A REVIEW ON THE CHARACTERISTICS AND DIFFERENT TYPES OF CMT WELDING PROCESS VARIANT

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Abstract

Some welding tasks can be difficult to solve with conventional arc welding processes, due to the applied high heat input, thus the different welding machine manufacturers have developed different processes and process variants. One such development was the CMT (cold metal transfer) process variant. The process is based on a short-circuit version of gas metal arc welding (GMAW) process, but the main difference is, that during the CMT process, the droplet deposition is controlled by the retraction of the wire, which also has the advantage of providing a joint with almost no spatter. Subsequently, several different process variants of the CMT have appeared in recent years, which have other beneficial properties. Therefore, the aim of this paper is to summarize the CMT process variants and the different types of them and their potential applications.

Keywords: *Cold Metal Transfer (CMT), CMT process variant, short-circuit, welding*

1. Introduction

Arc welding processes are widely used in various industries, but in general one of the disadvantages of conventional processes is that the material to be welded is subjected to high heat exposure during the process, which changes its microstructure and mechanical properties (Balasubramanian et al., 2020). Another problem with conventional processes is the spattering, which can be a costly and time-consuming process to remove (Tapiola, 2016). Therefore, many manufacturers have developed various "special technologies" to solve these problems. Some examples of such technologies are summarized in *Table 1*.

Table 1

Different manufacturer's "special technologies" (Gyura, 2010)

Manufacturer	**"Extra low" heat input processes**	**Controlled short-circuit processes**	**"Special" high-performance processes**	**"Special" pulse-arc processes**	**Dual pulse technology**	**Other "special" technologies**
CLOOS	Cold weld	Control weld	Rapid weld	Vari weld Speed weld	Duo Pulse	
ESAB		Qset			Aristo Superpulse	Aristo Superpulse
EWM	(coldArc) RootArc	coldArc (RootArc)	ForceArc		SuperPulse	PipeSolution
FRONIUS	CMT CMT Advanced	SteelRoot (CMT)	SteelsDynamic PCS (Pulse Controlled Sprayarc)	CMT Pulse	SynchroPulse	CMT Pulse Advanced
LINCOLN		STT Power Mode	Power Mode	RapidArc	Pulse on Pulse	
LORCH	SpeedRoot	(SpeedRoot) (SpeedArc)	SpeedArc	SpeedPulse	TwinPuls S-TwinPuls	SpeedUp

The CMT process variant is shown in *Table 1*, corresponding to a modified gas metal arc welding (GMAW) process, which was developed by the Austrian company Fronius in 2004 (Silvayeh et al., 2017). In the previous years, it has been used in many industries with the aim of reducing the heat exposure of the metals to be welded. CMT technology itself has several advantages over conventional fusion welding processes, such as GMAW or gas tungsten arc welding (GTAW), where the heat input is considered to be relatively high (Satheesh et al., 2020; Roy et al., 2021).
The CMT technology is based on short-circuit material transfer, which still presents challenges for development. Therefore, in this paper, the process, advantages, different applications and some process variants of the CMT are summarized.

2. CMT process variant

2.1. General information about the CMT process variant

The CMT process variant is a modified GMAW technique in which the movement of the wire and the droplet deposition are controlled together, thereby controlling the heat exposure of the metal to be welded. During each phase of the short-circuit, the current is reduced, and the wire retraction is controlled, thus achieving a fully controlled heat input without spattering. The wire movement can be controlled up to an average frequency of 70 Hz (Selvi et al., 2018; Kannan et al., 2019; Babu et al., 2020). The principle of CMT is illustrated in *Figure 1*. During the process, the wire moves towards the weld pool *Figure 1(a)*, then dips into the weld pool and the arc is extinguished *Figure 1(b)*, after this the wire moves backwards, to make easier the droplet deposition (which is mechanical and therefore different from the conventional GMAW process) *Figure 1(c)*, while keeping the short-circuit current at a low value. Afterwards, the filler material starts to move again towards the weld pool and the entire process is repeated *Figure 1(d)* (Girinath et al., 2020).

