

THE ENGINEERING EQUIPMENT AND MATERIALS USERS ASSOCIATION

**RECOMMENDATIONS FOR
TUBE END WELDING:
TUBULAR HEAT TRANSFER EQUIPMENT
(Part 1 — Ferrous Materials)**

(formerly OCMA Specification No. TEW 1)

PUBLICATION No. 143



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45 Beech Street
London
EC2Y 8AD

Tel 0171 628 7878
Fax 0171 628 7862

e-mail sales@eemua.co.uk
www.eemua.co.uk



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THE ENGINEERING EQUIPMENT AND MATERIALS USERS ASSOCIATION

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OIL COMPANIES MATERIALS ASSOCIATION

SPECIFICATION NO. TEW-1 RECOMMENDATIONS
FOR TUBE END WELDING: TUBULAR HEAT TRANSFER
EQUIPMENT, PART 1 – FERROUS MATERIALS

FOREWORD

A joint meeting was convened in October, 1966, of members of the Oil Companies Materials Association Welding Panel and representatives of the Heat Transfer Society to exchange information on experience gained in making welded joints between heat exchanger tubes and tube plates; by welded joint, it is meant that the type of leaktight welded tube to tube plate joint considered in this specification, is intended to provide for the support of all loads envisaged and not merely a 'seal' to prevent leakage at the end of the expanded tube. It was the opinion of that meeting that an urgent need existed for standardised procedures to be established for the design, fabrication, inspection and testing of these and similar components. There being no national or international standard in existence which covered adequately this important subject, members agreed to pool their knowledge and experience, and to co-operate in preparing a recommended practice for Tube End Welding and Testing. Such a recommendation could then be used as a basis for specifying requirements for the oil, chemical and other industries.

This advisory document which is in SI units summarises the findings of the working group at the present time. After a period of circulation within industry, it is intended that these preliminary recommendations be subject to a complete review and the format rearranged to give a final presentation in three parts as follows:—

- PART 1 : (a) GENERAL
- (b) FERROUS MATERIALS
- PART 2 : NON-FERROUS MATERIALS
- PART 3 : MISCELLANEOUS

This document was produced under the auspices of the OCMA Welding Panel with the assistance of representatives of the Heat Transfer Society.

The Member Companies of OCMA expressly declare that they are completely at liberty to buy goods which do not comply with this specification whenever they desire to do so.

SPECIFICATION

1. SCOPE

- 1.1 This recommendation covers procedures for the tube end welding of tubes ranging from $\frac{1}{2}$ in. (15 mm) to $1\frac{1}{2}$ in. (40 mm) nominal diameter and from 1.6 mm to 4.1 mm in wall thickness to tube plates of 15 mm and over in ferritic and austenitic materials.

It may also be used for applications outside these limits provided that care is taken to ensure that all its requirements are relevant.

1.2 Examination of Materials

Tubes: All tubes shall be subject to visual examination before fitting. For some special duties it may be necessary, prior to assembly, to inspect the ends of the tubes for defects, by non-destructive testing; where this is specified, techniques and acceptance levels shall be subject to agreement between purchaser and manufacturer.

Tube Plates: All tube plates shall be examined visually for surface defects. It is recommended that the tube plate should be examined ultrasonically; acceptance levels shall be subject to agreement between purchaser and manufacturer.

2. WELDING PROCESS AND JOINT DETAIL

- 2.1 Care should be taken when designing, to ensure that an adequate ligament is obtained between tubeholes and spigots or division grooves.
- 2.2 The joint details shown in Appendix A are generally in accordance with the recommendations of I.I.S./I.I.W.-237-66 "Welded Connections for Pressure Vessels Part 6 Tube to tube plate connections".* Appendix B, Table 1, lists the typical combinations of joint detail and welding process commonly used in current practice. Special care should be taken when qualifying and using procedures which differ from these suggested typical arrangements.
- 2.3 In general, the qualification of welding procedures, competence, quality control and acceptance tests have been formulated with the following processes in mind (See Appendix D):—
- (i) Metal Arc
 - (ii) T.I.G. (with or without added filler)
 - (iii) Automatic T.I.G.
 - (iv) M.I.G. (semi- and fully automatic).**
- 2.4 When other welding techniques or joint preparations are used it may be necessary either to modify or to extend these requirements to ensure that adequate precautions are taken for the avoidance of faults peculiar to the procedure used. Special requirements of this character must be subject to prior agreement.

