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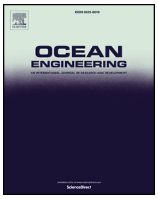

Corrosion degradation of ship hull steel plates accounting for local environmental conditions

A. Zayed[1], Y. Garbatov, C. Guedes Soares*

Centre for Marine Technology and Ocean Engineering (CENTEC), Instituto Superior Técnico, Universidade de Lisboa, Av. Rovisco Pais, 1049-001, Lisboa, Portugal

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ABSTRACT

Corrosion degradation of ship plates is predicted at different ship locations based on limited information on the local environmental conditions. The ship spaces are classified according to their chemical and physical characteristics that affect the corrosion behaviour. The parameters of the calibrated models, expressing the corrosion degradation from both sides of ship plates, are used to derive other parameters for corrosion models expressing the corrosion degradation at each side of the corresponding plates. The derived models are then used to develop corrosion models for other ship spaces, where no real corrosion measurement data are available.

1. Introduction

The importance of the studies of marine corrosion increased considerably in the last few decades because there is a strong need to predict better the corrosion degradation, especially in oil tankers that have been prone to some remarkable disasters. Statistics for ship hull damages show that around 90% of ship failures are attributed to corrosion, including corrosion fatigue (Emi et al., 1991).

At the ship design stage, the corrosion additions will increase the required net thickness of structural hull members to compensate for the expected thickness reduction during the assumed ship life. After commissioning, ships are surveyed regularly to examine their condition, and any worn structural members are replaced, based on a wastage allowance as defined in IACS. This wastage allowance depends on the structural member location and orientation. It is a function of the physical and chemical characteristics of the space surrounding each structural member.

Several studies have investigated the corrosion phenomenon through regression and statistical analyses of collected data sets (Yamamoto and Ikegami, 1998; Guedes Soares and Garbatov, 1999; Paik et al., 2003; Sone et al., 2003; Wang et al., 2003a; Wang et al., 2003b; Garbatov et al., 2007; Garbatov and Guedes Soares, 2008). Ship owner associations and the Classification Societies collect thickness measurement data and some databases are already available worldwide as reported in (TSCF, 1992).

The present study aims to introduce a simplified method to estimate the corrosion degradation in the different ship spaces based on limited information about the environmental conditions in those spaces. The different ship spaces are classified according to their main characteristics, which affect the corrosion degradation. Each space will be assumed to have almost a uniform property through it. A specific corrosion model is developed for each space based on the available data. As the available corrosion data are thickness measurements taken during the surveying periods, so, this data, as well as its corresponding calibrated models, will represent the thickness loss from both sides of the structural components.

The parameters of the available calibrated models will be used to obtain their corresponding parameters of other corrosion models expressing the corrosion degradation at each side of the structural components. These single side models will be used as reference ones in order to develop other corrosion models for the other spaces, which have not corrosion data available. Then, the corrosion models corresponding to the spaces surrounding each ship panel will be combined in order to obtain a corrosion model representing the corrosion degradation from both sides.

The developed models based on the present study can be used as reference ones as defined by (Guedes Soares et al., 2008, 2009, 2013). Then, these reference models can be corrected in order to obtain the corrosion degradation at any time, ship space and environmental conditions. While in those references the models consider that both sides of a ship plate are subjected to the same type of corrosion, the models proposed in this paper account for the real case that many ship plates have different environmental conditions around them. Thus the two faces of the same plate are subjected to different corrosion mechanisms and have therefore different corrosion rates.

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* Corresponding author.
E-mail address: c.guedes.soares@centec.tecnico.ulisboa.pt (C. Guedes Soares).

[1] Presently at the Naval Architecture and Marine Engineering Department, Alexandria University, Egypt.

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2. Classification of ship environments

The corrosion degradation process is affected by many factors. Many uncertainties are involved, which increases its randomness and so increases the difficulty of deriving a corrosion model solely based on theory. The environments surrounding ship structures are complex. The deck plating is aggressively attacked by corrosion activated by green water, rain and service water collection, besides high humidity and oxygen levels and aggressive marine atmosphere. The side shell plating is subjected to three different environments. The upper part of it is subjected to a harsh atmospheric environment, rich with chloride contents, oxygen and other corrosive compounds. The relative humidity through this part is high beside the sea water spray rising from the ship motion and wave effects but without a significant splash.

