# Controlled short-circuiting MIG/MAG welding (CCC) – Process analysis tools

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**Mainly in developing countries, the root pass in pipe welding is still predominantly performed using stick electrodes. This weld critically influences the speed at which a pipeline is constructed. In order to achieve an increase in the overall productivity, short-circuiting MIG/MAG welding processes with current control have been developed and applied to this operation. These semi-mechanised, slag-free processes yield welds with satisfactory properties with higher productivity, avoiding the inconveniences of the conventional MIG/MAG welding by means of current waveform control. The applied software methods provide arc and weld pool stability and permit short welder training times. One of these systems was developed by the Welding Laboratory of the Federal University of Santa Catarina, Brazil (LABSOLDA/UFSC). Process evaluation methods were needed in order to enable the development of the software-based controlled short-circuiting MIG/MAG welding process, called CCC, since monitoring systems for conventional MIG/MAG welding do not apply. Hence, computational tools were designed and implemented specifically for the analysis of the CCC. They are based on oscillographic and statistical information obtained from welding data acquisition, showing the influences of parameter adjustment on the achieved results. This allows an adequate iterative optimisation of the process and procedures.**

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## 1 Introduction

The costs involved in the field of oil and natural gas production and distribution are extremely high. Thus, major significance is attached to the constant pursuit of high-productivity technologies.

In pipeline construction for oil and natural gas transport, the root pass weld is still predominantly performed using stick electrodes. Due to its very nature compared to the MIG/MAG process, the stick electrode has lower productivity. The main causes for this are the need for slag cleaning, electrode changes during a root pass and other secondary times resulting from the characteristic spattering of the stick electrode. In order to increase productivity, an upgrade to a semi-mechanised welding process was desired. Nevertheless, what was lacking before was a MIG/MAG variant capable of achieving good results in this specific application with no need for a long training time and great ability of the welder.

The development of the current waveform control technique in the short-circuiting transfer mode of the MIG/MAG welding provided a stable transfer of the molten droplets and ease of welding. LABSOLDA's version of this process is called CCC. As a variant of the MIG/MAG, it is a slag-free process (solid wire electrode), with continuous feed of the material. The difference lies in its very low spattering and high drop transfer regularity, irrespective of a perfect torch manipulation of the welder or variations in the contact-tip-to-work distance (CTWD). This last feature is specially desired in offshore applications since the sea balance would increase the tendency of variation in the CTWD, implicating increased current variation and root heterogeneities, as well as a tendency to lack of fusion or burn-through. Additional advantages can be achieved by the current waveform control technique in short-circuiting MIG/MAG: less fumes, better pool visualisation, better pool control, flexibility of heat input adjustment, lower susceptibility to weld defects and better weld geometry [1...3].

The development of variants of arc welding processes demands proper observation of the phenomena resulting from parameter adjustments. This is accomplished by means of process monitoring. In contrast to the advantages provided by the short-circuiting MIG/MAG with current control, the high number of parameters to be adjusted during the process development phase and their temporal correlation with the progress of the metal transfer makes the parameterisation stage complex. An adequate and robust parameterisation is important to enable a stable and easy-to-use welding process. Hence, the formulation and implementation of computational process analysis tools dedicated specifically to the CCC were imperative and represent the main objective of this work. These tools consist of histograms and oscillograms which are obtained from welding data acquisition and processing. This information serves to highlight the influences of parameter adjustments on the process development phase, enabling suitable process design.

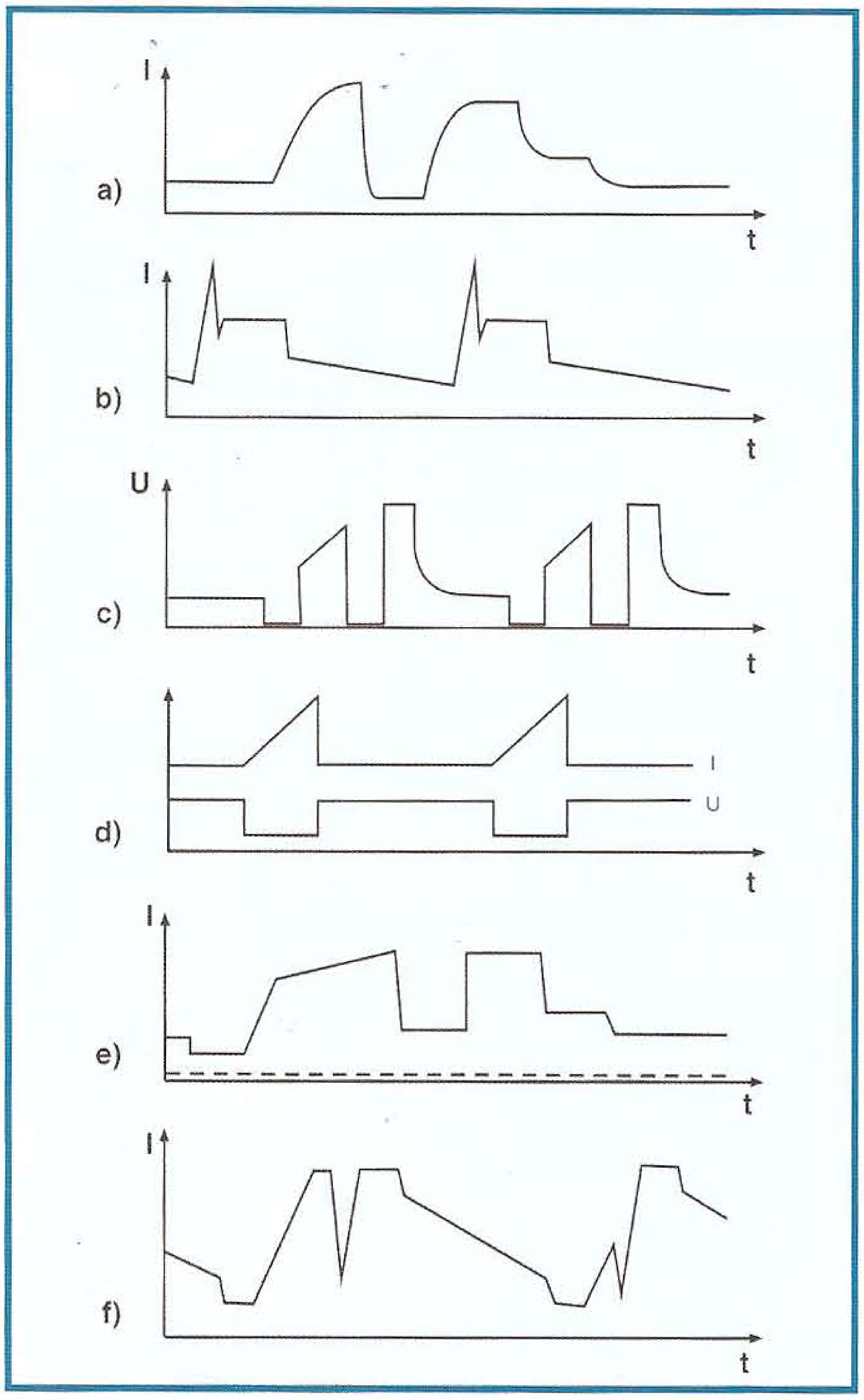


***Fig. 1.*** *Waveforms of current-controlled short-circuiting MIG/MAG welding processes:* ***a)*** *[5];* ***b)*** *[5];* ***c)*** *[1];* ***d)*** *[6];* ***e)*** *[2]; f) [3] (I is current, U voltage and t time).*

