Heavy steel forgings
for Pressurised Water Reactor program

With the successful completion of this project, India has now acquired the technological know-how and capability to manufacture forgings of thicknesses 350 mm to 750 mm essential to manufacturing of reactor pressure vessel for pressurized water reactor program.

Photo description refer to cover page photo caption

Pressurized Water Reactor (PWR) program requires high purity special grade low alloy steel forgings of relatively large size to manufacture Reactor Pressure Vessel (RPV), a vital and critical component for the plant. The challenging aspects of RPV forging are relatively high thicknesses, maintaining desired chemistry and microstructure coupled with demand for high mechanical properties over entire thickness, good weldability and freedom from hydrogen induced micro-cracks. This involves special technological know-how that needs to be developed through R&D.

With vision for indigenous capability building in heavy thickness RPV forgings, a development project was undertaken successfully at Heavy Engineering Corporation Ltd, Ranchi for small size forgings. Based on experience gained from this project, the next phase of development for heavy forgings (large size and high thickness) was initiated at L&T Special Steels and Heavy Forging Pvt Ltd, Hazira, a joint venture of L&T and NPCIL, considering available infrastructure.

Three prototype scale shell forgings (inner diameter ϕ4.2m and ϕ3.8m) of different thickness were developed successively, with lab scale experiments, industrial scale trials and extensive testing, to progressively improve and optimize the manufacturing processes. The development involved steel melting, refining, vacuum degassing and vacuum casting (control of H, O & N) to produce large size ingots. The ingot is forged to desired shape on a hydraulic press and then subjected to specialized heat treatments multiple times, to achieve the desired metallurgical and mechanical properties. High purity steel was aimed (with very low-level impurity and trace elements) to get superior properties like resistance to embrittlement due to irradiation and thermal ageing. The targeted alloy chemistry for a specific forging thickness was decided based on past experience and prototype trials. Pre-heating of input materials, double degassing and introduction of special prolonged (up to 1000 hours) anti-flaking heat treatment cycles developed at BARC for reducing hydrogen content after forging resulted in control of hydrogen to less than 1 ppm.

Cooling rate at mid-thickness during quenching treatment, an important parameter governing the through thickness properties, was determined for each forging. To establish the heat treatment cycle for each forging having a different mid-thickness cooling rate, BARC developed an innovative technique of lab-scale simulation. Using this technique, the heat treatment parameters were optimized through large number of lab scale trials (~300 trials with ~3000 test specimens), followed by industrial-scale validation before implementing on the prototype forgings.

Ultrasonic testing of these thick forgings was carried out by BARC specialists with stringent sensitivity requirements (100% scanning by normal and angle beam) from all surfaces. Material characterization involves destructive test in all the three directions and five through thickness locations at three orientations at two elevations. This includes mechanical tests (impact toughness & tensile strength) at room temperature and high temperature, drop weight test, fatigue strength

Shri P. K. Mishra, SO/H, Shri Vivek Shrivastav, SO/G, Shri Rajit Kumar, SO/G, Shri Harish, SO/D, Shri R Dinesh Babu, OS & Dr Sujay Bhattacharya, DS, from Reactor Projects Group, and Dr R. N. Singh, OS of Materials Group, BARC,Trombay contributed for this article.

evaluation, fracture toughness tests, metallographic examination and evaluation of thermal embrittlement resistance of steel. Around 2500 test specimens were tested for acceptance of each forging. The quality and properties of the forgings developed meet the acceptance norms of various international codes with high margins.

With successful completion of this project, the country has now acquired the technological know-how and capability to manufacture forgings of thicknesses 350 mm, 550 mm and 750 mm. Specialists of various divisions of BARC and industry worked in tandem in this development and with this, India joins the premier league of very few countries in the world having such capability. It is an important scientific and technological achievement which paves the way for manufacturing capability of RPV forgings required for PWR program. The achievement marks a major step in line with the vision of "Aatmanirbhar Bharat".

The material grade developed is rightfully named "APURVA" (अपूर्वा) (**A**dvanced **P**urified **R**eactor **V**essel **A**lloy) considering the nature, scale and importance of this development.

Acknowledgements

Shri S. K. Mohanty, SO/G, AgS; Shri Arun Kumar, SO/G, LWRD; Shri Deepak Sharma SO/E, LWRD and Shri K. K. Yadav, SA/E were involved in the implementation of the project.

The project review team included Shri P. Sreenivas, Head, LWRD (retd); Shri Joe Mohan, Head, RPD; Shri S K Jakhotiya, IFA and Shri Himanshu Shankar, former IFA was helpful in achieving the desired objectives.

Team comprising of Dr. G. K. Dey, Former Director, Materials Group; Dr. Madangopal Krishnan, Former Director, Materials Group; Shri Rakesh Kumar, Head, IFFF and Dr. Rajeev Kapoor, SO/H, MMD certified overall acceptance of the development.

Shri V. K. Mehra, Director, RPG (retd); Dr. Sekhar Basu, Chairman, AEC (retd); Dr. A. K. Mohanty, Director, BARC; Shri R. S. Yadav, Director, RPG (retd); Dr. A. B. Mukherjee, Director, RPG (retd); Dr. A. K. Mohanty, Director, BARC and Shri K. N. Vyas, Chairman, AEC provided guidance and direction in execution of the project.