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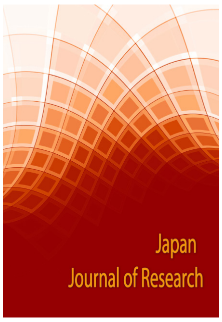

The Physical and Technological Background of the GMA Process

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Abstract

Gas Metal Arc (GMA) welding is widely used in the world manufacturing industry of modern metal structures, such as buildings, bridges, yellow goods, thanks, pressure vessels, piping, pipelines, etc., ensuring high-efficiency and high-quality semiautomatic, automatic and robotic welding. This paper describes the basic physical and technological backgrounds of GMA welding process and provides comprehensive analysis of the influence of basic GMA welding parameters on efficiency of welding and the quality of welded joints. Examples of GMA welding applications are given.

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Introduction and Physical Backgrounds of GMA welding

Process of arc welding that uses heat input of an electric arc between continuously fed consumable wire electrode and weld pool in a shield of the inner gas is called MIG (Metal Inert Gas) or the shield of the active gas is called MAG (Metal Active Gas) or both called GMA (Gas Metal Arc), Figure 1. During GMA welding electric arc locally melt the base metal and melt the consumable wire electrode create liquid weld pool (melt-in welding mode) that cools to form a welded joint, The properties (mechanical, corrosion resistance etc.) of a weld metal are function of the chemical composition of base metal and consumable wire electrode and the dilution rate - D, that for GMA welded joints can be controlled by proper selection of welding parameters (heat input) in the range 20-50% (in the case of GMA narrow gap welding technique below 10%), Figure 1.

The GMA welding, invented in 1920’s, is the most commonly used process in the global industry for semi-automatic, automatic and robotic permanent joining of construction elements made of all weldable low alloys and high alloys steels, aluminum, magnesium, titanium, nickel and cooper alloys [1-18]. The newest, most efficient industrial application of the GMA automatic and robotized welding of (U)HSS and aluminium alloys structures is hybrid welding technology of thicker butt and T-joints being connection of laser beam + GMA (LHW) and plasma transfer arc + GMA (PHW), Figures 2 and 3 [19, 20]. All kind of welded joints: butt, overlap, edge and T-type are made by automatic feed consumable electrode in the form of a solid wire or metal or flux powder cored wire, at a constant speed (it is the basic welding - heat input parameter), in the external shield of inner or active gas, Figures 1 and 4. The filler wire stick-out distance is resistance preheated by flow of welding current supplied by a contact tube and next is melted by the high temperature of the electric arc and turns into droplets, Figure 5. The droplets detach from the tip of the filler wire and impinge onto weld pool of the welded joint area, with the influence of the plasma arc pressure, gravity and electromagnetic force. Finally, the molten weld pool being the mixture of melted filler wire and melted parent metal, solidifies and forms the weld bead of the joint.

The GMA welding apparatus combines an electrode feed unit and a constant-potential (voltage) inverter power source with flat volt-ampere curve and provides automatic self-regulation of the electrical characteristic of the GMA arc, providing that the arc length and the welding current (wire feeding speed) are automatically maintained on the set, constant level, Figure 6 [3]. The GMA welding can be carried out semi-automatically, automatically or in a robotic manner, in workshop and in-field environment, in all positions, for all kind of welded joints, Figures 7-9. The GMA arc can be supplied with direct current (DC+) or (DC-), constant or pulsating, or alternating AC, sinusoidal or modulated pulsed, depending on the type of a metal being welded, the type of a consumable electrode material, welding technique, etc.

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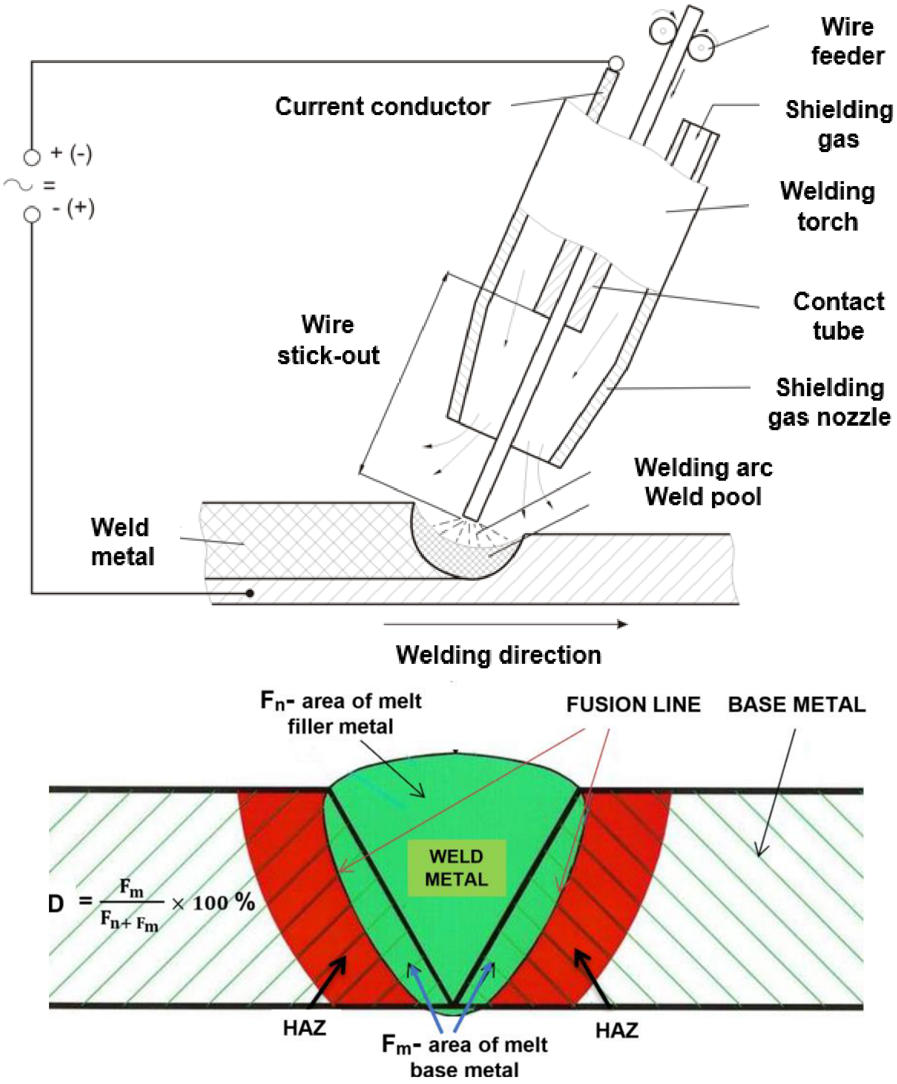

Figure 1. *Schematic view of the GMA welding process and the droplets driving forces and the dilution rate [1-18]*

