Protecting metallic materials from corrosion

CSIR-CECRI

The Council of Scientific and Industrial Research (CSIR) and the Central Electrochemical Research Institute (CECRI) had the perspicacity and foresight to set up the CSIR-CECRI's Corrosion and Materials Protection (CMP) division way back in the 1940s when the knowledge of electrochemistry in India was at its nascent stage. The work of the CMP division over the years has been invaluable in the protection of important buildings and structures and their maintenance

THE Council of Scientific and Industrial Research is an autonomous body which was established in 1942, under the vision of the first prime minister of India, Jawaharlal Nehru. Six years later, on 25 July 1948, the Central Electrochemical Research Institute (CECRI) was established at Karaikudi, Tamil Nadu. This is the era when the knowledge of electrochemistry in India was at its nascent stage. The institute was established with departments such as Corrosion and Materials Protection (CMP), Fuel cells, Fundamental electrochemistry, Hydro/pyro metallurgy, and Electrochemical material science. Since the institute's inception, the CMP division contributes to achieve the vision of the institute and CSIR organisation. This division has shown an outstanding record of success in dealing with industrial

partners as well as nourishing the fundamental aspects of corrosion. CMP division has completed more than one thousand industrial projects, which include various types of industries such as private, government, and other public funded projects. Several projects for strategic sectors such as DRDO, ISRO have also been completed successfully. The major activities of this division are diversified into five major areas as mentioned here:

- Metallurgy and Failure Analysis
- Paints and Coatings
- Marine, Bio-corrosion and Inhibitor
- Cathodic Protection
- Concrete Corrosion

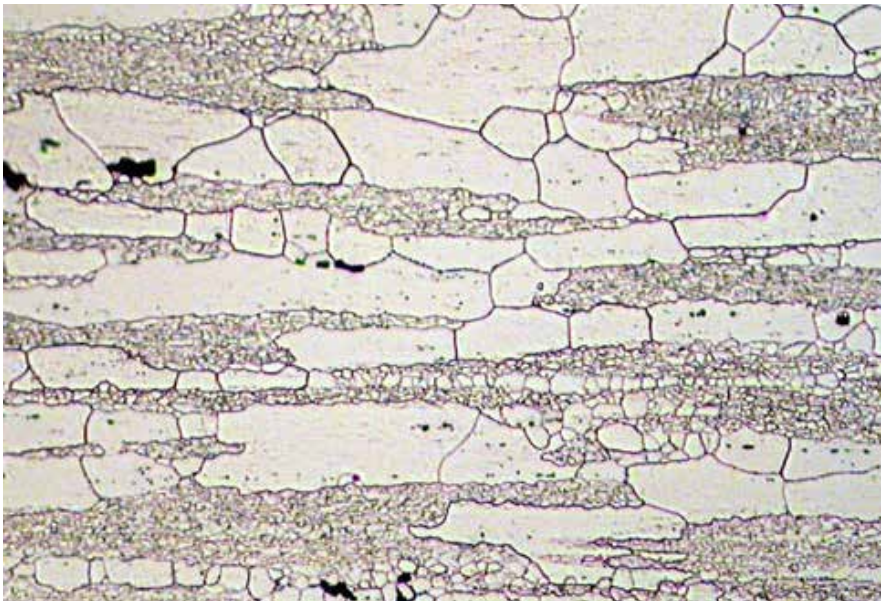
The phenomenal works of the lab caters the solutions to various corrosion related problems to different industrial sectors. The division also accomplishes societal requirements of corrosion. The testing facilities hosted by this historical laboratory are unique and can also design appropriate equipments to simulate various actual environments depending on the client requirements. The CSIR–CECRI has an extension centre in Mandapam which comes under the purview of the CMP division. The facilities available at Mandapam can be used to study the aspects of marine corrosion process in real time. The broad outline about research activities and major technologies developed by each subgroup of CMP division are elaborated in the following sections.

METALLURGY AND FAILURE ANALYSIS

Corrosion of metallic materials is inevitable due to their thermodynamic instability in the environment where they are being used. This corrosion issue causes severe threat to operational safety and increase in processing cost. Hence controlling these issues is considered to be paramount in various industries. CMPD's Metallurgy and Failure Analysis Group provides vital contribution in terms of technical advice and knowledge generation for different industrial sectors which includes but are not limited to: automotive, chemical processing, food processing, petrochemical industries, mining, and metal processing industries, both renewable and non renewable energy industries. The main focus of this group is to evaluate various types of corrosion in the aforementioned industrial sectors and to suggest appropriate preventive measures to counteract respective corrosion damages. This group also involves in design of new alloys with superior corrosion properties. Proper material selection for particular application is very crucial as it determines the durability, integrity, cost and the life of the structural components. Failures due to improper material selection may lead to loss of properties and human lives. This group offers best solutions in this area. Many applications require metals with higher resistance to hydrogen damage in the given environment. Our group has sophisticated testing facilities to evaluate the resistance of different types of metallic materials to hydrogen induced cracking. At present, additive manufacturing (AM) methods are dominating the manufacturing industries. AM is used to produce components with superior metallurgical, mechanical and corrosion properties. Recently our group focuses on development of alloys via this novel manufacturing route.

