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Welding of Steel Sheets with Zinc Protective Coatings versus the Emission of Welding Fumes into the Work Environment

Abstract: The article presents the results of tests aimed to assess the effect of the gas-shielded metal arc welding of protectively coated sheets on the emission of welding fumes (CO, NOx). The tests made it possible to identify the correlation between the welding method, protective coating type, current parameters and filler metals and the emission of pollutants. The tests involved the MAG, CMT, ColdArc and AC MIG Pulse welding of steel sheets provided with various protective (anticorrosive) coatings. The filler metals used in the tests were solid wire grade G3Si1 having a diameter of 1.2 mm and metallic flux-cored wire grade T3T Z M M 1 H15 having a diameter of 1.2 mm.

Keywords: emission of welding fumes, gas-shielded welding, zinc protective coatings

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Introduction

Presently, steels sheets with protective coatings find numerous applications in many sectors of the economy, primarily in the automotive industry, building engineering and the production of household equipment. In the work environment the fusion welding, braze welding and pressure welding of steel sheets provided with protective coatings entails the emission of welding fumes responsible for numerous adverse health-related consequences, particularly, yet not only, affecting the respiratory system. The list of diseases related to welder's work includes, among other things, metallic fever, bronchial asthma (allergic and non-allergic), chronic obstructive pulmonary disease (COPD), pneumoconiosis (dust disease) and lung cancer [1-8]. Metal fume fever (also referred to as zinc fever) is likely to be the most common condition affecting the respiratory system among workers welding zinc-coated sheets [3]. According to some medial references, as many as 30% of welders have suffered from this disease. The reason for metal fume fever is one-time exposure to fumes containing metal oxides (zinc, copper, magnesium, aluminium, iron manganese or nickel). Small particles containing metals enter the respiratory tract and after bonding with proteins form pyrogenic compounds (pyrogenic substances affect the thermoregulatory centre of the body). Exposure to chemical substances triggering metal fume fever leads to the occurrence of clinical symptoms including irritated mucous membranes, cough, chest pains, flue-like symptoms (general weakness, muscular pains, headaches, nausea etc.) and fever. Recurring occupational exposure to the high concentration of zinc oxide leads to lesions in

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Table 1. Chemical composition of the base materials used in the tests [9]

Steel grade	Coating type	Chemical composition [%] max				
		C	Si	Mn	P	S
DX 54D Z 100 MBO (1.8 mm thick)	Z100 MBO – zinc coating, improved quality of zinc surface, oiled, coating thickness: 5-12 μm	0.12	0.50	0.60	0.10	0.045
DX 54D ZF 100 RBO (1.8 mm thick)	ZF100 RBO – coating made of zinc and iron alloy, improved quality of zinc surface, oiled, coating thickness: 5-12 μm,	0.12	0.50	0.60	0.10	0.045

the respiratory system, whereas metal fume fever is recognised as the primary reason for occupational factor-related asthma [1].

Objective and the range of tests

The tests aimed to assess the effect of technological welding process parameters of the gas-shielded metal arc welding of protectively coated steel sheets on the emission of welding fumes (CO, NOx). The tests resulted in the identification of the correlation between a welding method, protective coating type, current parameters and filler metals and the emission of pollutants. The tests involved MAG, CMT, ColdArc and AC MIG Pulse methods and 1.8 mm thick steel sheets provided with various types of anticorrosive protective coatings, i.e. DX 54D Z 100 MBO and DX 54D ZF 100 RBO. The chemical composition of the base materials used in the tests is presented in Table 1.

The filler metals used in the tests included solid wire grade G3Si1 having a diameter of 1.2 mm and metallic flux-cored wire T3T Z M M 1 H15 having a diameter of 1.2 mm. The chemical composition of the filler metals used in the tests is presented in Table 2. The welding processes were shielded by a mixture of 82% Ar+18% CO_2.

