Jolanta Matusiak, Joanna Wyciślik

Analysis of influence of material-technological conditions of alternating polarity MIG welding of aluminium alloys on welding fumes emission

Abstract: It has been presented laboratory experiments on the influence of material-technological conditions of welding of four grades of aluminium alloys, namely EN AW 5251, EN AW 6082, EN AW 2017 A and EN AW 5754, by innovative methods such as AC Pulse and Cold Process, on the pollutants emission level. Investigation methodics has been discussed, the test stand has been presented and the relationships between the fume and gases emission quantity and the kind of aluminium alloy subjected to welding, the grade of filler metal and current-voltage prameters of welding have been analysed in detail. The fume emitted during welding of aluminium alloys by conventional MIG method has been compared to that generated during welding by pulse MIG, double pulse MIG and by low heat input methods (CMT, ColdArc, AC Pulse and Cold Process). The purpose of the investigation was to determine a method of aluminium alloys welding which would be an advantageous alternative to the above mentioned methods in respect of work environment protection and reduction in pollutants emission.

Keywords: welding, fumes emission, MIG, AC Pulse, Cold Process

Introduction

In automotive, aviation and electro-technical industries, as well as in the civil engineering sector, aluminium is currently considered to be a material of the future [1]. The development of aluminium applications is related to advances made in the production of new aluminium alloys which can reach the strength of good quality carbon steel while being about 3 times lighter. As of today, aluminium alloys find applications in building engineering (constructing structures) (20%), manufacturing means of transport (26%), production of wrappings (20%) and electronics (9%) [2]. In the years to come it will be possible to observe an increase in demand for aluminium alloys in sectors characterised by high innovativeness such as aviation, automotive industry and ship building. Alloys of the EN AW 5xxx series, characterised by very good weldability, find many applications in the production of modern means of transport. Alloy EN AW 5352 is used in the production of sections of spatial frameworks and floors in Audi A2 cars, whereas alloy EN AW 5083 is used in the production of door

dr inż. Jolanta Matusiak (PhD Eng.), mgr inż. Joanna Wyciślik (MSc Eng.) – Instytut Spawalnictwa, Zakład Technologii Zgrzewania i Inżynierii Środowiska /Department of Resistance and Friction Welding and Environmental Engineering/

and window frame pillars in modern trains [2]. The use of aluminium alloys for frames and floors in cars reduces their weight by 45% when compared to steel materials [1]. High-strength weldable aluminium alloys applied in modern ship building are those of series 5xxx (5383, 5059) and 7xxx (7020M) [3]. These alloys are used in the construction of increasingly large ship structures due to economic and environmental reasons as a 50% reduction in weight when compared to similar-sized vessels made of "conventional" materials provides numerous advantages.

Without appropriate joining methods aluminium alloys will not be used in the production of modern means of transport. The development of new methods of welding aluminium and their increasing application in various industrial sectors are connected with hazards to the work environment and human body. The years to come will see an increase in the number of welders exposed to noxiousness caused by the welding of aluminium alloys. High emission of fume and gases as well as the chemical composition of the fume and the toxic effect of aluminium on the human organism has led to aluminium welding being included in the group of technological processes being the subject of research works in occupational medicine as well as triggers the development and improvement of welding technologies. A factor shaping work conditions and affecting welders' health is mainly the emission of welding fume containing aluminium (Al_2O_3), magnesium, manganese and zinc oxides as well as silicon dioxide (silica). Implementing innovative arc welding methods for joining aluminium and its alloys in industrial conditions enables an increased reduction of pollution. Welding with a pulsating arc, having a double-pulsed arc, as well as the use of low-energy arc welding methods (CMT, ColdArc) for joining sheets made of aluminium alloys holds the key to the improvement of work conditions [4-7]. Research conducted at Instytut Spawalnictwa also confirmed that AC Pulse MIG welding (i.e. MIG welding with variable polarity current – developed by the OTC Daihen company and Cold Process – applied in devices manufactured by the Cloos company) used for joining small-thickness elements made of aluminium alloys makes it possible to limit the emission of fume and gases into the work environment.

This article analyses the impact of material and technological conditions of welding aluminium alloys by means of innovative AC Pulse and Cold Process methods on the size of pollution emission [8].

Tests, laboratory testing station and testing methodology

Tests on the emission of fume and gas pollutions generated during welding with a Cold Process method (S-Pulse CP and AC Pulse variants) were carried out for four aluminium alloys (EN AW 5251, EN AW 6082, EN AW 2017 A and EN AW 5754). The aluminium welding tests involved the use of a 2 mm thick sheet as well as filler metals differing in mechanical properties and chemical composition. The alloys

Table 1. Material scope for tests of pollution emissions

Welding method	Cold Process (S-Pulse CP)/ AC Pulse		
Base metal	Thickness [mm]	Filler metal (chemical symbol)	Wire diameter [mm]
EN AW 5251 (PA2) AlMg2Mn0.3	2.0	AlMg4.5MnZr	1.2
		AlMg5Cr	1.2
EN AW 6082 (PA4) AlSi1MgMn	2.0	AlMg4.5MnZr	1.2
		AlSi5	1.2
EN AW 2017A (PA6) AlCu4MgSi	2.0	AlMg4.5MnZr	1.2
		AlCu6MnZrTi	1.2
EN AW 5754 (PA11) AlMg3	2.0	AlMg4.5MnZr	1.2
		AlMg5Cr	1.2

Table 2. Chemical composition of base metals [9]

Alloy designation		Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti
Numerical	Chemical symbol	in % (m/m)							
EN AW 5251	AlMg2Mn0,3	0.4	0.5	0.15	0.1-0.5	1.7-2.4	0.15	0.15	0.15
EN AW 6082	AlSi1MgMn	0.7-1.3	0.5	0.1	0.4-1.0	0.6-1.2	0.25	0.2	0.1
EN AW 2017A	AlCu4MgSi	0.2-0.8	0.7	3.5-4.5	0.4-1.0	0.4-1.0	0.1	0.25	-
EN AW 5754	AlMg3	0.40	0.4	0.1	0.5	2.6-3.6	0.3	0.2	0.15

Table 3. Chemical composition and mechanical properties of filler metals used in tests [10]

Alloy designation	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Rm [MPa]	Rp0.2 [MPa]
Chemical symbol	in % (m/m)									
Al 5087*) AlMg4.5MnZr	0.25	0.4	0.1	0.7-1.1	4.5-5.2	0.05-0.25	0.25	0.15	275	125
Al 5356 AlMg5Cr	0.25	0.4	0.1	0.05-0.2	4.5-5.5	0.05-0.2	0.1	0.06-0.2	265	120
Al 2319 AlCu6MnZrTi	< 0.20	< 0.30	5.8-6.8	0.2-0.4	< 0.02	0.1-0.25	0.10	0.1-0.2	240	180
Al 4043 AlSi5	4.6-6.0	0.8	0.3	0.05	0.05	-	0.1	0.20	165	40

*) Filler metal Al 5087 contains additionally 0.1 – 0.2 % zirconium

of 5xxx series were welded by means of AlMg5Cr (Al 5356) and AlMg4.5MnZr (Al 5087) electrode wires with a diameter of 1.2 mm. Welding aluminium alloys of 6xxx series involved the use of a recommended filler metal containing magnesium and manganese (AlMg4.5MnZr ϕ1.2 mm) as well as a filler metal containing silicon AlSi5 (Al 4043) ϕ1.2 mm. The alloys of 2xxx series were welded with two different filler metals, i.e. a wire AlMg4.5MnZr (Al 5087) and a wire containing from 5.8 to 6.8% copper AlCu6MnZrTi (Al 2319). The wire AlMg4.5MnZr was used in all tests (for all aluminium alloys put to tests). Table 1 presents base and filler metals used in the tests of the emission of pollutions generated while welding aluminium alloys by means of the Cold Process and AC Pulse methods. Tables 2 and 3 present the chemical composition of the base and filler metals used in the tests.

All the tests of pollution emissions were used with an argon-based arc shielding gas. Current-voltage parameters, filler metal feeding rate and welding rate were selected for all measurements having in view the aesthetics of a joint (overlay weld), the absence of excess weld reinforcement and the elimination of porosity.

The station for testing the emission of pollutions is presented in Figures 1 and 2.

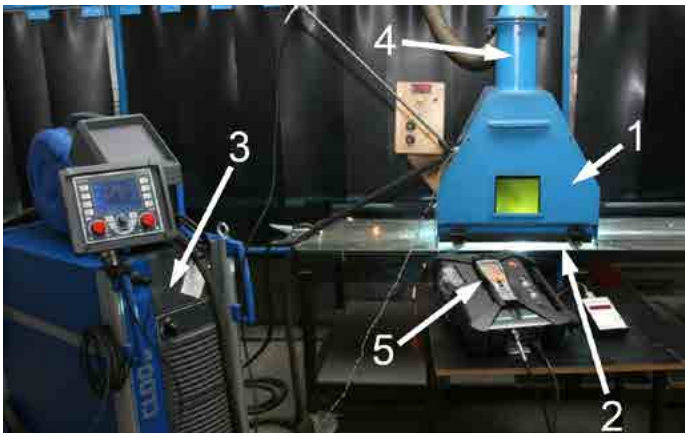

Fig. 1. Test station for testing emissions of dust and gases during welding with Cold Process method, device QINEO CHAMP 450 Cloos

1. Dust chamber;
2. Welding table;
3. Welding device;
4. Suction duct and dust filter;
5. Analyser TESTO 350

Fig. 2. Test station for testing emissions of dust and gases during welding with AC Pulse method; device DW 300 OTC Daihen.
1. Dust chamber; 2. Welding table; 3. Welding device

The device Qineo Champ manufactured by the Cloos company is equipped with several synergic lines used for welding aluminium and its alloys. The tests were carried out using the Cold Process option enabling the use of variable polarity current - variant S-Pulse CP (the name of a synergic line CP in the control system of the Qineo Champ device). In the case of the device DW 300 manufactured by the OTC Daihen company the tests involved the use of variable polarity GMA welding with pulsation - AC Pulse.

