Ryszard Krawczyk

Welding parameter ranges in relation to metal transfer method in welding arc

Abstract: The study is concerned with MAG welding. The issues presented are directly related to the transfer of metal in the welding arc depending on power applied. The main objective of the study was to present the ranges of welding parameters in relation to the mode of metal transfer in the welding arc. The subject of the study was inspired by the introduction of new standard PN-EN ISO 9606-1 concerning the qualification of welders. This standard features the mode of metal transfer in the welding arc as a new welder qualification variable. As a result, these issues have acquired new significance in terms of this process.

Keywords: metal transfer methods, welding arc, welding parameters, MAG, PN-EN ISO 9606-1

Introduction

Welding processes used in the production of various structures are rated among special processes. This fact results from the complexity of welding processes characterised by numerous variables which are often difficult to define and sometimes even impossible to predict. In order to ensure the proper course of welding processes, it is necessary to extensively qualify welding technologies and personnel participating in their execution. This requirement concerns personnel directly involved in welding processes (welders and welding station operators), surveillance personnel (welding engineers and junior personnel) and inspection personnel (welding inspectors and NDT personnel). The primary objective of qualification is to ensure the most convenient conditions for the proper course of welding processes at various stages of their execution. This special task includes welder qualification. The new PN-EN ISO 9606-1 standard concerning the qualification of welders, includes a new welder qualification variable taking into consideration also the mode of metal transfer in the welding arc. This concerns the MAG 135, MAG 138 and MIG 131 welding processes. The revision requires good knowledge of the operation of a heat source used in these processes, i.e. an electric arc as well as the application of welding parameter ranges in relation to the mode of metal transfer in the welding arc. The objective of this study is to introduce these issues in the scope contained in PN-EN ISO 9606-1.

Welding arc characteristics

The welding arc can be simply defined as a "**discharge in the inter-electrode area**". The arc used in welding engineering is characterised by many variables depending on the type of a welding process. The basic welding arc variables include the following:

dr inż. Ryszard Krawczyk (PhD (DSc) Eng.) – Częstochowa University of Technology, Welding Technology Department

1. Type of power supply forming the character of a discharge:
   - type and polarity of current,
   - static and dynamic characteristics of the welding power source,
   - control conditions and power supply parameter values,
   - disturbance in the supply circuit.
2. Type of electrodes:
   - character of fusibility,
   - thermal and electric properties,
   - diameter or thickness,
   - introducing and maintaining stability,
   - purity.
3. Formation of inter-electrode area:
   - type and efficiency of a gas shield,
   - inter-electrode distance and its stability,
   - **changes taking place as a result of material transport in the arc area.**

The basic types of arc welding processes commonly used in production include the following methods:

- **MMA (111)** – *Manual Metal Arc*,
- **MAG (135 and 138)** – *Metal Active Gas* (with solid wire electrode – 135 and metal cored electrode – 138),
- **MIG (131)** – *Metal Inert Gas*,
- **TIG (141)** – *Tungsten Inert Gas*,
- **SAW (121)** – *Submerged Arc Welding*.

The most convenient conditions affecting arc burning stability are present in TIG welding and include, among others, the following:

- solid non-consumable electrode,
- constant distance between the electrode and the material,
- stable (steep) arc supply characteristics,
- noble gas shield,
- absence of disturbance caused by the transfer of a metal drop in the arc area.

In turn, the most inconvenient conditions affecting arc burning stability are present in MMA welding and include, among others, the following:

- consumable electrode,
- changeable distance between the electrode and the material,
- non-uniform gas shield,
- disturbance caused by the transfer of a metal drop in the arc area.

Significant differences characterise TIG and MMA despite using electric arc power supply sources having the same features, i.e. steeply drooping characteristics. The measure of these features is the significant difference present in the conventional voltage waveform for both processes, illustrated in the diagram (Fig. 1).

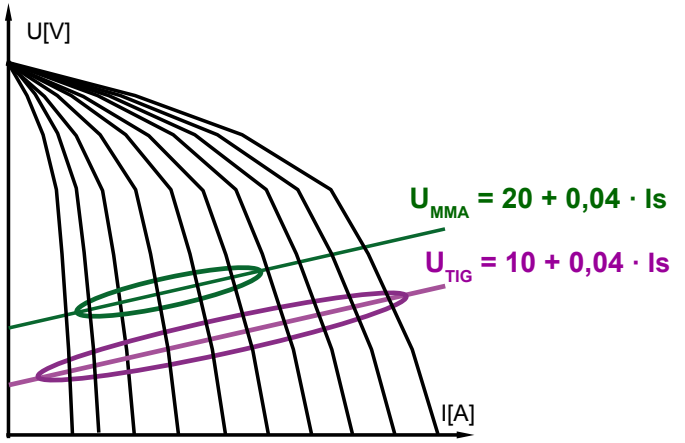

Fig. 1. Voltage static characteristics and welding arc conventional characteristics in MMA and TIG

Modes of Metal Transfer in Welding Arc

The transfer of metal in the welding arc is directly connected with consumable electrodes and is related to most arc welding processes, e.g. 111, 135, 138, 131 and 121, as well as their varieties.