Table 2. Chemical composition of the filler metals used in the tests [9]

Filler metal wire grade	Chemical composition (%)			
	C	Mn	Si	Al
Solid wire G3Si1	0.11	1.40	0.85	-
Flux-cored wire T3T Z M M 1 H15	0.40	1.20	0.30	<3

Table 3. Material-technological range of emission-related tests [9]

Welding method	Base material	Filler metal	Shielding gas	Technological parameters			
				I [A]	U [V]	V_{dr} [m/min]	V_{sp} [mm/min]
MAG	DX54D ZF 100 RBO	G3Si1	82% Ar + 18% CO_2	80-120	16.7-17.2	2.0-3.2	350-630
		T3TZMM1H15		80-120	15.7-17.0	1.1-2.0	350-630
	DX54D Z 100 MBO	G3Si1		80-120	16.5-17.2	2.0-3.2	350-630
		T3TZMM1H15		80-120	15.7-17.0	1.1-2.0	350-630
ColdArc	DX54D ZF 100 RBO	G3Si1		80-120	17.5-18.5	2.0-3.2	350-630
		T3TZMM1H15		80-120	14.1-15.6	1.9-3.2	350-630
	DX54D Z 100 MBO	G3Si1		80-120	17.6-18.9	2.0-3.2	350-630
		T3TZMM1H15		80-120	14.2-16.7	1.9-3.2	350-630
CMT	DX54D ZF 100 RBO	G3Si1		80-120	12.0-13.6	1.8-3.2	350-630
	DX54D Z 100 MBO			80-120	12.4-13.9	1.9-3.2	350-630
AC MIG Pulse	DX54D ZF 100 RBO	G3Si1		80-120	16.2-17.9	2.8-4.5	350-630
		T3TZMM1H15		80-120	14.4-15.5	2.0-3.2	350-630
	DX54D Z 100 MBO	G3Si1		80-120	16.2-18.0	2.8-4.5	350-630
		T3TZMM1H15		80-120	13.7-14.7	2.0-3.2	350-630

The tests concerned with the emission of total dust and of gases (CO, NOx) generated during ColdArc, CMT, AC MIG Pulse and MAG welding were performed in relation to 3 values of current-voltage parameters, filler metal wire feeding rate and a welding rate. The material-technological range of emission-related tests is presented in Table 3.

The test rig used in the investigation concerning the emission of welding fumes during arc welding is presented in Figure 1.

The specimens used in the tests were sampled using the gravimetric method. The emission of gases accompanying the CMT, ColdArc, AC MIG Pulse and MAG method-based process involved the use of a Testo-350 analyser featuring the direct reading of gases (NO, NO_2, CO) and temperature.

Analysis of results

The analysis of test results concerning the emission of total dust and gases during the MAG, ColdArc, CMT and AC MIG Pulse welding of steels sheets provided with zinc protective coatings aimed to identify the effect of a welding method, protective coating, base material, filler metal and current parameters on the size of welding fumes emissions [9].

Effect of a welding method on the emission of dusts and gases

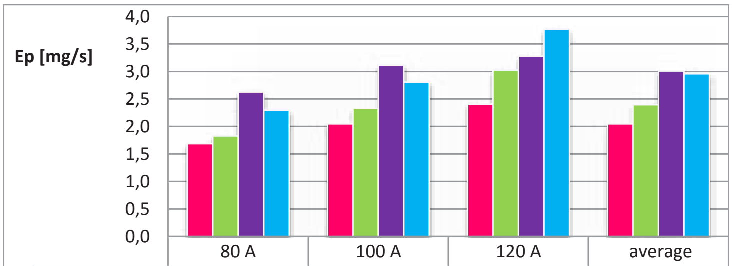
The tests revealed the effect of a welding method on the emission of welding fume. The emission of pollutants in relation to test current parameters, i.e. 80 A, 100 A and 120 A is presented in Figures 2-3. When welding galvanised sheets, the dominant factor adversely affecting workers'

Fig. 1. Test rig for investigating the emission of welding fumes during the CMT, ColdArc , MAG and AC MIG Pulse welding process

health is the emission of total dust. In addition, the work environment is polluted by the significant amount of carbon monoxide, which was related to the presence of 18% of CO_2 in the shielding gas composition. However, the primary source of carbon monoxide during arc welding is carbon dioxide. Carbon monoxide is emitted to the work environment as result of the thermal dissociation of CO_2. The analysis of the test results revealed that, when welding protectively coated sheets using solid wire grade G3Si1 having a diameter 1.2 mm, the ColdArc method proved the most favourable as regards the reduction of the emission of total dust and carbon monoxide. The highest emission of the above-named pollutants accompanied the use of the AC MIG Pulse method. During the ColdArc welding of the Z type-coated sheet, the reduction of dust emission stood at 33%, whereas that of carbon monoxide was by nearly 20% lower that the above-named emission indicators characteristic of the AC MIG Pulse method (Fig. 2). When welding the sheet provided with the protective coating composed of zinc and iron (ZF type), the replacement of the AC MIG Pulse method with the ColdArc process reduced the emission of total dust by 42% and that of the carbon monoxide by more than 25%.

