TENDENCIES IN DEVELOPMENT OF CONTROL OF METAL TRANSFER PROCESSES IN SHIELDING GASES (Review)

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Trends in development of modern arc power sources and gas-shielded consumable electrode welding technologies are analyzed. Different types of electrode metal transfer and the possibility of controlling them by varying the welding current parameters are considered. A high potential of the controllable gas-shielded pulsed-arc welding process is substantiated.

Keywords: *metal transfer control, consumable electrode arc welding, shielding gases, short-circuiting, rotating arc*

Gas-shielded consumable electrode welding takes a leading position among arc processes in the industry of Western Europe, USA and Japan [1, 2]. However, new functional capabilities of welding equipment, including arc power sources, which are opened up due to development of power electronics, do not always promote appearance of qualitatively new welding technologies. Developers often advertise welding equipment implementing various control algorithms, but ensuring just one type of electrode metal transfer, as entirely new technologies.

In this work the author has analyzed the tendencies in development of control of metal transfer in shielding gases and consumable electrode welding technologies, and has shown the role of pulsed-arc process with controllable transfer of electrode metal.

Many characteristics of gas-shielded welding process depend on the type of electrode metal transfer, which has an essential influence on various technological characteristics of the welding arc, for instance, heat balance, its spatial stability, intensity of running of metallurgical reactions in the welding zone, burning and spattering losses, as well as penetration depth, parameters and shape of welds [3].

There exist several types of electrode metal transfer in shielding gases [4], the main of which are fine-drop or globular transfer with short-circuiting (SC) of the arc gap; fine-drop or globular transfer without arc gap SC and spray process, and rotating spray process is also found. Metal vapour transfer is present to varying degrees in all the gas-shielded consumable electrode welding processes. However, mixed metal transfer types are often found, due to variation of welding process parameters. Control of metal transfer by the principle of «one pulse per drop» should be treated separately.

Type of metal transfer, as well as forces acting on electrode metal in the arc, are quite comprehensively described in works [4, 5]. Each type of metal transfer is characterized both by advantages and disadvantages. Therefore, transfer type determines many technological characteristics of the process of gas-shielded consumable electrode welding, for instance, welded thickness range.

Each type of electrode metal transfer has its own range of values of welding currents and arc voltages (Figure 1). For consumable electrode pulsed-arc welding (CEPAW) the most effective range of average welding currents is from 60 up to 300 A, that of arc voltages — from 16 to 32 V.

Metal transfer type depends on many welding process parameters. The main parameters in terms of process control are composition of electrode wire and shielding atmosphere; value, polarity, density and shape of welding current; applicability of various mechanisms of welding wire feed. There exist various disturbing impacts that should be taken into account in welding equipment design, as they can change metal transfer type. For instance, at CEPAW reduction of mains voltage or electrode extension may lead to a change of transfer from fine-drop without SC to transfer with SC [6]. Condition of wire surface also can influence the change of electrode metal transfer type. Gas-shielded welding, as a rule, is performed at direct

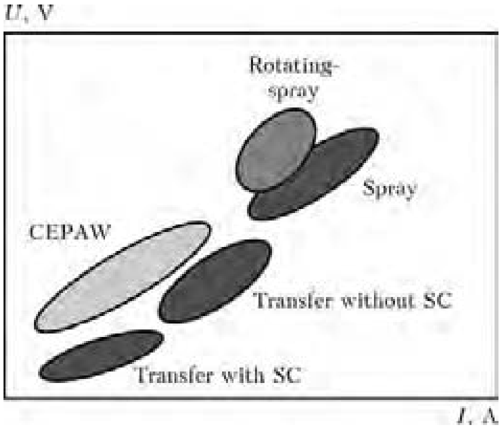

Figure 1. Range of welding currents and arc voltages at various types of metal transfer

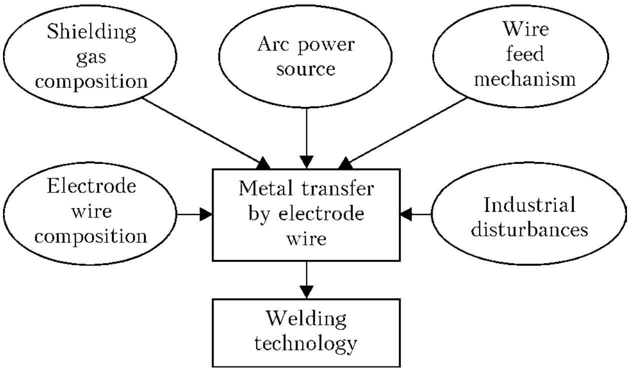

Figure 2. Schematic of the main welding process parameters acting on electrode metal transfer

current. Presence of magnetic blow in the welding process changes the arc length and shape that in its turn, influences drop formation and detachment. Figure 2 shows the schematic of the main components of the welding process, affecting electrode metal transfer.