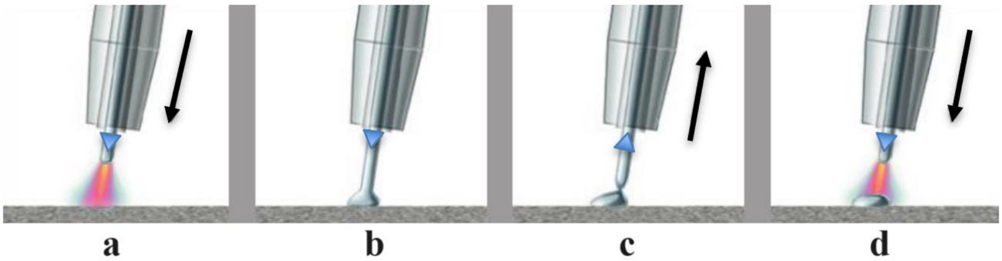

Figure 1. *Schematic illustration of the CMT process variant* (Tapiola, 2016)

Figure 2 shows some high-speed camera images illustrating the CMT process.

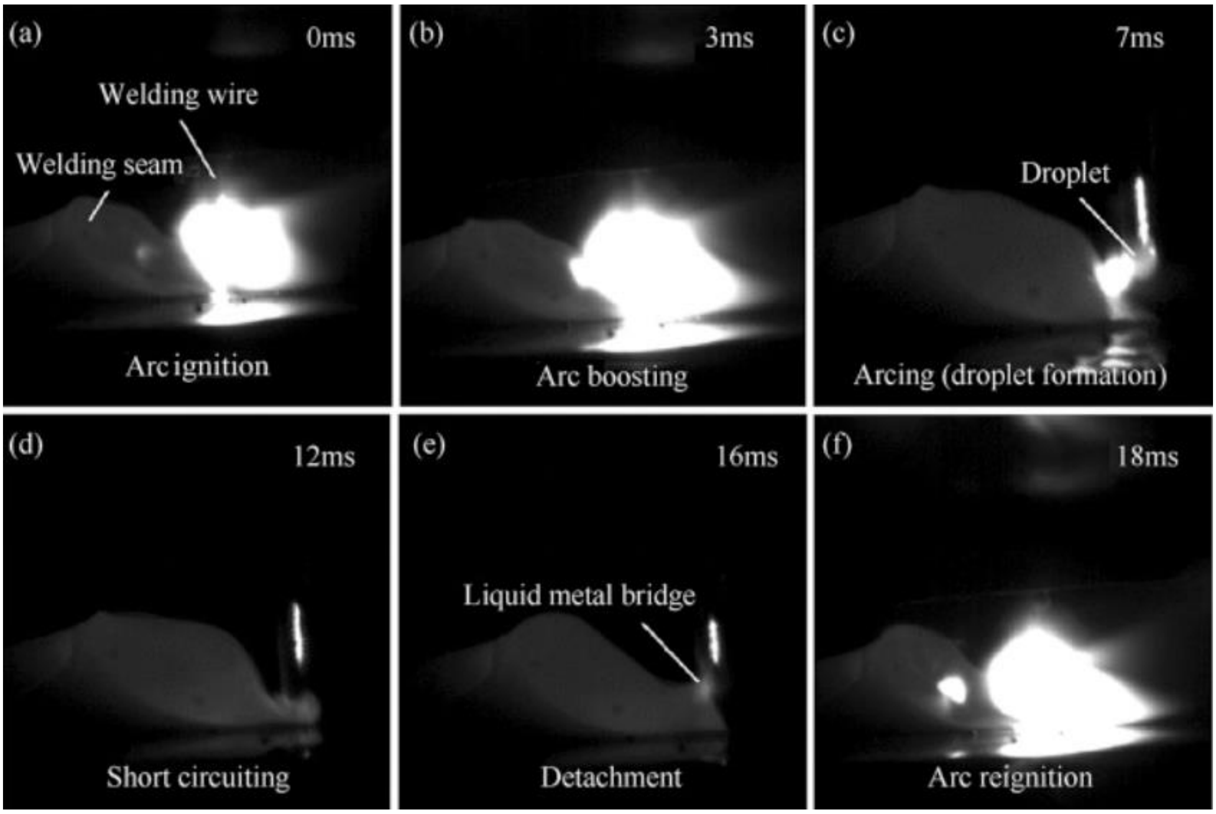

Figure 2. *High-speed camera images about the CMT process variant* (Selvi et al., 2018)

