Development status of Anti-corrosion Technology for Power Transmission Tower’s Steel Structure

XinmeiLi1, ZhongwenZhang1*, BaoshuaiDu1, WenLi2 and ShuaiSuo2

1State Grid Shandong Electric Power Research Institute, Jinan, 250002, China
2Shandong Power Industry Boiler & Pressure Vessel Inspection Center Co. Ltd., Shandong, Jinan, 25002, China;

*Corresponding author’s e-mail: zzwh1013@163.com

Abstract: Higher requirements have been brought forward on the reliability and service life of power transmission tower’s steel structure along with the growing of power generation capacity. This paper analyzes types of corrosion of power transmission tower’s steel structure and the status of research on corrosion and summarizes categories of protective coating for steel and iron materials. Hot-dip galvanizing still remains as the main anti-corrosion method for power transmission tower’s steel structure in China, while the promotion and application of cold spray technology, cold zinc-spraying anti-corrosion technology and weathering resistant steel provide more options of anti-corrosion technologies for power transmission tower. The engineering practice proves that cold zinc-spraying anti-corrosion technology has achieved superior application effects in on-site reinforcement and repair of power transmission tower.

1. Introduction

Along with the constant development of grid technologies and the increasing capacity of electric transmission lines and transmission distance, the requirements on the reliability and service life of power transmission tower’s steel structure have become higher and higher. The power transmission tower’s steel structure is mainly made of low-alloy high-strength steel and hot-rolled low-carbon structural steel, connected by bolts and welding. Since power transmission towers are often built in the open air, they are subject to erosion under different natural environment, as well as acid, alkali, salt and many other chemical erosion in the air and soil in the coastal areas and industrial parks. Such exposure will severely undermine the reliability and service life of power transmission tower’s steel structure. Therefore, special protection technologies should be adopted to prolong the service life of power transmission tower.

According to differences in the physical state of corrosive medium and types of corrosion of steel, as well as geological and climate conditions, two kinds of anti-corrosion technologies are generally applied on power transmission tower. The first one refers to steel alloying, namely, adding copper, chromium, nickel and other metallic elements during the smelting process to enhance steel’s resistance against atmospheric environment (such as weathering resistant steel), and the second one refers to corrosion protection coating, namely, coating two or more layers of protection coating on the surface of steel to separate the corrosive medium from steel substrate surface or sacrificial anode to achieve the corrosion resistance. At present, anti-corrosion iron tower is only applicable to specific power transmission line as a trial. Most power transmission towers in China are covered with hot-dip galvanizing coating. However, along with the worsening of natural environment and climate and the
formation of seriously corrosive environment, traditional hot-dip galvanizing technology fails to meet the requirements on service life. Meanwhile, considering that the hot-dip galvanizing technology will result in severe environmental pollution, new anti-corrosion technologies are desperately in need. This paper analyzes types of corrosion of power transmission tower and the status of research on corrosion and then summarizes categories of protective coating for steel and iron materials. After the engineering application and practice of reinforcement and repairing techniques of power transmission towers, anti-corrosion technologies applicable to the on-site repair of power transmission tower’s steel structure are available.

2. Types of Corrosion of Steel Structure
In the damage process of steel structure, the corrosion damage is a major damage form. Corrosion will lead to the decrease of cross-sectional area of steel members, the dropping of bearing capacity, and the reduction of service life of the whole structure[1]. When the medium acts on the surface of materials, corrosion occurs. Corrosion occurrence should meet the following two conditions: formation of the new phase with the corrosive medium as well as the decrease of free energy of corrosion system. Corrosion of steel can be divided into physical, chemical and electrochemical corrosion according to the nature, and uniform corrosion, non-uniform point corrosion, crevice corrosion, inter-granular corrosion and stress corrosion according to the pattern of manifestation.

3. Research Status of steel structure corrosion
Scholars at home and abroad have carried out a series of studies on the corrosion of steel structure, mainly including corrosion model of members and the influence of member corrosion on its bearing capacity. Atmospheric corrosion models of steel mainly consist of power function model, exponential function model, Grey Model GM (1,1), back-propagation neural network model and others[1].