* See References, Item 1.

** See References, Item 2. (B.S.499 Part 1).

3. QUALIFICATION OF WELDING PROCEDURE

- 3.1 The non-destructive testing techniques currently available for the final acceptance of tube end welds cannot be relied upon to detect faulty welds with complete certainty. Therefore it is essential that procedure tests are conducted in strict accordance with this recommendation. Only such proven techniques shall be used in production.

At the discretion of the purchaser the results of previously authenticated procedure tests shall be acceptable.

The procedure test shall consist of the welding of nine tubes, if of square pitch. If the tubes are of triangular pitch, a three, two and three row formation shall be welded (see Appendix C. Sheet 1. Figs. 1 and 2). The test plate shall be welded in the same position as will be used in production, unless otherwise stated.

All tubes used for procedure testing shall be of the same diameter, wall thickness and nominal chemical composition as those proposed for production. Plate material to be used for the procedure test shall also be of the same nominal composition as that to be used in manufacture. The thickness of the sample tube plate shall equal that of the plate to be used in production, except that it need not exceed 40 mm thickness. If tube expansion after welding is specified, it may be necessary for a sample of full plate thickness to be employed (see Clause 14). The test piece shall be at least 25 mm greater in size all round than the limits of the tube hole array.

The completed test piece shall be sectioned by sawing or machining (as shown in Appendix C. Sheet 1. Figs. 3 and 4) and then polished and etched.

The sections shown in Figs. 3 and 4 shall also provide:

- (i) One transverse section of one weld crater for macroscopic examination.
- (ii) Two specimens for tear testing, where this test is specified by the purchaser.

3.2.1 Visual Examination

A visual examination of the welds shall show uniform contour without excessive reinforcement with the bores of the tubes free from any spatter, obstruction, weld spillage or overfill, which is considered to be detrimental.

On polishing and etching the section, the minimum throat thickness or leak path of each weld shall be not less than $0.7t$, where 't' is the nominal wall thickness of the tube. The size of imperfections other than as specified in Clause 3.2.3 shall be taken into account in assessing the dimensions of the minimum leak path.

The transverse sections of welds, including weld craters, shall be free from cracks, fissures and lack of fusion. Slag inclusions and gross porosity shall not exceed the limits specified in Clause 3.2.3.

3.2.2 Tear Tests (where specified)

The tube section of the tear test specimens shall be tongue bent to show the extent of weld penetration (see Appendix C, Sheet 1. Fig.5). The underside of the weld shall show evidence of adequate and uniform weld penetration.

3.2.3 Radiographic Examination

The three remaining complete welds shall be used to confirm either by X-radiography or by repeated skimming parallel to the tube plate surface, that the welds are free from porosity or other defects which would result in leakage in service. If radiography is used, the tube plate shall be reduced in thickness to not less than the maximum weld depth into the tube plate plus 2.5 mm but in any case the resultant thickness shall not be less than 6.5 mm. A fine grain high contrast film shall be placed in contact with the face of the tube plate and an ISO wire type Image Quality Indicator shall be placed on the face remote from the film. Sensitivity shall be better than 2%.

No cracks or cracklike defects shall be acceptable. Slag inclusions and isolated gross pores greater than $0.25t$ in diameter, where 't' is equal to the wall thickness of the tube, shall be unacceptable. Such pores in a procedure test shall automatically result in a retest which must not contain similar pores. Smaller pores may be allowable to a proportionately greater degree, at the discretion of the inspectorate.

- 3.3 Failure of any specimen from the welding procedure qualification test shall require complete requalification.

3.4 Weld Strength Tests

For ferrous materials, welding procedures that comply with the requirements of this recommendation will normally provide welds approaching or attaining the full tensile strength of the tube. Strength tests are not mandatory for ferrous materials. If a test of weld strength is specified, it is recommended that the tube should be pulled out through the back of the tube plate and the breaking load recorded (see Appendix C, Sheet 2); provided that all requirements of this recommendation are met, the minimum acceptable strength shall be as agreed between purchaser and manufacturer. Where fracture occurs in the weld, this shall not necessarily be cause for rejection, but the fracture should be examined for any evidence of faulty workmanship. "Push through" tests, where the tube is pushed from the back and through the face of the tube plate, are unreliable; they may indicate exceptionally high strength due to the deformation of the tube under high compression stress, resulting in the tube expanding into the tube plate and developing a high frictional force in addition to the force required to cause failure of the weld joint.

