कांच, सिरेमिक एवं कार्बन-आधारित प्रगत पदार्थ का विकास
Development of Glass, Ceramics and Carbon-based Advanced Materials

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Glass & Advanced Materials Division (G&AMD) has been actively involved in Development of glass, ceramics and carbon-based advanced materials for nuclear, defence, energy and biomedical applications. Some of the important contributions are:

Development of Yttrium-aluminosilicate Glass Microspheres (Bhabhasphere) for Radiotherapy Applications

Radiation therapy is used as one of the most effective treatments for cancers. Glass microspheres containing therapeutic radionuclides are effective for delivering high radiation doses to deep-seated tumors, especially liver cancers. Conventional external radiation often damages healthy tissue and is less effective for deep tumors, so radionuclide-loaded microspheres are used to provide targeted internal radiotherapy. β-emitting radionuclides such as Y-90, Ho-166, Lu-177, and Re-188 are suitable for treating primary and metastatic liver malignancies. Up until now an imported material 'Therasphere®' was being used for treatment of liver cancer. A similar material, Bhabhasphere, was developed by G&AMD, BARC at affordable costing one tenth of the imported cost. Yttrium-aluminosilicate glass microspheres (Bhabhasphere) having composition 40 Y_2O_3 – 20 Al_2O_3–40 SiO_2 (Bhabha sphere) were synthesised. Clinical trials of Bhabhasphere have been concluded and more than 25 doses have already been delivered. The Bhabhasphere was found to be on par or better than Therasphere® in terms of all properties. The glass microspheres were synthesized by melt-quench method, followed by grinding of glass frits to prepare feed particle for flame spheroidization. Microspheres of 20–35 μm diameter, suitable for arterial injection, were formed through flame sherardization and later neutron-activated to produce therapeutic radioactivity.

The Ho-166 and Lu-177 loaded glass microspheres, which are in an advanced stage of development, offer additional advantages: higher neutron absorption cross-sections and weak gamma emissions useful for diagnostics. Ho-166 has a 26.8 h half-life, while Lu-177 emits low-energy beta particles (0.4 MeV) with a longer 6.7-day half-life.

Carbon Technologies for Nuclear Energy Applications

Carbon is indeed a versatile material with a wide range of structures and properties that can be tailored to suit various applications, including those in the nuclear field.

Nuclear-grade graphite is used as a moderator and reflector in high-temperature nuclear reactors and molten salt breeder reactors. Being import restricted, indigenous nuclear-grade graphite has been developed using meso carbon microbeads (Fig.1).

Carbon nanotubes (CNTs) and graphene, as carbon nanomaterials, find applications in various aspects of the nuclear fuel cycle. Functionalized CNTs or graphene are used for the selective recovery or separation of lanthanides and actinides, which are important components in nuclear fuel processing.

CNTs and graphene with controlled porosity have the potential for use in nuclear desalination, where they can be used to purify water through advanced filtration methods. The high specific surface areas of CNTs make them useful for the adsorption of gases or vapours, which is relevant in various nuclear applications, such as gas storage and separation. CNTs and graphene can be incorporated into polymer and ceramic matrix composites to improve mechanical properties. These composites have applications in the nuclear field for structural and functional components.

A significant challenge lies in translating the unique properties of carbon nanomaterials from the nano-scale to the engineering scale. Technologies have been developed for CNT fibres (Fig.2), CNT sheets, and graphene oxide-based high compressive strength concrete, to address this challenge.

In summary, carbon-based materials play critical roles in various aspects of nuclear technology, from reactor components to fuel cycle management. Materials Group, BARC is actively engaged in research and development efforts to harness the potential of these materials for nuclear applications.

Development of SiC for Nuclear Applications

Silicon carbide (SiC), owing to its thermal stability, radiation tolerance, mechanical strength, and corrosion resistance, is widely regarded as a leading material for advanced nuclear systems. Its potential applications span fuel cladding, core structural components, and accident-tolerant

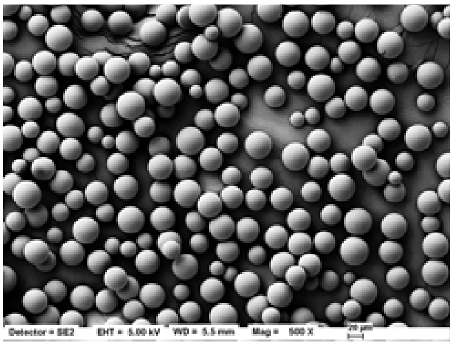

Fig.1: Y-89 aluminosilicate glass microspheres.