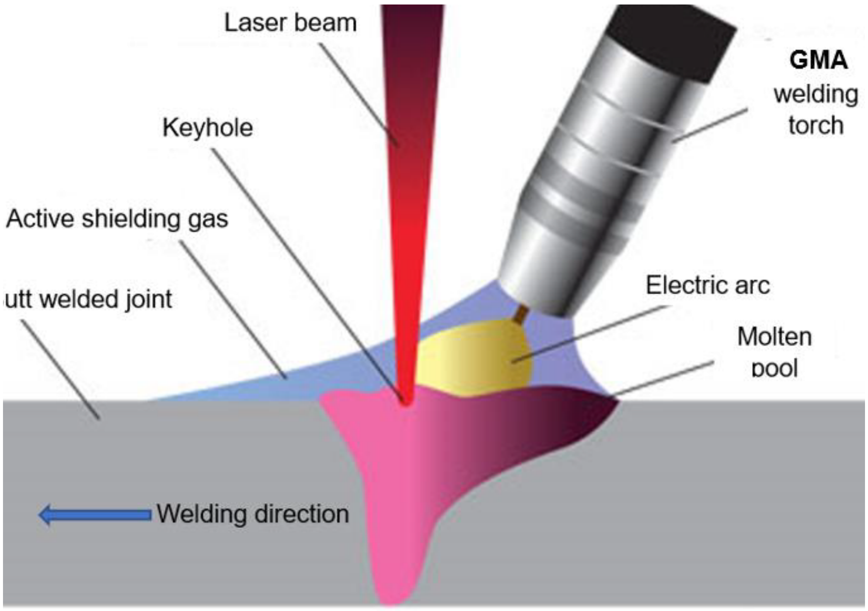

Figure 2. *Schematic diagram of the laser hybrid welding process: laser beam + GMA (LHW) [19]*

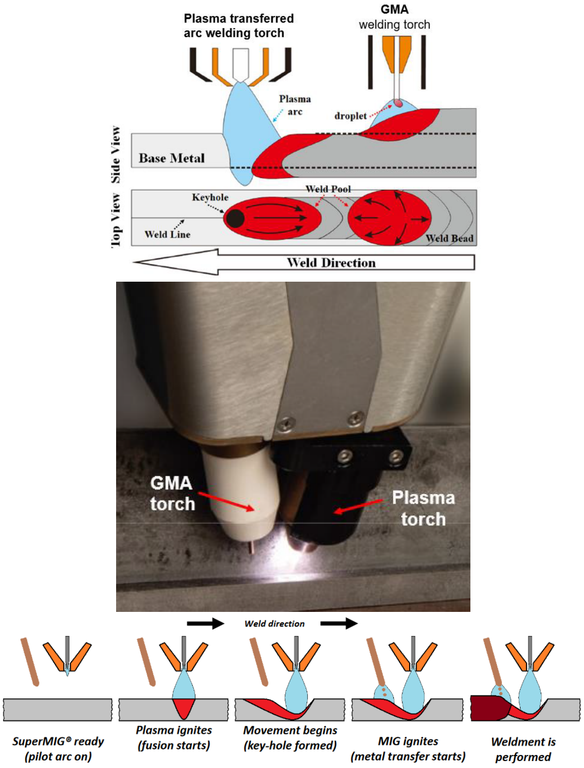

Figure 3. *Schematic diagram of the hybrid plasma transferred arc+GMA (PHW) welding and a view of PHW SUPER MIG torch and the PHW welding sequence [19,20]*

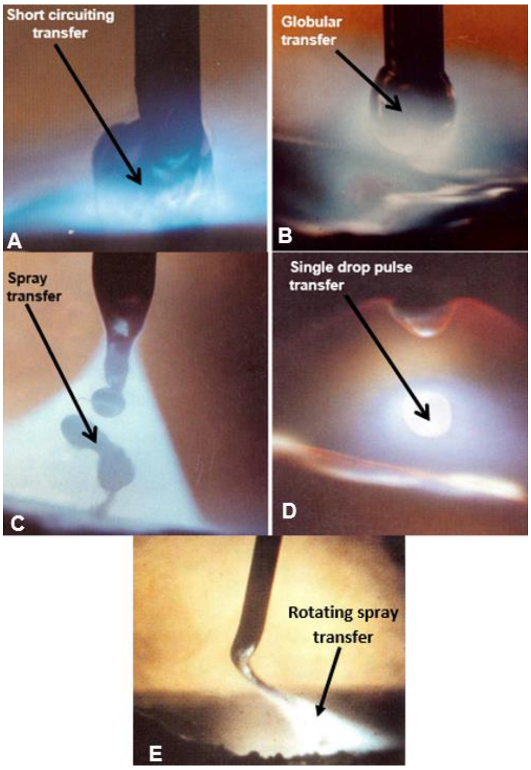

Figure 5. *Schematic diagram of the hybrid plasma transferred arc+GMA (PHW) welding and a view of PHW SUPER MIG torch and the PHW welding sequence [19,20]*

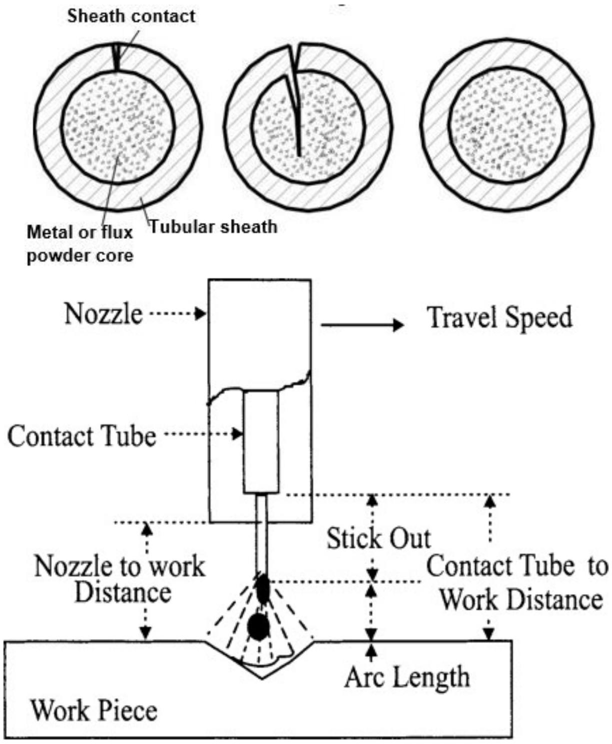

Figure 4. *Schematic view of metal and flux or metal powder cored wires and the GMA welding terminology [1, 2, 13-16]*

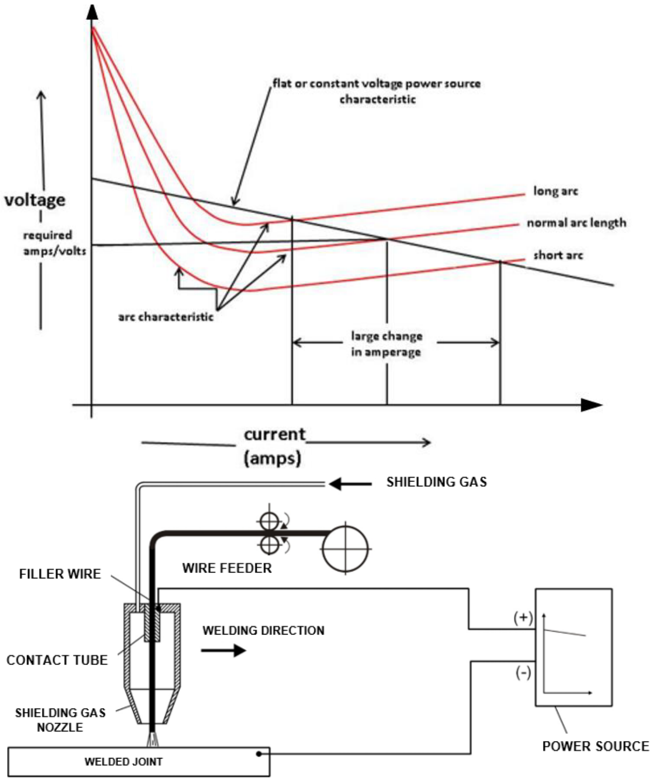

Figure 6. *The GMA welding Volt-Ampere relationship for a constant voltage inverter digital power source and the scheme of GMA welding installation [1-16]*

