HERITAGE RAILWAY ASSOCIATION

GUIDANCE NOTE

WELDING PROCEDURES & PROCESSES
Applicable to Locomotive Steam Boilers

Purpose
This document describes good practice in relation to its subject to be followed by Heritage Railways, Tramways and similar bodies to whom this document applies.

Endorsement
This document has been developed with and is fully endorsed by Her Majesty’s Railway Inspectorate (HMRI), a directorate of the Office of Rail Regulation (ORR).

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1. Introduction

This Guidance Note is one of a series dealing with Locomotive Boilers that were produced by the “Steam Locomotive Boiler Codes of Practice” practitioners’ meetings.

Railway locomotive boilers are designed to create, store and distribute steam at high pressure. The working life of such a boiler can be considerably shortened if due care is not taken at all stages of inspection, repair, running maintenance and day-to-day running.

In the past there have been a series of accidents and explosions due to work being undertaken without having due regard to the inherent risks involved. It is with that in mind that HMRI and HRA set up the series of meetings of boiler practitioners to discuss the issues; distil good practice and codify it into this series of Guidance Notes.

This guidance is written for the assistance of people competent to perform these tasks. In places the terminology used may be specific to such practitioners.

This guidance should also be useful to those in a supervisory or more general role. However no work should be undertaken unless the persons concerned are deemed competent to do so.

2. Recommendations

This guidance note is issued as recommendations to duty holders.

Where duty holders decide to take actions that are not in agreement with these recommendations following appropriate risk assessments or for other reasons, it is recommended that those decisions are reviewed by the senior management body of the organisation concerned and a formal minute is recorded of both the decision reached and the reasons for reaching it.

3. Dimensional Notation

The dimensions in this document are variously described in a mixture of imperial and metric units. Where practical equivalent dimensions have been shown but in some cases the dimensions do not easily equate and so the units in force at the time that the original designs were documented have been used.

4. Personal Protective Equipment

Before undertaking any work a risk assessment must be conducted.

Protective equipment is to be supplied and used at work wherever there are risks to health and safety that cannot be adequately controlled in other ways.

The equipment must be:

- Compliant with the latest Personal Protective Equipment regulations.
- Properly assessed before use to ensure it is suitable.
- Maintained and stored properly.
- Provided with instructions on how to use it safely.
- Used correctly by those undertaking the work.

5. General points concerning Welding

The welding activity must be carried out in an environment that is not detrimental to the finished weld

Method statements should take account of the specific risks associated with the welding procedure being used.

Before commencement of any welding process approval must be obtained from the Competent Person. The Competent Person may require to witness the plate preparation, root run, the finished weld and its testing.

A welding procedure is required taking into account material specification, location of weld, weld process and welder qualification.

It may not be possible to introduce a localised welded repair due to the poor condition of the components. If this is the case a new boiler or platework should be considered.
6. **Competent Person**

The Responsible Person should seek guidance from the boiler Competent Person before proceeding with any welding procedures.

7. **Weld Procedure**

A Welding Procedure Specification (WPS) is a formal written document describing the welding process, which provides direction to the welder or welding operators for making metallurgically sound welds. The purpose of the document is to guide welders to the accepted procedures so that suitable and repeatable welding techniques are used. A WPS is developed for each material alloy and for each welding type used. A WPS is developed by a competent person such as a welding engineer. A WPS is supported by a Procedure Qualification Record (PQR or WPQR). A typical example of a welding qualification is shown in Appendix B.

A Weld Procedure Qualification Record (WPQR) is a record of a test weld performed and assessed by a combination of non-destructive and metallurgical testing to demonstrate that the welding procedure will produce a satisfactory weld. A single WPQR can in some cases cover a number of related weld procedure specifications. Weld procedure qualification tests are normally witnessed and certified by an independent inspection body.

A Welder Qualification is a qualification test by which individual welders are certified to carry out welding to a defined WPQR. A Welder Qualification Test Record (WQTR) demonstrates the welder has the understanding and demonstrated ability to work within the specified WPS. Welder qualification tests are normally witnessed and certified by an independent inspection body. WQTR need to be periodically reviewed to demonstrate that welders are maintaining their competency.

All written documents should be retained with the boiler's records and copies made available to the Competent Person and inspecting authority.

Further reference: Procedures EN ISO 15609 -1:2004 Formerly BS 288 part 2

8. **Welder qualification**

All welding on pressure vessels must be carried out by an approved welder to a certified welding procedure, see Appendix B

The welder's qualification must be verified by the Competent Person to ensure that it is appropriate for the weld being undertaken, see Appendix A

9. **Material**

Existing boilers are not all made of the same material i.e. mild steel boiler plate. The main materials currently in widespread use are mild steel boiler plate, 2% nickel steel plate, carbon manganese steel plate and copper.

If any doubt exists, the material should be chemically analysed to establish its specification and suitability for weld repair.

