Jolanta Matusiak, Piotr Szłapa, Joanna Wyciślik, Wojciech Marczak

Experimental Tests on the Effect of Gas-shielded Arc Welding Technological Conditions on Sound Level

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Abstract: During various welding processes workers are exposed to activities connected with audible and ultrasonic noise. In spite of the continuous development and improvement of production means, robotisation of welding works and the development of measures protecting workers against noise, the exposure to noise continues to be one of the major issues in welding engineering. The article presents experimental tests focused on the effect of gas-shielded metal arc welding technological conditions on the level of sounds generated during welding processes. The study discusses the results of tests performed for 7 selected gas-shielded arc welding methods, i.e. MAG, MAG Pulse, CMT (Cold Metal Transfer), ColdArc, RapidArc, MAG Double Pulse and AC Pulse. The test-related analysis was concerned with the correlations between welding material-technological conditions and the acoustic pressure level of sound A as well as the acoustic pressure level in the 1/3 octave bands of audible and ultrasonic noise spectrum.

Keywords: audible noise, ultrasonic noise, gas-shielded arc welding

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Introduction

Over 100 domestic industry sectors use fusion welding, weldbrazing, pressure welding and thermal cutting processes. It is estimated that welding technologies are used in industrial processes in 7 thousand Polish companies [1]. The number of workers connected with the manufacture of welded structures reaches 130-150 thousand. In this group there are between 60 and 80 thousand welders. The remaining part is made up by workers operating manual, mechanised or robotic welding or cutting machines as well as welding coordination personnel. During various welding works employees are exposed to work connected with audible and ultrasonic noise. In spite of the continuous development and improvement of production means, the robotisation of welding works and the development of personnel protective equipment preventing exposure to noise at work, it can be stated that exposure to noise in welding engineering remains one of the major problems.

The primary sources of noise accompanying welding production include devices and technological processes of fusion welding, pressure welding and metal cutting, surface treatment processes such as mechanical cleaning, grinding, cold shaping and straightening as well as the transport of elements. In addition, technological production halls are equipped with machines being significant noise sources, e.g. machine tools, drills, milling machines, slotting

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dr inż. Jolanta Matusiak (PhD (DSc) Eng.), mgr inż. Joanna Wyciślik (MSc Eng.) - Instytut Spawalnictwa; mgr Piotr Szłapa (MSc), dr hab. Wojciech Marczak (PhD hab.) - Institute of Occupational Medicine and Environmental Health, Sosnowiec

machines as well as general and local ventilation systems.

In cases of workers exposed to excessive noise, regulations require the implementation of programmes aimed to improve work conditions. Such programmes include many various activities whose main purpose is the protection of worker's hearing against noise-induced damage. The creation of a hearing protection programme starts with the identification of hazards and the determination of priorities where the hazard is the greatest. Activities aimed to identify noise hazards accompanying welding processes are addressed in the project entitled "Investigation and Development of a Measurement-Analytical System for Assessing the Level of Sounds Emitted in the Manufacture of Welded Structures" executed by the scientific and industrial consortium composed of Instytut Spawalnictwa, Instytut Medycyny Pracy i Zdrowia Środowiskowego (Institute of Occupational Labour and Environmental Health), Politechnikę Śląską Wydział Inżynierii Materiałowej i Metalurgii (Silesian University of Technology – Faculty of Materials Science and Metallurgy) and Wojskowe Zakłady Mechaniczne WZM S.A. (Military Mechanical Works JSC) in Siemianowice Śląskie. The primary objective of the project is the development of an innovative measurement-analytical system combining the monitoring of welding a wheeled armoured vehicle Rosomak (Wolverine) with the continuous monitoring of sound level and analytical-advisory modules in the management of the whole production process in correlation with the acoustic climate state. The project-related research involved the experimental tests of the effect of the technological conditions of MAG welding on the level of sound generated during the process. This article presents test results for seven gas-shielded arc welding methods, i.e. MAG, MAG Pulse, CMT (Cold Metal Transfer), ColdArc, RapidArc, MAG Double Pulse and AC Pulse.

Noise in the Work Environment

Noise includes any undesirable, unpleasant, irritating, or harmful sounds affecting the hearing organ and other senses and organs of the human body [2]. The space surrounding the source around which sounds propagate is referred to as the acoustic field. In each place, the acoustic field can be characterised by the sound intensity (I), i.e. the amount of acoustic energy per area unit. The measurement of sound intensity (I) using a direct method, poses numerous methodological difficulties due to the fact that the quantity I is vectorial. This problem can be solved by measuring the quantity of acoustic pressure (p) or the level of acoustic pressure (Lp) which correlate positively and linearly with the quantity of acoustic intensity. In practice, most acoustic phenomena are described using the value of p or that of Lp. In this article the issues of noise emission were analysed on the basis of measurement results related to acoustic pressure (Lp).

Along with a growing distance from the source of the sound (noise), the intensity of the sound changes as energy emitted is spread over a greater area and is absorbed by the environment. The propagation of sounds and the course of sound changes in air result from the overlapping of various phenomena accompanying the propagation of sounds, i.e. reflection, refraction and transmission by material factors (walls, ceilings, window panes) as well as the absorption by obstacles. The space to which the sound is emitted also contains various objects being obstacles to the propagation of sounds. The sound can be reflected, can be fully or partially absorbed, or can be bent by an obstacle. The higher the frequency of the sound, the better it is absorbed by air [3].

The human ear is capable of hearing sounds of a frequency between 20Hz and 20 kHz. The sounds from this range are referred to as audible. Sounds inaudible to humans having a frequency below 20 Hz are called infrasounds, whereas those of a frequency exceeding 20 kHz are referred to as ultrasounds (Fig. 1). The term of noise includes audible sounds. In addition to the term of "noise" there is also the notion of "infrasound noise" and that of "ultrasound noise".

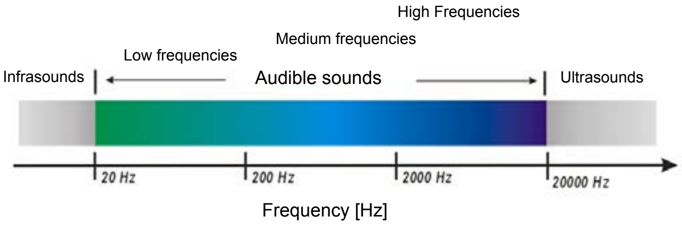

Fig. 1. Division of sounds in relation to frequency [4]

Noise is one of the surrounding environmental factors affecting the whole human organism. Noise can be a threat to human health or even life; it can make work much harder or even impossible. Noise also influences human mental activity, the efficiency and quality of work as well as the possibility of sleep and rest at home. Noise at work is responsible for occupational hearing damage, has a detrimental effect on the whole human body, increases accident likelihood and decreases work efficiency. For many years occupational hearing damage has been at the top of the occupational diseases list [3]. Noise-induced hearing defects appear slowly and at specific frequency scale points. Noise results accumulate in time. The continuous exposition to noise is more harmful than intermittent as even short exposition breaks enable hearing regeneration [5]. Exposition to noise, particularly to noise impulses of a considerable peak level (above 140 dB) can cause instant damage to anatomic ear structures resulting in abrupt deafness. In addition to hearing, noise also affects other human organs. People exposed to intense audible noise tend to suffer from cardiovascular and respiratory system diseases more often; they also more frequently experience problems with balance, have hypertension, suffer from stomach ulcers etc. [3]. Summarising the results of exposure to noise at work, it should be stated that the primary hazard is related to hearing damage. At the same time, noise causes various extra-hearing changes, reduces psychophysical efficiency and occupational satisfaction, leads to accidents at work and reduces work efficiency.

Laboratory Test of the Effect of Gas-shielded Arc Welding Technological Conditions on Sound Level

The sound level tests were performed for welding methods used at the Military Mechanical Works and for innovative gas-shielded arc welding methods being technological solutions applied in the production of numerous welded structures and products. The levels of acoustic pressure were conducted for 7 gas-shielded arc welding methods, i.e. MAG, MAG Pulse, CMT (Cold Metal Transfer), ColdArc, RapidArc, MAG Double Pulse and AC Pulse [6]. The methods presented above were recognised as representative of the methods used in the production of welded structures and products in many industrial sectors.