Figure 7. *A view of robotized GMA welding torch with cooling system of 9°- Long duration tip system COLD Tip and automatic bug GMA girth welding of pipeline butt joints in fixed PG (5G) position [3, 12]*

Figure 8. *A view of automatic bug GMA flux cored wire welding of a butt joint of API 5LX80 Hatton-Silk Willoughby pipeline [11]*

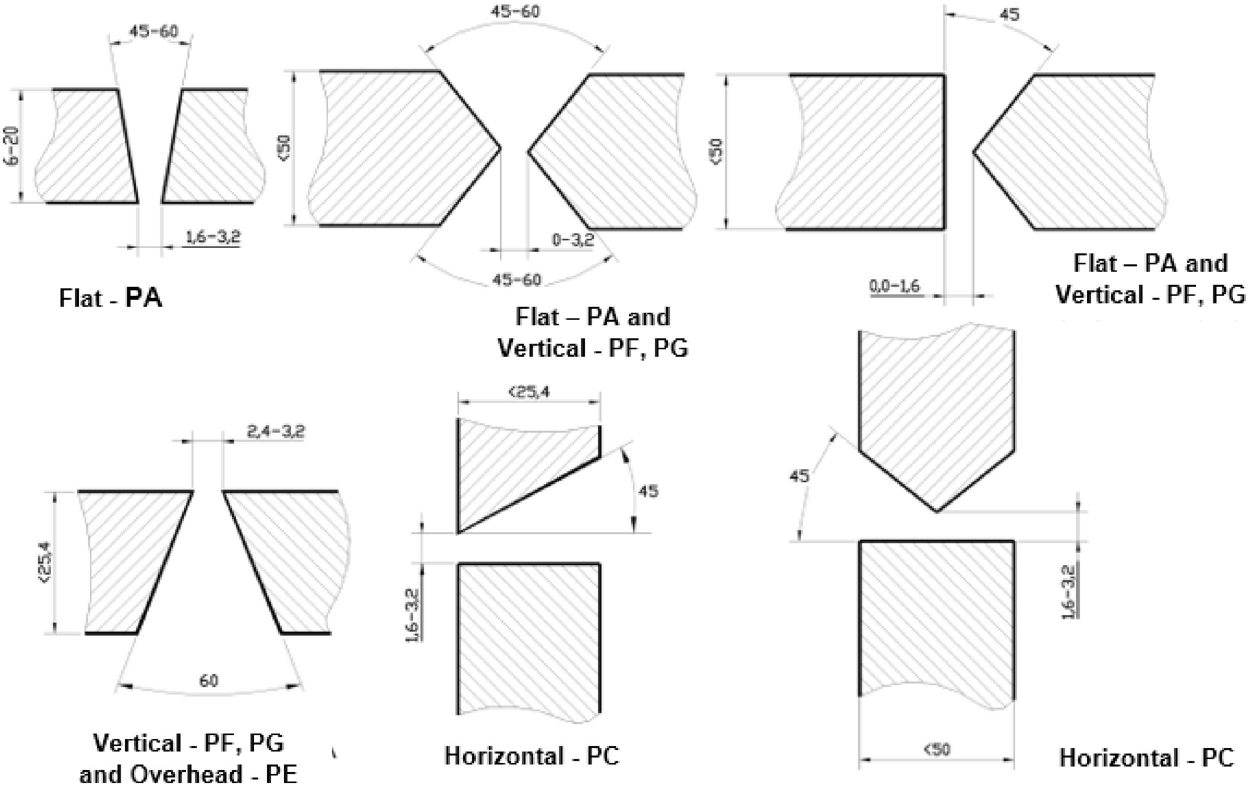

Figure 9. *Typical butt welded joint designs for GMA welding in all positions [1, 2, 13-16]*

The vast majority of steel structures GMA welding applications use direct current electrode positive DC(+) which yields a stable arc, smooth metal transfer, low spatter, good weld bead characteristics and greatest depth of penetration for a wide range of currents, Figures 10 and 11. The consumable electrodes have a typical diameter in the range of 0.5 to 4.0 mm, and are fed to the welding area by a special feeding system (wire feeder), at a constant speed of 2.5 to even 50 m/min. The basic shielding gases used for GMA welding are mixtures of inert gases: Ar or He and chemically active gases: e.g. CO2, Ar + 2 to 5%O2 , Ar + 5 to 25%CO2 and Ar + 10%CO2 + 5%O2. The precise shielding of the GMA welding arc in the GMA welding torch, between the consumable electrode and the welded joint, ensures that the weld metal is formed under very favourable thermal and metallurgical conditions. GMA welding can therefore be used to make high-quality joints of carbon steels, low-alloy steels, high alloy steel and in specific (U)HHS steel structures [1-11].

When the GMA arc is supplied by direct current (DC-), i.e. the consumable electrode (solid wire or flux or metal powder cored wires) is the cathode, approx. 70% of the thermal energy is released at the electrode and as the result, the electrode melts at high speed and efficiency, Fig. 11 and 12. This is due to the fact, that the area of the cathode spot on the consumable electrode is much smaller than the area of the anode spot on the welded workpiece, so intensive bombardment of a small area of the cathode spot with heavy plasma gas ions and ions of metal vapours, results in the release of much more heat energy on the cathode (filler wire) than on the anode (welded joint), and metal transfer is globular, so DC(-) current finds mainly application in GMA surfacing processes [13-16]. On the other hand, when GMA arc is supplied by direct current (DC+) (the consumable electrode is the anode, Fig. 8), most of the thermal energy of the GMA arc is released in the area of the welded joint, ensuring large penetration depths. In the case of GMA flux cored wires welding, there are additional components coming from the melting and metallurgical reactions of the flux core of the wire, which, among other things, stabilize the GMA arc and can even significantly raise or lower its temperature. The use in the flux core the special emissive elements with a low ionization potential, such as calcium, magnesium, sodium and potassium oxides, calcium carbonate and calcium fluoride, ensures in flux cored wires stable arc glow at negative current polarity (DC-) and reduces the amount of heat released at the cathode as a result of increasing the surface of the cathode spot, so the melting speed of the flux cored wire is lower, and the depth of penetration strongly increases [1, 2, 9-16].

