APEC Workshop on AI in Atmospheric Corrosion Assessment to Address Climate Change Impact

APEC POLICY PARTNERSHIP ON SCIENCE, TECHNOLOGY AND INNOVATION

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APEC Policy Partnership for Science, Technology and Innovation

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1. Background

One significant impact of climate change is an accelerated corrosion on metallic infrastructure as reported by Zhang et al. [1]. Extreme weather events increase the risk of structural failure before their design lifetime. The economic loss due to increased corrosion rate by climate change in the coastal zone of the United States could be greater than $200 - $500 million [1]. Several climate parameters such as temperature, relative humidity, and chloride deposition rates influence the corrosion loss. Due to unique climatic-environmental factors in each economy, it is necessary to collect and analyze domestic data to obtain corrosion prediction tool and be prepared for the climate change impact. This corrosion prediction model can be derived by machine learning approach. Relevant research works have been launched and conducted in some APEC economies such as China [2,3], New Zealand [4], and Japan [5], focusing on digital transformation to predictive model development. However, it is only in an initiation level for other economies such as Thailand, Viet Nam, and Indonesia.

To support APEC Putrajaya Vision 2040 and Aotearoa Plan of Action (APA), a two-day workshop was implemented by "PPSTI_201_2023A Workshop on AI in Atmospheric Corrosion Assessment to Address Climate Change Impact". The primary goal was regarding the environmental & climate challenges and natural disasters addressing climate change impact on corrosion. The secondary goal was related to the digital economy and global interconnectedness enabling digital transformation innovation by applying AI to corrosion prediction.

APEC workshop provided an opportunity for the experts to share their knowledge which was beneficial for researchers in preliminary level to implement proper design and maintenance planning for metal structures according to the change of climate pattern.

2. Objectives

Besides the abovementioned PV 2024 and APA goals, the objectives of this project were to build capacity of APEC member economies to understand the impact of climate change on corrosion of metal structures via innovation of machine learning approach and to enhance the collaboration in APEC member economies to drive online tools, and policies to overcome this challenge together.

3. APEC Workshop Event

APEC Workshop was organized on 30 – 31 July 2024 at Thailand Science Park, Pathum Thani, Thailand. The key activities included 10 technical presentations, 3 technical workshop stations, breakout group discussion on potential collaboration, and recommendation brainstorming session. Financial supports were from APEC, Ministry of Higher Education, Science Research and Innovations (MHESI, Thailand) and National Metal and Materials Technology Center (MTEC, Thailand).

Speakers were experts from Japan, New Zealand, People's Republic of China, The Philippines, Viet Nam, and Thailand. There were 3 APEC-funded speakers and 7 MHESI-MTEC-funded speakers.

Participants included 10 TEE participants from Peru, Indonesia, The Philippines, Viet Nam, and Thailand, 35 local participants from Thailand.

3.1 Technical Seminar

Keynote Talk (Day 1): *Galvanic corrosion and its protection methods of multi-material automobile bodies to reduce CO_2 emissions in the future* by Dr. Sakae Fujita (Hokkaido University)

Higher greenhouse gases emission contributes to climate change affecting the shorter steel structure lifespan. At the same time, the demand of metal will exceed the existing resource by 2050. Metal must be manufactured and utilized sustainably. Lifespan can be improved by better anti-corrosion materials or coatings. For the automobile industry, innovative R&D projects focus on reducing the vehicle weight to reduce CO_2 emissions. In this regard, various combinations of dissimilar material joining were studied to optimize the lower weight and better galvanic corrosion resistance. The Innovative Structural Materials Association (ISMA) was established to promote R&D in weight reduction of automobiles by cooperating with the car makers, academia, and research institutes as well as raw material manufacturers. The outcome of R&D showed that aluminum/ Galvanneal yielded the lowest galvanic corrosion. In addition, corrosion classification for under trailer floors were calculated and proper anti-corrosion measures were proposed. Finally, a multiscale simulation model was constructed to simulate galvanic corrosion of high strength steel and Al6061. These three ISMA projects demonstrated innovative automotive technologies that will reduce CO_2 emission in the future.