The most interesting form of metal transfer in the welding arc is present in MAG and MIG welding processes and is directly connected with significant current density, the rate of current density changes and the wide range of welding arc power. These features result mainly from small diameters of electrode wires fed within a wide range of feeding rates and from supplying the arc with flat characteristics power sources within a wide power range, which enables significant freedom of melting rate changes. As a result, depending on welding arc power applied the welding methods mentioned above are characterised by widely diversified modes of metal transfer in the arc. The basic modes of metal transfer in the arc are the following:

1. **short-circuit** (fine droplet),
2. **globular** (coarse droplet, mixed),
3. **spray** (stream),
4. **rotating** (eddy),
5. **pulsed** (in pulsed arc).

The first four modes of metal transfer in the welding arc (short-circuit, globular, spray and rotating) are present in a natural process usually referred to as standard, as distinct from the pulsed arc process developed in the 1990s. The basis of the pulsed arc process is the uniform pulsed mode of metal transfer in the arc. The pulsed metal transfer has all the features of the spray transfer, yet it takes place within the whole range of applied welding arc power. Figure 2 illustrates the static characteristics and conventional arc voltage dependence in the MAG standard process taking into consideration various modes of metal transfer in the arc zone in the current range up to 400 A.

The dependences of conventional arc voltage presented in Figure 2 concern Ar82CO$_2$18 gas-shielded welding of group 1 steels using a G3Si1 electrode wire with a diameter of 1.2 mm

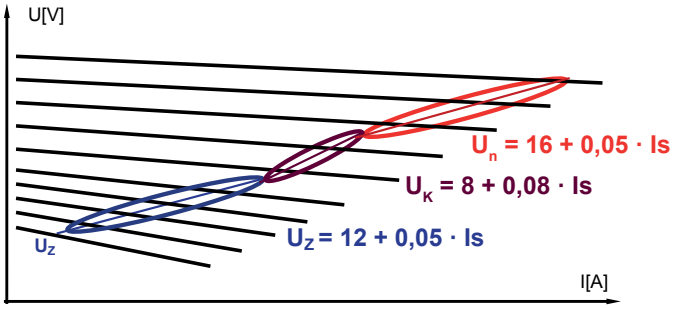

Fig. 2. Static power supply characteristics and conventional arc voltage characteristics in the MAG standard method with various modes of metal transfer in the arc zone

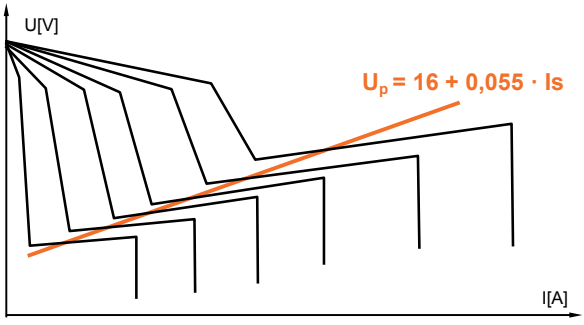

Fig. 3. Static power supply characteristics and conventional arc voltage characteristics in the MAG pulse method in the entire current range up to 400A

and at the same time are concerned with current ranges related to various modes of metal transfer in the welding arc in the MAG standard method. The analogous illustration of static power supply characteristics and dependence of conventional arc voltage in the MAG pulse method is presented in Figure 3.

The dependence of conventional pulsed arc voltage concerns Ar82CO$_2$18 gas-shielded welding of group 1 steels using a G3Si1 electrode wire having a diameter of 1.2 mm in a current range up to 400 A.

