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Gas-Shielded Metal Arc Welding

Abstract: The article discusses the history of MIG/MAG welding, pointing out the primary achievements and patents connected with the evolution of the MIG, MAG and Arcogaz (steam-shielded) welding methods, as well as presents related Polish welding equipment and works related to the implementation of the above-named method in the Polish industry.

Keywords: consumable electrode, inert gases, carbon dioxide, steam

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Introduction

Arc welding requires the elimination of the negative impact of air on properties of joints. For this reason, in the 1940s, researchers attempted to perform welding processes involving the use of non-consumable electrodes and inert shielding gases (TIG). The method was applied for the joining of non-ferrous metals and alloy steels. The fact that TIG welding was then characterised by low efficiency triggered the search for new shielding gas-based solutions [1].

Methods developed in parallel to argon or helium-shielded welding processes with non-consumable electrodes involved techniques where arc was shielded by gases, whereas the electrode wire was used as one of the arc poles and, at the same time, as the source of filler metal filling the weld groove.

The technique developed as first was inert gas-shielded welding (Metal Inert Gas - MIG). The creation of MIG welding was followed by the development of CO2-shielded welding (Metal Active Gas - MAG). Processes developed afterwards involved the use of shielding gas mixtures. Presently, the above-named methods are the primary processes used to join elements characterised by low and medium thickness.

MIG welding

MIG welding was pioneered by P. Alexander (1924), who invented a hydrogen(!)-shielded process, yet the electrode (in the form of a wire) was unwound from a reel and fed to the welding zone by guide rolls (Fig. 1) [37]. In 1936, Porter Brace patented a machine enabling the performance of a welding process involving the use of a consumable electrode and shielded by many gases (Fig. 2), i.e. a process resembling MIG welding [38].

The GMAW method was developed in 1943 by C. Voldrich, P. Rieppel and M. Cary from Dow& Northrup Co. The authors used a small-diameter aluminium electrode, argon as shielding gas and a DC welding power source [4].

Officially, MIG welding started in 1948, i.e. when at the Battelle Memorial Institute, under the patronage of Air Reduction Co., a technology enabling the performance of inert gas-shielded metal arc semiautomatic welding was developed [5]. The owner of the patent obtained in April 1950 was the Air Reduction company; the authors of the patent were Al Muller, Glen Gibson and Nelson Anderson (Fig. 3) [6].

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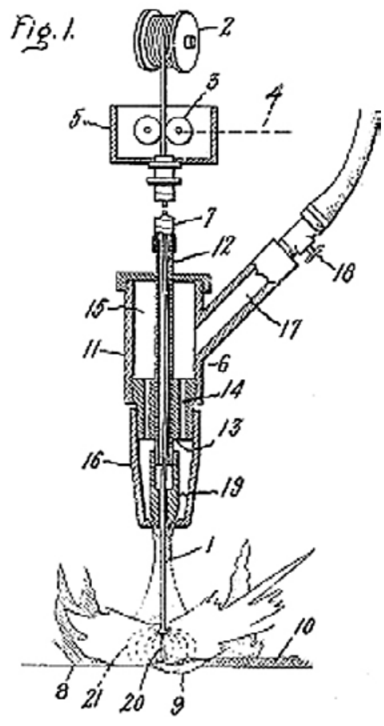
Fig .1. Schematic diagram of the P. Alexander method [2]

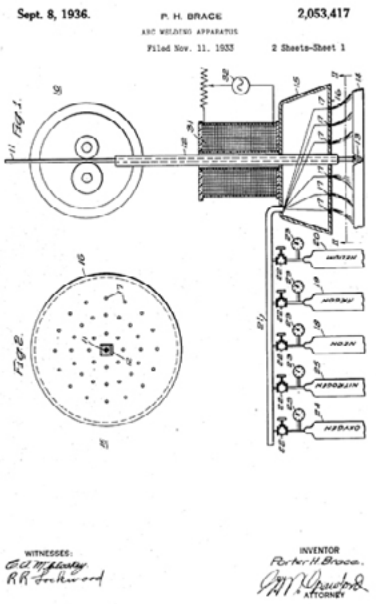

Fig. 2. P. Brace: patent no. 2053417 "Arc welding apparatus": 8.08.1936 [3]

Initially, the method was named "Aircomatic" (after the company being the patent owner) [1]. Later, the process was named as SIGMA (Shield Inert Gas Metal Arc Welding) and finally as MIG [7].

From the very beginning, the MIG method was subjected to numerous improvements and modifications. To enable the performance of joining processes involving the use of electrode wires of larger diameters as well as to control the liquid metal pool and limit spatter, in the years 1958-59, "short arc" MIG welding was developed and quickly became the most popular MIG method [8]. The applicability and, consequently, popularity of the process significantly increased after the implementation of flux-cored wires [9].

