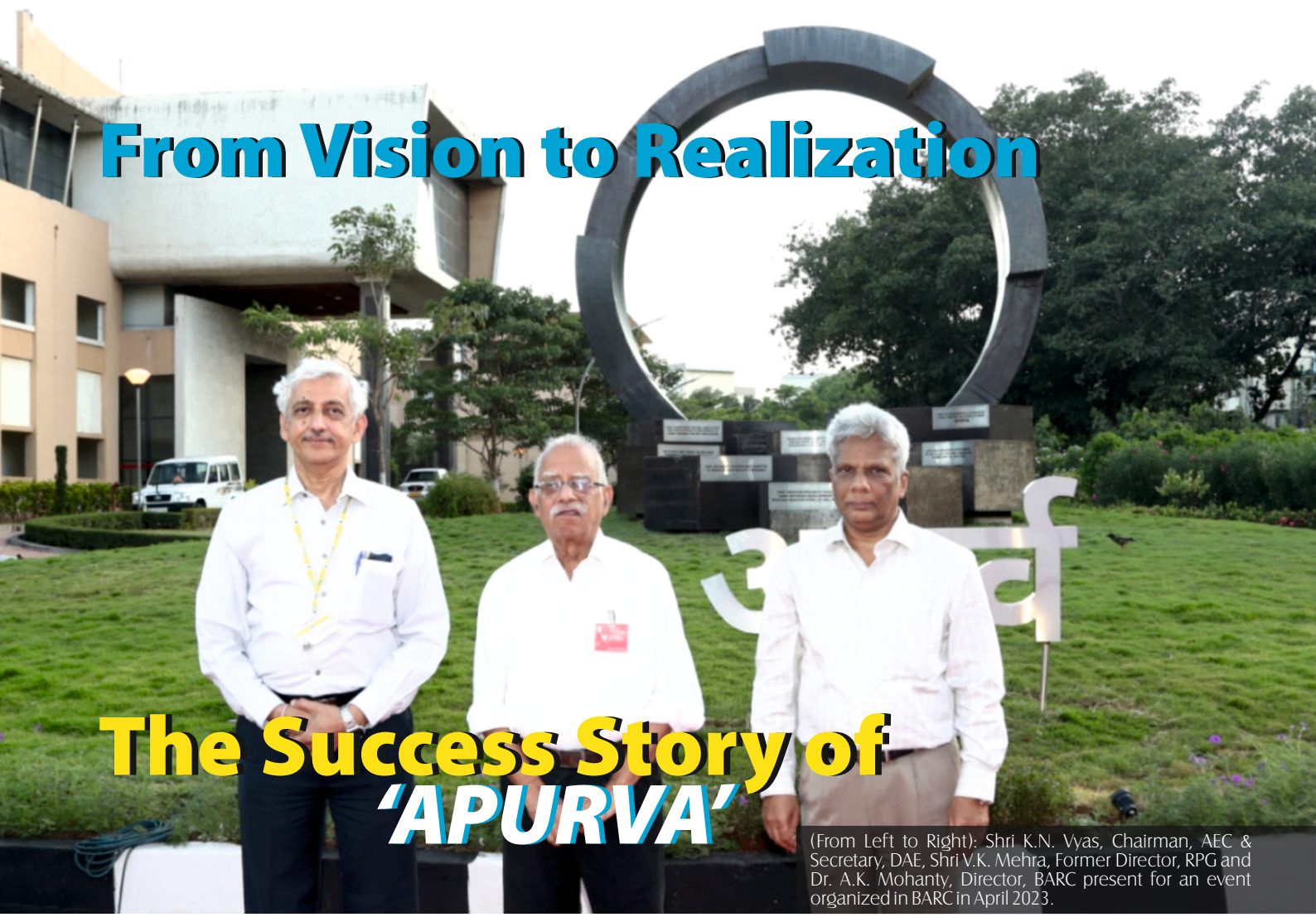
From Vision to Realization

The Success Story of 'APURVA'



(From Left to Right): Shri K.N. Vyas, Chairman, AEC & Secretary, DAE, Shri V.K. Mehra, Former Director, RPG and Dr. A.K. Mohanty, Director, BARC present for an event organized in BARC in April 2023.

