Paper No.

08006

12th Middle East Corrosion Conference & Exhibition

Ensuring the Integrity of Critical Pipe-to-Cathodic Protection System Connections

Chris Googan
Anticorrosion Engineering Limited
Shrewsbury, England
E-mail: chris@anticorr.com

Glenn Symington
BAC Corrosion Control Limited
Telford, England
Fax: +44 1952 290325
E-mail: glenn.symington@bacgroup.com

ABSTRACT

Achieving cathodic protection (CP) on buried or immersed pipelines requires the connection of copper conductors to carbon steel. Connections are needed both for the primary current drain cables; and for the various test leads and bonds that enable the CP system to be monitored and managed. These connections are all too often made in less than ideal conditions (in the field or offshore), and with the urgency needed to keep pace with the pipeline installation schedule. Moreover, once made, they will be permanently out of sight; yet must remain intact throughout the entire life of the pipeline. This paper recaps the history of the available cable connection techniques in common use: thermite welding, pin brazing and conducting adhesives; and compares their relative merits. The comparison assesses their practicability, including health and safety, cost and the reliability of the resulting connections. In addition, the effects of the thermal processes on the metallurgical condition of the pipe wall are reviewed in the light of micro-hardness measurements. The metallurgical implications of using thermal connection techniques on high strength (>700 MPa) thin walled lines, of the type currently under review for future projects, are considered.

1. INTRODUCTION

The cathodic protection (CP) of buried or immersed equipment involves the application of tried and trusted electrochemical principles. This electrochemistry is implemented, monitored and controlled by means of electrical circuitry, the design of which is rarely complex. CP circuits resemble any other electrical application, in that a break at a connection negates the intended function. However, CP circuits differ from most other applications in that many of the vital electrical connections are out-of-sight for the life of the system.

As a matter of experience, the greatest threat to electrical integrity derives from the positive (anode) side connections in impressed current systems. Of particular concern are the connections made in the field, particularly the anode groundbed current feeds. Where these are buried or immersed, any defect in the insulation is likely to result in very rapid electrolytic dissolution of the exposed conductor, and a break in the circuit. It is little surprise, therefore, that the anode feeder cables and connections receive most attention in CP design and installation practice.

However, it is worth remarking that the positive side connections, made in the field, benefit from being copper-to-copper mechanical joints, made using industry standard splicing kits.

By contrast, the connections to the pipeline or structure receive less attention. This is not unreasonable. As they are in the cathodic part of the circuit they are expected to be fully protected against corrosion.

Nevertheless, the importance of the cathode-side connections should not be overlooked in any CP project. Typically, there are more of them. In addition to the impressed current CP (ICCP) current drain point connections, there will be a requirement to attach test leads, sacrificial anodes (direct, or via test posts) and bonding connections (direct or resistive). There will also be an occasional requirement for non-buried connections, e.g., for attaching polarization cells. In all of these cases, there is the intrinsic difficulty of connecting a copper conductor to a cathode which is usually carbon steel.

Although the cathode-side connections are protected (providing, of course, that the CP system is functioning correctly), they remain prone to mechanical damage; particularly as a result of ground movement and soil stresses. There is also at least one report[1] of poorly insulated cathode connections failing due to local galvanic attack where CP systems have temporarily been inoperative. In these cases, any bare copper wire can promote pitting of exposed steel.

In onshore ICCP systems, a resistive or open-circuit connection in the main current supply should become apparent very quickly. Rectification is relatively straightforward; and should be carried out promptly. By contrast, where ancillary connections (e.g., test posts, sacrificial anodes, bonding cables) fail, the problem can go unnoticed for a considerable time.

Breaks in CP circuits are not newsworthy, so there are no data regarding the reliability of connections. However, anecdotal evidence suggests that failures of ancillary cathode-side connections are not uncommon; particularly in older CP installations. For example, there has been more than one close interval potential survey (CIPS) contractor who, on downloading the data obtained during a hard day in the field, has been dismayed to observe nothing but the confused potential response of a broken copper cable.

Cable-to-cathode connections are no less important in offshore situations. Here, CP is invariably provided by sacrificial anodes. It could be argued that there is a tolerance to the frailty of cable connections inbuilt into the design codes. For example, DNV RP F103[2] suggests that, when carrying out bracelet anode spacing calculations for a subsea pipeline, *the loss of an anode is taken into account*. However, despite any comfort we may take from the conservatism of the codes, the loss of a connection on an offshore system is likely to go undetected for a considerable time; and will be disproportionately expensive to repair.

It is, therefore, timely to review the methods of connecting copper conductors to carbon and alloy steel cathodes.

2. CONNECTION METHODS

2.1 Mechanical Connections

Mechanical connections can be made where the opportunities arise. Typically, this might involve fitting a cable lug to a flange bolt on an above-ground installation. Providing, any paint coating is locally removed, and the contact area is thoroughly cleaned, there is no reason why a serviceable connection cannot be achieved. It is essential that any such connection must be remade properly if the flange is separated for maintenance work. Regrettably, such details are occasionally over-looked.

Generally speaking, however, permanently bonded connections are preferred. For example, BS 7361[3] tells us that *welded, brazed, soft soldered, conductive adhesive or thermit welding are preferable to bolted or clamp type connections*. Moreover, there are usually no options for making mechanical connections to welded pipelines. Here the requirement is for a bonded connection that provides an intimate, low resistance, contact between the steel and the cable.