In March 1953, Arthur Bernard submitted an application for a patent for a MIG method-related flux-cored wire (Fig. 4) [10]. However, the author failed to provide information about whether and what gas should be used. In 1959, the Lincoln Electric company introduced a self-shielded flux-cored wire named Innershield [11].

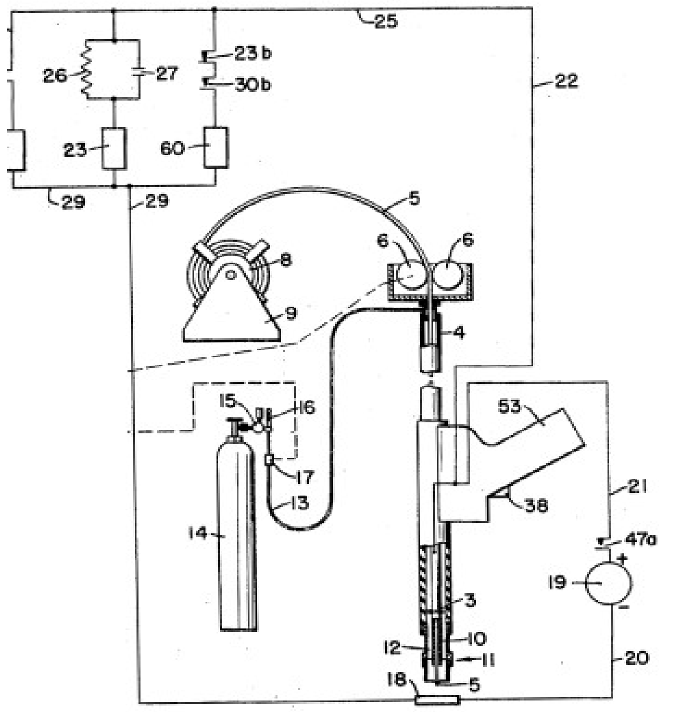
Fig. 3. A. Muller: patent no. 2504868 "Electric arc welding": 18.04.1950 [6]

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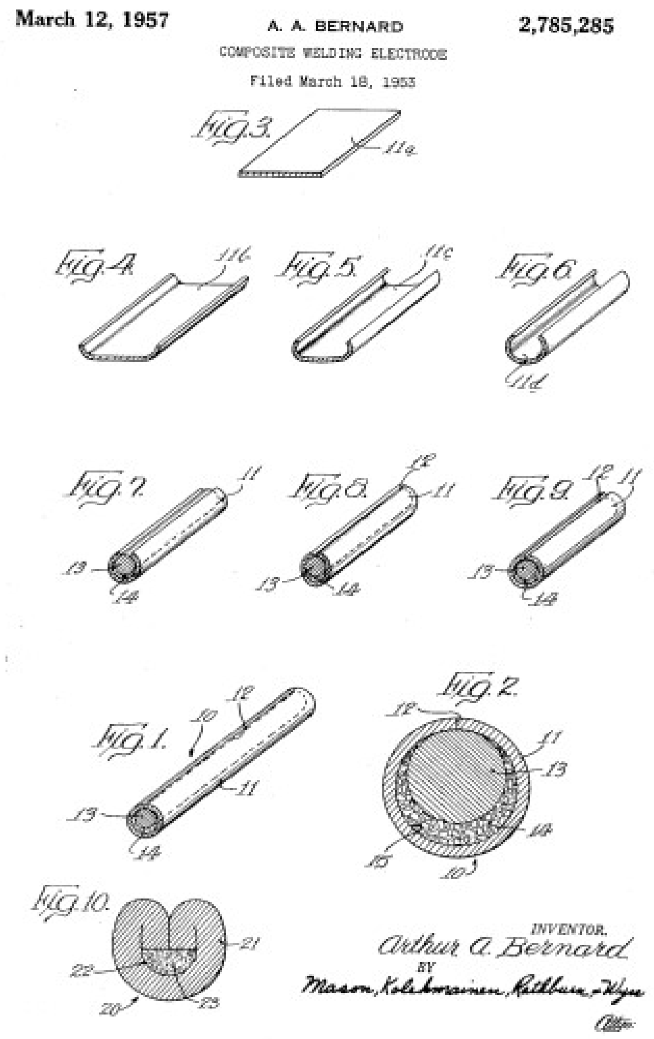


Fig. 4. A. Bernard: patent no. 2785285 "Composite welding electrode"; 12.03.1957 [10]