The specifications of materials used in boiler construction include:

- Carbon Manganese steel plate BS 1501 – 224 – 490B – LT50
- 2% Nickel steel plate, originally B.R SPEC III. There is no equivalent modern specification but the chemical analysis comprises: C 0.2-0.25%, Si 0.1-0.15% Mn 0.5-0.7% Ni 1.75-2.0%, S< 0.04% P< 0.04%
- Copper plate BS 2875 Grade C107 (phosphorous deoxidise arsenical), now BS EN 1652:1998 and BS EN 1653:1998.

Copper plate BS 2875 Grade C105, is not recommended for welding
10. **Welding consumables**

It is important to select the correct grade of welding electrode or filler suited to the parent plates being joined and ensure these are stored and prepared for use in accordance with the manufacturer's instructions.

If MMA is selected for the process E7018 or E7016 low hydrogen electrodes should be used when joining boiler plates made to BS EN 10029-1991 and BS EN 10028 -1-2-3 :1993.

E6013 general purpose rutile rods may be used for non-critical joints such as seal welds, subject to prior approval by the Competent Person.

## Welding Process Steel plates ##

Manual metal arc (MMA) is the preferred and proven process by which best results will be achieved on plate work especially for repair work. On new build it may be possible to use the Metal Active Gas (MAG) process. Other welding processes can be applied providing they have been demonstrated to produce satisfactory results.


11. **Weld Location and Preparation in Steel Plate**

Once the material specification has been verified attention needs to focus on the positioning and configuration of the weld itself. Any weld needs to avoid, where possible, high stress areas or areas prone to cracking to minimise the possibility of repeat failure. Wherever possible a weld should be placed between stay rows and away from radii etc. The problem with inserts in radii is trying to achieve correct profiles. As most welds involving the replacement of plate work are only accessible from one side, all weld preps will be of a single vee type. If access is available from both sides a double vee enables a full penetration weld to be effected with a smaller cap. J-type or fillet preparation may be required for items such as welded firebox stays, washout plug bosses and mounting pads. The plate preparation details should be included in the welding procedure. Typical examples of weld preparations and details are covered in BS2790: 1992, BS EN 12953:2002 and Weld joints & preparations BS 499-1 2009.

New plate of the original design thickness should always be used or a metric equivalent thicker than original plate may be considered provided that it is not more than 20% greater than the plate it is being welded to. Care should be taken to maintain alignment and keep distortion to a minimum.

12. **Welding of Steel Boilers – Significant Change in Design**

Traditionally only the inner steel firebox, where fitted, was welded; all outer construction being of the riveted design.

All significant design changes, such as replacement of a riveted design by welding or changes of material used will require a formal design assessment by the Competent Person.

13. **Common Defects and Permissible Repairs to Inner Steel Fireboxes**

A full NDT survey must be carried out by a suitably approved qualified specialist to the requirement of the Competent Person before repairing to identify the full extent of any defects.

1 - Fractured sealing welds on tubes, where possible, may be machined out and re-welded using the MMA process.

2 - Cracking from stay holes in the throat plate adjacent to siphon necks, breaking zones and stays in fire area where possible, can be ground out and re-welded using MMA process.

3 - Plate thinning in firebox areas; these can be cut out and replaced with the correct specification material and welded with a single vee weld. The weld preparation dimensions should be left to the repairer based on their own weld procedure qualification. All welding should be carried out from the fireside.

4 - Waterside grooving adjacent to foundation ring may be repaired by machining or grinding out and re-welding on removal of the foundation ring.
5 - Ex Merchant Navy & West Country Classes, A feature of this type of steel fireboxes is the fitting of thermonic syphons welded between the crown sheet and throat plate. Cracking occurs at the connection between syphon and syphon neck. This can be repaired by grinding out and re-welding or by complete removal of weld to stress relieve the component and then re-weld.

14. Weld Repairs to Riveted Outer Fireboxes and Barrel

Listed below are common defects and permissible repairs in steel fireboxes. A full NDT survey must be carried out by the competent person or approved qualified specialist before repairing to identify the full extent of any defects.

1 - Waterside stress cracking in the door plate shoulders between washout plug holes and cracking between stay holes in end vertical rows at the breaking zones to the door plate, throat plate and to a lesser degree both side plates. All may be welded if access is available from the waterside. A fully satisfactory repair using MMA process is achievable by grinding to remove the crack and then welding. If this is not the case it will require a welded insert or a patch laid over. If the cracking is too extensive either in width or length a new section should be fitted. If a patch is to be laid over, further approval will be required from the Competent Person. In the case of a welded insert the joint needs to be made between stay rows or as a minimum on a flat area and not on a bend due to possible variation in profile.

2 - Waterside stress cracking in the top corners of sloping throat plate, i.e. knuckle areas; repair by grinding out the cracking and welding, which should be done from the waterside.