The test station and testing methodology were developed in accordance with the requirements of standard PN-EN ISO 15011 [11, 12]. Sampling fume for emission determination was based on the gravimetric method. The fume testing principle requires collecting fume on measurement filters during welding in a hermetic chamber using the suction device. A detailed preparation of the methodology for testing fume emissions for various arc welding methods is mainly related to the selection of a proper fume chamber design, measurement filters and welding time. In the case of welding with low-energy methods the design of a fume chamber and the whole test station enable welding test elements made of thin sheets. In order to prevent the heating of a test element it was necessary to adopt a solution in which a chamber is moved at an appropriate travel rate along a sample being welded. Testing fume emission is carried out properly only when no pollution leaves the fume chamber. In order to properly determine the size of fume emission it is necessary to select appropriate measurement filters as mass stability, allowing for humidity, prior to and following a measurement, ensures the repeatability of results independent of environmental conditions. Filters used for the quantitative determination of fume emission were PTM-B type filers with a diameter of 150 mm. Another important factor ensuring the repeatability of test results during the quantitative determination of fume emission is the proper adjustment of welding time. In the case of low-energy methods welding time was determined on the basis of initial tests. It was assumed that the minimum time of welding in a chamber should amount to 60s as this time, independent of current parameters, ensures obtaining a minimum fume growth (10mg) on a measurement filter. Testing gas emissions accompanying welding is carried out directly, i.e. using an analyser Testo-350 with a direct readout of gases (NO, NO_2, CO) and temperature.

Table 4. Technological parameters for testing emission of dust and gases during welding aluminium alloys with Cold Process and AC Pulse methods

Cold Process		
Welding current intensity, [A]	54-61	80
Arc voltage, [V]	14.8	15.8
Filler metal feeding rate, [m/min]	3.4	4.9
Welding rate, [mm/min]	420	830
AC Pulse		
Welding current intensity, [A]	51-54	75-84
Arc voltage, [V]	15-18	16-20
Filler metal feeding rate, [m/min]	3.2-3.6	4.7-5.1
Welding rate, [mm/min]	420	830

Tests results concerning the impact of material-technological conditions on the emission of fume and gases during welding aluminium alloys with Cold Process and AC Pulse methods

The tests of pollution emissions during welding aluminium alloys with Cold Process and AC Pulse methods revealed the impact of many factors on the emission of fume and nitrogen oxides. The size of pollution emission is related to the type of an aluminium alloy being welded, the type of a filler metal applied and the current-voltage parameters of the process. The tests determined the indicators of pollution emission related to specific material and technological conditions. The comparison of emission size and the analysis of dependences between welding conditions and pollution emission can be carried out taking into consideration test input data such as the joining method, the same kind of base metal, the same grade of electrode wire and the diameter of the electrode wire. The size of pollution emission is also conditioned by the current parameters of a process. For this reason the tests were conducted for a short-circuit arc varying in energy supplied to a joint. Table 4 presents welding technological parameters for which pollution emission tests were carried out [8].

Emission of fume and nitrogen oxides during welding aluminium alloy with Cold Process method

The analysis of test results revealed that the size of fume emission for all tested aluminium alloys welded with the same filler metal is diverse (Fig. 3). The highest fume emission indicators were determined for welding with the wire AlMg4.5MnZr of EN AW 5251

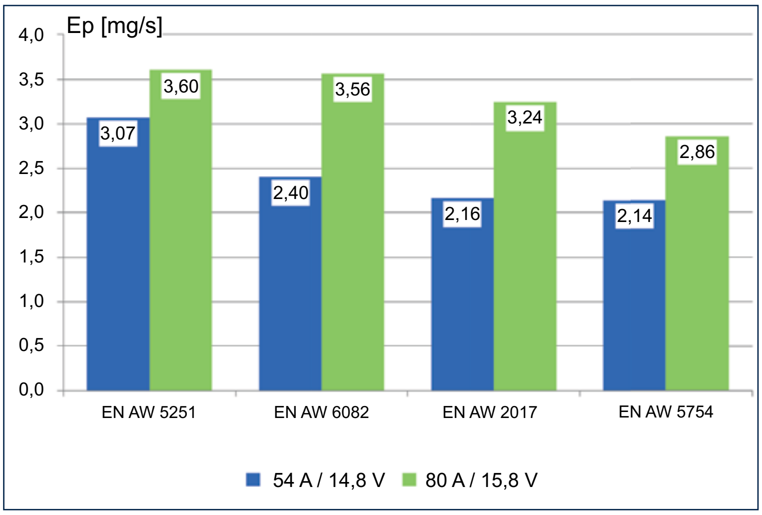

Fig. 3 Dust emission while welding aluminium alloys of 5xxx, 6xxx and 2xxx series with Cold Process method using filler metal grade AlMg4.5MnZr ϕ1.2 mm, in Ar-based shielding gas

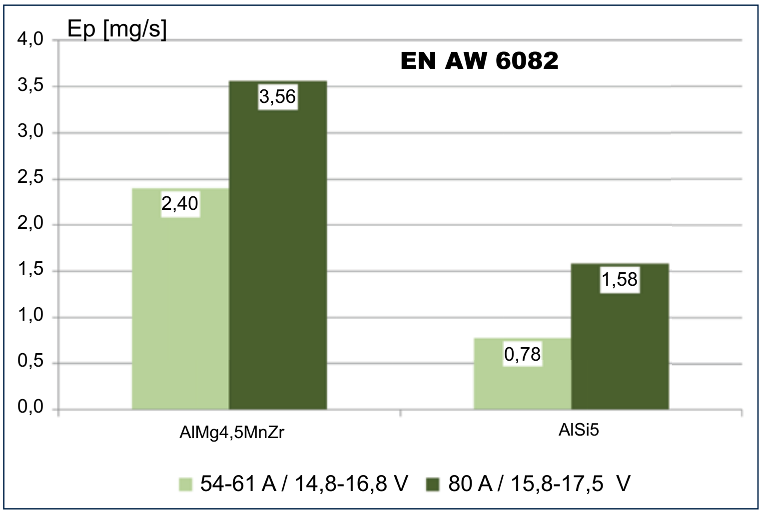

Fig. 4 Dust emission while welding aluminium alloy EN AW 6082 with Cold Process method using filler metal grades AlMg4.5MnZr and AlSi5r ϕ1.2 mm, in Ar-based shielding gas

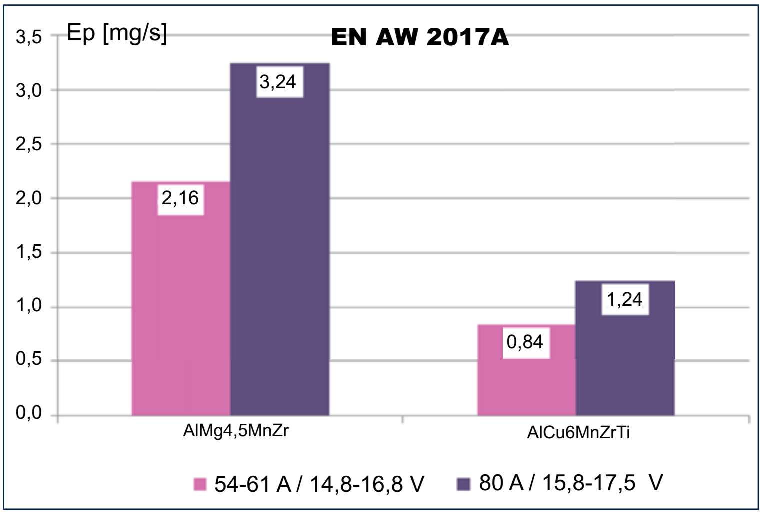

Fig. 5 Dust emission while welding aluminium alloy EN AW 2017A with Cold Process method using filler metal grades AlMg4.5MnZr and AlCu6MnZrTi ϕ1.2 mm, in Ar-based shielding gas

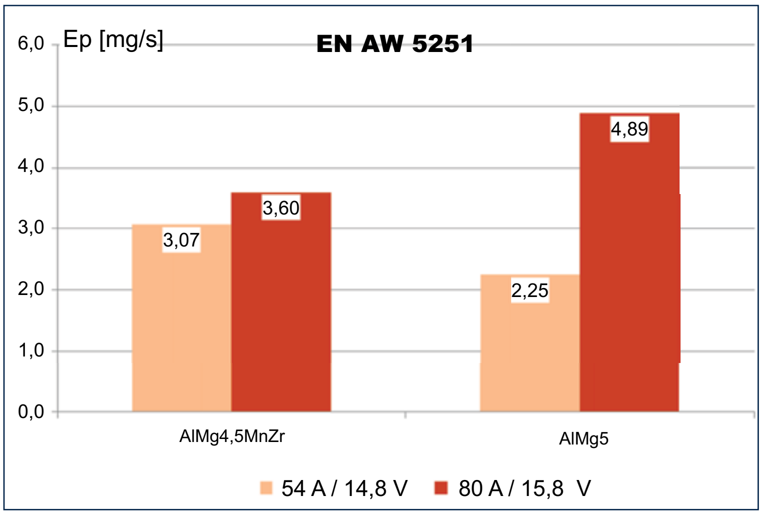

Fig. 6 Dust emission while welding aluminium alloy EN AW 5251 with Cold Process method using filler metal grades AlMg4.5MnZr and AlMg5Cr ϕ1.2 mm, in Ar-based shielding gas