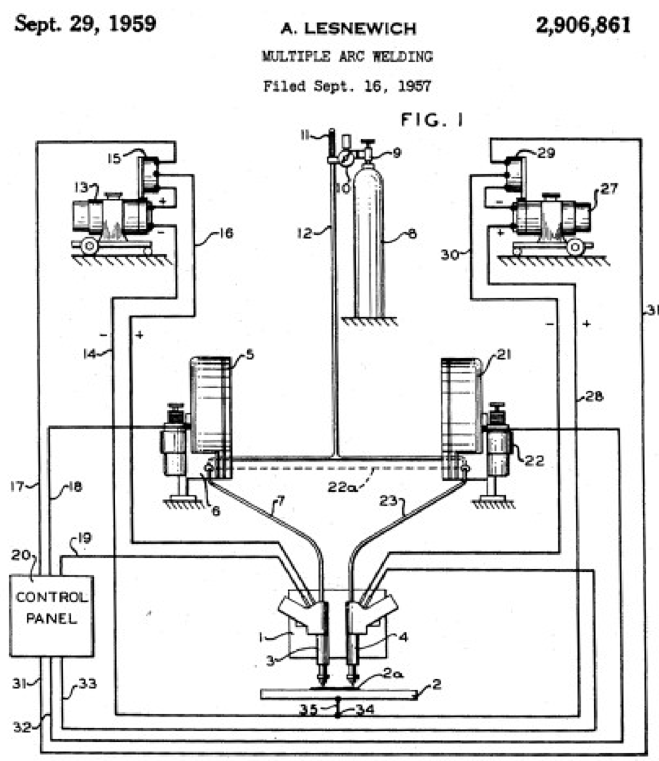


Fig. 5. A. Lesnewich: patent no. 2906861 "Multiple arc welding"; 29.08.1959 [11]

Another innovation was welding with two wires (Tandem MIG). In the first patented solution of 1957, the station consisted of two torches and two DC sources (Fig. 5); the patent claim also included the possibility of using alternating current [11]. However, the solution did not turn out a commercial success [9]. The second system, developed for the welding of aluminium and magnesium, assumed the use of two wires and one DC source (Fig. 6), which provided the same current conditions for both electrodes [13].

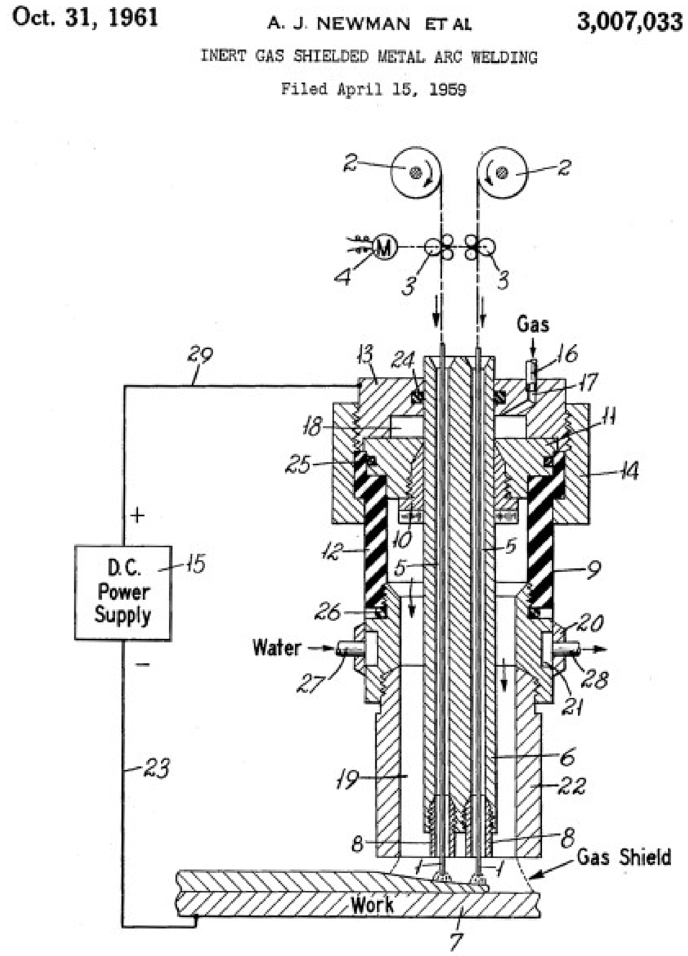


Fig. 6. A. Newman: patent no. 3007033 "Inert gas shield metal arc welding"; 31.09.1961 [12]

The MIG welding produced good results during the welding of thin elements, yet it failed to provide appropriate penetration in cases of thick plates. Because of this, in the early 1960s, a pulsed arc welding method was developed. The method was created by Christopher Needham, who in the patent filing (submitted in June 1963) wrote that "The primary principle is that arc functions in a cyclic manner at a minimum of two cyclically repeating levels" [13]. A variety of the Pulsed Arc method was ripple (Ripple Arc) patented by A. Manz in 1966. [9].

In the early 1970, in a Philips laboratory in Eindhoven, a MIG welding method involving the use of contracted arc was developed. The method was named plasma MIG. The plasma MIG welding machine was first presented at a fair in Essen in 1973. [14]. At the same time, thyristor devices were introduced and synergic sources were developed [8], marking the beginning of the full automation of welding processes.