The experimental research on atmospheric corrosion in China came out relatively late, and till 1983, Chinese researchers started to conduct experimental study on the atmospheric exposure corrosion of some steel[2], which had obtained huge amounts of data. The dynamic atmospheric corrosion map recently developed by State Grid Shandong Electric Power Research Institute has been successfully installed in many areas to provide basic data for the corrosion resistance of power transmission tower. In the atmospheric exposure corrosion test, outdoor atmospheric corrosion test is the most popular method since it can truly reflect the corrosion of materials during the using. However, this method is not applicable to extensive promotion due to long test duration, slowness, large amount of consumption in human resources and materials and strong localization. In order to obtain the results of atmospheric corrosion test soon, researchers usually simulate the real atmospheric environment in the lab to speed up the corrosion of steel to obtain experimental data, and get many valuable test results. The test methods of stimulating the atmospheric environment in the lab usually consist of cyclic wet-dry immersion test, cyclic wet-dry alternation test, damp heat cyclic test, salt fog test and multiple-factor cyclic composite corrosion test and others. In the literature [3], the cyclic wet-dry alternation test method is adopted to study the influence of corrosion of outer rust layer on carbon steel and weathering resistant steel. The corrosion rate of carbon steel with outer rust layer is faster than that removing the outer rust layer, while, the weathering resistant steel removing the outer rust layer has little effect on the corrosion. When simulating the marine atmospheric environment, the rust layer on Q235 steel and weathering resistant steel has no obvious protective effect[4]. In the literature [5], the researchers, by simulating the atmospheric environment of polluted atmosphere and adding H2SO4 to NaHSO3 for reacting and generating SO2, studied the corrosion of galvanized steel in the atmospheric environment polluted by SO2.

Atmospheric corrosion on steel is one special form of electrochemical corrosion. In the atmospheric conditions, a layer of thin electrolyte film will form on the surface of steel, and metal beneath this layer will be corroded by electric alchemical reaction. The mechanical properties of corroded steel will change a lot, and the degradation of steel caused by corrosion is a microscopic damage process. In the literature [6] [7], the scanning electron microscope (SEM) and other methods
are adopted to analyze the morphology and structure of rust layer of corroded steel. In the literature [8], researchers conducted the mechanical property test on steel undergoing accelerated salt-spray corrosion to get the relationship between the yield strength, ultimate strength, decrease of elongation of corroded Q235B steel and its weight loss ratio. In the literature [9], the concept of micromechanics is introduced into the prediction of elastic properties of corroded steel to build the model calculating the elastic properties of steel damaged by corrosion pits on the surface. Corrosion will not only undercut the mechanical properties of steel, but also affect the bearing capacity and deflection of steel structure. According to the research, point corrosion at the upper and lower flange of steel channel will lower the flexural capacity [10], the bearing capacity of welded H-beam after corrosion will decline significantly, and the mid-span deflection value under the corresponding load will increase obviously [8]. In the literature [11], the model calculating the load-deflection relation curve of uniformly eroded steel channel beam was built, and according to the study in the literature [12], the influence of corrosion on grid structure mainly depends on the characteristics of the grid structure.

For nearly a century, plenty of scientific achievements on the atmospheric corrosion on steel under the natural environment have achieved. But there are many aspects needed to be further studied. For example, the structure, composition and protection mechanism of rust layer on the steel are still unclear, the prediction accuracy of atmospheric corrosion on steel should be further improved, and the scope of application needs to be expanded. Therefore, more efforts should be paid to the research to accumulate more corrosion data of all types of steel including the existing ones and newly developed ones under the natural environment.

4. Categories of protective coating on steel and iron materials

The protection of steel against atmospheric corrosion is generally achieved by alloying or coating. The common approach is to conduct the surface coating or metal coating surface treatment on the weathering resistant steel while using the low-alloy weathering resistant steel to further enhance the atmospheric corrosion resistance of weathering steels. The overseas study on weathering resistant steel started earlier [13], and weathering resistant steel has been applied in the bridge and tower structure a long time ago [14]. While the study on the weathering resistant steel in China is relatively lagging, with lots of problems related to the application to power transmission towers needed to be solved [15-17]. Till now, the coating protection technologies are adopted in most cases. The protective coating on steel and iron materials mainly include hot-dip galvanization coating, electroplating coating, chemical plating coating, thermal/cold spray coating, diffusion coating and non-metallic coating.

(1) Hot-dip galvanization coating

Hot-dip galvanization is a method to immerse steel and its products into the molten metal to form the metal coating. The melting point of coating materials is much lower than that of substrates. The popular coating materials include zinc, aluminum, tin and others. The coating and the substrate will react to form metallurgical binding force and thicker coating with better corrosion resistance. However, hot-dip galvanization will consume more energy and lead to severe pollution. Due to the excellent corrosion resistance and cathodic protection effects as well as the realization of galvanization of large steel structure, hot-dip galvanization coating is widely applied to power transmission tower, electric power fittings, bridges, mining machinery and other fields. In order to meet the corrosion resistance of coating in marine, industrial atmospheric environment and other special cases, alloying the coating has become the research hotspot in the hot-dip galvanization technologies. Researchers plan to add alloying elements into the galvanizing bath to improve the features of galvanizing bath or enhance the corrosion resistance, such as Zn-Ni, Zn-Sn, Zn-Mg, Zn-Al and Zn-Al-Mg alloy coating systems.