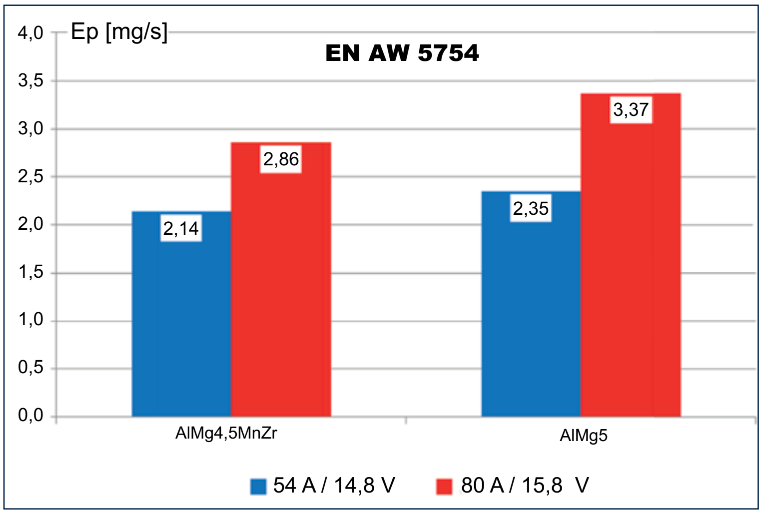

Fig. 7 Dust emission while welding aluminium alloy EN AW 5754 with Cold Process method using filler metal grades AlMg4.5MnZr and AlMg5 ϕ1.2 mm, in Ar-based shielding gas

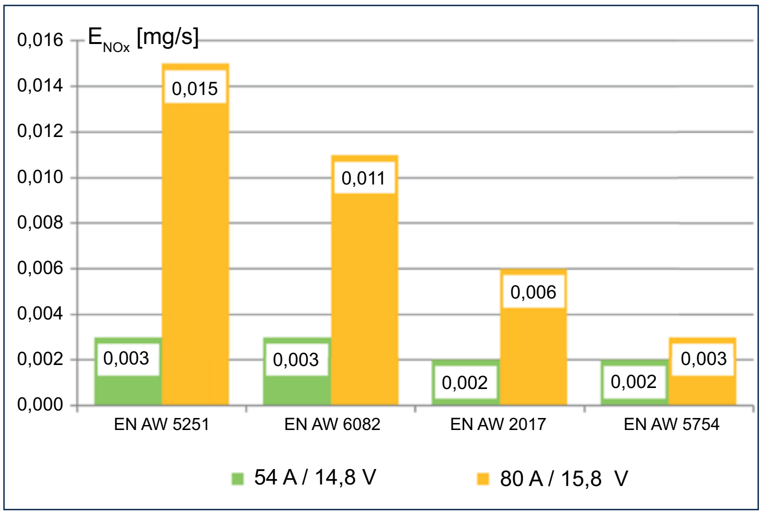

Fig. 8 NO_x emission while welding aluminium alloys of 5xxx, 6xxx and 2xxx series with Cold Process method using filler metal grade AlMg4.5MnZr ϕ1.2 mm, in Ar-based shielding gas

alloy, whereas the lowest fume emission was determined for the alloy EN AW 5754. The sizes of fume emission accompanying welding alloys of 6xxx and 2xxx series with the use of the filler metal grade w gat. AlMg4.5MnZr were similar (Fig.3).

The grade of a filler metal has a significant impact on the size of fume emission during welding aluminium alloys. This tendency was revealed for all the aluminium alloys tested. Particularly significant differences were observed while welding alloys EN AW 6082 and EN AW 2017A. In the case of the alloy 6xxx, the wires AlMg4.5MnZr and AlSi5 were used; for the filler metal AlSi5 the size of fume emission within a tested current range was approximately 2.5 times lower in comparison with that obtained for the wire AlMg4.5MnZr (Fig. 4). For welding the alloy 2xxx the wires AlMg4.5MnZr and AlCu6MnZrTi were used; for the filler metal AlCu6MnZrTi the size of fume emission within a tested current range was also approximately 2.5 times lower in comparison with that obtained for the wire AlMg4.5MnZr (Fig. 5). While welding aluminium alloys of 5xxx series (EN AW 5251 and EN AW 5754) the selection of the filler metal grade AlMg4.5MnZr proved convenient as regards to the size of fume emission (Fig. 6, 7). For the aforesaid filler metal the size of fume emission was smaller if compared to the fume emission generated with the filler metal AlMg5Cr.

The wire grade AlMg5Cr was characterised by higher emission during welding alloys of 5xxx series. A difference in the chemical composition of the wires AlMg4.5MnZr and AlMg5Cr is concerned with the content of manganese and magnesium. According to reference publications manganese is a chemical element which does not significantly affect the size of fume emission. An increase in fume emission is attributed to greater magnesium content in the filler metal composition [13]. In the case of the filler metals tested the content of magnesium amounted to 4.5-5.2 [%, m/m] in the wire AlMg4.5MnZr and to 4.5-5.5 [%, m/m] in the wire AlMg5Cr. A difference in magnesium content in the wires tested can be between 0.5 and 1%, with greater magnesium content in the wire AlMg5Cr. The emission of fume during welding with the wire AlMg5Cr is approximately 10-30% higher if compared to that generated while welding with the wire AlMg4.5MnZr.

The impact of magnesium content in the filler metal on the size of fume emission during welding the alloy EN AW 2017A is clearly visible while analysing the emission of fume generated using two wires differing in a chemical composition, namely AlCu6MnZrTi and AlMg4.5MnZr. As mentioned above, for the filler metal AlCu6MnZrTi the size of fume emission was approximately 2.5 times lower than in the case of the wire AlMg4.5MnZr. In the case of the filler metals tested the content of magnesium was < 0.02 [%, m/m] in the wire AlCu6MnZrTi and 4.5-5.2 [%, m/m] in the wire AlMg4.5MnZr. A negligible amount of magnesium in the wire AlCu6MnZrTi was a probable reason for the lower emission of fume generated during welding the alloys of series 2xxx. The lowest fume emission was observed for the electrode wire grade AlSi5 (welding alloy EN AW 6082) and the wire AlCu6MnZrTi (welding alloy EN AW 2017A). The highest fume emission indicators were determined for the filler metal AlMg5Cr during welding

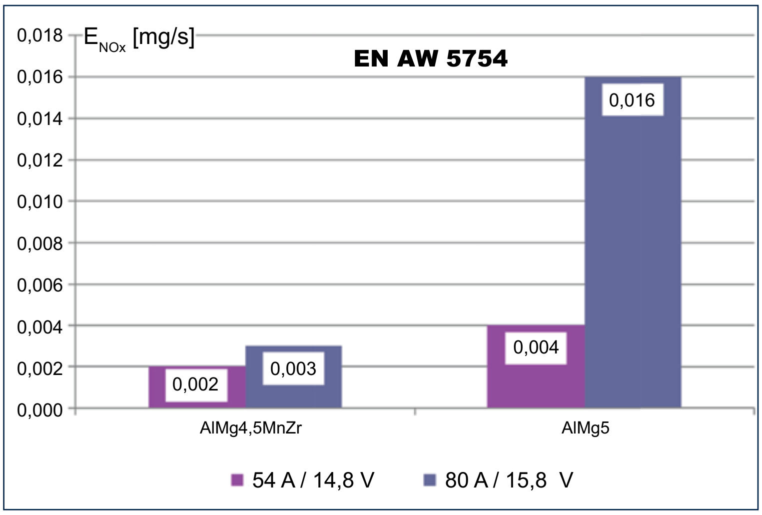

Fig. 9 NO_x emission while welding aluminium alloy EN AW 5754 with Cold Process method using filler metal grades AlMg4.5MnZr and AlMg5 ϕ1.2 mm, in Ar-based shielding gas

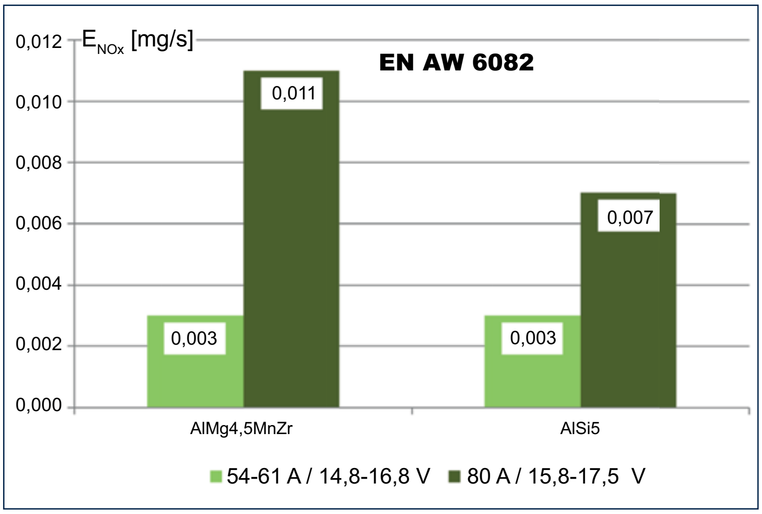

Fig. 10 NO_x emission while welding aluminium alloy EN AW 6082 with Cold Process method using filler metal grades AlMg4.5MnZr and AlSi5r ϕ1.2 mm, in Ar-based shielding gas

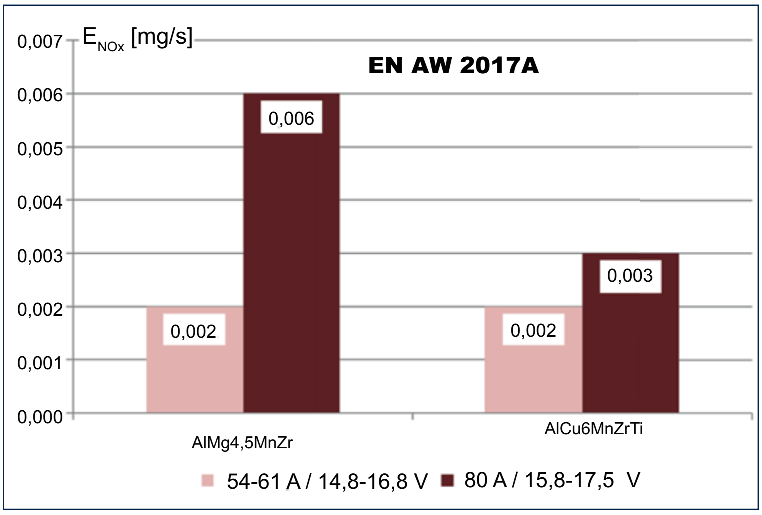

Fig. 11 NO_x emission while welding aluminium alloy EN AW 2017A with Cold Process method using filler metal grades AlMg4.5MnZr and AlCu6MnZrTi ϕ1.2 mm, in Ar-based shielding gas alloys EN AW 5251 and EN AW 5754. The comparative analysis of the emission of fume generated while welding aluminium alloys of 5xxx, 6xxx and 2xxx series with the Cold Process method revealed that the selection of a filler metal significantly affects the size of fume emission.