During the CMT process variant, a typical weld cycle can be defined as the time required to deposit one droplet. In order to study the energy distribution of the different phases of the droplet deposition, it is essential to analyze the current and voltage waveforms (Sun et al., 2015). The welding cycle can be divided into three parts as follows:

- Peak current: A high current pulse with a constant voltage, at which the arc ignition can be easily achieved, and which heats the wire electrode for droplet formation.

- Base current: A phase of reduced amperage in order to prevent to the globular transfer of the liquid droplet formed on the wire tip (this phase lasts until the short-circuit occurs).
- Short-circuit: The arc voltage drops to zero and at the same time the wire feeder receives a signal and pulls back the wire. At this stage the drop deposition occurs (Feng et al., 2009).

The complex waveform of the welding current and the pull-back of the filler metal, which results in mechanical metal transfer, makes the understanding of the relationship between welding parameters, metal transfer and heat transfer difficult (Lorenzin et al., 2009). For better understanding, *Figure 3* illustrates the wire speed rate, current and voltage as a function of time during the CMT cycle.

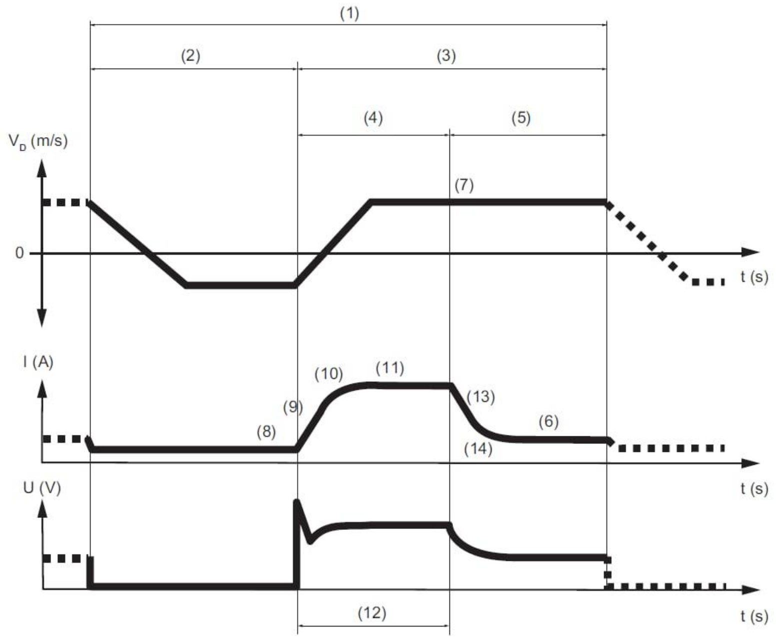

***Figure 3.** Wire speed rate, current and voltage curves during the CMT cycle* (Tapiola, 2016)

The notations on the diagram are: (1): CMT cycle time, (2): Short-circuit phase, (3): arc phase, (4): boost phase, (5): arc burn phase (6)–(14): parameters that can be set at programming (Fronius, 2021).

The notations marked as ‘parameters that can be set during programming’ refer to the adjustable values of the welding machine. These include e.g. wire feed speed, base and peak current levels, the timing of short-circuit and arc phases, as well as polarity switching in advanced variants. By modifying these parameters, the operator can optimize penetration depth, droplet transfer stability and arc length.

Because of the perfect arc length control and the high tolerances that can be applied to the joining of the plates, the CMT process can provide solutions to many welding problems (Lorenzin et al., 2009). During welding, the control unit detects the short-circuit and controls the droplet deposition by moving the wire. As this process is continuously repeated, the arc produces heat for a very short time. During the short-circuit and the wire pull-back time, the current is small, and the welding can be considered as almost spatter-free (Cornacchia et al., 2018; Kannan, et al., 2019). In addition, the arc length during the process is well monitored and easily controlled. As a result, the arc is stable even at faster welding speeds, regardless of the material surface, and therefore the process variant can be used in all positions (Srinivasan et al., 2022).