3 - Waterside grooving on outer firebox plates adjacent to foundation ring as well as wastage and corner cracking on the foundation ring. If the foundation ring is removed it should be possible to effect a repair by grinding and welding any grooving / cracking to the platework and ring.

4 - Waterside stress cracking on radius of front steel tube plate. The steel tube plate should be removed for this repair.

5 - Where electrolytic corrosion around copper stay heads, pitting on barrel inside & outside, plate thinning around firebox or localised wastage in various areas and components occurs, small areas of localised pitting / thinning may be repaired by building up with weld. Any one area of pitting of over 6 sq” (2” x 3” for example) should not be repaired by welding nor should the total amount of welding in any one foot square of plate exceed 6 sq”. The total area of welding in any plate should not exceed 24 sq”.

6 - Barrel extension to smokebox wasted. Corrosion of barrel extensions occurs ahead of steel tube plate and therefore ahead of the pressure joint; effect a repair using materials and procedures as for any weld on the boiler.

15. Non-Destructive Testing and Weld Inspection (Steel)

On completion of welding all welds to be tested to specifications approved by the Competent Person.

The major methods of testing and inspection available are;

BS EN ISO 17637:2011 Visual testing of fusion-welded joints
ISO 3452 : 2008 parts 1 to 6 Penetrant testing
BS EN ISO 17638 : 2009 Magnetic particle inspection
BS EN ISO 17640 : 2010 Ultrasonics
BS EN ISO 17636 : 2013 Radiography
BS EN 9712: 2012 NDT and certification/qualification of NDT personnel

## Welding Of Copper Fireboxes ##

16. Characteristics of copper

Copper is tough, ductile and malleable. On the application of cold work the metal hardens and loses some of its ductility, but the ductility can be restored by annealing. The metal melts at about 1083 degrees C and
when molten is very fluid. The thermal conductivity of copper is extremely high, equal to about eight times that of steel. As the material becomes hot, copper rapidly loses its mechanical properties, particularly from 300 degrees C upwards. At 500 degrees C, the tensile strength is only 40% of that at normal temperature, and will collapse near the melting point unless care is taken.

When the metal is in the molten or in the plastic state it absorbs gases very easily. It absorbs oxygen, hydrogen, carbon dioxide and the majority of the commonly occurring gases. In the annealed condition copper is not very strong, and has tensile strength of about 14 tons per square inch, but after work hardening, the tensile strength may be up to 25 tons.

There are two main types of copper used in firebox construction:- C107 phosphorus deoxidised arsenical copper to BS2875 1980, now BS EN 1652:1998 and BS EN 1653:1998, and C105 Tough pitch arsenical copper plate for riveted and studded construction only, both consisting of about 99.2% of copper with 0.3 /0.5% arsenic.

Tough pitch copper, C105, does not weld satisfactorily due to the fact that copper containing even a small amount of oxygen is quite unsuitable for welding. The metallurgical explanation is that oxygen unites with the copper to form a compound, cuprous oxide. As small a quantity as one part of cuprous oxide in a thousand parts of copper is sufficient to cause a great modification of the mechanical properties of the copper. Cuprous oxide is soluble in liquid copper, but only slightly soluble in the solid metal. The cuprous oxide, therefore, which is dissolved in copper when the metal is liquid, separates out as the molten metal cools down and solidifies. The oxide forms a network around the crystals of pure copper and renders the material brittle. On applying any hot work or cold work to the solid metal a series of inter-crystalline cracks is formed and the material is useless for locomotive firebox purposes. Consequently it is necessary to use de-oxidized copper for welding known as C107. De-oxidized copper is copper which has been manufactured in the usual way, but to which has been added about 0.015 to 0.080% of phosphorus as a de-oxidizing agent which will combine with the oxygen in the copper and so prevent formation of cuprous oxide.

Further reference: Fusion welding of copper – BS EN 9606-3-1999

17. Preparation for copper welding

The welder should bear in mind that merely heating the copper to red heat in the atmosphere and allowing it to cool down is sufficient for oxygen to be absorbed and give rise to toxic cuprous oxide which also weakens the metal.

It will be appreciated that not only must the material being welded be de-oxidized copper, but the welding rod used must be similarly a special rod and not just a rod of pure copper. There are several proprietary brands of welding rod available, each containing a sufficient quantity of a suitable de-oxidizing agent.

As most welds involving the replacement of plate work are only accessible from one side, all weld preps will be of a single vee or J type. Weld preparations and details are covered in several British standards; Welding procedures should be approved to BS EN ISO 15614-6 and welders should be approved to BS EN ISO 9606-3

The surfaces are thoroughly cleaned and the edges are prepared by grinding and chipping. Copper has a high coefficient of expansion, and it is necessary therefore to set the plates diverging at the rate of 3/16 per ft. run, because they come together so much on being welded. Since copper is weak at high temperatures, the weld should be well supported where possible and a fireproof sheet placed between the weld and the backing strip of steel to prevent loss of heat.