The emission of nitrogen oxides generated during welding aluminium alloys with the CP method is mainly connected with the grade of filler metal used. The impact a filler metal on the size of NO_x emission was revealed for all aluminium alloys tested (Fig. 8-12). While welding the alloy EN AW 5754 with the filler metal AlMg5Cr the emission of NO_x for higher current parameters of the process was 5 times higher than the emission generated while welding with the wire AlMg4.5MnZr (Fig. 9). In turn, while welding the alloy EN AW 6082 with the filler metal AlMg4.5MnZr the emission of NO_x was higher than while using the wire grade AlSi5 (Fig. 10). The lowest emission of nitrogen oxides was that of the electrode wire AlCu6MnZrTi used during welding the alloy EN AW 2017A. The highest NO_x emission indicators were determined for the filler metal AlMg5Cr used while welding EN AW 5251 and EN AW 5754 alloys. The tests revealed that the size of nitrogen oxide emission is related to the current parameters of the process. In the case of all the tested aluminium alloys welded with various filler metals an increase in current intensity and arc voltage was accompanied by an increase in nitrogen oxide emission.

The dependence between current intensity and arc voltage and the emission of fume and nitrogen oxides during welding aluminium alloys of 5xxx, 6xxx and 2xxx series with the Cold Pro-

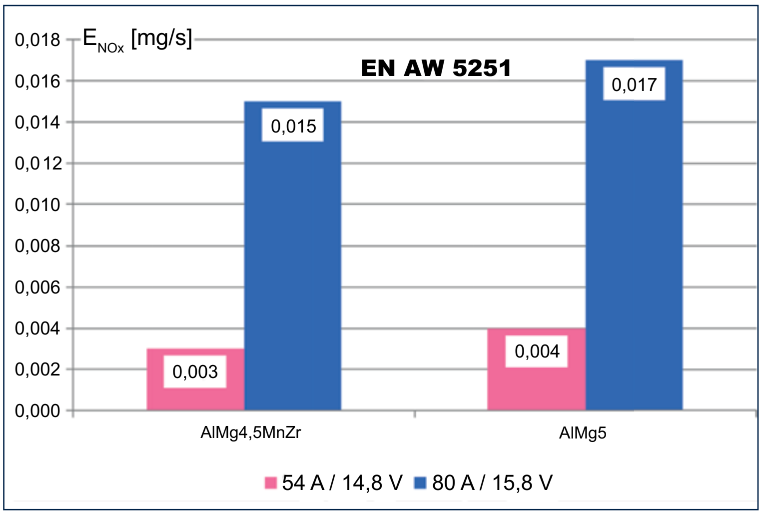

Fig. 12 NO_x emission while welding aluminium alloy EN AW 5251 with Cold Process method using filler metal grades AlMg4.5MnZr and AlMg5Cr ϕ1.2 mm, in Ar-based shielding gas

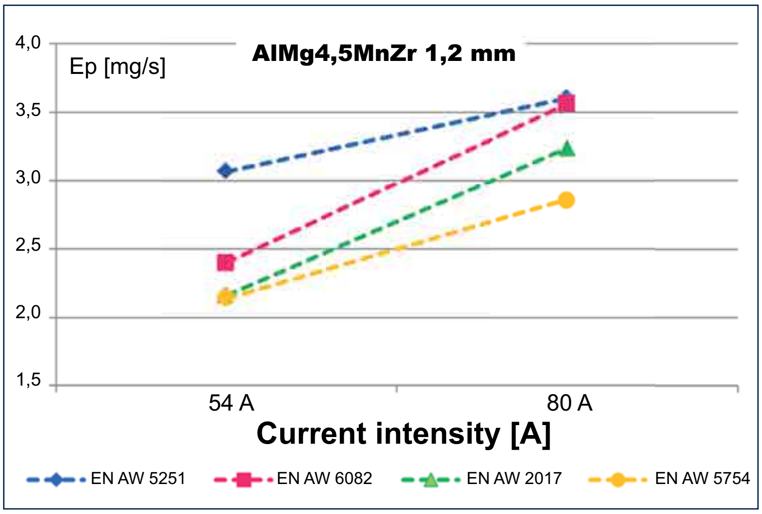

Fig. 13. Impact of current intensity on dust emission while welding aluminium alloys of 5xxx, 6xxx and 2xxx series with Cold Process method using filler metal grade AlMg4.5MnZr ϕ1.2 mm, in Ar-based shielding gas

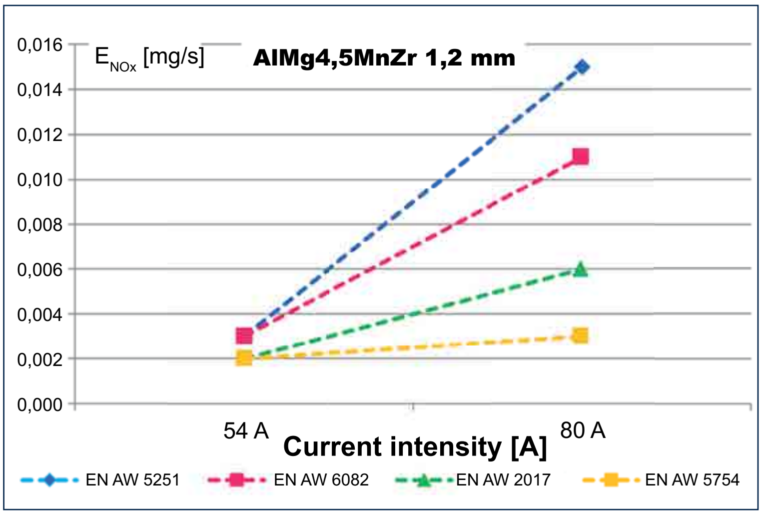

Fig. 14. Impact of current intensity on NO_x emission while welding aluminium alloys of 5xxx, 6xxx and 2xxx series with Cold Process method using filler metal grade AlMg4.5MnZr ϕ1.2 mm, in Ar-based shielding gas

cess method was determined for all the filler metals tested. Higher current intensity and arc voltage applied while welding with the Cold Process method increased the emission of total fume and of NO_x (Fig. 13-14). For instance, the fume emission for the filler metal AlMg4.5MnZr used during welding the alloy EN AW 5251 was from 3.07 mg/s (low--power arc I=54 A, U=15.8 V) to 3.60 mg/s (higher power arc: I=80 A, U=15.8 V) (Fig. 13). It was possible to observe a 15% increase in the size of fume emission for the higher current parameters of the process. In the case of the wire AlMg5Cr used for welding the alloy EN AW 5251 this dependence is even more visible as the emission of fume is between 2.25 mg/s (I=54 A, U=14.8 V) and 4.89 mg/s (I=80 A, U=15.8 V): higher arc power and greater filler metal feeding rate doubled the emission of fume (Fig. 6). The impact of current-voltage technological parameters of Cold Process welding is particularly evident for the emission of nitrogen oxides. While analysing the results of NO_x emission for welding the alloy EN AW 5251 with the wire AlMg4.5MnZr it was possible to observe that emission increased 5 times in the case of higher current-voltage parameters (I=80 A, U=15.8 V) in comparison with a current intensity of 54 A and voltage of 14.8 V (Fig. 12). During welding the alloy EN AW 5251 with the filler metal AlMg5Cr the emission of nitrogen oxides is between 0.004mg/s (I=54 A, U=14.8 V) and 0.017 mg/s (I=80 A, U=15.8 V); for higher arc power and greater filler metal feeding rate the emission of NO_x increased 4 times.

