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Naval Materials and Energy Systems

Technology Focus focuses on the technological achievements in the organization covering the products, processes and technologies.

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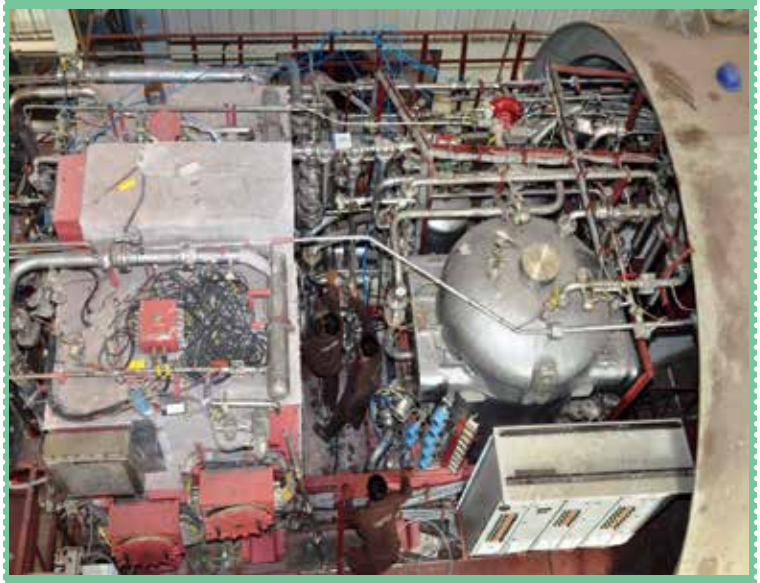

Land-based Protoype for AIP

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From the Desk of Guest Editor

The thrust areas of R&D at Naval Materials Research Laboratory (NMRL) are along the four verticals, viz., energy systems and associated materials; stealth materials and systems; advanced materials; and protective technologies. Virtually every defence system requires energy and power to function. Fuel cells are energy devices that directly convert chemical energy into electrical energy and this conversion is not limited by the Carnot cycle, leading to high energy efficiencies. NMRL initiated basic research on phosophoric acid fuel cell (PAFC) in mid nineties and became a nodal technology centre with capabilities to build modular design fuel cell power packs up to 13.5 kW capacities. Associated technologies like catalyst, carbon paper, fuel generators and packaging have been established and transferred to industries. The laboratory has been actively pursuing research on other variants of fuel cells such as Polymer Electrolyte Membrane Fuel Cell (PEMFC), Solid-Oxide Fuel Cell (SOFC), and sediment-based Microbial Fuel Cell. Supercapacitors, which can store and release pulsed power for applications such as electromagnetic launch of projectiles and torpedo release, are in an advanced stage of development.

NMRL has been at the forefront of research on stealth materials and systems for reduction of signatures of Naval vessels. A significant contribution have been made on development, certification, production and ToT of underwater acoustic stealth items and associated processing materials. This has enabled Indian Navy (IN) to be self-reliant on underwater acoustic stealth materials technology. For mitigation of Radar Cross-section (RCS) of Naval vessels, radar absorbing paint has been developed and accepted by Navy. An Active Shaft Grounding (ASG) system has been developed to reduce Extremely Low Frequency Electromagnetic (ELFE) signatures of IN surface warships. An efficient vibration damping mastic has been inducted into IN for attenuation of structural vibrations of Naval platforms.

The laboratory is the nodal agency on R&D efforts in Welding and Weldability of Naval steel and has successfully developed weld consumables and welding technology for indigenously developed marine grade steels.

On the materials front, some of the notable technologies developed by NMRL in recent years are piezocomposites for sonar transducers, transparent armour based on magnesium aluminate spinel, semi-solid metal processing technology for aluminium alloy near net shape casting, acid resistant rubber lining system for submarines battery pit, and composite ball valve for sea water flow control, and Poly-LIST dock blocks, among others.

The entire IN fleet is today operating with indigenous protective technologies developed by NMRL. The marine environment represents one of the most varied and severe ecosystems with its saline water, winds, waves and plethora of living organisms. To meet these challenges, a host of marine paint systems with a range of functionalities such as anti-corrosive, foul release, self stratifying, self cleaning, fire retardant and anti-microbial, have been developed and inducted into the Services. In addition, NMRL has developed a microcontroller-based modular Impressed Current Cathodic Protection (ICCP) system for corrosion protection of ship propellers.

NMRL has also developed a highly efficacious technology for accelerated bioremediation of pollutant oil using green biological agents to protect marine environments. An auto controlled carbon dioxide curtailment system has also been developed for purification of air onboard IN submarines and has been inducted into the Services.

This issue of *Technology Focus* highlights the work in the area of Naval materials and energy systems carried out by the NMRL.