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An installation erected near Engineering Hall-11 BARC, christened APURVA, which stands for "**A**dvanced **PU**rified **R**eactor **V**essel **A**lloy", was inaugurated on 29th April, 2023 by Shri K.N. Vyas, Chairman, AEC & Secretary, DAE, in the august presence of Dr. A.K. Mohanty, Director, BARC. Shri V.K. Mehra, former Director, Reactor Projects Group, who had championed the vision of self reliance in nuclear reactor technologies for Compact Light Water Reactors (CLWRs), was the guest of honour for this special event. The event was hosted by the Reactor Projects Group (RPG), lead by Shri Joe Mohan, Associate Director, RPG.

The APURVA installation, built for inspiring the present and future generations of young scientists and engineers, symbolizes the successful indigenous development of reactor pressure vessel (RPV) forging technology for large-sized commercial Pressurized Water Reactors (PWRs). The project was executed with collaborative efforts of BARC and M/s. L&T Special Steels and Heavy Forgings (LTSSHF), Hazira. The forged steel developed through these efforts has been christened "APURVA" (अपूर्व), meaning "unprecedented", or, "first time ever".

Historical Background

The foundation stone for indigenous development of RPV forging technology in the country was laid down by Shri V.K. Mehra former Director of RPG and his team, way back in 1984, when the first attempt of manufacturing RPV forgings was undertaken in association with Heavy Engineering Corporation (HEC), Ranchi. The first breakthrough was achieved with the successful development of smaller size RPV forgings for Compact Light Water Reactors (CLWRs) in the year 2000.

Development of APURVA grade Steel Forgings

The main challenges associated with large size RPV forgings are, relatively higher thicknesses, maintaining the desired chemistry and purity level, controlling chemical segregation, achieving a favourable microstructure and high mechanical properties over the entire section thickness, along with good weldability and freedom from hydrogen induced micro-cracks. Realizing that this work called for special technological know-how to be developed through collaboration between R&D and the industry, a development contract was signed with LTSSHF in the year 2015 (Project XII-N-R&D-57).