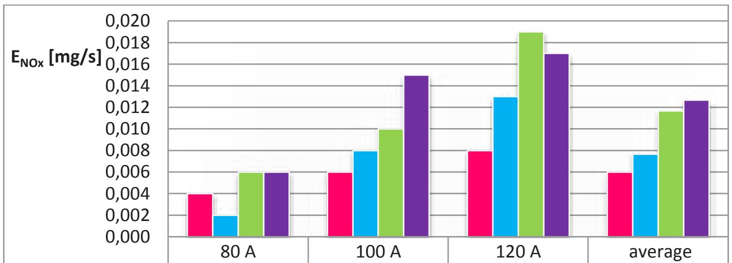
Base material: DX 53D Z 100 MBO; Filler metal: solid wire grade G3Si1

Emission of total dust (E_p)



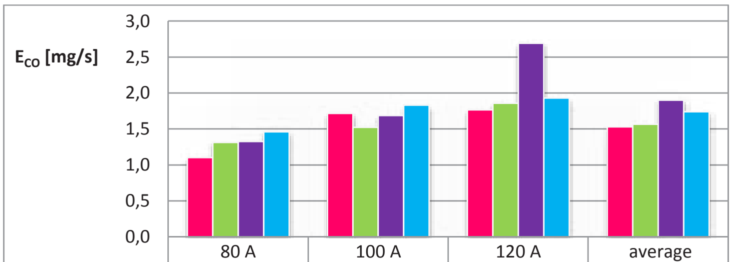
	80 A	100 A	120 A	average
ColdArc	1,69	2,05	2,41	2,05
CMT	1,83	2,33	3,03	2,40
AC MIG Pulse	2,63	3,12	3,28	3,01
MAG	2,30	2,81	3,77	2,96

Emission of nitrogen oxides (E_{NOx})



	80 A	100 A	120 A	average
ColdArc	0,004	0,006	0,008	0,006
MAG	0,002	0,008	0,013	0,008
CMT	0,006	0,010	0,019	0,012
AC MIG Pulse	0,006	0,015	0,017	0,013

Emission of carbon monoxide (E_{CO})



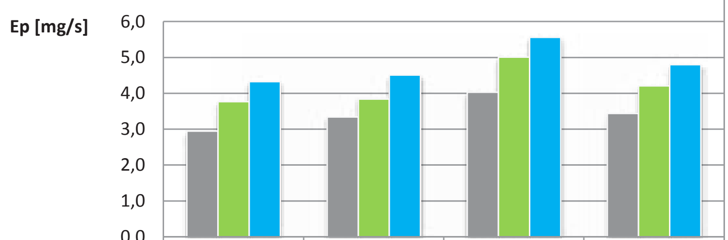
	80 A	100 A	120 A	average
ColdArc	1,102	1,719	1,767	1,529
CMT	1,313	1,524	1,859	1,565
AC MIG Pulse	1,327	1,688	2,694	1,903
MAG	1,460	1,832	1,931	1,741

Fig. 2. Emission of welding fume during the 82%Ar+18% CO_2–shielded welding of plate DX54D Z 100 MBO using solid wire grade G3Si1

The ColdArc method also proved the most favourable as regards the reduction of the emission of total dust and carbon monoxide during the welding of sheets provided with the Z and ZF type protective coatings performed using flux-cored wire grade T3T Z M M 1 H15. In turn, the highest emission of dust and CO accompanied the welding process involving the use of the MAG method. The replacement of the MAG method with the ColdArc process when welding the sheets provided with the DX54D Z 100 MBO zinc protective coating reduced the emission of total dust by 5% and that of carbon monoxide by more than 30%. During the ColdArc welding of the DX54D ZF 100 RBO sheet using the flux-cord wire, both the emission of total dust and that of carbon monoxide was reduced by 30% (Fig. 3).

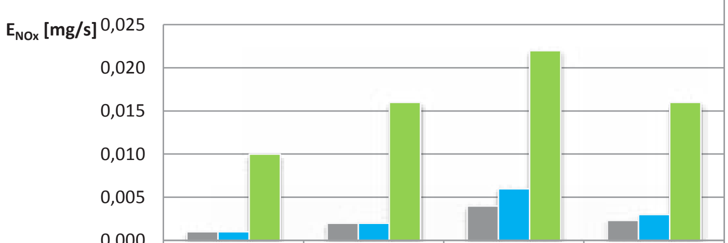
Base material: DX 53D ZF 100 RBO; Filler metal: flux-cored wire grade T3T Z M M 1 H15