Characteristics of basic dependences and welding parameter ranges for unalloyed steels in relation to mode of metal transfer in welding arc in MAG-135 method

Complete characteristics of the changes of the basic (voltage-current) dependences for M21 (Ar82CO$_2$18) gas-shielded MAG welding of S235 unalloyed steels with G3Si1 electrode wires having diameters of 1.2; 1.0 and 0.8 mm, using the standard arc and various modes of metal transfer in the welding arc and with a pulsed arc are presented in Figures 4, 5 and 6. Tables 1, 2 and 3 contain detailed information concerning basic arc control parameter ranges (v, U and I) in relation to the modes of metal transfer in the arc (short-circuit, globular, spray and pulsed).

Welding parameter ranges for unalloyed steels in relation to mode of metal transfer in welding arc in MAG-138 Method

Detailed information related to the ranges of basic arc control parameters (v, U and I) in the MAG-138 method in relation to the modes of metal transfer in the arc (short-circuit, globular, spray and pulsed) is presented in Tables 4 and 5. The data refer to M21 active gas-shielded welding of S235 low-carbon steels using metallic flux-cored wire having the diameters of 1.6 and 1.2 mm. As regards the materials mentioned above, manufacturers do not recommend using

Data for the electrode wire with the diameter of 1.2 mm

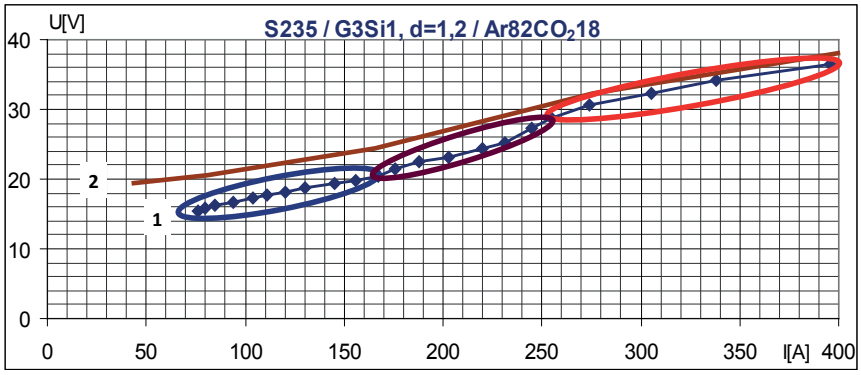

Fig. 4. Arc voltage dependences in the function of welding current in arc control in the MAG standard method with various modes of metal transfer in the arc zone (curve 1) and MAG pulse (curve 2)

Table 1. Ranges of the basic arc control parameters (v, U, and I) depending on the modes of metal transfer in the arc

Parameter type	Parameter ranges due to metal transfer mode in arc			
	short-circuit	globular	spray	pulsed
v [m/min]	1.5–4.0	4.2–7.5	8.0–14.0	1.2–14.0
U [V]	15.5–20.0	20.5–28.0	29.0–36.5	19.0–39.0
I[A]	75–160	165–250	260–400	40–400

Data for the electrode wire with the diameter of 1.0 mm

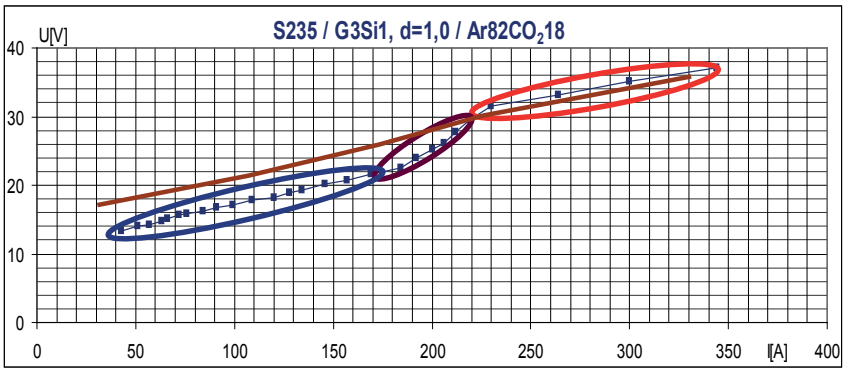

Fig. 5. Arc voltage dependences in the function of welding current in arc control in the MAG standard method with various modes of metal transfer in the arc zone (curve 1) and MAG pulse (curve 2)

Table 2. Ranges of the basic arc control parameters (v, U, and I) depending on the modes of metal transfer in the arc

Parameter type	Parameter ranges due to metal transfer mode in arc			
	short-circuit	globular	spray	pulsed
v [m/min]	1.5 – 7.0	8.0 – 10.5	11.0 – 19.0	1.4 – 21.0
U [V]	13.5 – 21.5	22.0 – 28.0	29.0 – 37.5	17.0 – 35.5
I[A]	45 - 170	180 – 215	220 - 350	30 - 335

