VOL. 11, NO. 12, JUNE 2016 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

PROPOSED GUIDELINES FOR WELDING PROCEDURES TO ENSURE QUALITY WELDING OF CREEP STRENGTH ENHANCED FERRITIC (CSEF) MATERIALS

Muhammad Sarwar, Mohd Amin Bin Abd Majid and Mokhtar Che Ismail
Mechanical Engineering Department, Universiti Teknologi Petronas, Bandar Seri Iskandar, Tronoh, Perak, Malaysia
E-Mail: sarwar_sa@hotmail.com

ABSTRACT

The creep-strength enhanced ferritic (CSEF) materials are enormously used for noncorrosive high-temperature application with very high strength at elevated temperatures. The use of these materials for steam piping, super-heater headers, boiler tubes, boiler drum and pressure vessels in supercritical power plants, do require special attention and consideration as the cost of repair is normally higher than the original work cost. The aim of this paper is to provide the guidelines for necessary checks and inspections to be carried out to prevent any defect or premature failure of welds. The focus of these guides, supplement to the well-known ASME and EN standards, is the welding of CSEF materials for combined cycle, supercritical and ultra-supercritical power plants. Assessment of base metal and filler materials, prior to start of any activity is vital for a quality weld. The qualifications of welding procedures and welders obligatorily be done according to the welding procedure specification. The welding techniques and associated equipment come in precautionary phase. The welding input parameters require strict control during welding and appropriate preheat and post weld heat treatments mandatorily be carried out, It is noted that if applicable and appropriate checks are carried out, the weld with required properties can be made and premature failure of these sensitive welds can easily be prevented.

Keywords: CSEF, P91, welding, WPS, WPQR, WQTR, NDT, preheat, PWHT.

INTRODUCTION

The development of Cr-Mo ferritic steels, ranging from 1% to 12% Cr-Mo for ultra-supercritical power plants has led to motivate the power plants to review the welding procedures that are used to fabricate pipe works etc. using these steels. Among these steels is the modified 9Cr-1Mo-0.2V (P91) alloy steel. The P91 is now extensively used all over the world in petro chemical industries, power generating plants and fossil fired boilers (Sireesha *et al,* 2001).

The choice of this material is due to its improved and exceptional properties compared to other materials with same diameter and thickness. Nearly 2:1 reduction in thickness and an increase of 44 to 170% in allowable strength in the 510-570 ºC temperature range is noted when compared to P (T) 22 material (Coussement C, 2001).

Welding is the important means of fabrication for many of these applications and hence the welding characteristics of P-91 alloy steel constitute an important criterion for its selection (Arivazhagan *et al*, 2009).

It has been noted that P-91 steel can be welded satisfactorily by many processes including shielded metal arc welding (SMAW), gas tungsten arc welding (GTAW) and submerged arc welding (SAW) process (AWS WHB-1.9 2002).

In any welding process the input parameters have an influence on joint's mechanical properties. By varying the input process parameter's combinations such as welding current, voltage, welding speed, size and type of consumable, pre and post weld heat treatment, the output would be different welded joints with significant variation in their mechanical properties (Shibli at et, 2007).

During the welding of P-91, the pre-heat and inter-pass temperature helps to prevent the possibility of hot cracking while after welding, the application of post weld heat treatment (PWHT) is absolutely necessary to reduce the residual stresses that remain locked in a structure as a consequence of manufacturing processes and lead to cracking (Shibli at et, 2007).

For the CSEF steels, proper preheat, PWHT, and monitoring are not optional, they are mandatory. Lessons learned with P(T)91 weldments have truly demonstrated that these advanced chromium-molybdenum (Cr-Mo) steels are quite different and require significantly more attention than the P(T)22 and more traditional chromium molybdenum alloys. Greater attention to weld metal selection, preheat, and post-weld heat treatment are some of the reasons that the CSEF alloys must be treated differently (Fab91, 2011).

Competent, experienced engineering and supervision are required to successfully obtain the mechanical properties that can be realized with the CSEF steels. All rules, technical requirements, and procedures must be followed, verbatim. Overlooking these facts will more than likely result in problems and/or premature failure (Fab91, 2011).