(2) Thermal/cold spray coating

Thermal spray refers to spray the molten or semi-molten coating materials heated by heat sources in tiny particles on the work-piece surface via jet stream to form solid covering layer. The thermal spray method, featured with simple equipment, easy operation, is suitable for large work-pieces. But corresponding workers are encountered with poor working conditions and high labor intensity.

Cold spraying zinc, also known as cold galvanizing, galvanization via coating, is a new
anti-corrosion material that can achieve the coating with the content of pure zinc sprayed over 96% under ambient temperature conditions. Cold spraying zinc, featured with advantages of both hot-dip galvanization and zinc-rich paint, can provide the cathodic protection and barrier-type protective effects, with distinctive corrosion resistance and easy to construct under ambient temperature.

(3) Non-metallic coating

Non-metallic coating refers to attach non-metal to work-piece surface by brushing or other specific process to separate from environmental medium. The application of non-metallic coating in the power transmission tower field is used for post-operation maintenance. Coating non-metallic coating on the hot-dip galvanization coating can also improve the corrosion resistance of iron powers.

(4) Electroplating coating

Electroplating refers to put work-piece (cathode) and coated metal (anode) into electrolyte, and coated metal will sediment on the work-piece surface under the effect of direct current. The electroplating coating can change the surface properties of materials, improve the surface characteristics of materials, but the attachment between the coating and substrate is in the form of atoms, without metallurgical bonding, which means that the electroplating coating is quite thin. The arising waste liquor is an important source of water pollution.

(5) Chemical plating coating

Chemical plating refers to reduce the metal iron in the solution via adding proper reducing agents and make the metal iron to sediment on the surface. Without energizing, the uniform coating will form on the surface of complex work-pieces, with dense coating, less voids and higher corrosion resistance and abrasion resistance. However, the chemical plating is featured with volatile chemical plating solution, higher working temperature and relatively fragile coating.

(6) Diffusion coating

The coating of substrate formed in the medium of coated metal under the temperature easy for fast diffusion can be divided into diffusion coating, chemical vapor deposition (VCD), physical vapor deposition (PVD) and iron implantation. The coating and substrate are attached via diffusion bonding or metallurgical bonding, which are quite solid.

5. Application of Anti-corrosion Technologies in Power Transmission Tower’s Steel Structure

With the successive launch of energy conservation and emission reduction measures as well as environmental pollution prevention measures, hot-dip galvanization and thermal spraying zinc technologies will be further restricted, and relevant enterprises will be driven to transform towards new technologies, such as smokeless flux and non-chrome passivation, adopt all kinds of new technologies to save energy, reduce consumption, reduce pollutants, accelerate the recycling of resources and perfect the galvanization technology via automatic control technology, all of which are critical to the expansion of development space of enterprises.

Till now, the main anti-corrosion method for power transmission tower’s steel structure in China is still the hot-dip galvanizing, and some researchers have carried out the anti-corrosion research at different atmospheric and geographical environment. The hot-dip galvanizing method can be divided into continuous hot-dip galvanizing and batch hot-dip galvanizing according to the type of work-pieces. Since batch hot-dip galvanizing can be applicable to the galvanization of large steel structure, this method is widely power transmission tower, electric power fittings, bridges, mining machinery and other fields. Hot-dip galvanizing is featured with excellent corrosion resistance as well as heavy pollution and high energy consumption. Zinc-rich paint, due to the restriction of original protection principles, can generally achieve 5-10 years of anti-corrosion term; meanwhile, it can only be applied at the fixed workshops rather than construction site, thus remaining certain limitation in the application of steel structure works.