## 2 Fundamentals of current-controlled short-circuiting MIG/MAG welding

Several designs of waveforms for current-controlled short-circuiting MIG/MAG welding are either on the market or have already been investigated within the framework of scientific and/or technological work. The Welding Laboratory of the Federal University of Santa Catarina (LABSOLDA/UFSC) started investigating this MIG/MAG variant in the 90's and the application by that time was hyperbaric welding [4]. Fig. 1 shows some of the waveforms found in the literature [1...5]. Fig. 2 shows the first LABSOLDA's software-controlled version of CCC.

Each of these variants has its own process control methods but most of them, including the CCC, basically work in the following manner, Fig. 3: the transfer of the molten droplet from the wire electrode tip to the molten pool is divided into phases which are correlated with the current waveform in order to maintain a stable and regular weld. In the first phase, the arc burns at a low current, just in order to sustain the arc and the temperature of the molten droplet and the molten pool. Phase 2 starts when a short circuit is detected by means of voltage reading. The current is lowered and the droplet wets smoothly over the molten pool by means of surface tension. Phase 3 provides a high current for the pinch effect. The contact-tip-to-work distance (CTWD) is read during this phase, in the case of CCC via the welding voltage. Also, the dynamics of the liquid bridge between the wire electrode tip and the molten pool surface are monitored in order to detect collapsing imminence. In CCC, this is provided by means of monitoring of the welding resistance. When the bridge break is imminent but has not yet occurred, the current is lowered to phase 4 where the droplet is finally totally transferred in a smooth low-spattering way. The system is then driven to phase 5 where a high current pulse melts another droplet and increases penetration. Using the CTWD reading performed in phase 3, the pulse time is automatically regulated, according to previous parameterisation, to keep the regularity of the droplet size and thus the stability of the metal transfer. The CTWD exerts an influence on the quantity of heat supplied to the wire electrode tip and consequently on the size of the molten droplet. In some systems, the current drop back to phase 1 is damped in order to avoid a violent vibration of the welding pool.