In order to obtain results characterising acoustic conditions in the wide range of welding production, the sound level tests were performed for thicker parent metals, i.e. 6÷8 mm thick and for materials having a thickness of 1÷2 mm. The parent metals used in the tests were Armox 440T, Armox 500T and S235J2 grade steels. The filler metal used in the tests was an OK Autrod 12.51 electrode wire having diameter of 1.0 and that of 1.2 mm. The acoustic pressure level tests accompanying arc welding were performed for 3 various shielding gas mixtures, i.e. Ar+8%CO_2, Ar+18%CO_2 and Ar+12%CO_2+2%O_2. The shielding gases applied differ in their physico-chemical properties. The range of welding technological parameters used in the tests is presented in Table 1.

The tests of acoustic pressure levels were performed using an experimental stand at Instytut Spawalnictwa (Fig. 2). The dimensions of the welding table enabled the obtainment of a weld/ overlay weld being 1600 mm in length. The table was connected to a moving element with a mounted automatic welding machine

Table 1. Range of technological parameters [6]

Welding method	Parent metal	Electrode wire	Shielding gas	Process technological parameters			
				I [A]	U [V]	Vdr [m/min]	Vsp [mm/min]
MAG	Armox 440T, 8 mm	OK Autrod 12.51 ϕ1 mm,	1) Ar+8%CO_2 2) Ar+18%CO_2 3) Ar+12%CO_2+2%O_2	70	15.0	2.4	190
				100	18.0	3.6	200
				120	20.6	5.0	220
				180	24.5	9.0	380
				240	30.0	11.0	600
		OK Autrod 12.51 ϕ1.2 mm,	1) Ar+8%CO_2 2) Ar+18%CO_2 3) Ar+12%CO_2+2%O_2	70	15.0	1.9	190
				100	16.3	2.7	200
				120	17.1	3.2	220
				180	18.7	5.5	380
				240	26.1	7.8	600
MAG Pulse	Armox 440T, 8 mm	OK Autrod 12.51 ϕ1 mm,	1) Ar+8%CO_2 2) Ar+18%CO_2 3) Ar+12%CO_2+2%O_2	70	21.0	3.5	190
				100	23.0	4.8	200
				120	25.0	5.8	220
				180	28.0	10.5	380
				240	31.0	14.0	600
		OK Autrod 12.51 ϕ1.2 mm,	1) Ar+8%CO_2 2) Ar+18%CO_2 3) Ar+12%CO_2+2%O_2	70	20.6	2.3	190
				100	23.0	3.2	200
				120	24.0	3.8	220
				180	26.0	6.0	380
				240	29.0	8.8	600
	Armox 500T, 6 mm	OK Autrod 12.51 ϕ1 mm,	1) Ar+8%CO_2 2) Ar+18%CO_2 3) Ar+12%CO_2+2%O_2	70	21.0	3.4	190
				100	23.0	4.8	200
				120	24.0	5.8	220
				180	28.0	10.6	380
				240	31.0	14.2	600
		OK Autrod 12.51 ϕ1.2 mm,	1) Ar+8%CO_2 2) Ar+18%CO_2 3) Ar+12%CO_2+2%O_2	70	20.5	2.3	190
				100	23.0	3.3	200
				120	24.0	3.8	220
				180	25.8	6.0	380
				240	29.0	9.0	600
	Armox 500T, 8 mm	OK Autrod 12.51 ϕ1 mm,	1) Ar+8%CO_2 2) Ar+18%CO_2 3) Ar+12%CO_2+2%O_2	70	20.3	3.5	190
				100	22.0	4.9	200
				120	23.5	5.9	220
				180	28.0	10.5	380
				240	31.0	14.0	600
		OK Autrod 12.51 ϕ1.2 mm,	1) Ar+8%CO_2 2) Ar+18%CO_2 3) Ar+12%CO_2+2%O_2	70	20.0	2.3	190
				100	22.0	3.2	200
				120	24.0	3.8	220
				180	27.0	6.0	380
				240	29.0	9.0	600

Table 1. Range of technological parameters [6]- continuation

Welding method	Parent metal	Electrode wire	Shielding gas	Process technological parameters			
				I [A]	U [V]	Vdr [m/min]	Vsp [mm/min]
CMT	S235J2; 1 mm	OK Autrod 12.51 ϕ1 mm,	1) Ar+8%CO_2 2) Ar+18%CO_2	70	9.1	2.2	300
				100	10.6	4.2	600
				120	11.5	5.0	1000
	S235J2; 2 mm	OK Autrod 12.51 ϕ1.2 mm,	1) Ar+8%CO_2 2) Ar+18%CO_2	70	10.6	1.2	220
				100	11.2	2.2	280
				120	11.7	2.9	420
Cold-Arc	S235J2; 1 mm	OK Autrod 12.51, ϕ1 mm,	1) Ar+8%CO_2 2) Ar+18%CO_2	70	17.5	2.5	300
				100	19.0	4.0	700
	S235J2; 2 mm	OK Autrod 12.51, ϕ1.2 mm,	1) Ar+8%CO_2 2) Ar+18%CO_2	70	17.0	1.7	200
				100	18.5	2.7	250
				120	19.0	3.3	380
Rapi-dArc	Armox 440T, 8 mm	OK Autrod 12.51, ϕ1.2 mm,	1) Ar+8%CO_2 2) Ar+18%CO_2 3) Ar+12%CO_2+2%O_2	200	24.5	6.5	380
				300	26.0	10.4	700
	Armox 500T. 8 mm			200	24.0	6.5	380
				300	26.0	10.4	700
MAG Double Pulse	S235J2; 1 mm	OK Autrod 12.51 ϕ1 mm,	1) Ar+8%CO_2 2) Ar+18%CO_2	70	19.5	3.5	600
				100	23.5	5.2	1300
	S235J2; 2 mm	OK Autrod 12.51, ϕ1.2 mm,	1) Ar+8%CO_2 2) Ar+18%CO_2	70	21.5	2.2	200
				100	24.0	3.3	400
				120	27.0	4.1	600
AC Pulse	S235J2; 1 mm	OK Autrod 12.51 ϕ1 mm,	1) Ar+8%CO_2 2) Ar+18%CO_2	70	19.5	3.4	500
				100	21.5	5.2	1000
				120	22.5	6.6	1500
	S235J2; 2 mm	OK Autrod 12.51, ϕ1.2 mm,	1) Ar+8%CO_2 2) Ar+18%CO_2	70	18.5	2.5	300
				100	21.5	3.6	600
				120	22.5	4.2	800

used for shifting the torch with a measuring microphone. The location of measuring microphones around the welding stand is presented in Figure 3.

Methodology of Acoustic Pressure Level Measurements

The measurements of the acoustic pressure levels of sound A and of the levels of the acoustic pressure of spectra in 1/3 octave bands of mid-band frequencies from 125 Hz to 1600 Hz were performed using the measuring set A (Svan 958 four-channel noise and vibration analyser). The measurements of the acoustic pressure levels in the range of ultrasonic noise spectrum (1/3 octave bands of mid-band frequencies 10 – 40 kHz) were performed using the measuring set B (Svan 912 AE noise and vibration analyser). The characteristics of both measuring sets are presented in Table 2. Microphones 1A , 2A and 3 A (measuring set A) were mounted on stands at a height of approximately 1.5 m and 1 m away from the welding area. Microphones 4 A (set A) and 1B (set B) were mounted on a self-propelled automatic welding machine at a height of approximately 0.7 m above the welding area. The measurements included digital recording of momentary values of acoustic pressure levels using frequency correction A - LA and frequency uncorrected acoustic pressure levels in ⅓