The recently developed cold spraying zinc technology is featured with advantages of both hot-dip galvanization and zinc-rich paint, can provide the cathodic protection and barrier-type protective effects, with distinctive corrosion resistance and easy to construct under ambient temperature. This technology makes “galvanization” to be as easy as painting, and thus becomes the best substitute of
hot-dip galvanizing. In recent years, all kinds of cold spraying zinc products have been applied in many major projects[18]. For example, New Baiyun Airport in Guangzhou, train ferry terminal for Guangdong-Hainan Railway, Sutong Bridge, Hangzhou Bay Bridge, Xinlong Super bridge in Guangdong, Datang Power Plant in Guangdong, Gaobeidian Sewage Treatment Plant, Beijing, Beijing Lize Bridge, Guangzhou Metro Line 4, National Centre for the Performing Arts of China, 2nd Tian-Ping Transmission Line in Pingguo Substation 500kV, Lingbao back-to-back convertor station and other projects have successively adopted cold spraying zinc anti-corrosion technology, and achieved perfect anti-corrosion effects. State Grid Shandong Electric Power Research Institute started to apply the cold spraying zinc technology into the reinforcement and repair of power transmission towers since 2013, as shown in Figure 1 and Figure 2. After six years of tracking investigation, they find that even the column foot exposing to soil also shows perfect corrosion resistance. Therefore, cold spraying zinc products will certainly become popular by virtue of its excellent corrosion resistance, convenient construction properties and outstanding environmental protection property.

6. Conclusion
Along with the constant deepening of lean management on grid equipment, grid enterprises are also continuously focusing on the entire life-cycle management of power transmission towers. The adoption of hot-dip galvanized zinc alloy, hot-dip galvanized aluminum alloy, thermal spraying aluminum alloy and other technologies will all boost the technology level and market competitiveness of these enterprises, while the promotion and application of cold spraying technology, cold spraying zinc technology and weathering resistant steel will lay the foundation for building enterprises producing environment-friendly power transmission towers.

References
[1] LI X., LI H.R, MA T., et.al. (2019) Research development of hot dip galvanized coating on steel surface. Hot Working Technology, 48(2): 7-9.
[2] LIANG C.F., HOU W.T. (2005) Sixteen-year atmospheric corrosion exposure study of steels. Journal of Chinese Society for Corrosion and Protection, 25(1): 1-6.
[3] ZHANG X., Yang S., Zhang W., et al. (2014) Influence of outer rust layers on corrosion of carbon steel and weathering steel during wet–dry cycles. Corrosion Science, 82(5): 165-172.
[4] ZHANG L., WANG Z.Y., ZHAO C.Y., et al. (2014) Study on corrosion behavior of carbon steel and weathering steel in salt spray test. Equipment environmental Engineering, 11(2): 1-6.
[5] YUN Z., ZHANG J.X., Ji X.W., et.al. (2013) Glycerine-water solution humidity-controlling
method and its effects on SO$_2$ atmospheric corrosion of hot galvanized steel. Corrosion & Protection, 34(2): 114-116.

[6] CHEN X.P., WANG X.D., LIU Q.Y., et.al. (2009) Anti-corrosion mechanism of rust layers with atmospheric corrosion resistance. Corrosion & Protection, 30(2):241-243.

[7] GE Z.J., ZHANG Q., HUANG Y., et.al. (2016) Corrosion behavior of transmission tower weathering steel under different atmospheric conditions. Electric Power, 49(12): 8-14.

[8] SHI W.Z., TONG L.W., CHEN Y.Y., et.al. (2012) Experimental study on influence of corrosion on behavior of steel material and steel beams. Journal of Building Structures, 33(7):53-60.

[9] XU S.H., REN S.B. (2015) The calculation model of elastic modulus and yield strength for corroded steel. Materials for Mechanical Engineering, 39(10): 74-78.

[10] XU S.H., REN S.B., CUI H.P., et.al. (2014) Experimental study of bending capacity of corroded channel steel member. Journal of Experimental Mechanics, 29(4):506-512.

[11] YU F., LI D.G., XU G.S., et.al. (2013) Study on load-deflection relationship of corroded channel steel beams. Steel construction, 28(2): 78-81.

[12] LI Y.J. (2007) Research and analysis on the influence of the corrosion on the performance of the grid structure. Sci-tech information development & economy, 17(14): 193-194.

[13] LIU L.H., QI H.B., LU Y.P., et.al. (2003) A review on weathering steel research. Corrosion science and protection technology, 15(2): 87-89.

[14] ZHANG Q.C., WU J.S. (2000) Current status of R & D work on weathering steel. Materials Reports, 14(7): 12-14.

[15] YANG F.L., HAN J.K., YANG J.B., et.al. (2008) Study on corrosion resistant performance tests of weather-proof steel node used in transmission towers. Electric power construction, 29(9): 23-28.

[16] HE C.H.. (2010) Development trend of steel used for transmission towers. Electric power construction, 31(1): 45-47.

[17] LI M.H., YANG J.B., LIU S.Y. (2011) Development of structure steel materials for transmission towers. Engineering journal of Wuhan university, 44(S1): 191-195.

[18] LI Y. (2007) Application of cold galvanizing in anti-corrosion field. Shanghai coatings, 45(7): 13-16.