In the solid wire (DC+) GMA welding process, in a pure argon shield, at low welding currents, the liquid metal from the wire is transferred to the weld pool in the form of droplets with a diameter larger than the diameter of the electrode and the length of arc, Fig. 5B. The size of the droplets is approximately inversely proportional to the current magnitude, and they flow at a frequency of several drops per second. If the GMA arc is long enough to avoid short circuits, Figure 5A, at the relatively low welding currents, regardless of type of shielding gas, globular transfer takes place with the diameter of molten metal drops greater than the electrode dia. Above a certain critical magnitude of the welding current, the liquid metal of the wire is transferred in the sprayed mode, with fine droplets and with a diameter much smaller than the diameter of the electrode, detaching from the conical shape electrode with a frequency of up to several hundred droplets per second, Fig. 5C. Metal transfer in the GMA arc in the case of welding with a flux powder and metal powder cored wires is similar to the metal transfer mechanism in the GMA arc with a solid wire, but flux and metal cored wires provide more uniform shape of the welded joint penetration Figure 12.

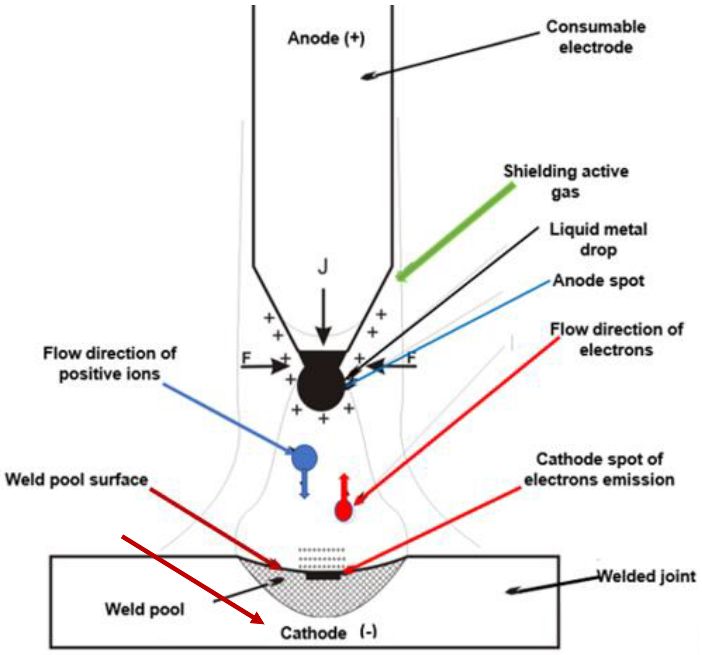

Figure 10. *Typical butt welded joint designs for GMA welding in all positions [1, 2, 13-16]*

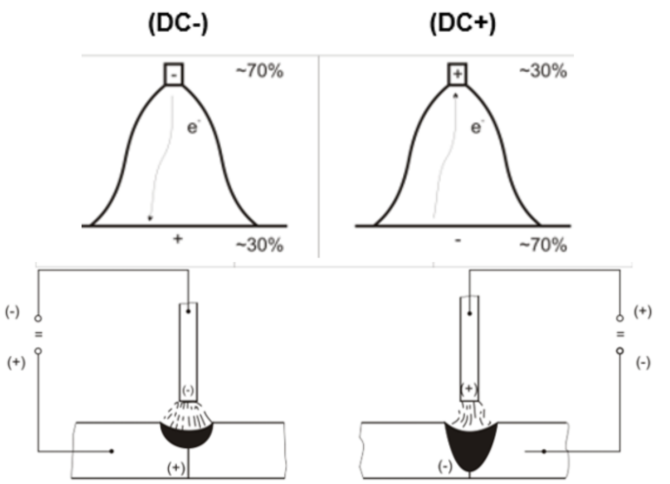

Figure 11. *Typical butt welded joint designs for GMA welding in all positions [1, 2, 13-16]*

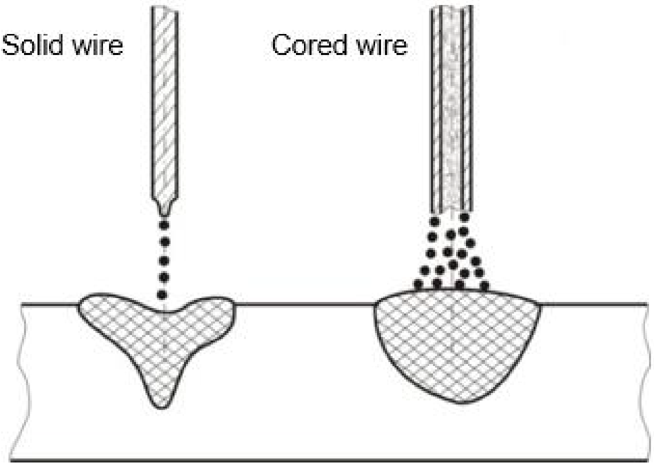

Figure 12. *Typical butt welded joint designs for GMA welding in all positions [1, 2, 13-16]*

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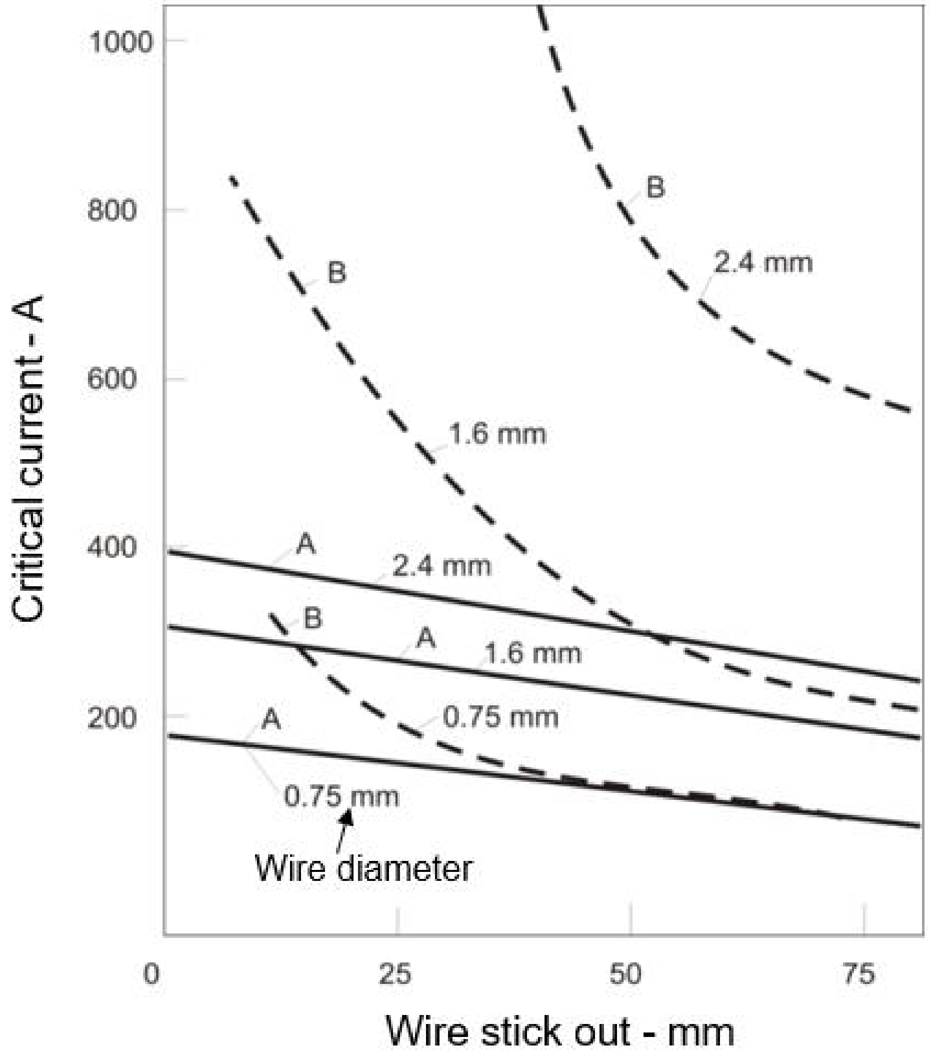