The MIG method continues to develop using the latest scientific and technical achievements. MIG welding has been widely used in industry since the early 1950s. The method is used for the welding of aluminium alloys, copper and its alloys as well as alloy steels. Because of susceptibility to gas pore formation in the weld, attempts to use the MIG method in the welding of carbon steels proved unsuccessful [14]. Because of this, in the years 1950-51 the gas shielding was modified by adding a small amount of oxygen to argon (approximately 5%) [15]. As a result, the nature of gas shielding changed from inert to active, which could be recognised as the birth of a new method, i.e. mixed gas-shielded MAG welding.

MIG welding reached Poland 10 years after it was patented. The first attempts were performed at Instytut Spawalnictwa. The lack of appropriate equipment resulted in the adaptation of a Kjellberg SII machine, initially intended for covered electrode welding. The original head of the automatic machines was replaced with a new head, provided with a feeder; wire feed nozzle and electrode clamps. The gas-electric nozzle (Fig. 7) was also developed at Instytut [16].

The first Polish welding machines, i.e. an Ema-400 and Emb-160 semiautomatic welding machines (Fig. 8) were constructed in the years 1961-62 at Instytut's Zakład Prototypów Urządzeń Spawalniczych (Prototype Welding Machinery Production Company) [17]. As welding power sources were imported, the industrial implementation of the MIG method was limited. Because of this an EPVa-300 rectifier (Fig. 9) was developed; it was produced by Bielawska Fabryce Prostowników (Rectifier Production Plant) from 1963 [19]. The Ema-400 and Emb-160 machines were manufactured until 1966, when they were replaced by the next generation of machines, i.e. PS-300 (1966-1970), Emd-300, Emd-400 (1968-1972) and Sla-300 (1971-1979). Afterwards, a series of MAGPOL MINIMAG machines (for solid and flux-cored wire welding) were introduced by the OZAS company from Opole [14]. At the same time, the Polish market saw the import of welding equipment from overseas companies.

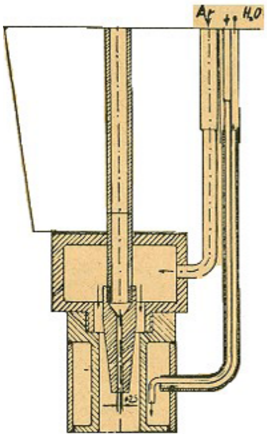
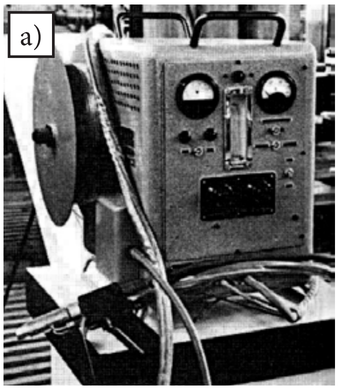


Fig. 7. Gas-electric MIG welding nozzle [16]

a)



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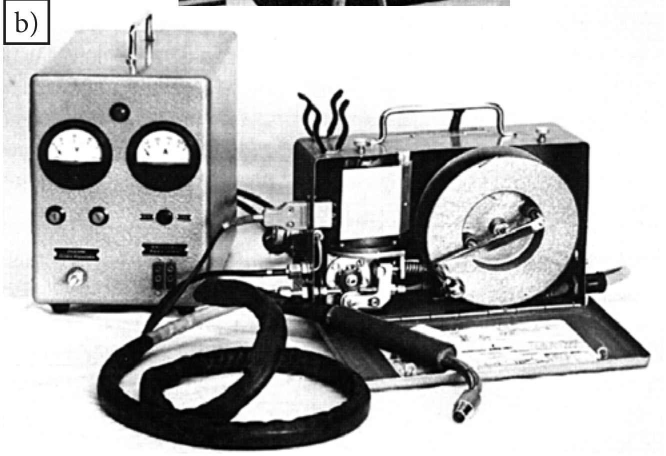

Fig. 8. First Polish MIG welding machines, a- semiautomatic welding machine Ema-400, b- semiautomatic welding machine Ema-160 [17]

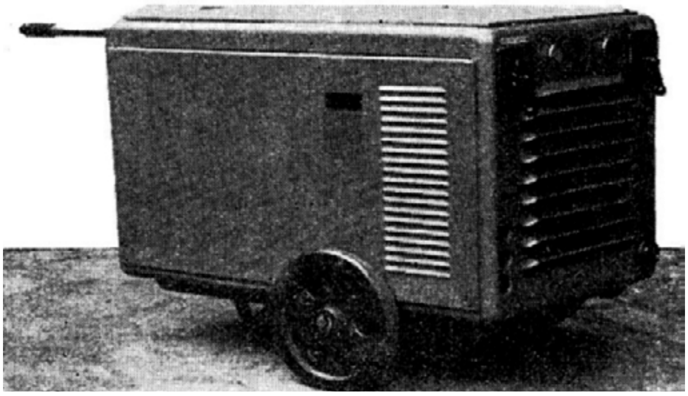

Fig .9. First Polish rectifier EPVa-300 [19]

Difficulties getting appropriate welding machinery combined with the poor quality and high price of the shielding gas were responsible for the fact that, initially, the MIG method developed relatively slowly. However, the 1970s saw the dynamic development of this technique in Poland [18].