Compositions of shielding gas mixture and welding wires are varied to improve the quality of weld metal, acting primarily on the metal surface tension forces and degree of welding arc constriction [7–9]. Here fine-drop metal transfer is achieved at lower values of welding current.

Welding wire feed mechanisms also allow effective control of drop detachment process, particularly in welding with SC [10, 11]. Welding arc power sources have a special role in achieving the required type of electrode metal transfer. Variation of welding current shape allows effectively controlling the processes of drop formation, time of its staying in the arc and many other parameters.

Optimization of parameters in Figure 2, influencing metal transfer in consumable electrode welding, depends on specific technology goals. As a rule, first one parameter is optimized, and then, allowing for control effectiveness — the next one. For instance, in CEPAW of steels in gas mixtures, first gas mixture composition was optimized.

Modern pipeline transportation requires high values of working pressure of energy carrier pumping and application of high-strength pipe steels X80 and X100. Consumable electrode welding of such steels necessitated development of new shielding mixtures, for instance Ar + 12 % CO_2 + 5 % He, allowing good fusion with side walls at multipass automatic welding [9]. Then the shape of welding current pulses is optimized, and systems of automatic stabilization of process parameters are developed.

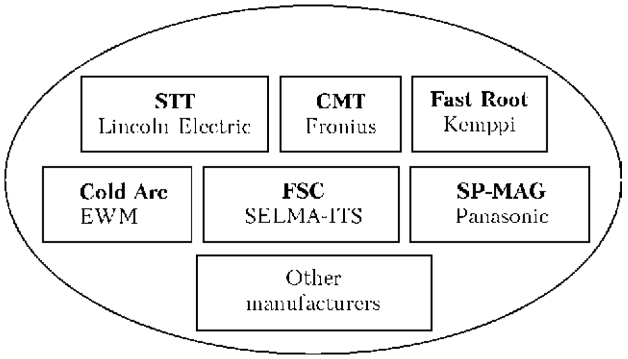

Figure 3. Manufacturers of equipment for gas-shielded welding with SC

Many techniques are used to control the process of consumable electrode welding with arc gap SC [12]. Figure 3 shows the main companies, manufacturing equipment which implements the processes of welding with SC.

Advantages associated with application of SC metal transfer are described in different ways by welding equipment manufacturers. Surface Tension Transfer (STT) process of Lincoln Electric, uses a fast inverter power source for operation, which allows controlling welding current shape [13, 14]. An improved Waveform Control Technology is applied in the arc power source, which provides considerable advantages compared to traditional MIG with SC welding. This process is predominantly designed for welding root welds, as well as lowering spatter, particularly in pure CO_2.

Cold Metal Transfer (CMT) process of Fronius is realized through wire feed reversal [15, 16]. The advantages include slight spatter, also when pure CO_2 is used, possibility of welding over a larger gap due to reduced heat input and brazing, as well as welding metal with different thermophysical properties, for instance steel to aluminium [16].

EWM implements Cold Arc process, designed for welding with SC, which allows joining steel sheets from 0.3 to 1.5–2.0 mm thick, as well as zinc-plated sheets, reliably control welding of root welds in difficult-of-access places, performing welding of magnesium alloys, welding of steel–aluminium, steel–magnesium and aluminium–magnesium joints.

Fast Root technology of Kemppi also realizes the process with SC by numerical control of welding current and arc voltage. Fast Root was mainly developed for welding root welds, but it can also be used for thin metal welding [10].

SELMA-ITS developed a welding process with forced SC (FSC) of the arc gap [10, 13], allowing spatter to be reduced in pure CO_2.