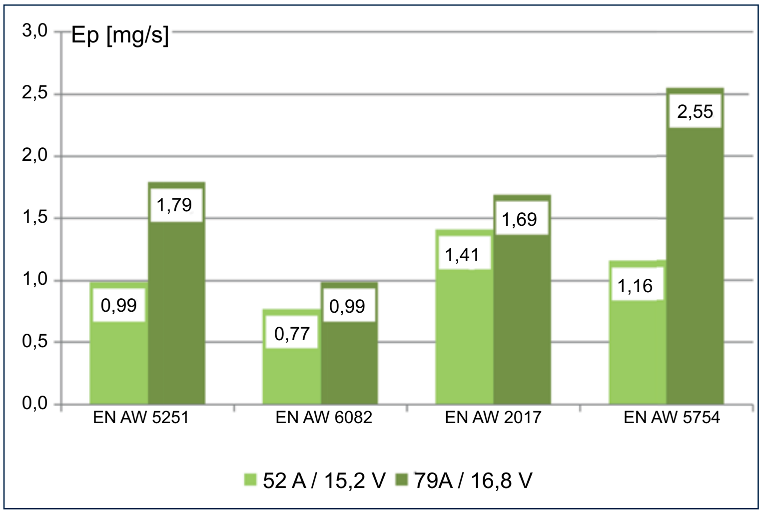

Fig. 15 Dust emission while welding aluminium alloys of 5xxx, 6xxx and 2xxx series with AC Pulse method using filler metal grade AlMg4.5MnZr ϕ1.2 mm, in Ar-based shielding gas

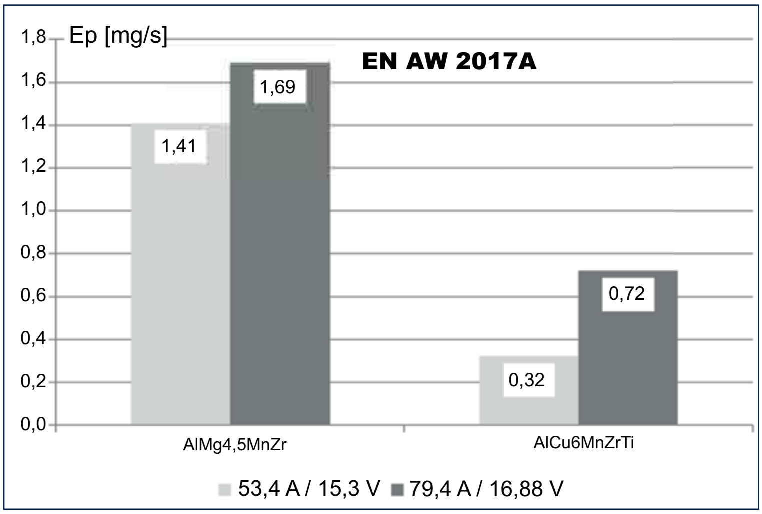

Fig. 16 Dust emission while welding aluminium alloy EN AW 2017A with AC Pulse method using filler metal grades AlMg4.5MnZr and AlCu6MnZrTi ϕ1.2 mm, in Ar-based shielding gas

Emission of fume and nitrogen oxides during welding aluminium alloy with AC Pulse method

The analysis of the test results revealed that the size of fume emission for all the tested aluminium alloys welded with the same filler metal was diverse (Fig. 15). During welding the aluminium alloys of 5xxx, 6xxx and 2xxx with the AC Pulse method and the AlMg4.5MnZr filler metal wire with a diameter of 1.2 mm the emission of fume was between 0.77 mg/s (EN AW 6082) and 1.41 mg/s (EN AW 2017) for current-voltage parameters of 52A/15V and between 0.99 mg/s (EN AW 6082) and 2.55 mg/s (EN AW 5754) for current-voltage parameters of 79A/16.8V. The highest fume emission indicators were determined for welding the alloy

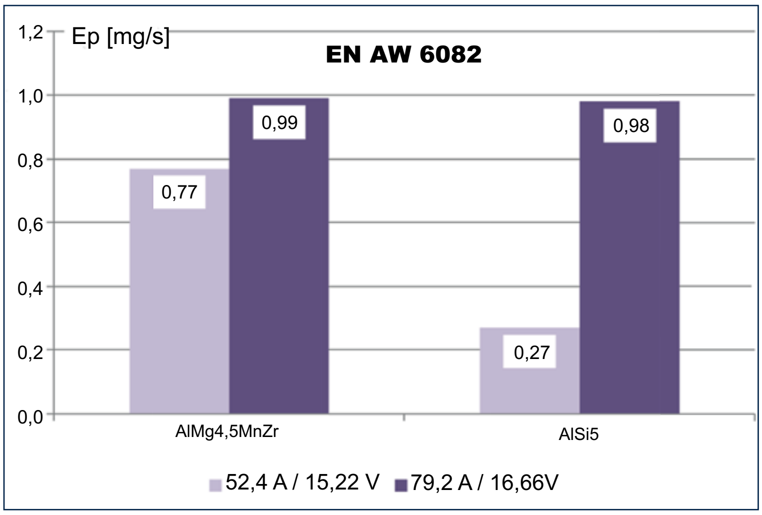

Fig. 17 Dust emission while welding aluminium alloy EN AW 6082 with AC Pulse method using filler metal grades AlMg4.5MnZr and AlSi5r ϕ1.2 mm, in Ar-based shielding gas

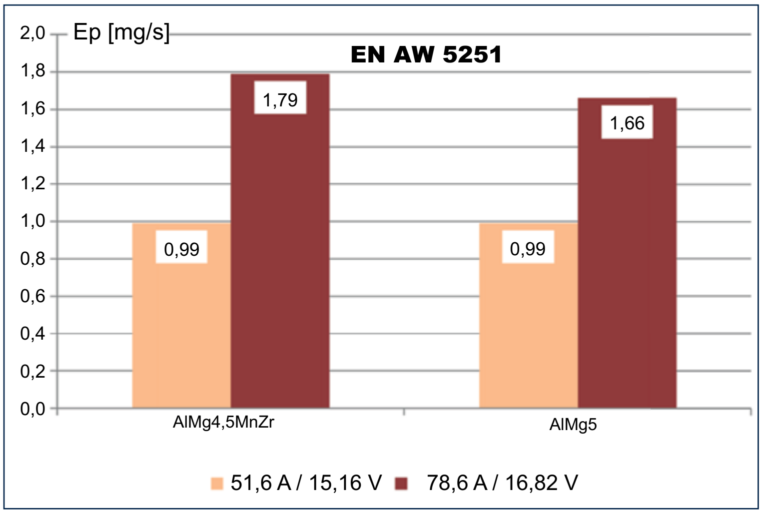

Fig. 18 Dust emission while welding aluminium alloy EN AW 5251 with AC Pulse method using filler metal grades AlMg4.5MnZr and AlMg5Cr ϕ1.2 mm, in Ar-based shielding gas

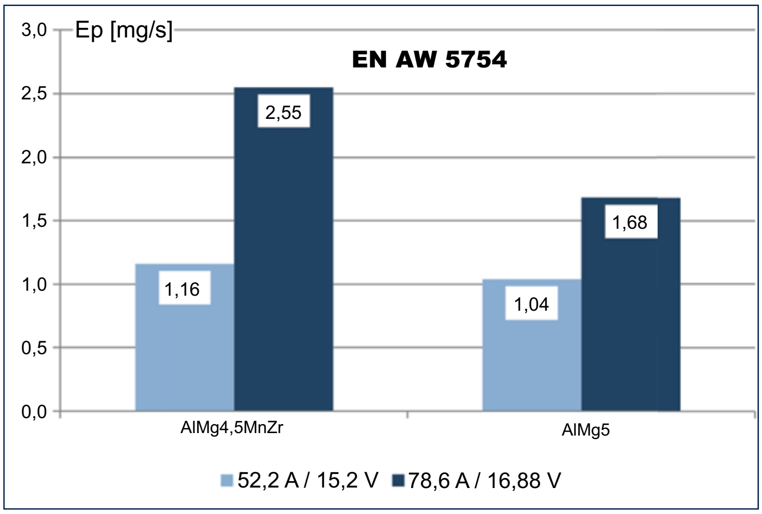

Fig. 19 Dust emission while welding aluminium alloy EN AW 5754 with AC Pulse method using filler metal grades AlMg4.5MnZr and AlMg5 ϕ1.2 mm, in Ar-based shielding gas

EN AW 5754 and EN AW 2017 with the wire AlMg4.5MnZr, whereas the lowest fume emission was observed in the case of the alloy EN AW 6082.

The tests revealed that the grade of filler metal has a significant impact on the size of fume emission. The aforesaid dependence was observed in the case of all the aluminium alloys tested. Particularly visible differences were observed during welding the alloy EN AW 2017A. The alloy of 2xxx series was welded with the wire AlMg4.5MnZr and AlCu6MnZrTi; for the filler metal AlCu6MnZrTi the size of fume emission in the tested current range was approximately 3 times lower if compared to the emission accompanying the use of the wire AlMg4.5MnZr (Fig. 16). During welding the alloy EN AW 6082 lower fume emission accompanied the use of the wire AlSi5 (Fig. 17). During welding of 5xxx series aluminium alloys (EN AW 5251 and EN AW 5754) it was possible to observe that the use of the filler metal AlMg5Cr had an advantageous effect as regards the size of fume emission (Fig. 18, 19). During welding the alloy EN AW 5754 with the AlMg5Cr wire the emission of fume in the tested current range was 25% lower if compared with the emission during welding with the filler metal AlMg4.5MnZr. In turn, during welding the alloy EN AW 5251 with the filler metal AlMg5Cr the emission of fume was lower by 8%.

Filler wires used for welding the aluminium alloys of 5xxx series with the AC Pulse method were the grades AlMg4.5MnZr and AlMg5Cr. The analysis of test results revealed lower values of fume emission (in the range 8-25%) for welding with the wire AlMg5Cr. In order to reduce fume emission during welding the aluminium alloys of 5xxx series with the Cold Process method it is advisable to use the wire grade AlMg4.5MnZr. During welding 5xxx series alloys with the CP and AC Pulse methods it was not possible to determine the identical correlation between the grade of a filler metal selected for welding and the size of fume emission.

The tests of fume emission accompanying welding 2xxx series alloys with the AC Pulse method, similarly as in the case of the Cold Process method, confirmed the impact of magnesium content in the filler metal on the size of fume emission. The alloy EN AW 2017Awas welded with the wire grades AlCu6MnZrTi and AlMg4.5MnZr. The fume emission for the filler metal AlCu6MnZrTi was approximately 3 times lower if compared to the emission generated during welding with the wire AlMg4.5MnZr. In the case of the filler metals tested the content of magnesium was < 0.02 [%, m/m] in the wire AlCu6MnZrTi and 4.5-5.2 [%, m/m] in the wire AlMg4.5MnZr. A negligible amount of magnesium in the wire AlCu6MnZrTi was a probable reason for the lower emission of fume generated during welding the alloys of 2xxx series. While welding the alloys of 2xxx series with the CP and AC Pulse methods it was possible to observe that the emission of fume was lower when the filler metal grade AlCu6MnZrTi was used.

