A GAN-based Prediction for Corrosion Progress of Paint-coated Steel with Different Defects (Proceedings of Symposium on Applied Mechanics)

Feng JIANG, Osaka University
Ayato HAMADA, Osaka University
Mikihito HIROHATA, Osaka University
E-mail: f-jiang@civil.eng.osaka-u.ac.jp

The numerical analysis of corrosion characteristics to accurately predict the progress of corrosion has received much attention from researchers. In actual construction, steel is often treated with coatings to prevent corrosion. In this research, A-type and C-type paint-coating system generally used for steel structural members was applied to SS400 steel. Two types and different sizes of defects were artificially created on the coating to simulate the corrosion after the coating was damaged. The corrosion tests were carried out under the accelerated corrosion test ISO 16539 Method B. The corrosion data of the steel plate surface at different stages were used as datasets. A generative adversarial network (GAN) based prediction model was used to simulate the corrosion progression at the coating defects. According to the experimental results, the prediction model can predict the corrosion at the final stage in the area of coating defects on the steel plate surface.

1. Introduction

Monitoring and controlling corrosion of steel structures is critical to maintaining the integrity and function of these structures. Regular inspection and maintenance of steel structures can help detect corrosion early so that timely repair and preventive measures can be taken. This can help extend the life of steel structures, reduce the risk of failure, and save on costly repairs or replacements. Therefore, it is important for practical maintenance if fast and accurate corrosion prediction models are developed. In recent years, deep learning has shown great potential in many fields and they have been widely used in modeling and prediction tasks. In a previous study, a deep learning-based method was proposed to predict the corroded surface status of uncoated steel (Jiang, F. and Hirohata, M.[1]). This method showed good performance for corrosion prediction of uncoated steel with uniform corrosion. However, in actual steel structures, steel is mostly coated for corrosion protection. In general, paint-coated steel is less susceptible to corrosion than uncoated steel because the coating provides a barrier between the steel and the environment. Nevertheless, paint-coated steel is not immune to corrosion, and the coating will be damaged over time due to various factors. Therefore, it has more practical significance to study corrosion after coating damage.

In this study, adversarial learning was used to simulate future stages of the corroded surface with a data set derived from actual paint-coated steel specimens (taken from two actual bridges). The accelerated corrosion test ISO 16539 Method B was conducted (Jiang, F., et al[2]). The model can be used to predict the next stage of corrosion based on previous corrosion situations. The method proposed in this study can predict corrosion progress quickly and accurately, and this prediction method can save significant cost and time for corrosion assessment of steel structures with paint-coated steel.

2. Specimen and corrosion test

Two coatings commonly used in steel structures, A-type and C-type paint-coatings, were applied to SS400 steel. As shown in Fig. 1, these specimens were cut into 150 mm × 70 mm × 9 mm steel plates. There were 6 specimens for each type of coating, and a total of 12 specimens were used for corrosion test. The coated surface of the specimen was machined to introduce initial defects (brown area in Fig. 1) to simulate the corrosion of the paint-coated steel surface after damage in a real environment. Linear defects and circular defects were used to increase the complexity of the coating defects. The width of linear defects was 1 mm, 2 mm, and 3 mm, and the diameter of circular defects was 3 mm, 6 mm, and 9 mm. Each specimen has 3 different size coating defects on the surface. Therefore, a total of 36 corrosion samples. The back and sides of the specimens were protected with anti-corrosion tape, and the uncorroded parts of the edges were used as reference surfaces after the corrosion tests (black area in Fig. 1). After each stage of the corrosion test, a laser focus measurement system was used to measure the corrosion depth data of the corroded surface in the measurement area (red area in Fig. 1). It has a resolution of 0.2 μm and a measurement interval of 0.1 mm.

ISO 16539 Method B is a recently proposed accelerated corrosion test for use on steel structures, using a spray device to apply artificial seawater at a concentration of 3.5% to the surface. The drying and wetting process was repeated consisting of three hours of drying (60°C, 35% RH) and three hours of wetting (40°C, 95% RH) with a one-hour transition time from dry to wet and from wet to dry, each cycle being 8 hours. This was done in 8 cycles (3 days) and 11 cycles (4 days) alternately. Under this corrosion test, corroded surface data were measured for 0, 1, 3, and 4 months for each specimen.

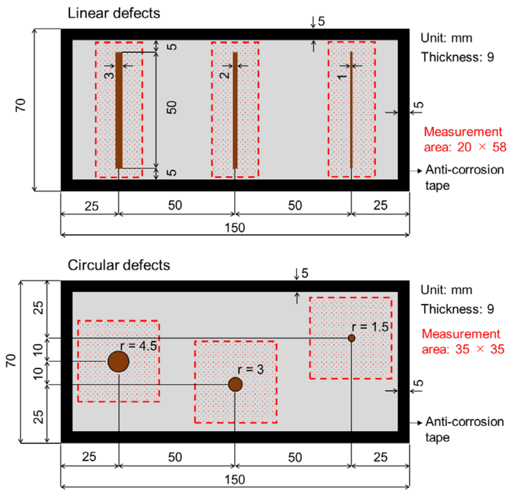

Fig. 1 The size of specimens with different defects and corrosion measurement area

