BACK-END NUCLEAR FUEL CYCLE FACILITIES

Fabrication and Quality Assurance for Process Equipment

Deep Gupta, Jitendra Kumar, Yogendra Singh, Ramakant and P. D. Maniyar

ABSTRACT

India has adopted the three stage nuclear power programme with recycling of spent fuel forming an integral part of the scheme. Thus, reprocessing of spent fuel and management of radioactive nuclear waste are an essential part of the plan. Reprocessing plants and high level waste management facility are key components of the back-end of the nuclear fuel cycle besides management and disposal of low and intermediate level waste. Both of the above plants operate under highly aggressive process medium and necessitate the development and deployment of process equipment with highly stringent fabrication and quality assurance requirements. This article covers critical aspects of material, fabrication and QA requirements for process equipment for nuclear fuel recycle and waste management plants.

KEYWORDS: Stainless steel, NAG, Quality assurance, Metallurgical cleanliness, Inter granular corrosion, Grain size, Radiography, Ultrasonic examination, Dye penetrant test.

THE NUCLEAR Recycle Group (NRG) of the Bhabha Atomic Research Centre (BARC) is entrusted with the responsibility of back-end of nuclear fuel cycle activities at Trombay. These include design, engineering, construction and operation of spent fuel reprocessing plants and waste management plants. Besides, NRG is also responsible for R&D activities applicable for these plants and manufacturing of products utilizing radionuclides present in nuclear waste for societal benefits like Ru-106 eye plaques, Cesium-137 pencils, and Yttrium-90. These plants are basically chemical plants with nitric acid based processes, having very high level of radio-activities loaded in the process medium. The combination of a highly radioactive and acidic environment leads to enhanced corrosion in these environment. Indeed, proper care must be employed during fabrication of process equipment to avoid corrosion "hot-spots" that may then trigger wider corrosion issues in service. This is especially important as the equipment becomes inaccessible to future maintenance due to high background radiations and contamination. Thus, there is a need for careful selection of the materials for the construction and quality assurance requirements for fabrication to ensure equipment life meets performance criteria in real plant environments. Critical aspects of fabrication and QA requirements for process equipment of nuclear fuel recycle and waste management plants are addressed briefly in this article.

The authors are from Nuclear Recycle Group Projects, Bhabha Atomic Research Centre, Mumbai.

Materials of Construction

The process medium is highly oxidizing in nature and for such environments, the performance of 304L grade Stainless Steel (SS) is well established, leading to its use in the construction of process equipment and piping components. However, the presence of corrosion promoters in process solutions arising at the back end of the fuel cycle makes SS of commercial purity (CP) grade 304L vulnerable to corrosion. Hence, there was a need to develop SS304L material with special requirements to suit the process environment prevailing in these plants. Accordingly, a special grade *viz.* SS304L Nitric Acid Grade (NAG) was evolved with stringent corrosion resistance in nitric acid process media. Table 1 indicates comparison of chemical composition of SS304L (CP) and SS304L (NAG).

Table 1: Comparison of SS304L (CP) and SS304L (NAG).

Wt. %	304 L (CP)	304 L (NAG)
C	0.03 max	0.02 max
Mn	2.00 max	1.8 max
Si	0.75 max	0.35 max
P	0.045 max	0.025 max
S	0.030 max	0.005 max
Cr	18-20	18 - 20
Ni	8.0-12	10 - 12
N	0.10 max	0.05 max

Table 2: Inclusion rating requirement

Type	Thin (max)	Heavy (max)
A	1	0.50
B	1	0.5
C	0	0
D	1.5	0.5
A+B+C+D	4.5	

Metallurgical cleanliness of the material is an important aspect for SS304L (NAG) and a strict criterion of the inclusion rating has been specified for the material. Table 2 gives information regarding the inclusion rating requirement measured as per ASTM E-45.

Quantification of the corrosion rates is required for identification and selection of suitable material using relevant corrosion test method. As ASTM A 262 IGC Pr C specifies the method to evaluate corrosion rates in boiling HNO_3 medium, simulating the process medium in the back end of the fuel cycle, the same is used to qualify the material for the application. Maximum permitted corrosion rates when tested to IGC Pr C is 10 mils per year (mpy) for all product forms *viz.* plates, pipes, tubes, rods etc. The equipment is of welded construction and the IGC Pr C is specified even for the welding consumables and weldments. Commercially available material generally does not meet the IGC Pr C requirements as specified above necessitating the manufacture of special heats and lots.