Emission of total dust (E_p)



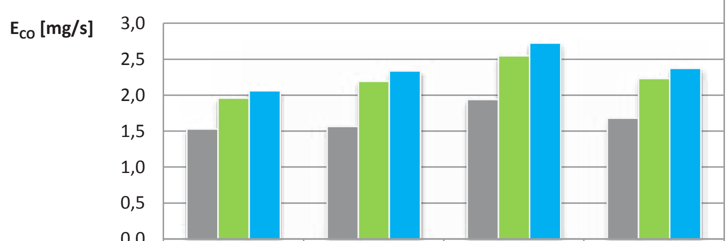
	80 A	100 A	120 A	average
ColdArc	2,95	3,34	4,03	3,44
AC MIG Pulse	3,77	3,84	5,01	4,21
MAG	4,33	4,51	5,56	4,80

Emission of nitrogen oxides (E_{NOx})



	80 A	100 A	120 A	average
ColdArc	0,001	0,002	0,004	0,002
MAG	0,001	0,002	0,006	0,003
AC MIG Pulse	0,010	0,016	0,022	0,016

Emission of carbon monoxide (E_{CO})



	80 A	100 A	120 A	average
ColdArc	1,531	1,567	1,941	1,680
AC MIG Pulse	1,959	2,193	2,546	2,233
MAG	2,063	2,337	2,725	2,375

Effect of a protective coating type on the emission of welding fumes

The tests concerning the emission of pollutants involved 1.8 mm thick hot galvanised steel sheet grades DX 54D Z 100 MBO and DX 54D ZF 100 RBO. The tests revealed that types of protective coatings affected the emission of welding fume. Higher dust emission indicators were observed during the welding of sheets provided with the DX54D Z 100 MBO zinc protective coating (Fig. 4). Similar to the emission of