Although there are standards available to provide guidelines for the welding of steels, these are not structured in a simple and straightforward way. This study aims to develop structured guidelines for the welding of P91.

METHODOLOGY

The methodology for the necessary checks and inspections, to prevent any defect or premature failure of

VOL. 11, NO. 12, JUNE 2016 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

weld, for the welding of CSEF materials for supercritical power plants are shown in Figure-1.

These guidelines are supplements to the standard technical requirements for welding and non-destructive examination (NDE) to be performed by the Erection Contractor during field prefabrication and site erection of power plant pipework and associated support equipment made from such creep-strength enhanced ferritic steels.

These guidelines also define in particular the applicable Codes and Standards, the welding and heat treatment requirements, NDE of welded joints and reference in process control documents.

It is normal contractual responsibility of the erection contractor (if required by contractual agreement), for the arrangement of proper material, the welding consumables, preparation and qualification of welding procedure specifications (WPSs), the qualification of welding and NDE personnel, the performance of NDE and interpretation of test results, the follow-up of welding and NDE results, the compilation of prefabrication and erection conformity data packages as required by the relevant Quality Control Plans (QCPs) and/or Inspection and Test Plan (ITP) and/or Erection Control Programme.

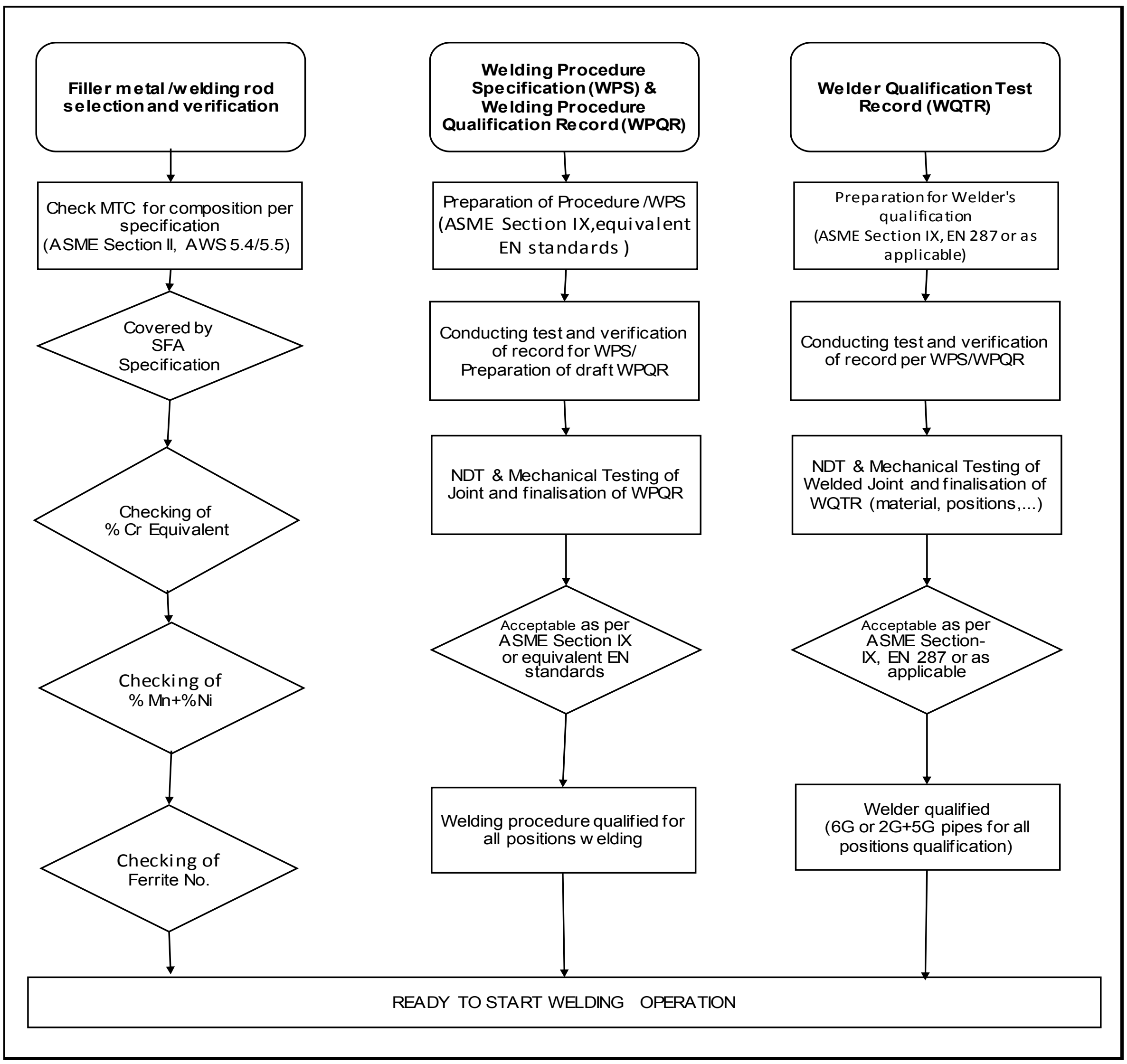

Figure-1. Pre welding checks of creep strength enhanced ferritic (CSEF) materials for combined cycle and supercritical power plant.

RESULTS AND DISCUSSIONS

The welding and NDE requirements provided in these guidelines are mainly based on the relevant book sections of the ASME Boiler and Pressure Vessel Codes, 2010 Edition.

It must be noted that some of the requirements given in these guidelines are over and above the Code requirements and are based on the experience of power plant construction experts.

SELECTION OF FILLER METALS

The filler metals used to produce CSEF welded joints must be procured with batch certificates to the relevant SFA specifications.

A filler metal not incorporated in SFA specification can be used only if a procedure qualification test is first successfully made in accordance with ASME IX.

Filler metals procured for the welding of austenitic stainless steels must have a delta ferrite number (FN) between 3 and 15FN. The FN must be shown on the batch certificate. The FN of GTAW filler wire may be predicted from its chemical composition. The FN of SMAW electrodes must be measured on a weld pad in accordance with AWS A5.4.

