (VI) and nickel content in welding fume. The content of chromium (VI) and nickel increased along with the increase of current intensity. This relation occurred for all shielding gases and for all electrode wires and rods grades applied in the tests. The change of the chromium (VI) and nickel content in welding fume is connected with the oxidation reaction intensity. This intensity in the arc depends on the temperature of plasma, which is dependent on current intensity. For higher current the arc column increases as well, which is accompanied by the growing amount of dissociated oxygen. For higher amount of atomic oxygen in the arc area, chromium (III) can be easily oxidised to the form of chromium (VI). The presence of the atomic oxygen contributes to the creation of nickel oxides.

The influence of shielding gas composition on the fume emission and hazardous substances content is an important issue. Research have revealed that the impact of the shielding gas composition on total fume emission, chromium (VI) and nickel content in fume is significant. During testing of X6Cr17 steel, seven various gas mixtures were applied (Figures 1, 4). Shielding gases varied in respect of oxidising factor (I_0). Gases of high oxidising factor I_0 = 9-8 (82 % Ar + 18 % CO_2, 92 % Ar + 8 % O_2), gases of medium factor I_0 = 4-5 (92 % Ar + 8 % CO_2, 95 % Ar + 5 % O_2) and gases of low oxidising factor I_0 = 1,5-2 (97 % Ar + 3 % CO_2, 98 % Ar + 2 % O_2) were applied during research. It has been found that shielding gases of high and medium oxidising factor caused high content of chromium (VI), while gases of low oxidising factor resulted in its lower content (Figure 4).

The analysis of research results have revealed the relation between total fume emission and gas shield constitution in MIG/MAG welding of chromium ferrite steel. In general, it can be stated that the highest fume emission occurred while applying gas mixtures of Ar + CO_2. Shielding gases of Ar + O_2 caused significantly lower emission of total fume.

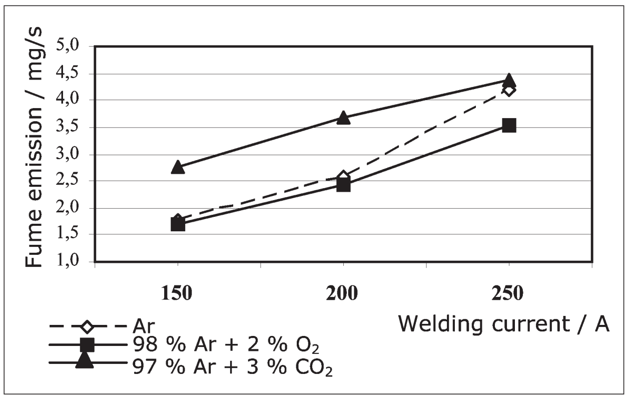

Figure 1 The influence of welding current and the composition of shielding gases on the welding fume emission during MIG/MAG welding of austenitic steel

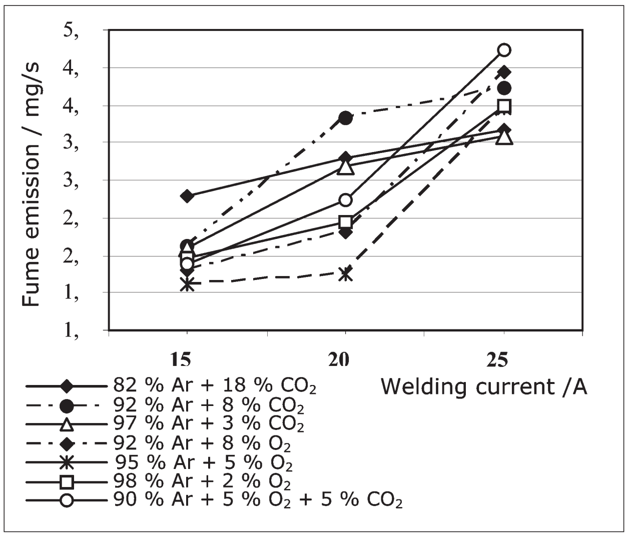

Figure 2 The influence of welding current and the composition of shielding gases on the welding fume emission during MIG/MAG welding of chromium-ferritic steel