2.2 Conventional Welding

In many ICCP pipeline projects, the main cathode drain point connection is made by welding a doubler plate, complete with a stud, to the pipeline[4]. The CP negative feed cable is then attached to the stud. However, the installation of fully welded doubler plates rarely extends beyond the drain point connections. They are not normally used for the connection of test post cables, bonds or sacrificial anodes.

2.3 Thermite Welding

The thermite process, which is also known as an alumino-thermic reaction, takes place when an intimate mixture of aluminium powder and iron III oxide is ignited. The resulting reaction:

$$2Al + Fe_2O_3 \rightarrow Al_2O_3 + 2\,Fe$$

is vigorously exothermic. It generates temperatures well in excess of 2000ºC, and enough heat to produce iron in the molten form.

The process was developed in 1893 by Hans Goldschmidt. His original aim was to produce a small sample of high purity iron; but he quickly appreciated the wider applicability of the process. In particular, he demonstrated that it could be used to join steel rails in-situ on the Essen tram system. Goldschmidt called his welding compound Thermit®, since which time the two spellings, *thermite* and *thermit*, seem to have become used inter-changeably in the CP literature.

The adaptation of the process to welding copper cables to steel came about in the 1930's. The need for this emerged in the railway industry, where electrical continuity along the rails was needed for the conduction of both electrical power and electrical signals. At the time, the established method of joining lengths of rail was to use bolted fishplates. These contained crevices which acted as moisture traps, leading to rusting and increases in electrical resistance. The problem was addressed by Charles Cadwell, a physicist working for the Electric Rail Improvement Company (ERICO) in Ohio. He adapted the thermite process to produce a procedure for attaching electrical bonds to rails. Unsurprisingly, he coined the term Cadweld® for the process.

The introduction of the thermite welding process into the area of CP seems to have been such an obvious step that we have found no documented record of the event. However, given that CP of welded steel pipelines was becoming well established in the US around the time Cadwell was developing his process, the technology probably transferred across relatively quickly.

The procedure for making a thermite weld connection to a pipeline has changed little since the technique was first introduced.

1. An area on the top of the pipe is abraded to remove any coating or scale
2. The copper conductor is laid on the abraded pipe and a graphite mould placed over the cable end.

3. The thermite powder cartridge is placed in the upper part of the mould.
4. The powder is ignited and the strongly exothermic reaction takes place. This produces molten iron which flows down through the mould and envelops the cable end, welding it to the pipe.
5. The mould is then removed and the quality of the connection tested with a hammer blow.

Igniting the thermite charge (step 4) requires a temperature of about 1300ºC. There are a number of options for this. Although this temperature can be attained with a propane torch, it is more usual to use either a strip of magnesium or a pyrotechnic mixture as the initiator.

2.4 Soldering and Brazing

Whereas the temperatures involved in welding are high enough to melt steel, soldering and brazing use alloys that melt below the melting point of the metals being joined. The term soldering is usually restricted to the use of joining alloys (or solders) that melt at below 425ºC. The most commonly used solders are the lead-tin alloys with melting points in the range 160°C to 300ºC. These are sometimes referred to as *soft* solders. The joints are acceptable providing there is no requirement for mechanical strength.

Soft soldering is a standard method for joining copper to copper. In principle the technique can also be used for joining other metals. In all cases, it is vital that the surfaces being joined are exceptionally clean so that they are effectively wetted by the molten solder. Any oxide present on the surface needs to be removed. This is achieved by a combination of abrasion and the use of chemical compounds (fluxes). Achieving reliable connections between copper and steel using soft soldering is difficult. So, although it is referred to in some standards, it is rarely employed in practice. Soft soldering is even more problematic when it comes to making connections to stainless steel because its oxide film is much more strongly adherent.

Brazing, which is sometimes referred to as *hard* soldering, uses a higher melting point (>425ºC) filler metal to achieve the bond. For joining copper to steel it is usual to select one of the range of silver based brazes specified in AWS A5.8[7]. These have melting points in the range 620-970ºC.

The dominant form of brazing used for achieving CP connections is *pin brazing*. Like thermite welding, this technique was originally developed for the rail industry. By the early 1950's the thermite process was in common use world-wide. However, work in Sweden raised a concern that the high temperatures involved in attaching bonding cables by this technique led to grain growth in the copper conductor. This made the copper brittle such that bonds were prone to fail due to the fatigue induced by the small relative movements between the rails as trains passed. A lower temperature connection method was sought. The result was pin brazing[5,6].

The pin brazing technique has been refined, but not fundamentally altered, over the half century or so since its introduction. There are two variations of the technique. The copper cable can be directly bonded to the pipe, as is the case with thermite welding. Alternatively, a threaded stud can be brazed to the pipe; and the cable lug then fixed in place with a nut. This is a feature that is not available when thermite welding.

The key to the pin brazing process is the pre-assembled welding pin and the gun. The pin (Figure 1) consists of a stud in which a quantity of flux is encapsulated in the selected brazing alloy. The gun is illustrated in Figure 2. It comprises a spring loaded holder for the pin. When the trigger is pressed, current flows through the pistol via the pin to the steel pipe. At the same time the electromagnet is energized. This draws the pin holder and pin away from the steel surface forming an electric arc.

