Inspection and Welding Repairs of Pressure Vessels

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ABSTRACTS

Repairs are required for pressure vessels in order to restore its original / intended operating condition, safe operation and to prolong trouble free service life. The vessel condition deteriorate due to various factors mainly Mechanical Problems, Process Related Problems and Corrosion Problems. Repairs are required to be planned and carried out under the strict supervision and control of a competent Inspector.

The paper briefs the various steps involved in:

- Decision making for the repairs depending on location and nature of defect within the pressure vessel as per ASME as well as API 510 code.
- Welding procedure qualifications .
- Materials and Welding consumables to be used for procedure qualification .
- Requirements and limitations of controlled deposition welding as an alternative to PWHT, or where Impact testing is a requirement .
- By using preheating methods where Impact testing is not a requirement .
- Method of “Temper bead techniques” .
- Method of “Half bead technique”.
- NDT that can be employed before, during and after welding .
- Necessity of PWHT and Hydrostatic tests .
- Repairs and precautions during overlay weld repairs.
- Methods and precautions to be taken during alterations and re-rating of pressure vessels.
- Aspects of reporting and re-inspection .

The Paper aims to brief the interested audience involved in welding inspection and repairs of pressure vessels that can be conducted in Shut downs within Chemical, Refinery, Petrochemicals and Fertilizer industries; various methods of weld repairs and related activities such as testing after welding.

Key Words:

- *Owner user:* *Owner or a user organization of the equipment.*
- *Repairer:* *The agency or organization, appointed by the owner user for repairs of the equipment.*
- *Inspector:* *A competent inspection engineer having full knowledge of the pressure vessel construction, in-service inspection welding etc.*
- *Designer:* *A competent Pressure Vessel Design Engineer.*
- *Code:* *Code or standard used for design / construction and Inspection of Pressure vessel.*
- *NDT inspector:* *A competent NDT inspector having thorough knowledge and experience of NDT techniques involved in Construction and repairs.*
- *PWHT:* *Post Weld Heat Treatment given to the Pressure vessel during construction or repairs.*

1.0 Introduction:

Repair and maintenance of parts and components is a major activity in any process industry. Repair welding can be carried out as a logical procedure that ensures the part is usable and safe. If repairs are done with proper care or precautions, it can avoid premature failures, large warranty claims, safety of property and personnel and result in satisfied customers. Failures of pressure vessels are still observed, which result in a costly down time of production and product losses also sometimes it results in environmental hazards and unsafe working conditions or disasters. Every owner user wants to extract highest possible safe service life from equipment.

The pressure vessel repairs also cannot be an exception this philosophy. Modern pressure vessels are constructed in accordance to a recognized code and established fabrication and welding practice.

2.0 Method of Inspection and decision for repairs.

Pressure vessels are designed to any recognized code of design and construction. We must under stand that the design thickness can be considerably lower than the actual Fabricated . During design itself corrosion allowance is added in the base metal thickness and the manufacturer fabrication chooses the next available thickness. Thereby we have a excess thickness available for the service which result in a considerably lower operating stress value.

Steps involved in the decision making for repairs.

- Operating conditions, Inspection history, Material of construction of pressure vessel .
- Reasons for failure .
- Location of the damaged area by visual inspection and evaluation by NDTs.
- Re-evaluate the need for repairs (Back to design calculations).
- Repair Methods, (For pressure retaining parts) .
- Preparation of repair procedures.
- Replacement of major components.

2.1 Operating conditions, Inspection history, Material of construction of Pressure vessel:

A careful study of the operating parameters and inspection history and properly maintained internal inspection reports, materials of construction, its behavior with the process fluid, welding techniques used during construction, design consideration etc, also gives an adequate confidence level about the use of pressure vessel. Such information is also useful for making the repair decision.
Carefully selected material of construction and the fabrication procedures, welding procedures as well as inspection and certification by the competent inspection authorities during fabrication stage, always intend to give such information.

2.2 Reasons for failures:

Undesirable premature failures can occur due to any one or more of the following reasons . Faulty design, faulty workmanship, wrongly selected material of construction, wrong welding techniques such premature failures generally occur in an early service period, where as the normal service failures are attributed to corrosion, changes in the working parameters, operation of the vessel for which it is not designed, impurities in the operating fluids, metallurgical changes in the base metal etc.
Once the damage is identified the pressure vessels must be thoroughly inspected to evaluate the extent of damage, need for repair and the repair method.

Thorough visual inspection of the pressure vessel can be supplemented by a suitable NDT examination, to locate the defects and the extent.

2.3 Location of the damaged area by visual inspection and evaluation by NDT.

On opening the equipment it is necessary to make it safe for entry as the remaining fluid or fumes of gases could be dangerous for human life. The personnel may be required to stay for internal inspection there could be possible repairs where hot work is involved, there fore a safe entry permit from a competent authority i.e from the safety and operation departments.

