MATELECT

Products for crack growth measurement and monitoring

A Primer & Guide: V3/2025

E-PD

Connections & Wiring

www.matelect.com

IMPORTANT

Thank you for your purchase of Matelect PD products. This is a quick guide to making connections to your specimens prior to beginning potential drop testing. It is intended as advice – and in no way should be regarded as a prescription for every connection, on every possible specimen, in every possible testing scenario.

Please read this guide carefully before you embark on making any connections to your test specimens. Please pay particular attention to any safety information that deals with equipment that is mains operated or generates high voltages (such as spot-welders), as given here, or in the instruction manuals covering individual instruments and products.

For your safety, and that of the Matelect instrumentation, please do not attempt to make connections to specimens, using welding apparatus, with electronic instrumentation connected to the wiring. The input amplifiers of potential drop instruments are protected against inappropriate inputs, but there are limits to this, and discharging a spot welder into a sensitive instrument, such as a CGM-7 or a DCM-2, will invariably result in permanent and expensive internal damage.

End-users are responsible for performing any appropriate and local risk assessment, associated with usage of spot-welding apparatus, and Matelect E-PD instruments in general, but you can use the information and advice contained in this guide to help assess the risks and plan appropriate mitigation.

Introduction

The need for connections

Electrical potential drop (EPD, or just PD) is a four-point measurement methodology. This means that PD requires four connections per measurement location – and all those connections need to be ohmic and of low value resistance. For ACPD studies, these connections are a way of measuring the specimen's impedance (which will hopefully alter as the specimen cracks, or in the presence of a crack) whereas in DCPD, it is the electrical resistance that is being measured. Resistance and impedance cannot be measured directly – they need a current to be passed, and a voltage drop (hence PD) to be measured. In the simplest case of DCPD, the resistance is then calculable by using Ohm's law. Of the four connections, two pass the current to and from the specimen, and the second pair (normally located inboard of the current wires) measure the resultant potential drop.

Differences in connections between AC and DCPD

Given metallic specimens are effectively "short circuits" of finite, but low resistance, the currents that are required in DCPD, in order to obtain a measurable voltage, are of the order of tens of amperes. This requirement made first generation DCPD systems large and bulky. Also, the high currents were traditionally passed continuously, and this usually leads to a gradual (but perceptible) rise in the specimen temperature, especially at contact points where the current enters the specimen. Such a rise will alter the measured DCPD value, given that most metals exhibit a finite temperature dependency of their resistivity. In modern DCPD instruments, the currents are pulsed, so reducing the on-time and hence specimen heating, but even so, it is always a good idea to use as thick and chunky a wire/connection as possible for the DCPD current, especially if end-users are after the highest crack depth measurement sensitivity possible.

The voltage signal connections can be far thinner in gauge, because no current flows along these wires. It is much the same for ACPD wiring, with the added benefit that the skin effect means that large ACPD signals are generated with far more modest excitation currents (typically 2A is enough for most specimens/materials that are found in testing environments), hence why ACPD does not need to be pulsed and the excitation current is continuous (although varying in time).

Practicalities

ACPD connection locations

In general, if the user has chosen no specific test regime or standard that they are following, the configuration shown in Fig 1, should be employed for something such as a CT specimen.

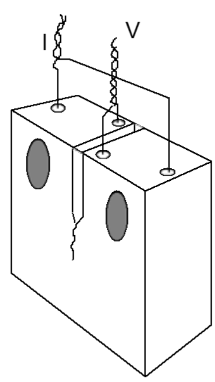


Figure 1. Possible locations for EPD system set-up (ACPD in this case)

Once connections are made, the wiring is usually twisted to ensure that "pick-up" effects are reduced (for more on the origins of pick-up see Matelect's Guide to ACPD or the instruction manual for our ACPD instrument, the CGM-7. The CGM-7 is a two channel (as standard) instrument, so a second set of voltage contacts (or a second specimen) could be employed as a reference channel. References enable data normalisation of the active signal against such effects as temperature variations. Converting the signals obtained into true crack depths normally requires a prior calibration (see the Guide to ACPD for more details).

DCPD connection locations

In general, calibration of DCPD responses is more standardized in the literature (especially international standards) and there are three options that can have an effect on the configuration of connections in DCPD work. If calibration is performed post-test, then the choice of connection locations for the user is pretty "free". If calibrations are going to be transferred between specimens, then clearly the end-user needs to take care to reproduce the locations for subsequent specimens. Likewise, for numerical calibrations in which modelling has been used to predict the DCPD vs crack length response, (and can also help predict the "best" location for the current and signal connection points).

For analytical calibrations (equations developed in the literature) the locations are fixed with regard to the calibration model – so care needs to be taken in positioning contacts at all times. The calibration will often be reasonably dependent upon the location of the current connections as well as the voltage connections.