Japanese specialists are also working on the process of arc welding with SC. Work on control of welding current pulse shape SP-MAG (superimposition of currents) is of interest [17]. Advantages of the method include low metal spatter, arcing stability, as well as possibility of heat input control. Developed Metal Transfer Stabilization (MTS) control system prevents formation of large drops and reduces spatter.

Thus, manufacturers produce under various trade marks electric welding equipment realizing the process of welding with SC with the above advantages. It is applied in various industries — car, transportation engineering, food and chemical industry, sheet metal forming.

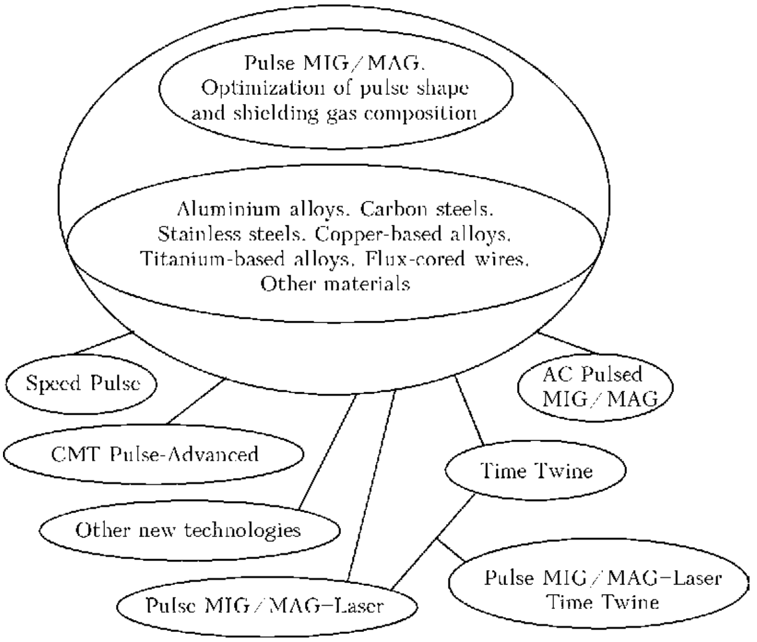

Figure 4. Schematic of CEPAW process development

Technologies implementing the processes of welding with spray and rotating spray transfer of electrode metal are improved. EWM, Germany, introduced integral-inverter MIG 5000 HIGH-SPEED system, realizing high-speed welding by a rotating arc [18].

As a rule, processes of welding with longer electrode extension and transition to rotating-spray arc found limited technological application. German researchers applied continuous wires of 1.2 mm diameter, Ar + 4 % O_2 shielding gas, extension was 25–35 mm, and welding speed was up to 30 m/h. Obtained results of investigation of rotating arc welding process lead to the conclusion of availability of a possible alternative to submerged-arc welding [18].

Controlled pulsed-arc transfer has a special place among the various types of electrode metal transfer [19]. It is applied not only for welding dissimilar materials, but also for realization of new intermediate types of metal transfer, as well as combined hybrid welding technologies. Figure 4 shows the diagram of development of CEPAW applications.

Intensive development is found in the direction associated with regulation of the shape of welding current pulse for CEPAW process. This direction emerged at PWI as far back as in 1980s [20, 21]. Also highly important are the thermophysical properties of the materials being welded, that is reflected, for instance, in construction of systems for automatic stabilization of CEPAW process [22].

Work by Japanese experts in the field of controlling the welding current shape for CEPAW is of scientific interest [23]. In the case of aluminium-magnesium alloys at square-wave shape of welding current pulses, drop detachment leads to fine spatter. Therefore, a pulse shape is proposed which allows elimination of spatter sticking to the item and improvement of weld appearance (Figure 5, *a*).

Shielding gas with 20–25 % CO_2 is used for carbon steel. In the shop at large mechanical engineering plants, which have centralized feeding of gas mixture, variations of mixture composition can be up to several percent. This destabilizes drop transfer of metal acting by «one drop per pulse» principle. Therefore, Japanese specialists form two-step pulses (Figure 5, *b*). Thus, drop transfer of metal is achieved even at up to 30 % CO_2 content in the mixture, and formation of very fine spatter which appears after detachment of the main drop, is suppressed. In addition to spattering reduction, also saving of shielding gas (argon) is achieved.