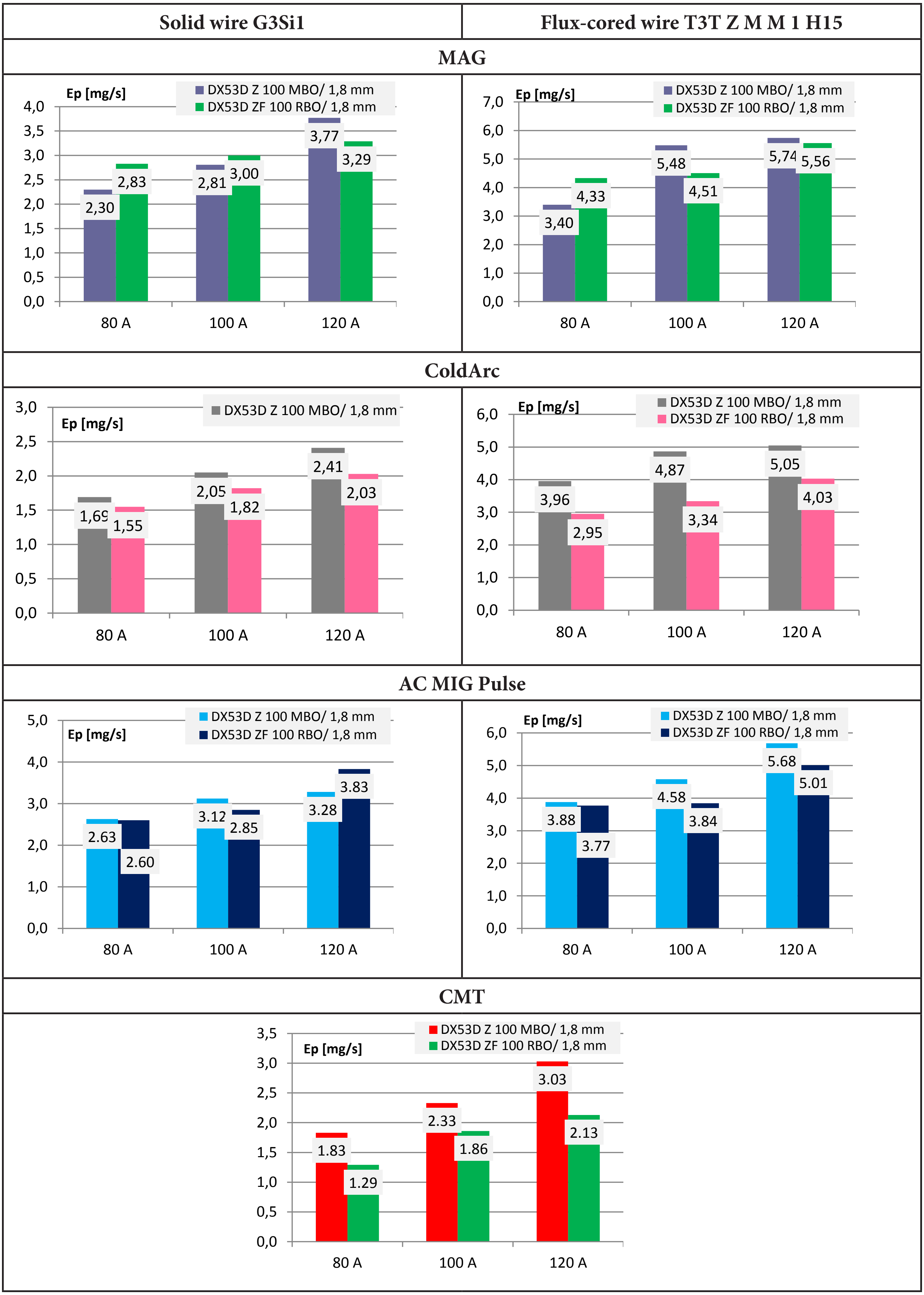


Fig. 4. Effect of the protective coating type of the steel sheets on the emission of total dust during MAG, ColdArc and AC MIG Pulse welding shielded by gas mixture 82% Ar + 18% CO_2

total dust, the emission of gases (nitrogen oxides and carbon monoxide) was higher during the welding of the zinc-coated sheet (Z type). The CO emission accompanying the welding of the sheet provided with the Z-type coating was, on average, higher by 25% than the emission of carbon monoxide accompanying the welding of the sheet provided with the ZF-type coating. The higher emission of NOx was characteristic of the welding of the sheet provided with the Z-type coating, in relation to all of the welding methods subjected to analysis, both in terms of the solid and the flux-cored wire.

Effect of a filler metal type on the emission of dusts and gases

The tests were performed in relation to two types of filler metals, i.e. solid wire grade G3Si1 having a diameter of 1.2 mm and metallic flux-cored wire T3T Z M M 1 H15 having a dimeter of 1.2 mm. The test results revealed the effect of a filler metal type on the size of welding fume emission (Fig. 5-7). The analysis unequivocally demonstrated that the higher emission of total dust occurred when welding by means of metallic flux-cored wire T3T Z M M 1 H15. The above-named tendency was observed in relation to all three welding methods, both filler metal grades and within the entire current range (Fig. 5). The emission of dust accompanying the MAG welding performed using the solid wire was by approximately 38% higher than that accompanying the welding process performed using the flux-cored wire. During ColdArc method-based welding involving the use of the solid wire the mean value of dust emission was by 48-55 % lower than that accompanying the welding process performed using the flux-cored wire. During the AC MIG Pulse welding process performed using the solid wire the mean value of dust emission was by 26-36% lower than that accompanying the welding process performed using the flux-cored wire.

The analysis concerning the effect of the filler metal type revealed that during MAG and ColdArc welding, the greater emission of nitrogen oxides accompanied the welding process of the Z and ZF-coated sheets (Fig. 6) involving the use of metallic flux-cored wire grade T3T Z M M 1 H15. In terms of the MAG welding of the Z and ZF-coated sheets performed using the solid wire, the mean value of nitrogen oxide emission was by twice higher than that accompanying the use of the flux-cored wire. During the ColdArc welding of the Z and ZF-coated sheets involving the use of the flux-cored wire, the emission of nitrogen oxides was between 0.8 to 2.5 higher than that accompanying the use of the solid wire. During the AC MIG Pulse welding of the Z and ZF-coated sheets involving the use of solid wire grade G3Si1, the mean emission of NOx was by more than 30% lower than the mean emission of NOx accompanying the welding process performed using flux-cored wire grade T3T Z M M 1 H15.

The tests also revealed the effect of the filler metal wire on the emission of carbon monoxide. Similar to the emission of total dust, the greater emission of carbon monoxide accompanied welding processes performed using metallic flux-cored wire grade T3T Z M M 1 H15. The above-named correlation was observed in relation to all of the welding methods, both filler metal grades and within the entire range of current parameters (Fig. 7). During the MAG welding process involving the use of the solid wire, the mean emission of CO was by 30-40% lower than that accompanying the process performed using the flux-cored wire. During the ColdArc welding process involving the use of the solid wire, the emission of carbon monoxide was by 20-25% lower than the emission accompanying the process performed using the flux-cored wire. During the AC MIG Pulse welding process performed using the solid wire, the emission of carbon monoxide was by nearly 20% lower than that accompanying the process involving the use of the flux-cored wire.

