Abstract: Recent changes in environmental norms worldwide have forced all major refineries in the world to produce oil with extremely low sulfur level. As a result, large numbers of Heavy walled Hydrocracking & Hydrotreating Reactors are being manufactured using conventional Cr-Mo & advanced Cr-Mo-V base material. The vessel material selection is based on – (a) high temperature creep resistance- Cr-Mo / Cr-Mo-V steel and (b) corrosion resistance to hydrogen atmosphere through use of SS 347 cladding / overlay on inside surface. Several high thickness reactors have been manufactured at Larsen & Toubro Limited in recent past. The complexities of the equipment and the design requirements posed number of challenges in design, manufacturing technologies and execution levels. Some of the critical manufacturing technologies developed are:

1. **Narrow Gap Submerged Arc Welding (NG-SAW)** for Longitudinal and Circumferential seams of Shell courses by DC-AC Tandem SAW;
2. **Hemispherical Head Welding by NG-SAW** — all Petal # Petal and Crown # Petal seams of Hemispherical heads;
3. **Continuous Electro Slag Strip Cladding (ESSC)** with H₂ disbonding requirements using 90 & 120mm wide strips (with ‘step over’ technique);
4. **Shape Welding Technology** for rectangular Catalytic Support ring build-up inside the reactor;
5. **Tandem SAW (DC-AC)** for Lip build-up on bottom Head for Head # Skirt weld;
6. **Mechanized Internal Bore Overlay of Nozzle Forgings, Pipes and 90°Elbows using Flux Cored Arc Welding (FCAW)** — in nozzle assemblies up to 2300mm long and on ID as small as 38mm;
7. **Mechanized Nozzle # Shell / Head butt joints using Orbital SAW nozzle welder** — in house design and assembly of Orbital SAW nozzle welders for welding of Nozzles with and without sagita;
8. **Dissimilar metal joining** for welding of Top & Bottom spool Elbow # Pipe / Forging joints using Inconel consumables;
9. **3-D Contour Machining for Inclined / Offset Nozzle Forgings** — to create circular butt weld contour suitable for NG-SAW on these nozzle welds;
10. **Development of modular furnace** (9m wide X 8m high X 32m long) to avoid Local Stress relieving.

This paper deals with the details of some of the above manufacturing challenges and technology upgradation carried out at Larsen & Toubro Limited.
1.0 Introduction:

Hydrocracking / Hydrotreating reactors are vessels meant for hydrogen service in oil refineries and are the most vital part of gas oil cracking / treating plant. These are high pressure, high temperature reactors, which break complex hydrocarbon chains and remove the sulphur bonded to the complex hydrocarbon chains. The reaction occurs in the presence of catalysts and at a pressure of more than 100Kg/ cm² (g) and temperature between 425°C and 482°C. Hydrogen is added in the process and results in the formation of hydrogen sulphide. The presence of hydrogen under very high pressure and temperature creates potential situation for hydrogen disbonding and cracking. The situation is aggravated by the presence of highly corrosive hydrogen sulphide atmosphere. The combined effects of these factors make these reactors among the most critical equipment in refineries. Larsen & Toubro Limited – India have manufactured several such high thickness reactors made of Cr-Mo and Cr-Mo-V base material for refineries in India and abroad.

2.0 Reactors - Details

2.1 Reactor Construction:

Mainly there are two different types of reactors –

- Clad-type –
  - Base material: 1.25Cr-0.5Mo / 2.25Cr-1Mo / 2.25Cr-1Mo-0.25V steel plates / forging in Normalized and Tempered or Quenched & Tempered condition with impact requirement down to (-)30°C;
  - Clad material: 3mm thk. SA240 Type 347/ Type 304L.

- Weld overlay type –
  - Base material: 1.25Cr-0.5Mo / 2.25Cr-1Mo / 2.25Cr-1Mo-0.25V steel plates / forging in Normalized and Tempered or Quenched & tempered condition with impact requirement at (-)30°C;
  - Weld overlay: Double layer (SS 309L + SS347/308L) or single layer SS347/308L meeting 3mm clean SS347/308L chemistry at the top.

Typical construction of reactors (Fig:1) involve:

- Shell courses – clad or weld overlaid with one / two longitudinal seams if made out of plates or weld overlaid on forging
- Heads -- crown-petal type for clad jobs and bigger diameter overlaid jobs -- in two halves for smaller diameter overlaid jobs;
- Catalytic grid support rings welded on the inside surface of vessels–
  - Weld build-up rings – >50mm thick X >100mm wide rectangular cross section with matching weld metal as that of base material. The same needs to be fully covered with SS weld overlay subsequently.
  - Plate rings made of 25–50mm thick plates – either of SS or Cr-Mo/ Cr-Mo-V base material covered with SS weld overlay;
- Butt joints between Nozzle # Shell/ Head – use of self reinforced forging, completely overlaid with SS309L+ SS347/308L on complete internal surface and gasket face;
• Lip build-up on bottom dished end to create butt joint with the skirt or ‘Y’ ring connecting Skirt & Head to the bottom most Shell course.
• SS321/ 347 internals -- 50~100mm thick internal beams with Tee joints -- Full penetration support cleats welded on vessel inside.