Figure 13. *The influence of the solid low-alloy steel wire diameter and the length of the wire stick out on the critical welding current during the GMA (DC+) welding in the Ar+1% O2 shield: A - critical welding current curve between globular drop and spray metal transfer, B – second critical welding current curve between spray and rotary liquid metal transfer, Fig. 3 [1, 2, 4]*

The spray arc metal transfer during GMA welding is advantageous not only because of the axial transfer of the liquid metal droplets in the direction of the consumable electrode, but also because of the minimal or lack of a spatter [4-6]. The main force determining such metal transfer in the arc is the Lorentz electrodynamic force, which cuts off the metal droplets from the tip of the electrode, Figure 12. This Lorentz force is proportional to the square of the current and arises as a resultant force of the change in the density of the magnetic field lines surrounding the tip of the electrode, caused by the change in the current density in the narrowing section between the electrode and the drop of liquid metal. The electrodynamic force is also involved in the short-circuit transfer of liquid metal droplets from the tip of the electrode to the weld pool, Figure 5A. The GMA critical welding current depends on many factors, such as: the chemical composition of the consumable electrode, its diameter and length of the stick out, and the type of shielding gas. Increasing the length of the wire stick-out lowers the critical current, as does adding a few percent of oxygen to the argon shield. At very high current intensities, above the second critical value of the welding current, the transfer of the liquid metal to the weld pool takes place in a rotational manner, with tiny metal droplets transported with high frequency along a helical path, Figures 5E and 13.

Technological Background of the GMA welding

The basic parameters of the GMA welding process are as follows:

- type and value of the welding current - A,
- consumable electrode feed speed - m/min,
- DC+ and DC+ pulse modulation parameters,
- arc voltage - V,
- welding speed - m/min,
- type and flow rate of shielding gas - l/min,
- type and diameter of consumable electrode - mm,
- length of stick out - mm,
- inclination of the welded joint or the GMA torch - o.

Solid wires GMA welding is mainly carried out with direct current (DC+), stable or modulated pulsating current (GMA-P), Figure 14 [1,2,13-16]. On the other hand, flux components of flux cored wires (in metallic powder wires, flux elements are also introduced to stabilize the glow of the arc) will also allow welding with (DC-), recommended, for example, for welding joints of thin steel sheets to reduce the welding heat input. The GMA welding with direct current (DC+) or GMA-P, provides very precise control of welding heat input and welding efficiency, and it is also possible to automatic or robotic welding in all positions, especially joints of very thin sheets [1, 2, 13-18]. The value of the GMA welding current is proportional to the wire feed speed and length of the wire stick out, Figure 15. Increasing or decreasing the wire feed speed increases or decreases the welding current accordingly. The depth of penetration, for a given wire diameter, increases with increasing the value of welding current (DC+), but excessive welding current makes the weld bead face irregular with excessive reinforcement. On the other hand, too low welding current increases spatter, and the liquid metal is transfer in irregular and globular mode, Figure 5. At the same time, the amount of nitrogen in the weld metal may increase and defects of a weld porosity may appear. At a given wire feed speed, the welding current value changes with the change in the length of the wire stick-out, Figure 4. When the length of the stick-out increases for a given wire diameter, the welding current intensity decreases, and vice versa. The value of the welding current affects the consumable electrode melting efficiency, which also depends on the chemical composition of the flux cored wires and the length of the wire stick-out. When the welding current increases or decreases, the arc voltage is proportionally increased or decreased to maintain the optimal relationship between amperage and arc voltage, Figure 6.

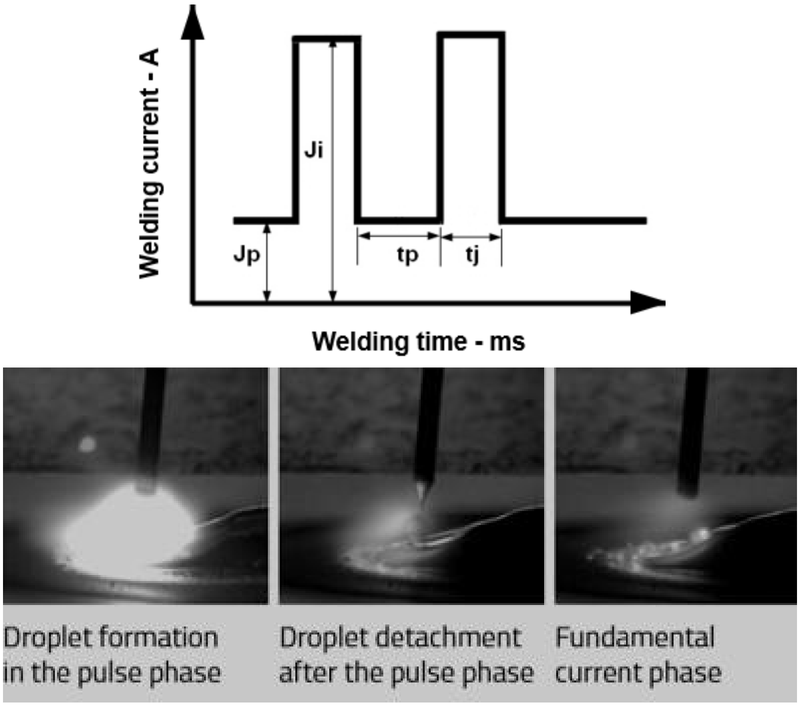

Figure 14. *A view of the waveform of GMA-P modulated pulsating welding current: J_i –pulse current, t_i –pulse time, J_p – fundamental current, t_p – fundamental current time*