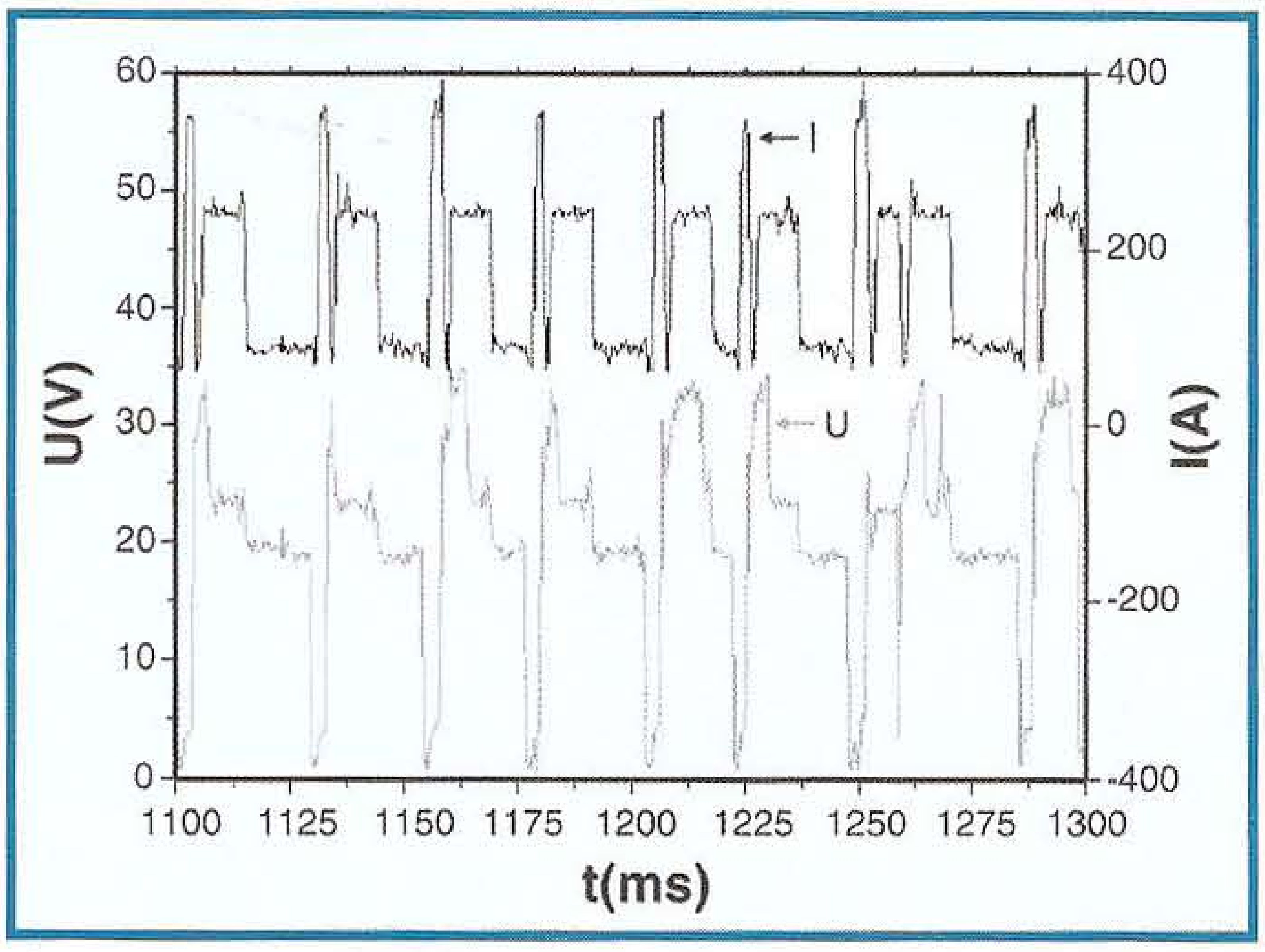


***Fig. 2.*** *First CCC version [4].*

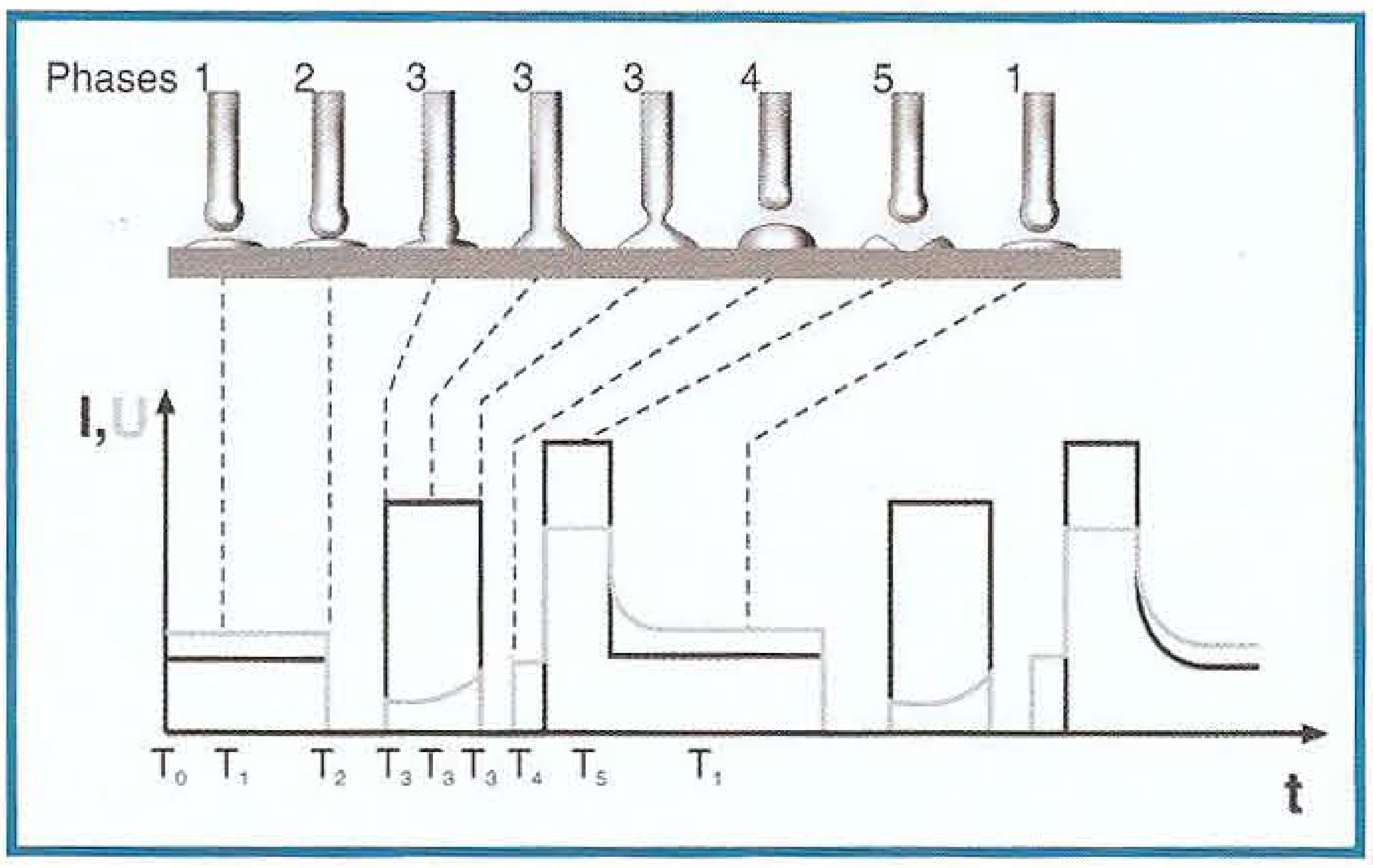


***Fig. 3.*** *Fundamentals of current-controlled short-circuiting MIG/MAG welding.*

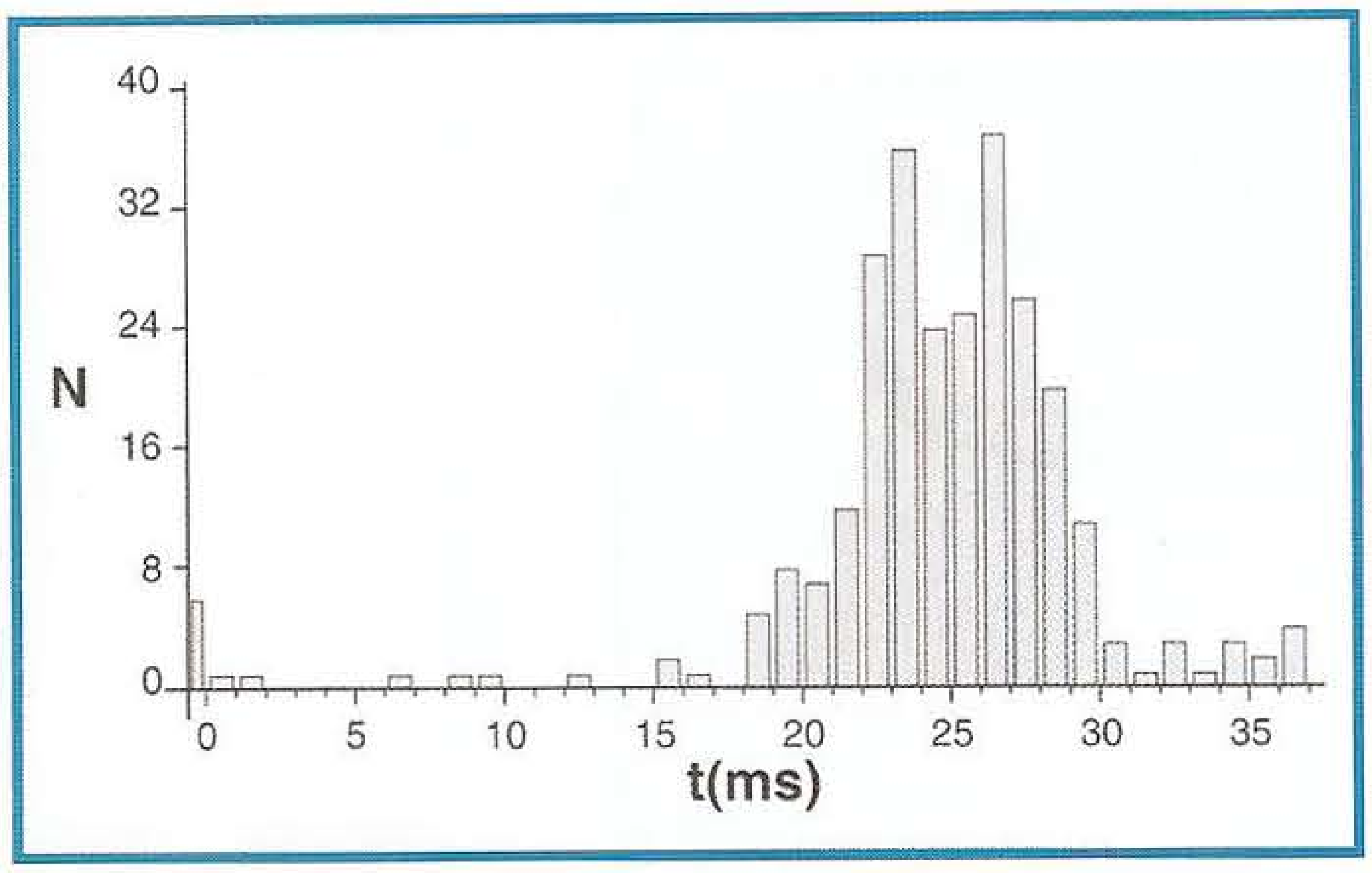