Session 1: Atmospheric corrosion data collection and corrosion map

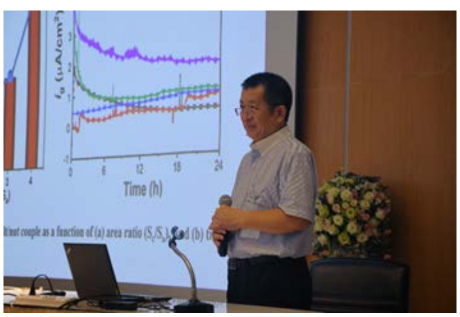
Corrosion rate map development and risk-based maintenance of steel structures by Mr. Teruhisa Tatsuoka (Tokyo Electric Power Company)

TEPCO developed a corrosion rate map from atmospheric corrosion monitoring (ACM) sensor data. ACM sensor is a galvanic sensor for measuring corrosion reaction. Steel coupons were exposed with the ACM sensor on transmission towers on the coastal area. A regression model was applied to correlate the corrosion rate and environmental as well as weather data. A corrosion map of the transmission towers was obtained. Mild to severe corrosion zones can be identified. In addition, paint degradation map was also studied by using accelerated corrosion test with an effect of UV. The paint degradation map can be applied to determine appropriate recoating time. Risk maps are important tools for reducing life cycle cost and for designing sustainable transmission towers.

Atmospheric Corrosion Studies of Zinc and Zinc Alloy Steel Panels under Philippine Environments: ITDI Experience, Challenges, Opportunities and Outcome by Dr. Araceli Monsada (ITDI-DOST, Philippines)

Atmospheric corrosion studies in the Philippines on Zinc and Zinc alloys were reviewed. The weather in the Philippines was significantly influenced by high rainfall in wet season due to typhoons. Corrosion resistance from low to high was galvanized steels < Galfan < Galvalume. Commercial metal sheets were examined and turned out to have too thin Zinc alloy coating posting concern in their performance in industrial and marine atmosphere. The research team proposed an industrial standard “PNS 67:2014 Hot-dip metallic-coated steel sheets for roofing – Specification Source: Bureau of Philippine Standards (BPS) –DTI” from the corrosion field test results.

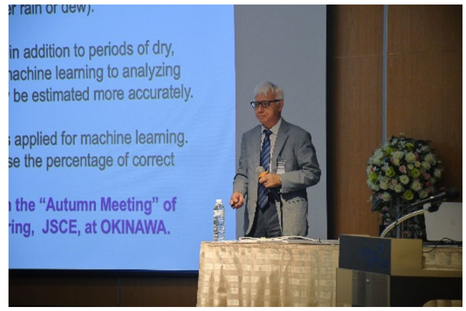
Study on Corrosion Mechanism of Carbon Steel and SS304 Stainless Steel Bolt Fasteners and Protection Countermeasures by Prof. Junhua Dong (IMR, China)



Crevice corrosion in fasteners were studied on carbon steel vs. stainless steel by exposure test and sensor test. For carbon steel, corrosion outside the crevice was uniform and inside the crevice was localized with less corroded area. For stainless steel, corrosion was more severe in the crevice due to lack of oxygen to repassivate the passive film. The difference in corrosion of exposed and crevice regions was driven by galvanic couple due to different oxygen distribution, different solution environment, and different active-passive surfaces. In outdoor conditions, structures with fasteners must be designed with crevice corrosion risk consideration to minimize the corrosion loss.

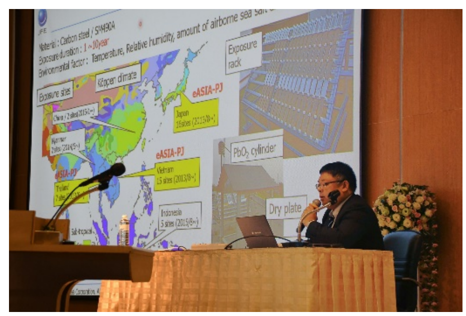
Session 2: Corrosion monitoring sensor and data science in corrosion rate prediction

Evaluation of Atmospheric Corrosion by ACM Sensor - Possibility of applying machine learning by Dr. Tadashi Shinohara (Tokyo University of Marine Science and Technology, Japan)



Atmospheric corrosion monitoring sensor was applied to correlate output current with the actual corrosion rate. The type of ions such as SO_4^{2-}, Cl^-, and NO_3^- and their concentration had different effects on ACM current output according to simulated rain test in a chamber. The influence of ions and concentration occurred during chemical dew when relative humidity is below 80%. Corrosion rate estimation equations from ACM output were proposed based on rain, chemical dew, physical dew, fog, or transition. Currently, machine learning classification model has been applied to classify the wet-dew-dry condition to analyze big data effectively.