The alloys of 6xxx series were welded with the wires AlSi5 and AlMg4.5MnZr. The tests of fume emission accompanying welding the aforesaid alloy with the CP and AC Pulse methods revealed the same dependence between the grade of a filler metal and the size of fume emission; lower values of fume emission were observed for the wire AlSi5.

After analysing the results related to the four filler metals used for welding

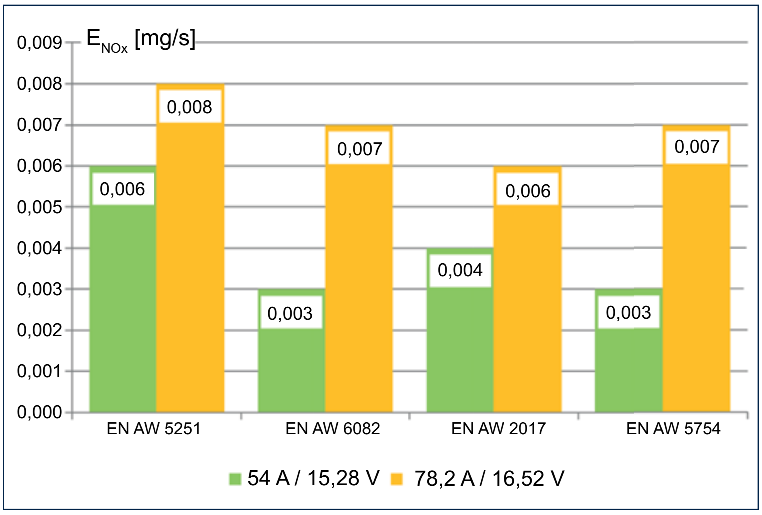

Fig. 20 NO_x emission while welding aluminium alloys of 5xxx, 6xxx and 2xxx series with AC Pulse method using filler metal grade AlMg4.5MnZr ϕ1.2 mm, in Ar-based shielding gas

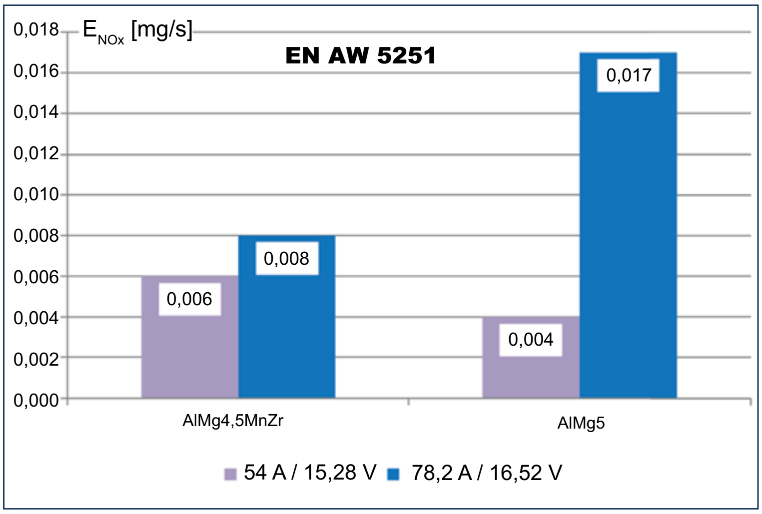

Fig. 21 NO_x emission while welding aluminium alloy EN AW 5251 with AC Pulse method using filler metal grades AlMg4.5MnZr and AlMg5Cr ϕ1.2 mm, in Ar-based shielding gas

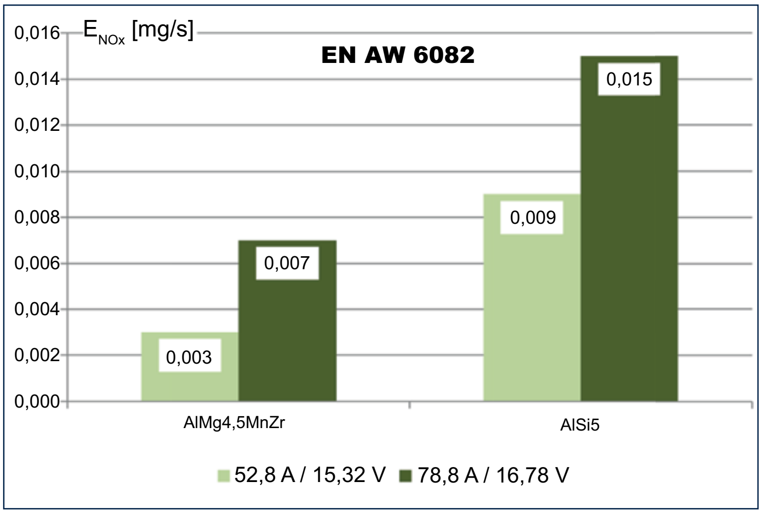

Fig. 22 NO_x emission while welding aluminium alloy EN AW 6082 with AC Pulse method using filler metal grades AlMg4.5MnZr and AlSi5r ϕ1.2 mm, in Ar-based shielding gas various aluminium alloys it was possible to conclude that the lowest fume emission accompanied the use of the electrode wire grade AlSi5 – during welding the alloy EN AW 6082 and the use of the wire AlCu6MnZrTi - during welding the alloy EN AW 2017A. The highest fume emission indicators were determined for the filler metal AlMg4.5MnZr used during welding the alloys EN AW 5251, EN AW 5754 and EN AW 2017A. The analysis of the fume emission generated during AC Pulse welding of 5xxx, 6xxx and 2xxx series aluminium alloys revealed that a filler metal affects the size of fume emission and may hold the key to the reduction of fume emission.

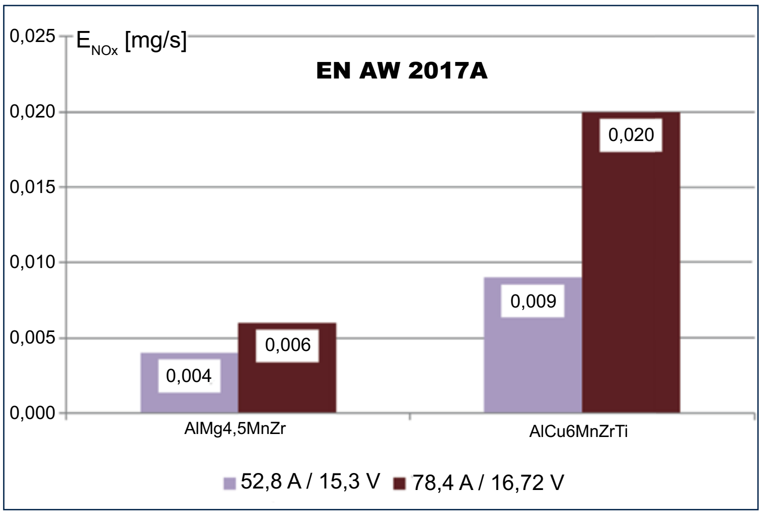

Fig. 23 NO_x emission while welding aluminium alloy EN AW 2017A with AC Pulse method using filler metal grades AlMg4.5MnZr and AlCu6MnZrTi ϕ1.2 mm, in Ar-based shielding gas

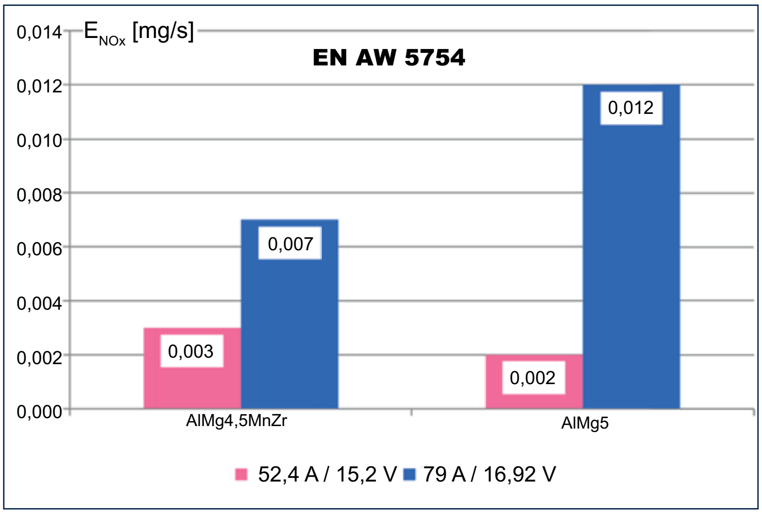

Fig. 24 NO_x emission while welding aluminium alloy EN AW 5754 with AC Pulse method using filler metal grades AlMg4.5MnZr and AlMg5 ϕ1.2 mm, in Ar-based shielding gas

The emission of nitrogen oxides generated during welding aluminium alloys with the AC Pulse method depends on the grade of a filler metal used. The impact of a filler metal grade on the size of NO_x emission was observed for all the aluminium alloys tested (Fig. 20-24). During welding the alloy EN AW 5251 with the wire AlMg5Cr the emission of NO_x for higher current parameters of the process was 2 times higher in comparison with the emission generated with the wire AlMg4.5MnZr (Fig. 21). During welding the alloy EN AW 6082 with the wire AlSi5 the emission of NO_x was 2-3 times higher than while using the wire AlMg4.5MnZr (Fig. 22). During welding the alloy EN AW 2017A higher emission of nitrogen oxides was observed for the filler metal AlCu6MnZrTi; within a tested current range the emission was 2.5 times higher in comparison with the emission generated with the wire AlMg4.5MnZr (Fig.23). The reduction of nitrogen oxide emission during welding the aluminium alloys of 5xxx 2xxx and 6xxx series with the AC Pulse method requires the use of the filler metal grade AlMg4.5MnZr as the use of this filler metal grade generated the lowest emission of NO_x. A similar impact of a filler metal grade on the size of nitrogen oxide emission was observed during welding the alloys of 5xxx series with the Cold Process method. The use of the wire AlMg4.5MnZr for welding the alloys EN AW 5251 and EN AW 5754 with the CP method proved advantageous as regards the reduction of NO_x emission to the work environment. The analysis of the test results revealed that the size of nitrogen oxide emission was connected with the current parameters of the process. During welding all the tested aluminium alloys with various filler metal grades it was possible to observe