*Fig. 4.* *DIGI20TA.0, histogram of the arcing time for each droplet transfer.*

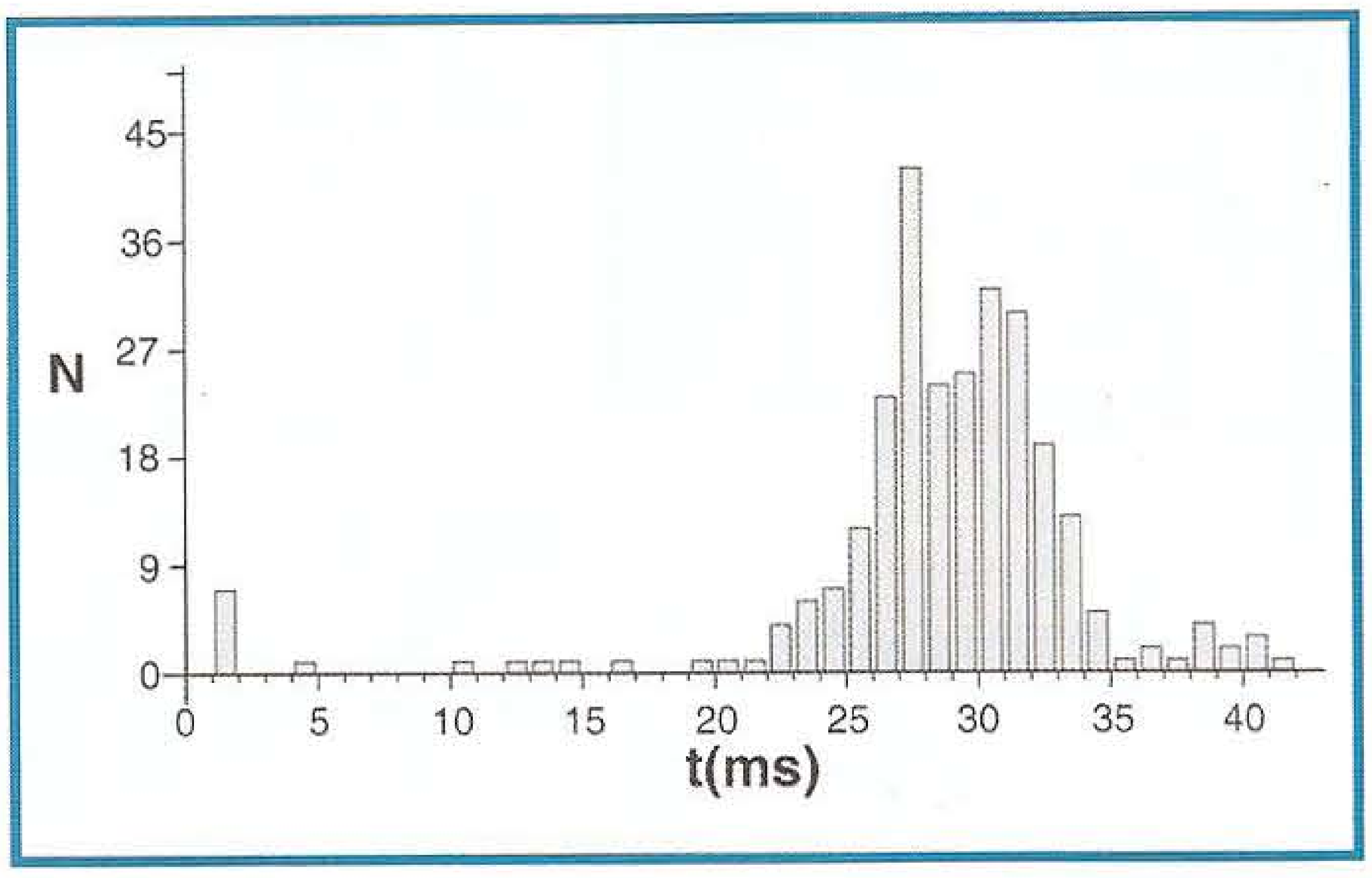


*Fig. 5.* *DIGI20TP.0 file, histogram of the droplet transfer periods, this file also provides the total time monitored.*