2.2. Applications

One of the biggest advantages of the process is accuracy and good controllability. By properly controlling the welding current, the pulses and the heat input can be perfectly controlled. As the process itself is automated and electronically controlled, welding tasks are very reproducible and the quality of the joint is not affected by the skill of the welder, so the chance of human mistakes are greatly reduced (Eder, 2010). In conventional fusion welding processes, the mechanical properties of the welded materials are greatly altered due to the high heat input, whereas in CMT, the heat input is minimal, resulting in minor changes in the properties of the materials, and thus high quality joint can be produced (Li et al., 2019). Another advantage of the process variant is that it does not require the use of backing compared to conventional welding processes, in order to prevent burn-through (Milani et al., 2019).

CMT technology is the most suitable for joining thin sheets due to its low heat input. The application results in less deformation and does not require complex surface cleaning processes, and even allows mixed joints of aluminum and steel, which is difficult to achieve with conventional fusion welding processes. With CMT technology, even galvanized plates can be easily joined, and it has also been shown to be advantageous for welding magnesium and titanium (Srinivasan et al., 2022). In addition, it is also suitable for joining Inconel, brass, stainless steel, etc. Although it is mainly used for thin plates, it is also suitable for welding thick plates using different variations of the process variant (Wang et al., 2016).

The CMT process variant is widely used for welding offshore structures, in the automotive industry, for engines and pipelines and for joining plates (Zhang et al., 2015). In addition, its high accuracy makes it an optimal choice for the electronics industry as well (Sevvel et al., 2020).

3. Different types of the CMT process variant

There are several different types of the CMT process variant, of which the three most common are CMT Pulse, CMT Advanced and CMT Pulse Advanced. In addition to these variants, CMT Dynamic (Srinivasan et al., 2022), CMT Twin (Xiang et al., 2017), CMT Pin (Somoskői et al., 2013) and CMT Brazing (Cao et al., 2014) are also mentioned in the literature.

The following sections describe the different types of the CMT process variant.

3.1. CMT Pulse

CMT Pulse is a combination of CMT and pulse welding. With CMT Pulse, a pulse cycle is added to the CMT process, which results in a higher heat input, but increases the welding speed and adds an extra droplet deposition to each cycle, which increases productivity. The first part of the cycle corresponds to the CMT process, followed by a pulse arc phase where the wire electrode is moving towards the workpiece and a drop deposition is performed at the same time. This is followed again by a normal CMT cycle (Tapiola, 2016). The process is illustrated in *Figure 4*.

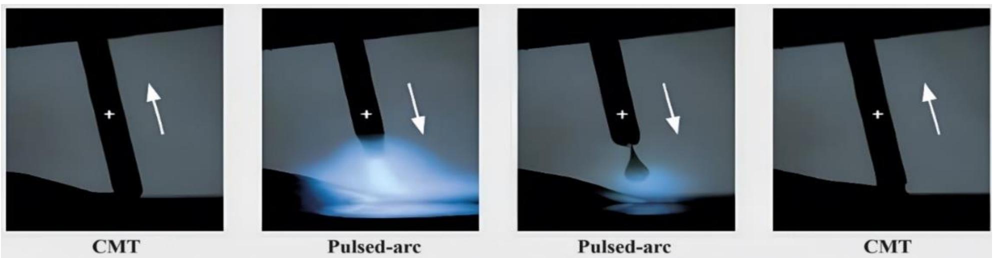

Figure 4. *CMT pulse cycle* (Imoudu, 2017)

Figure 5 shows the CMT Pulse characteristic curves. In the presented example, there are two pulses in the pulse cycles. The notations on the diagram are: (1): CMT cycle, (2): pulse cycle, (3): arc phase, (4)–(17): parameters that can be set at programming, KSP: short-circuit phase, BoP: boost phase, BrP: arc burn phase (Fronius, 2021).