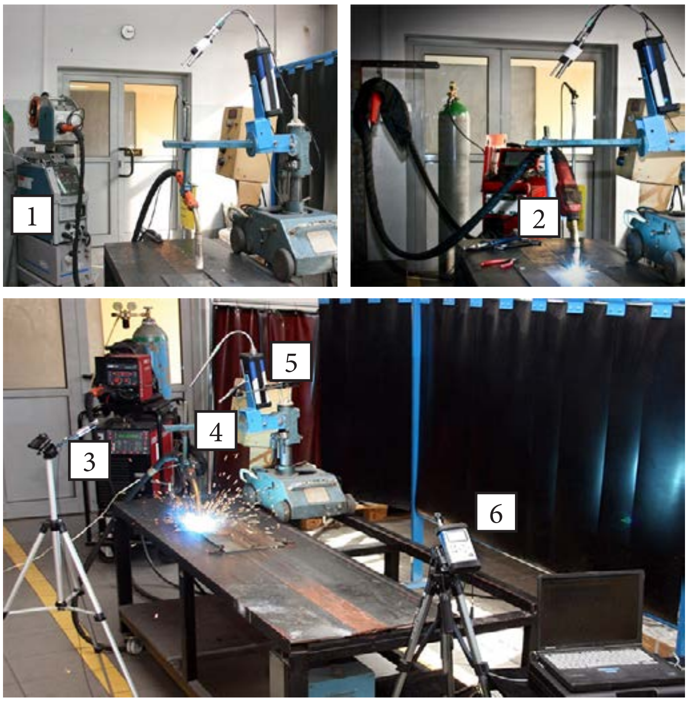

Fig. 2. Experimental stand for testing acoustic pressure levels during gas-shielded arc welding [6]
1. DW 300 OTC Daihen device (AC Pulse); 2. CMT Fronius device (Cold Metal Transfer); 3. EWM (ColdArc); 4. measuring microphone; 5. Svantek Svan 912 AE noise and vibration analyser; 6. Svan 958 four-channel noise and vibration analyser

octave bands of mid-band frequencies fi - Lfi. The measurements performed with set A included 1-second sampling intervals, whereas the measurements in the ultrasonic range (set B) were performed using ½ second sampling intervals. The levels of acoustic pressure were measured during 20 second welding cycles performed for each of the adopted combinations of technical parameters. For individual combinations three welding cycles were performed.

In order to test the homogeneity of acoustic absorption of the measurement area it was necessary to measure the reverberation time at microphone locations. The tests were performed using measuring set A following the requirements of standard PN-EN ISO 3382-2 "Acoustics. Measurement of Room Acoustic Parameters. Part 2: Reverberation time in ordinary rooms" using the method of impulse response integration. The sources of acoustic impulses were balloon explosions. The test results revealed the homogeneity of the acoustic absorption of the whole area where the measuring microphones were located, which means that the test results of acoustic pressure levels in a given place did not depend on the location. The analysis of measurements included:

- calculating the values of the equivalent acoustic pressure levels of sound A referred to 20 second welding intervals – $L_{Aeq20\ s}$
- calculating the values of the equivalent acoustic pressure levels at ⅓ octave audible and ultrasonic noise spectrum bands referred to 20 second welding intervals – $L_{fi\ eq\ 20\ s}$.

The calculations of the values $L_{Aeq20\ s}$ and $L_{fieq20\ s}$ were performed using Svan PC ++ and Svan PC Win software.

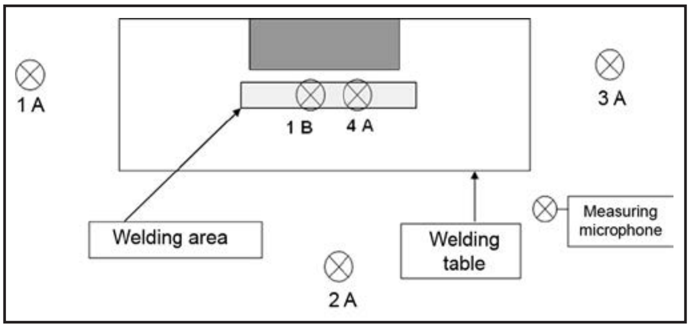

Fig. 3. Location of the measuring microphones in the experimental welding stand area [6]
1÷4 A - Svan 958 four-channel noise and vibration analyser; 1B - Svan 912 AE noise and vibration analyser

Table 2. Measuring sets used in acoustic tests

Set	Analyser	Pre-amplifier	Microphone	f_{max} [kHz]
A	Svantek Svan 958 four-channel noise and vibration analyser	Svantek SV 12L (4 units)	½ inch, Svantek SV 22 type (4 units)	20
B	Svan 912 AE noise and vibration analyser	Svantek SV 01 A	¼ inch, Gras 40 BF type	90

Analysis of Acoustic Pressure Level Test Results for Gas-shielded Metal Arc Welding

The main objective of the laboratory tests of sounds emitted during welding processes was the determination of the acoustic pressure level for various welding methods as well as the determination of correlations between the welding technological conditions and the acoustic pressure level of sound A and the acoustic pressure level in ⅓ octave audible and ultrasonic noise spectrum bands. The analysis of the results was concerned with two issues, i.e. welding of thick-walled elements (6÷8 mm thick plates) and welding of thin-walled elements (1÷2 mm in thickness). The selected sound A acoustic pressure level measurement results in relation to the welding method, parent metal grade, electrode wire diameter, welding current and shielding gas are presented in Figures 4-11.

The measurements revealed that the equivalent level of the acoustic pressure level of sound A (L_{Aeq20s}) for all the welding methods tested depends on the values of welding current, electrode wire diameter, parent metal thickness and shielding gas chemical composition. While welding 8 mm thick steel plates using the MAG method and the $Ar+12\%CO_2+2\%O_2$ shielding gas mixture, the equivalent acoustic pressure level of sound A at the process time of 20 s was between 87.72 dB for a welding current of 70 A, 92.83 dB for a welding current of 100 A, up to 97.71 dB for a welding current of 240 A. An increase in welding current led to an increase in the acoustic pressure level of sound A. During MAG welding it was revealed that an increase in the electrode wire diameter was responsible for the higher values of the equivalent acoustic pressure level of sound A (Fig. 4).

While welding 8 mm thick steel plates using the MAG Pulse method and the $Ar+12\%CO_2+2\%O_2$ shielding gas mixture, the equivalent acoustic pressure level of sound A (L_{Aeq20s}) was from 85.98 dB for a welding current of 70 A up to 95.89 dB for a welding current of 240 A (Fig. 6a). The correlation between the welding current and the acoustic pressure level for the MAG Pulse method had a positive character; an increase in welding current led to an increase in the acoustic pressure level of sound A. While welding using the MAG Pulse method it was not possible to unequivocally demonstrate the correlation between the electrode wire diameter and the higher values of the acoustic pressure level of sound A (Fig. 5, 6). However, the acoustic pressure level of sound A was affected by the thickness of parent metal welded; joining thicker plates was accompanied by an increase in the acoustic pressure level. The analysis of the test results revealed that while welding steel plates using the MAG and MAG Pulse methods the acoustic pressure level of sound A was similar for the same technological conditions.

While welding 8 mm thick steel plates using the RapidArc method and the $Ar+12\%CO_2+2\%O_2$ shielding gas mixture, the equivalent acoustic pressure level of sound A (L_{Aeq20}s) was from 89.97 dB for a welding current of 200 A up to 94.79 dB for a welding current of 300 A (Fig. 8a). Welding using the RapidArc method revealed the positive correlation between the welding current and the acoustic pressure levels of sound A.