4. QUALIFICATION OF WELDING OPERATORS

- 4.1 Every operator employed for welding shall be required to produce evidence of his ability by making a test sample similar to that prescribed for welding procedure qualification in Clause 3. This sample shall be subject to the same tests and acceptance limits.
- 4.2 The purpose of this operator qualification test is to demonstrate that both the welding operators and/or welding machines are capable of producing satisfactory joints (See Clause 10.1).
- 4.3 Welders who have previously qualified within the last six months or who are currently working on similar materials using similar techniques shall be acceptable without further qualification. (See Clause 18).
- 4.4 An operator who welds test pieces that meet the requirements of Clause 3 is deemed to qualify for production welding.

5. PREPARATION OF TUBES AND TUBE PLATES

- 5.1 The ends of the tubes which are to be welded shall be cleaned and degreased with a suitable non-residue forming solvent, both inside and out, for a length equal to the tube plate thickness plus not less than 25 mm. It is recommended that the solvent used for degreasing materials should be chloride free, e.g. acetone*. For welding with the T.I.G. process, the outside ends of the tubes for a minimum distance of 13 mm shall be finished to bright metal, e.g. by finishing or power brushing. For metal arc welding the tube ends may be grit blasted prior to cleaning and degreasing as agreed. Tubes with score marks or any other surface irregularities at the ends shall not be used if considered to be detrimental to the production of sound welds (see Clause 3.2.1).
- 5.2 The tube plates shall be machined and the tube holes bored or drilled as required by the design; the holes so formed shall be normal to the tube plate surface, parallel, circular and shall have smooth internal surfaces. They shall be free from burrs and the shell side edges of the tube holes shall be chamfered or radiused to 1.5 mm approx. It is recommended that the limits of tolerance of tube holes shall not exceed those defined by T.E.M.A.** Immediately prior to assembly, the plates shall be thoroughly cleaned and degreased using a non-residue forming solvent.

It is recommended that the solvent used should be chloride free, e.g. acetone.

- 5.3 The face of the tube plate, the holes and the tubes shall be free from dirt, grease, scale and other foreign matter when they are assembled. To avoid possible damage during assembly or entrapment of contaminants, baffle and support plate holes should be free from burrs and effectively cleaned prior to the commencement of tube threading.

6. TUBE LOCATION

- 6.1 An accurate fit-up and intimate contact between the tube extremity and tube plate is recommended; to achieve this, the tube end may be flared slightly by means of a *clean dry* tapered drift or punch. Alternatively, when it is required to move the assembly prior to welding, a light roller expansion to a maximum depth of 40 mm is permissible. Such expansion may cause difficulties during welding and for this reason, it is not recommended. To minimise attendant difficulties, expansion should be made without the use of lubricant and preferably by means of a tapered expander.
- 6.2 When manual T.I.G. welding with filler is to be used, the tubes may be located by means of "tack" welds. All such "tacks" shall be completely fused during subsequent tube end welding.

By agreement, special punches or methods may also be employed to secure tubes to the tube plate, e.g. the punch may be designed to enable three equally spaced teeth to throw burrs from the tube plate hole towards the tube. All burr depths must be sufficiently shallow to enable all such areas to be fully fused out during welding.

* The use of acetone involves a fire hazard and appropriate precautions should be taken. See also References Item 3.

** See References. Item 4.

7. PREHEAT AND INTERPASS TEMPERATURE

- 7.1 Even in tube plates of considerable thickness, the effect of metal removal to form a large number of holes arrayed in close proximity, usually separated only by comparatively thin ligaments, results in a significant reduction in the mass quench effect.

Due to the variation in geometric profile, ligament thickness and joint detail which influence the quench rate, it is impracticable to simulate actual production welding conditions in conventional tests devised to determine appropriate preheat temperatures.