System connections - general

If a reference is employed, then this can be on the same specimen (the most common option) or two specimens (in close proximity to each other) can be employed. The latter is illustrated below for a DCPD set-up – two specimens are utilised, one acting as the test specimen and one acting as the reference specimen.

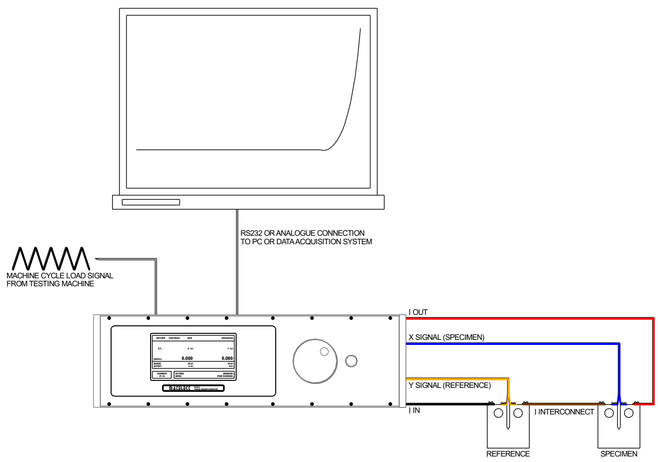


Figure 2. General schematic view of a typical EPD system set-up (DCPD in this case)

As described earlier, a reference specimen is used to counter any thermal effects that occur due to a variation in the ambient temperature. The value of the DCPD from the test specimen is normalised via a division using the DCPD value from the reference specimen. This method will only work if both the test and reference specimens are subjected to the same ambient temperature and also that any temperature variations are uniform in nature. For example, bright sunlight shining only on one side of the test or reference specimen can seriously affect the DCPD values obtained.

Matelect's DCM-2 performs a simple X/Y normalisation as standard and both displays this on the front panel graphics screen and outputs it as an analogue signal through the rear panel analogue output BNC sockets. If the optional computer control software is employed, then this output is also available in the software.

For ACPD, much the same applies, although referencing is not normally employed unless large variations in ambient temperature are expected. That said, it is often a good idea to use a reference in ACPD in order to check for thermally induced fluctuations.

Users must obey the usual sign conventions when connecting the current and signal cables to the test (and reference) specimens. The signal-high wire on the signal cable (coloured red) should always be connected to the side of the specimen nearest the red current terminal. The signal-low (black) wires should similarly be situated nearest the connection to the black current terminals. This applies to both AC and DCPD.

Users should always employ the standard cables as supplied by Matelect with their PD system. For DCPD, the current cabling is substantially thicker than for ACPD, although the signal cabling is the same. Matelect DCPD current cables contain multiple (over 600) strands of high purity copper to both reduce the in-line resistance and be exceptionally flexible (else too much strain can be placed on the connections themselves). If cables have had to be lengthened, end-users must ensure that the same types of cables are used and that the connections to the mating sockets of the relevant instruments are made correctly.

For both AC & DCPD, using cabling for the excitation current of a lower rating will quickly lead users to find that the voltage compliance (maximum drive voltage that can be applied) of the current source is reached well before it is possible to pass the maximum current. This may especially be applicable for high resistivity specimens. Long cable lengths also have the same effect – so if end-users are planning to employ long cables, then advice should be sought from Matelect.

Specimen connections - methods

In DCPD at room temperature, securing the current cables to the specimen is best accomplished using a large gauge threaded fastener, such as a machine screw, to either capture a wire underneath, or better still use a solder tag (eyelet) terminated wire.

Ensure that the contact surfaces are free from corrosion and any poorly or non-conducting surface layers, as these can also force a lower maximum current by causing the voltage compliance to be reached. It is better to use an insulating washer between the solder tag and the specimen, to ensure that the current is carried into the specimen at a precise location, and not determined by which part of the solder tag is most tightly in contact with the specimen (as this can affect the current distribution and hence generate a difference from the calibration).

The signal contacts can be made using finer screw fasteners or they can be spot-welded. Other methods such as conductive glues or soldering can be used for specialist applications.

Matelect manufacture a range of pre-wired pins that can be spot welded (strictly "stud" welded) on to test specimens, plus supply a range of spot welders based on capacitive discharge technology capable of handling these pins and of providing a fairly straightforward and reliable connection methodology (see below for further details).

If pre-wired pins are not used, stud welding can still be used, but it is necessary to connect wires to the studs (post weld) and this can be done by suing soft solder at low temperatures or hard solders up to approximately 850 DegC. Beyond this, it is better to spot weld wire (e.g. of nickel, or even platinum) directly to the specimen and this can be done in the "normal" sense of spot-welding – using a solid electrode under which a wire is trapped and then resistance welded to the specimen. Capacitive discharge welders are usually fine for this method of connection, although welders that generate a high current pulse at low voltages are better when the wire shank is in contact with the specimen rather than the wire point.

