Technical requirements and characteristics of the ecological welding processes

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1. Introduction

The ecological welding processes must comply with the technical requirements concerning the environment protection and labour health, according to the ISO 9000, ISO 14001 and ISO 18001 standards regarding the integrated management system of quality, environmental protection, occupational health and safety, as well as the standards of these domains [1, 2].

The emissions of green house gases (carbon dioxide) and polluting substances must be reduced to a minimum or eliminated, for the purpose of the environment protection, as stated in the international agreement well known as the Kyoto Protocol of 1997, concerning the 5.2% reduction of the emissions that cause global warming [1, 2]. These requirements were confirmed at the International Conference on Environment of 2009 in Copenhagen.

The concentrations measured in the breathing air at the work place, of the hazardous and noxious substances exhaled during the welding and allied processes, must be reduced bellow the allowed limits, in order to assure the health and labour safety conditions for the work personnel.

Reducing the energy consumption has an indirect ecological effect, as the share of emissions of green house gases and polluting substances is lower, by generating the electric power, based on the present conventional processes. It also has effects on cost savings [6].

2. Technical requirements for the ecological processes

2.1. Greenhouse gases emissions

The major commitment of this century concerning the environmental protection is to lower as much as possible the global warming effect, that thretens to cause dramating changes in the life on our planet. The industry is considered as the main factor in the emission of gases with greenhouse effect, which means mainly carbon dioxide, but also methane, nitrous oxide and sulphur hexafluoride, hydrofluorocarbons and perfluorocarbons, as mentioned in the Kyoto Protocol. Nitric dioxide and water vapour should be added. Global surface temperature has increased 0.74 ± 0.18°C during the 20th century. It is likely to rise by 1.1 to 6.4 °C in the 21st century [1].

Another main factor of pollution is considered the automobile. In terms of the specific emission related to the path, an automobile type BMW Alpina B3 with a 3.300 litres motor capacity has a carbon dioxide (CO_2) emission level of 257 g/km; a Ford Transit car having a 2198 ccm motor has a CO_2 emission level of 208 g/km; the Honda Civic hybrid automobile with a 1339 ccm motor has a CO_2 emission level of 116 g/km; a Dacia Logan 1.4MPI car with a 1390 ccm motor has a CO_2 emission level of 165 g/km.

The conventional method for electric power generation is also a pollution factor. A power plant on natural gas, with combined cycle, has emissions of 400 g/kWh, respectively a power plant on coal has emissions of 915 g/kWh, respectively a plant based on coal capture and store has the emission level of about 200 g/kWh. Only nuclear and wind power plants bring better results, with mean emission levels of 6...25 g/kWh şi 11 g/ kWh.

2.2. Greenhouse gas emission by welding

As industrial fabrication technologies applied all over the world, the welding and its allied processes have their share in the pollution and global warming, by means of emissions and power consumption. Welding is responsible for the emission of carbon dioxide as a greenhouse gas, in the industrial application the gas metal arc welding process (GMAW), based on carbon dioxide as a shielding gas. For instance, by welding 2...4 mm thick steel plates this emission is in the range 10...15 litres/min, as shielding gas flow rate, which means 19...35 litres/m of weld or 37.56...69.19 g/m. This extent can be compared to the specific CO_2 emission level of 120...165 g/km of a conventional automobile, rated with 55 kW and 1.390 litres motor.

Related to the energy consumption, the CO_2 emission level of the GMAW process is 397.62...426.65 g/kWh, in the case of welding 2...4 mm thick steel plates. These extents are comparable to the emissions of an electric power plant on natural gas or coal has carbon dioxide emissions of about 400 g/kWh, respectively 915 g/kWh. The average emissions of the power supply system must be added to the specific emissions of the welding process, in order to assess the actual share of the polluting effect of the GMAW.

2.3. Noxious substances exhaled by welding

The welding and allied processes have also emissions of noxious and hazardous substances, exhaled as fumes and gases. In the table 1 some concentration limits in the tidal air at the work place are mentioned [3] –[6].

Table 1. Limit concentrations of the noxious substances exhaled by welding [3] –[6].