The arc heats the steel and starts to melt the tip of the pin. This causes the flux to melt and flow onto the steel, dissolving the oxides.

The current flow is terminated by one of two methods. In some equipment a pre-set timer is used. Alternatively, the tail of the pin acts as a fuse which melts when the brazing alloy is at the correct temperature. When the current flow ceases, the electromagnet de-energizes and the spring forces the molten stud onto the fluxed pipe surface. With the arcing stopped, solidification is very rapid.

The pin brazing process is illustrated in Figure 3.

1. An area of the pipe is abraded to remove any coating or scale. Unlike thermite welding, however, it is not mandatory to make the connection at the 12 o'clock position on the pipe.
2. The pin and a ceramic ferrule, used to contain the arc and the molten brazing material, are fitted into the brazing gun, and the gun connected to the power supply.
3. The earth lead from the power supply is connected to the pipe using a magnetic contact.
4. The gun is placed on the pipe and the trigger pressed. The brazing process then takes place automatically. The arc time will be no more than a couple of seconds.
5. The gun is removed and a hammer blow used to remove the discarded ferrule and to confirm the quality of the connection.

2.5 Conductive Adhesives

In this application, a threaded stud is fixed to a small plate (by welding or brazing). The plate is then attached to the pipeline using a proprietary conductive adhesive; taking care to achieve a high degree of cleanliness on the mating surfaces. Typically, these adhesives use epoxy resins formulated with a high loading of a conducting pigment; such as graphite, copper or silver. When the adhesive sets, the pigment particles form the connecting pathway between the pipe and the plate.

Conductive adhesives are used only on a very small proportion of cable to cathode connections. Their use is invariably restricted to hazardous areas where hot work would not be permitted. They can only be relied upon for connections for potential measurement; not for conducting current.

3. LITERATURE

There is no shortage of published information on the art of cathodic protection. However, the crucial issue of making electrical connections between the copper conductors and the ferrous alloy cathodes seems generally to have received scant attention. Arguably the three most consulted reference works are those of Peabody[8], Morgan[9] and von Baekmann & Schwenk[10]. However, none of these texts evaluates the relative merits of the connection techniques. Peabody's book describes the thermite welding process in connection with the attachment of magnesium sacrificial anodes; and gives a passing reference to brazed or soldered connections. It also tells us that exothermic welding is "usually" used for the attachment of test leads. However, the book contains no definitive assessment of the connection options in impressed current systems. Neither Morgan nor von Baekmann & Schwenk are any more illuminating on this point.

In addition to the established reference works, CP is governed by a suite of internationally recognized standards[2-4 ,11-24]. Some of the earliest CP standards still in current use were developed by NACE. This is not surprising. The origins of the organization can be traced back to the Mid-Continent Cathodic Protection Association which was formed in 1936. Moreover, as mentioned above, the development of

CP on welded pipelines followed shortly after the development of exothermic welding for railway systems. It is, therefore, not surprising that this became the established practice for joining copper cables to steel. For example, section 4.5.3 of NACE RP0169[11] discusses the attachment of test leads by thermite welding or soldering, but makes no reference to brazing techniques. Similarly, neither of the standards first issued in the mid-1980s, RP0186[12] (for well casings) or RP0285[13] (for underground tanks) refer to brazing. The standard for the CP of rebar (RP0290)[15] does not refer to cable connection techniques. However, the more recent RP0100[14] code for pre-stressed concrete cylinder pipe does make reference to brazing for bonding the pipe sections.

Other relevant standards emanating from the US include ASME B31.8[16] and B31.4[17] and the military CP maintenance standard[26]. Each refers to thermite welding, but none mentions brazing.

European standards are also non-prescriptive when it comes to cable connection techniques. Some present pin brazing as a viable alternative to thermite welding. Moreover, the European standards generally place a greater emphasis on the importance of cable to structure connections. DNV RP-B401[18] (for fixed offshore structures) stresses that the mechanical integrity of anode fastenings must be included in the CP detailed design report. It also advises that welding or brazing should not be applied to equipment under pressure. Although it does not discus the relative merits of cable connection techniques, it points out that thermite welding should not be used for corrosion resistant alloys. Pin brazing or soft soldering are recommended as suitable alternatives. DNV RP F103 (for offshore pipelines) likewise offers no advice on selecting between connection methods; for which it states that thermite welding or brazing are acceptable. This standard does states that the thermal process must not cause the hardness in the heat affected zone to exceed 300 HV for a ferritic or martensitic steel, or 350 HV for a ferritic-austenitic (duplex) stainless steel.

The advice in PR B401 not to use thermite welding on corrosion resistant alloys is also given in ISO 15589 Part 1 (on-land pipelines)[19] and Part 2 (offshore pipelines)[20]. Part 1 qualifies the use of thermite welding on carbon steel by advising that …*the welding procedure shall ensure that any copper penetration into the metal is less than 1 mm and that the local pipeline hardness remains within the specification.*

In contrast to DNV RP B401, which prohibits welding to equipment that is under pressure, ISO 15589-1 permits thermite welding on live pipelines providing a safety procedure is developed beforehand. This procedure is required to cover:

- testing the pipe wall integrity prior to welding
- heat transfer, and dissipation, by the fluid, and
- the effect (if any) the welding will have on the fluid.