After pioneering years, problems with the availability of equipment, the poor quality of welding consumables and shielding gas, numerous modifications and improvements, the MIG found extensive industrial applications all over the world.

MAG welding

Relatively high prices of inert gases inspired the search for other gases applicable during the welding of metals. Cheap and, at the same time, easily available gas was carbon dioxide, discovered about 1640 by a Flemish chemist Jan B. van Helmot, who, after burning charcoal in a closed container, noticed that ash was lighter than burnt charcoal. The scientist stated that the process of burning was accompanied by the emission of an unknown substance, named by him as "gas" or "Spiritus Silvestris" (wild spirit) [20]. A hundred years later, Joseph Black, a Scottish doctor noticed that the heating of calcium carbonate led to the obtainment of gas heavier than air, not affecting the flame or animal life. Joseph Black also proved that the gas was present in the atmosphere, could form chemical compounds and was present in exhaled air [21]. The first practical application of CO_2 was discovered by English chemist Joseph Priestley, who, by dissolving the gas in water, created a slightly tart drink, i.e. fizzy (carbonated) water [22]

In 1823, carbon dioxide was liquefied by H. Dave and M. Faraday. In 1835, A.J. Thilorier obtained CO_2 in the solid state [23]. The first attempt to apply carbon dioxide during welding was undertaken by John P. Lincoln (in 1918), who supplied the gas to the welding zone using a tubular carbon electrode and noticed that the idea resulted in the stabilisation of arc and the obtainment of joints characterised by favourable properties. In 1926, John P. Lincoln patented the above-presented method (Fig. 10) [24]. Test performed at the same by time P. Alexander proved unsuccessful as obtained joints were strongly oxidised and brittle [26]. Negative experience of P. Alexander as well as the development of welding technologies shielded by methanol vapours, hydrogen, and, primarily, by helium and argon, resulted in the discontinuation of research concerning the application of CO_2.

In 1936, N.G. Ostapienko, a researcher of the Welding Institute in Kiev, developed a welding method involving the use of a carbon electrode, carbon dioxide (used as shielding) and the atmosphere of a burning paper string [26]. The above-named welding method was used in the 1940s-1950s in the lot production of tubes and thin-walled tanks [27]. At the same time, the Institute carried out tests of CO_2-shielded metal arc welding, yet the results were unsatisfactory [28].

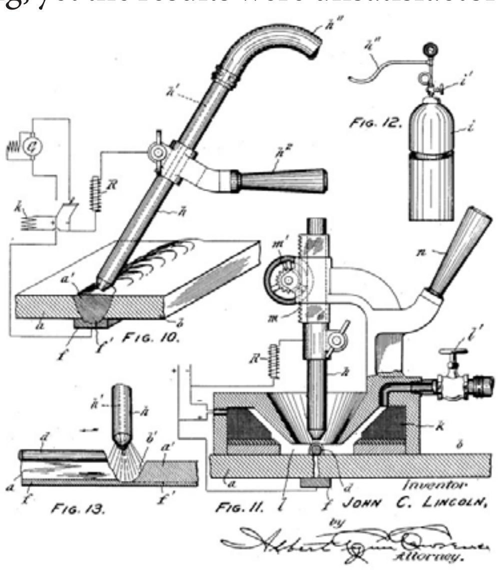

Fig. 10. Patent by J.P. Lincoln, no. 1589017 "Method and means for electric-arc welding"; 15.06.1926 [24]

In the West, the application of CO_2 aroused interest again after the end of WW2. In 1946, W.M. Mallet and P.J. Rippel supplied carbon dioxide to the arc zone using a tube made of low-carbon steel, being a consumable electrode at the same time, and ascertained that the CO_2-based shielding had a stabilising effect on arc. In the same year, G.J. Gibson, as the first scientist, informed about the properties of overlay welds made using the above-presented method (Rm=473 MPa, A=13%). At the same time, he emphasized that the overlay welds did not contain nitrogen and that the welding rate was by twice higher than that during unshielded welding [29].