During internal inspection, some responsible operator should always be accessible to the inspector performing internal inspection. Such assistance can always be handy for any critical situation.

The external surface should be checked for any corrosion below the insulation, obvious leakages, structural attachments, connections, foundations, leak proof tightness of pressure relief valves etc.

The internal surface should be reasonably cleaned so as to visually verify its condition , condition of threaded connections, Flange connections, closures, internalsand damage due to corrosion. Different corrosion problems anticipated are pitting, line corrosion., General uniform corrosion, grooving, Galvanic corrosion, Fatigue, Creep, temperature, Hydrogen attack / Embritterment, Stress corrosion cracking, Inter-granular corrosion, etc.

The identified damage can be supplemented by NDT for the extent, where by decision for repairs can be taken confidently, various NDT possible, are UT thickness measurement, UT scanning, RT, MPI and LPT.

2.4 Re-evaluate the need for repairs (Back to design calculations)

Based on the NDT results obtained, the same can be verified by the designer and inspector by performing design calculations, to ensure that the remaining thickness is still safe, and whether the repairs are warranted or not.

Based on the remaining thickness corrosion rates are calculated and the MAWP at the available thickness also calculated. If the MAWP required is lower that the calculated MAWP then the repairs are not warranted provided the owner user is ready to carry out internal inspection as per next scheduled interval.

Location of defect is also important. On base metal away from the weld metal, a monitor thinning can be left unattended. In event there are borderline case the thickness can be recalculated by carrying our full RT and thereby revising the Joint efficiency.

Following design considerations are reviewed during re-evaluation

- Patch repairs welded by fillet welding can be used on temporary basis. Such repairs shall be checked and verified by the design Engineer. The same should be replaced with permanent measure at the next available maintenance opportunity. A fully encirclement lap joint may be considered as a permanent repair method. Such full encirclement patches shall also be designed to meet the code requirements.
- Minimum thickness observed shall be evaluated for MAWP and the corrosion rate, so as to decide the next inspection interval.
- Location of localized corrosion, such as on the base metal, away from L seam, Away from C seam, on the weld joints, on crown portion of the head, etc. thereby, comparing the original design requirement. e.g. by carrying out L seam Radiography, the joint efficiency can be revised to 1 and the remaining thickness acceptable can be revised.
- The Inspector should think out all such possibilities and advise the owner user, so as to take a precise judgment on the repair.

2.5 Repair methods: (For pressure retaining parts)

- The cracks are gouged out or removed and weld repairs can be carried out from both sides, if approach is available,
- The deep pits or localized corrosion can be weld built to restore the original thickness.
- The larger area, which cannot be welded by build up, can be replaced with patch or a shell course or a head.

So far SMAW or GTAW has been the most widely accepted welding processes in the industry, for its availability of welding equipment and skilled welders. However FCAW or GMAW processes can also be used if sufficient expertise and equipment are available.

Need less to state that any code requirements, contractual requirements or any statutory / regulatory requirement must be complied during weld repairs.

Original construction drawing, calculation data and inspection records are important for repairs. If the original construction data is not accessible, then an analysis of the base material, including previous weld deposits, becomes mandatory. If dimensions require close tolerances or if flatness is critical, then benchmarks that will aid the repair without causing excessive and expensive damage to the work piece must be established.

The crack in weld joint or a defect in the base metal can be repaired by preparing a “U” or a “V” groove to the full depth and length of crack and then fill up by weld metal deposit as described here. If the crack exists in the stress

concentration region then consult a competent pressure vessel design Engineer. Corroded area may be restored by weld metal deposition as described here.

2.6 Preparation of a repair procedure:

The repair procedure should take care of the requirements of the base metal, welding consumables, sequential weld deposits, requirements of preheat, Interpass temperature, post weld heating, PWHT, impact test and the NDT requirements.

The repair procedure shall be qualified as per the recognized code such as ASME sec IX, using an experienced welder. Maintain the records of procedure qualification as well as performance qualification.

If PWHT is required in original construction and it is not practicable or advisable during repairs, then the Inspector and the Pressure Vessel Design Engineer shall review the reason for original PWHT of the equipment. If the Original reason why PWHT was done is due to the service requirements, then the alternative methods given below may be avoided, Details of Repair Procedures and consideration are given in 3.0 of this article. It is allowed by the Repair & Inspection code to avoid the PWHT as well as Pressure test after repairs.

3.0 Considerations for repair Procedures: *[1 , 2]*

3.1 *Repair procedure alternative to PWHT, Pre heating method, where impact testing is not done on the original equipment.*

- Impact testing is not required when this welding method is used.
- This procedure is limited to P1-Gr. 1 & 2; P3 –Gr. 1 & 2 (Excluding Mn-Mo steels)
- The weld area is pre heated and maintained at a minimum 150 deg C, during welding. The temperature is measured to ensure 4” material or 4 times thickness (whichever is greater) from the each edge of weld is maintained during welding.
- The maximum Interpass temperature does not exceed 315 deg C
- Carry out welding as per the qualified procedure.