4. EVALUATION

Given that conductive adhesive has such a limited application, the only techniques that warrant comparison are thermite welding and pin brazing.

4.1 Health, Safety and Environment

Both thermite welding and pin brazing are safe procedures when performed by properly trained operators using the appropriate personal protective equipment and following the correct procedures. Similarly, neither poses a threat to the environment. However, it should be noted that thermite welding imposes the requirement to provide secure storage for the stocks of thermite powder.

Thermite welding is regarded as inherently the more hazardous of the two. It involves a pyrotechnic reaction which, once initiated, cannot be controlled. It is not suitable for those of a nervous disposition. This is in contrast to pin brazing, which possesses an “off” switch. Nevertheless, we have found no data to support any assertion that one technique is more hazardous than the other.

It should be noted, however, that the thermite welding process is more sensitive to moisture than pin brazing. Any water that might be accidentally present on the pipe or the internal surface of the mould would vaporize on contact with the molten iron. This could give rise to the potentially dangerous situation of molten iron being spat out of the mould. Thus, for applications in damp environments, particularly offshore, pin brazing is obviously preferred.

4.2 Reliability

As noted, failures of CP connections are not generally reported; so it is not possible to offer a statistical analysis of the relative reliability of the two techniques. It is perhaps sufficient to note that both are widely accepted in the industry, with track records of over 70 years (thermite welding) and over 50 years (pin brazing).

Tensile load tests have been carried out on 16 mm^2 cable connections made by pin brazing and thermite welding. The thermite welded connection failed at the copper cable’s heat affected zone at a load of 163 kg. The pin brazed connection took a higher applied load; parting at 227 kg. In that instance the failure occurred at the crimped connection. Thus, on a limited sample, pin brazing was found to produce the stronger bond. However, in both cases the loads at failure were beyond those anticipated in normal service. Providing the correct procedures are followed, both techniques will provide mechanically satisfactory, low resistance connections.

4.3 Cost

Figure **4** provides an illustrative price guide. The thermite welding process is the cheaper option in terms of equipment and consumables. Where the requirement is for only a small number of connections, the capital outlay on the pin brazing equipment has a noticeable impact on the price per connection. However, where the capital outlay on the equipment is spread across a progressively larger number of brazes, the impact on unit cost reduces. If there is a requirement for more than a couple of connections per week then the cost difference reduces to about $15 per connection.

For either technique, the cost of the equipment and consumables will invariably be trivial compared to the cost of mobilizing the work crew to the site; and supporting them while they are there. Moreover, the cost of making the cathode-to-cable connections is only a small portion of the overall cost of an installed CP system. This, in turn, is only a tiny fraction of the value of the installation it protects.

4.4 Practicality

In onshore applications there are some minor differences between the two in terms of practicality. Because of the need to use a battery power source the pin brazing equipment is heavier than the thermite welding equipment. On the other hand, thermite welding is limited to applications on horizontal surfaces. This is not a problem when dealing with a pipeline in a trench; but it can be inconvenient when connections are required at above ground installations. Thermite welding is also subject to the weather conditions. As noted above, it is unsafe in a wet environment. Windy conditions also present problems when it comes to transferring the powder to the mould. Pin brazing on the other hand is not usually disrupted by wind or rain.

Another practical advantage of pin brazing is its ability to attach a threaded stud. This offers the advantage of allowing temporary disconnection of cables for test purposes. This is an invaluable option for the CP specialist when setting up, monitoring or trouble-shooting complex ICCP systems.

For offshore applications the convenience of pin brazing makes it the method of choice for integrating into pipe laying operations. It makes rapid and reliable connections between sacrificial anodes and the pipe, and between anodes and piggy-backed lines; without impacting on the flow of the laying operation. Moreover, the availability of electrical power from the welding sets on a pipe lay vessel removes the inconvenience of having to use batteries.

4.5 Speed

For a single connection, under ideal conditions, there is little practical difference between the time needed for pin brazing or thermite welding. The duration of either operation is only a small part of the overall time needed to set-up, make the bond, reinstate the coating and clear away.

However, differences do emerge when many connections are required, or where conditions are less than ideal. As noted above, this makes pin brazing the widely preferred option for pipe laying operations offshore.

Pin brazing can also benefit onshore projects. This is illustrated by a recent AC mitigation exercise carried out on a major gas pipeline in North America. The project required the attachment of two AWG#2 cables in each of over 350 bell holes. The schedule was originally based on using thermite welding. However, upon review, this was changed to pin brazing. This brought the major advantage that progress was not unduly hampered by inclement weather or by the need for thorough drying of the work areas. The reduction in down-time produced by the switch to pin brazing was a significant factor in the project being completed two months ahead of schedule.

4.6 Metallurgical Effects

Any thermal process carried out on a pipeline steel will affect the metallurgical condition to a greater or lesser extent. It is therefore, not surprising that codes urge caution when employing such techniques. For example, both parts of BS 8010[4,21] advise that the pipeline design should take into account… *changes to the metallurgy of the parent metal due to localized heating during the attachment process*. In this context, there are two metallurgical effects that need to be considered: microhardness and copper penetration.