For test specimens that are to be submerged in an electrolyte (e.g. water) it is important to use fastening materials and methods that are electrochemically compatible. Corrosion of the current contacts can be especially problematic in DCPD studies but the use of pulsed current as opposed to continuous, has reduced these effects dramatically.

The figures below show a range of connection methodologies.

Figure 3 Screwed current connections (DCPD) into a CT specimen

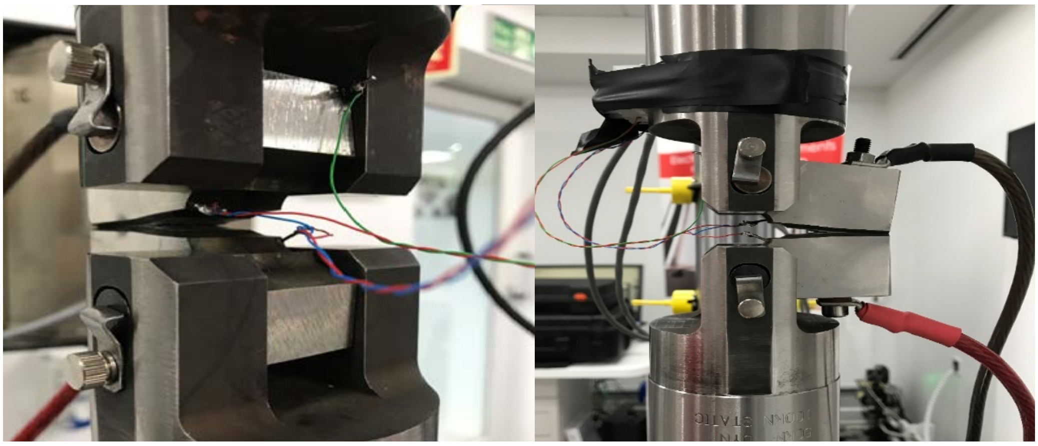


Figure 4 Pins "stud" welded to a CT specimen (includes on-specimen reference) suitable for AC or DCPD. Current connections are screwed solder tags (so DCPD). Note twisted wiring for signal wires even for DCPD use. A local connection block is used to reduce the strain on the delicate signal wires and welded pins (see later).

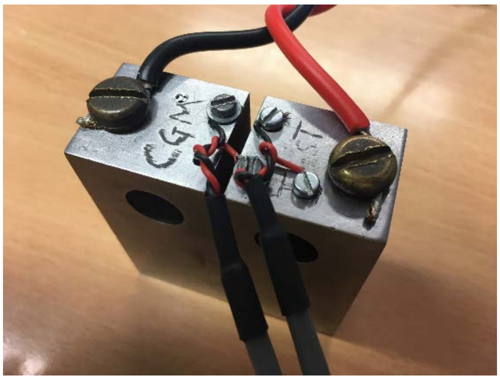


Figure 5 Fully screwed connections to a CT specimen. This is not ideal as the precise location of the voltage pick-up and current delivery is unknown and can vary between specimens, but for many configurations provides enough reproducibility to warrant consideration, and also avoids issues associated with welding.