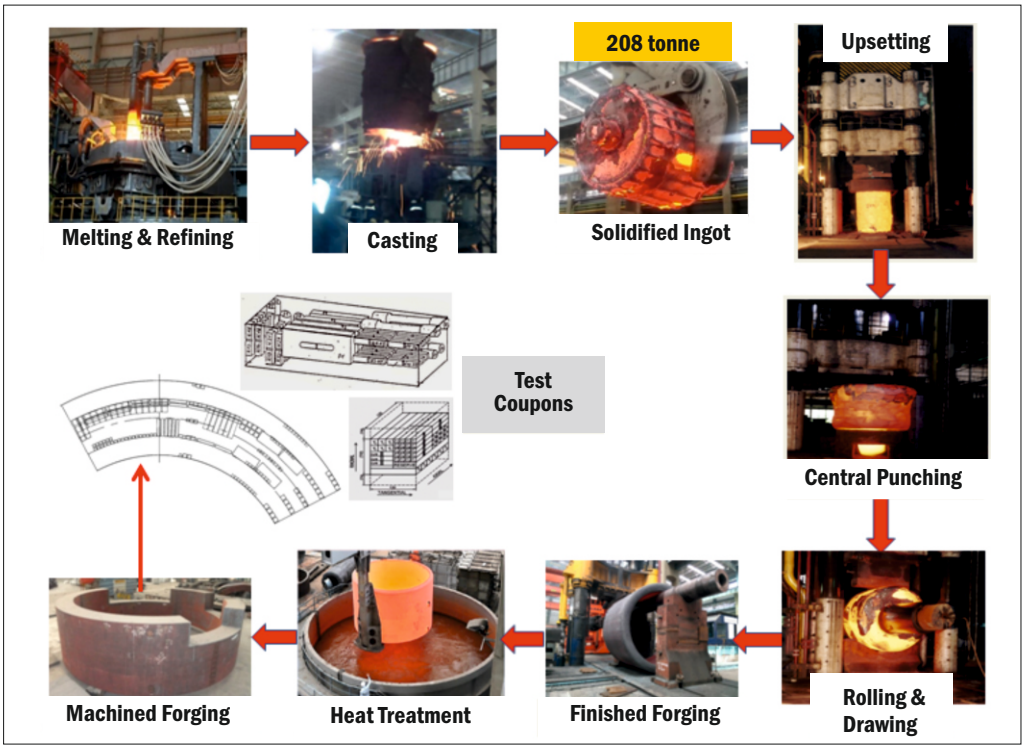


Fig.1: Schematic of Manufacturing Technology of APURVA Steel Forgings

Manufacturing Technology

A mix of specially selected pure steel scrap and direct reduced iron (DRI) are melted in a 100 t Electric Arc Furnace (EAF) followed by refining and alloying additions in a 100 t Ladle Furnace (LF). The chemistry adjusted molten steel is then degassed in a 100 t Vacuum Degassing (VD) unit operating at a vacuum of < 1.0 torr to remove hydrogen. Two such 100 t melts, after degassing, are cast sequentially in to a 200 t ingot mould placed inside a Vacuum Ingot Casting (VIC) set up under a vacuum of < 1.0 torr. This is followed by forging, heat treatment, machining and testing as shown in Fig.1.

Research & Development

Large shell & ring forgings (inner diameter ~ 4.0 m) of different thicknesses, 340 mm, 550 mm & 750 mm, were manufactured successively, with lab scale experiments, industrial scale trials and extensive testing, to progressively improve and optimize the manufacturing processes. Optimum chemical composition and technological process parameters were evolved for each forging. Cooling rates achievable during quenching treatment were determined by analysis for each thickness and validated through large scale quenching experiments.

Heat treatment, which largely governs the microstructure and mechanical properties, was developed specifically for each thickness. Reactor Projects Group developed an innovative technique for laboratory scale physical simulation of heat treatment of the actual forging, utilizing the facilities and support from the Atomic Fuels Division. The heat treatment parameters were optimized using this technique through a large number of lab-scale simulations (~300 nos., involving ~3000 test specimens) carried out at LTSSHF, followed by industrial-scale validation before implementing on the prototype forgings. Materials Group provided their laboratory facilities for extensive microstructural characterizations.

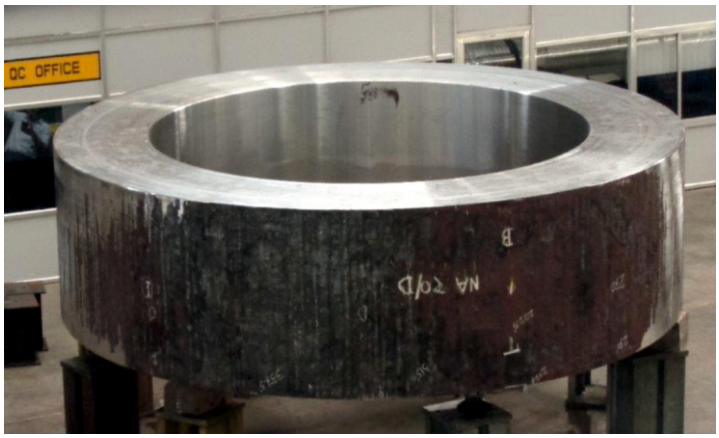
Results

The forgings developed were rigorously tested for ultrasonic soundness, chemical homogeneity, through-thickness mechanical properties, fracture toughness, low cycle fatigue, thermal endurance and weldability. The quality and properties of the forgings developed meet the acceptance norms of various international codes with high margins (see Fig.2 for typical test results). The project was concluded successfully in 2020.

Salient Features of APURVA Steel Forgings

- Si-modified Mn-Mo-Ni Low Alloy Steel grade, equivalent to KTA 20MnMoNi55 and ASME SA508 Gr3 Cl1
- Ultra-clean Steel P<0.004%, S<0.002%, Cu<0.05%, As, Sb, Sn<0.005% each
- Hydrogen ≤ 1.0 ppm
- RTNDT ≤ -25 °C for 340mm thick forging; ≤ -12 °C for 750mm thick forging
- High strength and toughness throughout section thickness
- High resistance to irradiation and thermal embrittlement