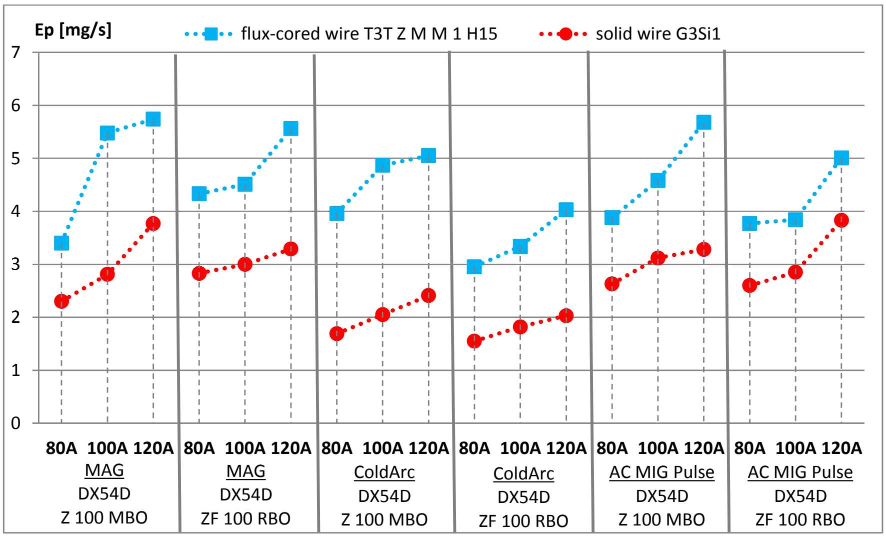


Fig. 5. Emission of total dust during the 82%Ar+18%CO_2-shielded MAG, ColdArc and AC MIG Pulse welding of protectively coated sheets involving the use of solid wire grade G3Si1 and flux-cored wire grade T3T Z M M 1 H15

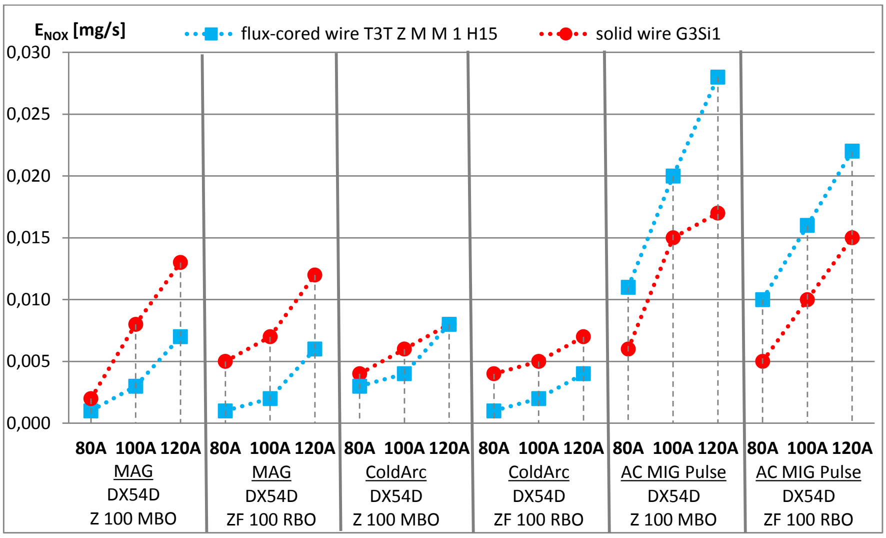


Fig. 6. Emission of nitrogen oxides during the 82%Ar+18%CO_2-shielded MAG, ColdArc and AC MIG Pulse welding of protectively coated sheets involving the use of solid wire grade G3Si1 and flux-cored wire grade T3T Z M M 1 H15