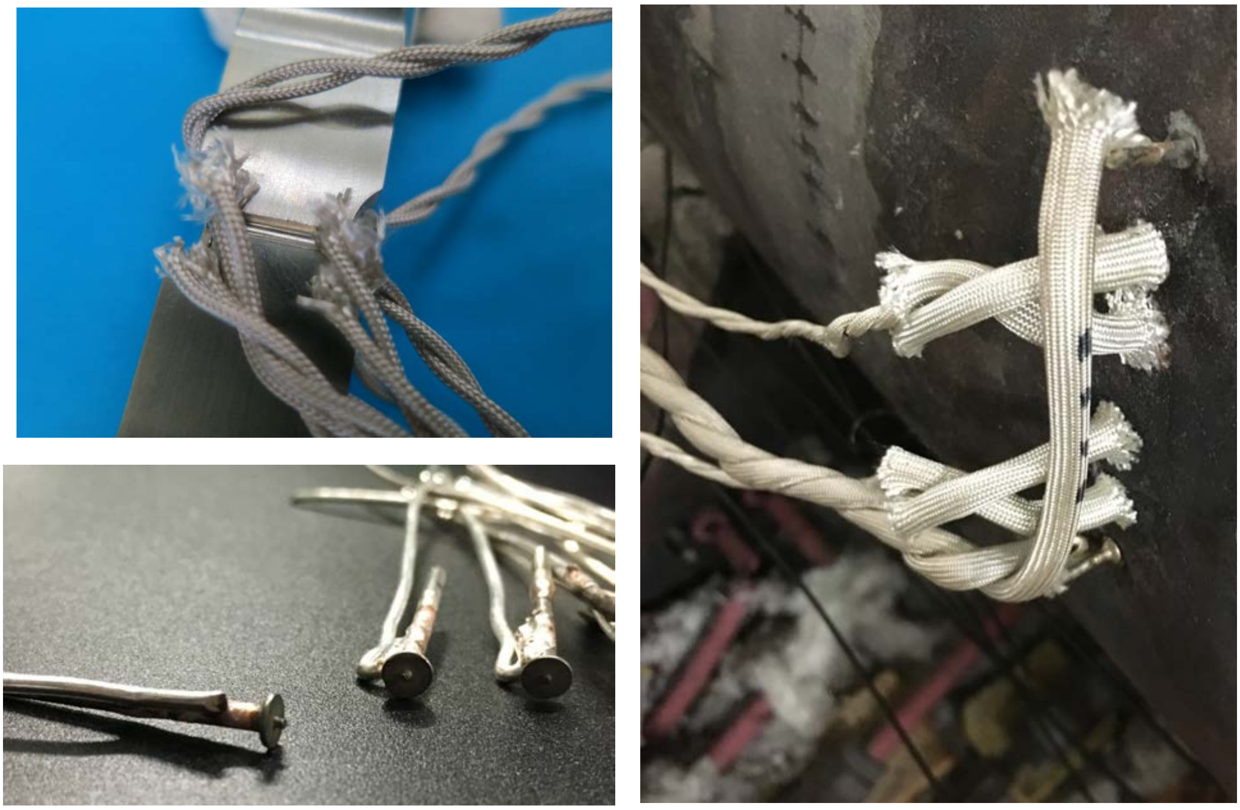


Figure 6. Connections for PD at high temperature. Top left – silica braid used to insulate platinum wire directly resistance welded to a superalloy test specimen. Two notches exist, so two sets of signal contacts (active and reference) are being used. The current is fed through the grips. RHS, a pair of signal connections across a weld in a pressure vessel (one for each HAZ). The current connections are outboard, making a total of 6 connection points. Connections are stud welded using preconnected studs "tails" comprising stainless steel shouldered studs with silver soldered silver conductors (lower left). Upper temperature is ca. 850 DegC. Note tightly twisted wiring.

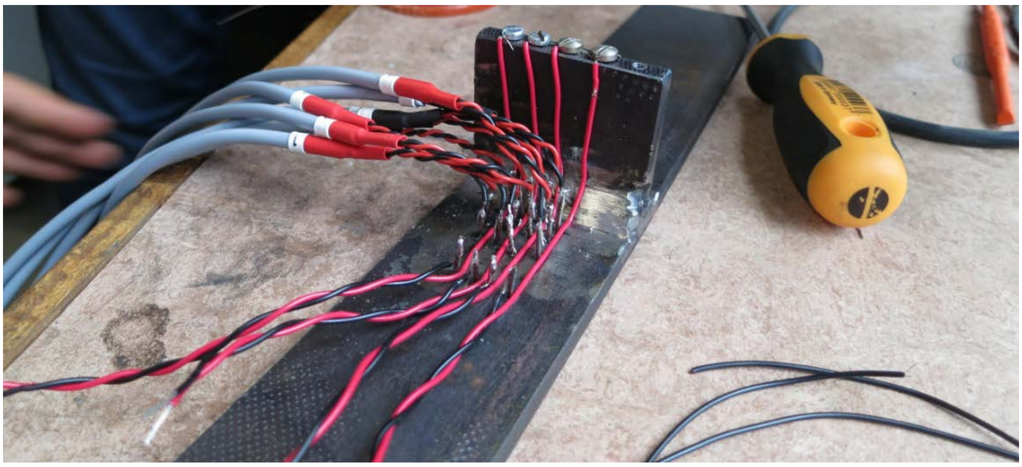


Figure 7 Multiple connections (ACPD) used to monitor crack growth along a front – in this case along a T butt weld. Two pairs of voltage connections are employed per measurement "line"- one across the weld (active) and another as the reference. Here the reference deals more with variations in current flow (due to the developing crack) rather than variations in temperature. Changes in flow path will theoretically affect both (as long as they are in line). The current supply is being fed at lower left, and at the top of the vertical T piece.

Specimen connections – other issues affecting signals

In DCPD work, thermoelectric EMF's are generated wherever dissimilar metals are in contact with each other. These can be of the same order of magnitude as the value of the actual DC signals due to the specimen resistance. Such EMF's can therefore destroy the integrity of DCPD results. Again, the use of pulsed currents has effectively eliminated the thermoelectric effects. Pulsing allows the EMF's to be measured during the current OFF period. The OFF reading is subtracted from the ON reading thus eliminating the thermoelectric EMF's. This method assumes that no temperature change occurs between the two sets of readings. This is a fair assumption unless abnormally high rates of heating or cooling are occurring. ACPD is immune from such issues.

