1 Research background and current situation

Chinese marine engineering manufacturing industry has achieved great progress since the implementation of the national maritime strategy, *Towards Deep Blue*. Guangdong Province has also clearly proposed to actively develop the marine engineering equipment industry in *the 13th five-year plan* for the development of strategic emerging industries but restricted by severe material failure under complicated marine environment, especially in the South China Sea. Therefore, it is urgent to establish an intelligent evaluation and management system for the service performance of marine engineering equipment materials, so as to provide technical support for their safety service and life extension.

The rapid development of new generation of information technology in recent years makes the appliance of digital twin system in industries available. The digital twin system for engineering materials performance evaluation proposed in our project will extract physical model from huge amount of material service performance data, which is acquired from experiments under multiscale, multifield coupling and various failure conditions, and combine data mining and artificial intelligence to construct the digital simulation model for failure dynamics that builds the mapping between simulation and practical engineering materials and equipments. Taking the advantage of the iteration of on-site and real-time inspection data, our system will be able to improve simulated prediction model to obtain higher accuracy on the evaluation of service performance of materials. However, due to the lack of data of service performance of complicated marine engineering material and inadequate research on its failure mechanism, the validation and optimization of the prediction model in the system can’t be executed, which are also affected by the deficiency of on-site inspection and the inability to assess the service performance of huge, full scale entity subsection, or scalable equipment.

Thus, our project plans to employ the resource contained in the national major science and technology infrastructure of the initiating unit, experiments of huge and full scale materials under complicated service conditions, software and hardware platform for simulation and safety assessment, and selects the marine engineering equipment as research material and develops detection system to inspect environmental load spectrum and service status by material-component-equipment multifield experiments and simulation. We expect to acquire data of service performance of equipment material under multifield coupling environment from various aspects, and extracts the failure mechanism and the influence of environmental factors on models, and connect the digital twin system for engineering materials performance evaluation with the prediction technology of life span. National and even worldwide frontier and difficult problems are expected to be solved by our project.

2 Scientific issues

For the development of the digital twin system for marine engineering materials performance evaluation, we need to reveal the scale-span association and the evolution law of the service performance of marine engineering materials under multi-field and multi-factor coupling environment, and solve the problems in scale domain, environmental domain and time domain and their coupling effect.



**Scientific issues in scale domain (scale effect)**

Current experimental data of marine steel accumulated in the laboratory are mostly based on the test results of the sample-level samples, but due to the non-uniformity of the composition and microstructure of the structure (inclusion phase, segregation, defects and et cetera), welded parts in equipment, the different metal connection and gap structure in fastening and moving parts and et cetera, the data from the sample-level samples are not capable of predicting the service performance of structure and equipment. So, the internal connection among material components, structure, environmental load and service performance needs to be uncovered and the correlation of microscopic and macroscopic properties of marine steel is going to be established.

**Scientific issues in environmental domain (environmental coupling effect)**

Different parts of marine equipment serving in marine atmosphere zone (saline-fog environment, aging effect and thermal effect of sunlight), wave splash zone, tidal zone, full immersion zone, sea mud zone and et cetera, is affected by its structural load, machining residual stress, wind load, surge load and other complicated physical factors. And the surface coating protection system and the working state of the underwater protection system plays an important role in the prevention of corrosion as well. So, for solving scientific issues in environmental domain, it is essential to reveal the complex nonlinear coupling mechanisms and rules of service behavior of marine engineering material with the influence of above-mentioned multi-field and various environmental factors.

**Scientific issues in time domain (time effect)**

Focusing on the remaining life prediction and evaluation requirements of life extension of marine engineering equipment, it is necessary to grasp the time-dependent nonlinear evolution characteristics of service performance of material in complex and force-coupled environments. The key is to refine the laboratory (accelerated) evaluation method and verify its equivalence with the on-site service data, so as to construct a time-dependent evolution model of service performance, which lays a solid foundation for deriving long-term service behavior based on short-time service data.

3 Research content

1 Selection of research target

For the efficient construction of the digital twin system for engineering materials performance evaluation, a typical marine engineering equipment is required as research target among a great variety of marine engineering materials and equipment, which service under complicated environments and fail due to the coupling of sundry failure mechanisms.