Using computational modelling, many alloy systems can be studied for their corrosion properties. This helps in reducing the number of physical experiments required to estimate the right composition of an alloy for a given environment. This group has been involved in computational modelling of many metallic systems to understand their corrosion properties.

This group also carries out theoretical modelling of electronic structures for aluminium-based self healing alloys. Application of advanced characterisation tools offers better understanding of the fundamental research in the corrosion process as well as in failure analyses. The institute houses the well-built Central Instrumentation Facility with sophisticated characterisation tools such as High Resolution Transmission Electron Microscopy (HR-TEM) with electron energy loss spectroscopy (EELS), TEM, Scanning Electron Microscopy (SEM), Fourier Transform Infrared (FTIR) Spectroscopy, X-ray Photoelectron, and Spectroscopy (XPS). All these equipment are frequently used to solve corrosion-related industrial problems.



PAINTS AND COATINGS

The Corrosion and Materials Protection Division has developed various anti-corrosion products as well as processes to prevent corrosion. This division has contributed enormously to industrial and strategic sectors such as DRDO, IOCL, NPCL, etc. One of the major anti-corrosion coatings developed by scientists at CMPD, CECRI is the epoxy-based four coat system which has been used by the Railways and National Highway authorities at the Pamban Bridge in Rameswaram. This typical coating system which can withstand extremely aggressive environment is being coated for various concrete bridges and various industrial buildings across the length and breadth of the country. The rust converting coatings developed at CECRI could be effectively applied for various installations in fields where surface preparation is a challenge. Other notable coatings developed at CECRI are high build epoxy coatings for pipelines, strippable coatings, and speciality coatings for wet surfaces, and cement polymer composite coatings. Many of these coatings have been commercialised and licences have been brought by leading paint manufacturers.

The research laboratory facility at CMPD for the development of coatings and its testing is of international standards with cutting-edge technologies and all necessary equipments for carrying out standard corrosion tests. The latest electrochemical instruments which can investigate corrosion at micro scale are also available in our laboratory. Cur-

rently, the research and development activities at the coating laboratory aim at the development of smart coatings such as self-healing and super hydrophobic coatings. Scientists at CECRI have developed environmentally friendly conducting polymer-based primer coatings to replace the chromate-based coatings, which is being used currently in the aerospace industry.

In addition to the above mentioned fundamental research to develop novel coating formulation, our lab undertakes various consultancy projects to test and certify coating formulations developed by paint manufactures. The life prediction of structures and coating failure analysis for various industries such as thermal power plants and oil-refineries are also being carried out by coating research group at CMPD, CECRI.

CATHODIC PROTECTION

The Cathodic Protection technique (CP) is one of the more economical and effective ways of mitigating pipeline corrosion of underground and submerged environment. In CP the metal to be protected is made completely a cathode by implementing an auxiliary electrode reaction by implementing in two ways:

i) Sacrificial type in which more electronegative metal alloys (Zinc, Magnesium, Aluminium) is connected to a steel structure.

ii) Impressed current cathodic protection (ICCP) system using external DC source. CECRI has developed a technology of sacrificial anodes and impressed current (ICCP) anodes. Supervisory control and data acquisition (SCADA) technology developed for the automatic control of the ICCP system can be used both in underground and offshore structures.

At present, the corrosion group focuses on R&D work for the development of flexible ICCP anodes used for mounded LPG bullet storage tanks, IoT-based centralised corrosion monitoring of the oil pipelines based expert systems for cathodic protection, and internal corrosion and permanent reference electrode for underground steel structures. CECRI provides consultancy services in design of CP systems for underground pipelines, steel piles in shipyard, offshore jetties, cooling water system for nuclear reactors, etc. In order to assess the health of the existing CP system, close interval potential survey (CIPS) and interference studies for both AC/DC can be carried out. Developmental projects for corrosion failure analysis under CP conditions, evaluation of dis-bondment of coating and evaluation of sacrificial anode as per ASTM standards are routinely taken up for evaluation.

MICROBIOLOGICALLY INDUCED CORROSION

Corrosion is a global problem that affects a large variety of industries and municipal services such as oil refinery, sewage and drinking water systems, shipping, construction, and maintenance of historical buildings and statues. It refers to the deterioration of metallic as well as non-metallic materials such as iron, steel, concrete, and stone. As per estimates, India annually loses almost $100 billion due to corrosion. A NACE (National Association of Corrosion Engineers) study estimated the global cost of corrosion at around $2.5 trillion annually. Microbiologically influenced corrosion (MIC) refers to the possibility that microorganisms are involved in the deterioration of these materials and is usually estimated to account for 20 percent of the total cost of corrosion. Microorganisms can affect cathodic and/or anodic reactions and thus influence the electrochemistry at the bio film and metal interface. Other mechanisms of MIC include production of corrosive chemicals, degradation of protective coatings and acceleration of cathodic reactions. Many microorganisms such as sulphate-reducing bacteria (SRB), acid-producing bacteria, nitrate-reducing bacteria or iron-reducing bacteria are reported to cause MIC of carbon steels, stainless steels, aluminium alloys, and copper alloys in different environmental conditions. MIC typically manifests itself as localised corrosion with wide variation in rate of loss. Since microorganisms are ubiquitous in nature and can survive in most extreme environments, it is very difficult and challenging to determine accurately the degree to which MIC contributes to corrosion and to implement effective corrosion management.