Microhardness

The primary concern is whether the welding or brazing increases the hardness of the pipeline steel. For example, Annex B of BS 4515[25] deals with brazing and thermite welding of CP leads. It recommends a procedure qualification in which a specimen joint is sectioned and hardness measurements made in the heat affected zone (HAZ) and the parent plate. This is illustrated in Figure 5 which, it must be noted, intentionally exaggerates the depth of the fusion line. Compare the diagram with the section of a pin brazed joint shown in Figure 6.

BS 4515 advises that the hardness should not exceed 300 HV10 (275 HV10 for wall thickness < 9.5 mm) for sour service, or 325 HV for non-sour. However, in respect of sour service, the hardness limits given in Table A.1 of ISO 15156[27] are more stringent. Although this document does not deal with welded connections, its advice in respect of the HAZ adjacent to the cap of a pipeline butt weld is relevant. The maximum permitted hardness is 250 HV, unless certain conditions are met. Only then is the hardness limit permitted to be increased to 275 HV. Those conditions are:

- the parent plate must be > 9 mm thick, and
- the weld cap must not be exposed to the sour environment, and
- the escape of hydrogen is not impeded, e.g., by cathodic protection.

Table 1 summarises the results of hardness tests carried out on 6 mm thick samples of HS-80 (similar to API 5L X80) grade carbon steel to which 16 mm^2 cable had been joined by pin brazing and thermite welding.

Table 1 – Effect of Brazing and Thermite Welding on HAZ Microhardness

Location	**Readings**	**Microhardness HV5**	
		Pin Brazing	**Thermite Welding (15 g charge)**
Parent Plate	6	209 (mean)	209 (mean)
HAZ	4	302 (mean)	294 (mean)
		318 (max.)	322 (max.)

Based on these measurements, neither pin brazing nor thermite welding is acceptable on thin walled API 5l X80 pipelines designated for H_2S-containing (i.e., sour) service. According to BS 4515 both are acceptable for non-sour service. Moreover, both are acceptable for offshore use according to DNV RP B401[18] which sets an upper limit of 350 HV for carbon steel; but not necessarily according to DNV RP F103 which sets a limit of 300 HV.

In viewing the data in Table 1 it needs to be appreciated that the measured hardness result is influenced by a large number of factors. This is illustrated for pin brazing in Figure 7, which is a scatter diagram of the results collated from various pin brazing qualification tests. The individual results are not readily comparable, because they relate to different steel grades (API 5L X52 and X65), the attachment of studs and lugs, and different cable sizes. Nevertheless, the data exhibit the following features.

- Hardness values increase the closer the measurement is to the fusion line
- Values above 350 HV are all within 0.5 mm of the fusion line, and predominantly within 0.15 mm.
- Within the range of materials studied, there is no obvious correlation between the hardness in the HAZ and hardness of the parent plate.
- Different brazing configurations produce different hardness values.

The last point indicates that, with pin brazing, that there is an opportunity to derive a procedure that will keep the HAZ within the 275 HV limit required by ISO 15156, should it be required. This is unlikely to be the case for thermite welding because the thermal effects for any given charge size are essentially uncontrollable.

The practical relevance of the hardness of the HAZ is a moot point; and it can reasonably be argued that the rigid application of ISO 15156, or even the more relaxed requirement of DNV RP B401, to cable connections is unduly conservative.

ISO 15156 is predominantly concerned with sulphide stress cracking (SSC). This is a complex phenomenon that can occur in wet hydrocarbon streams containing even small levels of H_2S. It is a matter of both experiment and experience that the risk can be eliminated by controlling of the hardness of the pipeline steel. In this respect, the limit of 250 HV for the parent plate, and the roots of butt welds, is appropriate. It is, however, questionable that the limit should be applied to the caps of the butt welds, which do not contact the H_2S. It is also debateable whether the limit for butt weld cap hardness should also be imposed on a thermite welded or brazed cable connection.

On the other hand, the 350 and 300 HV limits set by DNV RP B401 and F103 seek to mitigate the risk of hydrogen embrittlement (HE), where the source hydrogen derives from the action of the CP. Clearly, these limits are directly relevant to CP cable connections.

Nevertheless, even where a combination of metallurgical and environmental circumstances favours either SSC or HE, failure would still require a tensile stress. Since cable connections ought not to be highly stressed, the probability of failure must be regarded as low. Moreover, even if failure were to occur, it would be in the high hardness plane of the HAZ. That is parallel with, and very close to, the outer pipe wall. Such a failure would not compromise the mechanical integrity of any pipeline built and operated according to recognized codes. Failure of the connection would, of course, be detrimental to the CP system; so it remains important to exercise control over the pin brazing process.

Furthermore, any future move towards higher strength, thinner walled pipeline materials should be accompanied by further evaluation of the metallurgical effects of pin brazing and thermite welding. A case in point is the current evaluation of pipeline steels with yield strengths of > 700 MPa. At the very least, qualification testing as prescribed in BS 4515 should be carried out.

Copper Penetration

Under certain circumstances, molten copper can penetrate the grain boundaries of carbon steel causing embrittlement. For this reason codes such as ISO 15589[19,20] require that, where thermite welding is used, the welding procedure ensure that copper does not penetrate more than 1 mm into the pipeline steel. This is not an issue for pin brazing. Tests carried out in the mid-1980's revealed a maximum copper penetration of 0.02 mm.