At CEPAW of stainless steel, which has higher surface tension, Ar + CO_2 mixture with high argon content and O_2 addition is applied. However, synchronous metal transfer through the arc is often disturbed. Therefore, pulse shape was developed, which slows down the process of drop detachment as it grows (Figure 5, *c*).

Method with superposition of low-frequency pulses for grain refinement and lowering of sensitivity to solidification cracking is of interest. PWI also performed such welding current modulation. So, in CEPAW of butt joints on AMg6 alloy, low-frequency modulation in the pause enabled elimination of burns-through and disturbance of weld formation because of fit-up inaccuracies [24].

Pulsed-arc welding was further developed in new technologies. Pulsed arc power sources were introduced, which implement the upgraded Speed Pulse process [25]. The proposed approach enables detachment of several electrode metal drops per pulse, and involving part of the spray process in low-current region. Thus, pulsed arc becomes more effective — penetration depth is increased and welding speed rises.

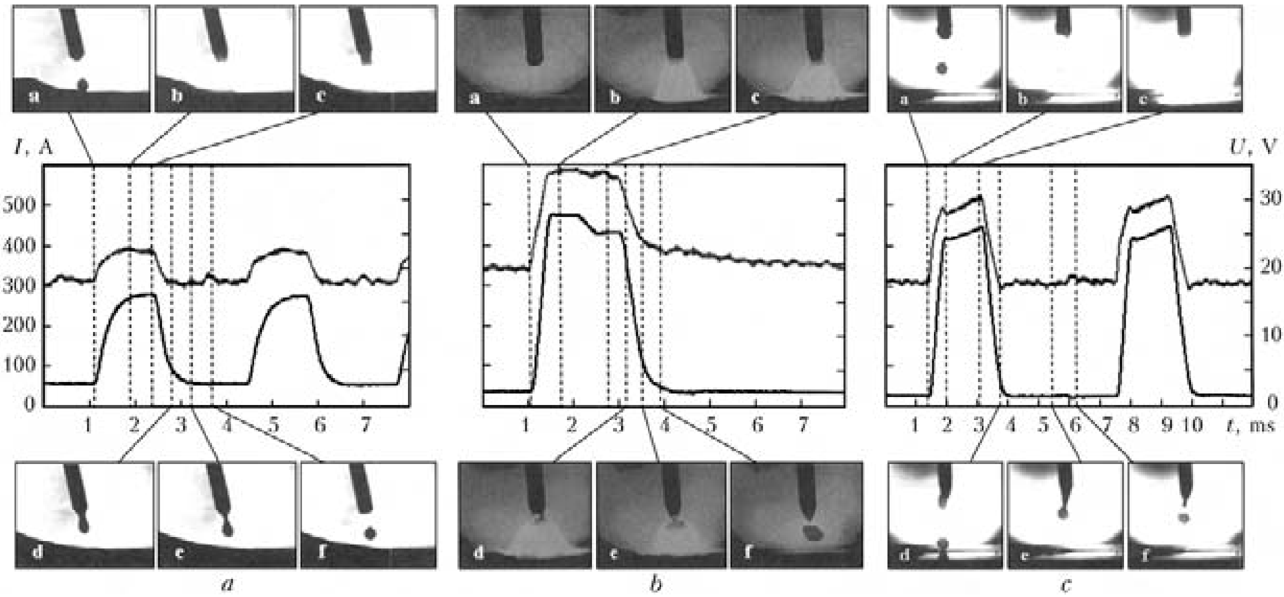

Figure 5. Welding current shapes and nature of electrode metal transfer at CEPAW of aluminium-magnesium alloys (*a*), carbon (*b*) and stainless (*c*) steels [23]

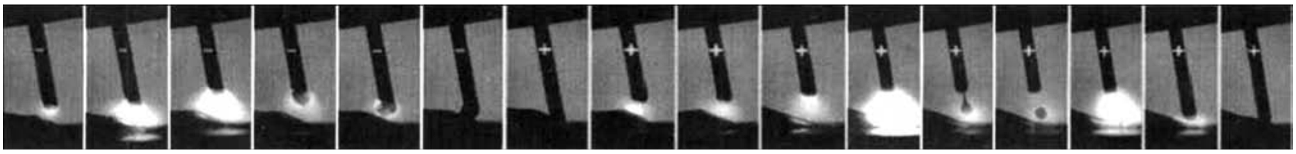

Figure 6. CMT Pulse-Advanced process [26]

The new process was well-established in carbon steel welding [25].