Dr. Manoranjan Patri
Outstanding Scientist & Director, NMRL

Naval Materials Research Laboratory (NMRL) is one of the oldest laboratories of DRDO with a charter to develop state-of-the-art materials and energy systems for the Indian Navy and other armed forces. Established in 1953 as Dockyard Laboratory with a scope of work confined to routine testing of samples and fleet support to the Indian Navy, the laboratory was subsequently renamed as Naval Chemical and Metallurgical Laboratory (NCML) in the year 1954 and was inducted into DRDO in the year 1958. The scope of the laboratory progressively widened as a result of continuous interaction with the users and requirements of the Navy. A gradual transformation from fleet support towards import substitution to R&D activities leading to better materials such as high strength steel, transducer ceramics and specialty polymeric materials started taking roots in the laboratory. Expertise gained in R&D of materials and the laboratory's success in delivering a reasonably good number of products to the user led in further widening the scope of the lab & in 1995 the lab was rechristening as Naval Materials Research Laboratory (NMRL). Over the years, the laboratory has earned the distinction of being a single-window solution for all the material requirements of the Indian Navy. At present, the laboratory is working on a mission mode project of indigenously developing an "Air Independent Propulsion System" for Indian diesel electric Naval submarines.

Dockyard Laboratory (1953)

Naval Materials and Research Laboratory

Energy Systems

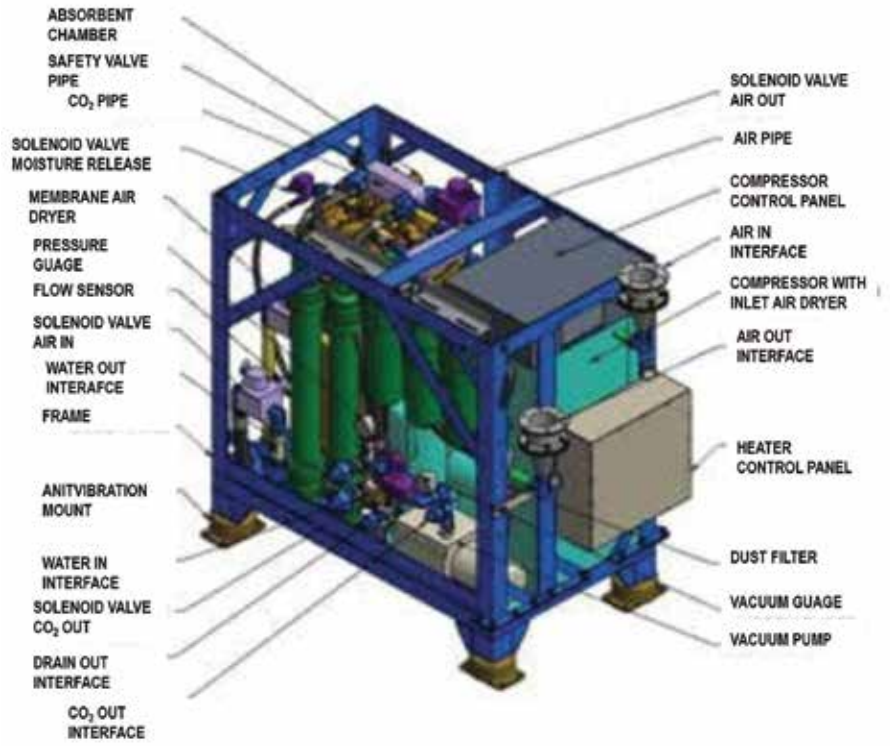
Onsite, efficient energy sources and power devices are essential for any modern battlefield. Fuel cells are considered to be futuristic power generation systems for the defence platforms owing to their high efficiency. NMRL has been at the forefront of fuel cell technology through the development of new materials, manufacturing processes, design approaches and product engineering. The laboratory has industrialized fuel cell-related materials, components and high power stacks based on Phosphoric Acid Fuel Cell (PAFC) technology through a comprehensive research initiatives.

Some of the power systems developed include 100 W field power source with an integrated hydrogen generator; 1 kW PAFC power pack, which can be used as an electric generator in a remote area while using methanol as primary fuel; continuous field power generator of 10 kW capacity with superior conversion efficiency than generator set for camp powering in the remote location; ruggedized 11.5 kW PAFC stacks for Naval application, etc.

Recent development includes a state-of-the-art marine PAFC stack and modular PAFC stacks can be scaled up to a 500 kW power generating system. The stacks can either use pure hydrogen or reformed hydrogen/air as fuel depending upon the type of catalyst. The technology has in-house developed components such as porous conducting carbon paper and corrosion resistant catalyst.

Porous conducting carbon paper serves as the fuel cell electrodes substrate for a chemically stable electrode with the ability to form three phase contact with controlled porosity and electrical properties. The technology has been transferred to M/s AIC Pvt Ltd., Nashik.