The bio-corrosion group of the CSIR-CECRI Corrosion Division has a dedicated team of researchers who mainly focus their research to understand and elucidate the possibility and mechanism of microbial induced corrosion in many

industrial installations including oil and gas industries. Evaluation of inhibitors and biocides is another thrust area of interest. The group has successfully completed various projects related to cooling water systems, corrosion in petroleum industries, corrosion in railways, etc and have clients from various sectors.

The division has well equipped molecular and microbiological facilities for various studies related to microbial induced corrosion. Also there are facilities like Rotating cage electrode, Rotating cylinder electrode, Wheel test for evaluating the efficiency of inhibitors in flow environment. It is to be noted that sophisticated analytical facilities has been a largely ignored and the most important of modern-day corrosion studies. While we marvel at the growth of technologies at newer level of top-down approaches, it becomes mandatory to look at the beginnings and fundamentals of corrosion at the minutest level accessible to modern science. These newer fields of research using analytical tools have far-reaching implications in science as well industries due to the level of flexibility and hold they offer on basic corrosion processes. Herein, equipment like electrochemical scanning tunnelling microscopy, atomic force microscopy, X-ray photoelectron spectroscopy plays a pivotal role in putting corrosion science on a firmer platform. These instruments help us observe corrosion processes at the nanoscale and even offer tailoring and control over them in-situ. Such an approach opens pathways like atomic reorientation studies, tribology, and surface modification, which have great impact on strength of metal structures, mechanism of sulphate bacteria, molecular catalytic activities, and heterogeneous phenomena. CSIR-CECRI has a sophisticated analytical instrumentation facility equipped with high-resolution scanning electron microscopy (FESEM), atomic force microscopy (AFM), transmission electron microscope (TEM), XRD, XPM, HR-TEM, etc to complement various studies in the area of corrosion.

CONCRETE CORROSION

In the annual production of steel rebars, a substantial portion of more than 10 million tons of steel rods are used as reinforcements in RCC structures. Due to rebar corrosion problems, often more than the cost of construction is being spent on repair of bridge structures in ports and industrial areas. Especially for RCC structures repairs are to be carried out within 2-3 years of construction. Nearly 10-15 percent of cost of annual construction was spent towards repair and renovation. CSIR-CECRI has a very strong group working on various aspects of reinforced concrete corrosion related problems and how to solve it. Our research spans through a wide variety of corrosion problems including the corrosion monitoring and health assessment of important structures like bridges, high-rise structures, nuclear reactors, thermal power plants, etc.

The study and analysis of concrete structures has been a core part of the group's R&D itinerary. As the research on concrete is largely application oriented, the group has consistently been involved with several projects of national importance including the Pamban bridge, Naini bridge, Thane creek bridge, Kudankulam, Tarapur, and Kaiga nuclear reactors etc.

Research on development of novel materials to mitigate reinforcement corrosion: In this regard cement slurry coating and cement polymer composite coating to steel rebar technology has been developed and it has been commercialised and is being used in many of the flyovers in India. Though we concentrate on various aspects of concrete, durability is the main parameter which decides the service life of the concrete.

The concrete corrosion group has developed technologies related to the corrosion monitoring and control of civil infrastructures. The technologies include:

1. Activated fly ash cement
2. Composite corrosion inhibiting admixtures
3. Rapid repair technology for concrete structures
4. Geopolymer concrete
5. Migrating corrosion inhibitors
6. Multi component inhibitor formulation for electro injection process
7. Smart sensors like MnO2 and Thin film Nickel Ferrite sensors
8. An integrated sensor gadget operated through a mobile app for monitoring corrosion of high strength concrete materials
9. Cement slurry coating
10. Cement Polymer Composite Coating.

The group has also carried out several challenging projects from various industries.

Summary of technologies developed by CMP Division

- Anticorrosive treatment for steel reinforcement rods
- Biodegradable inhibitor for preventing scale and corrosion deposits of steel pipeline in cooling water system and process thereof
- Cement polymer composite coating system for corrosion protection of reinforcing and pre-stressing steels
- Corrosion resistance, thermal coating for hydroclaves
- Corrosion-resistant inhibitive admixture for Portland Pozzolana cement
- Cost-effective metallic coating for rebars embedded in concrete structures
- Formulation of neutral paint removing jelly
- High-performance epoxy PAB coating system
- Integrated corrosion monitoring sensor (ICMS) gadget through a mobile app
- Multicoat protective scheme for concrete structures and bridges
- Redox active polymer encapsulated lamellar (REL) compound based anticorrosive coating for reinforcement bars
- Simultaneous detection and inhibition of corroding steel structures by imine functionalised silica aero gels and its process thereof
- Triboluminescene signal identifying smart camera for crack detection of structural components