नाभिकीय अनुप्रयोग के लिए संरचनात्मक पदार्थ विकास - एक संक्षिप्त अवलोकन

12

Structural Materials Development for Nuclear Application-A Brief Overview

Komal Kapoor
Nuclear Fuel Complex, Department of Atomic Energy, Hyderabad-500062, INDIA

Indigenous development of Ni-Mo-Cr alloy seamless Tubes

Nuclear energy is proven as an inevitable option across the globe, for sustainability and commitment towards climate control. Government of India laid an ambitious roadmap towards significant enhancement in share of nuclear power in the energy matrix and contribute towards net zero emission. This not only entails accelerated growth in the proven Pressurized Heavy Water Reactors (PHWRs), but requires simultaneous development of advanced reactor technologies. In this regard, structural material development plays a pivotal role for realizations of the milestones. Severe operating conditions prevails in nuclear reactors impose enormous challenges on material performance. Sustainability under higher operating temperature and aggressive corrosive environment, better fuel efficiency and accident tolerant designs, are additional requirement in new generation reactors. Therefore, continual improvement in materials and associated processing techniques remain one of the key factor. Zirconium alloys (zircaloys and Zr-Nb alloys) remains the work horse for core structural in water cooled reactors. However, new reactor designs and adoption of advance reactor technologies require enhanced material performance of the conventional alloys, as well, demand development of several alloys viz. special grades stainless steels, superalloys, titanium based and niobium based alloys etc.; in order to sustain high operating temperature (upto 1000°C) and severe corrosive environment.

Nuclear Fuel Complex (NFC), has been in the forefront in transformative contributions towards indigenous development and manufacturing of structural materials for critical applications in nuclear power programme, as a testament towards 'Atmanirbhar Bharat'[1]. The development of these manufacturing technology involves establishing series of thermo-mechanical operations with combination of hot extrusion, forging, cold pilgering, heat treatment along with surface finishing operations. Design aspirations of structural materials have been accomplished at NFC through combination of two approaches viz. (a) improved metallurgical characteristics engineered through advancement in processing technologies, (b) indigenous development of 'high performance alloys'. This article gives a brief overview of indigenous development of important nuclear structural materials at NFC, in strong collaboration with BARC. Indeed, article emphasizes on the fact that collaborative approach has a profound impact and remains the prime strengthening mechanism in the entire saga of materials development.

Development of Nb-1%Zr-0.1%C alloy test loop

Nb-1%Zr-0.1%C alloy has been considered as structural material for the Compact High Temperature Reactor (CHTR), which is envisaged to operate at high temperature (~1000°C) containing molten Pb-Bi as coolant [2]. Refractory alloys remain the obvious choice for such combination of operating temperature and aggressive environment. Thermal hydraulic behaviour of the molten Pb-Bi eutectic alloy for CHTR, required a test loop with Nb-1%Zr-0.1%C as material of construction. However, refractory alloys like Nb-1%Zr-0.1%C, exhibit poor fabricability, was hardly investigated with respect to alloy preparation, establishing thermo-mechanical processing aspect. NFC, in collaboration with BARC team led by Dr. R. Tewari, shouldered the task of fabricating the test loop with difficult to process refractory alloy. Alloy melting has been successfully achieved by electron beam melting under high vaccum and technology development for forming the material in various shapes has been accomplished in record time. Rich experience of Dr. Tewari in the frontier of material research and characterization, has contributed extensively in bringing insights on material behavior during hot deformation processing and thermo-mechanical operations. Fig.1 illustrates the designed vis-a-vis as-fabricated test loop of CHTR, developed utilizing tubular and sheet products successfully manufactured through complex combination of thermo-mechanical processing and optimization of electron beam welding technique for several weld configurations.