Materials for special Applications

a. Materials for High Temperature Application: High level waste management process involves use of glass matrix and the process requires very high temperatures (950-1000°C). For such aggressive process conditions, material with high nickel and chromium contents (Alloy 690) is employed. The high temperature requires good creep & oxidation resistance under corrosive glass environments and Alloy 690 exhibits excellent properties to sustain in such environments. Therefore, equipment subjected to high temperature glass environments are made using this alloy *viz.* Process Pot, Susceptor, Electrodes etc.

(b). Materials for treatment of Alpha Bearing Waste: Alpha bearing wastes are extremely challenging to manage and process. Ag (II) Mediated Electrolytic Dissolution process in 8 M nitric acid was used to manage such wastes in the Alpha Demonstration Facility (ADF) at WIP Trombay. The process medium is highly aggressive, and most metals will not survive the highly oxidizing environment of the process medium. Polyvinylidene Fluoride (PVDF) is a material which exhibits excellent corrosion resistance in such highly aggressive media and was tested in a simulated process environments. In the laboratory tests, the PVDF showed excellent performance and it was found to be unaffected in the process medium and was thus selected for the construction. Accordingly, process equipment (reactor and generators) with PVDF coting on SS304L material were designed, developed, and successfully deployed for the ADF. The performance of the material and equipment in the ADF has been satisfactory. Alternate materials for such process medium are Titanium or Zirconium alloys. PVDF is an economical option of material of construction for such process media.

Fabrication Aspects

Since the equipment, once hot commissioned, becomes inaccessible for any maintenance, utmost diligence is required during fabrication. The above requirement is adhered to by an elaborate Quality Assurance Plan (QAP) with constant monitoring at various stages during fabrication. Special attention is given to the orientation and technical briefings to the supplier engaged to enable an understanding of the specialized requirements. It is imperative that contamination from iron and chloride is prevented. Hence, fabrication is permitted only in clean and dust free shop floor dedicated for stainless steel works. In addition, cross contamination from other nearby carbon steel jobs either direct or indirect through tools and tackles must be prevented. At various stages, special test procedures are also performed to check and eliminate contaminants (iron and chloride).

Forming of the stainless steel material in various raw material product forms e.g. plates, pipes etc. must be carried out to obtain usable shapes like shell, dished ends, bends, coils etc. By design, it is ensured that the resultant strains in the components are minimized. In case of unavoidable excess strains, solution annealing operation is performed to eliminate the effects of the forming. Hardness survey is carried out on the formed components to ensure that the material has not suffered excessive strain hardening, which has detrimental effects on the corrosion resistance of the material.

The process equipment are in welded construction, hence, welding is an essential stage of the equipment during manufacturing. The process of welding must be qualified as per the provisions of the ASME Section IX codes and also for special requirements like delta ferrite and IGC Pr A & C. Gas Tungsten Arc Welding (GTAW) process is adopted owing to its cleanliness and better control. Argon gas of very high purity (min 99.995%) is used to reduce formation of defects in the weldments. The heat input to the job is also controlled by employing lower currents and by minimizing repairs. Local repairs for any spot are permitted only once to minimize Heat Affected Zones (HAZ). Welding consumables are also of special chemistry with controlled range of delta ferrite (4 to 10 FN) which ensures prevention of hot cracks and that the corrosion rates of the weldment is within acceptable range of 10 mpy.

Quality Assurance Aspects

Quality assurance is an essential part of the overall program. The program covers various stages starting from design, construction, installation & operation of all back end fuel cycle facilities to ensure that adequate levels of safety and reliability are achieved concurrent with the designed plant operating life. Accordingly, a well detailed Quality Assurance Plan (QAP) is devised enlisting stages of inspection, parameters, reference standards, acceptance norms and extent of examination. The QAP is the main stay of the fabrication process and is followed in letter and spirit. Experience of the QA engineer also plays a major role hence only experienced personnel are deployed for such critical jobs.