All cables leading from the specimens to the pre-amplifier input of the PD instrument should be shielded from stray EM radiation, and as short as practicable. Remember that the voltage resolution at the specimen surface ranges from a few hundred nanovolts to a few tens of nanovolts (dependent upon gain) so any noise can seriously affect the integrity of the measurements. Noise is an issue for DCPD studies and its elimination requires signal averaging methods, which slows the data acquisition down, compared to ACPD. The latter, however, still suffers from a form of noise relating to the "pick-up" of EM radiation at the frequency of the excitation current – so again, shielding is recommended.

Unlike ACPD, DCPD specimens should ideally be electrically isolated from the test machine. A significant portion of the DC current will flow through the testing machine to earth if the parallel current path through the testing machine is of low enough resistance. Ideally the path through the specimen should be 0.1% of the resistance through the parallel current path. Damage to equipment is unlikely to occur if this rule is not adhered but the voltage readings obtained under such a situation will likely deviate from prior calibration. Additionally, any alternative current paths may not exhibit a constant resistance during a test, and this can also cause deviations from the calibration – and additional signal fluctuations (so a form of noise) – thus specimens should be electrically isolated.

In ACPD studies, isolation is not usually needed, as the current path through the specimen is nearly always significantly easier than that through the testing machine.

Most users have their own method of specimen isolation but in general, any thin strips of paper or adhesive tape can be used to insulate the specimen surface from the testing machine grips. In the case of standard CT specimens for example, the pins that permit the specimen to be stressed must also be isolated from the specimen. Conventional pins are usually machined to be a tight fit into the specimen locating holes so as to minimise "slack". Smaller pins will therefore have to be machined in order to permit insertion of an isolating layer. Some testing machine manufacturers also supply isolated grips. Remember only one side of the specimen need be isolated.

Specimen connections – peripheral wiring

In addition to the connections made at the specimen's surface, it will be necessary to route wiring to the Matelect E-PD instrumentation. All Matelect E-PD instruments are supplied with standard cables of ca. 2m length to be able to deliver the required excitation current, and collect and transmit the resultant E-PD signals. The signal wiring is normally made of shielded twisted pair, multistrand conductors, sheathed in a self-extinguishing PVC.

The current wiring for ACPD work is similarly specified, although supplied in a thicker gauge to be able to carry the excitation current.

For DCPD, the current cabling is in the form of single conductors, there and back from the specimen, sheathed in silicone, and of ca. 8AWG thickness. Each conductor is made from over 700 strands of individual copper wire, to ensure exceptional flexibility in everyday use. The large ross-sectional diameter of the DCPD current wiring is necessary for two reasons – a) to ensure as small a voltage drop across the specimen-cable-connector-DCM2 (and back) chain, as possible, and b) to ensure that the cabling can easily handle the full 50A current capability of the DCM2 without significant warming over prolonged tests.

End-users may wish to depart from some of the cabling constraints generated by the supplied cables. This might occur if the distances to the specimen have to be longer that 2 metres, or if the cabling needs to be delivered through pressure chamber feedthroughs (for example), or if the cabling has to survive extreme conditions such as within a furnace or oven.

End-users ae advised to discuss such requirements with Matelect before commencing on changes to the supplied cabling. Matelect can supply cabling to match individual needs as well as cabling to handle extreme temperatures ranging from cryogenic to 1500 DegC, but are also happy to advice end-users on an individual basis.

Sometimes, (especially with DCPD work), the large diameter current cables are unwieldly when dealing with small and/or delicate specimens. The obvious solution is to employ thinner wiring adjacent to the specimen and then transfer to standard Matelect wiring as soon as possible. This situation also applies to E-PD testing at elevated temperatures, where the conductors employed are usually single core, possibly made of silver or platinum, sheathed in glass or silica braid, and unlikely to be twisted tightly – and therefore in need of conversion to standard copper at the earliest opportunity.

If any of these situations apply, the connection to standard cabling is normally best managed using a connection block – with an array of terminals that can support and secure the input and output wiring. The connection block can be conveniently mounted as close to the specimen as practicable, and provides valuable strain-relief as well as a neat and tidy solution to the multiple wires employed in E-PD work.

Matelect manufacture a range of connection blocks, depending on the number of connections required, and on the thermal environment encountered – but the majority of situations can be handled by the DC-CP1 (for DCPD) (see below Figure 8.) or the AC-CP1 (for ACPD) (see below Figure 9).