The erection contractor must control the storage, drying and issue of welding consumables to the welders in accordance with a written procedure approved by the main contractor.

WELDING PROCEDURES AND QUALIFICATIONS

General requirements

The erection contractor, responsible for the welding performed by his organisation, must produce his own WPSs based on the guideline procedures provided by the main contractor or as per the applicable codes and standards for use either in the site prefabrication shop or at site. No welding to be permitted without a WPS qualified by Third Party or Notified Body.

The qualification of welding procedures must be complied with the requirements of ASME Section IX and the applicable design code. Heterogeneous welding must also be qualified according to ASME requirements, especially, P91 welding with P22. Qualifications of a WPS to previous Editions of ASME Section IX is permitted only subject to review of the WPS and its supporting PQR.

A WPS for a pipe butt weld must be qualified using a single V-groove test coupon consisting of two pipes. The V-groove to be filled with the test coupon orientated either in 2G and 5G positions or in 6G position to cover the all positional welding requirements of ASME IX. The qualification of WPS for the butt welding of a pipe using a plate butt weld is not permitted. However, a WPS qualified for a pipe butt weld is also qualified a WPS for a plate butt or fillet welds.

The welder or welding operator who produces the test coupon is automatically qualified within the positional scope of the test coupon. The actual testing operations such as bend testing, tensile testing, radiography or macro etching hardness testing must be conducted by independent laboratory (ies) on test specimens removed from the qualification test coupon under the direction of the erection contractor.

Mechanical testing for WPS/WPQR

The test coupons produced for WPS qualification are subjected to the same level of PWHT and NDE as the production welds, prior to removal of specimens for mechanical testing. The specimens must be located outside the region of gross imperfections (e.g. porosity, slag inclusions, etc.) revealed by NDE. The specimens for mechanical testing must be removed from the test coupon by mechanical methods in accordance with figures shown in QW-463, ASME IX.

The number of specimens required for the mechanical tests and the acceptance criteria are defined below:

Transverse tensile tests:
Number of specimens: 2
Acceptance criteria:

a) Specified minimum tensile strength of the base metal; or

b) Specified minimum tensile strength of the weaker of the two base metals; or

c) If the specimen breaks in the base metal outside the weld or fusion line, the test shall be accepted as meeting the Code requirements, provided the strength is not more than 5% below the specified minimum tensile strength of the base metal.