4.7 Effects on Internal Coatings/Fluids

As noted, ISO 15589-1 requires consideration of the effect of external welding on the internal fluid. In addition, where a line is internally coated, it is reasonable to question whether or not there is the potential for thermite welding or pin brazing to cause any damage to this coating. Tests have been carried out on uncoated samples of API 5L grade B pipe to investigate this issue. The internal wall temperature was measured using a digital readout thermocouple during both thermite welding and pin brazing. The results are given in Table 2.

The times taken to reach the peak temperature were 12-13s in the case of the pin brazing and 13-15s for the thermite welding. Unsurprisingly, the results show that thermite welding causes more heating of the internal pipe wall; raising the temperature by up to 81°C compared to no more than 32°C for pin brazing. However, neither set of results gives any cause for concern. For pipes with wall thicknesses of 7 mm and above there would be no reason to anticipate any damage to either a contained fluid or a polyethylene or fusion bonded epoxy lining. In this respect the advice in DNV RP B401 not to weld to a live line is conservative in respect of both pin brazing and thermite welding.

Table 2 – Effect of Brazing and Thermite Welding on Internal Pipe Temperature

Pipe Wall Thickness (mm)	Internal Pipe Wall Temperature (^oC)		Connection Type
	Start	Peak	
Pin Brazing			
8.2	26	58	Cable
8.2	26	47	
7.1	25	55	
8.2	25	45	M8 Stud
7.1	26	50	
7.1	26	54	
Thermite Welding			
8.2	26	107	Cable
8.2	26	102	
8.2	26	90	
7.1	26	103	

5. CONCLUSIONS

The two established methods of making a metallurgical bond between a copper cable and a steel pipeline or structure are thermite welding and pin brazing. Both techniques originated in the railway industry, and each has a successful track record spanning many decades. Generally speaking, the CP literature does not communicate any strong preference for one technique over the other. Standards emanating from North America tend to reflect the traditional use of thermite welding; those developed in Europe are more likely to lean towards pin brazing.

Properly used, both techniques provide satisfactory joints. For most organizations, the choice between the two probably owes more to established practice than the results of a technical evaluation.

Thermite welding has the advantage that it is less expensive, and the equipment is lighter, than pin brazing. However, its use is weather dependent. It is difficult on windy days, and unsafe and unreliable when it is wet. Moreover, some standards prohibit its use on corrosion resistant alloys.

Pin brazing has a number of advantages over thermite welding. It is not restricted to use on horizontal surfaces. It is tolerant of moist environments and not sensitive to the wind conditions. This makes it the preferred option for offshore use. Pin brazing is also a more controllable, lower temperature process than thermite welding. Thus, there are measurable differences in that pin brazing causes less embrittlement of the copper conductor; less heating of the inner wall of the pipe and a less pronounced heat affected zone. Although these differences are of little practical significance in relation to fixing CP cables to carbon steel pipelines, they may be significant in any proposed future applications to high strength, thin walled lines.

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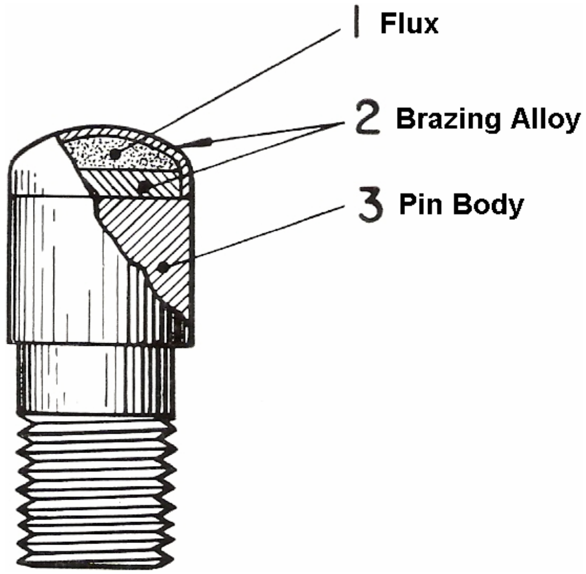
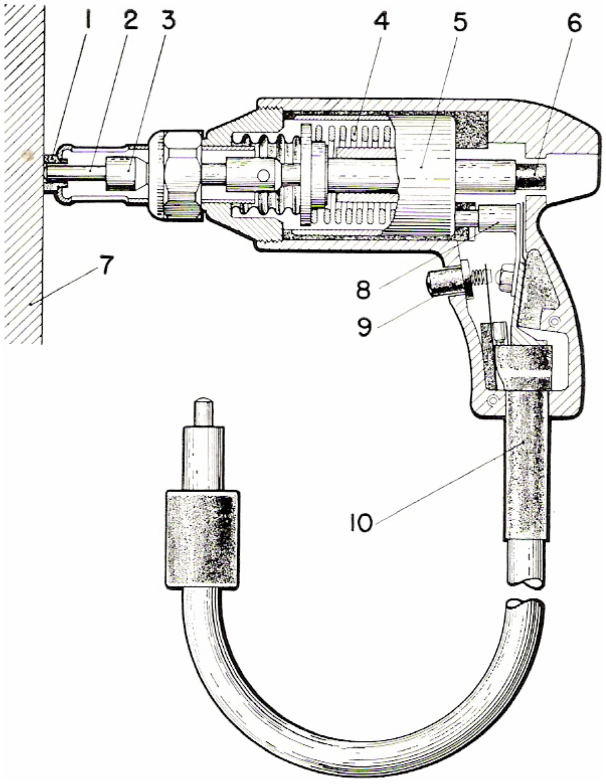