High surface area and high Pt loading electrocatalyst on graphitic support have been developed for PAFC technology. This technology gives a method for preparation of 10 per cent to 50 per cent Pt on graphitic support with uniform distribution of nano platinum of 3 nm to 6 nm. The corrosion-resistant catalyst technology has been



Schematic of the CO_2 adsorption system with various components

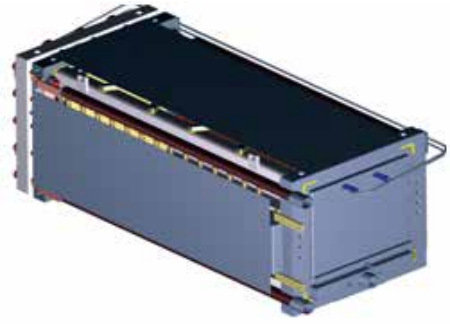
100 W Fuel integrated field power source

Skid mounted 10 kW PAFC

1kW Stationary powerpack

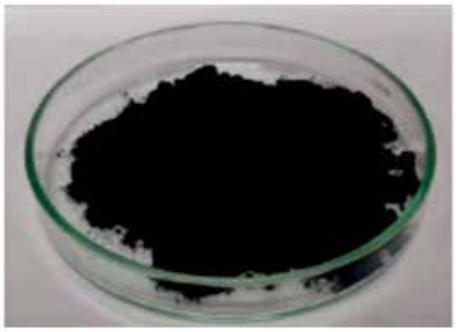
11.5 kW PAFC stack

transferred to M/s AIC Pvt Ltd, Nashik and M/S Procat Tech LLP, Dombivali. All the manufacturing and assembly processes related to PAFC stack technology have been developed considering adaptation for industrial

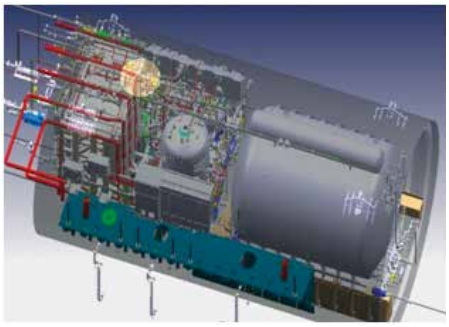


13.5 kW PAFC stack

Porous conducting carbon



Corrosion resistant catalyst for PAFC



Land-based prototype (LBP) of AIP

production. The modular PAFC stack technology has been transferred to M/s Thermax Ltd. Pune for defence production.

Air Independent Fuel Cell-based Propulsion

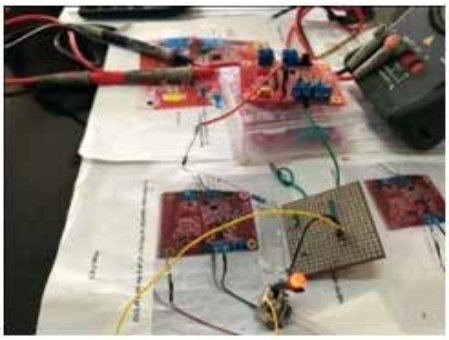
NMRL is working on developing indigeneous Naval Air-independent propulsion (AIP) technology based on the PAFC power system. This marine propulsion technology will facilitate a non-nuclear submarine to operate without access to atmospheric oxygen by surfacing or using a snorkel. It will increase the underwater endurance of IN submarine with enhanced submerged period of conventional submarines.

Marine Sediment Fuel Cell

Marine Sediment Fuel Cell (MSFC) is a bio-electrochemical device that converts organic matter into electricity directly. It is a renewable source of power from the ocean in which the marine sediment is the fuel and dissolved oxygen is the oxidant, thereby generating continuous power. Naturally present anaerobic and aerobic bacteria are catalysts and the net oxidation-reduction reactions cause a voltage gradient at the sediment–seawater interface, which is tapped by the fuel cell. An MSFC prototype has been developed with an open circuit potential of 0.75 V. The fuel cell integrated with a power management system with an output voltage of 4.2 V which could charge a 0.1 F supercapacitor (E = 0.9 Joules) in about 330 minutes. MSFC power could also be stored in

a rechargeable battery (1.2 V, 840 mAh). This stored energy can be used to power underwater sensors.

Marine Sediment Fuel Cell



LED glowing with charged capacitor

Polymer Electrolyte Membrane Fuel Cell

Polymer Electrolyte Membrane Fuel Cell (PEMFC) offer high power density at moderate temperatures due to their compact design. NMRL has developed a poly (2,5 benzimidazole) based nanocomposite membrane for application in high-temperature PEMFC. The membrane in a doped state possesses high conductivity, thermo-mechanical stability and excellent oxidative stability. The membrane has exhibited life of more than 600 h under accelerated testing conditions. A 100 W stack was realized using the nanocomposite membrane and has demonstrated a lifetime of 750 hrs.