Application of locally weighted partial least squares to atmospheric corrosion prediction using e-ASIA PJ data by Dr. Masataka Omoda (JFE Steel Corporation, Japan)



The atmospheric corrosion rate in Asia is different from that in Europe due to different wet environments and lower SO_2 deposition rate trends. The total time of wetness increased at temperature above 10 °C. Therefore, the Dose response function in ISO 9223 cannot be applied. The new prediction equation is proposed based on the non-linear locally weighted partial least square method (LW-PLS). This method yielded more accurate corrosion loss prediction compared to ISO 9223 and could also be applied for long-term corrosion loss.

Predict Atmospheric Corrosion of Carbon Steel Using Machine Learning – Applied to Viet Nam and Asian Areas by Dr. Le Thi Hong Lien (IMS, Viet Nam)

Atmospheric corrosion prediction model developments were reviewed and compared based on both conventional (statistic) models and machine learning (ML) models. Each model proposed different influencing factors depending on the atmosphere. Recently ML models, especially ANN model, have been applied and provide high accuracy. From Viet Nam atmospheric corrosion data (1995 – 2013), ML models were explored. Gradient Boosting Regression Tree and Random Forest models performed exceptionally well with R^2 = 0.9985. In the future, ML models suitable for small data is required since number of exposure test data is limited and takes time and budget to collect big data.

Keynote Talk (Day 2)

Use of Artificial Intelligence to Predict and Control Corrosion Damage by Prof. Wei Gao (University of Auckland, New Zealand) (Keynote)

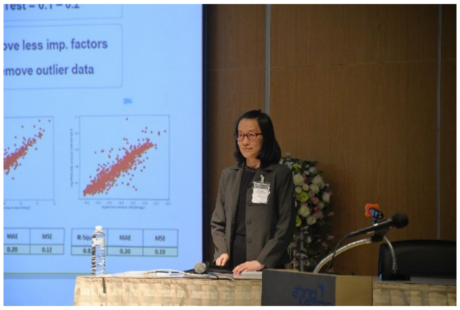
New Zealand has developed digital corrosion map using 40 years atmospheric corrosion data including weather parameters along with computational modeling. In the preliminary work, 31 influencing parameters were explored. The most important ones were temperature, elevation, and distance to the coast. Recently, a corrosion monitoring device was developed to monitor corrosion via galvanic sensor with weather with ions sensors, which will collect big data for machine learning model prediction. In addition, smart corrosion protection methods have been developed. For instance, self-healing coatings are made from 2D C/ CN/ BNN materials which can be synergized with inhibitors to improve protective properties. Climate change has significant effects on corrosion rates, thus better corrosion control is important for economic sustainability.

Session 3: Machine learning on corrosion prediction from big data

Predictive model of atmospheric corrosion from environmental data using machine learning by Dr. Hideki Katayama (NIMS, Japan)

In Japan, aging steel bridges increase steadily. Current corrosion prediction models by statistical methods could not capture complex correlations. Machine learning (ML) is a suitable approach for correlating corrosion loss with environmental data. By comparing Lasso/ Decision Tree/ Gradient Boosting (GB)/ Random Forest (RF) models on existing data, the GB and RF models were the most accurate. The top three important factors were maximum temperature, wind velocity, and wind velocity squared. The model was validated by 2018 exposure test data. Two out of three locations agreed with the ML prediction. The future work should include more training and testing data.

Corrosion rate prediction by machine learning on weathering steel bi-electrode sensor data by Dr. Wanida Pongsaksawad (MTEC, Thailand)



Climate change and increased greenhouse gases cause frequent extreme weather events and sea level rise. These parameters significantly accelerate atmospheric corrosion for steel structures. In Thailand, the southern coastal areas exhibit high rainfall and chloride deposition rates that conventional weathering steel cannot be applied. The corrosion rate of advanced Ni weathering steel was studied by bi-electrode sensor in Songkhla test site. Electrochemical impedance spectroscopy and electrochemical frequency modulation were conducted to collect corrosion rate data. By applying machine learning model, Random Forest model predicted the corrosion rate from weather data with R^2 = 0.923 for Q420NH and R^2 = 0.837 for 3Ni weathering steels. Improved accuracies were achieved by important factor selection and outlier data removal. Corrosion prediction is achieved by Machine Learning approach on bi-electrode sensor data.