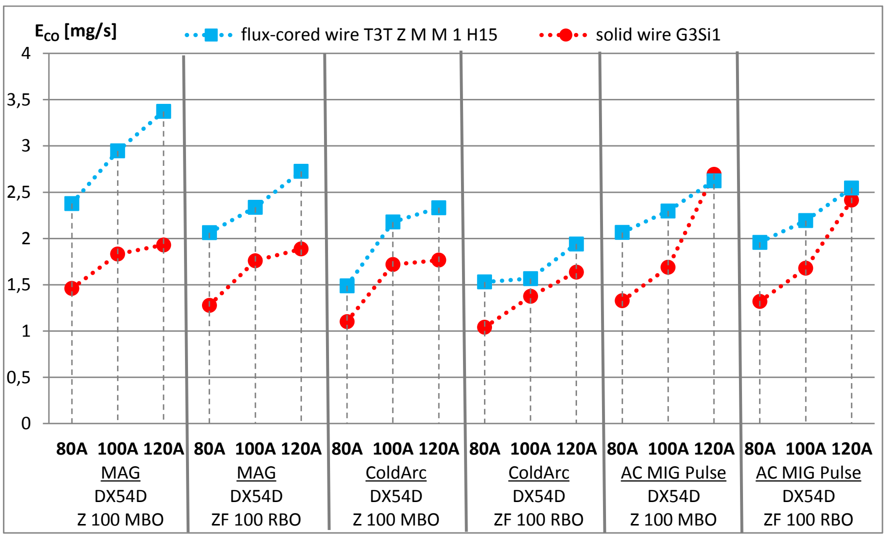


Fig. 7. Emission of carbon monoxide during the 82%Ar+18%CO_2-shielded MAG, ColdArc and AC MIG Pulse welding of protectively coated sheets involving the use of solid wire grade G3Si1 and flux-cored wire grade T3T Z M M 1 H15

Effect of current-voltage process parameters on the emission of dusts and gases

The emission of pollutants accompanying MAG, ColdArc, AC MIG Pulse and CMT welding was tested in relation to welding current restricted within the range of 80 A to 120 A and arc voltage restricted within the range of 12.0 V to 19.0 V. The graphic analysis of the correlation between current and the emission of dust in relation to the MAG, ColdArc, AC MIG Pulse and CMT welding of protectively coated sheets performed using the solid wire and the flux-cored wire is presented in Figure 8. The diagrams also presents regression lines and value R2 – (R-Square), (determination coefficient), i.e. information to what extent the equation of regression explains the variability of a dependent variable.

The analysis of the emission of welding fume revealed the general correlation between the value of current during arc welding and the emission of dust. The ascertained correlation was full and positive (directly proportional relationship), i.e. an increase in current was accompanied by an increase in the emission of dust, nitrogen oxides and carbon monoxide. The directly proportional positive correlation between the value of current and the emission of pollutants was identified in relation to all of the welding methods, base materials and filler metals.