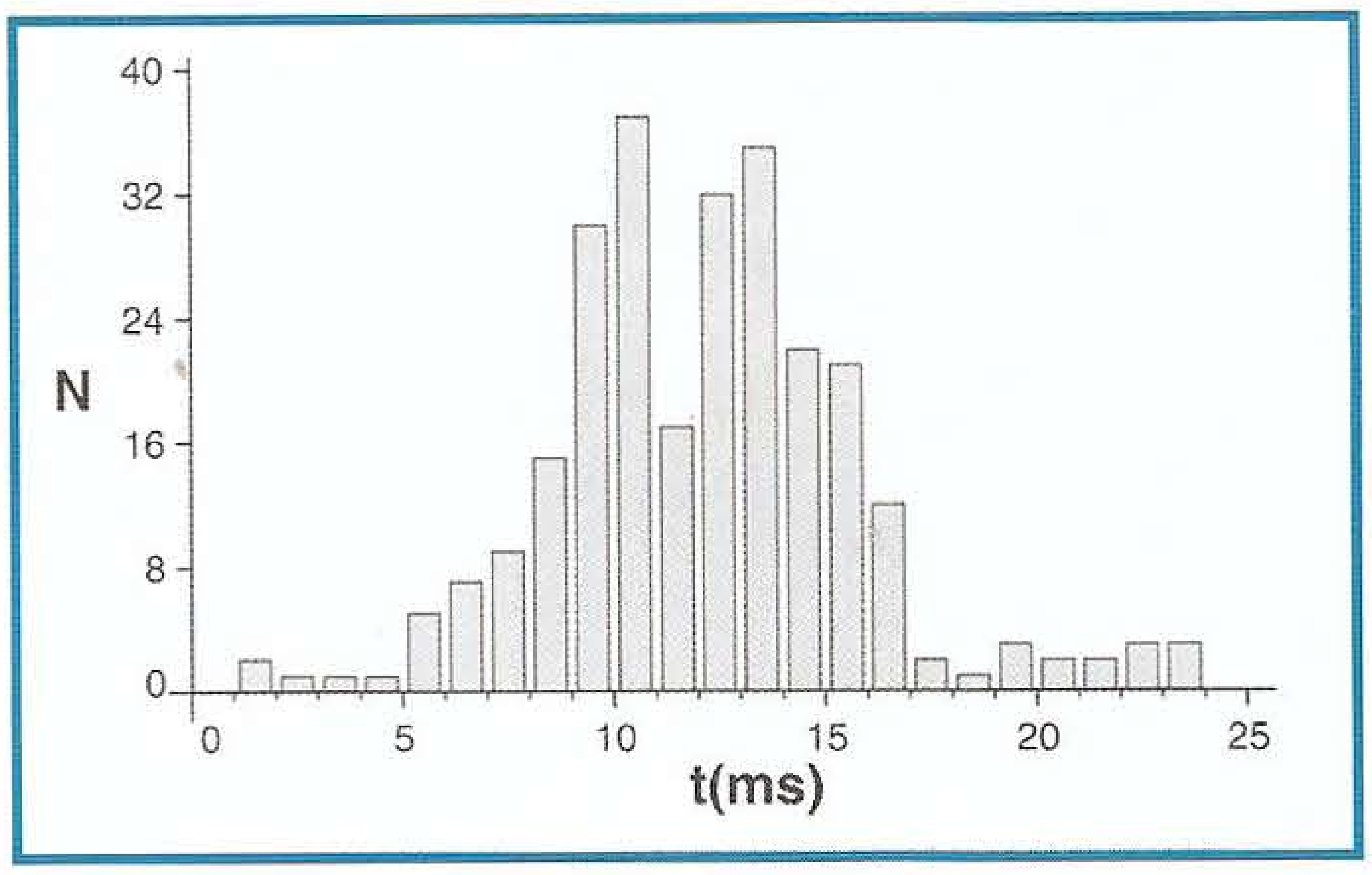


*Fig. 6.* *DIGI20TF1.0, histogram of the times in phase 1.*

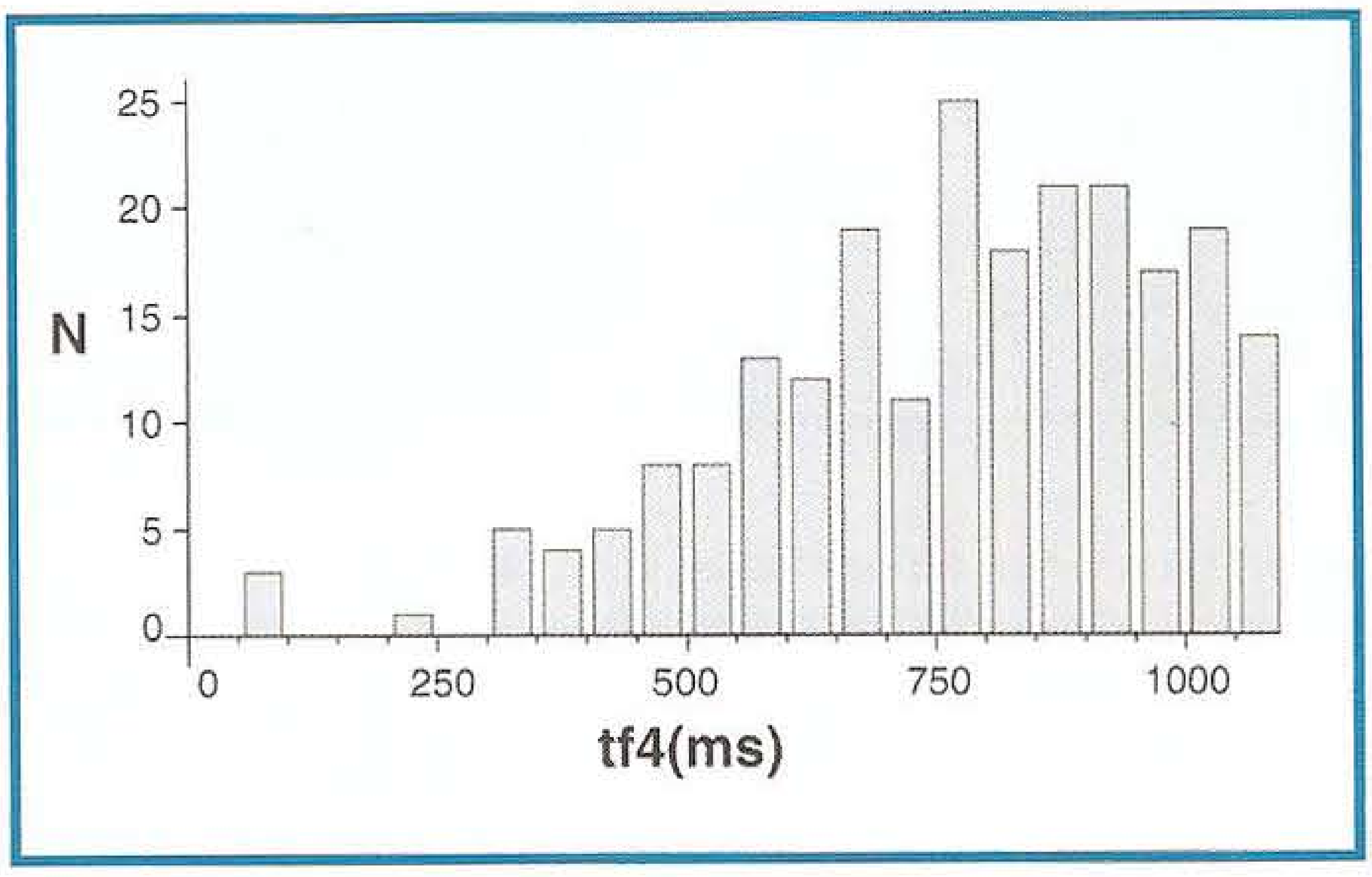


*Fig. 7.* *DIGI2TF4, histogram of the arc restriking occurrences in phase 4.*

## 3 Development of the CCC process analysis tools

In order to refine the CCC waveform, it was necessary to develop software tools which provided accurate information about the progress of the weld. They had to yield statistical data regarding the regularity of the droplet size and the transfer as well as the quality of the transfer. In other words, these tools must show, in a very visual way, if the system is working properly, enabling an adequate process evaluation and evolution.

The control software was modified, so that each weld made and monitored provided a package of files (named DIGI2000 package) which, transformed into histograms, show the system's performance regarding the regularity and the correlation between the metal transfer and the current waveform. Table 1 shows the files and their respective functions.

In fact, the files consist of tables of the welding time, the current, the voltage and the resistance. As mentioned, they are input into a graphics-generating software yielding histograms and oscillograms. The files which result in histograms (DIGI20TA, DIGI20TC, DIGI20TP, DIGI2TF1, DIGI2TF3 and DIGI2TF4) also output the total number of occurrences of that specific phase throughout that weld. In contrast, DIGI2TF4 results from the number of arc restriking occurrences within phase 4. For example, in addition to the time distribution (histogram) of all „phases 1", the DIGI2TF1 file also yields the number of „phases 1" which occurred in a weld (hence, the number of short circuits). The histograms permit a regularity evaluation.