Guided-bend tests:
Number of specimens: 4
Mandrel diameter: as per QW 466.1, ASME IX
Bending angle : 180º
For T < ¾" (19 mm): 2 face bends + 2 root bends or 4 side bends
For T ≥ ¾" (19 mm): 4 side bends
Where T = base metal or specimen thickness.

Acceptance criteria: No open defects > 1/8" (3 mm) in weld or heat affected zone (HAZ) in any direction on the convex surface.

NB. As a guide, the length of the bend test specimens should be at least 1.5 x mandrel o.d. with a minimum of 150mm and a maximum of 400mm

Macrographic examination

A transverse section must be removed from any suitable position from the test coupon and prepared for metallographic examination by conventional grinding, polishing and etching methods. The prepared test specimen must not exhibit any crack or lack of fusion type of defects. A photo-macrograph of the specimen must be included in the PQR.

Hardness tests

Hardness measurements must be made according QW 462.12, ASME IX, on the base material, HAZ and weld metal on the transverse section taken for macrographic examination. The hardness test results must be included in the PQR and must not exceed the guidance values given in applicable code.

The number of specimens required for the mechanical tests (Transverse tensile tests, Guided-bend tests, Macro graphic examination, Hardness tests etc.) and the acceptance criteria for WPS/PQRs must be according to the ASME IX requirements.

WELDER QUALIFICATIONS

General requirements

It is standard erection contractor's responsibility to conduct welder performance qualification of all welders in his employment in accordance with the requirements of ASME Section IX. All performance qualifications must be performed at the erection contractor's welding facilities at site or at a designated location and must be qualified by Third Party or Notified Body.

The actual testing operations such as guided bend testing and radiography must be performed by independent laboratory on test specimens removed from the qualification test coupon under the direction of the Third Party or Notified Body.

Performance test records of welders issued by a previous employer in lieu of welder qualification tests performed by the erection contractor are not acceptable.

The erection contractor must maintain written records of his welder performance qualifications. The records must contain the WPS used for qualification, the qualified range of base metals and thickness range, pipe diameters, qualified positions and renewal date. These records must be kept at site and to be made available for review.

Welding positions

The test coupon for a welder performance qualification for pipe welding must be welded in either 2G and 5G positions or 6G positions to qualify for all positional welding as required by ASME IX. When the all positional qualification test is carried out in 2G and 5G positions by a team of welders, a 6", 8" or 10" or larger diameter pipe must be used as the test coupon.

The deposited weld metal thickness for each welding process used by each welder must be recorded. For performance qualification in 6G position, the range of pipe diameters, thicknesses, joint geometry and steel grades requiring qualifications must be according to the job requirements.

Visual examination

Visual examination of performance test coupons must show complete joint penetration and fusion between base metal and weld metal over the entire circumference, both inside and outside.

Mechanical testing for WQTR

Type and number of guided bend test specimens required for welder qualification is governed by the pipe thickness and the position in which it was welded. The location of bend test specimens is shown schematically in QW-463, ASME IX. The acceptance criteria for guided bend tests are given in QW-163, ASME IX.

Radiographic examination

Performance test coupon produced for welder qualifications at site are examined by radiographic method in lieu of mechanical testing. The results of radiographic examination must be assessed in accordance with QW-191, ASME IX.

Table-1. Summary of technical requirements for welding and non-destructive examination (NDE) of P91.

JOB	APPLICABLE CODE/STANDARD	
WELDING Welding procedure qualification Welder's qualification Record	ASME IX ASME IX	
NON DESTRUCTIVE EXAMINATIONS	Performance requirements	Acceptance Criteria
Radiographic examination	ASME V	ASME B31.1 + ASME VIII , DIV 1 - UW52
Ultrasonic examination /Phased Array UT (in lieu of radiography)	ASME V	ASME B31.1
Liquid penetrant examination	ASME V	ASME B31.1
Magnetic particle examination	ASME V	ASME B31.1
Visual examination	ASME V	ASME B31.1
NDE operator qualification	SNT-TC-1A Level 2	SNT-TC-1A Level 2
NDE operator qualification for PED projects	EN 473 Level 2	EN 473 Level 2

WELDING PREPARATION

Welding processes

Gas tungsten arc welding (GTAW) is usually prescribed for on-site prefabrication and erection of alloy steel pipework and associated supports for root runs and filling (for pipes with small wall thickness). The use of backing rings and peening of weld metals is prohibited.