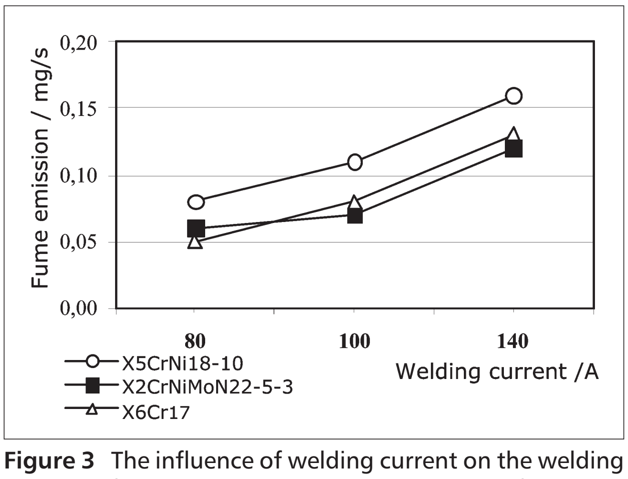

Figure 3 The influence of welding current on the welding fume emission during TIG welding of stainless steels

During research into welding of austenitic steel three different shielding gases, including two mixtures of Ar + O_2 and Ar + CO_2 type as well as inert gas – argon were used. Tested gas mixtures have low oxidising factor.

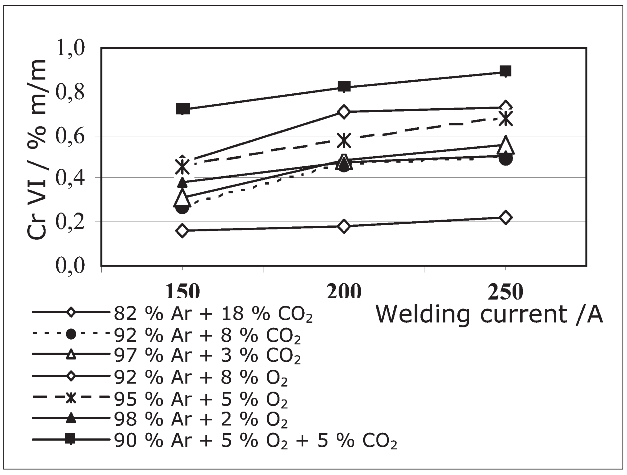

Figure 4 The influence of welding current and the composition of shielding gases on the contents of chromium (VI) in fume during MIG/MAG welding of chromium-ferritic steel

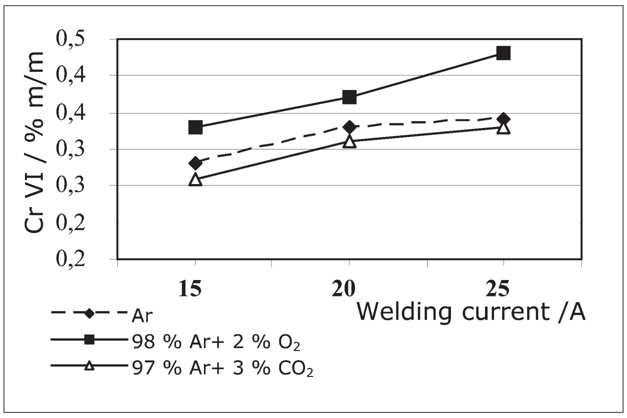

Figure 5 The influence of welding current and the composition of shielding gases on the contents of chromium (VI) in fume during MIG/MAG welding of austenitic steel

Like in case of chromium ferritic steel welding an influence of shielding gas constitution on fume emission during testing of hazardous substances has been found. Analysis of the results has revealed that the mixture of argon + oxide type creates favourable conditions for reduction of total fume emission. Similar tendency is achieved for argon shielded welding. In case of austenitic steel welding higher content of chromium (VI) was detected for shielding gas with higher oxidising factor (98 % Ar + 2 % O_2) (Figure 5). Whereas shielding gas containing 97 % Ar + 3 % CO_2, hose oxidising factor amounts to 1,5, during welding contributed to the reduction of chromium (VI) content. The mechanism of creation of chromium (III) and chromium (VI) during welding can be described in the following way:

- the arc plasma reaches high temperature, chromium from parent metal and welding consumable achieves the form of pure metal vapours,
- with the presence of atomic oxide, oxidising process to the chromium (III) occurs in accordance to the reaction

$$4Cr + 3O_2 \rightarrow 2Cr_2O_3 \quad (1)$$

The presence of strongly active atomic oxide provokes further oxidation to the chromium (VI) form. Stable form of hexavalent chromium bonded by oxide takes the form of CrO_4^{2-} or $Cr_2O_7^{2-}$. The presence of atomic oxide in the arc area also influences the formation of nickel oxides (NiO, NiO_2, Ni_2O_3). During the analysis of the nickel content in welding fume it has been found that for Ar and the mixture Ar + O_2 gas shielding the content of nickel reaches the highest values (Figure 6). The mixture Ar + CO_2 reduces the nickel content in welding fume.

The investigation into fume emission and carcinogenic substances content in welding fume during stainless steels welding with MIG/MAG process were conducted using solid wires and tubular cored electrode. Tubular cored electrode was applied in the process of welding of X6Cr17 austenitic-ferritic steel. The results have revealed that welding with tubular cored electrode implies high emission of total welding fume and particularly high content of chromium (VI) in welding fume.

During testing of the fume emission and total chromium, chromium (VI) and nickel content in welding fumes during welding of stainless steels with MMA process, electrodes of various coverings were applied. For austenitic stainless steel welding basic, rutile-acid and rutile coated electrodes were used. For austenitic-ferritic steel basic and rutile coated electrodes were applied, whereas chromium ferritic steel was welded with basic electrodes. While summing up the research into carcinogenic substances content in the fume arising from covered electrodes it has been revealed that the covering type fails to have significant influence on the percentage of chromium (VI) and nickel. High content of chromium (VI) in welding fume however occurs during welding of stainless steels with all types of covered electrodes. The electrode coating determines the total fume emission in the tested MMA process, so indirectly the electrode covering influences the emission of chromium (VI) and nickel to the work environment (see Table 1).

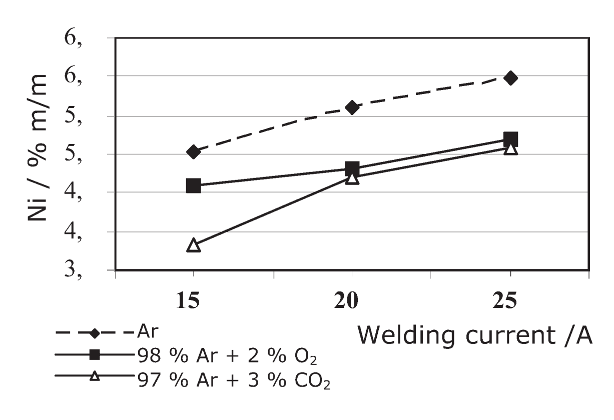

Figure 6 The influence of welding current and the composition of shielding gases on the contents of nickel in fume during MIG/MAG welding of austenitic steel.

From the research a conclusion can be drawn that of three tested processes of welding stainless steel, i.e. MAG/MIG, TIG and MMA the highest potential hazard connected with chromium (VI) and total chromium is caused by welding of steel with covered electrodes. It is not only because of the higher content of chromium (VI) in the fume but also with several times greater temporary emission of total fume.

CONCLUSION

Basing on the research result several conclusions can be drawn, which are of great importance for optimisation of the process of stainless steel welding, having in view improvement of work conditions:

Table 1 **The fume emission and contents of total chromium, chromium (VI) and nickel during the welding of stainless steels**

Steel	Welding process / parameters/ gas shielding	Fume mg/s	Components content / % m/m		
			Cr	Cr (VI)	Ni
X5CrNi18-10	MIG/MAG 150 A / Ar	1,76	13,4	0,3	5,1
	TIG 100 A / Ar	0,11	13,7	0,2	4,4
	MMA / 120 A	8,05	4,5	3,9	0,4
X2CrNiMoN22-5-3	MIG/MAG / 150 A 82 % Ar + 18 % CO_2	2,97	10,8	1,1	0,8
	TIG 100 A / Ar	0,07	9,8	1,5	4,7
	MMA / 120 A	13,47	5,9	4,7	0,8
X6Cr17	MIG/MAG 150 A 95 % Ar + 5 % O_2	1,62	12,5	0,5	-
	TIG 100 A / Ar	0,08	11,2	0,2	-
	MMA / 110 A	3,17	3,9	3,3	-

1. Material and technological conditions of stainless steel welding using MIG/MAG, TIG and MMA processes influence the total fume emission as well as total chromium, chromium (VI) and nickel contents in welding fume.
2. Shield gas constitution has significant effect on the total fume emission as well as total chromium, chromium (VI) and nickel contents in welding fume occurring during stainless steel joining with MIG/MAG welding process.