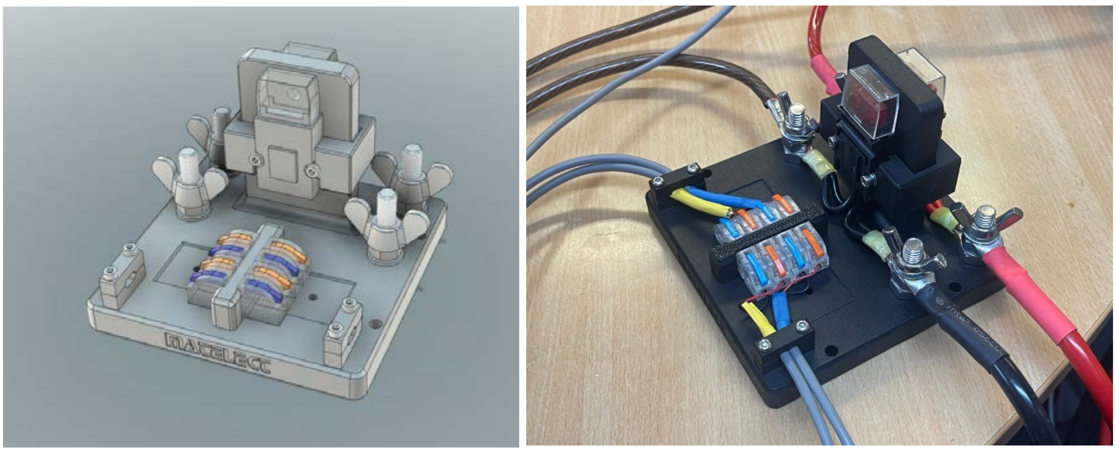


Figure 8. The DC-CP1 connection block, as supplied and wired for DCPD use

These connection blocks are simple to operate and straightforward to wire up. The Matelect supplied cables needs to be connected to one side and the end-user wiring to the opposite, however the DC-CP1 is equipped with an additional fuse holder, which needs to be fitted with an appropriate fuse. This is because whilst the Matelect supplied DCPD current supply cables are rated to operate well beyond a continuous current value of 50A, the same cannot be said of end-user cabling. Therefore, the cabling connected by the end-user, needs to be protected to not exceed its rated current carrying capacity – and the best way of achieving this is by employing a suitably sized fuse.

A range of automotive "blade" fuses are supplied with the DC-CP1. End-users need to fit the one appropriate for their wiring to avoid excessive heating in the current supply line to their specimen.

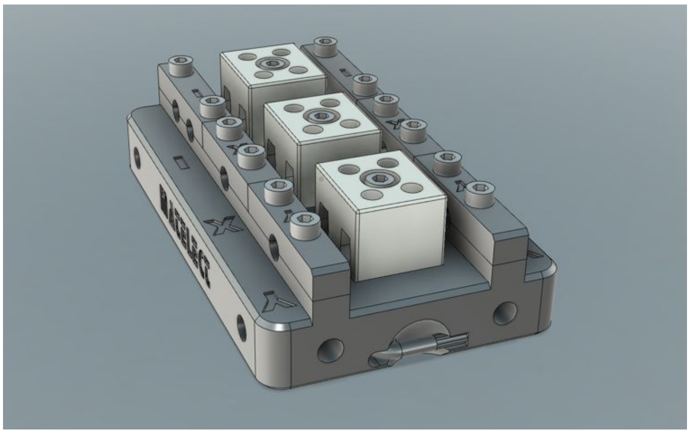


Figure 9. The AC-CP1 connection block as supplied (with high temperature terminals for Current (I) and X and Y ACPD signals

Note that the same concerns might apply to tests using ACPD instrumentation – especially if the end-user wiring (for the excitation current) is exceptionally thin. The CGM7 ACPD instrument can deliver up to 5A of current (depending on the model) – so it is theoretically possible to heat the connection wires up significantly, if they are very thin. If this is the case, then a DC-CP1 connection plate should be employed instead, and an appropriate blade fuse fitted, and the CGM-7 set to deliver a current below this rating.

Spot welding

A quick guide to using Matelect spot-welders & pre-wired pins

To assist in making spot welded connections, Matelect manufactures and supplies pre-wired pins which can be used in specially modified welding "heads" as supplied with a standard range of spot/stud welding equipment.

For heavy duty work, for example, for current connections in DCPD studies or for multiple connections in industrial contexts, a stud gun welding system is supplied (the Soyer stud welder).

For lighter duty work a smaller thermocouple welding unit (the Stork TAU) can be employed, with a Matelect "pen-head", and this will suffice for small test specimens and (in particular) signal (i.e., voltage) connections.

Matelect also manufacture a spot welder unit (the SPW-1) which can handle both current and voltage connections on the majority of laboratory specimens. This guide covers all three spot-welding units – although the instruction manual for each unit should be consulted for detailed information about a welder's operation.