Noxious substance	Exposure limit (8 hours a day, 5 days a week)
CO	33 mg/m^3; 30 ppm
NO_2	9 mg/m^3; 1 ppm
NO	30 mg/m^3; 1 ppm
O_3	0.2 mg/m^3; 0.2 ppm
CCl_2O	0.4 mg/m^3; 0.1 ml/m^3
Fumes	5 mg/m^3 (total)
Fumes	5 µg/m^3 (stainless steel)
CrVI	0.5 mg/m^3; 0.1 mg/m^3
CrIII	0.5 mg/m^3
Be	0.002 mg/m^3
Cd	0.025 mg/m^3
Co	0.1 mg/m^3
Ni	0.5 mg/m^3
Fluoride	2.5 mg/m^3
Fe_2O_3	5...10 mg/m^3
Mn	0.5 mg/m^3
Cu	0.2 mg/m^3
Pb	1.5; 30; 50 µg/m^3
Hg	0.05; 0.10 mg/m^3
CO_2	5%; (asphixia)
Argon	5% (asphixia)

These limits sould not be exceeded, in order to comply with the regulations of environmental protection, as well as occupational health and safety.

2.4. Compared emission levels of the welding processes

The increasing order of the fumes and gases emission of the welding processes is the following:

1. Microwelding;
2. Friction welding;
3. Electron beam welding;
4. Ultrasonics welding;
5. Laser welding;
6. Submerged arc welding;
7. Gas tungsten electrode welding (GTAW);
8. Gas metal arc welding (GMAW) that uses both inert (argon, helium) and active (carbon dioxide and mixtures) shielding gases;
9. Manual metal arc welding with covered electrodes;
10. Plasma welding and cutting processes;
11. Gas metal arc welding with cored wire.

3. Characteristics of the ecological welding processes

According to some preliminary estimations, the joining processes that comply with the requirements regarding the emissions of green house gases and noxious substances are the following: friction stir welding (FSW), laser welding and ultrasonics welding. They are considered and promoted as ecologic welding processes for the industry [6].

3.1. Friction Stir Welding (FSW)

The FSW process has the essential ecological advantages of completely eliminating the polluting emissions of: carbon dioxide, carbon monoxide, nitric oxides and other noxious gases and fumes. FSW has the zero emissions level. Besides it has no exhalation of argon and produces no ultraviolet radiation.

Figure 1. Experimental FSW equipment [7].

As principle of this process, a rotary tool moves, stirs and mixes the metal of the two plates, making a joint. Various equipment types were developed in many countries, with different applications. An equipment used in the FSW experiments by ISIM of Timisoara is presented in figure 1.

The solutions developed by GKSS [8]-[10] have involved the use of Neos Tricept type robots. These robots have a parallel kinematic structure, which yields a significantly stiffer structure than the serial structures typically used with other industrial robots. However, these type of robots have rather limited working envelopes, compared to serial robots. Their cost is higher. In FSW studies, similar laboratory and prototype successes have been reported with the use of this family of robots.

The most significant advancement is the achievement of serial kinematic robots with much higher payloads. There are several industrial robot companies (e.g. ABB Robotics, Kuka Robotics) that now provide robots with payloads up to 500 kgf. One such robot is IRB7600 of ABB Robotics. This payload is approximately 2.5 times greater than what was previously available. Another change is the parallel kinematic robot from ABB Robotics (IRB 940). This has significantly lowered the cost [8].

A FSW system based on an IRB7600 robot of ABB consists of a spindle, a motor, a mechanism to drive the motor, and software to control the system. The spindle and motor are attached to the robot's wrist, while the motor drive mechanism is either external to the robot cabinet or within the cabinet. The software resides on the robot controller and is developed in the robot's native high level programming language.

3.2. Laser welding

Most commonly used welding lasers are Nd:YAG (Neodymium-Doped Yttrium-Aluminum-Garnet) and CO_2. YAG lasers are solid-state lasers and generate wavelength at about 1.064 microns. YAG lasers are used in both pulsed and CW (continuous wave) modes. A gas-based CO_2 laser generates light of 10.64 microns. It is primarily used in the continuous wave (CW) mode. More recent advances include fiber lasers that have a solid-state laser medium. They are pumped with laser diodes as a source of input energy. Another recent development is the direct diode laser [11]. The power consumption of a laser is reduced, due to energy concentration on a small spot.