3.2 Technical Workshop

Station 1: Atmospheric Corrosion Monitoring Sensor

Moderator: Dr. Tadashi Shinohara, Ms. Benjawan Moonsri, and Mr. Warut Butratsamee

ACM sensor invented by Dr. Shinohara *et al.* is a galvanic-type sensor which has been widely applied in field studies to monitor atmospheric corrosion. This station connected a Fe-Ag ACM sensor to a small data logger to demonstrate real-time data collection.

Current output increased when a drop of NaCl solution was placed on the sensor surface indicating corrosion reaction.

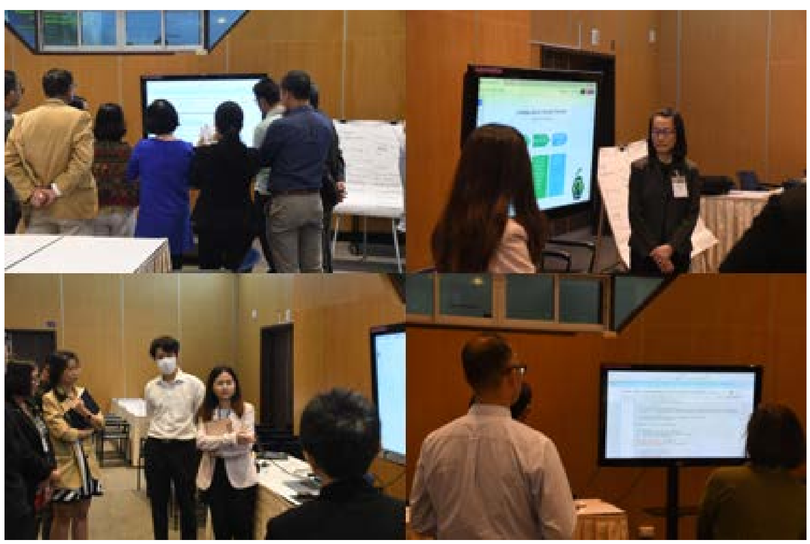
Station 2: Bi-electrode sensor

Moderator: Prof. Junhua Dong, Ms. Pranpreeya Wangjina, and Mr. Piya Khamsuk

A bi-electrode sensor developed by Prof. Dong *et al.* is made of the same alloy on both electrodes. It was connected to a potentiostat to measure electrochemical impedance spectrum and electrochemical frequency modulation signals. Both measurement methods provided information of corrosion rate of the metal and has been validated by atmospheric corrosion test in China and Thailand.

Station 3: Machine Learning 101

Moderator: Dr. Wanida Pongsaksawad and Ms. Benjamat Takhwan



Once the sensor data were collected from the field test, it is important to apply machine learning (ML) to understand the correlations of the signal. ML models can provide the prediction equation from the influencing factor data. During the demonstration, we introduced a Random Forest model to learn corrosion current output influenced by temperature, relative humidity, and exposure time data. The output showed the most important factors ranking and R^2 from the test data.

3.3 Group Discussion and recommendations

Day 1 Potential Collaboration

The audiences and experts were divided into 3 groups based on their organization. Each group discussed their expertise, challenges, and interests. Then the common need and expertise were identified as potential collaboration topics.

	Academia	Research Institute	Private sector
Facilitators	Dr. E. Viyanit Dr. T. Shinohara	Dr. A. Chianpairot Dr. G. Priyotomo	Dr. W. Pongsaksawad Dr. S. Fujita
Members org.	Kasetsart U. KMUTNB Rajamangala University of Technology Isan U. of Auckland Kaiyodai Pontificia Universidad Católica del Perú De La Salle U. Universitas Pertamina	MTEC NECTEC NANOTEC TISTR MMRI IMR IMS ITDI BRIN NIMS	Bangchak PTT PTTEP SSI Welding Alloy JFE TEPCO
	Academia	Research Institute	Private sector
1. Expertise	• Atmospheric corrosion ML model from environmental parameters • IoT for corrosion monitoring • Atomistic modeling of corrosion • Soil corrosion + marine corrosion platform	• Atmospheric corrosion • EIS sensor • Stress corrosion cracking • Organic, metallic coatings	• Materials Science • Electrochemistry • Mechanical Engineering • Automobile and transportation • Standardization
2. Challenges	• AI/ ML • Sensing technology • Lifetime prediction • Corrosion protection technology	• Aging infrastructure • Lack of funding • CO_2 emission reduction	• Inspection by human is slow and high error. • Expensive automated sensors • No data sciences in the team • IT people don't understand corrosion problems.