For stainless steels and alloy steels, an argon back purge is essential for the root pass and has to be maintained until the thickness of deposited metal reaches 5mm minimum. Argon backing is usually used in accordance with the qualified WPS.

Weld types-butt welds

Weld end preparations for pipework usually consist of a single bevel (or chamfer) V- preparation for materials up to 22 mm in wall thickness and a compound double bevel V-preparation for materials above 22 mm in thickness. The dimensioned groove preparation is usually identified in the WPS, and the applicable drawing.

Alignment of parts to be welded

All piping alignment must be done by mechanical methods of restraint or by clamps. Preheating, when required by the WPS, is performed with the clamps in-situ.

For circumferential butt welds, the misalignment of inside diameters of pipes less than 20mm thick is normally within T/20 + 1mm parameter (where T = thickness), and for pipes 20mm or greater in thickness the misalignment of inside diameters is kept 2mm maximum. Where the internal misalignment due to diameter differences exceeds the above limits the item with the smaller inside diameter is counter-bored with a slope of 30^{o} maximum provided the minimum design wall thickness (including corrosion allowance) is maintained.

Tack welding

Tack welding must be performed by qualified welders using the same welding process and parameters as those specified on the WPS for the root run. When preheat is specified on the WPS, it is applied prior to tack welding. On completion, the tack welds are wire brushed and visually examined for cracks. Defective tack welds are removed or repaired. The stop/start positions of a tack weld are feathered by grinding and the tack weld blended into the root run. The spacers used are of same material grade as the parts to be assembled.

WELDING PREHEAT

Preheating must be carried out using one of the following types of equipment.

- Induction heating
- Resistance heating.

Preheating with electrical equipment is mandatory for alloy steel pipework.

The minimum width of the preheated band on each side of the joint to be welded must be equal to three times the pipe wall thickness. Preheat and interpass temperatures may be measured by thermocouples or contact thermometers. When preheating two components with different preheat temperature requirements, the higher preheat temperature shall be used.

For P. No. 5B (ASTM A335 Gr. P91), the weld have to be cool down to 70°C minimum just before this post heat treatment.

PERFORMANCE OF WELDED JOINTS

Welding equipment

The suitability of the welding sets must be proven by the results of the WPS qualification tests. The welding cables must be inspected regularly to detect any damage or defect in their insulation. The cable connections must be correctly insulated and the earth connections fixed securely to prevent any stray arcing on surrounding pipes and components. The electrode-holders must be of a recognized model and kept in good condition.

Surface conditions

The surfaces to be welded must be clean, free of grease, varnish, paint, etc. for a 25mm wide band on either side of the groove edge.

Welding

The joint preparation and surrounding base metal up to a distance of 25mm on both sides of the joint shall be cleaned by a mechanical method and degreased using a lint free cloth soaked in a halogen free solvent, e.g. white spirit. The joint preparation shall be continuously back purged with pure argon to prevent oxidation during deposition of tacks and/or root run. The back purge shall be maintained until a minimum of 5mm of weld thickness has been deposited.

The complete joint shall be filled using stringer bead technique with a minimum of weave. The interpass temperature during welding shall not exceed 200 ^{o}C.

Weld defect repair

Repair welds must meet the same requirements as the original weld (WPS, welder's qualification, preheat, PWHT and NDE). The excavation for repair welding shall be a similar as possible in shape to the original weld preparation. The excavation shall be inspected by a suitable surface crack detection method before repair welding.

Maximum of three (3) repair welds are allowed on the same area of a joint. If further repairs are required, the causes of these successive repairs shall be analysed by the erection contractor and presented to the main contractor's representative, who shall decide whether further repairs are permissible.

Interruption of welding

Once welding has commenced, the normal field practice is to completely fill the joint without interruption to welding. However, if an interruption in welding is required, then it is essential that the deposited weld

ARPN Journal of Engineering and Applied Sciences

thickness is equal to the lesser of 10mm or 25% of the joint thickness. The partially filled weldment must be immediately covered with thermal insulation blankets, kept dry and the weld allowed to cool slowly.