The development of offshore wind energy is entering an accelerated status in China and Guangdong province plans to build 23 offshore wind farms with a total installed capacity of 66.85 million kilowatts by 2030. At present, most sites for wind power construction are located in the intertidal zone, in where the service environment is more demanding than the offshore platform and alternation of wetting and drying is more frequent on the surface of steel structure and the effect of surge and spray gets severer. The coupling effect of the unique wind load on the sea and the harsh corrosive environment makes the failure forms of marine engineering equipment materials more complex and diverse. At the meantime, the constructions of remote inspection on service status and real-time management system for risk assessment and maintaining decision are desperately required for the reason that the development of the Chinese offshore wind power gradually reaches toward the far sea. However, due to the short operating life of offshore wind power in China, a system that assesses the service performance and predicts life span of materials has not been formed for the lack of data of service performance of materials and accumulation of failure mechanism, comparing with other marine engineering equipment. Therefore, our project takes typical offshore wind equipment as research target, which is urgently needed and possesses inadequate accumulation of data of service performance, and conquers the key scientific issues in the evaluation of service performance of engineering materials, and constructs the digital twin system for material service performance of offshore wind equipment, and finally demonstrates their appliance.

2 Research content

**1) Multiscale performance evaluation for offshore wind equipment under multi-field and multi-factor coupling environment**

Our project takes typical offshore wind power metal materials, its structure (welding zone and connection sections), important equipment and its protection material as research targets, and collects multiple environmental load spectrums of marine atmosphere and seawater, unique wind load and wave load, and et cetera, and develops material-component-equipment multiscale (accelerated) evaluation experiment methods. The research on multiscale evaluation experiment and its accumulation of experiment data from typical materials, structures and service performance of equipment in the environment under the circumstance that nears the working condition and possesses the coupling of multi-field forces and certainty of failure mechanism of equipment material and the influence of environmental factors on the rule models are also included in our project.

**2) Cross-scale modeling and simulation for service performance of offshore wind power equipment materials**

Based on the evolution mechanism model of offshore wind power equipment service performance under multi-factor coupling conditions, the multi-scale digital modeling and simulation of the service behavior of offshore wind power equipment is carried out; To realize the cross-scale correlation of material, structural environmental damage behavior, the cross-scale transmission of key parameters in simulations in various scales ,nested regions and other methods are going to be simulated. The comparison and validation of simulation and the above-mentioned multi-scale experimental data can rectify the simulation models and their parameters to support further analysis of the failure mechanism and law of equipment materials; Meanwhile, the association between the corresponding mechanism model and data can be used as the basis of physical information fusion to support the construction of the subsequent offshore wind power digital twin system.

**3) The development of real-time inspection technology for service load spectrums and normal status of the offshore wind power equipment**

Built upon the characteristics of offshore wind power equipment service, an all-solid-state environmental factor monitoring sensor, which is suitable for marine environment, and a corrosion characteristic quantity monitoring sensor based on multi-electrode technology are going to be developed. On the basis of the Internet of Things technology, the inspection system and equipment that are suitable for huge offshore wind power equipment will be developed to acquire key status parameters in the service of offshore wind power equipment, like stress and strain levels of key components, the local environment and its corrosive monitoring data, the working status data of the cathodic protection and other protection systems, to provide status evaluation of the offshore wind power equipment and the selection and optimization of maintaining strategy of key components.

**4) Development of digital twin prototype system for service performance of the offshore wind power equipment**

The merge of multi-source heterogeneous data, evaluation model for full life span of material, failure traceability of key materials and the prediction of material lifetime are expected to achieved on the basis of multiscale evaluation experiment, simulated results and collected failure cases. The construction of material-component-partial system-full equipment prototype digital twin system is going to be built specially for the key components to realize the rigorous ranking of local environment, the classification of risk ranking of key components and initially form failure probability analysis and life prediction capability of marine wind power equipment materials.

**5) Technical integration and validation of the intelligent evaluation system for the service performance of offshore wind power equipment**

The integration of the digital twin prototype system, the online monitoring system and the existing monitoring and operation system of the offshore wind power equipment is going to be carried out. And the realization of the safety evaluation of the offshore wind power equipment and the competence of the demonstrative application of the digital wind power equipment evaluation system for offshore wind power equipment will be finished by using the relevant data, models, methods and tools provided by the digital twin system. Finally, based on the on-site real-time monitoring data, the iteratively optimized failure probability and life prediction model, an integrated real-time intelligent digital twin evaluation system will achieve following functions, the status monitoring of offshore wind power equipment service, the assessment and prediction of service safety and the risk warning and the protection decision.