The histogram derived from DIGI2TF4 points out more than the regularity of the welding. In fact, it also provides information about the efficiency of the regulated CCC variables and parameters in reducing spatter generation, i.e. if most arc restriking occurrences take place within phase 4 (low current) and, additionally, the restriking concentration is central or a bit displaced to the end

*Table 1.* *Files contained in the DIGI2000 package.*

| File | Function |
|---|---|
| DIGI2000.0 | Complete current (I), voltage (U) and resistance (R) oscillograms, indicating phase transition points |
| DIGI200R | I, U and R at CTWD reading moment |
| DIGI20TA | Arcing time histogram |
| DIGI20TC | Short-circuit time histogram and number of short circuits |
| DIGI20TP | Transfer period histogram and total monitoring time |
| DIGI2TF1 | Histogram of phase 1 times |
| DIGI2TF3 | Histogram of phase 3 times |
| DIGI2TF4 | Histogram of arc restriking in phase 4 and number of restriking occurrences in this phase |

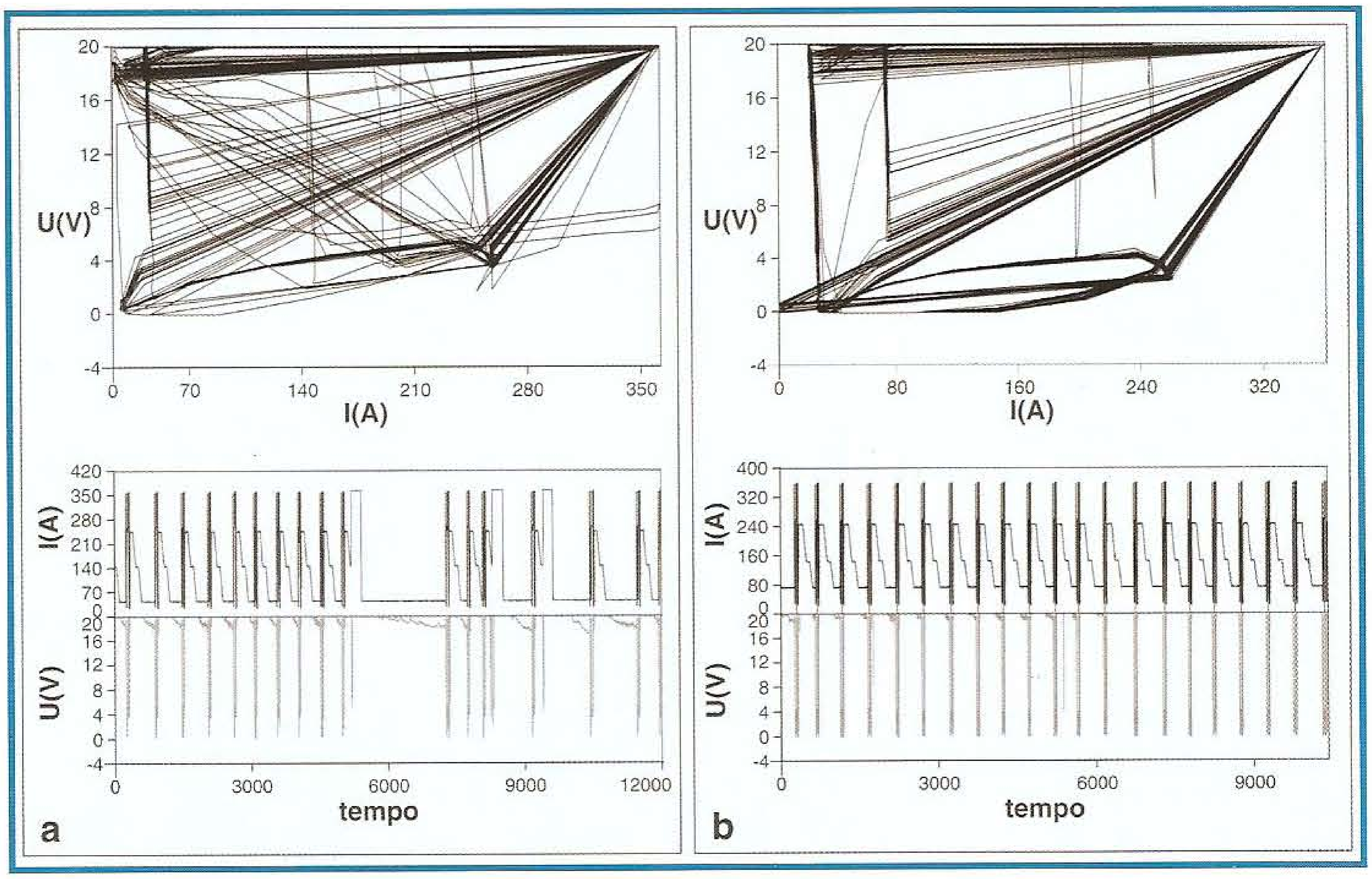


***Fig. 8.*** *Voltage (U) x current (I) curves and oscillograms of instable* ***(a)*** *and stable* ***(b)*** *welding procedures of CCC.*

of this phase, that represents an adequate correlation between the metal transfer (droplet detachment) and the current waveform. It is well-known that even weld machines with good dynamics have a certain current drop rate. The current transition from phase 3 to phase 4 is actually a slope rather than a straight fall. If the arc restriking occurrences were concentrated in the initial part of phase 4, they would more likely already occur during the current fall, meaning still at a high current. That tends to cause higher spattering.

The voltage x current static curve, which is also obtained from process monitoring and data processing, was also considered when analysing the process stability.

## 4 Results and discussion

The first current waveform studied at LABSOLDA, Fig. 2 [4], was taken as a starting point for process parameterisation. The welding data acquired and processed by the CCC control software during the parameterisation phase resulted in the evaluation graphics as described above. By these means, the values of the current and the time of each phase of the waveform as well as the reference parameter for the detection of the arc restriking (Krab [7]) were iteratively optimised to a stable, regular weld progress. Figs. 4 to 7 show examples of resulting histograms.

The difference between stable (a) and instable (b) procedures can be visualised on Fig. 8. Not only is the voltage x current curve much more erratic for an instable procedure but the wrong progress of the metal transfer can also be noticed – there should be a decrease in the voltage at the end of phase 3, caused by the current drop, and the voltage should already increase in phase 4, as a result of the arc restriking in this phase. When arc restriking occurs at a higher level, there is a significant increase in spattering, as can be seen on Fig. 9.

After parameterisation, a stable process was achieved, yielding a regular and adequate oscillogram, as well as a weld bead with satisfactory properties, Fig. 10.

The DIGI2000 tools were also applied to CCC parameterisation for $CO_2$ as the shielding gas. The resulting oscillogram is shown on Fig. 11 and a comparison between this procedure and conventional $CO_2$, keeping the same wire electrode feed rate, can be observed on Fig. 12.