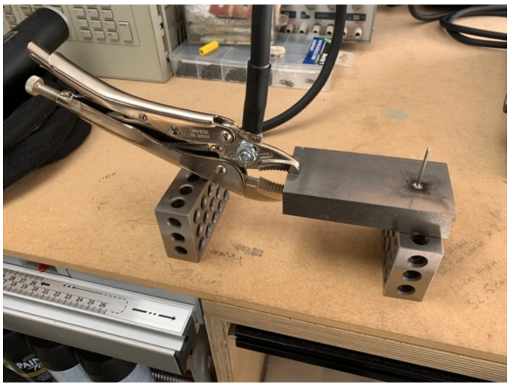
Stud welding with the Soyer unit

To use the Soyer stud welder, read and follow these general steps:

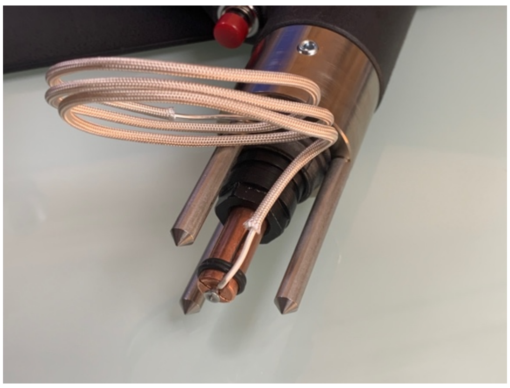
1. ENSURE! You read the entire Soyer stud welding device operating instructions manual.
2. ENSURE! You pay close attention to the Important Safety instructions in section two of the manual you read above!
3. Do wear hearing protection - welding noise can be loud and can damage hearing with prolonged use!

4. You MUST wear eye protection as the sparks from the welding procedure can fly long distances, are hot and could do generate eye damage. Ideally the protection should also include a tint so that the UV and visible emissions from any sparks do not damage eyes. If this cannot be done, the advice is to LOOK AWAY from the welding area when triggering the weld.
5. Connect the gun to the stud welding device.
6. The correct stud chuck for Matelect pre-wired pins has already been fitted and adjusted to the device. Note the widened grove, this should be used to insert the silver wire of our pre-wired pins.

7. Connect at least one but where possible both earth clamps from the stud welding device to the workpiece. Use blocks etc to ensure a solid and stable setup.



8. Clean the workpiece area to a metallically bright finish.
9. Insert a Matelect pre-wired pin into the chuck of the gun, ensuring the silver wire is positioned into the wider grove of the chuck.



10. The charging voltage of the stud welding device should be set between 50-60 on the front panel for our pins.

11. Press the gun firmly against the workpiece, ensuring even pressure on all three gun legs, the gun should now be at 90 degrees to the workpiece.
12. Push the release button of the gun, the welding will occur instantaneously. Ensure the gun is held steadily during the welding process. Remove the gun vertically from the workpiece in order to avoid damage to the chuck and prolong its work life.

In the standard issue stud welding kit supplied by Matelect, there is included a small plastic jig that allows six pins to be connected in a row, allowing for two 1.5mm current wires to be soldered at each end with four 0.5mm signal wires in between. This allows the user to create consistent and repeatable connections to a workpiece, such as a large pressure vessel.

For small specimen, such as CT, this is clearly not suitable, but an alternative could easily be designed and build by the end-user to help with consistency of connection placement.

The welding guns three legs fit firmly into the jig allowing for precise positioning each time.


Pin welding with the TAU unit

To use the Stork TAU, attach the pen-head to the Stork unit (in place of the usual pliers termination).

Follow the same procedures 1-9 as given above for the Soyer unit, paying particular attention to the safety advice. The figures below show a view of the Stork and the Matelect pen-head, then from 10 onwards:

10. Press Start on the Stork unit and then select the Manual setting (on the front panel of the Stork) and setting “2” on the power control. Offer up the pen head and inserted pin to the specimen and lightly ush down to compress the internal spring. The weld is made once the “Discharge” button is pressed. This should suffice for most specimens and stud wire of 1mm diameter.

Users can experiment if the spot welds are not sufficiently strong. This can be determined simply by applying gentle sideways pressure on the welded pin. A good spot weld is normally achieved when a strong enough arc has been struck between the pin and the specimen – causing the end of the pin and a tiny part of the specimen to liquify.

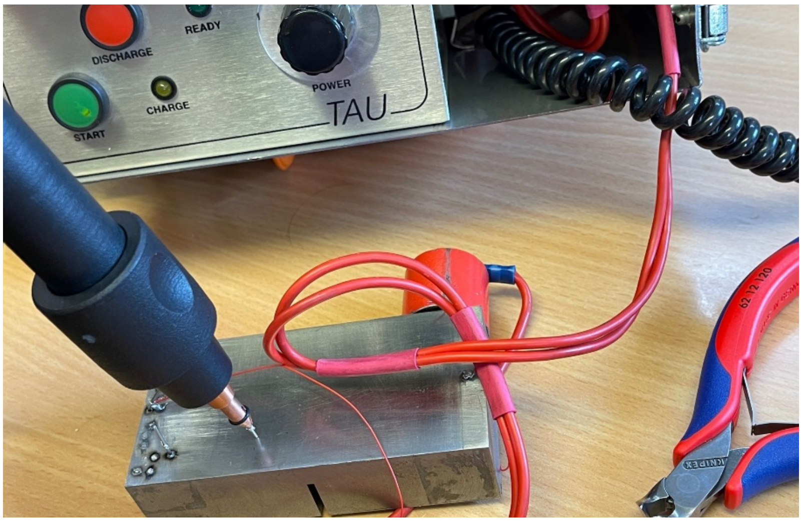


Figure 15 The Tau thermocouple welder connected to the Matelect pin welding head, with several welds already having been made, and a pin located in the weld head ready for operation of the Discharge button. Note the second electrode is in the form of a magnet. For non-magnetic specimens, the specimen can either be placed on a steel plate (assuming both are in good electrical contact) or a mechanical clamp could be used.