Typical weld preparations for copper are shown in diagram:

In order to prevent the molten metal from falling through when using an underhand technique, a fireproof sheet may be used as a backing. Dry out any moisture in the material by moving the blowpipe over the sheet.

(Diagram dimensions are in inches)
Copper Welding rod Filler Materials

Covered and bare welding consumables are available for welding copper. When selecting the size of filling rod this should be larger than for welding steel of a similar thickness. Copper electrodes and rods are generally produced with a minimum copper content of 98% for gas metal arc welding of deoxidized copper. Covered /cored electrodes are generally manufactured with deoxidized copper core wire, for TIG and MAG use BS2901 Part 3 C1, C7 or C21 and for oxy-acetylene use BS EN 12536:2000

Preheating

The relatively high thermal conductivities of copper result in the rapid conduction of heat from the weld joint to the surrounding base metal. Heat loss from the weld zone can be reduced by preheating the base metal to decrease the temperature differential.

The optimum preheat temperature depends on the welding process and the metal thickness or mass. Thin sections or high energy welding processes, such as gas metal arc, generally require less preheat than do thick sections or low energy welding processes, such as gas tungsten arc and oxy-acetylene welding.

When preheat is used, the base metal adjacent to the joint must be heated uniformly to temperature. The temperature should be maintained until the joint is completed.

Heat loss should be minimized, where appropriate, by insulating the parts with appropriate materials.

Gas torch / Blowpipe

The procedure and technique of welding de-oxidized copper is of great importance, as also is the regulation of the oxy-acetylene flame. Skillful manipulation of the blowpipe alone is insufficient; attention must be paid to the correct welding flame, which should be a neutral or very slightly carbonizing (excess acetylene) flame. Too much oxygen will cause the formation of copper oxide and the weld will be brittle. Too much acetylene will cause steam to form, giving a porous weld, therefore close the acetylene valve until the white feathery plume has almost disappeared. On account of the very high heat conductivity of copper, it is necessary to use a nozzle much larger than for welding steel of the same section. A torch nozzle size of 2.5mm is recommended for plate thickness of 0.500 to 0.750 inches (12-20mm).

All welds should be completed in one run, and on no account should the line of welding be smoothed over with the blowpipe.

18. Oxyacetylene Welding of Locomotive Fireboxes

Traditionally all new copper firebox wrapper sheets were either formed of a one piece sheet or two pieces welded together down the centre of the crown from one side only and whilst in situ.

Currently it is not always possible to obtain large sheets of copper so a newly constructed firebox may consist of more than one weld. I.e. either a single weld along the crown or a weld either side running along the firebox between stay rows. This method is acceptable provided all welds are between stay rows.

The edges of the plates, which may be ½ in to ¾ in thick, are machined to form a single bevel joint with an included angle of about 90 degrees. A special type of copper backing bar, of section as shown in ‘A’, which permits full root penetration, is placed underneath the joint, supported in turn by a layer of fireproof material and a steel plate. The copper backing bar remains welded to the plates and enhances the strength of the joint. Copper end pieces, provided with a special cavity, as shown in ‘B’ are placed across the ends of the seam, their purpose being to prevent the molten metal from running out of the joint. These plates are cut off afterwards and provide test pieces.
With the seam horizontal, the plates are clamped in such a way that a tapering gap allows for expansion. As the gap closes up during welding, the clamps are adjusted.

The welders take up their position in the firebox, one in line with the seam and the other alongside it. After heating up the parent metal for a short period, the first operator begins to melt the metal near the root of the joint and proceeds to deposit metal from his filler rod. He is followed by the other welder, who melts the sides of the V-Joint higher up and completes the filling-up process with his own rod. The distance between the two blowpipes may only be 1in to 1 ½ in and before long they are moving ahead of a pool of molten metal about 3 in long. Dry sand is thrown on the seam as it solidifies, in order to protect the joint from the atmosphere. After having welded about 3 ft of the seam, the operators are relieved by two others who continue the work immediately without allowing the pool to solidify.

The work is allowed to cool down, after which the joint is dressed by means of a pneumatic hammer and chisel. It is finally hammered and is brushed with a wire brush until the surface is level and smooth.

19. Firebox Welding Repairs

Items that may require welding include: - Replacing half sides, Flange inserts in doorplate or tube plate, Firehole inserts, Firehole bulbs, Welding cracks between stay holes, Building up flanges, Building up tube plate between tube holes, filling in flange rivet holes, Welding cracks from rivet holes, Welding fractured tube plate bridges and Welding fractures in flange radii in tube plate and door plate.

Standards and parameters for repair welding are the same as for new construction apart from techniques applicable to each type of repair. See Platework guidance note HGR-B9020 for minimum plate thickness permissible.