In 1952, K.W. Lubawski and N.M. Novozilov presented a carbon dioxide-shielded metal arc welding method (patent SSSR no. 104283, 1952) [30]. The researchers welded low-carbon steels and alloy steels using wires containing deoxidisers, i.e. Mn and Si. In spite of using special wires, the welding of stainless steels was accompanied by the burning out of alloying agents, the instable melting of the wire and the formation of significant spatter. As a result, the further development of CO_2–shielded welding was bidirectional, i.e. involving the modification of the chemical composition of electrode wires and the adjustment of welding parameters [27].

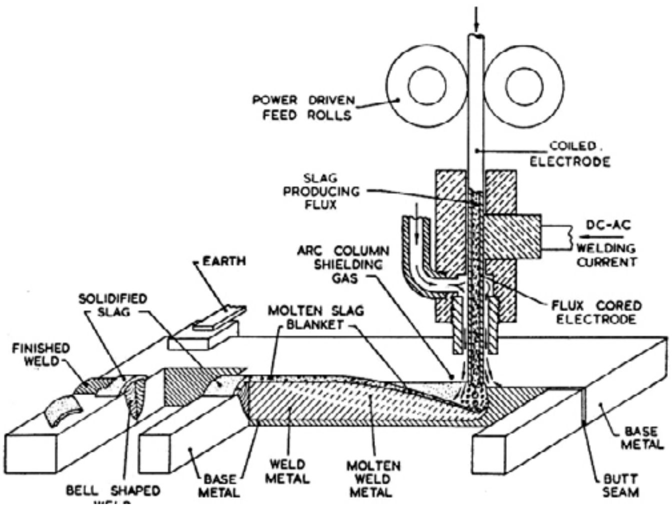

Fig. 11. Schematic diagram of the welding method developed by A. Bernard [31]

In 1954, A. Bernard developed a method enabling CO_2-shielded flux-cored welding (Fig. 11). When performing tests involving wires, the diameters of which were restricted within the range of 1.5 mm to 6.25 mm, A. Bernard noticed that the melting rate of the electrode wire was five-fold higher than that accompanying the conventional flux-cored welding method.

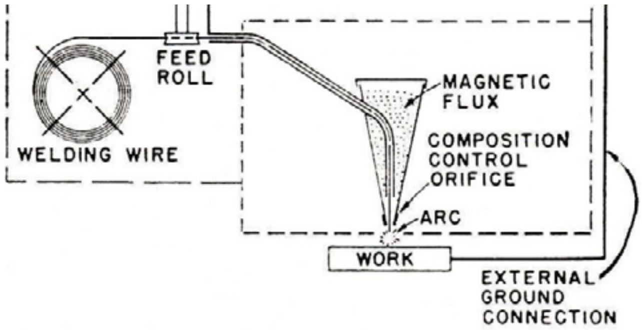

Fig. 12. Schematic diagram of the semiautomatic Amsco welding method [31]

A year later, E.J. Mitchel and W.E. Freeth applied double shielding composed of carbon dioxide and gases formed as a result of the melting of the electrode wire containing magnetic flux [1]. The method known as "Fusarc-CO_2" or "Amsco" was used for some time in Europe, where it was applied for the automatic welding of carbon steels. In turn, in the USA the aforesaid method was used in semiautomatic welding (Fig. 12) [31].

Tests of wires performed at the Welding Institute in Kiev in 1957 revealed that the application of a thin layer of the aqueous solution of caesium and sodium carbonate on the wire surface and the addition of between 0.03% and 0.07% of rare-earth elements to the electrode composition increased arc stability, decreased spatter to between 3% and 5% as well as reduced the content of N2 and H2 in the weld [27].

In the same year, at the same time in the USA and the SSSR, electrogas MAG welding (similar to electroslag welding) was developed [14] and research on double gas-shielded welding was initiated. The method involved the use of a special welding torch transporting argon through an internal nozzle and carbon dioxide through a concentric nozzle [32]. The above-presented solution, known as MAGCI, was implemented as late as in 1972 [14]. In the early 1960s, both in the USA and the SSSR, mixed gas-shielded solid wire MAG welding (i.e. initially carbon dioxide with oxygen, and next CO_2 with oxygen and argon) was developed. However, as mentioned before, as early as in 1950, the welding of carbon steels was performed using argon with a slight addition of oxygen. Subsequent years saw the significant development of welding power sources, modification of electrode wires and shielding gases as well as the further automation of the welding process.

In Poland, the first attempts at CO_2-shielded welding were performed in 1958, whereas abroad the method was already applied on an industrial scale. The welding technology used at Instytut Spawalnictwa in Gliwice for the welding of carbon steels involved the use of a wire having a diameter of 1.2 mm and 2 mm, containing 0.07% C, 0.97% Mn and 1.0% Si. Because of the lack of appropriate machine, welding was performed using a welding power source of dropping characteristics. The device was a modified semiautomatic submerged arc welding machine, where the terminal with a funnel feeding flux was provided with a torch designed at Instytut Spawalnictwa (Fig. 13). In spite of the aforementioned difficulties, obtained joints where characterised by a proper shape and favourable properties. As a result, it was decided that the method could be used industrially for repairing casting defects in large steel castings as well as for the welding of non-pressure tanks and statically loaded steel structures [33].