Non-Destructive Examination

Various NDE techniques are employed for implementing QA plan and are performed meeting the requirements of various codes and standards. All the weld joints appearing in the equipment are properly identified before manufacturing and non-destructive examination requirements are listed and defined. A check list of the joints and its completeness with regard to specified NDTs is always maintained. The defect acceptance criteria exceed the specifications in the governing codes. Following examinations are carried out for the equipment during fabrication:

a. ***Visual Examination***: Careful and complete visual inspection of weld joints and parent material is carried out during the inspection. Tools like fiberscope, magnifier, mirrors etc. are used to identify the possible surface defects like deep scratches, roll marks, die marks, dents etc. Inspection of the nozzles from inside is an important aspect because these are thin objects and often, burn through can occur if proper care is not taken during welding and weld-fit up stages.

b. ***Liquid Penetrant Examination***: Defects, that are open to the surface and extremely small in size, can be detected by LPE. Acceptance norms of LPE are very stringent e.g. no indications are permitted on surfaces which are in contact with process medium. While for other surfaces, acceptable indication can be maximum 0.8 mm. The LPE is specified for root weld, final weld, back chipped and refilled surface. The LPE is a specified requirement even for the bevel edges also to eliminate any chances of laminar type of defects.

c. ***Radiography Testing***: Only full penetration butt weld joints are permitted in the pressure boundary of the equipment and 100% radiography is a specified volumetric examination technique for the same. For the equipment, only X-ray is permitted which produces very high quality of radiographic images. Sensitivity requirements of the radiography are also stringent and Image Quality Indicators (IQI) as mentioned in ASME section III Div I NC or NB are selected.

d. ***Ultrasonic Examination***: The through penetrating nozzle joints and corner welds are also checked by ultrasonic testing to stringent acceptance criteria. Ultrasonic examination is performed on the raw material (plate, pipe, tubes etc) to ensure that the raw materials are also free from unacceptable discontinuities.

e. ***Helium Leak Testing***: Heat exchangers, cooling/heating coils and thermowells are some of the most critical components, through which the radioactive contents may come to the inactive areas of plant due to failures. Such components are given special care while manufacturing and are tested by helium leak testing methods.

f. ***Contamination Check Tests***: All equipment are thoroughly pickled and passivated as per approved procedure before closure and contamination check tests are performed. The equipment are checked for contaminations of iron and chloride which are detrimental to stainless steel.

Conclusions

Back end of the fuel cycle facilities deal with high level of radioactivity in a highly corrosive process medium. The equipment is not accessible for maintenance after the hot commissioning of a facility. As such, it is essential to design and fabricate the equipment maintaining strict quality assurance requirements. The raw materials employed for such critical applications must be checked to maintain stringent quality requirements and it is equally important to maintain proper checks during the fabrication stages through an elaborate Quality Assurance Plan. Further, control of contamination is also a very important aspect to protect the equipment from detrimental effects of the contaminants. As a result, process equipment, thus fabricated and deployed in back-end facilities, have quite good track records with satisfactory performance as intended in design.

References

[1] Technical specifications for process equipment fabrication.

[2] V. Kain, S. S. Shinde and H. S. Gadiyar "Mechanism of improved corrosion resistance of type 304L stainless steel, nitric acid grade, in nitric acid environments", *Journal of Materials Engineering and Performance* Volume, 1994, **3**, 699–705.

[3] A guide to welding of Stainless Steel. Publication by M/s AVESTA, Sweden .

[4] Hot cracking resistance of austenitic stainless steel weld metals CD Lundin, Chou *et.al* *Welding journal*, Aug. 1980.

[5] Hauser D & Vanecho, "Effect of ferrite content on austenitic stainless steel weld" *Welding Journal*, Feb 1982.

[6] C. L. Briant, R. A. Mulford and E. L. Hall (1982), "Sensitization of Austenitic Stainless Steels, I. Controlled Purity Alloys", *Corrosion*, September 1982, **38**(9), 468.

[7] Mars G. Fontana, *Book on Corrosion Engineering*, Ed. 3, p. 74.

[8] Standard Practices for detecting Susceptibility to Intergranular Attack in Austenitic Stainless Steels, ASTM A 262.