The test results revealed that the shielding gas has a significant effect on the sound level during welding. While welding the Armox 440T and Armox 500T steels three various shielding gas mixtures were used, i.e. $Ar+8\%CO_2$, $Ar+18\%CO_2$ and $Ar+12\%CO_2+2\%O_2$. While welding with the MAG method the lowest values of the equivalent acoustic pressure level of sound A (L_{Aeq20s}) accompanied the use of the $Ar+18\%CO_2$ shielding gas mixture. In turn, an increase in the acoustic pressure level was connected with the use of the three-component shielding gas, i.e. $Ar+12\%CO_2+2\%O_2$ (Fig. 4). The identification of the most advantageous shielding gas in terms of reducing the sound level during the MAG Pulse welding, was considerably more difficult. The effect of gas on the acoustic pressure level of sound A results from the welding current, electrode wire diameter and the thickness of the parent metal welded. While welding 6 mm and 8 mm thick Armox 500T grade steel plates using a wire having a diameter of 1.2 mm, the lowest acoustic pressure level of sound A accompanied the use of the $Ar+12\%CO_2+2\%O_2$ mixture; the highest acoustic pressure level of sound A accompanied the use of the $Ar+8\%CO_2$ shielding gas mixture (Fig. 5b, 6b). In turn, while using the MAG Pulse method for welding the same plates using the electrode wire having a diameter of 1.0 mm the lowest acoustic pressure level of sound A accompanied the use of the two-component $Ar+8\%CO_2$ shielding gas; the two remaining gases were characterised by a similar acoustic pressure level (Fig. 5a, 6a). The advantageous reduction of the acoustic pressure level of sound A during RapidArc welding was revealed for the three-component $Ar+12\%CO_2+2\%O_2$ shielding gas (Fig. 7). While summarising the effect of the shielding gas type on the acoustic pressure level of sound A for the MAG, MAG Pulse and RapidArc methods it should be noted that it is not possible to select and use a shielding gas of universal composition allowing the reduction of the acoustic pressure level of sound A for all the methods.

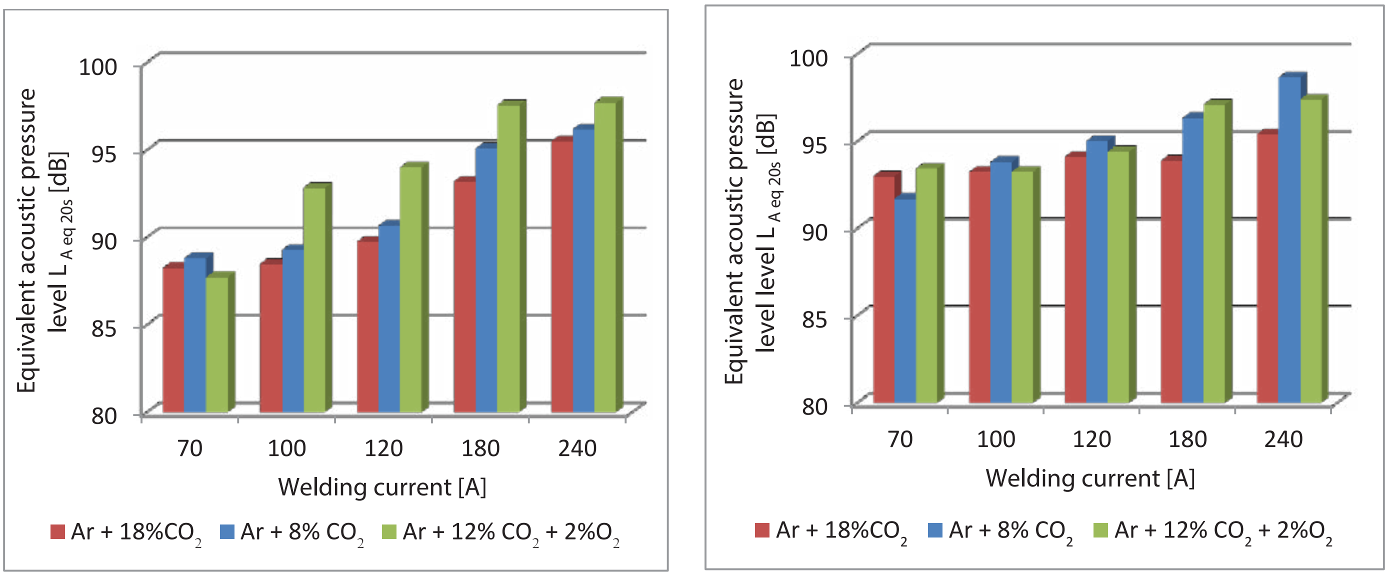

Fig. 4. Equivalent acoustic pressure level of sound A for MAG welding of 8 mm thick Armox 440T grade steel plate. Filler metal: a) OK Autrod 12.51 ϕ 1 mm, b) OK Autrod 12.51 ϕ 1.2 mm

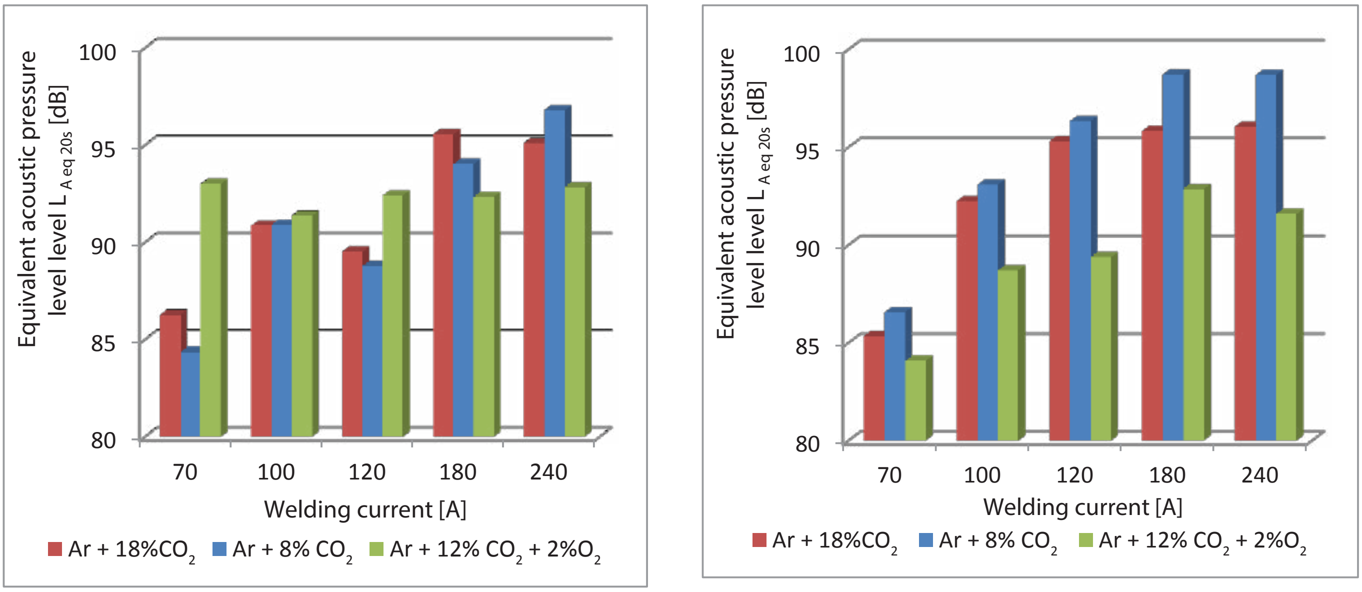

Fig. 5. Equivalent acoustic pressure level of sound A for MAG Pulse welding of 6 mm thick Armox 500T grade steel plate. Filler metal: a) OK Autrod 12.51 ϕ 1 mm, b) OK Autrod 12.51 ϕ 1.2 mm