	Academia	Research Institute	Private sector
3. Interests	• R&D in aging infrastructure • Mitigation method for aging infrastructure • Implementation of atmospheric corrosion research in industry	• H_2 embrittlement • Weathering steel • Atmospheric corrosion of infrastructure • Technical sharing • Research initiation • Product development	• Applying AI to learn and build predictive model from historical data (condition-based management -> risk-based management) • Reduce CO_2 emission and energy consumption • Machine health monitoring • Corrosion database
Summary of possible collaboration.	Common interest: Aging infrastructure, CO_2 reduction Technology: AI/ ML, sensors, computational model, data collection on same standards Outcome: Corrosion prediction/ control for any environment towards lower CO_2 emission Funding resources are required to carry out international collaboration. It is important to convince the funding agency about the important of sustainable steel structure.		

Group #1 University Facilitator: Dr. Shinohara and Dr. Ekkarut		 	 
Group #2 Research Institute Facilitator: Dr. Gadang and Dr. Amnuaysak		 	 
Group #3 Private Sector Facilitator: Dr. Fujita and Dr. Wanida		 	 

Day 2 ML model development and action plans for sustainable structure in climate change

Experts and active participants discussed the action plan to drive the potential collaboration that is to reduce CO_2 emission by applying AI/ ML for sustainable aging infrastructure maintenance.

Aging infrastructure maintenance needs

- Corrosion protection technology that is eco-friendly
- Corrosion monitoring both the steel and painting life evaluation (short-time evaluation is preferred.)
- Corrosion prediction model from monitoring data via AI/ ML analysis and risk map including atmospheric, soil, and geothermal corrosion
- Life cycle assessment in the design process
- An evidence of climate change pattern using AI/ ML in our economies from historical climate data and corrosion rate data (20 – 30 years) to help us understand the impact and raise awareness
- New database based on a universal standard to obtain a universal dose-response function.

Policy to support technological development on this topic includes

- Technical standards which align the measurement methods (relative humidity sensor, corrosion sensor and chloride deposition rates sensor), generalized corrosion rate equation (one equation that fits any continent), construction standard with corrosion allowance in the design, and AI model validation
- Awareness regarding the climate change impact on aging infrastructure and the newly constructed infrastructure environmentally and economically
- Corrosion consortium to drive carbon neutrality to share knowledge and efforts of sustainable development.

Education for the next generation should consider

- Data science skills in corrosion engineers
- Technical sharing/ exchange at international level
- Training engineers to apply LCA and circular economy into their work.

In addition to aging infrastructure maintenance, corrosion engineers can contribute to CO_2 emission reduction in other fields. For example, CO_2 capture, utilization, storage, and transportation technology will face corrosion problems in the wet environment. H_2 economy also needs to evaluate corrosion risk in using NH_3 for automobile and airplane fuel. Therefore, to achieve carbon neutrality, corrosion engineers play an important role in overcoming corrosion risk and advance the future technologies.








4. Conclusion

APEC workshop on AI in Atmospheric Corrosion Assessment to Address Climate Change Impact was organized on July 30 – 31, 2024 at Thailand Science Park, Thailand. The workshop consisted of ten technical presentations, three technical workshops, and two group discussions. Experts shared their knowledge on the topic of corrosion monitoring, corrosion mapping, and corrosion predictions by statistical model and AI models. All these technologies provide the possibility to understand the corrosion rate of steel structure when climate change occurs. The design of steel structure for a sustainable world must consider these effects. During the workshop discussion, a common interest and intention pointed towards the goal to reduce CO_2 emissions. Various recommendations for action plan included a better maintenance program for aging infrastructure, universal standard for atmospheric corrosion database collection method, and LCA - circular economy approach. Moreover, corrosion problems are challenging in the development of advanced technology related to carbon neutrality such as CO_2 capture, utilization, storage, and transportation technology and H_2 fuel applications. The outcome of this workshop inspires APEC member economies to initiate further collaboration and implementation of the knowledge gained from this event.

5. References

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