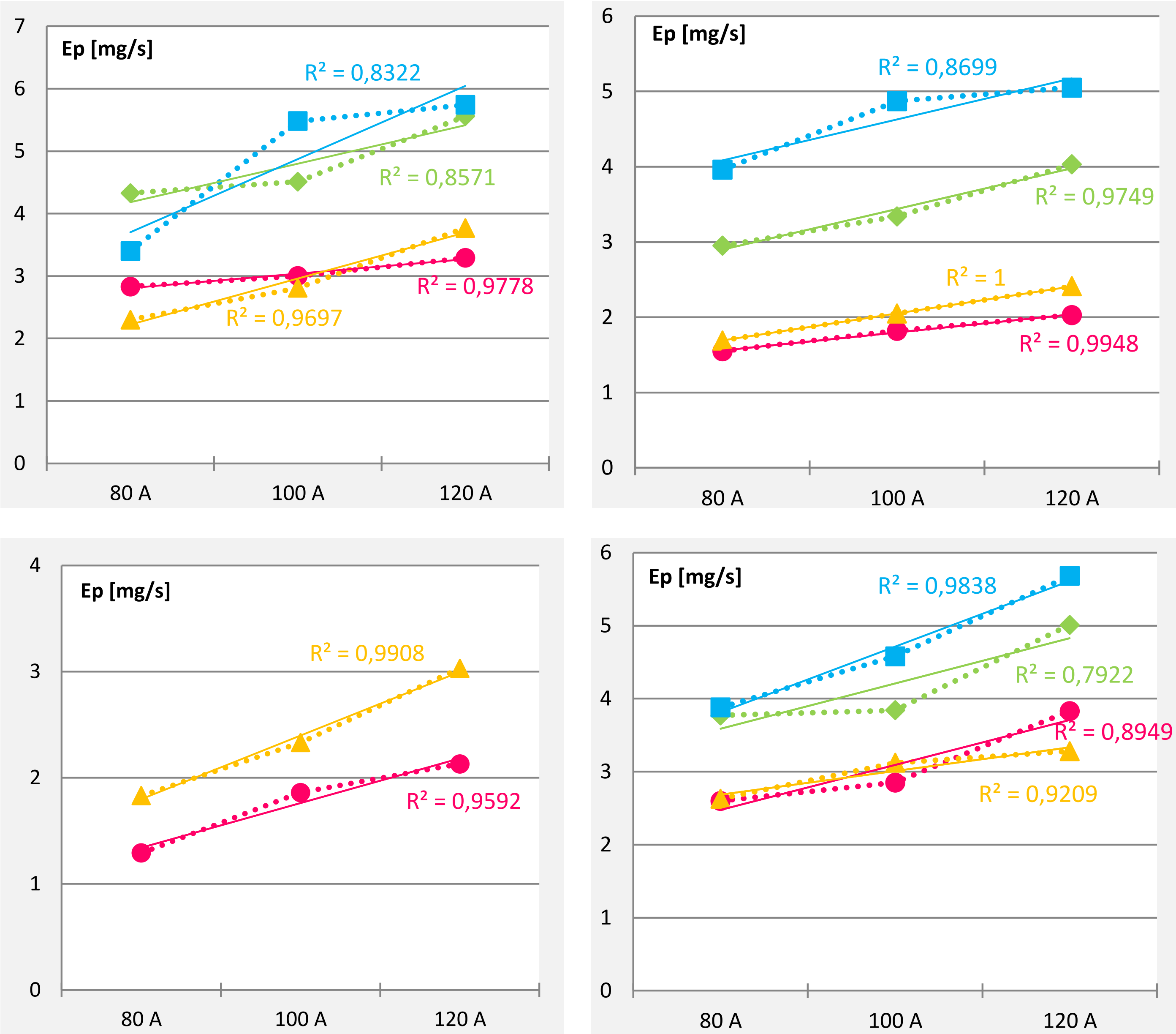


Fig. 8. Correlation between current and the emission of dust in relation to the MAG, ColdArc, AC MIG Pulse and CMT welding of protectively coated sheets performed using the solid wire and the flux-cored wire

Conclusions

1. The tests revealed the effect of a welding method on the emission of welding fume. The dominant factor affecting workers' health is the emission of total dust. The use of the 82%Ar +18% shielding gas mixture when welding protectively coated sheets is accompanied by the significant emission of carbon monoxide into the work environment.
   - As regards the welding of protectively coated sheets using solid wire grade G3Si1 having a diameter of 1.2 mm, the ColdArc method proved the most favourable as regards the reduction of the emission of total dust and that of carbon monoxide. In turn, the least favourable method was AC MIG Pulse.
   - As regards the welding of the Z and ZF-coated sheets using flux-cored wire T3T Z M M 1 H15, the ColdArc method proved the most favourable as regards the reduction of the emission of total dust and that of carbon monoxide. In turn, the highest emission of total dust and that of carbon monoxide accompanied the MAG welding process.
   - The indicators related to the emission of nitrogen oxides were considerably lower and in relation to all of the combinations did not exceed 0.03 mg/s. The highest values

of NOx emission accompanied the AC MIG Pulse welding of the Z and ZF-coated sheets. The above-named method was the least favourable both in terms of the process performed using solid wire grade G3Si1 and flux-cored wire T3T Z M M 1 H15.

2. The tests demonstrated the effect of a protective coating type on the emission of welding fume.
   - The welding of sheet with zinc coating, i.e. DX54D Z 100 MBO, was accompanied by the higher emission of total dust and carbon monoxide.
3. The tests demonstrated the effect of a filler metal type on the size of welding fume emission.
   - The higher emission of total dust and carbon monoxide occurred during welding involving the use of metallic flux-cored wire T3T Z M M 1 H15. The above-named tendency was observed in relation to all three welding methods, both filler metal grades and within the entire current range.
   - In relation to MAG and ColdArc welding, the higher emission of nitrogen oxides accompanied processes performed using solid wire grade G3Si1. In turn, in relation to the AC MIG Pulse welding of Z and ZF-coated sheets, the higher emission of nitrogen oxides accompanied the process performed using metallic flux-cored wire grade T3T Z M M 1 H15.
4. The analysis of the emission of welding fumees demonstrated the general correlation between the value of current during arc welding and the emission of dust. The ascertained correlation was full and positive (directly proportional relationship), i.e. an increase in current was accompanied by an increase in the emission of dust, nitrogen oxides and carbon monoxide. The directly proportional positive correlation between the value of current and the emission of pollutants was determined in relation to all of the welding methods, base materials and filler metals.

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