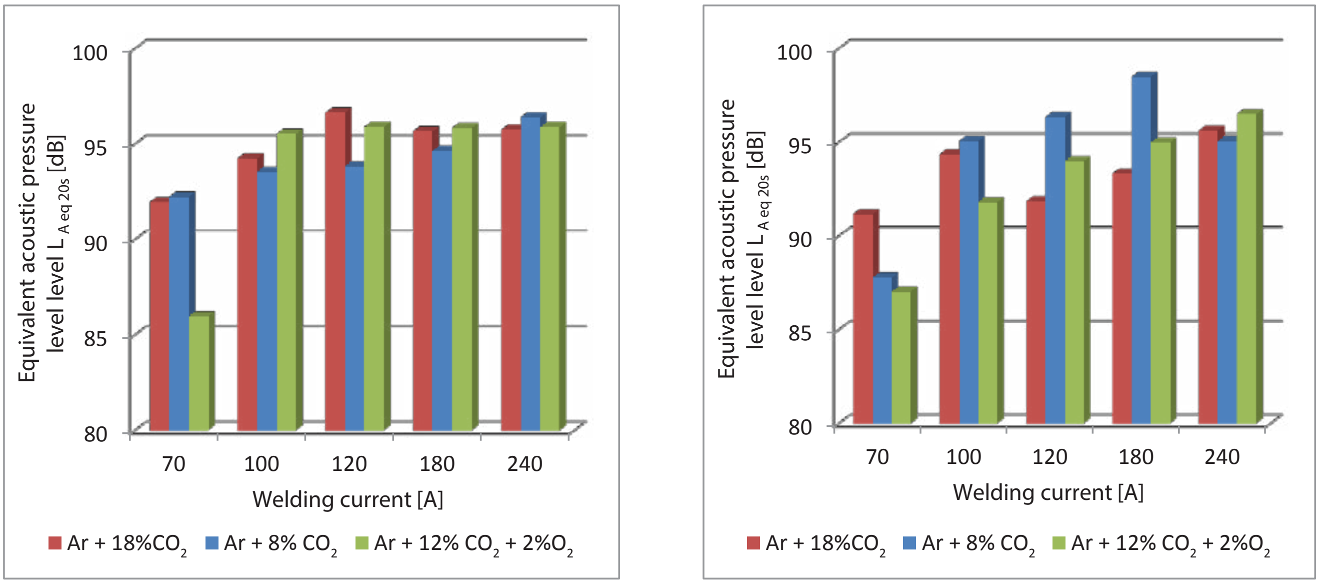

Fig. 6. Equivalent acoustic pressure level of sound A for MAG Pulse welding of 8 mm thick Armox 500T grade steel plate. Filler metal: a) OK Autrod 12.51 ϕ 1 mm, b) OK Autrod 12.51 ϕ 1.2 mm

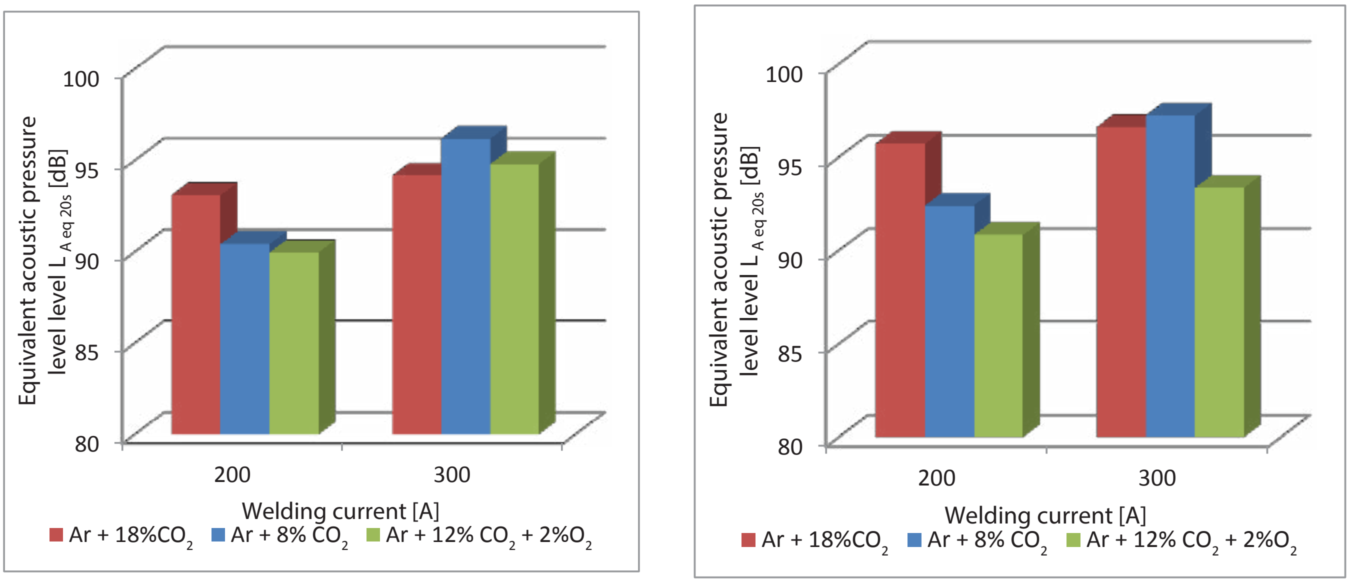

Fig. 7 Equivalent acoustic pressure level of sound A for RapidArc welding of a) 8 mm thick Armox 500T grade steel plate, b) 8 mm thick Armox 400T grade steel plate; filler metal - OK Autrod 12.51 ϕ 1.2 mm

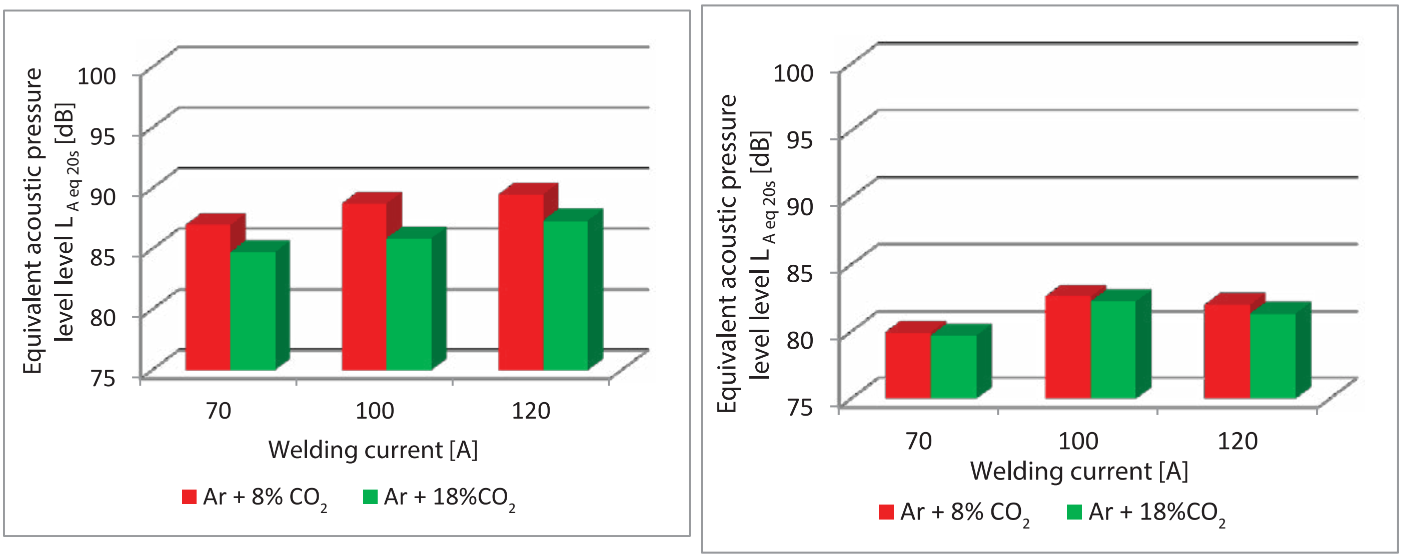

Fig. 8 Equivalent acoustic pressure level of sound A for CMT welding of a) 1 mm thick S235J2 grade steel sheet; wire OK Autrod 12.51 ϕ 1 mm and b) 2 mm thick S235J2 grade steel sheet; wire OK Autrod 12.51 ϕ 1.2 mm