A 100 W PEMFC stack prepared from indigenously developed nanocomposite membrane

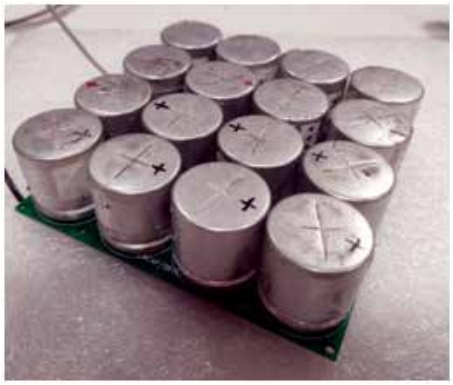
Solid Oxide Fuel Cell

Solid Oxide Fuel Cell (SOFC)- is an electrochemical device that produces electricity directly from oxidising a fuel and has a solid oxide or ceramic electrocyte. SOFC-based combined heat and power (CHP) generators are having energy conversion efficiencies as high as 75 per cent. Technology for the development of various component materials such as YSZ electrolyte, electrodes, glass sealants, etc. has been developed in-house. Assembling and testing protocol for SOFC stacks up to 100 W electrical power output has been established. At present, efforts are on to finalize the stacking parameters and SOP for 250 W stack with more than 1000 hrs of endurance.

SOFC Stack

Supercapacitors

Supercapacitors are electrochemical energy storage devices used for pulse power applications. NMRL has in-house facilities for supercapacitor fabrication and its characterization. Supercapacitors having capacitance from 35 to 1600 F with internal resistance in the range of 25 to 0.5 mΩ have been developed. Supercapacitor modules of 40 V-2 F and 125 V-32 F with active voltage balancing are being developed for pulse power applications in defence.



A 40 V - 2 F supercapacitor module

Stealth Materials Technology

Stealth technology is used for reducing an object's detectability by radar, sonar, mine sensors and other detection systems. The technology is crucial and critical for strategic maritime operations. NMRL has developed stealth materials and technologies to reduce acoustic, radar and ELFE signatures.

Acoustic Stealth

Underwater signature management of submarine is a strategic requirement to counter the detection by enemy sonar systems. Passive and active sonar systems are commonly used to detect ships or submarines using acoustic wave propagation. NMRL has developed a comprehensive underwater acoustic stealth materials technology to suppress underwater radiated noise (for a passive sonar threat) and/or acoustic target strength (for an active sonar threat) of IN submarines. Acoustic rubber tiles are being extensively used onboard strategic platforms of the IN. The rubber tile is multi-layered structure having cavities with an outer protective layer and inner sound absorbing layer. The design of the tile can be altered based on the requirement and frequency range of interest. Some of the variables that governs the acoustic performance of the tile are its thickness, size and distribution of the resonance cavities, dynamic properties of the rubber matrix, etc. A critical aspect of this technology is its processing methodology having tapered cavities of varying dimensions. Further, the tile is capable of withstanding variable hydrostatic pressure up to 4 MPa.

Acoustic rubber tile

Vibroacoustic tile

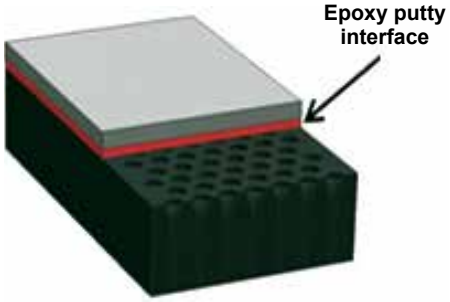
Vibration Damping Elastomer Coating

Vibroacoustic Tile

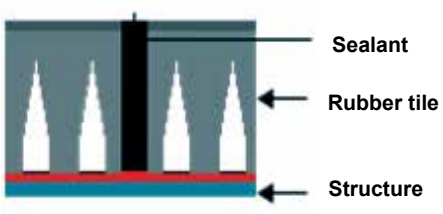
Vibroacoustic tile is used in the sonar dome of submarines to isolate the sonar transducers from structural vibrations and acoustic noise. This tile is also having a multilayered configuration with perforated layers in the core, which are attached to each other by a specialty adhesive.

To attenuate the structural vibrations in the decks and engine room floors of submarines and ships, a Vibration Damping Elastomeric Coating (VDC) has been developed and inducted into the Services. To conformably secure the acoustic rubber tiles on the hull surface of submarines a host of high performance adhesives, putty and sealant have been developed.

Epoxy-based putty is used for the leveling of surfaces and filling the gaps between metal to metal joints and also for adhering metal to rubber surfaces. It provides excellent metal to rubber adhesion and has a service life of more than 20 years and is primarily used to adhere to acoustic rubber tiles onto the underwater surface of marine vessels. Polyurethane sealant is used to seal the gaps between acoustic rubber tiles to deter seawater

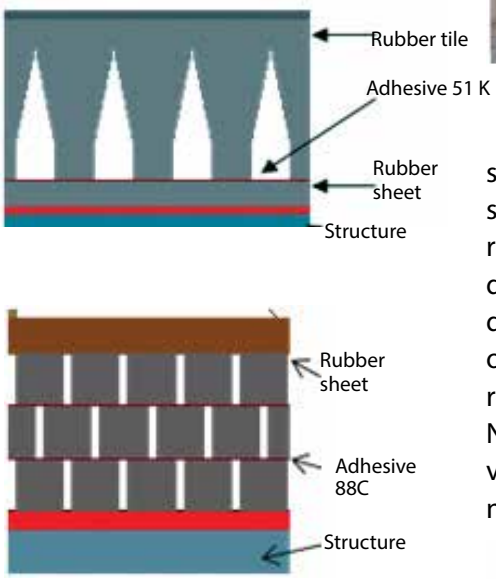


Schematic of tile-metal adhesion with epoxy putty



Sealant used for sealing the gap between rubber tiles

seapage from the underwater surface of vessels. It is capable of responding to reversibly dynamic conditions at various depths and speeds of the vessel. There have been several offshoots of this material which are used as an encapsulant for transducer assemblies of sonar, acoustic transparent and water barrier coating for composite sonar domes. Besides the epoxy putty and sealant, two high-performance adhesives known as NMR51K and NMR88C are being used for the rubber to metal and rubber to rubber adhesion.