The type of weld preparation process and procedure adopted will depend on the individual circumstance and conditions. Generally speaking it will not be possible to let in an insert into centre of the plate due to expansion and contraction problems resulting in weld cracking.

Where weld repairs are to take place any stays, rivets or flange studs in that area should be removed prior to welding and then replaced upon completion of repairs. Fire erosion is to be weld repaired after removal of copper or steel stays. Large areas would require plate renewal.

Extensive use is made of copper welding for repairs such as replacing worn three-quarter wrapper side-plates, building up wasted fire-door and tube flange plates, cutting away and welding flange radius cracks and welding tube plate bridge cracks. When a three-quarter side weld is made with the fire-door plate or tube plate in position, access to the ends of the seam is provided by cutting out a half-moon piece from the fire-door or tube plate flange, a new piece of plate being subsequently welded into the flange (see circle on diagram).

When welding the longitudinal seam of three-quarter sides, a steel backing bar with a machined groove of semi-circular section is used, permitting root penetration. With the seam horizontal, the plate is clamped in such a way that a tapering gap allows for expansion. The work is carried out by the rightward welding method. No flux is used. The welding is preceded by a preheater.

Replacement of ¾ of a side
After about 6in of the seam has been filled up, the blowpipes are extinguished and the hot metal is immediately given blows from the round heads of light hand hammers. At dull red heat, a pneumatic hammer is applied until the appearance of the metal is black. Welding is then resumed in stages as before, the technique being an adaptation of welding intermittently by the two-operator vertical method. The surface of the finished weld may be wire brushed, after which very little chipping and grinding should be necessary. End plates, as previously described, are placed across the beginning and the end of the seam. They are cut off after welding.

**Technique**

The position of the blowpipe should be at an angle of 60 – 80 degrees to the work, to conserve the heat as much as possible. Great care must be taken to keep the tip of the inner cone ¼ to 3/8 in away from the molten metal (The white cone of the flame should never touch the work), since the weld is then in an envelope of reducing gases, which prevent oxidation. The weld proceeds in the leftward manner, with a slight sideways motion of the blowpipe. Avoid agitating the molten metal, and do not remove the rod from the flame, but keep it in the molten pool.

Copper may also be welded by the rightward method, which may be used when the filler rod is not particularly fluid. The technique is similar to that for rightward welding of mild steel, with the flame adjusted as for leftward welding of copper. Do not overheat; the metal should flow calmly and freely and should not be forced.

Welding can also be performed in the vertical position by either single or double operator method, the latter giving increased welding speed.

Because of the high conductivity of copper it is essential to preheat the surface, so as to avoid the heat being taken from the weld too rapidly.

**20. Arc Welding De-oxidized Copper**

Welding of copper was carried out almost entirely by the oxy-acetylene process. Modern welding methods such as the gas tungsten arc and Metallic Active Gas (MAG) arc processes are now used.

A material of low conductivity, such as steel, can be arc welded satisfactorily at a comparatively high speed and usually less skill is required than for gas welding. Owing to the high thermal conductivity of copper, however, a larger heat input is required which necessitates some pre-heating and higher currents. An additional disadvantage is the ease with which gases are absorbed by the metal at the high temperature of the arc, resulting in porous welds.

**21. Gas tungsten arc welding**

Gas tungsten arc welding is best suited for joining sections up to 0.125 in thick. It can be used advantageously for thicker sections when welding in a position other than flat. Typical joint designs for gas tungsten arc welding of copper are shown in the figure to the left.

A grooved copper backing strip may be used to aid in control of root surface contour.

(Diagram dimensions are in inches)
Shielding Gases for Gas Tungsten Arc and MAG

Argon shielding is preferred only for welding thin sections. With thicker sections, low travel speeds and high preheat are required with argon shielding.

Helium is preferred for welding thicker sections. The weld pool is more fluid and cleaner, and the risk of oxide entrapment is considerably reduced. Compared to argon, it permits deeper penetration or higher travel speeds at the same welding current. The diagram to the right illustrates the differences in penetration in copper with argon and helium as well as the effect of preheat temperature with argon.

Effect of shielding gas and preheat temperature on weld bead penetration in copper when tungsten arc welding with 300 A dc at a travel speed of 8 in/min. Dimensions are in inches.

Mixtures of these gases result in intermediate welding characteristics. For welding positions other than flat, a mixture of 65 to 75% helium-argon produces a good balance between the penetrating quality with pure helium and the ease of control with argon.

Welding Technique

Either forehand or backhand welding may be used. Forehand welding is preferred for all welding positions. It can provide a more uniform, smaller bead than with backhand welding. However, a larger number of beads may be required to fill the joint.

The joint should be filled with one or more stringer beads or narrow weave beads. Wide oscillation of the arc should be avoided because it intermittently exposes each edge of the bead to the atmosphere and consequent oxidation. The first bead should penetrate to the root of the joint and be fairly thick to provide time for de-oxidization of the weld metal and to avoid cracking of the bead.