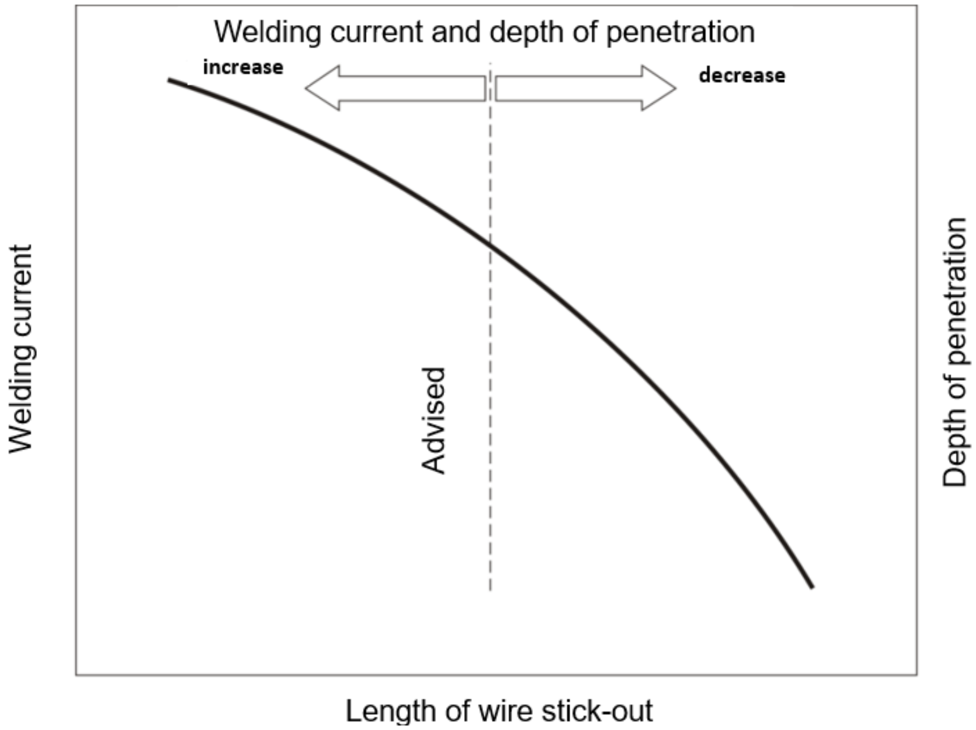

Figure 15. *The influence of welding current and flux-cored wire stick-out on the depth of penetration of GMA (DC+) welded butt joints [1]*

In the case of solid wires and metal powder-cored wires GMA welding, exceeding the second critical welding current, Figure 13, causes fine liquid metal droplets to move along a spiral path and the melting efficiency increases significantly [6]. At high current densities in the range of 600-700 A/mm2, the best welding results are obtained, and the GMA welding efficiency is also high, up to 20 kg/h. At the same time, the depth of penetration is high, but welding is only possible in the downhand position. At a constant welding current, the depth of penetration increases as the diameter of the consumable electrode decreases. During automatic and robotized GMA welding processes it is advised to use the highest possible welding currents and welding speeds at which welding process is still stable, the welded joint has the correct shape and the permissible welding heat input is not exceeded for point of view of the metallurgical weldability of a parent material [1,13-16].

The arc voltage in the GMA welding process, regardless of the type of welding current, strictly depends on the composition of the shielding gas or mixtures of gases, Table 1. An increase in arc voltage causes the width of the weld bead to increase and the depth of penetration to decrease. Excessive arc voltage leads to spatter, porosity, and irregularities of the weld bead face. Correct voltage selection is a function of many factors, such as the type and intensity of welding current, joint thickness, weld type, welding position, electrode diameter, type of material to be welded, and shielding gas composition. During GMA (DC+) welding in the downhand position, a higher arc voltage is advised than in all positions, especially when higher welding heat input is required. A lower arc voltage is recommended for welding thin sheet joints and at lower welding currents. When metal powder cored wires GMA welding, a higher arc voltage ensures fine-droplet, spray transfer of liquid metal in a much wider range of welding currents than it is possible when GMA welding with solid wire.

Table 1. *The influence of shielding gas composition on the critical welding current of GMA (DC+) 1,2 mm dia. solid wire welding of low-alloy steel joints [1]*

Shielding gas	Arc voltage V	Critical welding current A
Argon + 8% CO_2	31,7	220
Argon + 18% CO_2	30,8	242
Argon + 28% CO_2	31,5	250

Remarks: Welding speed – 0,55 m/min, shielding gas flow rate – 15 l/min.

The GMA welding speed at the welding current and arc voltage held constant, weld penetration is maximum at an intermediate welding speeds. When the welding speed is increased, the welding heat input transmitted to the welded joint from the arc is at first increased, because the arc acts more directly on the base metal, and the penetration increases. With further increases in welding speed the depth of penetration decreases, and with a further increase in speed, undercuts of a weld bead appears. Low welding speeds cause the depth of penetration to decrease, and the width and height of the weld bead face increase. Welding speeds that are too low, at high welding currents, can cause overheating of the weld metal, leading to the unevenness of the weld bead face and lack of penetration. Too high welding speeds, on the other hand, cause the irregular shape of the weld bead face and undercuts.

The type of a shielding gas in the GMA welding process determines not only the efficiency of the shielding of the welding area but also the way the liquid metal is transferred in the arc, the welding speed, and the shape and quality of the butt and fillet welds, Figures 16 and 17. Inert gases, argon, and helium,

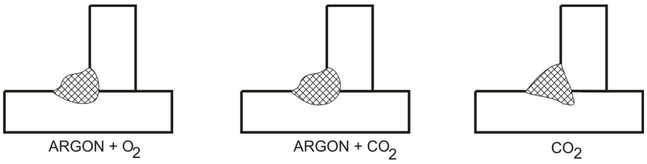

Figure 16. *Relative effect of O2 versus CO2 additions to the argon shield of GMA (DC+) on the fillet weld bead contour and penetration patterns [1, 2]*

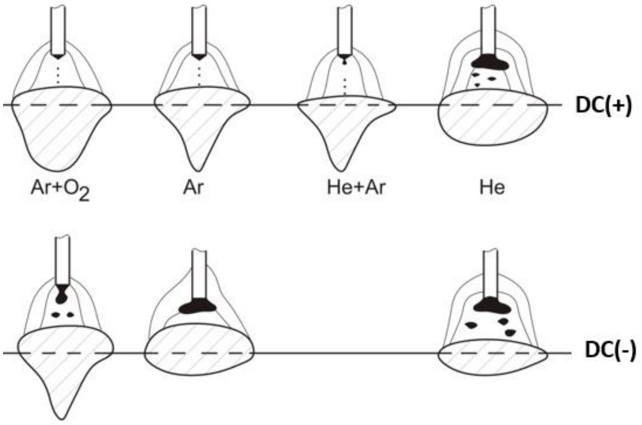

Figure 17. *Butt weld metal bead contour and penetration patterns for various GMA shielding gases [1, 2]*

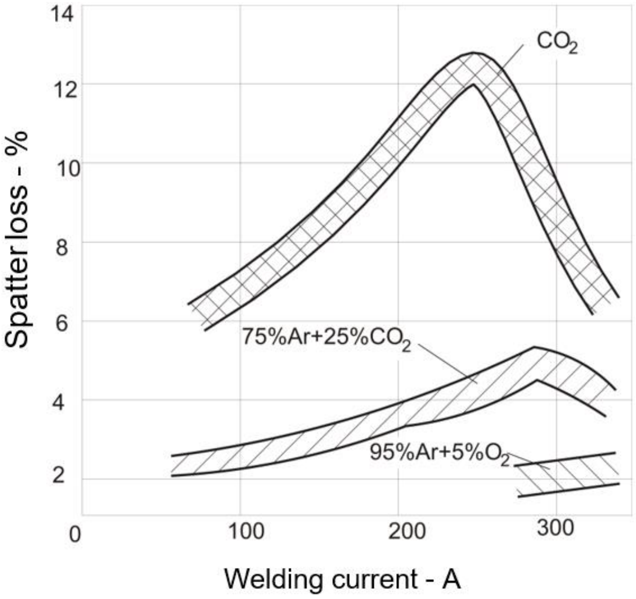

Figure 18. *The influence of CO2 addition to argon shield of GMA low-alloy solid wire 1,1 mm dia. welding on the spatter loss [1]*