Fronius proposed CMT Advanced and CMT Pulse-Advanced processes [26]. Compared to the already known technology of cold metal transfer, CMT Advanced ensures low heat input. New technology enables filling wider gaps as a result of variation of heat input cycles. Figure 6 shows a cinegram of CMT Pulse-Advanced process. Drop detachment occurs at the moments of SC and action of reverse polarity pulses (as in «classical» pulsed-arc welding). Thus, two types of electrode metal transfer — with SC and fine-drop pulsed-arc without SC — are combined.

«Classical» CEPAW is performed at single-polarity direct current. Hence, the issue of magnetic blow remains urgent. A direction, related to CEPAW, is developing, where the base arc current changes its polarity (Figure 7) [27, 28]. Thus, heat input is decreased. The advantages of AC Pulsed MIG process are low weld pool temperature (welding thin-walled items), better drop detachment, and prevention of magnetic blow.

CEPAW became developed in Time Twine, Pulse MIG/MAG–Laser and Time Twin Pulse MIG/MAG–Laser processes, where two pulsed arcs, a

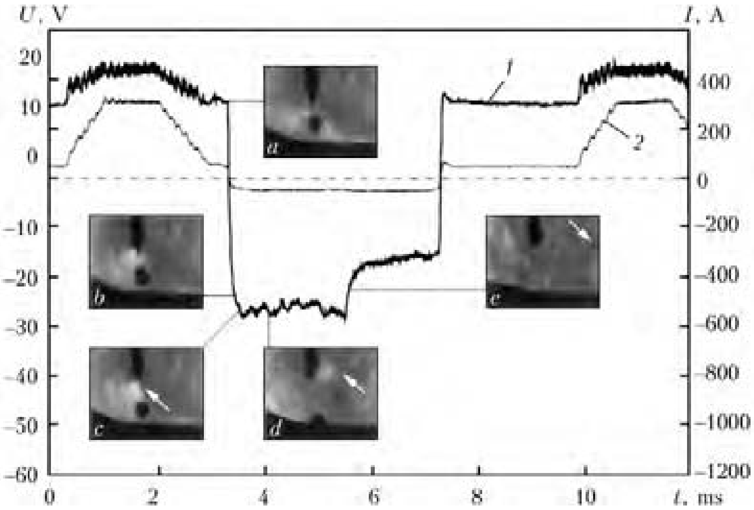

Figure 7. AC Pulsed MIG process [27]: *a*–*e* — cinegrams of electrode metal transfer; *1*, *2* — current values of arc voltage and welding current (1.2 mm A5356 wire; acting values of welding current of 100 A; acting value of arc voltage of 16.8 V, reverse polarity of 20 %)

pulsed arc and laser and three pulsed arcs and laser are used [29–32].

Thus, CEPAW process has its advantages both in joining various class materials, and at various types of electrode metal transfer. Figure 8 gives the applications of CEPAW process with various types of electrode metal transfer.

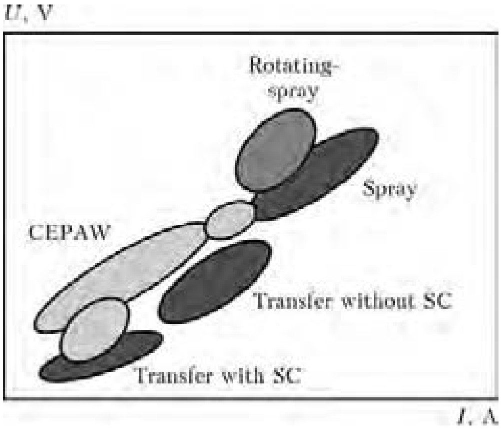

Figure 8. Applications of CEPAW process

CONCLUSIONS

1. Electric welding equipment for gas-shielded consumable electrode arc welding implements the main types of electrode metal transfer, and intermediate types of electrode metal transfer are being developed.

2. It is shown that the controllable pulsed-arc process is successfully applied in welding a wide range of metals, as well as in many combined technologies.

3. It is established that development of modern electric welding equipment implementing various types of electrode metal transfer, should be performed taking into account the controllable pulsed-arc welding process.

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