Fig.2: Indigenous nuclear graphite.

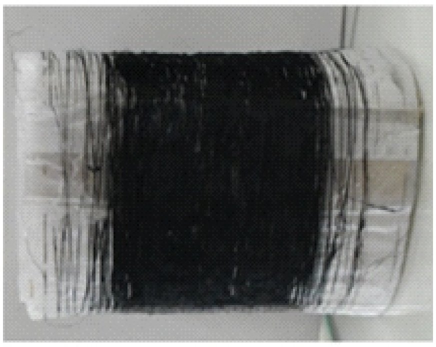

Fig.3: Continuously spun CNT fibre.

Fig.4: SiC coated Carbon fibre. Inset shows the micrograph of the fibre.

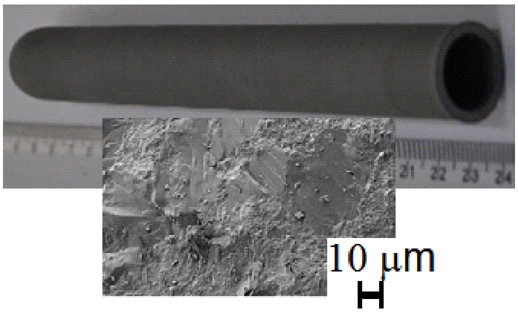

Fig.5: SRBSiC tube having >93% density. The micrographs revealed the dense structure present.

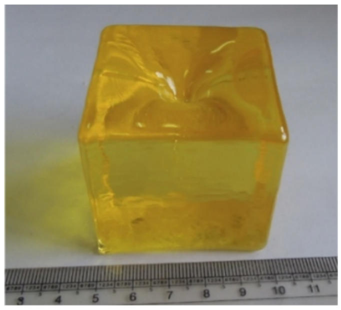

Fig.6: RSW glass.

fuel concepts in both fission and fusion reactors. However, the low fracture toughness of SiC necessitates the development of SiC fiber-reinforced composites to enhance toughness, damage tolerance, and reliability. Glass and Advanced Materials Division is actively engaged in the development of SiC fibre (fully converted and SiC coated C fibre) (Fig.4), monolithic and particulate-particulate composite of SiC (Fig.5), and SiC-based fibre–matrix composites using multiple processing routes. SiC fibres were synthesized by reacting SiO gas with carbon fibres at temperatures exceeding 1500 °C, where SiC formation initiates at the fibre surface and progresses inward. Dense SiC particulate composite (containing both α and β SiC) with >97% relative density, and <6 vol% free silicon, was successfully produced through the reaction-bonding (RB) method. In this process, a preform containing coarse α-SiC and fine carbon was infiltrated with molten silicon at temperatures above 1450 °C. The infiltrated Si reacts with the carbon in the preform to form in-situ SiC, which bonds the existing SiC particles, thereby increasing densification and enhancing mechanical strength. The optimized process was successfully applied to make more than170 mm long and 22 mm dia (wall thickness 2 mm) RBSiC tube (Fig. ACS-2). Preparation of SiC fibre matrix composite through RB method is under progress.

Preparation and Characterization of Lead Silicate Glass

Radiation shielding window (RSW) glasses are optically transparent shielding materials required for safe monitoring and handling of radioactive materials. RSW glasses required for BARC are mostly imported. The purpose of this work is in-house development of radiation shielding glasses so as an import substitute for RSW requirements in India. Composition optimization of CeO_2-BaO-PbO-K_2O-B_2O_3-SiO_2 glass system done with varying components to achieve density 4.5 gm/cc and having desired optical and radiation shielding properties. Successfully prepared glass blocks of dimensions 50 x 50 x 50 mm^3 and 100 x 100 x 40 mm^3 without casting defects. Then glass discs were prepared to study post irradiation changes in optical, thermal, mechanical and radiation shielding properties. Linear attenuation coefficient remained the same pre and post gamma irradiation. Glasses doped with CeO_2 showed radiation stability against browning up to 100 kGy in Co-60 gamma chamber. The post irradiation changes in physical properties are correlated with structural changes probed using Raman spectroscopy and positron annihilation lifetime spectroscopy. Radiation induced colors can be efficiently annealed by heating of the samples up to 300 °C temperature. However, heating of large glasses is not recommended because of the risk of braking. Possibility of UV annealing of color centers was studied post gamma irradiation. After 8 hours of UV treatment, considerable was improvement in transparency found in the glass. Though complete recovery of transmission was not observed however, it was sufficient to see the objects clearly through the glass.