Data for the electrode wire with the diameter of 0.8 mm

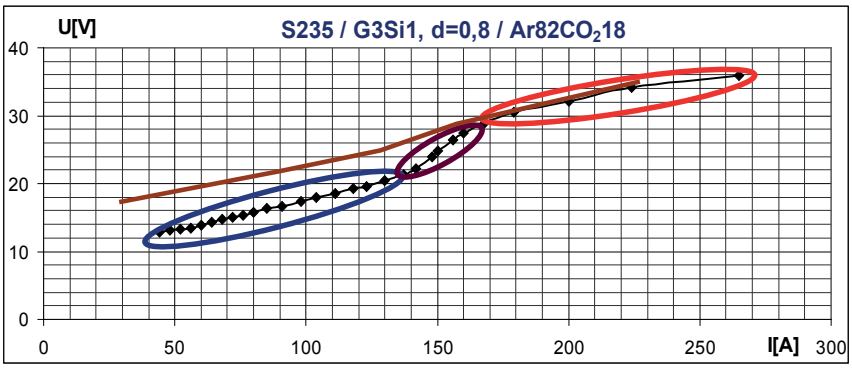

Fig. 6. Arc voltage dependences in the function of welding current in arc control in the MAG standard method with various modes of metal transfer in the arc zone (curve 1) and MAG pulse (curve 2)

Table 3. Ranges of the basic arc control parameters (v, U, and I) depending on the modes of metal transfer in the arc

Parameter type	Parameter ranges due to metal transfer mode in arc			
	short-circuit	globular	spray	pulsed
v [m/min]	2.0 – 8.5	9.0 – 11.5	12.0 – 25.0	2.0 – 23.5
U [V]	13.0 – 20.5	21.0 – 27.5	28.0 – 36.0	18.0 – 35.0
I[A]	45 - 130	135 – 160	165 - 265	30 - 225

welding parameters in the range of globular metal transfer (coarse droplet, mixed) in the arc.

MAG-135 welding parameter ranges for CrNi alloy steels in relation to the mode of metal transfer in a welding arc in the MAG-135 method

Further data presented in Tables 6, 7 and 8 concern using the MAG-135 method in M11 active gas-shielded welding of CrNi type alloy steels with wires having diameters of 1.2; 1.0 and 0.8 mm. The detailed information refers to the ranges of basic arc control parameters (v, U and I) in the MAG-135 method in relation to the modes of metal transfer in the arc (short-circuit, globular, spray and pulsed)

Conclusions

1. The transition from one mode of metal transfer in the welding arc to another takes place within the narrow range of current change referred to as critical. In this area, the transfer of metal in the arc takes on a mixed form.

2. The boundaries of the ranges of transition from one mode of metal transfer in the welding arc to another, i.e. the values of current in the critical area depend on the types of materials, diameters of electrode wires, types of shielding gases, exposed lengths of electrode wires, as well as on the static and dynamic properties

Table 4. Ranges of the basic arc control parameters (v, U, and I) depending on the modes of metal transfer in the arc for flux-cored wire with the diameter of 1.6 mm for M21 gas-shielded welding (Ar82C0218)

Parameter type	Parameter ranges due to metal transfer mode in arc			
	short-circuit	globular	spray	pulsed
v [m/min]	1.7 – 3.5	–	3.5 – 9.0	1.5 – 12.0
U [V]	14.5 – 20.0	–	25.5 – 36.5	18.0 – 36.0
I[A]	130 - 215	–	235 - 400	100 - 450

Table 5. Ranges of the basic arc control parameters (v, U, and I) depending on the modes of metal transfer in the arc for flux-cored wire with the diameter of 1.2 mm for M21 gas-shielded welding (Ar82C0218)

Parameter type	Parameter ranges due to metal transfer mode in arc			
	short-circuit	globular	spray	pulsed
v [m/min]	1.7 – 3.5	–	3.5 – 9.0	1.5 – 12.0
U [V]	14.5 – 20.0	–	25.5 – 36.5	18.0 – 36.0
I[A]	130 - 215	–	235 - 400	100 - 450

Table 6. Ranges of the basic arc control parameters (v, U, and I) depending on the modes of metal transfer in the arc for electrode wire 316LSi/d =1.2 mm for M11 gas-shielded welding (Ar98C022)

Parameter type	Parameter ranges due to metal transfer mode in arc			
	short-circuit	globular	spray	pulsed
v [m/min]	1.5-5.0	5.5-8.5	9.0-22.0	1.2-14.0
U [V]	14.0-20.0	20.5-26.0	27.0-36.0	15.0-31.0
I[A]	60-165	170-230	240-410	40-330