Typical pre-heating temperatures and welding conditions for gas tungsten arc welding of copper are shown below. The conditions should only be used as guides for establishing welding procedures for a particular application. The high thermal conductivity of copper and the rapid conduction of heat from the joint area into the components and the fixturing make it difficult to give welding conditions suitable for all applications. High welding current should not be used to compensate for lack or preheat.

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<tr>
<th>Metal thickness</th>
<th>Joint Design</th>
<th>Shielding Gas</th>
<th>Tungsten Electrode diam, in</th>
<th>Welding Rod diam, in</th>
<th>Preheat Temp °F</th>
<th>Welding current A</th>
<th>No. of passes</th>
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<td>0.5</td>
<td>D</td>
<td>He</td>
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<td>0.125</td>
<td>650</td>
<td>350-420</td>
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<td>0.62 and above</td>
<td>F</td>
<td>He</td>
<td>0.18</td>
<td>0.125</td>
<td>750 min.</td>
<td>400-475</td>
<td>As required</td>
</tr>
</tbody>
</table>
22. Gas Metal Arc Welding

Shielding Gases

A mixture of 75% helium - 25% argon is recommended for gas metal arc welding of copper. The helium-argon mixture is recommended for welding of thicker sections because the preheat requirements are lower, joint penetration is better, and filler metal deposition rates are higher.

Welding Technique

Type ERCu copper wire is recommended for welding copper. The proper wire size will depend on the base metal thickness and the joint design.

The filler metal should be deposited in stringer beads or narrow weave beads using spray transfer. Wide weaving of the electrode may result in oxidation at the edges of the bead. Approximate minimum conditions for spray transfer with copper electrodes and argon/helium shielding are given below.

<table>
<thead>
<tr>
<th>Metal thickness</th>
<th>Joint Design</th>
<th>Shielding Gas</th>
<th>Diam In.</th>
<th>Feed In/min</th>
<th>Preheat Temp°F</th>
<th>Welding Current A</th>
<th>Travel speed In/min</th>
<th>No. of passes</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.50 In.</td>
<td>C</td>
<td>75% He 25% Ar</td>
<td>0.062</td>
<td>210-270</td>
<td>600</td>
<td>330-400</td>
<td>8-14</td>
<td>2-4</td>
</tr>
<tr>
<td>0.63 and above</td>
<td>D</td>
<td>75% He 25% Ar</td>
<td>0.062</td>
<td>210-270</td>
<td>800</td>
<td>330-400</td>
<td>150-190</td>
<td>8-14</td>
</tr>
</tbody>
</table>

Suggested joint designs for gas metal arc welding of copper are shown to the left. Typical preheat temperatures and welding conditions are given above. These should only be used as a guide in establishing suitable welding conditions that are substantiated by appropriate tests.

The forehand welding technique should be used in the flat position. In the vertical position, the progression of welding should be up. Gas metal arc welding of copper is not recommended for the overhead position because the bead shape will be poor. Gas tungsten arc welding is the preferred method for this position.

Diagram dimensions are in inches

23. After treatment

Assuming that the copper welds are sound, the deposited metal is obviously in the cast condition and in order to improve the strength it is necessary to work-harden by light hammering the welded seam where practicable. It is best applied to the weld and to the metal adjacent to the weld at low heat as this serves to remove contractional stresses and to consolidate the surface of the weld.
24. **Tacking Joints**

Tacking to preserve alignment is not advised owing to the weakness of copper on account of the metal being “short” and possessing no tenacity at red heat. When welding long seams, tapered spacing clamps or jigs should be used to ensure correct spacing of the joint, care being taken that these do not put sufficient pressure on the edges to indent them when hot.

25. **Practical Testing Copper Welding**

The strength of the welds produced is nearly the same as that of annealed copper. A good copper weld can be bent through 180 degrees without cracking and can be hammered and twisted without breaking.

26. **Non-Destructive Testing and Weld Inspection of Copper**

On completion of welding all welds should be tested to specification approved by the Competent Person. The major methods of testing and inspection available are:

- ISO 3452 : 2008  parts 1 to 6 Penetrant testing.
- BS EN ISO 17640 : 2010 Ultrasonics.
- BS EN 9712: 2012 NDT and certification/qualification of NDT personnel.

27. **Acceptance of Weld Quality**

Assessment of the quality of welds is laid down in appropriate standards:

- Steel: refer to BS2790 Design and Manufacture of Shell Boilers of Welded Construction, also BS EN 12953:2002.
- Copper: refer to BS EN 12953 -Shell Boilers Part 4.