On a Nd-YAG laser welding equipment, type HP 124 P LCU, produced by Trumpf, having 5 kW maximal rated power, experiments for laser welding and cutting nonostructured composite materials were carried out [12], where gas emission concentrations were measured, for CO, CO_2, NO and NO_2. The measured concentrations are 3...5 times less than by GMAW using argon. The carbon monoxide emission is 50 times less, while the carbon dioxide emission is aproximately 500 times less, compared to GMAW using carbon dioxide.

Some exhausting and filtering systems for laser welding are commercially available [13]. Their selection is made based on technical specifications, depending on the application, as presented in the Table 2. The filters are special purpose kinds, depending on the laser equipment and on its destination: marking, engraving, welding, cutting. The materials processed on laser are very diverse: plastic (polyvinyl chloride, polyethilene e.a.), ceramics, metals, paper, metal foil, wood, glass, rubber, cardboard e.a. Fumes emission can arise when welding, marking or cutting plastic or a material coated with lacquer, varnish, paint or a special metal coating. Laser welding head with exhausting inlet is presented in the Figure 2.

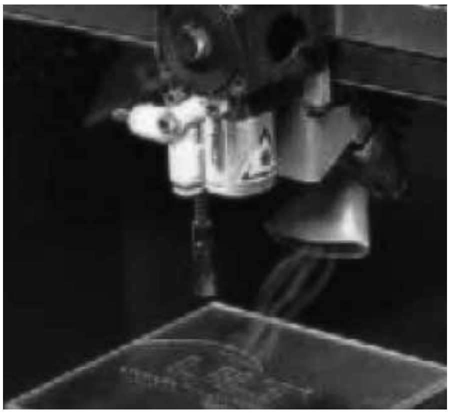

Figure 2. Laser welding head with exhausting inlet [13].

3.3. Ultrasonics welding

Ultrasonic welding of metals has no emissions of greenhouse gases or noxious substances. Instead, all thermoplastic materials release some vapors or gases at high temperatures. Users should take care in keeping the temperature of the thermoplastic materials below 200°C, at which point these materials may start to burn, degrade and exhale fumes and gases [14]-[16]. In case of such exhalations, exhausting systems should be applied. Harmful concentrations of gases or vapors do not occur if adequate ventilation is applied. Ultrasonic welding has also a reduced energy consumption, due to both the high efficiency and low rated power (0,8…3 kW).

Figure 3. Automated ultrasonic welding equipment, with an enclosure [15]

Due to the ultrasonic welding frequency, sub-harmonic vibrations, which can create annoying audible noise, may be caused in larger parts near the machine. This noise can be dampened by clamping these large parts at one or more locations. In situations where noise levels exceed OSHA limits [3]-[5], the problem can be solved by installing an accoustic enclosure, as presented in the Figure 3. It is fabricated from sheet steel, powder coated and fully lined with a special polymer cellular laminate to provide excellent noise suppression [15]-[17]. Local

Table 2. Storage filtering devices, with spare filters. Technical data [13].

Type, LAS series	Flow max. [m^3/h]	Suction Pressure max. [Pa]	Rated Flow [m^3/h] by [Pa]	Electrical Supply	Motor Power [kW]	Sizes L x W x H [mm]
Jum bo	170	2800	80 by 1400	230V / 50Hz	0.15	450x340x530
150	170	2800	60 by 1400	230V / 50Hz	0.15	370x370x1110
210 FQ	450	2600	250 by 2200	230V / 50Hz	0.37	630x400x470
210 EC	220	22000	200 by 3300	230V / 50Hz	1.20	630x400x470
220 EC	220	22000	200 by 3300	230V / 50Hz	1.20	370x370x1180
250 FQ	450	2600	250 by 2200	230V / 50Hz	0.37	520x370x1260
400-1	600	3300	400 by 2500	230V / 50Hz	0.70	630x580x1300
400-2	1500	3100	600 by 2500	230V / 50Hz	0.82	630x580x1300
400-2EC	440	22000	300 by 10000	230V / 50Hz	2.40	630x580x1300
1000	1700	2600	1000 by 1800	400V / 50Hz	1.50	790x680x1260
1000-V	1500	3100	1000 by 1800	230V / 50Hz	0.82	790x680x1260

noise barriers are another solution. Accoustic ear defenders are also recommended.

Ultrasonic noise has little effect on general health unless there is direct body contact with a radiating ultrasonic source. The threshold limit values TLVs®, presented in the Table 3, represent conditions under which it is believed that nearly all workers may be repeatedly exposed without adverse effect on their ability to hear and understand normal speech.. The 8-hour time-weighted average (TWA) values are an extension of the TLVs® for noise, which are TWA of 85 dBA for sound below 10 kHz.