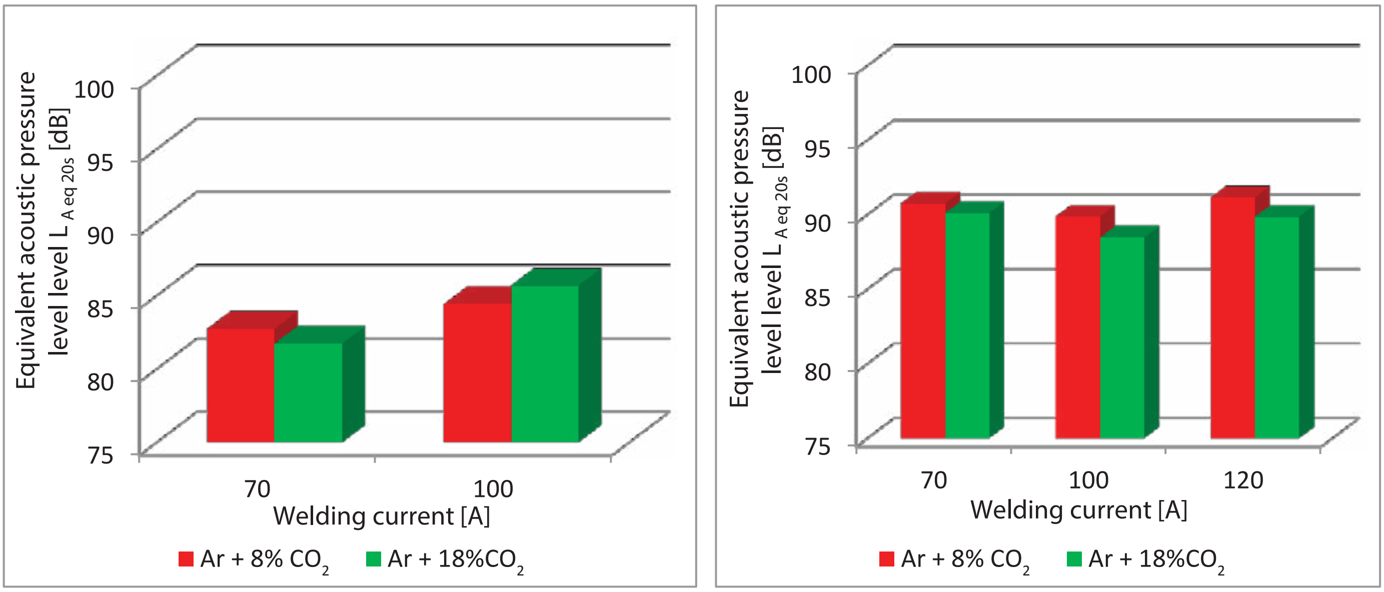

Fig. 9 Equivalent acoustic pressure level of sound A for ColdArc welding of a) 1 mm thick S235J2 grade steel sheet; wire OK Autrod 12.51 ϕ 1 mm and b) 2 mm thick S235J2 grade steel sheet; wire OK Autrod 12.51 ϕ 1.2 mm

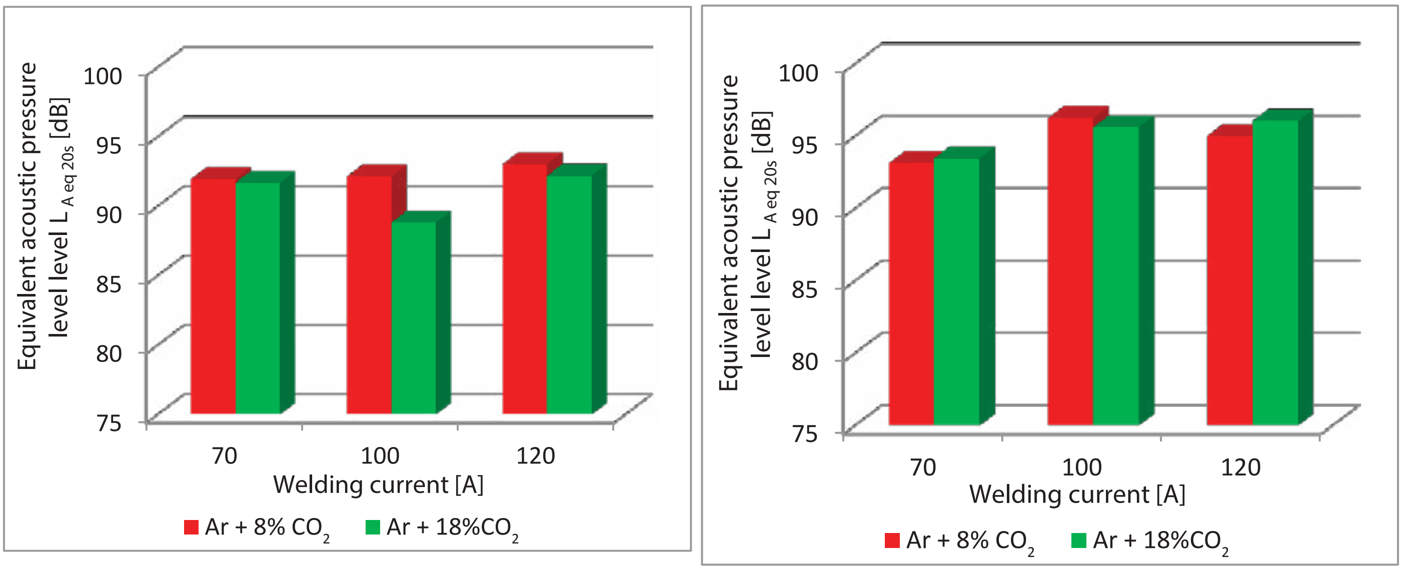

Fig. 10 Equivalent acoustic pressure level of sound A for AC Pulse welding of a) 1 mm thick S235J2 grade steel sheet; wire OK Autrod 12.51 ϕ 1 mm and b) 2 mm thick S235J2 grade steel sheet; wire OK Autrod 12.51 ϕ 1.2 mm

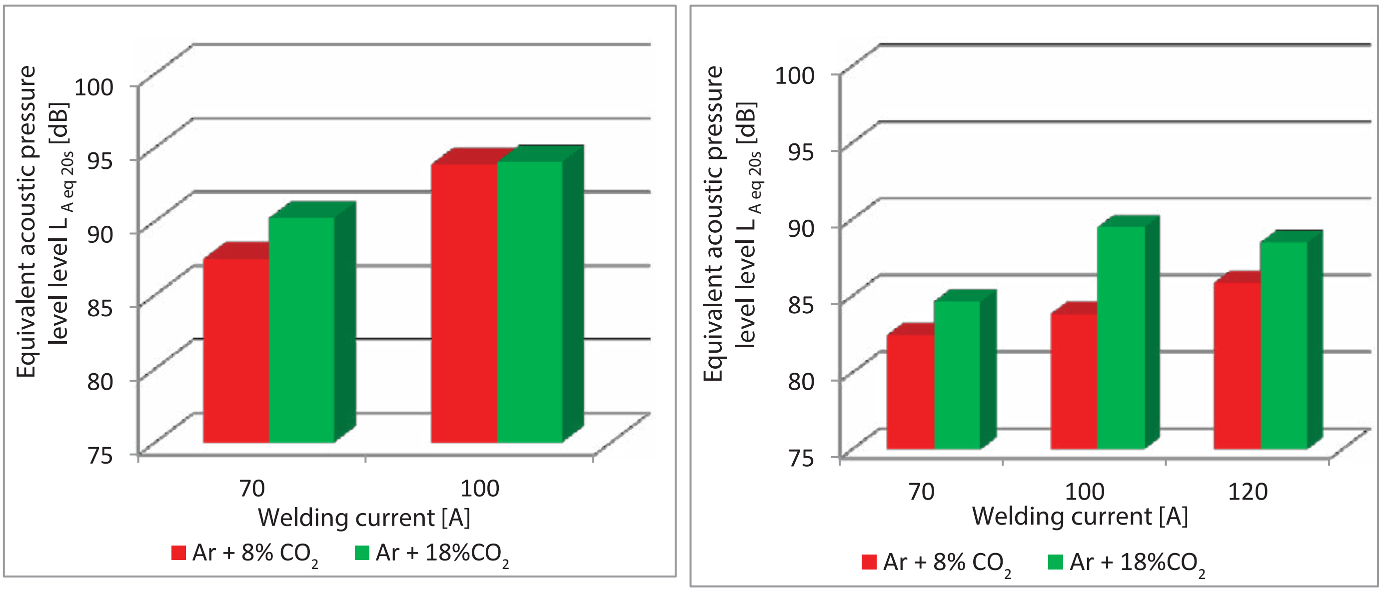

Fig. 11 Equivalent acoustic pressure level of sound A for MAG Double Pulse welding of a) 1 mm thick S235J2 grade steel sheet; wire OK Autrod 12.51 ϕ 1 mm and b) 2 mm thick S235J2 grade steel sheet; wire OK Autrod 12.51 ϕ 1.2 mm

The analysis of the test results related to welding the S235J2 (1 mm and 2 mm thick sheets) steel using the CMT, ColdArc, AC Pulse and MAG Double Pulse methods revealed that for most of the technological conditions tested the increase in welding current caused the increase in the acoustic pressure level of sound A. For example, while CMT welding 1mm thick sheet using the Ar+8%CO_2 shielding gas mixture the acoustic pressure level of sound A for a welding current of 70A amounted to 87 dB; the increase in the welding current up to 100A resulted in the increase in the acoustic pressure level of sound A up to 88.77 dB (Fig. 8a). During ColdArc welding the acoustic pressure level of sound A for a welding current of 70A amounted to 82.77 dB; the increase in the welding current up to 100A resulted in the increase in the acoustic pressure level of sound A up to 84.43 dB (Fig. 9a). During AC Pulse welding using the Ar+8%CO_2 shielding gas mixture the acoustic pressure level of sound A for a welding current of 70A amounted to 91.71dB; the increase in the welding current up to 100A decreased the acoustic pressure level of sound A to do 88.85 dB (Fig. 10a). Afterwards, the increase in the welding current up to 120A resulted in the increase in the acoustic pressure level of sound A up to 92.27A.