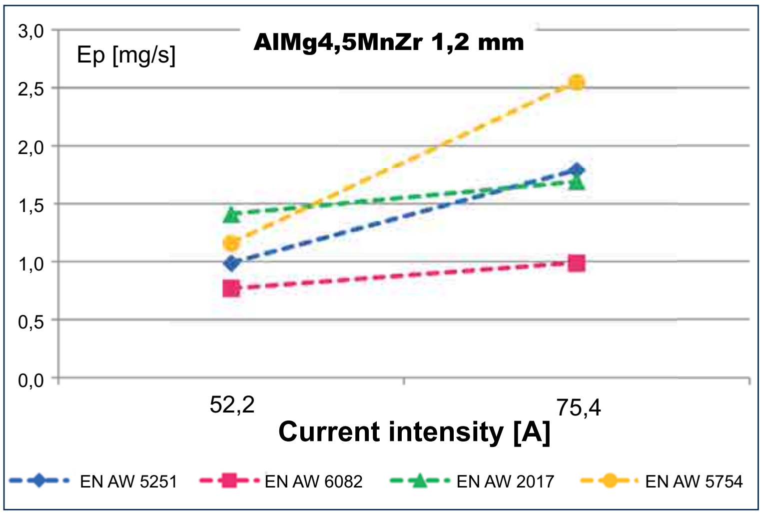

Fig. 25. Impact of current intensity on dust emission while welding aluminium alloys of 5xxx, 6xxx and 2xxx series with AC Pulse method using filler metal grade AlMg4.5MnZr ϕ1.2 mm, in Ar-based shielding gas

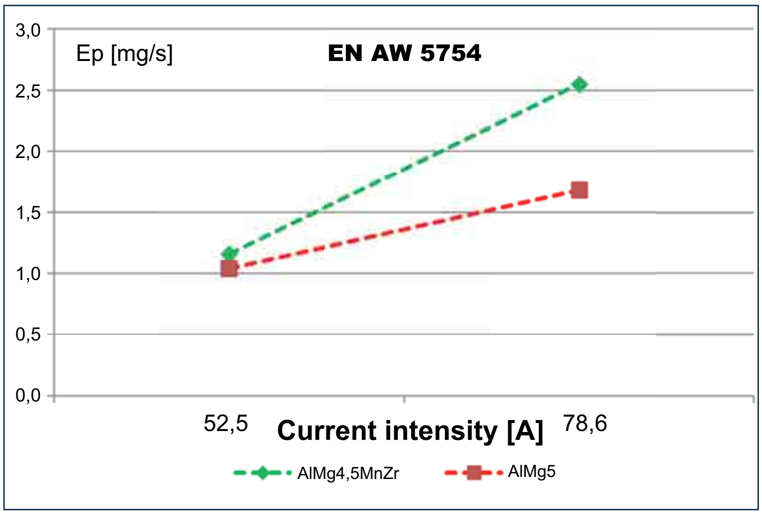

Fig. 26. Impact of current intensity on dust emission while welding aluminium alloy EN AW 5754 with AC Pulse method using filler metal grades AlMg4.5MnZr and AlMg5 ϕ1.2 mm, in Ar-based shielding gas

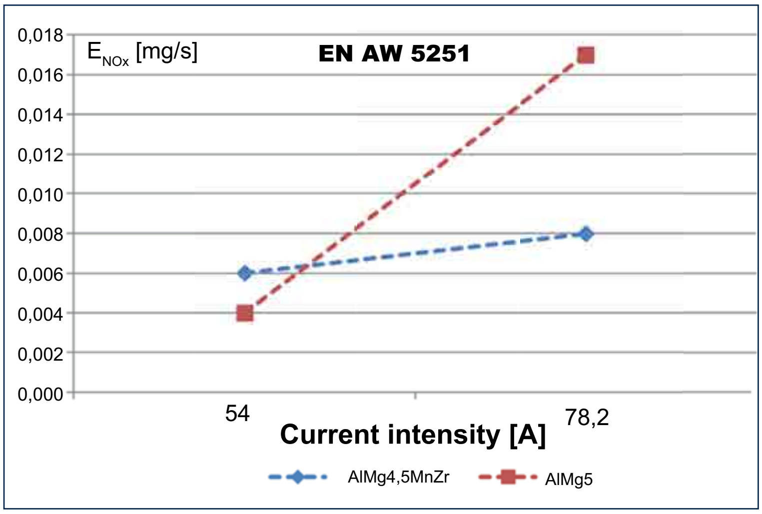

Fig. 27. Impact of current intensity NO_x emission while welding aluminium alloy EN AW 5251 with AC Pulse method using filler metal grades AlMg4.5MnZr and AlMg5Cr ϕ1.2 mm, in Ar-based shielding gas

the impact of current intensity and arc voltage on the size of nitrogen oxide emission.

The impact of current intensity and arc voltage on the emission of fume and nitrogen oxides was determined for welding the aluminium alloys of 5xxx, 6xxx and 2xxx series with the AC Pulse method and various grades of filler metals. Higher current intensity and arc voltage caused higher emission of total fume and of NO_x. Graphic correlations between current parameters and the emission of fume and nitrogen oxides during welding selected aluminium alloys with the AC Pulse method are presented in Figures 25 – 27. The analysis of the test results related to the emission of fume revealed a significant impact of current parameters on the size of fume emission during welding the alloy EN AW 5754 (Fig. 25,26). The emission of fume for the filler metal AlMg4.5MnZr was between 1.16 mg/s (low-power arc I=52 A, U=15 V) and 2.55 mg/s (higher power arc: I=78,6 A, U=16.8 V) (Fig. 26). The use of higher current parameters of the process increased the emission of fume more than 2-times. In the case of the wire AlMg5Cr this dependence is also visible as the emission of fume was between 1.04 mg/s (I=52 A, U=15 V) and 1.68 mg/s (I=78 A, U=16.8 V); higher arc power and higher filler metal feeding rate increased the emission of fume by 60%.

The impact of current-voltage parameters of AC Pulse welding is visible in relation to the emission of nitrogen oxides. While analysing the results of NO_x emission tests for welding the alloy EN AW 5251 with the wire AlMg5Cr it was possible to observe that the size of emission amounted to 0.017 mg/s for higher current-voltage parameters

(I=75,8 A, U=16,2 V) and was 4 times higher if compared with the emission of NO_x for the current intensity of 51.8 A and the voltage of 15.16 V (Fig. 27). During welding the alloy EN AW 5251 with the wire AlMg4.5MnZr the emission of nitrogen oxides was between 0.006 mg/s (I=54 A, U=15.2 V) and 0.008 mg/s (I=78.2 A, U=16.5 V).

Comparative analysis of test results concerning the emission of pollutants generated during welding aluminium alloys using low-energy methods

The tests carried out at Instytut Spawalnictwa and related to the emission of pollutions generated during welding aluminium alloys concerned several selected methods of gas-shielded arc welding [4,5,and 8]. The tests resulted in the determination of emission indicators for welding thin-walled elements made of 5xxx, 6xxx and 2xxx series alloys with the CMT, ColdArc, MIG welding with a pulsating arc and with a double pulse, Cold Process and AC MIG Pulse methods. The tests of pollution emission accompanying welding the aluminium alloys with the aforesaid methods revealed the impact of numerous factors on the emission of fume and nitrogen oxides. The emission of pollutions depends on the grade of an aluminium alloy, the thickness of a sheet, the grade and the diameters of a filler metal wire as well as on the method of welding and current-voltage parameters. The graphic analysis of the correlations between the size of fume emission and a low-energy method (CMT, Cold Arc, Cold Process and AC Pulse) used for welding selected aluminium alloys is presented in Figures 28-30. The tests revealed that the method characterised

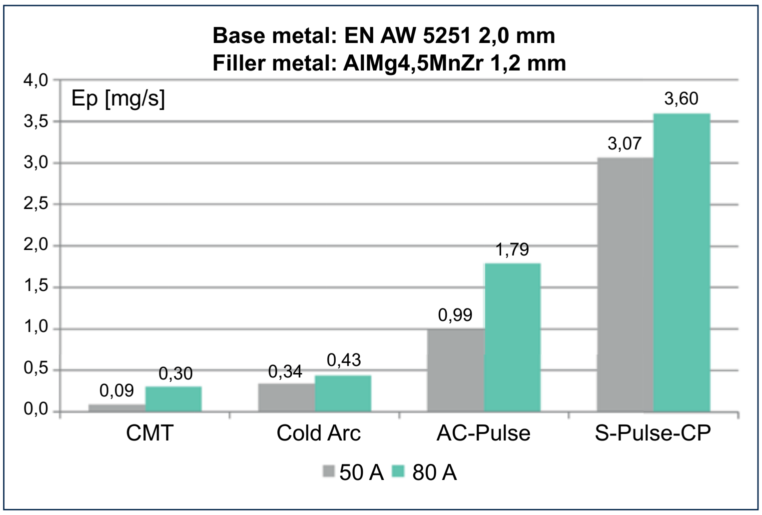

Fig. 28 Dust emission while welding alloy EN AW 5251 with CMT, ColdArc , Cold Process (S-Pulse-CP) and AC Pulse methods and filler metal AlMg4.5MnZr