See also:

- ASME Boiler and Pressure Vessel Code V Non destructive Examination.
- ASME Boiler and Pressure Vessel Code 1X Welding and Brazing Qualifications.
- BS EN ISO 5817:2007 Arc welded joints in steel, guidance on quality levels for imperfections.
- BS EN ISO 3834-1-2005 Quality requirements for welding.
- BS EN 13585:2012 Brazing and Brazer Appraisal.

28. **References**

- The Welding, Brazing and Soldering of Copper and its Alloys  Copper Development Association.
- The Application of Welding to Locomotive Firebox Construction – Paper no 511 Institution of Locomotive Engineers.
- Copper and Copper Alloys for Locomotive Firebox Construction Paper no 393 Institution of Locomotive Engineers.

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Appendix A: Qualified welder (coded welder)

The term coded welder refers to the American ‘codes’ of practice. Under British standards a qualified welder is referred to as being approved or certified. This statement alone may not qualify the welder to do the job; the following questions should be asked: Do they have a copy of their certificate? Is the certificate current? In which welding process are they certified? Which type of filler metal or alloy? Is it carbon steel or stainless steel? What position were they tested to? It is not the intention to embarrass or ridicule anyone by asking these questions, but merely to ensure that they are qualified for the welding they are going to carry out.

An example of a welder Approval test certificate is given below and shows the qualifications suitable for welding boiler plate work. It should be noted that the welding certificate would not cover smoke or flue tube welds due to their diameter being below the welder’s qualifications. Welders will normally have several additional qualifications to their main approval and these must be kept up to date.

Welder Approval Test Certificate

The welder approval test is carried out on a test piece which is representative of the joint to be welded, to demonstrate that the welder has the necessary skill to produce a satisfactory weld under the conditions used in production as detailed in the approved welding procedure or work instruction. As a general rule the test piece approves the welder not only for the conditions used in the test but also for all joints which are considered easier to weld.

The welder approval certificate remains valid subject to the requirements of the application standard. It can be extended at six monthly intervals by the employer for up to two years provided the welder has been successfully welding similar joints. After two years, prolongation of the welder’s qualification will need approval of the examiner who will require proof that the welder’s performance has been to standard during the period of validity. As the examiner will normally examine the company’s records as proof of the welder’s work being satisfactory, it is essential that work records are maintained by the company.

Further reference:
Welder Qualifications BS EN 287-1 2011
Testing copper BS EN 9606-3-1999 / steel BS EN 287-1-2011
Weld positions

Full and detailed information can be found in BS EN ISO 6947 and EN 287.

To understand a welding certificate a basic knowledge of weld position abbreviations is essential as not all welders are approved to weld in ‘all positions’. The certificate may state for example only ‘PA’ which would mean a flat welding position.

### Welding consumable (Designation)

Type of Electrode used for welder’s approval certificate

<table>
<thead>
<tr>
<th>electrode</th>
<th>E</th>
<th>42</th>
<th>4</th>
<th>-</th>
<th>B</th>
<th>3</th>
<th>2</th>
<th>H5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reference table</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
<td>7</td>
<td>8</td>
</tr>
</tbody>
</table>

1 Short symbol for manual arc welding
<table>
<thead>
<tr>
<th>Code number</th>
<th>Minimum yield strength(^*1) (R_y) (N/mm(^2))</th>
<th>Tensile strength</th>
<th>Minimum elongation after fracture (A_5)</th>
<th>Code letter or number</th>
<th>Minimum charpy impact value</th>
</tr>
</thead>
<tbody>
<tr>
<td>35</td>
<td>355</td>
<td>440 – 570</td>
<td>22</td>
<td>Z</td>
<td>none</td>
</tr>
<tr>
<td>38</td>
<td>380</td>
<td>470 – 600</td>
<td>20</td>
<td>A</td>
<td>+20</td>
</tr>
<tr>
<td>42</td>
<td>420</td>
<td>500 – 640</td>
<td>20</td>
<td>O</td>
<td>0</td>
</tr>
<tr>
<td>46</td>
<td>460</td>
<td>530 – 680</td>
<td>20</td>
<td>2</td>
<td>-20</td>
</tr>
<tr>
<td>50</td>
<td>500</td>
<td>560 – 720</td>
<td>18</td>
<td>3</td>
<td>-30</td>
</tr>
</tbody>
</table>

\(^*1\) Yield strength should be the lower yield point \(R\). If it is not distinct then choose the 0.2\% - yield strength \(R\).