For the four methods of welding thin-walled elements (1÷2 mm in thickness) the highest equivalent acoustic pressure levels of sound A (L_{Aeq20s}) were observed during welding with the AC Pulse and MAG Double Pulse methods. For the same material-technological conditions the lowest equivalent acoustic pressure levels of sound A (L_{Aeq20s}) were observed during welding with the low-energy (CMT and ColdArc) methods.

During welding thin-walled elements the welding arc was protected by two shielding gases, i.e. Ar+8%CO_2 and Ar+18%CO_2. The acoustic tests did not demonstrate the same effect of a given shielding gas on the acoustic pressure level of sound A for all the methods tested. While welding using the CMT, ColdArc and AC Pulse methods advantageous process sound level reductions required the use of the Ar+18%CO_2 shielding gas (Fig. 8, 9, 10). In turn, MAG Double Pulse welding (Fig. 11) required the use of the Ar+8%CO_2 shielding gas mixture in order to reduce welding process noise.

The test result analysis also involved calculating the values of the equivalent acoustic pressure levels in the ⅓ octave bands of audible and ultrasonic noise spectrum referred to 20 second welding intervals – $L_{fieq20s}$. The selected values of the acoustic pressure levels in the ⅓ octave bands of audible and ultrasonic noise spectrum for the welding methods and material technological conditions tested are presented in Figures 12-18.

The tests included determining the values of equivalent pressure levels in the ⅓ octave audible noise spectra in the mid-band frequency range from 125 Hz to 20 kHz as well as in the ultrasonic noise spectrum bands in the range from 25kHz to 40kHz. The test result analysis confirmed that in the audible noise spectrum the welding current affects the value of acoustic pressure level. As regards low-frequency sounds in the audible range, for some welding methods, e.g. MAG Pulse and RapidArc (Fig. 13, 14) the increase in welding current was not tantamount to the increase in the acoustic pressure level. From the mid-band frequency of the ⅓ octave band of 1600 Hz to the frequency of 20 kHz for most welding methods there was the directly proportional dependence between the welding current and the acoustic pressure level. In the case of the ultrasonic noise spectrum bands most of the welding methods tested demonstrated the significant increase in the acoustic pressure level for the ⅓ octave band with the mid-band frequency of 25kHz and 31.5 kHz (Fig. 12, 13). The frequency of 40 kHz caused the decrease in the acoustic pressure value. The MAG Double Pulse and RapidArc methods were an exception to the observations presented above as for these methods in the ⅓ octave band of the mid-band frequency amounting to 40kHz it was possible to observe a significant increase in the acoustic pressure level (Fig. 14, 17). Figure 18 presents the equivalent acoustic pressure level in ⅓ octave bands of audible and ultrasonic noise for welding the 2 mm thick sheet using the CMT, ColdArc, AC Pulse and MAG Double Pulse methods. The analysis of the measurement results revealed that in the audible noise bands the lowest acoustic pressure levels were observed during CMT and ColdArc welding, whereas the highest noise levels were recorded for the AC Pulse and MAG Double Pulse methods. In the ultrasonic noise spectrum bands with the mid-band frequency of 25 kHz and 31.5 kHz the ColdArc method was characterised by a significant acoustic pressure increase.

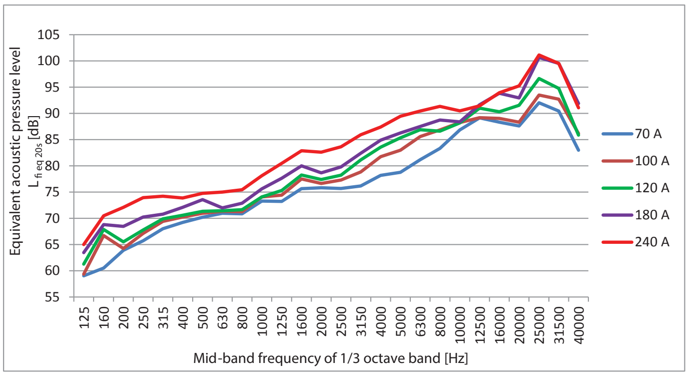

Fig. 12. Equivalent acoustic pressure level in ⅓ octave audible and ultrasonic noise spectrum bands $L_{fieq20s}$ for MAG welding of 8 mm thick Armox 440T grade steel plate; electrode wire OK Autrod 12.51 ϕ 1.2 mm; shielding gas $Ar+8\%CO_2$

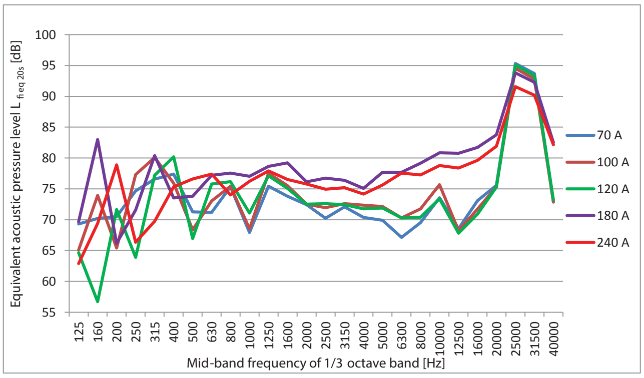

Fig. 13. Equivalent acoustic pressure level in ⅓ octave audible and ultrasonic noise spectrum bands $L_{fieq20\,s}$ for MAG Pulse welding of 8 mm thick Armox 440T grade steel plate; electrode wire OK Autrod 12.51 ϕ 1.2 mm; shielding gas $Ar+8\%CO_2$

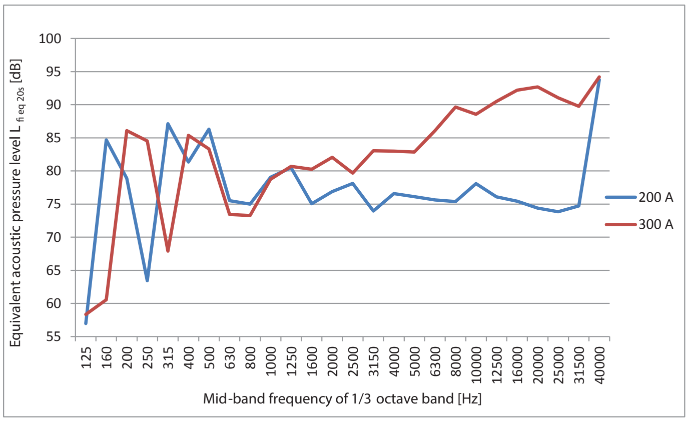

Fig. 14. Equivalent acoustic pressure level in ⅓ octave audible and ultrasonic noise spectrum bands $L_{fieq20\,s}$ for RapidArc welding of 8 mm thick Armox 440T grade steel plate; electrode wire OK Autrod 12.51 ϕ 1.2 mm; shielding gas $Ar+8\%CO_2$