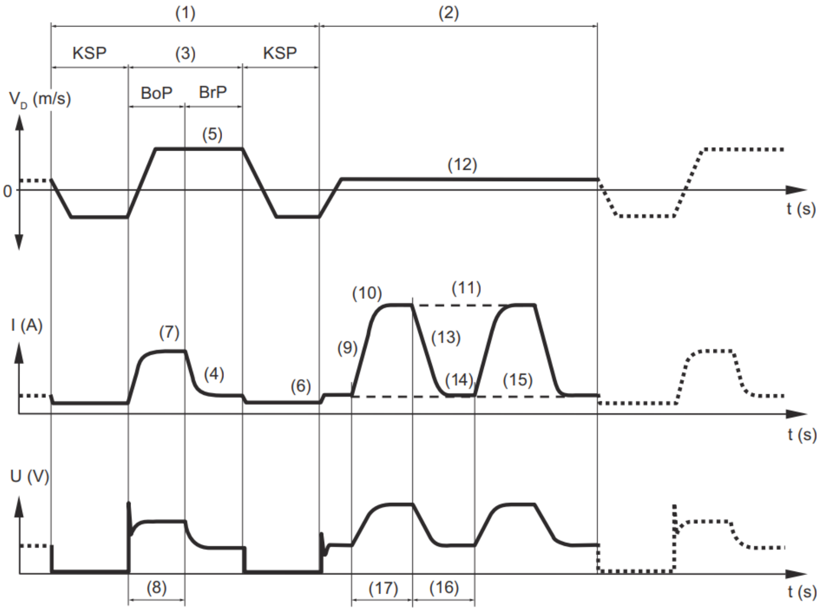

Figure 5. *Wire speed rate, current and voltage curves during the CMT pulse cycle* (Fronius, 2021)

The CMT Pulse process is mainly used for thin plates (0.5–3 mm) of CrNi alloyed steels and various aluminum alloys [29].

3.2. CMT Advanced

The CMT Advanced welding process alternates negative and positive polarity CMT cycles *(Figure 6)*, i.e. AC current is used. This means that the materials to be welded are exposed to even less heat than in conventional CMT. The polarity change occurs in the short-circuit phase, allowing even better control of the heat input, wider weld gaps to be filled and higher droplet deposition rates can be achieved (Imoudu, 2017).

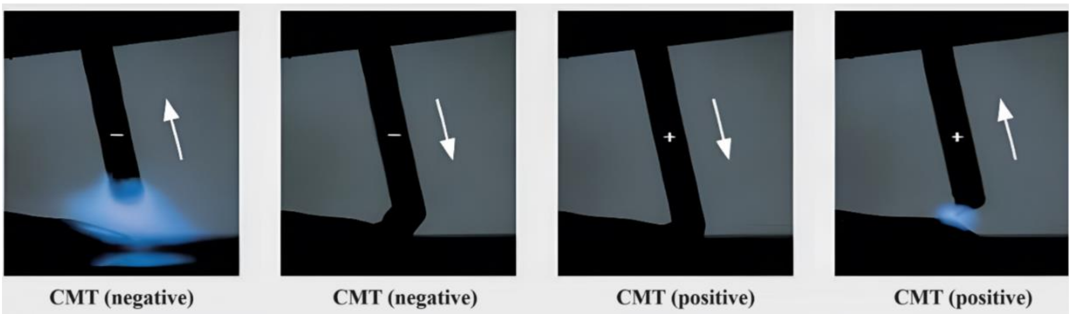

Figure 6. *CMT Advanced cycle* (Imoudu, 2017)

The characteristic curves of the CMT Advanced are shown in *Figure 7*. The notations used in the figure are (1): short-circuit, (2): arc phase, (3) boost phase, (4): arc burn phase, (5)–(13): parameters that can be set during programming. The grey color indicates the negative polarity region. This corresponds to the periods where the electrode is connected to the negative pole (Fronius, 2021).