Indigenous development of Ni-Mo-Cr alloy seamless Tubes

Molten Salt Breeder Reactors (MSBRs) technology is a promising advanced reactor technology mainly because of the liquid form of the fuel in the reactor. One key activity of this programme is the fabrication of MSBR loop to study the thermal hydraulics and corrosion attack from the liquid fuel and structural integrity up to service temperature of 650 °C. Again, the challenge boils down to materials development in high

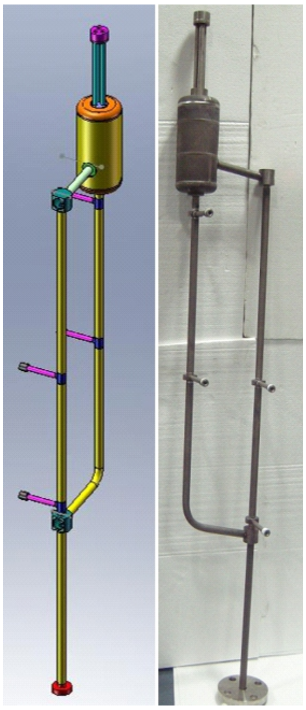

Fig.1: Designed and as-fabricated test loop for CHTR.

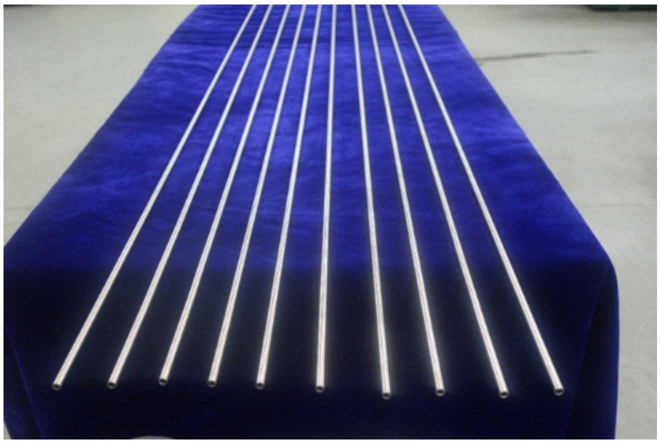

Fig.2: Ni-Mo-Cr alloy seamless tube developed for MSBR.

temperature corrosive fluid, which envisaged Ni-Mo-Cr alloy as material of construction owing to its excellent corrosion resistance in fluoride environment. Strength of collaborative effort of Materials Group, Reactor Design and Development Group, BARC and Nuclear Fuel Complex, Hyderabad jointly established the process route and produced 'difficult-to-process' Ni-Mo-Cr-Ti alloy seamless tubes (Fig.2), first time in the country. This collaborative effort in research and development mark a significant milestone in the advancement of Ni-Mo-Cr alloys, which are crucial for achieving self-reliance in molten salt breeder technologies.

Materials development for Small and Modular Reactor

Development of Small and Modular Reactor (SMR) technologies require development of structural material for longer in-reactor residence time. In this respect, the task of indigenous alloy development (Zr-Nb-Sn-Fe quaternary alloy for in-core and Alloy 690TT for steam generator aplication) and establishment of thermo-mechanical process flow sheet has been bestowed. Another milestone accomplished through successful establishment of thermo-mechanical process route and development of these seamless tubes. The expertise of Dr. Tewari and Dr. R.N. Singh, Materials Group, BARC has been the major support in deep explorations on various aspect of microstructural evolution, phase transformation, precipitate characterization etc.

Above are the few development activities in past 1-2 years to showcase the strong association of NFC and Materials Group, BARC.

Materials development for Small and Modular Reactor

The large thrust in nuclear energy and high order design aspirations, will entails enormous demand in materials development, in near future. This reminds the importance of collaborations, as resonated by Late Dr. Srikumar Banerjee, Dr. Raghavendra Tewari, and several others in bringing illustrious success stories for the department. With profound knowledge in the realm of material science and materials characterization, Dr. Tewari inspired, in several programme, as an esteemed member of NFC Board and other advisory committees.