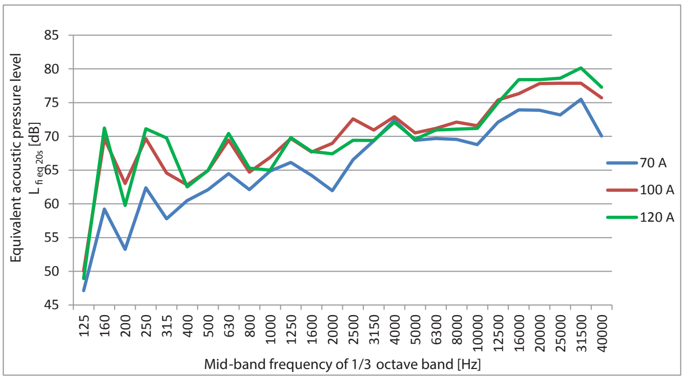

Fig. 15. Equivalent acoustic pressure level in ⅓ octave audible and ultrasonic noise spectrum bands $L_{fieq20\,s}$ for CMT welding of 2 mm thick S235J2 grade steel sheet; electrode wire OK Autrod 12.51 ϕ 1.2 mm; shielding gas $Ar+8\%CO_2$

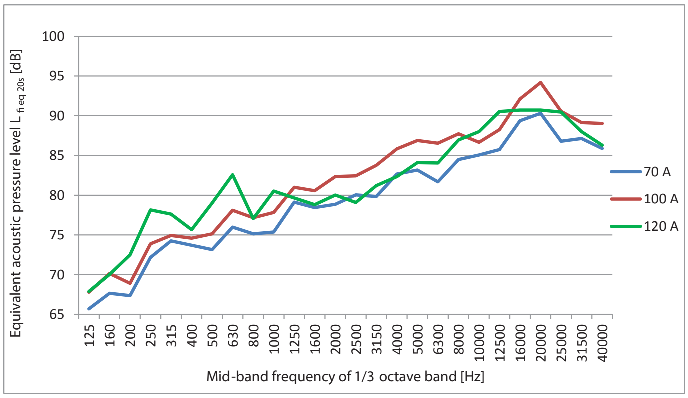

Fig. 16. Equivalent acoustic pressure level in ⅓ octave audible and ultrasonic noise spectrum bands $L_{fieq20\ s}$ for AC Pulse welding of 2 mm thick S235J2 grade steel sheet; electrode wire OK Autrod 12.51 ϕ 1.2 mm; shielding gas Ar+8%CO₂

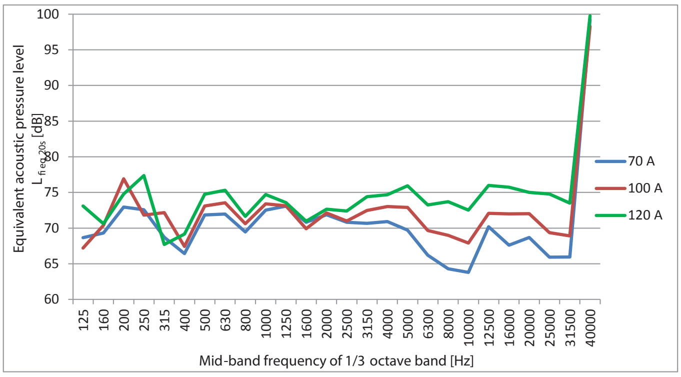

Fig. 17. Equivalent acoustic pressure level in ⅓ octave audible and ultrasonic noise spectrum bands $L_{fieq20\ s}$ for MAG Double Pulse welding of 2 mm thick S235J2 grade steel sheet; electrode wire OK Autrod 12.51 ϕ 1.2 mm; shielding gas Ar+8%CO₂

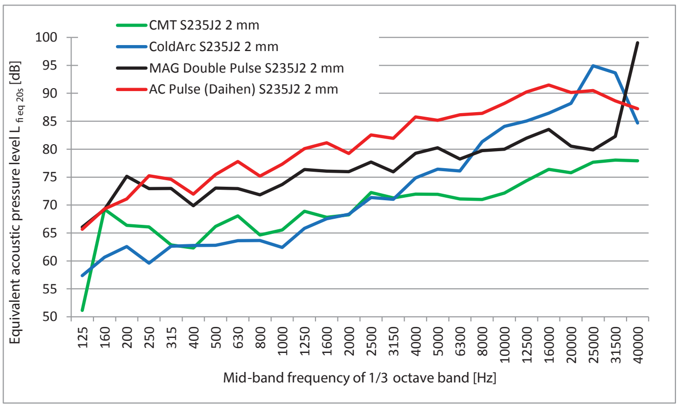

Fig. 18. Equivalent acoustic pressure level in 1/3 octave audible and ultrasonic noise spectrum bands $L_{fieq20\ s}$ for CMT, ColdArc, MAF Double Pulse and AC Pulse welding of 2 mm thick S235J2 grade steel sheet; electrode wire OK Autrod 12.51 ϕ 1.2 mm; shielding gas Ar+8%CO₂; welding current 100A

Summary

The tests of sounds emitted during gas-shielded metal arc welding were conducted in order to determine the acoustic pressure levels for various welding methods and to determine the correlation between the welding material-technological conditions and the acoustic pressure level of sound A and the acoustic pressure level in the ⅓ octave audible and ultrasonic noise spectrum bands. The tests were performed for welding thick-walled elements (6÷8 mm thick) and thin-walled elements (1÷2 mm thick). The tests involved the most popular welding methods, i.e. MAG, MAG Pulse and MAG Double Pulse as well as industrially innovative methods, i.e. CMT, ColdArc, AC Pulse and RapidArc.

The tests results obtained constitute the output basis for advanced tests of acoustic emission present during arc welding processes. The test result analysis has enabled the formulation of preliminary conclusions concerning the correlation between audible and ultrasonic noise emission levels and welding technological parameters as well as output theses for further research. The detailed analysis of the results demonstrating the acoustic emission levels for various combinations of technological parameters within various welding methods has led to the suppositions presented below:

- The correlation between acoustic emission levels and quantities characterising the welding process can have a multi-factor character, which means that the correlation equation changes with the method.
- For various welding methods the relations between acoustic emission levels and material-technological welding conditions can be classified as issues of so-called fuzzy systems [7]. This means that while considering the relationship between acoustic emission levels and specific welding parameters (e.g. welding current) a specific parameter value can correspond not to a strictly specified emission level but to a certain range of such values. In this case the variability of acoustic emission levels can, to a significant extent, depend on the size of a given parameter change. The theses presented above require further verification-oriented research.

On the basis of the tests conducted it was possible to formulate the conclusions presented below:

1. The level of acoustic pressure in audible and ultrasonic noise bands during gas-shielded metal arc welding depends on welding current, parent metal thickness, electrode wire diameter and shielding gas chemical composition.
2. While welding thick-walled elements (6÷8 mm thick plates) using the MAG, MAG Pulse and RapidArc methods and during welding of thin-walled components (1÷2 mm thick) using the CMT, ColdArc, AC Pulse and MAG Double Pulse methods most of the material-technological variants tested revealed the positive correlation between welding current and the acoustic pressure level of sound A.
3. The test result analysis revealed that the shielding gas has a significant effect on the sound during welding. However, it was observed that it is not possible to select and use a shielding gas of one universal composition enabling the reduction of the acoustic pressure level of sound A for all welding methods and technological conditions used in practice.
4. The acoustic pressure level of sound A also depends on the parent metal thickness; joining thicker plates is accompanied by greater acoustic pressure levels.
5. The tests did not reveal the positive correlation between the electrode wire diameter and the acoustic pressure level of sound A for all the welding methods tested.
6. As regards the four methods for welding thin-walled elements the highest acoustic pressure levels of sound A accompanied the AC Pulse and MAG Double Pulse welding processes. For the same material-technological welding conditions the lowest acoustic pressure levels of sound A accompanied the low-energy welding processes, i.e. CMT and ColdArc.

The test results presented were obtained within the confines of the project entitled "Investigation and Development of a Measurement-Analytical System for Assessing the Level of Sounds Emitted in the Manufacture of Welded Structures" - INNOTECH-K2/IN2/40/182367/ NCBR/13 I

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