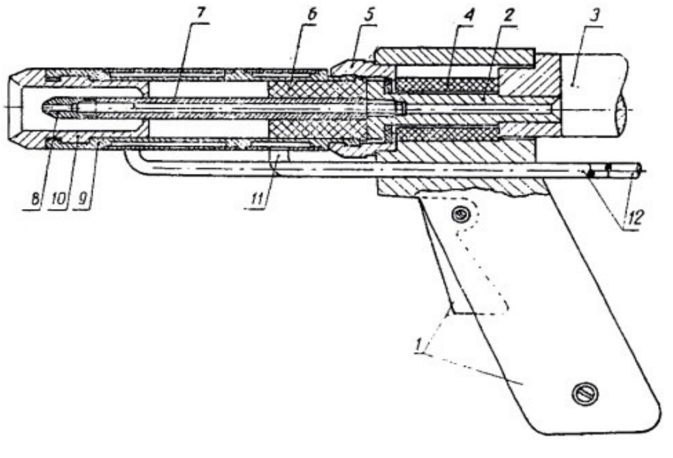

Fig. 13. Schematic diagram presenting the CO_2-shielded welding torch designed at Instytut Spawalnictwa in Gliwice [33]

However, the technology was implemented after several years. In 1960, the Polish metallurgical industry did not produce copper-clad wire containing the required concentration of Mn and Si. In turn, in Zakład Budowy Prototypów Urządzeń Spawalniczych (Prototype Welding Machine Production Company) only 3 semiautomatic machines for carbon dioxide-shielded welding were built [34]. The aforesaid machines were designated as Ema-400 and Ema-160; they could also be used for MIG welding (Fig. 8) [17]. The year 1963 saw the production of 20-30 machines (of both types). In turn, in 1965, it was expected that 305 machines and 800 tons of wire SP1GS would be produced [35]. As can be seen, although the technology was already known, the lack of appropriate welding machines was responsible for the low popularity of CO_2–shielded welding [36]. At the same time, there were overly few specialists capable of implementing the new technique. It was only in 1960 that Instytut Spawalnictwa held the first course in MAG welding (attended by 9 participants). In the years 1961-1963, Instytut trained 53 welders [37]. The use of the MAG method in Polish industry on an industrial scale started in the mid-1960s. After overcoming initial difficulties connected with the quality of equipment, wires and carbon dioxide, the technology developed increasingly fast [38]. The 1970s saw a wide range of MAG welding equipment, extended by imported semiautomatic and automatic welding machines. The further development of gas-shielded welding was connected with an increase in welding efficiency as well as the improvement of the quality, shape and cross-sectional dimensions of welds. New welding methods included spot welding, narrow-gap welding, pulsed (periodically interrupted) current welding and flux-cored arc welding [37].

Steam-shielded welding – "Arcogaz"

The search for the cheapest possible shielding gas led to the development of the steam-shielded welding technology. The method was developed by a Polish scientist Adam Kręglewski (PhD (DSc) Eng.). Numerous tests with flammable gases did not produce satisfactory results and steam was the only cheap non-flammable gas. Adam Kręglewski, along with his son Witold, started tests of a welding method, where the process was performed under a dome separating arc from the outside atmosphere. In 1946, the designer submitted a patent application for the design of the dome and the welding method. A year later, the author obtained two patents, the first of which was related to the design of the protective dome whereas the second concerned the welding of small-sized objects. Because of high temperature (under the dome), the dome had to be made of heat-resistant steel or glass. The patent file also contained a solution, where the dome was covered with an external cooling jacket, the walls of which were filled with (flowing) cold water or air. The base of the dome was exchangeable and could be adjusted in relation to a workpiece and the shape of a weld [39,40]. According to the above-named patents, the shielding medium was illuminating gas, acetylene or organic material combustion products.

The subsequent patented solution (filed as early as August 1946) revealed that excellent results could be obtained by shielding arc by means of superheated steam. Superheated steam was generated using a device triggering the sudden evaporation of liquid or could be supplied from outside (Fig. 14) [41].