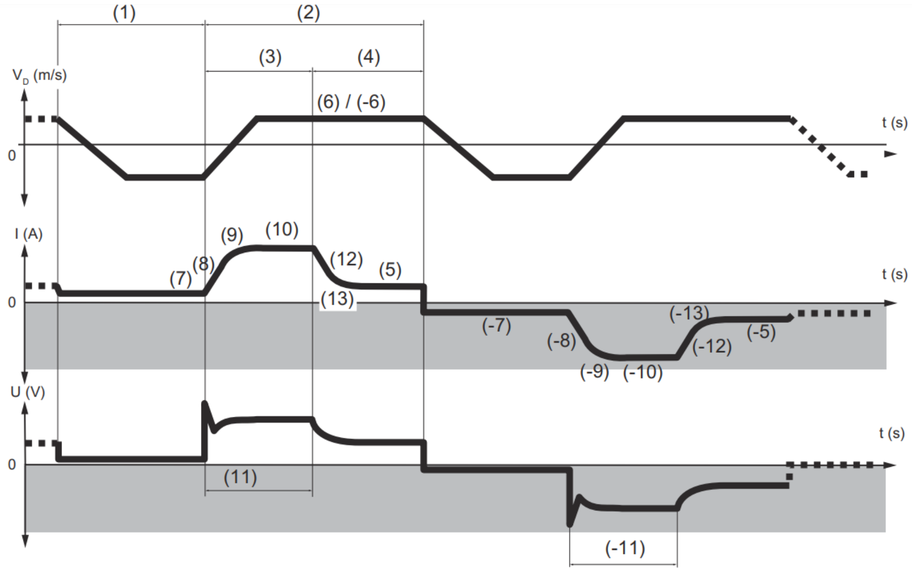

Figure 7. *Wire speed rate, current and voltage curves during the CMT Advanced cycle* (Fronius, 2021)

The CMT Advanced process variant is especially advantageous for aluminum and copper alloys (Cong et al., 2014).

3.3. CMT Pulse Advanced

Another type of CMT process variant is CMT Pulse Advanced. The process combines negative polarity CMT cycles and positive polarity pulses. An illustration of this process is shown in *Figure 8*. First, in the CMT phase, the wire is moved towards the weld pool, then after it enters the weld pool, a short-circuit occurs, and the machine starts to pull-back the wire electrode. Then the polarity change occurs, and the process continues with the pulse arc phase. Thus, the pulse arc phase is always completed with positive polarity (Tapiola, 2016).

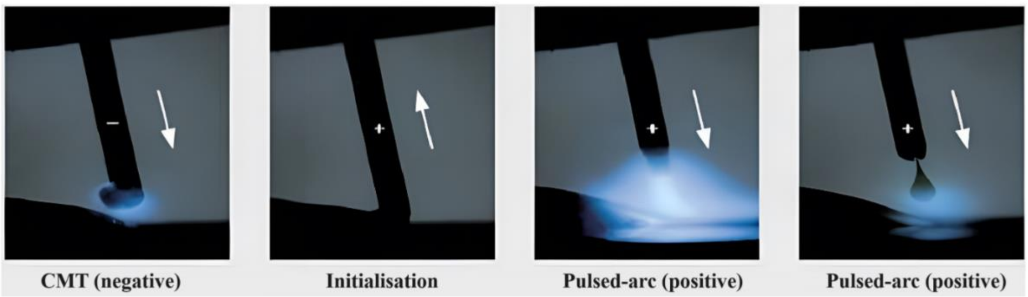

Figure 8. *CMT Pulse Advanced cycle* (Imoudu, 2017)

Figure 9 shows the CMT Pulse Advanced characteristic curves. In the figure, the notations are (1): CMT cycle, (2): pulse cycle, (3): arc phase, (4)–(19): parameters that can be set during programming, KSP: short-circuit phase, BoP: boost phase, BrP: arc burn phase. The grey parts indicate processes with negative polarity (Fronius, 2021).