340 mm thick Shell Forging for Nozzle Area of RPV-OD4900 x ID4220 x 2000L



750 mm thick Ring Forging for Flange Area of RPV-OD5300 x ID3800 x 700L

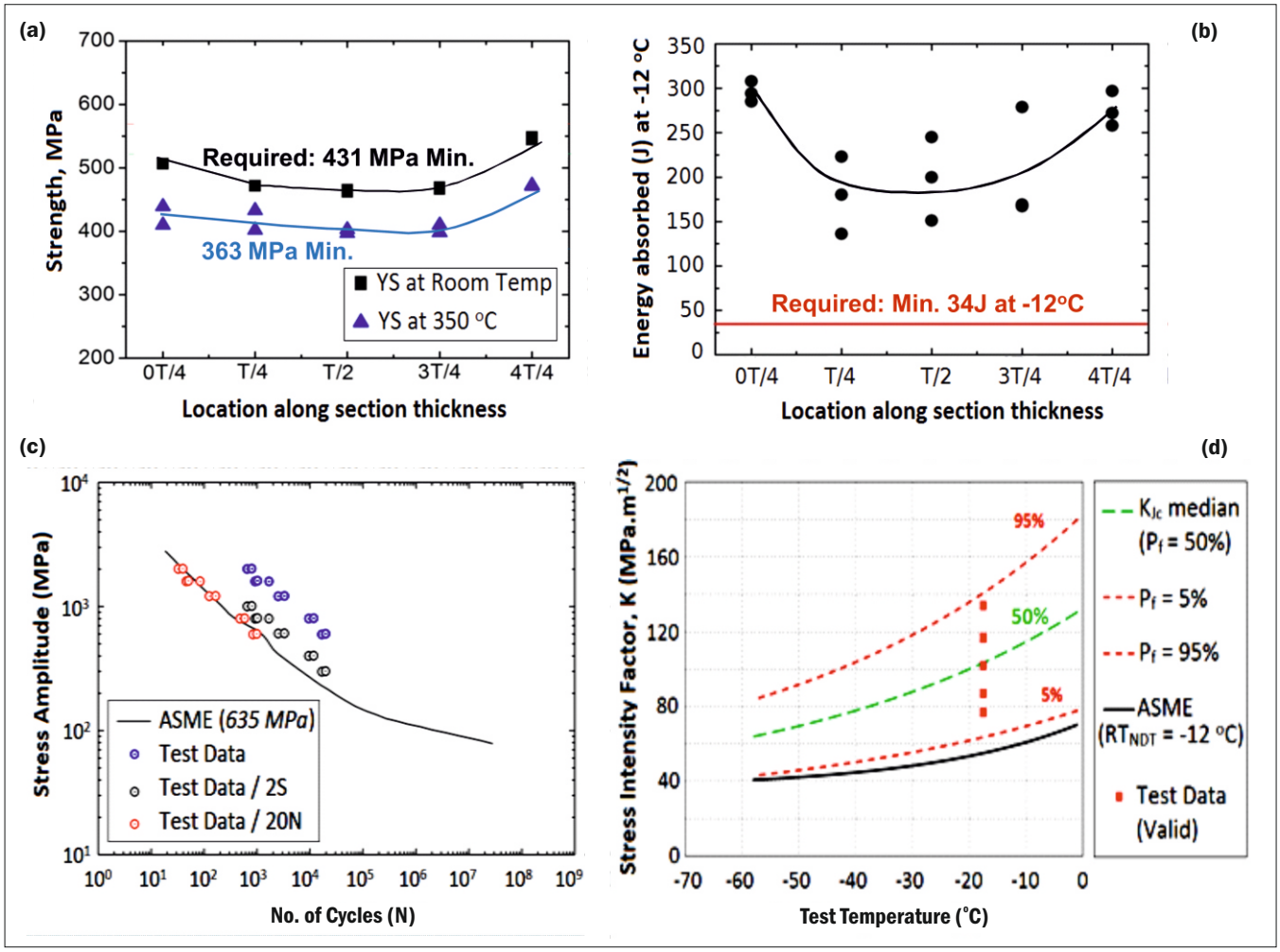


Fig.2: Typical test results of 750 mm thick APURVA grade Forging, (a) Yield strength, (b) Impact toughness, (c) Low cycle fatigue test as per ASTM E-606, and (d) Fracture toughness test as per ASTM E-1921.

Conclusion

The technology developed can be used for manufacturing of thick steel forgings for construction of RPV, Steam Generators and other such pressure retaining equipment of nuclear power plants of PWR, PHWR or SMR types for design temperatures of up to 350°C. The APURVA installation is built from the remnants of the 340 mm thick and 750 mm thick prototype forgings, to commemorate the achievement of this significant technological milestone in LWR technology. It also stands testimony to BARC's commitment towards the vision of self reliance through persistent efforts in partnership with the industry.