– Shielding gases of argon + oxygen type reduce the emission of total fume during welding of stainless steels using MIG/MAG process. For austenitic steel welding, shield gas of 98 % Ar + 2 % O_2 limits its fume emission on the average by 10 % in comparison to the argon shielded welding and by 30 % in the comparison to welding in gas shield of 97 % Ar + 3 % CO_2 composition.
– The highest emission of the total welding fume occurs while application of gas mixtures of argon + carbon dioxide type.
– Shielding gases of argon + oxygen type, characterised by high and medium oxidising factor cause higher content of chromium (VI) in welding fume.
– Shielding gases of argon + carbon dioxide make possible to achieve lower amounts of chromium (VI) in the welding fume. The content of chromium (VI) in welding fume during welding of chromium ferritic steel in a shielding atmosphere of 92 % Ar + 8 % CO_2 gases is on the average lower by 40 % than that occurring for the mixture of 92 % Ar + 8 % CO_2.
– Shielding gases of higher oxidising factors cause emission of higher amount of total chromium in the fume.
– The highest contents of nickel in the welding fume were achieved during welding in argon gas shielding. Gas mixtures of argon + oxygen and argon + carbon dioxide reduce the nickel content in welding fume.

3. Current intensity in MIG/MAG and TIG processes determines the total welding fume emission as well as total chromium, chromium (VI) and nickel content in the fume occurring during stainless steel welding.

– While welding of stainless steel with MIG/MAG process, the influence of current which determines the way of metal transfer in the arc has been specified for all shielding gases applied during research. Short circle transfer of metal in the arc for the current range of 150 to 200 A caused lower emission of total fume. For 250 A and mixed metal transfer, significant increase in the fume emission has been found. During austenitic steel and chromium ferritic steel welding fume emission for current of 250 A was approximately twice as high in the comparison to fume emission for the current of 150 A.
– During welding of stainless steel with TIG process, the increase of current causes higher total fume emission. For 140 A fume emission is twice as high in the comparison to that for current of 80 A.

4. The type of the covering in the case of welding of stainless steels with covered electrodes fails to significantly influence the percentage of total chromium, chromium (VI) and nickel content. It has been found that high amount of chromium (VI) in welding fume during welding of stainless steels with covered electrodes occurs for all covering types. The covering type determines the emission of total fume for selected MMA welding process, thus indirectly the electrode covering influences the emission of total chromium, chromium (VI) and nickel to the work environment.
5. Among the tested welding processes, the highest potential hazard associated with chromium (VI) and total chromium is definitely higher during welding of steel with covered electrodes. It results not only from the higher content of chromium (VI) in welding fume, but also it is associated with several times higher temporary emission of total fume.

REFERENCES

[1] V.E. Spiegel-Ciobanu, Chromium and nickel in welding and allied processes-some important aspects, IIW Doc. VIII 1799-97.

[2] P.J. Cunat, Chromium in stainless steel welding fumes, IIW Doc.VIII-1973-03.

[3] G. McMillan, Lung cancer and electric arc welding, IIW Doc.1988-05.

[4] J.C. Lippold, D.J. Kotecki, Welding Metallurgy and Weldability of Stainless Steels, Wiley – Interscience, J.Wiley & Sons Inc. Publication, 2005.

[5] J. Matusiak, A. Wyciœlik, Welding of stainless steels and the hazard of health and occupational safety of welders Hutnik. Wiadomoœci hutnicze. 9(2007), 538-545.

[6] J. Matusiak, The influence of technological conditions of stainless steels arc welding on the welding fume toxicity, Doctor’s thesis, Silesian University of Technology, 2007.

Note: The language lecturer for English was Barbara Dobaj-Tumidajewicz, Institute of Welding, Poland.