Schematic of the application of NMR51K and NMR88C adhesives

The second generation of acoustic coating materials has been developed for low-frequency sound isolation. Some of the new developments include (a) acoustic rubber tile MK III (b) reinforced coating and (c) noise silencers. The prototypes of these materials have been fabricated, tested and approved by the user for induction into the Services.

Reinforced coating

Noise silencer array

Research on the acoustic stealth structures of submarines primarily strives for low frequency, pressure resistance, and broad frequency domain absorption. NMRL developed damping mastic, based on the nanofiller reinforced epoxy resin is being used by the Indian Navy for attenuation of structural vibrations onboard IN ships. The nanocomposite based damping mastic compound is applied as a single layer of the coating as a free layer damping treatment. When applied on machinery and engine room foundations, it provides an excellent damping in the low and medium frequency range with significant system loss factors of 0.15 to 0.20.

Damping mastic

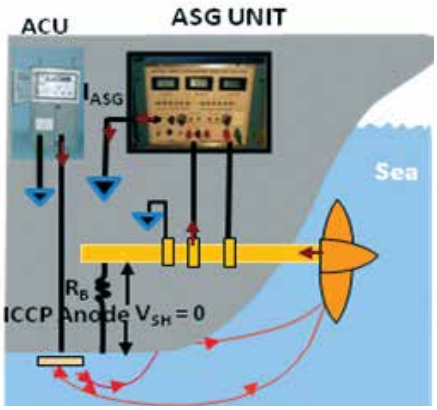
Radar Stealth

Radar stealth is crucial for both maritime as well as airborne platforms. NMRL has developed ferrite-based radar absorbing material (RAM) to reduce the radar cross-section in the X-band range (8-12 GHz). This active material has been incorporated in epoxy resin and rubbers to make radar-absorbing paint (RAP)/sheet (RASH)/ composite (RAC) structures. The RAP, RASH and RAC have been tested extensively and offer more than 10 dB attenuation in X-band radar. Indian Navy has accepted RAP for application on snort mast and periscope of a submarine, and superstructure of ships.

RAP applied on marine structure

ELFE Signature Management

The static and extremely low frequency electric and magnetic signatures of ships are easily detected with modern sensors. Electric fields, and coincident magnetic fields, arise around a ship due to the current flow from ICCP systems or the use of dissimilar metals during construction. To protect the ships from influence of mines, Active Shaft Grounding (ASG) system has been developed to reduce ELFE signatures. This device uses electronics to compensate for changes in shaft-to-hull resistance, thereby eliminating the modulation of the shaft current. The ASG system operates by using slip-ring sensors to measure the shaft-to-hull potential of the ship.



Schematic of the ASG layout

Protective Technologies

Steel and its alloys in various forms are the most widely used structural materials for building ships, submarines and offshore structures. A structure or platform exposed to the marine environment is susceptible to attack by various chemical and biological factors like corrosion, biofouling, etc. The detrimental effect of corrosion and fouling can be assessed from the fact that billions of dollars are spent worldwide to overcome these problems.

NMRL has developed the following technologies for protection of Naval platforms of IN.

Protective Coating

The use of organic protective coatings is one of the most effective and primary methods of corrosion prevention. These coatings produce a direct barrier layer separating the underneath metal substrate from the corrosive species in the external environment. Typical paint or coating system (used interchangeably) comprises an organic or polymeric binder and host of functional additives, which are mainly inorganic in nature.

Heavy Duty Non-skid Paint

The heavy duty non-skid paint prevents skidding of personnel and aircraft on flight, helo and weather decks of Naval ships. It can withstand thermal stress, due to intermittent heating, up to 250 °C. The paint scheme can also be applied on engine room floors and surfaces requiring anti-slip properties.


Heavy duty non-skid paint

High Performance Exterior Paint

The IN ships are painted with high-performance exterior paints for protection against the hostile marine environment. It is applied to exposed bulkheads and superstructure as well as on other structures and platforms functioning in the marine environment. It has excellent gloss retention and chalking resistance.