2.2 Welding procedures:
All procedures have to meet various technical requirements of ASME Sec IX, Manufacturing Code i.e. ASME Sec VIII Div.1 or 2, API 934 and all the additional requirements of customer / process licensor specifications:

2.2.1 Base metal welds:
- Cr-Mo / Cr-Mo-V welds required to meet room temperature and design temperature tensile value and impact property (40J average minimum) at (-) 30°C after minimum (one PWHT cycle of 8~10hrs) and maximum PWHT cycles (3 PWHT cycles of total 26~32 hrs) at 691 ± 14°C / 705 ± 10°C.
- Procedures qualified: SMAW, SAW (4mmΦ single wire), Tandem SAW (DC-AC using 4mmΦ wires) & GTAW processes.

2.2.2 Overlay welds:
- Double layer (Barrier layer of SS309L and subsequent layers of SS347/ 308L) or Single layer (with modified SS347/ 308L) to meet undiluted SS347/ 308L chemistry at top 3mm.
- Hydrogen disbonding test under high temperature (454~482°C), H₂ partial pressure of 80~105Kg/ cm²(g) and a cooling rate of 100~675°C / hr.
- Ferrite requirement of 3~8FN as per Delong constitution diagram at top.
- Procedures qualified: ESSC (using strips of 60, 90 and 120mm wide X 0.5mm thk), FCAW (in Flat & Horizontal position) and SMAW (in Flat, Horizontal and Vertical positions).

2.2.3 Inconel dissimilar metal joints:
- Elbow # Forging / Pipe welds on top and bottom spools.
- Inaccessible from inside for clad restoration after base metal welding.
- Special welding procedure developed using root pass of SS347 and subsequent fill-up of Inconel (E NiCrFe3).
- Procedures qualified with impact at (-)30°C.

2.3 Heat Treatment:
- Stress relieving PWHT - 691±14°C / 705±10°C – 8~10hrs minimum & 26~32hrs maximum.
- Dehydrogenation treatment at 350~400°C / 4hrs for Longitudinal & Circular seams in Shell / Head & Nozzles immediately after welding.
- Intermediate Stress Relieving (ISR) at 640~660°C / 2hrs for Nozzle # Shell / Head Welds and Support ring weld build-ups.

2.4 Non Destructive Testing (NDT):
- Base material joints (Longitudinal, Circumferential and Nozzle butt welds): 100%RT (before PWHT), 100% UT (before and after PWHT) including Recordable UT / TOFD and 100%MPT (before and after PWHT & after hydro).
- Weld overlays: 100% UT (before and after PWHT), 100% DP (after each layer and after PWHT), Chemical analysis and Ferrite check on final surface before PWHT.

2.5 Weld Deposition:
- Out of the total weld metal involved in manufacturing of a reactor, nearly 97.5% of the weld is being deposited by Mechanized / Semi-automatic processes and only 2.5% by manual welding process.

3.0 Challenges & Technology Upgradation at Larsen & Toubro Limited

Fabrication of Hydrocracking / Hydrotreating reactors involve highly critical manufacturing operations. Several new technologies have been developed over the years to meet these challenges. Some of them are described below:

3.1 Narrow Gap-SAW for Longitudinal and Circumferential Seam welding
- NG-SAW capability to weld joints (with 1° included angle) up to 300mm thick developed in-house using bi-axial seam tracker. NG-SAW of Longitudinal seams is an unconventional technique and requires meticulous fabrication procedures.
- Both Single wire (4mm diameter) as well as DC-AC Tandem SAW technique are being used for welding of these joints.

3.2 Hemispherical Head Welding by NG-SAW
- All Petal # Petal welds as well as Crown # Petal welds of hemispherical heads are being completely welded by NG-SAW.
- The head is mounted on a Welding Positioner and welding is carried out from outside by adopting sequential welding technique for various petals.