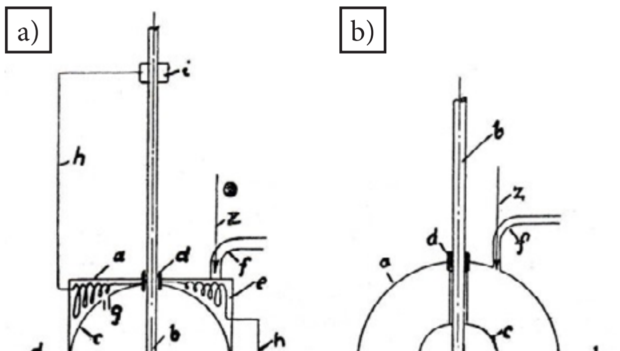

Fig. 14. Schematic diagram of a machine for steam-shielded welding with the heater generating steam (a) and without the heater (b) [41]

Adam Krędlewski obtained a total of five patients for this welding method (named by him as "Arcogaz"). The implementation of proposed solutions involved numerous and laborious experiments, the results of which were (initially) unsatisfactory. Welds were characterised by a very uneven shape and considerable porosity (with large-sized pores), particularly in relation to the overly low amount of steam. Finally, it was possible to obtain imperfection-free single-layer welds having a cross-sectional area of 1.5 cm2. The test revealed that the welds were characterised by strength Rm=390-430 MPa, elongation A=26-28%, area reduction Z=55-59% and toughness U=5-11 kJ/cm2. In 11 out of 12 specimens, the first cracks appeared after the specimen reached a bend angle of 180°. In one case, the first crack appeared in relation to a bend angle of 170°. The weld hardness was restricted within the range of 106 HB to 114 HB, which indicated the lack of impurities in the material [42].

The "Arcogaz" method was implemented in practice in Zakłady H. Cegielskiego (H. Cegielski Company) in 1948 in the mechanised welding of train bumpers (Fig. 15) [42]. It is also known that an automatic welding machine for making rectilinear joints was made, yet there is no information of its practical applications [1].

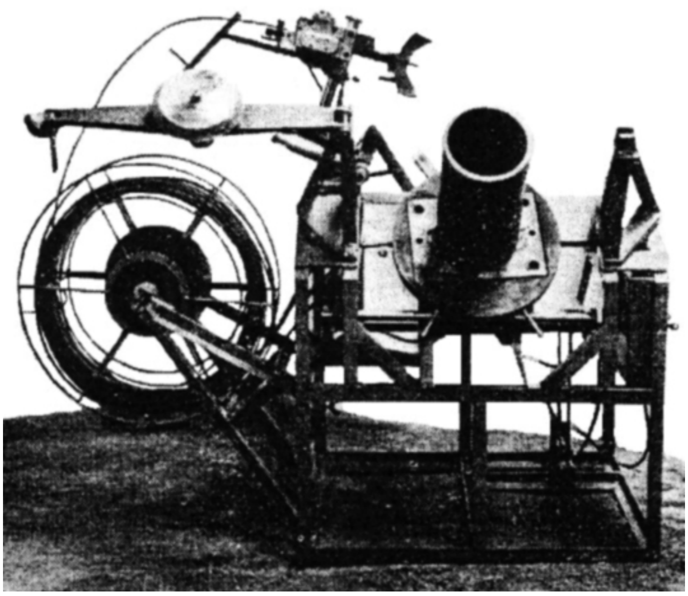

Fig. 15. Machine for the stem-shielded welding of train bumpers [42]

The idea of steam-shielded welding returned in the Soviet Union in 1959. In the Donetsk Machine Factory it was used for surfacing worn elements made of steel and cast iron [43]. In turn, in Odessa, the above-named method was used for the welding of thin-walled tubes [44]. Steam-shielded welding tests were also performed in Germany, where the test objectives included the identification of recommended welding process current parameters, welding rate, steam temperature, electrode extension and the wire diameter [45]. In the 1960s, the "Arcogaz" method was also tested in Czechoslovakia and Romania [1].

The development of the method stopped because of the development of other gas-shielded welding methods and as a result of permanent problems accompanying the obtainment of imperfection-free welds.

Summary

The 20th century witnessed the development of numerous welding methods, such as oxy-acetylene, thermite and electroslag welding as well as carbon arc welding and metal arc welding (involving the use of consumable and covered electrodes), under flux and gas-shielded welding. Initially, gas-shielded welding involved the use of methanol and hydrogen, next helium and argon and finally, inert and active gases. Many of the above-named methods have become extinct, some are used sporadically, yet gas-shielded welding continues to develop.

In Poland, material and human losses after World War 2 directly translated into the loss of significant achievements developed by Polish welding engineers in the interwar period. The basis of the post-war "revival" of the Polish welding sector was extremely poor and included Wytwórnia Elektrod Huty Baildon (Baildon Steelworks Electrode Plant), devastated Warszawska Fabryka Sprzętu Spawalniczego (Warsaw Welding Equipment Factory) "Perun", less than twenty oxygen producers and several producers of dissolved acetylene. Apart from transformers of rather dated design, electric welding equipment was not produced at all. In spite of such modest beginnings, the welding technology developed relatively fast and the manufacturing base of welding equipment and materials started to expand. The then-new methods, i.e. TIG and MIG/MAG were, after some initial problems and delays, successfully implemented in Polish industry. Presently, technologies and methods used in Poland's welding engineering sector are not different from those applied in other countries of the world.

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