Although the effect of ligament thickness variation, proximity to flanges, etc., must be borne in mind, the following preheat temperatures, tabulating empirical values based on practical experience may be used as a general guide.

Tube Plate	Preheat Temperature
Carbon ($\leq 0.26\%$) steel	No preheat *
Carbon ($> 0.26\%$) steel	50°C. min
C. $\frac{1}{2}\%$ Mo)	
1% Cr. $\frac{1}{2}\%$ Mo.)	100°C. min
1 $\frac{1}{4}\%$ Cr. $\frac{1}{2}\%$ Mo.)	
2 $\frac{1}{4}\%$ Cr. 1% Mo.)	200°C. min
4 $\frac{1}{6}\%$ Cr. $\frac{1}{2}\%$ Mo.)	
18% Cr. 8% Ni.	None *

* No welding is permitted if the plate temperature is below 5°C.

These preheat temperatures are appropriate when using filler metal of matching composition; when austenitic filler metal is used, the preheat may be substantially less and shall be established in the procedure test.

- 7.2 The preheat and interpass temperature used in production shall be, within practical limits, the same as that used in the procedure test. Experience has shown that because of the increased restraint offered by the larger assembly, the preheat necessary in production may exceed the minimum necessary to obtain satisfactory welds in the procedure test. For this reason an allowance should be made for this effect in determining the preheat temperature chosen for the procedure test. Temperatures shall be measured preferably by contact pyrometer; alternatively temperature indicating crayons may be employed, care being taken not to contaminate welding zones.
- 7.3 In the event of welding being interrupted, the weld joint shall be insulated and allowed to cool slowly if the interpass temperature is not maintained. Before welding is resumed, the section to be welded shall be brought back to the required preheat temperature.

When welding is completed, the joint shall be allowed to cool slowly.

- 7.4 Electrical means of pre-heating shall be used wherever possible. Fixed gas burners may be used for preheating and maintaining the preheat, provided that an adequate degree of control can be demonstrated.

8. WELDING

- 8.1 The tubes shall be welded to the tube plate using the approved procedure (Clause 3). Welding shall be carried out preferably in the flat position, i.e. with the tube plate horizontal. Welding with the tube plate vertical shall also be permissible where practicable, but attention is drawn to the difficulty of ensuring uniform throat thickness around the periphery of the weld. Welding with the tube plate in any other position shall also be acceptable provided it is proven by procedure test. Any over-run or spillage of weld metal into the bores of the tubes which is considered detrimental shall be cleaned out and spatter removed.
- 8.2 All tubes shall be welded individually. Such procedures as 'figure 8' welding and other complex welding patterns are not recommended.
- 8.3 The tube joints shall be welded in such a manner as to minimise distortion of the tube plate. Unless otherwise agreed, where multi-run welds are used, no second run shall be deposited until the first run has been completed, cleaned as necessary and the weld visually examined.
- 8.4 The final choice of the type of joint preparation detail which is influenced by many factors such as proposed service, design requirements, or selection of welding process to be employed, shall be limited to one of those illustrated in Appendix A, 'Joint Details' or specified in Appendix D 'Selection of Welding Process'. Other forms of preparation may however be utilised by agreement with the purchaser if shown to be satisfactory and if they meet the requirements of these recommendations.

9. POST-WELD HEAT TREATMENT

- 9.1 The post-weld heat treatment of complex assemblies such as welded tube end connections may present difficulties. Where acceptable, consideration should be given to methods of eliminating the need for post-weld heat treatment, including the possible use of austenitic stainless steel electrodes in preference to ferritic electrodes, even of the extra low carbon variety.

- 9.2 Where post-weld heat treatment is essential to reduce the hazard of stress corrosion cracking associated, for example, with nitrate or caustic service, it is important that the rate of heating and cooling during heat treatment is controlled to avoid the possibility of weld fractures and excessive tube distortion.

The heat balance between the tubes and shell, etc. must be controlled so as to avoid excessive temperature differences. Where practicable, the assembly shall be charged into a cool furnace, the temperature raised slowly and uniformly to the required post-weld heat treatment temperature and then allowed to cool to ambient temperature within the furnace. Provision for adequate tube support to limit distortion must be considered at the design stage. The precise procedure and temperature shall be agreed beforehand between purchaser and manufacturer.