3.3 Electro Slag Strip Cladding

3.3.1 Wide Strip ESSC (90 & 120mm wide strips)
- Developed for the first time in India – currents up to 2300Amp and deposition rate up to 42Kg/ arc-hr.
- 120mm wide*0.5mm thick strips are used for Double layer weld overlay techniques & 90mm wide * 0.5mm thick wide strips are used for Single layer weld overlay (Fig.-2).
- Provides two-fold increase in productivity with less than 10% dilution.
- Special arrangements have been made for power supply and current transfer connections, welding heads with magnetic steering devices, cooling and shielding arrangements.
- Specially designed preheating fixtures developed for achieving and maintaining uniform preheat across the shell for barrier layer weld overlay.
- Welding is carried out continuously with ‘step over’ technique till a wire spool of 200Kg gets consumed, thereby raising the daily productivity to ~700Kg per station.
3.3.2 ESSC on Heads:
- ESSC on heads is a critical operation considering the effect of head curvature on process stability. Rotation of heavy head at a constant speed with preheating is a complex operation.
- Heads are weld overlaid circumferentially with 60mm wide * 0.5mm thick strips using heavy duty positioners,

3.3.3 ESSC on Nozzle Inside Bore:
Technology has been developed for overlay on nozzle ID in order to take care of smaller inside diameter (down to 450mm ID), restricted access, preheating during barrier layer.
- Weld overlay on complete internal surface for all manhole nozzles as well as comparatively bigger diameter nozzles are carried out using 60*0.5mm or 30*0.5mm strips.
- Special miniature welding head is being used after necessary modification.

3.4 Shape Welding Technology for Support Ring Build-up
- Shape welding technology enables creation of specially configured shapes by weld build-up. The technology restricts the liquid weld metal flow progressively and achieves desired shape. Since the weld metal volumes are very high, automation and use of high productivity process like Tandem SAW is necessary (Fig.3).
- Support rings of rectangular cross section are built-up on inside surface of shells using this technology.
- Special shape welding reduces the weld deposition by 30% coupled with substantial reduction in man and machine hours. This was achieved by elimination of taper weld deposit on both sides of the nubs. These tapers are required to be machined / ground off while welding using conventional method.

3.5 Lip Build-up on Bottom Head by DC-AC Tandem SAW
- Bottom Head # Skirt butt joint is designed either through an Y-ring or through a lip weld build-up on head. A massive build-up of special configuration is carried out by DC-AC Tandem SAW using 4mm or 5mm diameter wires.
- Special shape welding technology is used to reduce quantity of weld build-up and thereby saving man-hour and machine-hour.

3.6 Mechanized Internal Bore Overlay of Nozzle Forgings, Pipes and 90°Elbows using Flux Cored Arc Welding (FCAW)
- Special FCAW ID overlay stations have been developed in-house for nozzle assemblies up to 2300mm long and on ID as small as 38mm.
- Mechanized ID overlay is being carried out by specially developed fixture and torch on 90° elbows down to 8” diameter.
- Mechanization results in excellent weld finish and weld quality.
3.7 **Mechanized Nozzle # Shell / Head Welding by Orbital SAW nozzle welder**

- Special Orbital SAW nozzle welders have been developed in-house for welding of nozzles. New SAW nozzle welder for welding of nozzles with sagita more than 30mm are under implementation at present.
- This results in higher weld deposition and consistently good quality.

3.8 **Inconel Dissimilar Metal Joints**

- Nozzle circumferential butt joints between Elbow and Forging / Pipe in top and bottom spools inaccessible for back chip and clad restoration, are welded by SS root run and subsequent fill up by Inconel-182 consumable.
- Special welding fixtures are developed and welders have been specially trained and qualified to weld these joints.

3.9 **3-D Contour Machining for Inclined / Offset Nozzle Forgings**

- To save cycle time and facilitate Orbital SAW Nozzle welding, 3-D contour machining is done in-house for Inclined / Offset Nozzles, to convert elliptical weld joint shape to circular shape.

3.10 **Modular Heat Treatment Furnace**

- Developed in-house to carry out Post Weld Heat Treatment for equipment up to 32m long (furnace size of 9m wide X 8m high X 32m long). The furnace has adjustable modules of 10m each.
- The diesel-fired furnace is able to produce heat treatment with close temperature control of +/- 10°C.

4.0 **Conclusion**

To keep up with the demand of increasing pressure and temperature conditions in Hydrocracking / Hydrotreating reactors, designers are coming up with more and more stringent requirements in terms of material of construction and other additional requirements.

Larsen & Toubro Limited, being located in India, is handicapped in terms of longer procurement cycle since procurement of raw materials, components and consumables is mostly from Europe, Japan and USA. Dispatch time for completed equipment is also much higher that other suppliers in Europe due to its geographic location. To remain competitive, all these drawbacks have to be overcome by squeezing the manufacturing time.

To meet these challenges, Larsen & Toubro Limited is continuously upgrading its facilities and manufacturing technology, which are directed towards higher productivity and better quality.
Fig- 1: Typical Sketch of a Hydrocracking / Hydrotreating Reactor
Fig- 2: Electro Slag Strip Cladding (ESSC) with 120*0.5mm strip

Fig- 3: Support Ring Weld built-up [Conventional vs. Shape Welding technique]