<table>
<thead>
<tr>
<th>Alloy short symbol</th>
<th>Chemical Composition</th>
<th>% Mn</th>
<th>% Mo</th>
<th>% Ni</th>
</tr>
</thead>
<tbody>
<tr>
<td>No short symbol</td>
<td></td>
<td>2.0</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Mo</td>
<td></td>
<td>1.4</td>
<td>0.3 – 0.6</td>
<td>-</td>
</tr>
<tr>
<td>Mn Mo</td>
<td></td>
<td>&gt; 1.4 – 2.0</td>
<td>0.3 – 0.6</td>
<td>-</td>
</tr>
<tr>
<td>1 Ni</td>
<td></td>
<td>1.4</td>
<td>-</td>
<td>0.6 – 1.2</td>
</tr>
<tr>
<td>2 Ni</td>
<td></td>
<td>1.4</td>
<td>-</td>
<td>1.8 – 2.6</td>
</tr>
<tr>
<td>3 Ni</td>
<td></td>
<td>1.4</td>
<td>-</td>
<td>2.6 – 3.8</td>
</tr>
<tr>
<td>Mn 1 Ni</td>
<td></td>
<td>&gt;1.4 – 2.0</td>
<td>-</td>
<td>0.6 – 1.2</td>
</tr>
<tr>
<td>1 Ni Mo</td>
<td></td>
<td>1.4</td>
<td>0.3 – 0.6</td>
<td>0.6 – 1.2</td>
</tr>
</tbody>
</table>

\(^2\) if not determined: Mo<0.2; Ni <0.3; V <0.0.8, Nb <0.05; Cu <0.3; individual values are maximum value.

<table>
<thead>
<tr>
<th>Short symbol</th>
<th>Recovery (%)</th>
<th>Type of current</th>
<th>Short symbol</th>
<th>Welding position</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>&lt;105</td>
<td>AC, DC</td>
<td>1</td>
<td>All positions</td>
</tr>
<tr>
<td>2</td>
<td>&lt;105</td>
<td>DC</td>
<td>2</td>
<td>All positions, except vertical down</td>
</tr>
<tr>
<td>3</td>
<td>&gt;105 – 125</td>
<td>AC, DC</td>
<td>3</td>
<td>Butt weld in flat position fillet weld in flat and horizontal position</td>
</tr>
<tr>
<td>4</td>
<td>&gt;105 – 125</td>
<td>DC</td>
<td>4</td>
<td>Butt weld and fillet weld in flat position</td>
</tr>
<tr>
<td>5</td>
<td>&gt;125 – 160</td>
<td>AC, DC</td>
<td>5</td>
<td>Fillet weld and acc. To code number 3</td>
</tr>
<tr>
<td>6</td>
<td>&gt;125 – 160</td>
<td>DC</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>&gt;160</td>
<td>AC, DC</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>&gt;160</td>
<td>DC</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Code</th>
<th>Maximum content of diffusible hydrogen (millilitres/100g melted weld metal)</th>
</tr>
</thead>
<tbody>
<tr>
<td>H5</td>
<td>5</td>
</tr>
<tr>
<td>H10</td>
<td>10</td>
</tr>
<tr>
<td>H15</td>
<td>15</td>
</tr>
</tbody>
</table>

\(^3\) proportion coating diameter to core wire diameter 1.6

---

end of appendix
Appendix B: Typical Welding Procedure

A Welding Company

A Street
A Town
A Country

WELDING PROCEDURE SPECIFICATION

Code/Testing standard: BS EN 288-3
Examination/Examinng body: N/A

Location: Workshops
Examiner Ref No: N/A

Manufacturer's WPS Ref No: WPSE2345
Method of prep and cleaning: Machined/Grounded

Manufacturer's WPS Ref No(s): 12445
Parent material spec: Carbon steel 1501 Gd 20A

Welding process: MMA
Material thickness (mm): 3mm to 25mm

Joint type: Single Vee Butt
Outside diameter (mm): 500mm and above

Welding position: All positions except vertical down

Weld preparations/details (sketch)

Joint Design | Welding Sequence

Welding Details

<table>
<thead>
<tr>
<th>Run</th>
<th>Process</th>
<th>Size of filler</th>
<th>Current A</th>
<th>Voltage V</th>
<th>Type of current/polarity</th>
<th>Wire feed speed [mm/sec]</th>
<th>Travel speed [mm/sec]</th>
<th>Heat input [kJ/mm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>MMA</td>
<td>2.5mm</td>
<td>70-85</td>
<td>-</td>
<td>DC ELECT NEG</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>2</td>
<td>MMA</td>
<td>2.5mm</td>
<td>70-85</td>
<td>-</td>
<td>DC ELECT POS</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>REST</td>
<td>MMA</td>
<td>3.25mm</td>
<td>210-320</td>
<td>-</td>
<td>DC ELECT POS</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Filler metal spec and trade name: BS6309 ES154 [110243], Form 700 HT

Any special baking/drying: 250°C for 1 hour
Back gouging: N/A

Shielding gas type: -
Preheat temperature (min): 5°C

Flow rate (LPM): -
Preheat temperature (max): 200°C

Purging gas type: -
Post weld heat treatment: None

Flow rate (LPM): -
Time, temperature, method: -

Tungsten type/size: -
Heating and cooling rates: -

Nozzle size: -
Other information (e.g., unwelding): -

end of appendices