Naval ship painted with high performance exterior paint

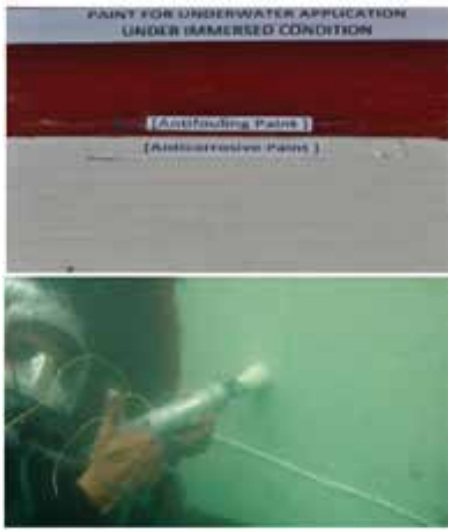
Intumescent Fire Retardant Paint

To mitigate the hazards of fire onboard Naval vessels as well as off-shore structures, a paint scheme with Intumescent Flame Retardant (IFR) characteristics has been developed and inducted into the Services. The mechanism of fire retardance of this paint scheme is based on the formation of a char upon exposure to fire or excessive heat, which protects the underneath substrate by

thermal insulation. The technology has applications in the interior compartments of ships, electrical installations, high rise buildings and railway compartments.

Anti-corrosive and Anti-fouling Paint for Underwater Applications

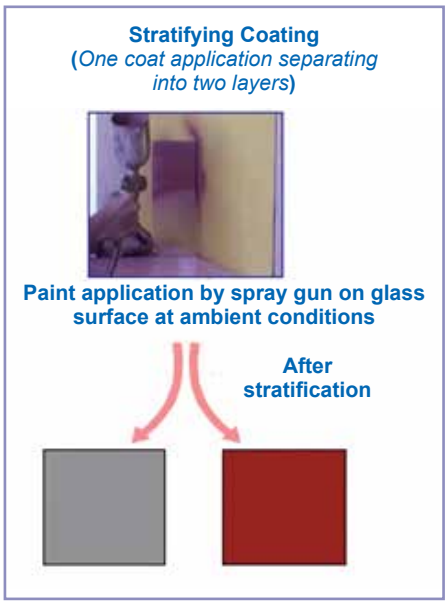
Anti-corrosive and anti-fouling paint composition developed by NMRL can be applied on submerged structures using an in-house developed application device. This technology provides a unique solution for on-site maintenance painting without bringing the ship to dock.



Anti-corrosive and anti-fouling paint application under immersed condition

Self Stratifying Coating

Conventionally, a paint system comprises a multi-layer scheme consisting of primer, tie coat and multiple top coats. All the layers are applied sequentially with an intercoat interval varying from a few minutes to hours. Thus the process is both time and labour intensive with environmental implications concerning the VOC used in the coating system. In order to address these issues, a state-of-the-art self stratifying coating technology has been developed. Self stratifying



coatings facilitate segregation of two distinct interconnected coating layers with complimentary properties in a single shot application thus obviating the need of multiple coating steps.

Self Cleaning Coating

Based on the self-stratification concept, a self cleaning coating system has been developed and the technology has been transferred to industries. The coating system

comprises hydrophobic PDMS resin and epoxy resin, which provide anticorrosive and self cleaning properties in a single coat application. The hydrophobic top surface ensures self cleaning of dirt and contaminants, while the epoxy layer underneath provides anti-corrosive properties and excellent adhesion to metallic substrates. This coating can be applied on superstructure and interior compartments of ships as well as for multifarious civilian applications.

Foul Release and Anti-corrosion Coating

Another important breakthrough in coating technology derived from self-stratification concept is combination of foul release and anti-corrosion properties with a single coat application. The coating design and working principle is similar to the self cleaning coating. The top coat layer shows foul

Facile release of bio-organisms from coatings exposed in seawater at Mumbai harbour

release characteristics so that the fouling organisms settled on it could be easily dislodged with a gentle water wash. The bottom coat, on the other hand is pigmented to show anti-corrosive characteristics with excellent adhesion to metallic substrates. The coating technology has been extended from protective to functional applications in the development of a drag reducing coating for high speed underwater crafts. The coating, upon contact with water, releases a high molecular weight water soluble polymer, which modifies the turbulent boundary layer. A proof of concept experiment was carried at the high speed towing tank facility by measuring the axial drag of a composite with and without the NMRL developed coating. The studies revealed a skin friction drag reduction of 10 per cent at 4 m/s of towing speed. The Mk-II variant of the coating has been developed, which would be effective at higher speeds up to 20 m/s, corresponding to the real time operational conditions of high speed watercrafts.

Advanced Impressed Current Cathodic Protection System

Besides coatings that primarily provides corrosion protection, the ship hulls are additionally fitted with an Impressed Current Cathodic Protection (ICCP) system. The ship hull is made as cathode with respect to external anode, which is termed as cathodic protection. This can be done through sacrificial anodes as well as ICCP. NMRL has developed various sacrificial anodes as well as an advanced ICCP system. The ICCP system comprises an auto control unit (ACU), Platinized Titanium (Pt-Ti) anode, Silver-Silver chloride (Ag/AgCl) reference electrode (RE). The ACU impresses the current through Pt-Ti inert anodes to the ship hull in order to maintain the protective optimum potential range i.e. -800 to -850 mV w.r.t. Silver-Silver Chloride Reference Electrode (Ag/AgCl RE).