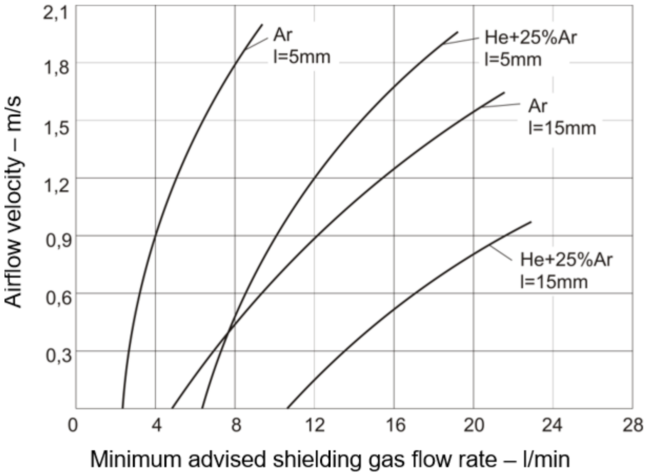

Figure 19. *The influence of airflow velocity transverse to the shielding gas flow of GMA (DC+) welding of steel joints, the stick-out – l = 5,0 or 15,0 mm, on the advised minimum shielding gas flow rate. GMA torch nozzle dia. 16 mm [1]*

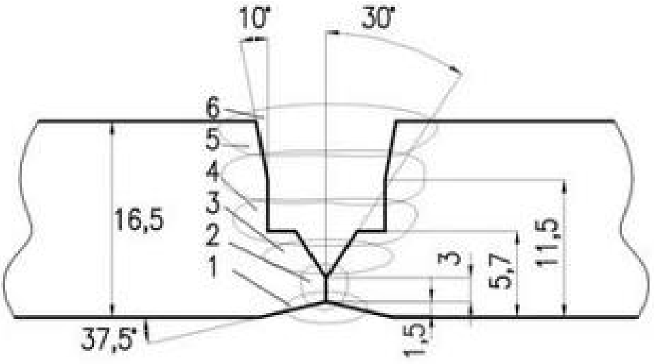

Figure 20. *Computer aided design of compound bevelling of butt girth welded joints of pipes, Fig. 5, Table 2 [1]*

although excellent at protecting the liquid metal of the weld pool from the atmosphere, are not suitable for steel structures GMA welding, due to high cost and causes an erratic arc and a tendency for undercuts to occur [1,8,9]. By mixing in appropriate proportions of helium or argon with chemically active gases like O2, CO2, N2 and H2, a change of the liquid metal transfer in the arc is achieved, the stability of the arc increases, and the possibility of influencing metallurgical processes in the weld pool appears. At the same time, it is possible to significantly reduce or eliminate spatter.

The primary active gases are: CO2, O2, N2 and H2. Of the active gases, only pure CO2 is used for GMA welding, but mainly with flux or metal cored wires, even high-alloy steels joints, and since it is a cheap gas, it compensates for the higher price of flux or metal cored wires compared to solid wires. CO2 is the cheapest of the protective gases, plus it provides a high depth of penetration, but GMA solid wire welding using CO2 shield the arc is unstable and spatter loss is very high, Figure 18. The appropriate chemical composition of the flux cored wire's flux powder (in contrary to the CO2 shielding destabilizing the arc glow of solid wire GMA welding), ensures the very stable spray transfer of liquid metal in the arc and no spatter. Deoxidizers and arc stabilizers must also be introduced into the composition of the flux powder and metal powder of cored wires, to reduce the oxidizing effects of CO2 on the weld pool metal and stabilize the GMA arc. The introduction of argon into the gas shield reduces the oxidation of the alloying elements of parent material, stabilizes the arc and ensures the spray transfer of liquid metal droplets in the arc, over a wider range of welding currents. The most common mixtures are those containing 50% Ar + 50% CO2 or 75% Ar + 25% CO2. In the case of welding with flux cored wires designed for welding in pure CO2 shielding, the replacement of pure CO2 shielding with Ar + CO2 shielding with a high argon content, can lead to an excessive content of Si, Mn and other deoxidizing elements in the weld, thus adversely altering the mechanical properties of the weld metal [13-16].

The flow rate of the GMA welding shielding gas has a significant effect on the quality of the welded joints and must be selected so that a precise shielding of the welding area is ensured, even with a transverse airflow caused by drafts or wind in workshop or in-field welding conditions, to exclude the air from contact with the molten weld metal, Figure 19. Too low gas flow rate makes the shielding insufficient and a weld metal porosity appears. Excessive gas flow rate causes gas turbulence in the arc area, resulting in porosity and/or irregularities of the weld bead face and undercuts [7]. The correct flow rate depends on the diameter of the GMA torch nozzle, the distance of the nozzle from the welded joint, and the air flow rate in the room, Figure 4. Flow rates of 15,0-25,0 l/min are recommended for low alloy and (U)HSS welded joints. When the welding area is a drought of air or when a larger wire stick-out is used, the flow rate should be set up to 30 l/min. A practical rule of thumb is to set the flow rate according to the criterion of 1,0 l/min for each millimetre of the nozzle diameter. The oxygen content in the steel's weld metal, caused by the addition of oxidizing gas to the GMA arc shield, has a significant effect on the mechanical properties of the welded joint, in particular, reduces the resistance to dynamic loads and at the same time increases the possibility of the formation of porosity and non-metallic inclusions of the weld metal.

The diameter of solid wires and flux and metal cored wires determines the current density, and, as the result, the depth of penetration of the welded joints and the liquid metal transfer mechanism of GMA welding, Figure 5. At a certain value of welding current, the wire melting efficiency increases with decreasing wire diameter, as the current density flowing through the wire increases. At the same time, the critical welding current of the wire with a small diameter is lower, and the weld pool has a smaller volume and solidifies quickly. Solid wires are produced with copper or mostly with a pure metallic outer surface to avoid the danger of hot weld cracks initiated by copper inclusions in the steel's weld metal [2,13-16]. Small-diameter solid wires, in the range of 0,4-1,2 mm, are recommended for GMA welding of thin steel sheet joints and welding in all positions, Figure 20 and Table 2. Larger wire diameters (from 1,2 mm to as much as 4,0 mm) are used for semi-automatic or automatic and robotic welding with the spray arc or rotating arc transfer, generally in the downhand position. The application of pulsed current for GMA-P (DC+) welding with larger diameter wires provides high welding efficiency and allows welding in all positions at the same time, Figure 14. For high-efficiency GMA welding of (U)HSS structures joints, wires of small-diameter 0,8-1,2 mm are recommended to take advantage of welding with very high current densities. The chemical composition of solid wires is usually selected based on the chemical composition of the material to be welded, taking into account the loss of alloying elements in the welding arc or according to the required special properties of the weld metal.