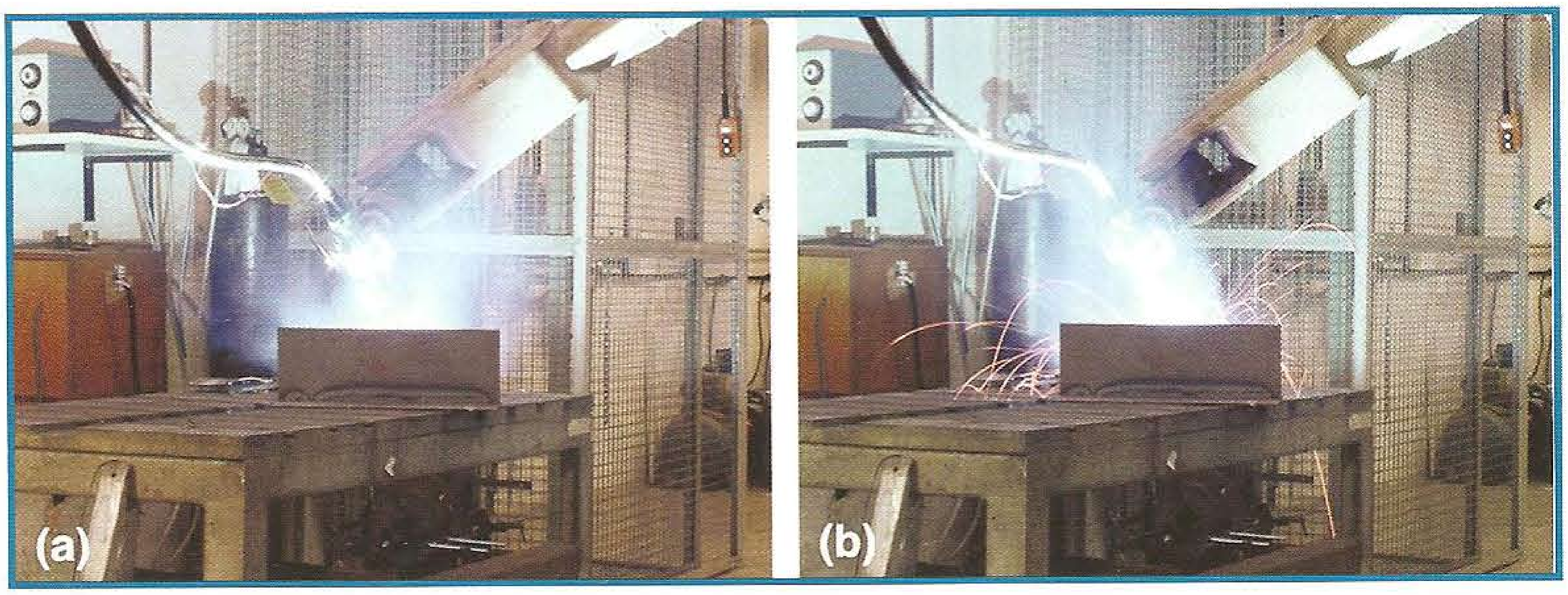
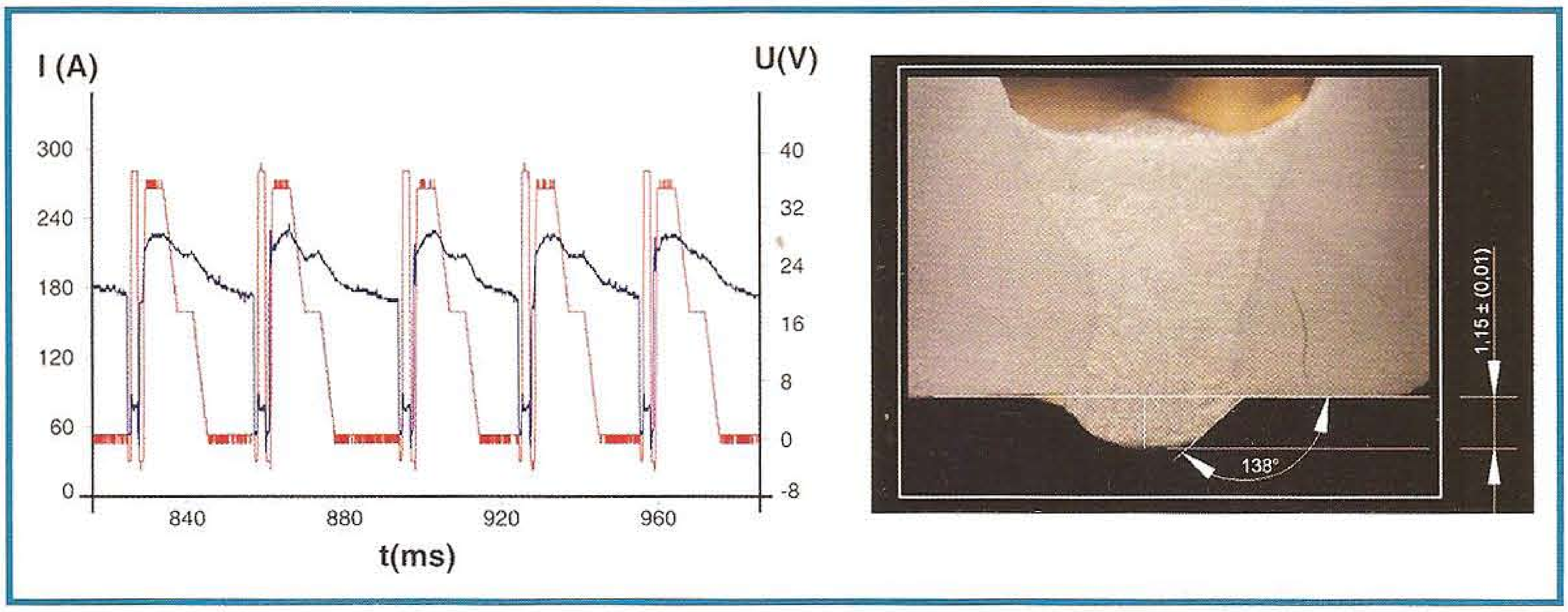


***Fig. 9.*** *Arc restriking at a low current* ***(a)*** *(adequate CCC progress) and at a high current* ***(b)*** *(spattering).*

*Fig. 10.* Stable and regular CCC oscillogram and resulting weld – shielding gas: Ar + 25% $CO_2$ (I is current in red, U voltage in blue and t time).



## 5 Conclusions

Stability and regularity analysis tools suitable for assessing the quality of CCC parameterisation operations were developed. The DIGI2000 package of files and the derived graphics showed their usefulness in optimising the waveform and are of most interest when developing other applications for the process which, apart from the most common root pass in pipe welding, can also profit from an increase in productivity.