The partially completed weldment in P. No. 5B (ASTM A335 Gr. P91) material shall receive an intermediate PWHT before resumption of welding. The temperature for intermediate PWHT shall be in the range of 670 – 700^{o}C for a minimum period of 2 hours, only after cooling of welding (70°C minimum). The rate of heating and cooling above 315^{o}C shall not exceed 100^{o}C per hour.

Miscellaneous welding requirements

Adequate protection from natural elements (wind, rain, snow, etc.) where welding is going to be performed, must be provided. The preheat and interpass temperatures used in welding must be in accordance with those specified on the WPS.

The root pass of single-sided circumferential butt welds, accessible from the outside only, must be made with GTAW process with added filler metal.

All piping filling and capping passes must be deposited in a circumferential direction only. Welded joints must be made by completing each weld layer before succeeding weld layers are deposited. At least two weld layers are required on pressure retaining butt and fillet welds.

All socket welds must have a minimum of two weld layers. Each weld layer must be visually inspected for defects. All defects and slag found must be removed by chipping and grinding prior to the deposition of the second weld layer. It is recommended that socket welds in pipe materials 6mm thick or less and 4" NPS or smaller are deposited using GTAW process.

All qualified welders must be provided with a low stress identification stamp. The welder must stamp each of his welds with his identification. The stamp must be located on the base material adjacent to the weld.

HEAT TREATMENT AFTER WELDING

Post weld heat treatment (PWHT) shall only be performed by induction heating or by resistance heating. The furnace heating is not recommended for P91 and P92, in order to protect base metals

The equipment used for PWHT shall be calibrated and the calibration certificates shall be available at site.

Prior to PWHT, the weld and surrounding region on either side shall be clean and free from injurious materials including low melting point materials such as tapes or markers. PWHT temperatures shall be controlled by thermocouples and recorded. Calibration certificates of temperature recording devices shall be available at site.

Heat treat requirements

Before applying preheat or PWHT, it must be ensured that the heat treatment parameters, i.e. temperature and time, are within the scope of a qualified WPS.

Typical preheat/PWHT cycle required for A335 Gr. P91 is shown in Figure-2.

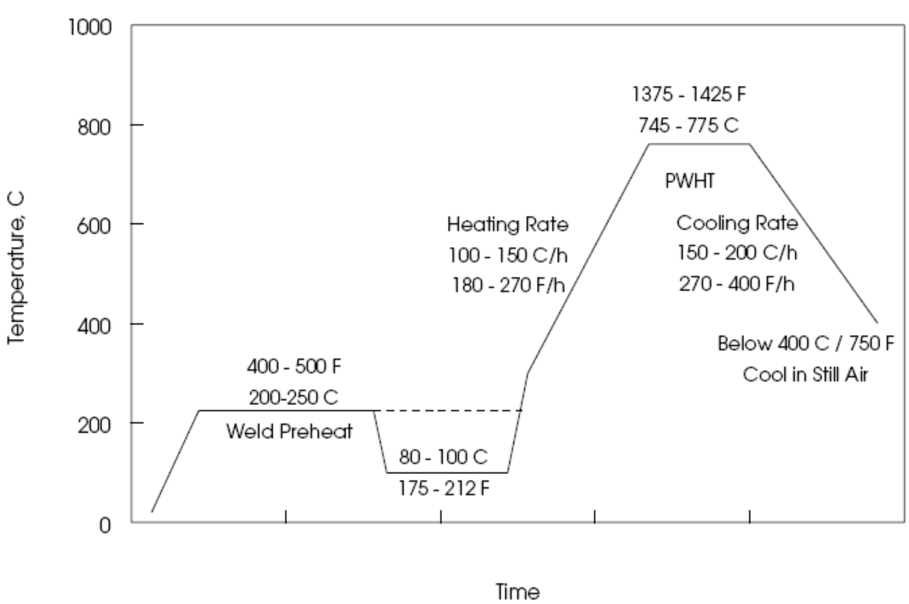

Figure-2. PWHT Chart for CSEF materials (ASME).