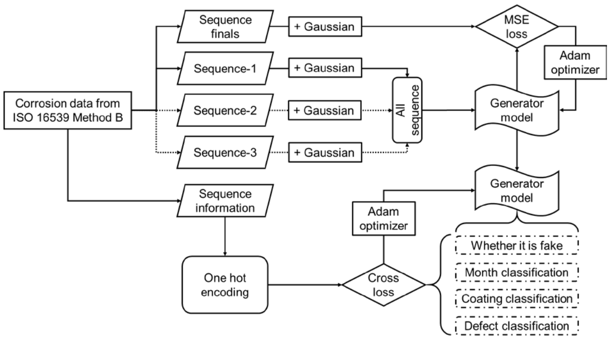

Fig. 2 Model structure

3. Method

Gaussian noise and generative adversarial network (GAN) were used to enrich the dataset. UNet + ViT were used as the generator and Mobilenetv2 was used as the discriminator. UNet has two paths. One is a systolic path, which is a traditional stack of convolutional and max-pool layers. The other path is the symmetric extension path, which allows precise localization using transposed convolution. ViT model, which introduces transformer structure to computer vision. It has more similarity between features obtained from shallow and deep layers. Mobilenetv2 is an effective model for feature extraction, object detection, and segmentation. It is a mobile architecture based on an inverted residual structure that uses deeply separable convolution as an effective building block. The generator was mainly used to simulate the next stage of regression of the input data. The role of the discriminator was to determine whether the input data was the data generated by the generator. In addition, the discriminator trained in this model could also be used to determine the type of coating and defect, and the current stage of the corroded surface. In this model, the adam optimizer was used as the optimizer. Fig. 2 illustrates the structure and the procedure of this corrosion prediction model.

4. Result

In this research, there were 36 samples of corrosion surface data, which were numbered as No.1-No.36. Since there were three specimens for each defect of each coating, the linear defects of coating A were numbered as No.1-No.9, the linear defects of coating B were numbered as No.10-No.18, the circular defects of coating A were numbered as No.19-No.27, and the circular defects of coating B were numbered as No.28-No.36. The corrosion data of No.3, 6, 9, 12, 15, 18, 21, 24, 27, 30, 33, 36 were used as the test sets and the rest as the training sets. Here using the prediction of the corrosion status of specimen No.3 and specimen No.21 for 4 months as an example. Fig. 3 shows the predicted corroded surface by the model and the real corroded surface comparison results. It can be seen that they have the same corrosion trend. It indicates that the model can predict the corroded surface of the paint-coated steel with defects. Table 1 shows the specific results of this prediction model. The RMSEs of the test sets all show good prediction results. However, comparing the prediction of the corroded surface with linear defects and the prediction of the corroded surface with circular defects, it can be found that the corrosion prediction model predicts the corroded surface with linear defects better than that of circular defects. The reason for this phenomenon is that the circumference of circular defects is very small, which means that the corrosion area where the coating damage occurs is actually smaller than that of linear defects. Therefore, the model did not learn enough about circular defects. The sample of paint-coated steel with circular defects needs to be increased in the future work.

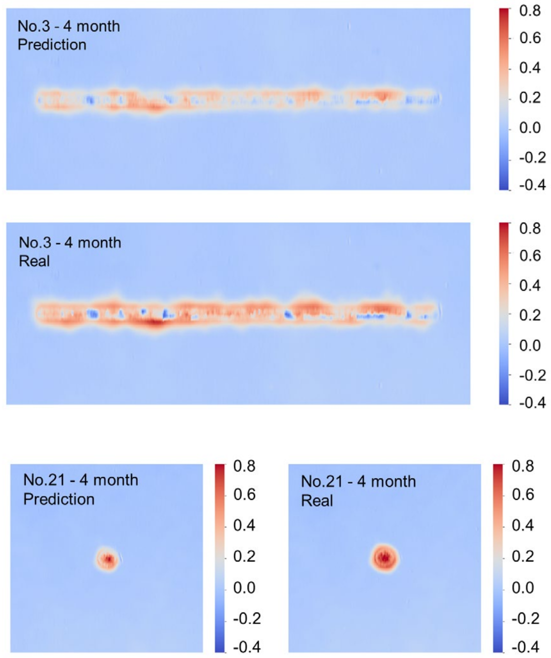

Fig. 3 Comparison results of specimen No.3 and No.21 for 4 months.

Table 1 RMSEs of the test sets.

Linear defects						
No.	3	6	9	12	15	18
RMSE	0.157	0.464	0.224	0.538	0.123	0.218
Circular defects						
No.	21	24	27	30	33	36
RMSE	0.654	1.141	1.893	0.424	1.114	1.123

5. Conclusion

Paint-coated steel is widely used in steel structures. Establishing a reliable corrosion prediction method for paint-coated steel is important for the maintenance of actual facilities. In this research, the corrosion of defective paint-coated steel was investigated to understand the damage that occurs on the actual coating. Corrosion tests were conducted on two paint-coated steels with different coating defects, and a GAN-based model was trained on the corroded surface data obtained from the steel plates to develop an effective corrosion prediction model. The model can predict the corroded surface of the next stage based on the corroded surface of the previous stage, and can also determine the coating type and defects, as well as the current corrosion stage. According to the experimental results, the model proposed in this research can predict the corroded surface quickly and accurately. This study helps to simplify the determination of the corrosion level of paint-coated steel structures and saves time and cost for actual maintenance.

References

1) Jiang, Feng, and Mikihito Hirohata.: A GAN-Augmented Corrosion Prediction Model for Uncoated Steel Plates, Applied Sciences 12, no. 9: 4706, 2022
2) Jiang, Feng, Mikihito Hirohata, Jia Liu, and Kazuki Ojima.: Application of accelerated cyclic test with synthetic ocean water salt-deposition process to the evaluation on corrosion characteristics of weathering steel, Corrosion Engineering, Science and Technology 57, no. 3: 280-289, 2022.