3.2 *Repair procedure alternative to PWHT, where impact testing is performed on the original equipment.*

When the original construction required impact test, Notch toughness testing as required by the code of construction is required. A procedure need to be qualified separately by using a groove welding on the plate Some additional requirements that can be considered over and above the supplementary essential variable are:

- This procedure is limited to P1; P3 and P4 steels.
- All supplementary essential elements of ASME Section IX para QW-250 are applied.
- The weld area is pre heated and maintained at a minimum 150 deg C, during welding. The temperature is measured to ensure 4" material or 4 times thickness (whichever is greater) from the each edge of weld is maintained during welding.
- The maximum Interpass temperature does not exceed 315 deg C .
- Maximum heat input shall be calculated and implemented during repairs. The maximum heat inputs as per qualified procedure must not exceed during welding.
- Qualification thickness for the plate material and the grooves are as per the table 1.
- If the welding is to be done under NACE standard, MR 0175, then additional test for hardness measure to be applied.
- For SMAW welding process, electrodes with additional supplemental diffusible hydrogen designator H8 or lower shall be used. The gas used in GTAW or GMAW or FCAW shall exhibit a dew point no higher than minus 50 deg C.
- Welding shall be carried out as per controlled deposition, temper bead or Half bead technique.
- After completion of welding, without allowing to reduce the preheat, the temperature is raised to 230 to 280 Deg C. and held for minimum period of about 2 Hrs to assist as Hydrogen bake out treatment.
- The Hydrogen bake out treatment can be omitted if electrodes having supplemental diffusible hydrogen designator H4 are used.
- After cooling the weld metal, the excess layer of reinforcement is ground off to match the surface contour of base metal.

3.3 Non-Destructive Examination and testing of repaired location.

- The prepared surface can be checked by using MPI or LPT before welding.
- After completion of welding, NDE acceptable to the Authorized Inspector or the owner user are selected and applied to ensure soundness of the weld.
- After repairs the need for pressure test is to be decided by the Inspector. The test temperature and the minimum design metal temperature of Pressure vessel shall be carefully evaluated.
- If Hydrostatic test is impracticable, then pneumatic test should be considered with appropriate safety consideration.

3.4 Repair to Stainless steel overlays and clad.

- In event any overlay or cladding area is removed, then the base metal gets exposed to the service environment.
- The Inspector should give consideration to remove the possible entrapped hydrogen if the service and the base metal is prone to hydrogen entrapment, hydrogen embrittlement, Temper embrittlement etc. A heating treatment such as Hydrogen bake out at 230 to 280Deg C, for about 2 Hrs. shall be given.

4.0 Execution of welding repairs*:*

- The repairer, under close supervision and surveillance of the Inspector, executes actual repairs. The written and qualified procedures are strictly followed. In case the Impact testing is specified, the welding parameters are also monitored and ensured to be within the range at which the procedure is qualified.
- Specified NDE before welding repairs and after welding repairs are carried out and shall be approved by the Inspector.
- After repairs the inspection record and the history of equipment, giving details of repairs, is updated and next inspection schedule shall be recommended to the owner user.

5.0 Welding techniques: [1, 2]

5.1 *Temper bead welding technique:*

The heat affected zone of the bottom bead due to the top bead applied with lower size electrode, leaves less than 20 to 30 % of the weld metal cross sectional area as a " typical columnar grains" and the balance is a normalized structure.

The top layer of the reinforcement mainly consisting of columnar grains, is required to be ground out, to match the surface contour.

5.2 *Half bead welding technique,*

After every pass, the top half of the weld bead is ground off before applying the next layer.

Such half bead technique also achievs the similar effect of temper bead technique, but then the consumption of welding electrodes can shoot up.

6.0 Conclusion:

I wish to draw the following conclusions:

- Repairs of pressure vessels are not always warranted, the decision of welding repairs must be taken with due consideration to the location of defect, carefully evaluated and interpreted NDE results, Design Calculations, Construction condition such as PWHT and Impact test.
- Once the decision of welding repairs is taken then it is necessary to document the repair procedure giving details of NDT test necessary, Per heat and PWHT, welding sequence, monitoring the welding parameters, pressure test requirements etc.
- Prepare the inspection reports and follow up inspection at a predefined inspection interval.

7.0 References:

- API 510 - Pressure vessel inspection code.
- ANSI NB 23 – National Board Inspection code.

Table 1: Qualification thicknesses for test coupon and test repair groove.

Depth of Test Groove	Repair groove Depth	Thickness of Test Coupon	Thickness of Base
t	< t	< 2”	Up to 2”
t	< t	> 2”	Above 2”

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