Manufacturing considerations for nuclear storage canisters

October 2016

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Overview

- Company overview & experience
- Ingot and steel making
- Casting
- Forging
- Machining
- Fabrication
- Conclusions & Challenges
Company Overview & Experience

- Over 200 hundred years old (originated 1805)
- 64 acre site in Sheffield
- A world leader in large scale forging and casting technology
- Largest forge and foundry capability in Europe
- Holds multiple manufacturing accreditations;
  - BS EN ISO 9001 Quality Management Standard
  - ASME approved Material Organization
  - ASME NPT (weld assembly/fabrication)
  - RCC-M approved (French Nuclear)
  - UKAS accredited Test House
Company History & Experience

Forge
- 10,000 Tonne Press
- 4,500 Tonne Press
- 2,500 Tonne Press

Foundry
- Annual capacity of 8,000 Tonnes
- Max. casting size 16m x 7.7m x 4.8m
- Max. weight casting of 360 Tonnes
- Largest ever cast weight 650 Tonnes

Machining
- Milling, turning & boring
- Turning up to Ø8 and 21m long
- Can bore lengths up to 20.5m
- Handle parts up to 400 Tonnes
Ingot and steel making

- Mechanical/design engineers should appreciate metals are not homogenous elastic bodies
- They contain variations in;
  - Chemistry (segregation)
  - Microstructure
  - Mechanical properties
  - Density (defects)
- This is especially true for large cast and forged products
- The material supplier and processor must understand this and design the processing route to minimise any detrimental impact on the finished component
Ingot Development

- SFIL have worked for many years to develop segregation prediction methods and minimise the effects in large steel ingots
- Full scale ingot (~13t) sectioned and mapped within a PhD project with Cambridge University
- Segregation model developed and verified against measured values
Hollow Ingot Technology

Furnace exit

Transfer to 10,000T press

Breakout time:
- 150t hollow ingot – 16hrs
- 150t solid ingot – 37hrs

Becking
Hollow Ingot Technology – SA508
THROUGH THICKNESS VARIATION

MEAN ANGULAR VARIATIONS
• Casting modelling carried out on high aspect ratio canister geometry

• Two methods explored – sand cores and steel cores

• Foundry and Melt Shop casting processed (sand or iron moulds)

• Two configurations of fuel rod assemble channels – square and round

• Very challenging;
  • Feeding problems during solidification inducing porosity
  • Parallel sidewalls are more difficult to feed than tapered geometries
  • Non tapered objects are difficult to strip
  • Manufacturing robust moulding cores
Casting

- Square fuel channels result in higher shrinkage defects due to increase ligament area and reduced thickness.

- Sand cores result in a lower population of shrinkage defects compared to a fabricated steel core assembly.

- A foundry method of casting generates a small population of shrinkage defects due to the slower heat extraction of the sand mould compared to the iron mould used in the Melt Shop method.

- NDT challenges exist in the vast majority of the component volume.

- Foundry sand casting, with sand cores generates the most favourable results, but challenges to make this a robust and repeatable process still exist.
Forming – Backwards Extrusion

- SFIL hydraulic press limited to 100 MN (10 000 t)
- Materials modelled - AISI 304, AISI 1015
- Forming temperature -1225 °C
Forming – Backwards Extrusion

- KPV’s investigated in current study
  - Friction coefficient
  - Forming temperature
  - Work piece cooling time
  - Cooling due to tool contact
  - Cross head velocity (≡ \( \dot{\varepsilon} \))
  - Billet geometry
  - Mandrel geometry

- On going work to optimise process and reduce manufacturing costs
Forming – Head Forming

Large scale civil nuclear head
Small scale canister closure head

Formed plate – Ø 1000mm, 100mm thick
Machining

- Off centre boring trials conducted on 4145H modified steel
- 210mm hole bored to a depth of 4530mm (AR ~ 22)
- Wall thickness was measured by UT scan
- Deviations in wall thickness used to infer hole deviation from its axis
Fabrication

- Along the length of the hole was 3.5 mm deviation, and can be considered a worse case estimate of the straightness that can be achieve.
- Deviation of up to 1.7mm/metre.
- Machining time was 26 hours comprising 14 hours of machining and 12 hours for setting and tool changes - 9 holes, ~234hrs, ~10 days.
- The production of the containment canister via this method of manufacture is technically feasible and considered by SFIL as low risk.
- Forgemasters are confident in their ability to produce the hole configuration.
- Future work will aim to reduce cycle time and tool changes.
Fabrication - RPEBW

Revision 1
• Unstable, fluctuating key hole results in collapse of the melt pool and trapping of weld vapour pockets leading to large voids in the weld root
Fabrication - RPEBW

160mm Wall thickness

200mm Wall thickness
Conclusions & Challenges

• Understanding, predicting and controlling segregation in steel making are key to product integrity and consistent mechanical properties.

• Casting of integral fuel assembly channels into steel canisters presents many manufacturing challenges that severely detriment canister consistency and integrity.

• Machining of high aspect ratio bores and holes is possible, but canister design and tolerances must be flexible enough to align with achievable manufacturing tolerances.

• High integrity fabrication methods such as out of chamber EBW demonstrate excellent welding characteristics but require more development and qualification in the nuclear industrial.

• Advanced forging and forming techniques are transferable to smaller scale components, but this is yet to be carried out and validated/approved.

• FE modelling has shown backwards extrusion of steel canisters is possible with process optimisation to remain within the operation limits of SFEL’s heavy forge.

• Early supplier engagement is essential to drive design for manufacture to make canister designs achievable and affordable.