Flux and metal powder cored wires are produced with diameters in the range of 0,8-3,2 mm, in the shape of a low-alloy steel sheath filled with powdered flux and alloying, deoxidizing and arc stabilizing elements or metallic powder with arc stabilizing elements, in the case of metallic powder core, Figure 4 [2,13-18]. The flux and metal cored wires provide deeper penetration and more regular shape of a weld metal and much lower spatter then solid wire, Figure 12. Cored wires with a diameter of 0,8-1,6 mm are recommended for GMA or GMA-P (DC+) welding, in all positions, and those with a diameter of 2,0 mm and larger are advised for welding in the downhand and horizontal positions, Table 3. The deposition efficiency of the flux powder wires is in the range of 80-90%, but the metal powder cored wires can reach up to 95%-98%. The deposition rate of cored wires depends mainly on the chemical composition of the flux or metal powder core, the shape and thickness of the tubular sheath and the length of the wire extension (stick-out) and can reach as high as 20 kg/h, with very high weld quality at the same time [1,2,11,13-18].

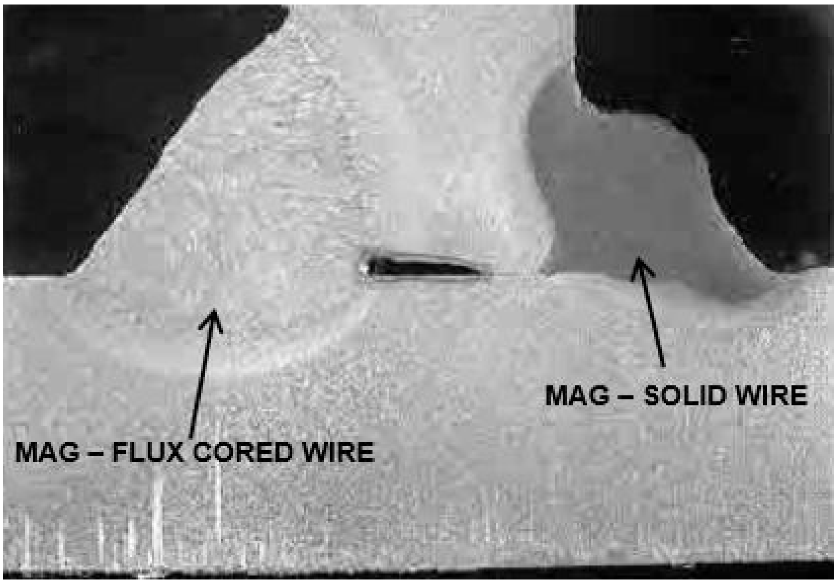

Figure 21. *A comparison of the penetration depth and the shape of a weld metal of GMA (DC+), welded the low-alloy steel T-joint, in horizontal position, using rutile flux cored wire 1,2 mm dia. OK Tubrod 15.13 (240 A / 25 V, Vs = 28 cm/min) and solid wire 1,0 mm dia. (190 A / 17 V, Vs = 18 cm/min). CO2 shielding gas flow rate 14-16 l/min [1, 13]*

Table 2. *Recommended automatic welding conditions of GMA (DC+) girth welding of butt joints of API 5LX 80 pipes 1420 mm dia., t = 16,5 mm of gas and oil pipelines in 5G position, Fig. 18 [1]*

Welding passes	**Type of solid wire 0,9 mm dia.**	**Shielding gas flow rate 15-20 l/min**	**Welding current A**	**Arc voltage V**	**Welding speed m/min**	**Heat Input kJ/cm**
root	ER70S-6	Ar+25%CO2	190-220	19-21	0,75	3.7
2 – hot pass	ER90S-G	CO2	240-260	24-26	1,27	3.1
3-5 - filling passes	ER90S-G	CO2	210-250	22-25	0,36-0,45	9.0
6 -Face pas	ER90S-G	Ar+25%CO2	200-230	20-22	0,26-0,41	8.6

Table 3. *Typical conditions for GMA flux and metal powder cored wires welding of low alloy steel butt joints [1]*

Wire dia. mm	Welding position	Type of shielding gas	Welding current A	Arc voltage V	Stick-out mm	Welding efficiency kg/h
1,2 flux cored	Overhead	Ar + 25% CO2	140-240	24-32	6,4-12,5	2,0-5,4
		CO2	130-230	24-32	6,4-12,5	2,0-5,0
	Vertical - PF	Ar + 25% CO2	110-210	23-30	6,4-10,0	1,6-4,9
		CO2	100-175	24-30	6,4-10,0	1,5-3,9
	Vertical - PG	Ar + 25% CO2	130-245	24-33	6,4-12,5	2,0-5,0
		CO2	125-270	25-34	6,4-12,5	2,0-5,5
	Downhand	Ar + 25% CO2	110-270	23-34	6,4-19,0	1,6-6,1
		CO2	110-255	24-40	6,4-19,0	1,5-6,1
1,6 flux cored	Overhead	Ar + 25% CO2	180-260	24-30	10,0-16,0	2,3-4,0
		CO2	150-250	24-30	10,0-16,0	2,3-4,0
	Vertical - PF	Ar + 25% CO2	130-250	23-31	10,0-19,0	1,7-4,7
		CO2	135-230	24-31	10,0-19,0	2,0-4,2
	Vertical - PG	Ar + 25% CO2	150-340	24-34	10,0-16,0	2,0-6,7
		CO2	135-340	24-34	10,0-16,0	2,0-6,7
	Downhand	Ar + 25% CO2	130-400	24-37	10,0-19,0	1,7-10,0
		CO2	130-400	24-37	10,0-19,0	1,7-10,0
1,6 metal cored	Downhand	Ar + 1÷2% O2, He + 7,5% Ar + 2,5% O2	230-270	25-28	12,5	3,6-5,4
2,4 metal cored	Downhand	Ar + 1÷2% O2, He + 7,5% Ar + 2,5% O2	375-425	27-29	19,5	5,2-6,0

Remarks: Shielding gas flow rate 12-18 l/min for flux cored wires GMA welding and 15-20 l/min for metal cored wires GMA welding.

Discussion

This paper reviews the physical and technological background of GMA welding process, and describes the influence of GMA welding parameters on the quality of welded joints. The highest influence on the quality of GMA welded joints have stable wire feeding speed (quality and robustness of the wire feeding unit) and uniform and stable flow of the high quality shielding gas. In the case of automatic and robotic GMA welding additionally the welding speed and welding path must be precisely controlled and monitored to ensure highest quality of GMA welded joints.

As a traditional welding process, GMA welding occupies most of the total welding world production of metal structures and has many design solution e.g. multi-wire, Plasma-MIG, GMA+SA, narrow gap and hybrid welding systems. Semiautomatic, automatic and robotized GMA welding assures high quality of all types of joints in all positions and in all harsh welding environments. The most modern GMA welding industrial application is laser+GMA and plasma+GMA hybrid welding, allowing to weld in one pass high quality steel and aluminium alloys joints up to 15,0 mm thick, but actually is limited to workshop conditions and both technique have to be developed for harsh in-field welding environment.

To ensure highest economic and quality demands of world producers of metal structures, the current industrial automatic and in specific robots GMA welding with the "teaching and playback" mode GMA apparatus, should be supported by the advanced sensing technology and implementation of digital twin supported online quality monitoring systems [20,21]. These systems use of computers and neural networks to mimic, strengthen, and/or replace human operators in sensing, learning, decision-making, online quality monitoring and control, etc. These are all challenges that metal-working companies are facing in order to maintain their competitiveness for the future welding works.

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