Figure 16. Close-up of the pin head unit for the Stork TAU welder.

If the end user applies too much pressure on the pin, then a poor weld can occur (as no arc is generated). Using a high current (low voltage) discharge resistance welder is better is such circumstances, as opposed to a capacitive discharge welder.

Using the pre-wired studs in the Matelect pen-head is the best way to achieve reliable connections, but any 1 mm wire can be used as a connection pin. Reliable stud welding is achieved if the end of the pin is sharpened – and this can be easily achieved by using a pair of side cutters to cut the wire to length – so creating a chisel point. Suitable materials include stainless steel or nickel, with nickel being marginally preferable.

A pin weld will take some side load, but will break before it bends. A good stud weld (as made with the Soyer unit) will be strong enough to allow the pin to be bent with pliers, thanks to the larger weld contact area generated by the shouldered design of the pins.

Welding with the Matelect SPW-1

Like most spot welders, the SPW-1 stores the energy required in a bank of capacitors (supercapacitors in the case of the SPW-1), however in addition to permitting the setting of a far more precise and hence reproducible energy pulse, the SPW-1 keeps the amount of energy dumped into the weld constant between subsequent welds, adjusting the pulse length automatically in real time, during the welding process - to achieve the overall set weld intensity.

The SPW-1 does this by monitoring the current (and hence energy) delivered into the weld. This recognises the fact that factors such as the resistance of the specimen, corrosion, and mechanical force applied, all affect the quality of the weld in a conventional spot welder.

Monitoring the weld current makes it easier to achieve consistent welds and reduces the chance of generating defects at the weld location in the process. The SPW-1 can also use this methodology to check the integrity of the weld that it makes, and it is equipped with an audible indication of whether the weld is of acceptably low resistance.

The SPW-1 (see below, Figure 17) can be employed to handle the vast majority of current and voltage connections to laboratory-sized specimens – but might struggle to cope with large “in-field” specimens such as pressure vessels, pipes, and structures, where an alternative spotwelding methodology based on stud welding (such as with the Soyer unit previously described).

The SPW-1 is supplied with its own instruction manual and guide, which should be consulted for more comprehensive advice on use and connection methodology.

The SPW-1 is not designed for stud (or pin-welding) and should always be used as a true spot-welder – by trapping the EPD connection wire between the welder’s principal electrode in its welding head, and the specimen surface. The SPW-1 can then be discharged using either a foot-switch or the built-in trigger in the welding head.

The secondary connection to the specimen can be made by a variety of ways depending on the specimen’s dimension, but it usually accomplished by a copper clamp, or a conductive magnetic contact (for iron-based specimens).

Figure 17. Key component parts of the Matelect SPW-1 universal spot-welder. LHS – main unit, with welding head attached. RHS – foot-switch, magnetic clamp and (inset) alternative sprung copper clamp.

Final words

Good connections are critical to good E-PD studies. A good connection is one that is able to withstand the physical rigours of the specimen being taken in and out of a testing machine, of the strain generated by the wiring (although this can be relieved by using supports and local connection/terminal blocks), and of the loads placed on the specimen due to the tests being performed. Connection methods, and materials, vary depending on whether tests are being conducted at high or low temperature, whether AC or DCPD is being employed, and whether specimens are in a lab context, or in an industrial context.

Spot welding provides the most reliable and robust of connection methodologies but also can cause issues (such as unintended fatigue crack initiation from the spot welds). Spot welding is also a skill that is not immediately learnt, and success will vary on the materials being spot welded as well. Mechanical connections are clearly less variable but not always able to be squeezed into the tightest of spaces in small specimens, or prepared in hard specimens, or in materials that are difficult to machine. Screwed connections are also less of a “point” and more of an area connection, and sometimes this can affect the sensitivity to crack initiation or growth that is achievable.

To assist the end-user in making reliable connections, Matelect is happy to offer free advice and support over the entire life of its products. In particular, we are always happy to hear from end-users who have very specific connection “issues’ that are critical to the successful deployment of E-PD in contexts ranging from lab testing to industrial in-field use and long-term continuous monitoring, where our significant experience can often make the difference that is needed to ensure testing success. Please use the details below to make contact.

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