Table 3. Noise level limits (OSHA, ACGIH) [3].

Mid-frequency of third-octave band [kHz]	Measured by head in air, re: 20 μPa [dB]		Measured by head in water, re: 1 μPa [dB]
	Ceiling values	8- hour time weighted average (TWA)	
10	105[a]	88[a]	167
12.5	105[a]	89[a]	167
16	105[a]	92[a]	167
20	105[a]	94[a]	167
25	110[b]	--	172
31.5	115[b]	--	177
40	115[b]	--	177
50	115[b]	--	177
63	115[b]	--	177
80	115[b]	--	177
100	115[b]	--	177

NOTES:

[a]Subjective annoyance and discomfort may occur in some individuals at levels between 75 and 105 dB for the frequencies from 10 kHz to 20 kHz especially if they are tonal in nature. Tonal sounds below 10 kHz might also need to be reduced to 80 dB.

[b]These values assume that human coupling with water or other substrate exists. These thresholds may be raised by 30 dB when there is no possibility that the ultrasound can couple with the body by touching water or other medium.

When the ultrasound source directly contacts the body, the values in the table do not apply. The vibration level at the mastoid bone must be used.

Contact exposure is exposure for which there is no intervening air gap between the transducer and the tissue. This may be via direct and intimate contact between the transducer and the tissue or it may be mediated by a solid or liquid. Contact exposure can in some cases provide nearly 100% energy transfer to tissue. Exposure to ultrasound in ultrasonic cleaners operating at frequencies between 20 and 40 kHz was reported to have caused pain in the hands of the volunteers [3]. However, exposure to ultrasound in an 80 kHz cleaner led to no immediate observable effects. No independently confirmed significant biological effects have been observed in mammalian tissues by the ultrasonic frequencies in the range of 1 to 10 MHz and the spatial peak time-average intensities, at the power density of 10^{-1} to 10^3 W/cm^2, measured in water, for exposure duration of 10^{-2} to 10^4 s. There are no reports of necrosis or bone degeneration due to persistent exposure to liquid coupled ultrasound. However, testicular damage was observed in 4 of 150 mice exposed to ultrasound from a 25 kHz tissue homogenizer operating at an intensity of 15 W/cm2 [18]. Exposure to the liquid-borne ultrasound from these devices clearly can cause tissue injury, and protection measures are necessary. A thermal injury was inflicted by a direct contact exposure with an ultrasonic bonding machine used for plastics, operating at 20 kHz. An exposure of only a fraction of a second was enough to cause a serious localized burn on the operator's finger. Therefore, appropriate precautions must be taken to avoid accidental exposure.

4. Conclusions

1. The emission of carbon dioxide of the GMAW process is in the range 19...35 litres/m or 37.56...69.19 g/m, that is comparable to the emission of an automobile.

2. The specific emission level of the GMAW is 397.62... 426.65 g/kWh, which is aproximately the same as the emission of a power plant.

3. According to the Kyoto Protocol of 1997 on environment protection, the greenhouse gas emission, that cause global warming, must be reduced by 5.2%. As a consequence, ecological welding processes must be implemented.

4. The requirements for the ecological welding and allied processes consist in complying with the standards for both the environment protection and occupational health. The emissions of greenhouse gases (carbon dioxide, nitric dioxide), polluting substances (cadmium, mercury, lead e.a), noxious and toxic substances must be reduced.

5. The noxious substances exhaled by welding are classified as follows:

- hazardous particles (dust) of metal and oxides; welding fumes (solid-microparticles of metals and oxides);
- poisonous gases (carbon monoxide, nitric oxides, etc.).

6. The friction stir welding (FSW) is an ecological process, due to its properties:

- zero emissions of greenhouse gases and polluting substances;
- no ultraviolet and infrared radiations;
- no shielding gases (argon and carbon dioxide).

7. Various types of FSW equipment and robots are used, having load forces in the range 5...20 kN.

8. By laser welding of composite materials, the emission concentration for carbon monoxide and carbon dioxide is 50, respectively 500 times less than by GMAW using active shielding gas (carbon dioxide).