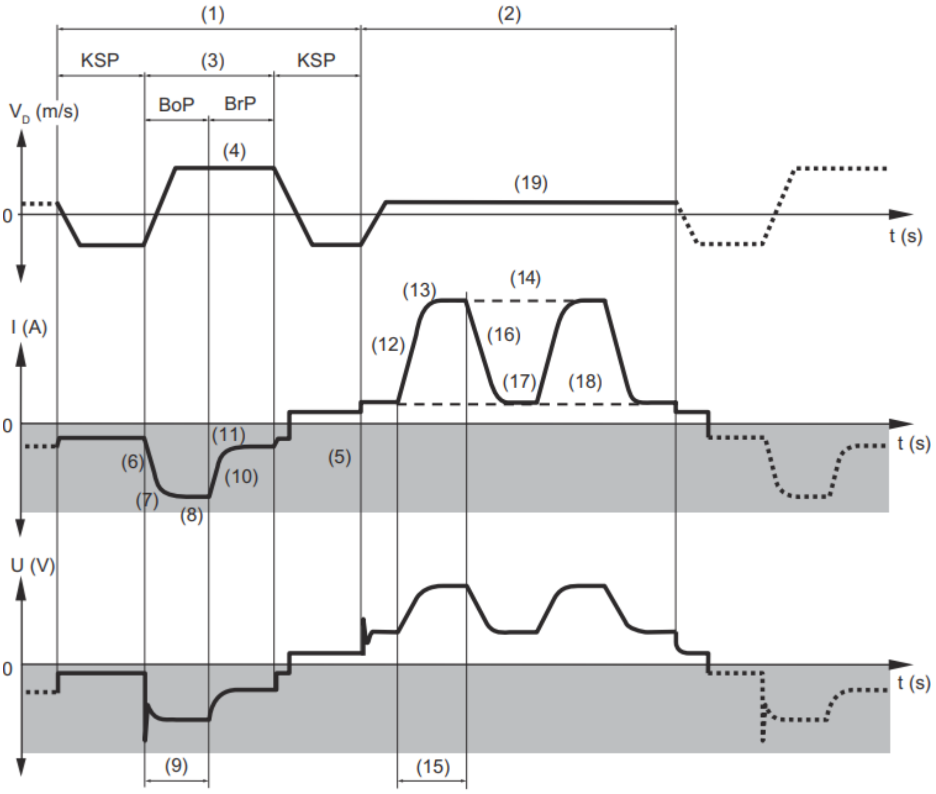

Figure 9. *Wire speed rate, current and voltage curves during the CMT Pulse Advanced cycle* (Fronius, 2021)

As the figure demonstrates, negative polarity is only applied during the CMT phases, during the pulse arc phase the polarity is always positive. So, the process variant itself is a combination of CMT Pulse and CMT Advanced.

In addition to the higher heat input, the process variant also offers the advantage of a non-short-circuited droplet transition during the pulse phase. Its application is advantageous for high strength steels, as it provides a low heat input with high deposition rates [30].

3.4. Other types of CMT process variant

The CMT Dynamic process is designed for welding thicker plates. The wire back and forth motion has been increased to 130 Hz, which greatly increases the limit of the basic process variant. It achieves deeper penetration and faster welding speed, but also results higher heat input compared to the basic CMT process variant (Srinivasan et al., 2022). In CMT Twin, welding is performed simultaneously with two wire electrodes driven by two independent power sources. Thus, the melting rate can reach up to 20 kg/h (Posch et al., 2013). The CMT Pin process allows the welding of various non-metallic materials e.g. polymer or rubber pins or pin-like elements to metal plates (Somoskői et al., 2013). The CMT Brazing process, on the other hand, was developed for welding materials with low melting points. In this case, the process is also based on the CMT process variant, but the melting point of the filler material is lower than in the case of welding processes (Cao et al., 2014).

3.5. Comparative summary of CMT process variants

For better comparability, the variation of voltage and current as a function of time for different process variants is shown in *Figure 10*. The data shown in the figures were recorded during welding of AA 2219 material with AA 2319 wire electrode. The shielding gas used was argon (Cong et al., 2014).