Figure 1 – Pin Brazing Stud (Schematic) (Ref. 6)



1	Porcelain ferrule
2	Pin
3	Brace
4	Solenoid and spring
5	Electromagnet
6	Mark for adjusting lift holder
7	Steel pipe or structure
8	Current conductor
9	Trigger
10	Current cable

Figure 2 – Pin Brazing Gun (Ref. 6)

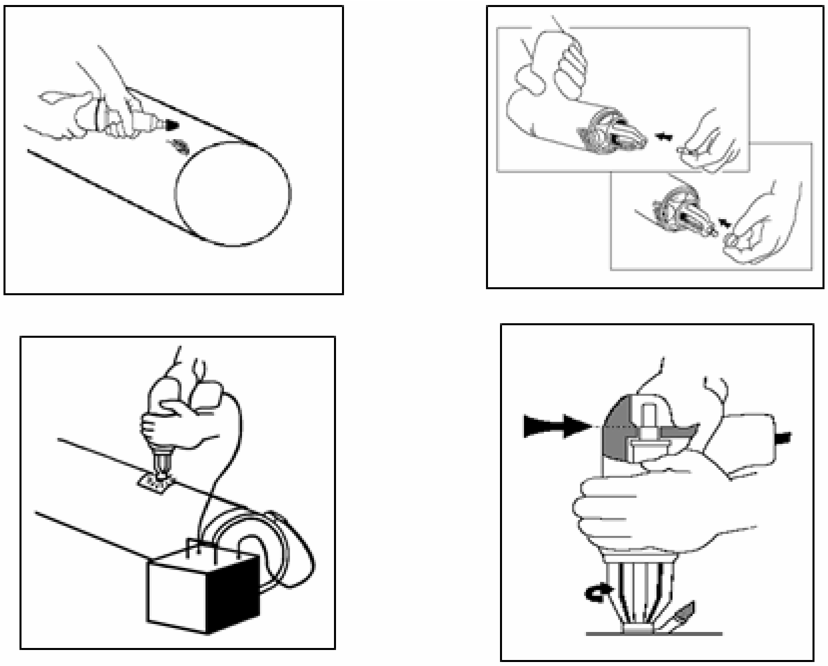


Figure 3 – Pin Brazing Process

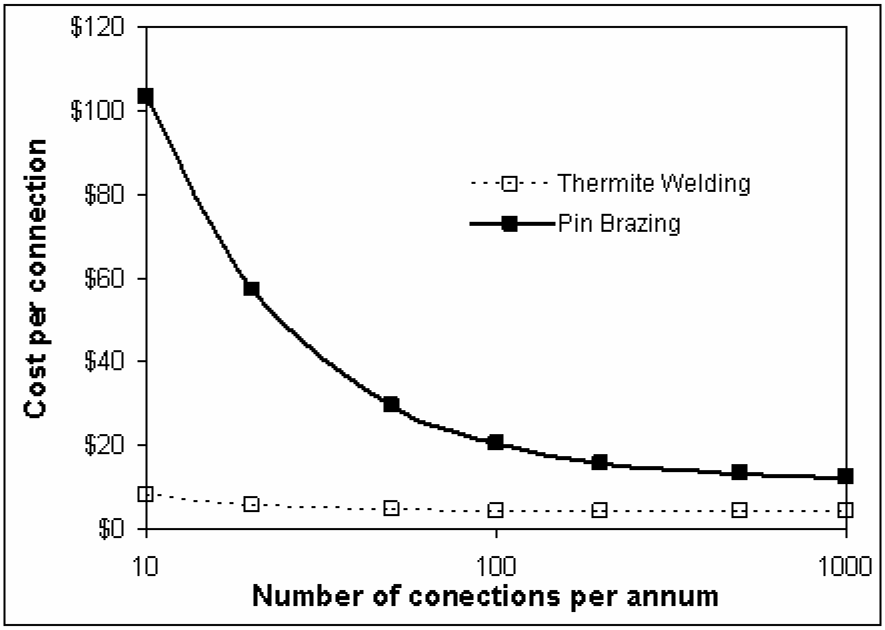