NMRL has also developed a microcontroller based advanced modular ACU to maintain uniform hull potential. A number of modules are integrated in one cabinet. Each module has dedicated anode, RE, power supply and a controller. It is used for corrosion protection of ships and for minimization of extremely low frequency electromagnetic (ELFE) signatures. The entire Indian Naval fleet is equipped with NMRL developed ICCP systems.

A model coated with NMRL developed drag reducing coating

Advanced Materials Technology

Welding of High Strength Naval Grade Steel

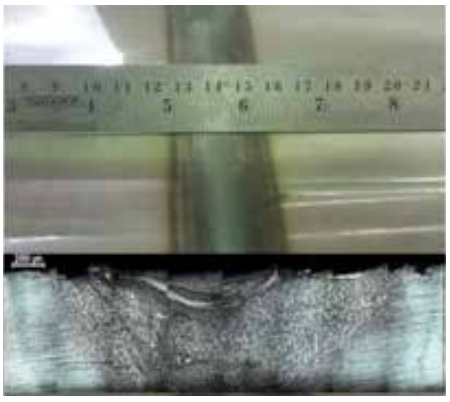
NMRL has been pursuing R&D on a wide spectrum of materials technology requirements of various systems and platforms of the Indian Navy. One of the major areas of work includes indigenous development of weld consumables and welding technologies for the welding of High Strength Naval Grade Steel for ships and submarines. Weld consumables such as electrodes, wires, rods, and fluxes, etc. for Shielded Metal Arc Welding (SMAW), Gas Metal Arc Welding (GMAW), Gas Tunsten Arc Welding (GTAW) and submerged Arc Welding (SAW) processes have been developed for steels having yield strength (YS) in the broad range of 390-800 MPa. For steels of YS in the range 390-560 MPa, NMRL developed Weld Consumables are being used extensively for surface ships, viz. aircraft carriers, corvettes, and

frigates. These consumables have also been certified for being used in critical hull structures for underwater applications. NMRL has also been working on advanced welding processes & technologies to increase weld productivity and weld quality using these indigenously developed and certified consumables. Further, weld consumables have been developed for steels having YS in the range of 560-800 MPa, particularly for underwater hull structures. Depending on the application areas, both ferritic and austenitic grade consumables have been developed and the technology of welding using these consumables is demonstrated at the shipyard.

Friction Stir Welding

NMRL is also working on the Friction Stir Welding (FSW) technology for joining of marine structures made of Aluminum alloys such as Al5083, Al6061 & Al2014. This technology utilizes a non-consumable rotating welding tool to generate frictional heat and deformation at the welding location, for the formation of a joint while the material is in the solid-state. FSW of 12 mm HSLA steel has been demonstrated and properties were found to be better than the conventional welding technology. The yield and ultimate strengths of FSW joints are 590 and 790 MPa, compared to 610 and 730 MPa in the base metal.

100 kN FSW machine



FSW of HSLA steel

High Vibration Damping Aluminium Metal Matrix Composites

NMRL has developed molten flux assisted reaction synthesis foundry technology to produce high vibration damping aluminium metal matrix composites. Ultrafine reinforcement of graphite and ceramic particles such as Titanium Diboride (TiB_2), Titanium Carbide (TiC), Boron Carbide (B_4C), etc. in suitable aluminium alloy matrix promotes high vibration damping capability required in the case of torpedo nosecone application. Prototype nosecone components have been produced with TiB_2/TiC/B_4C/Graphite reinforcement in three different Aluminum alloy by conventional foundry melting, ingot casting and forging route.

Torpedo node cone made of Aluminium alloys metal matrix components

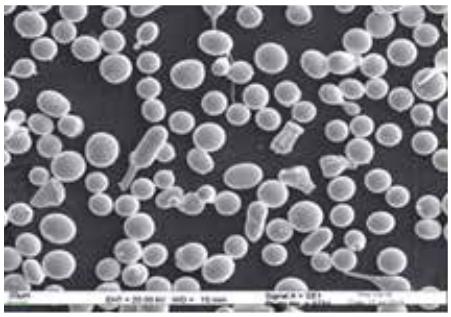
New Rheo-casting

A new rheo-casting (NRC) processing technology has been established to produce near net-shaped intricate thick and thin-walled components casting using real-time controlled high pressure die casting machine (Buhler Vision 53N). "Slurry on-demand" rheocasting methodology was adopted to promote the commercial viability of this technology. It has the dual advantage of the intricacy of casting and property attainment near to forging. Both thick and thin-walled components of A356 aluminum alloy have been realized to meet missile and aerospace application needs.