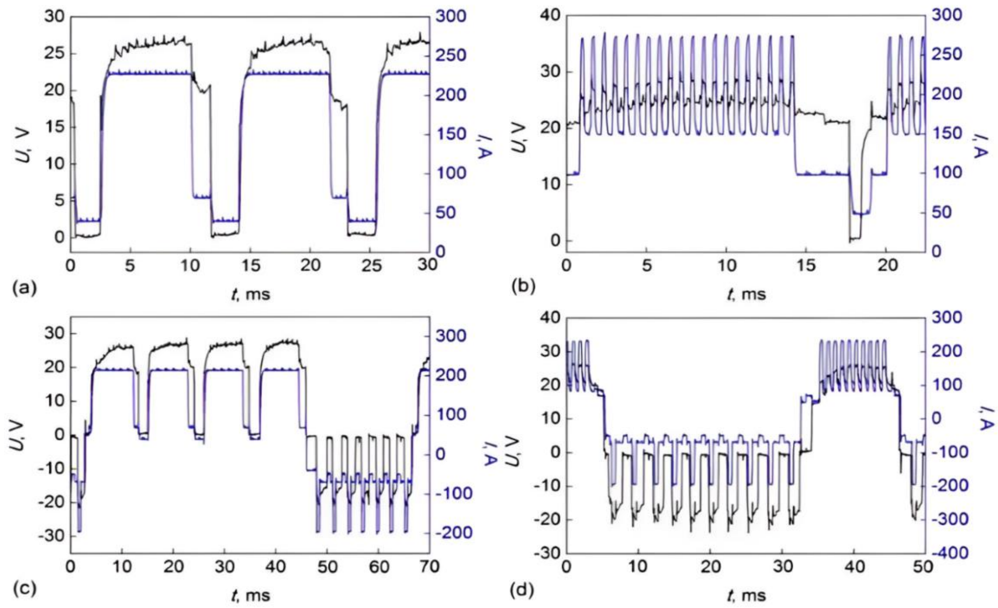

Figure 10. *Comparison of different CMT process variants, (a) CMT, (b)CMT Pulse, (c) CMT Advanced, (d) CMT Pulse Advanced* (Cong et al., 2014)

Figure 10(a) shows the curves typical of the conventional CMT process variant. *Figure 10(b)* illustrates the changing pulses and short-circuiting phases during the CMT Pulse process variant. *Figure 10(c)* shows the CMT Advanced process variant, during which the polarity switching takes place. The example in *Figure 10(d)* represents the CMT Pulse Advanced process variant, which demonstrates that this process variant is a combination of the CMT Pulse and CMT Advanced process variants. With use of CMT, the results generally confirm that the lower heat input reduces distortion and preserves the base material properties. CMT Pulse provides higher productivity but with slightly increased heat input, whereas CMT Advanced and Pulse Advanced variants improve weldability of aluminum and high-strength steels by lowering residual stress. Thus, the choice of variants has a significant effect not only on process stability but also on the resulting joint quality.

For a clearer comparison, the main features and application fields of the different CMT process variants are summarized in *Table 2*. This overview highlights the technological differences between the variants as well as their suitability for specific applications.

Table 2

Main features and application fields of the different CMT process variants

Variant	Main features	Applications
CMT	Low heat input, spatter-free, stable arc	Thin sheets, automotive, electronics
CMT Pulse	Higher heat input, added pulse cycle, higher productivity	Thin CrNi steels, aluminum alloys
CMT Advanced	Alternating polarity, reduced heat input	Aluminum, copper alloys
CMT Pulse Advanced	Combination of CMT Pulse and Advanced, positive polarity pulse	High strength steels
CMT Dynamic	Increased wire motion frequency, deeper penetration	Thicker plates
CMT Twin	Two wire electrodes, high deposition rate	High productivity applications
CMT Pin	Joining non-metallic pins to metals	Polymers, rubber
CMT Brazing	Uses low-melting filler material	Aluminum to galvanized steel, aluminum–copper, aluminum–titanium joining

4. Summary

Based on the literature review, the following conclusions can be made in relation to the CMT process variants:

- The retraction of the wire electrode during the short-circuit phase plays an important role in the process by controlling the droplet deposition, thus preventing spattering and resulting in a more aesthetic weld.
- A major advantage of the process is that it involves less heat input to the base material than, for example, the gas metal arc welding process, and is highly controllable and reproducible.
- In recent years, a number of different types of the CMT process variant have been developed, which further extend the application possibilities.
- The CMT process can be well combined with pulse arc (CMT Pulse), the combination resulting in increased productivity.
- The CMT Advanced process variant can also be used to achieve polarity changes, thus further reducing the heat exposure of the material to be welded.
- The CMT Pulse Advanced process variant is a combination of CMT Pulse and CMT Advanced, where the heat input remains low with high deposition rates.

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