Figure 4 – Price Comparison: Pin Brazing and Thermite Welding

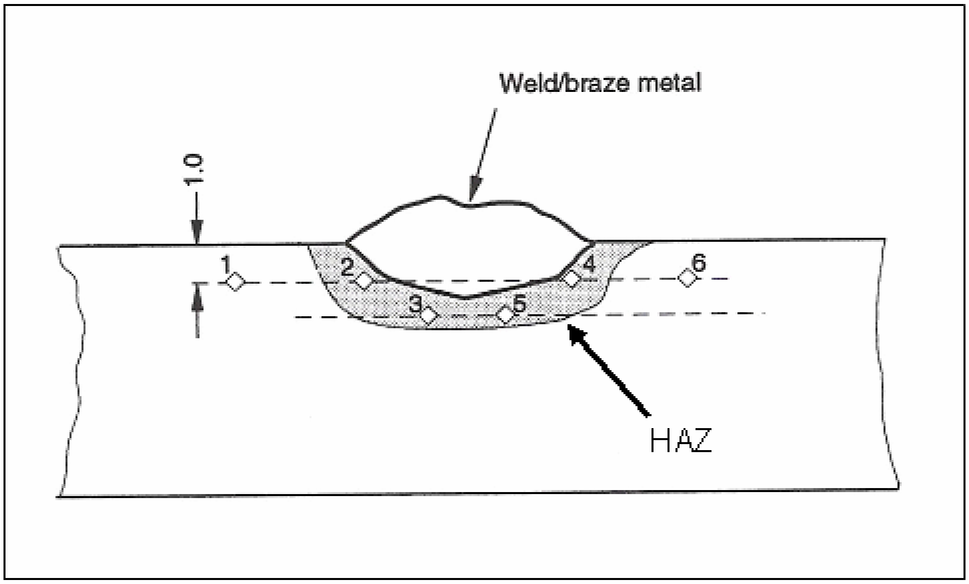


Figure 5 – Locations of Microhardness Measurements (per BS 4515)

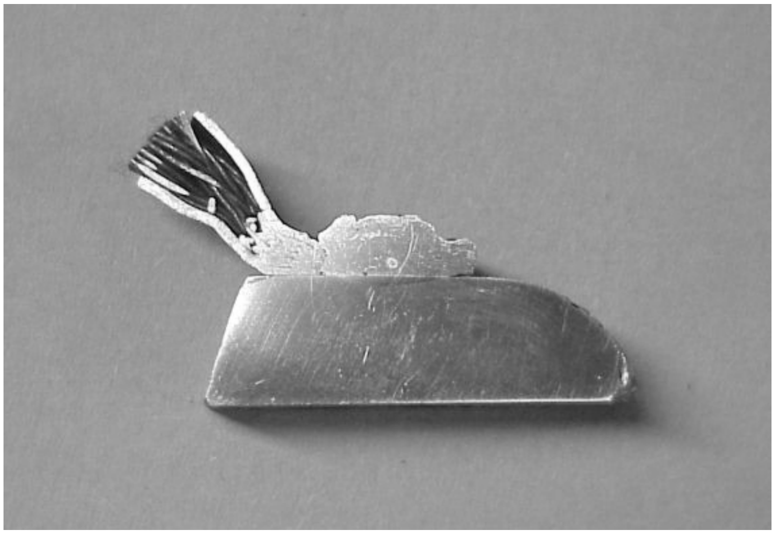


Figure 6 – Cross-section of Pin Braze

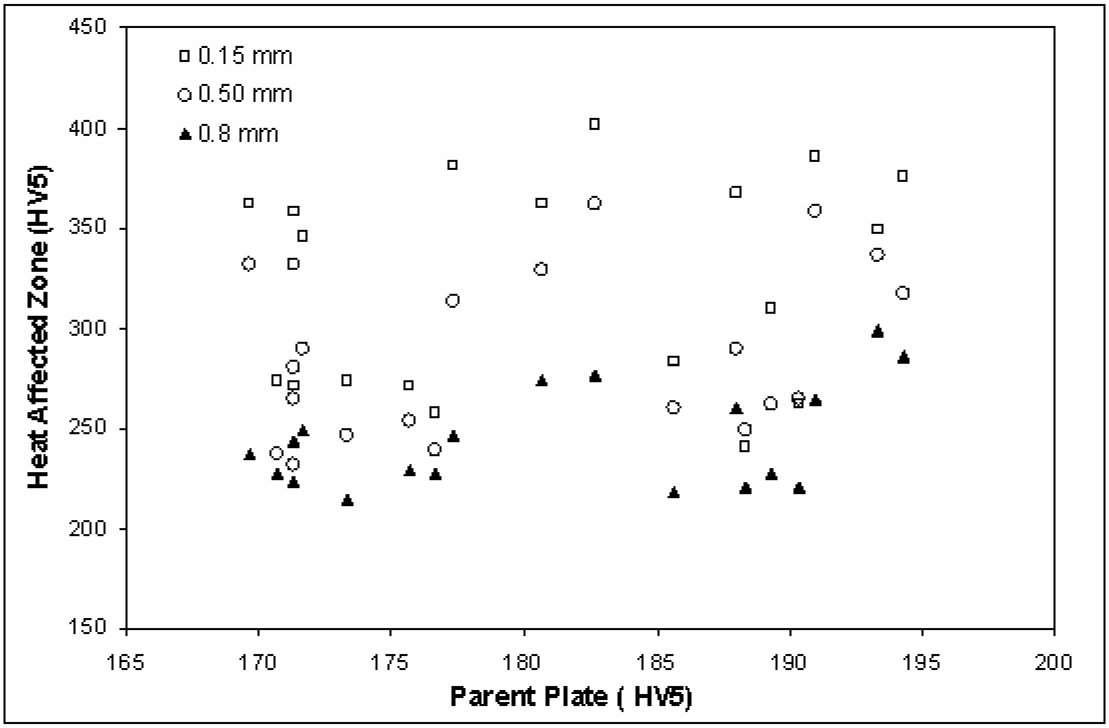


Figure 7 – Effect of Pin Brazing on Microhardness