Any deviation in these parameters beyond the limits given in the Code shall require review. Particularly for P91 weld, in the case of storage after welding and before PWHT, the maximum time should be one week and during this time the components must be kept dry. The preheat, post weld and PWHT are mandatory for A335 Gr. P91.

VOL. 11, NO. 12, JUNE 2016 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

During PWHT of a dissimilar metal weld between materials of two different P Numbers which require PWHT at different temperatures (P22 and P91), the PWHT temperature specified shall be for the material requiring higher PWHT temperature. However, it is essential to ensure that the higher temperature does not cause metallurgical damage to the weldment.

Thermocouples and temperature gradients

Thermocouples shall be attached to the work by the direct wire capacitance discharge method or a mechanical fastening method. Hot junctions shall be thermally insulated from direct radiation from the heating elements by application of a minimum of 3mm thick mineral or ceramic fibre insulation or high temperature putty.

The disposition of heating elements shall be such as to obtain a temperature profile which is approximately symmetrical about the weld centre line for a distance of 3T on either side of the weld centre line plus one weld width (where T = the thickness of the thickest part to be joined). The minimum width of band heated to the PWHT temperature shall be equal to a distance of 1½T from the groove edges on either side of the joint.

At least four thermocouples shall be used to control the PWHT cycle. The thermocouples shall be located at 12 and 3 o'clock positions on one side and at 6 and 9 o'clock positions on the other side of the joint. All thermocouples shall be placed at a distance of 1½T from the groove edges. For piping diameter equal or less than 2 inch with electrical heating, the number of thermocouples may be reduced to 1. On completion of PWHT, the thermocouples shall be removed by grinding.

In case of a power cut, cover the weld immediately with thermal insulation blankets in order to limit the cooling rate. Providing the cooling rate is less than 200 ºC/h, PWHT shall be resumed under the following conditions:

a) If PWHT is interrupted in the heating up period, resume PWHT from the temperature reached.

b) If PWHT is interrupted during the holding time at temperature, the new holding time at temperature is equal to the difference between the scheduled time lapsed and the remaining time multiplied by 1.5.

NON-DESTRUCTIVE EXAMINATION

All non-destructive examination (NDE) performed shall be in accordance with written procedures which must comply with the appropriate articles of ASME Section V.

NDE shall be performed by operators who are trained and qualified to SNT TC 1A Level 2 (personnel Qualification and certification in NDT) or an equivalent qualification. It must be ensured that the NDE operators qualification certificates and medical examination reports are kept up to date and are available at site.

It must also be ensured that all NDE equipment are calibrated and are in good working condition. Calibration certificates of NDE equipment shall be available at site.

Table-2. Summary of NDE requirement.

TEST	**ASME CODE**		
Design conditions	T>400ºC All Pressures	175<T≤400ºC & P>71 bars	Other
BUTT WELDS			
Visual examination ASME V, ASME B31.1	100%	100%	100%
Radiographic examination, ASME V, ASME B31.1	100% for ∅ > 2" & thickness ≤ 2”	100% for ∅ > 2" & thickness > 19mm Random for others	Random exam.
Ultrasonic examination/ PAUT ASME V, B31.1	100% for thickness > 2"	100% for thickness > 2"	-
Liquid Penetrant or Magnetic Particle Test ASME V, B31.1	100% for ∅ ≤ 2"	100% for ∅ ≤ 2"	-
Hardness for A335 P91, ASME II	**100%**	**100%**	-
PMI for A335 P91, ASME II	**100%**	**100%**	-

Note: Ultrasonic examination may be used in lieu of radiographic examination. The results of random examination will also be used to analyse the quality of a welder's performance and recorded in the follow-up documentation. The acceptance criteria shall be in accordance with ASME Section VIII Division 1 UW 52: "Spot Examination of Welded Joints".

NDE methods

The NDE methods shall consist of:

Visual examination

Visual examination shall be performed on all welds observing the joint preparation, cleanliness and fit-up, welding consumables, WPS and in process control, weld profile, surface appearance, weld root profile and reinforcement where possible and workmanship of finished weld.

Surface examination

Surface examination of a welded joint where required shall be performed by either magnetic particle or dye penetrant inspection methods given in ASME V and the results evaluated in accordance with ASME B31.1.