Thick and thin walled Al-Alloys A356 Al-Si Alloy HDFC components by NRC technology

Bulk Metallic Glasses

Bulk Metallic Glasses (BMG) have been found to exhibit very high strength, high elastic modulus, high corrosion resistance and several unique physical properties not observed in conventional crystalline metallic materials. NMRL has designed and developed Fe and Cu based alloy systems having a good glass-forming ability (GFA). Fe/Cu-based amorphous powders were coated on steel and Nickel Aluminum Bronze (NAB) substrate using the HVOF coating technique. The amorphous coating thus formed has shown high hardness in the order of 1000 VHN and excellent corrosion resistance in seawater, which is equivalent to cast super duplex stainless steel. The technology can be used for erosion-corrosion resistance coating of impeller, propeller and other Naval and defence components.



SEM images of Fe base amorphous powders of size ranging from 25 to 50 µm

BMG coated rotor shaft

Piezocomposite Acoustic Sensing Material

NMRL has developed the manufacturing process technology for 1-3 Piezocomposite Acoustic Sensing Material by an innovative dice and fill method for advanced

Piezocomposite elements of assorted dimensions

2-element Piezocomposite stacks for receiver and projector transducer arrays of Portable Diver Detection Sonar

sonar transducer applications. Piezocomposite elements are high promise alternative for conventionally used PZT piezoceramic material, which have limitations like high acoustic impedance, higher weight factor and poor mechanical properties. These materials exhibit low acoustic impedance, a wide range of dielectric constants, ease of dividing into acoustically isolated array elements and formability into curved shapes.

Piezocomposite based sonar transducers show enhanced receiving and transmitting response over a large frequency bandwidth and narrow beamwidth. The areas of application include but are not limited to Portable Diver Detection Sonar System (PDDS), Ship Wake Acoustic Measurement (SWAM), Miniaturized FET based piezo composite hydrophones, High-Frequency Acoustic Imaging and Thin Line Towed Array. The technology has been transferred to industries.

Transparent Poly-crystalline Ceramics

Various combat platforms of the Services and the paramilitary use transparent windows for soldier visibility and protection (armour). Futuristic 'directed energy weapon systems' onboard Naval, Air, or Ground platforms will also require high-performance transparent window for LASER transmission.

NMRL has developed technology for producing transparent polycrystalline ceramics namely magnesium aluminate spinel in the form of flat tiles of 4'' x 4'' dimension. The mechanical properties like hardness, flexural strength and fracture toughness are two-three times better than that of common float glass and semi-crystalline glass-ceramics currently being used in transparent armour. The in-line transmission of the material is 75-85 per cent in the visible region and 80-90 per cent in the IR region. The material has been tested against a 7.62 AP bullet. Technology can be up-scaled for practical size requirements.

Transparent polycrystalline spinel ceramic tiles of up to 4 inch x 4 inch dimension

Environmental Technologies

NMRL has developed critical environmental technologies for accelerated bioremediation of oil spills and carbondioxide adsorption for water and air purification, respectively.

Accelerated Bioremediation of Oil Spills

The release of hydrocarbons into the sea is the main cause of water pollution leading to detrimental effects on marine life, marine structures and seafood industry as well as maritime operations. Hazardous impact of the carcinogenic, mutagenic and allergic effects of hydrocarbons are also well documented. Thus, the management of oil spills in the sea and an effective oil spill remediation technology is a necessity to control ill effects of the oil spill problem. NMRL has developed an eco-friendly method for rapid and effective remediation of pollutant oil in sea water. Bioremediation (BR) is a preferred means of clean up of a petroleum hydrocarbon pollutants because it uses biological organisms and provides a permanent solution through biodegradation of oil contaminants into benign by-products.

Two bioremediation agents namely, Biomix, comprising of three highly efficient oil-degrading bacteria (ODB), and Nutrimix, a nontoxic, oleophilic nutrient formulation as a growth stimulant for ODB, have been developed for rapid degradation of pollutant oil. The application method is user friendly, which involves only a one-step spray over the pollutant oil. Complete bioremediation of pollutant oil takes place within 24-48 h. The effectiveness of the technology has been established for field applications and is being transferred to industries.

Pollutant Oil Contained | Spraying of BR Agents on Pollutant Oil

Adherence of BR Agents on Pollutant Oil | Emulsification and Disintegration of Oil

Complete Bioremediation of Oil in 24-48 hrs

CO_2 Adsorption System

Air Independent Propulsion (AIP) technology has allowed the next generation of conventional submarines which will remain submerged for several weeks, creating a need for regenerative air purification methods. Air inside a submarine is a complex mixture of compounds where the most obvious contaminant is metabolically produced carbon dioxide. It is important to maintain a habitable environment inside the submarine using a controlling concentration of oxygen and carbon dioxide to ensure the health of the crew.

NMRL has developed a microprocessor-based CO_2 control system to maintain an optimum level of O_2 and CO_2 inside a submarine. It consists of the following main components:

- Molecular sieve-based adsorption system for truncate CO_2 with air dehumidifying system and membrane for removal of moisture from the air
- Heating and cooling facilities for temperature swing adsorption/ regeneration
- Compressor and vacuum pump for circulation of CO_2 rich air and expelling adsorbed CO_2 after regeneration
- An auto control unit interfacing the adsorption system and a monitor for online monitoring of CO_2

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