9. Fumes emission can arise in case of welding, marking or cutting by laser, of plastic or material coated with lacquer, varnish, paint or certain metals. In such cases, exhausting and filtering systems can be applied, with a flow rate of 80...1000m^3/h.

10. Provided the specified safety and health conditions, laser welding can be considered as an ecologic process.

11. Ultrasonic welding of metals has no emissions of greenhouse gases or noxious substances.

12. By the ultrasonic welding of thermoplastic materials, the temperature should be kept below 80…200°C, to avoid fumes and gases, in the case exhausting is not provided.

13. By ultrasonic welding, vibration and noise caused by sub-harmonics can be avoided by an enclosure and ear defenders. Contact exposure should be avoided.

14. By ultrasonic processes, noise limits specified by ACGIH and OSHA must be complied. Subjective annoyance and discomfort may occur at levels between 75 and 105 dB for the frequencies from 10 kHz to 20 kHz.

15. Provided the specified safety and health conditions, ultrasonic welding is an ecologic process.

References

[1]. ***, Kyoto Protocol. http://en.wikipedia.org. http://www.kyotoprotocol.com.

[2]. Society of Motor Manufacturers and Traders Ltd: CO_2 Emissions Data. http://www.smmtco2.co.uk/co2.

[3]. American Conference of Governmental Industrial Hygienists. ACGIH® Worldwide, 2003. TLVs® and BEIs®: Threshold Limit Values for Chemical Substances and Physical Agents & Biological Exposure Indices. www.osha.gov.

[4]. AIHA American Industrial Hygiene Association. Protecting Worker Health: Welding Health and Safety. A Field Guide for OEHS Professionals. www.aiha.org.

[5]. ***, Health and Safety in Welding. http://www.twi.co.uk.

[6]. Verbiţchi V., Poşogan M.V., Cazacu A., Research Project PN107. Promotion of ecological joining processes having reduced energy consumption (In Romanian). ISIM Timişoara, 2009, pag.99+8; 15fig.;4tab.;85ref.

[7]. Dehelean D. e.a., Innovative and ecological technologies to process advanced materials by friction stir welding (in Romanian). Project Matnantech CEEX No.66/2006-2008.

[8]. Christopher B. Smith, John F. Hinrichs, & Wade A. (Crusan Friction Stir Link, Waukesha, WI, USA), Robotic Friction Stir Welding: State of the Art. http://www.frictionstirlink.com/publications

[9]. Zettler, R., da Silva, A.M., Rodrigues, S., Blanco, A. and dos Santos, J.F., "Dissimilar Al to Mg Alloy Friction Stir Welds", Advanced Engineering Materials, Volume 8 (2006), No. 5, 415-421.

[10]. Santos T.; Vilaça P.; Dos Santos J., Quintino L., Computational tools for modelling FSW and an improved tool for NDT. Welding in the world, Vol.53, No.5/6, 2009.

[11]. Miyachi Unitek Corporation: Laser welders and systems. www.northeastlaser.com/Laser_Welding_Processes.

[12]. Savu D. (University of Craiova, FIMST); Birdeanu V. (ISIM of Timisoara), Fume emission by pulsed laser processing nanostructured composite materials (In Romanian). International Conference. ISIM Timisoara. "Sudura" Publishing House. ISBN 978-973-8359-9, 2007, pag. 253 – 257.

[13]. ULT Umwelt – Lufttechnik: LAS fuer Laser-Rauch. Die LAS-Serie Absaug- und Filteranlagen fuer Laserrauch. http://www.ult.de/filebase/ULT-LAS_dt.pdf.

[14]. Oanca O. , Sârbu N.A., Aspects regarding the use of the ultrasonics energy in joining technics of polymeric materials in the automotive industry. (In Romanian). International Conference "Tima 08". ISIM Timisoara. "Sudura" Publishing House. ISSN 1844 – 4938, 2008, pag. 61 – 66.

[15]. ***, Telsonic advises on ultrasonic welding safety. http://www.manufacturingtalk.com.

[16]. ***, Branson's Series 30 Rotary Ultrasonic Welding Systems. www.globalspec.com.

[17]. Stapla Ultrasonics Corporation: Innovations that define ultrasonic metal welding. http://www.staplaultrasonics.com.

[18]. Health Canada, Guidelines for the Safe Use of Ultrasound. Part II - Industrial & Commercial Applications - Safety Code 24. http://www.hc-sc.gc.ca/home.