Table 7. Ranges of the basic arc control parameters (v, U, and I) depending on the modes of metal transfer in the arc for electrode wire 316LSi/d = 1.0 mm for M11 gas-shielded welding (Ar98C022)

Parameter type	Parameter ranges due to metal transfer mode in arc			
	short-circuit	globular	spray	pulsed
v [m/min]	1.5-7.0	7.5-8.5	9.0-24.0	1.5-20.0
U [V]	14.0-22.5	23.0-25.0	25.5-32.5	15.5-32.0
I[A]	45 - 145	150-160	170-320	35-285

Table 8. Ranges of the basic arc control parameters (v, U, and I) depending on the modes of metal transfer in the arc for electrode wire 316LSi/d=0.8 mm for M11 gas-shielded welding (Ar98C022)

Parameter type	Parameter ranges due to metal transfer mode in arc			
	short-circuit	globular	spray	pulsed
v [m/min]	2.5-8.0	8.5-14.5	15.0-25.0	2.2-23.0
U [V]	13.5-19.0	19.5-25.0	25.5-31.0	16.0-30.0
I[A]	45-110	115-160	170-250	30-210

of the welding arc power source.

3. Deteriorating conditions in the welding process are responsible for the decrease in the boundary of transition from the short-circuit arc to the globular arc and for the increase in the boundary of transition from the globular arc to the spray arc. In such conditions the area of the globular arc (coarse droplet, mixed) becomes extended.

4. The most convenient welding process conditions are obtained in the welding arc with short-circuit and spray metal transfer, as well as pulsed transfer while using the pulsed arc.

5. The most inconvenient welding process conditions are present in the arc with the globular metal transfer (coarse droplet, mixed).

6. The application of arc with various metal transfer modes is the following:

- short-circuit – welding of thin elements in various positions and thicker elements in restricted positions,
- globular – welding of thicker elements in flat and horizontal positions,
- spray – welding of thick elements in flat and horizontal positions,
- pulsed – welding elements of various thicknesses in flat and horizontal positions.

7. The qualification of welders according to PN-EN ISO 9606-1 has adopted preference conditions for welding processes 131, 135 and 138 with the short-circuit arc following the instruction: **"Welder qualification for short-circuit arc welding (short arc) (processes 131, 135 and 138) qualifies for other metal transfer modes, but not vice versa"**.

References:

1. Pierożek B., Lassociński J.: Spawanie łukowe stali w osłonach gazowych. Warszawa, WNT, 1987.
2. Kowarsch A, Zaczek Z.: Spawanie konstrukcji okrętowych w osłonie gazów. Gdańsk, Wyd. Morskie, 1984.
3. Collective work: Poradnik Inżyniera. Spawalnictwo, vol. 1 i 2: Warszawa, WNT, 2005.
4. Krawczyk R. Plewniak J. Sujewicz K.: Spawanie metodą MAG grubościennych rurociągów energetycznych ze stali 13HMF – optymalizacja warunków procesu. Przegląd Spawalnictwa, 2006, No. 7-10.
5. Kensik R., Krawczyk R., Plewniak J., Świentek A.: Synergiczne sterowanie w procesach MIG/MAG. Przegląd Spawalnictwa, 1997, nr 2.
6. Krawczyk R., Plewniak J., Kozłowski J.: Zastosowanie łuku pulsującego do spawania miedzi metodą MIG. Przegląd Spawalnictwa, 2003, No. 7.
7. Krawczyk R., Plewniak J.: Opracowanie specjalnych programów spawania do urządzenia SYNERMIG 402. Raporty z prac badawczych, 2005÷2006, PCz. - OZAS-ESAB w Opolu.
8. Krawczyk R., Plewniak J.: Badania własności technologicznych sterowania prototypu urządzenia SYNERMIG 402. Raporty z prac badawczych, 2004÷2005, PCz. - OZAS-ESAB w Opolu.
9. Kensik R., Krawczyk R., Plewniak J.: Opracowanie programów sterowania synergicznego półautomatu spawalniczego SYNERMIG 401. Raport z pracy badawczyej, 1998÷1999, PCz. - OZAS w Opolu.
10. Kensik R., Krawczyk R., Plewniak J.: Opracowanie programów sterowania synergicznego półautomatu spawalniczego SYNERMIG 400. Raport z pracy BZ, 1993÷1996, PCz. - OZAS w Opolu.