Radiographic examination

Radiographic examination shall be performed in accordance with ASME Section V, Article 2. Radiographs of field welds shall be evaluated in accordance with the acceptance criteria given in ASME B31.1. The double film exposure technique shall be used to obtain radiographs of field welds which require mandatory radiographic examination. The radiographic film used shall be ultra-fine grain Kodak M or AGFA D4 or equivalent. The single film exposure technique with fine grain Kodak AX or AGFA D7 or equivalent film may be used for random examination of other welds. Radiographic films must be developed and assessed within 24 hours after exposure.

Ultrasonic examination

Ultrasonic examination shall be performed in accordance with ASME Section V, Article 4. Ultrasonic of field welds shall be evaluated in accordance with the acceptance criteria given in ASME B31.1.

Phased array ultrasonic testing

Phased array ultrasonic testing (PAUT) or recordable UT shall be performed in accordance with ASME Section VIII, Division 1 and shall be evaluated in accordance with acceptance criteria given in ASME B31.1.

NDE of welded joints

The extent of NDE required for pressure retaining welds and attachment welds to pressure retaining systems are summarised below in Table-1 and Table-2.

CONCLUSIONS

The guidelines provided in this paper are the necessary checks and inspections to be carried out to prevent any defect or premature failure of weld for the welding of CSEF materials for combined cycle and supercritical power plants. The obligatory checks for the assessment of base metal and filler materials for actual chemical composition provide elementary confidence. The welders qualified according to the welding procedures qualification record enhance the assurance. When the welding input parameters are controlled during welding and proper preheat and post weld heat treatments are carried out timely, the weld with required properties can certainly be made and premature failure of these sensitive welds can definitely be prevented.

REFERENCES

Sireesha, M., Albert, S.K., Sudaresan, S., "Microstructure and Mechanical Properties of Weld Fusion Zones in Modified 9Cr-1Mo Steel", Journal of Marterial Engineering and Performance, pp. 320-330 (2001).

Coussement, C., “New Ferritic/Martensitic Creep Resistant Steels: Promises and Challenges in the New Century”, EPRI Conference on 9 Cr Materials Fabrication and Joining Technologies, Myrtle Beach, SC. (2001).

Arivazhagan, B., Prabhu, R., Kamaraj, M., Albert, S.K., Sudaresan, S., "Microstructural and Mechanical properties of 9 Cr-1 Mo steel weld fusion zones as a function of weld metal composition", Journal of Material engineering and Performance, 18(8), pp. 1000-1004 (2009).

Welding Handbook Volume 1 - Welding Science and Technology, (AWS WHB-1.9 2002).

Shibli, A., Starr, F.,"Some aspects of plant and research experience in the use of new high strength martensitic steel P91", International Journal of Pressure Vessels and Piping, pp. 114-122 (2007).

Fab91, “International Workshop on Fabrication and Processing of Grade 91 Material” Tiruchirappalli, India (2011).

Welding and PWHT of P91 Steels, Valve Manufacturers Association of America, USA (2013).

Guidelines and Specifications for High-Reliability Fossil Power Plants: Best Practice Guideline for Manufacturing and Construction of Grade 91 Steel Components. EPRI, Palo Alto, CA: (2011).

ASME Section II - Materials, (ASME Boiler and Pressure Vessel Code) American Society of Mechanical Engineers (2013).

ASME Section V - Non-destructive Testing, (ASME Boiler and Pressure Vessel Code) American Society of Mechanical Engineers (2013).

ASME Section VIII - Pressure Vessels - Division I, (ASME Boiler and Pressure Vessel Code) American Society of Mechanical Engineers (2013).

ASME Section IX - Welding and Brazing Qualifications, (ASME Boiler and Pressure Vessel Code) American Society of Mechanical Engineers (2013).

ARPN Journal of Engineering and Applied Sciences

ASME B31.1 - Power Piping, (ASME Boiler and Pressure Vessel Code) American Society of Mechanical Engineers (2013).

Manjung 4: An ultra-supercritical first in Southeast Asia, Power Report by PEi-Power Engineering International, Pennwell Corporation, Essex - UK (2012).

AWS D10.10 - Heating Practices for Pipe and Tube, American Welding Society (2010).