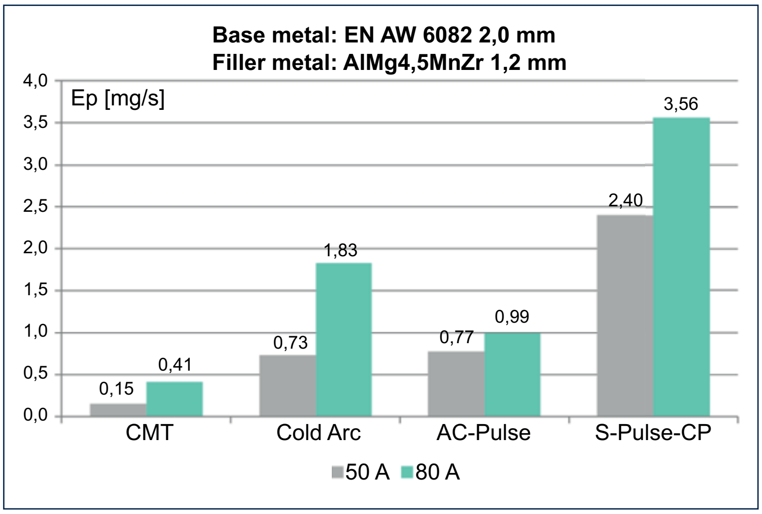

Fig. 29 Dust emission while welding alloy EN AW 6082 with CMT, ColdArc , Cold Process (S-Pulse-CP) and AC Pulse methods and filler metal AlMg4.5MnZr

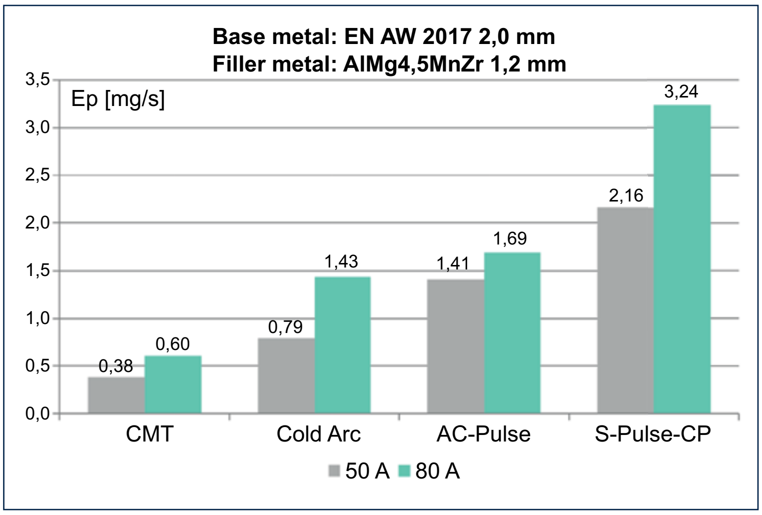

Fig. 30 Dust emission while welding alloy EN AW 2017A with CMT, ColdArc , and Cold Process (S-Pulse-CP) methods and filler metal AlMg4.5MnZr

by the lowest fume emission during welding aluminium alloys with different filler metal grades and arc welding methods with lower arc energy is the CMT method. In turn, the Cold Process method in the variant S-Pulse-CP and the AC Pulse method are characterised by an increase in fume emission in comparison with the CMT and ColdArc methods.

The comparison of fume emission sizes for welding aluminium alloys with other gas-shielded arc welding methods, i.e. conventional MIG welding, MIG welding with a pulsating arc, MIG Double Pulse welding and welding with low-energy methods are presented in Figure 31. In order to reduce the emission of pollutions it is advisable that thin-walled elements made of various aluminium alloys should be welded using low-energy methods. The lowest fume emission indicators were determined for the CMT method, the size of emission increased successively for the following methods: ColdArc, AC Pulse, MIG with a pulsating arc, MIG with a double-pulsed arc, Cold Process and conventional argon-shielded MIG welding.

Summary

The objective of the tests described in this study was to determine a method for welding aluminium alloys which could constitute an advantageous alternative as regards the protection of work environment and the reduction of pollution emission. A detailed comparative analysis of pollution emissions related to the use of various methods for welding aluminium alloys is presented in Figure 31. The tests revealed that the use of the CMT, ColdArc, Cold Process and AC Pulse methods for welding thin-walled ele-

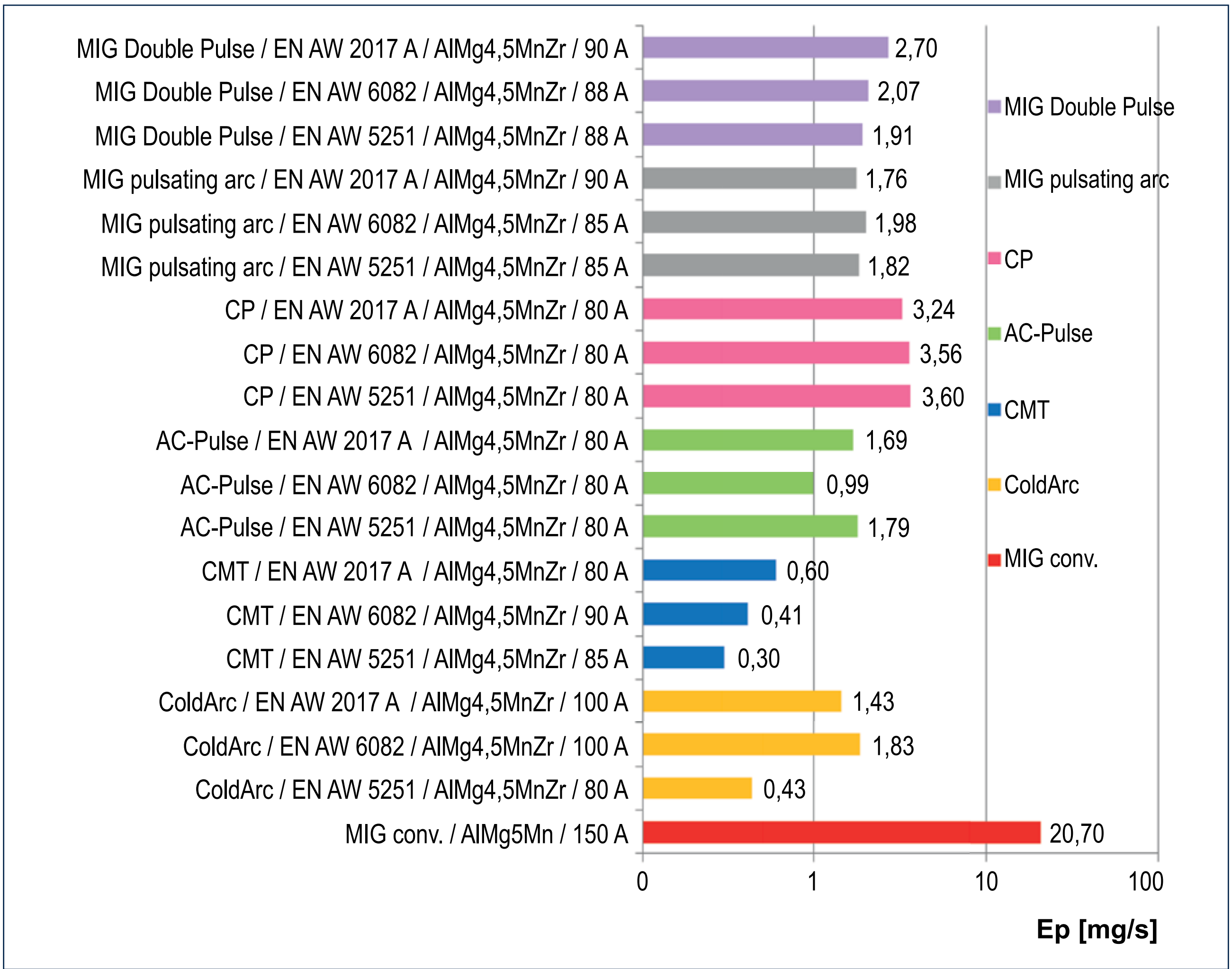

Fig. 31. Dust emission during welding of 5xxx, 6xxx and 2xxx series aluminium alloys with MIG welding and filler metal grade AlMg4.5MnZr

ments made of aluminium alloys can reduce the emission of fume and nitrogen oxides to the work environment.

The tests results concerned with pollution emission accompanying welding aluminium alloys with the Cold Process and AC Pulse methods enabled the formulation of the following conclusions:

1. The tests revealed the impact of many factors on the emission of fume and nitrogen oxides. The emission of pollutions depends on the grade of aluminium alloy, the grade of filler metal and the current-voltage parameters of the process.

2. During welding aluminium alloys with the Cold Process method the highest indicators of fume emission were determined for welding the alloy EN AW 5251 with the wire AlMg4.5MnZr. The lowest emission of fume was determined for the alloy EN AW 5754. The size of fume emission accompanying welding the alloys of 6xxx and 2xxx series with the filler metal grade AlMg4.5MnZr was similar.

3. During welding aluminium alloys with the AC Pulse method the highest indicators of fume emission were determined for welding the alloys EN AW 5754 and EN AW 2017 with the wire AlMg4.5MnZr. The lowest emission of fume was determined for the alloy EN AW 6082.

4. The emission of fume and nitrogen oxides accompanying welding aluminium alloys with the Cold Process and AC Pulse methods depends on the grade of a filler metal used. This tendency was revealed for all the aluminium alloys put to the test.

5. During welding aluminium alloys with the CP and AC Pulse methods higher current intensity and higher arc voltage increase the emission of total fume and NO_x. This dependence was revealed for all the aluminium alloys and filler metal grades tested.

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