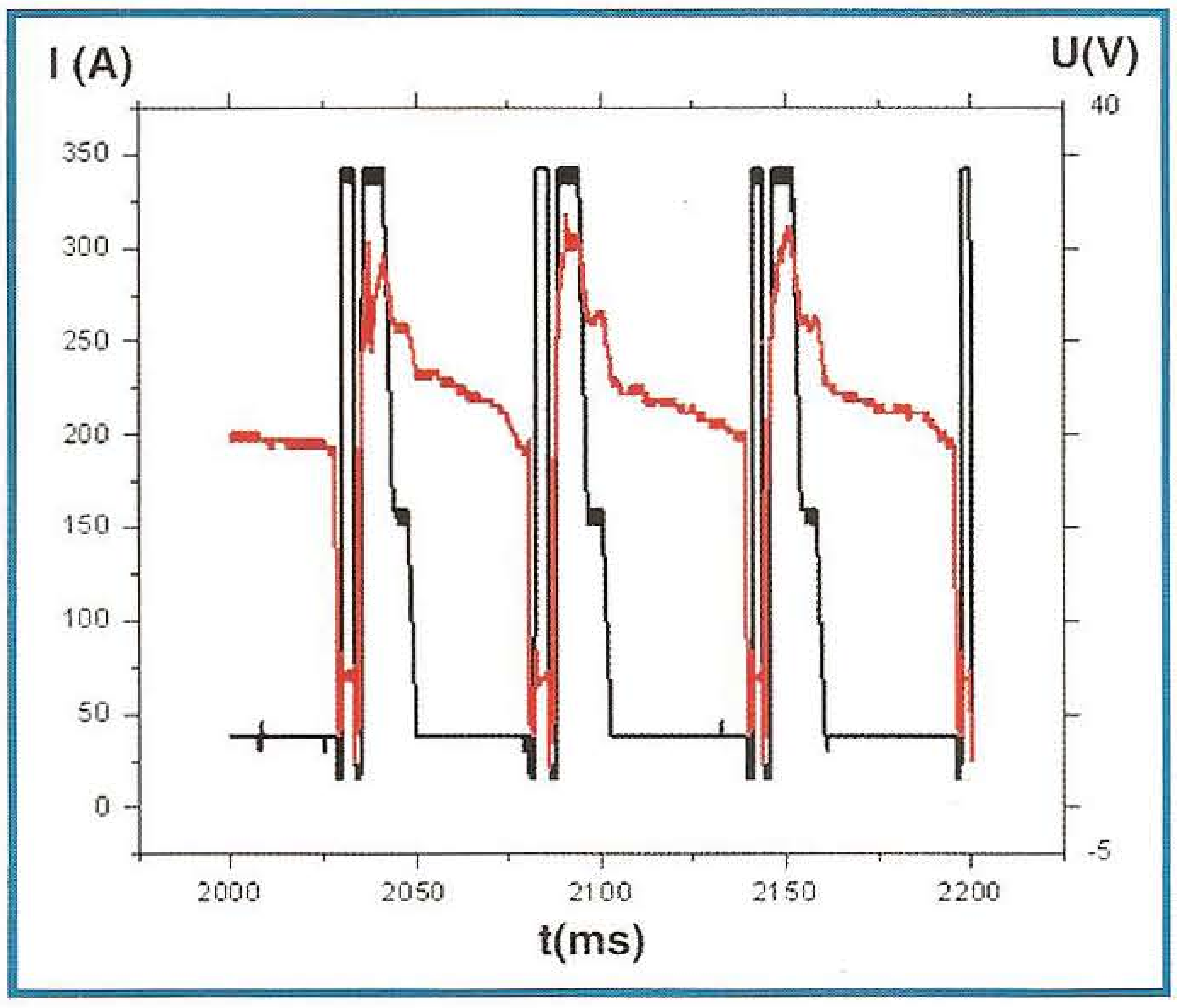


*Fig. 11.* CCC oscillogram with $CO_2$ as the shielding gas (I is current in black, U voltage in red and t time).

The adopted methodology proved to be adequate since any irregularities in the metal transfer which can exert an influence on the resulting weld are detected. This methodology can also be applied to monitoring other current-controlled MIG/MAG welding processes.

### Literature

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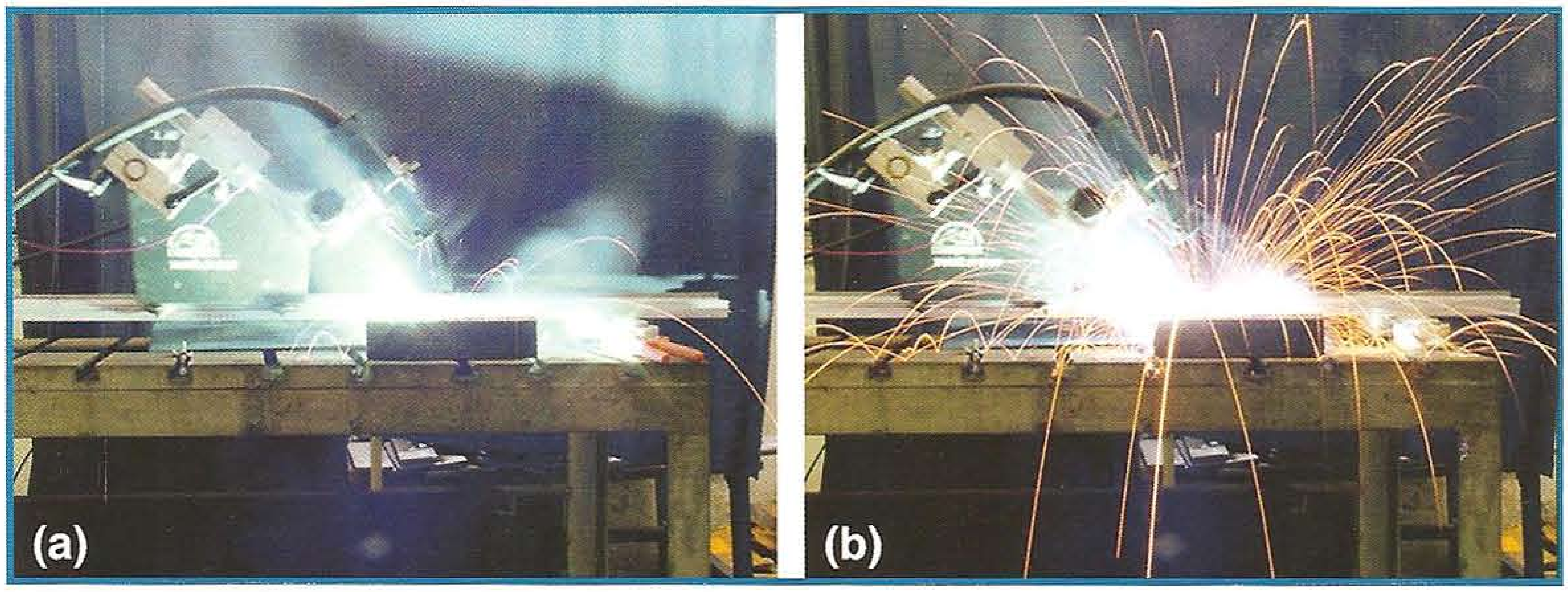

*Fig. 12.* Comparison between CCC **(a)** and conventional short-circuiting MIG/MAG **(b)** with $CO_2$ as the shielding gas.