Guedes Soares et al. (2009) studied the effect of relative humidity, chlorides, and temperature on the corrosion behaviour of ship steel structures that are subjected to marine atmosphere. Based on a literature review of the previous studies and the analysis performed in (Guedes Soares et al., 2009), the factors that have significant effects on the corrosion under marine atmospheric conditions were identified. Relative humidity (RH) influences corrosion through its effect on the duration of wetness. Duration of wetness determines the duration of the electrochemical process (Uhlig and Revie, 1985). Chlorides in the salt spray are principally responsible for metal corrosion in ocean environments and various studies have proved that (Ambler and Bain, 1955; LaQue, 1975). Temperature affects the relative humidity, the dew point, the duration of wetness, and the kinetics of the corrosion process. For corrosion under atmospheric conditions, the presence of moisture, as determined by the duration of wetness, is probably the most important factor (Ailor, 1982).

The lower part of the side shell of the ship is immersed in sea water. Water properties such as salinity, temperature, oxygen content, pH level and chemical composition can vary according to the ship location and water depth. The flow of water around the vessel through this part contributes to accelerated corrosion action. This occurs because the water that flows removes the rust deposits from the surface and exposes the fresh base metal to the corrosive agents resulting in a continued corrosion attack.

Between both of the immersed and the atmospheric part of the ship side, the side shell plating is subjected to a more aggressive environment. This zone is an aerated area because of the turbulence of the sea surface around the ship hull as a result of the interaction between the ship and the sea waves. This action increases the oxygen contents of the sea surface layer; besides the wear effects arising from the motion of the sea surface against the side shell and the wet and dry effect, make this region highly corroded zone.

The quay contact region on the ship side is also suffering from aggressive corrosion deterioration. The contact between the ship side and the fenders on the quay during the birthing period causes wearing to the ship plates and damage to the protective coating. This exposes the base metal to the corrosive environment which accelerates the corrosion degradation rates.

Inside ship tanks, different corrosive environments also exist. The corrosion in the ballast tanks is much different from that in the cargo tanks and both of them are different from the corrosion behaviour in the void spaces of the double bottom, double hull and machinery space. Even inside the same tank, the corrosion in the void space above the liquid level is different from that in the immersed part and both are different from the corrosion behaviour in the tank bottom.

In the ballast tanks, the void space above the water level is highly humid, rich with chlorides and is affected by the sloshing of the ballast water, which makes the corrosion through that region very severe. The immersed side and bottom parts of the ballast tank are attacked by corrosion, similar to the corrosion under sea water immersion conditions that happens at the external hull of the vessel. However, the ballast water remains almost stagnant with respect to the tank boundaries, while the relative flow of seawater with respect to the external hull of the vessel increases the corrosion attack. Significant corrosion of structural components in ballast tanks adjacent to heated cargo tanks or tanks with consumables is also possible.

In cargo tanks, the upper region (under-deck area and part of the side shell) suffers more from corrosive gases evaporated from the cargo, such as sulphur compound gases and carbon dioxide, which have harsh corrosive effects (Yasunaga et al., 2003). The side shell of cargo tanks is usually immersed in crude oil during loading condition. The corrosion attack through this region is so dependent on the chemical and physical characteristics of the crude oil. For cargo tanks loaded with heavy crude oils, a protective waxy film is formed on the side boundary of the tank protecting it from the corrosive environment. The protection of this film decreases as the viscosity of the cargo oil decreases until reaching a minimum value in the product tanks. At the bottom of the cargo tanks, where a lot of sediments, water and other impurities accumulate, a very corrosive environment develops beside the wear effects resulting from the motion of these impurities against the tank bottom (Katoh et al., 2003).

Time in ballast or cargo, tank washing and inerting (for tankers), the effectiveness of the corrosion protection systems and component location and orientation have a great effect on the corrosion behaviour. An increased degree of the local structural flexibility has been claimed to increase the corrosion rates as the time progresses because of the continuous scale loss.

These imply that the corrosion models developed on the basis of the statistical analysis of operational data will usually be different according to the ship type and cargo or structural member location and category. Hence, it is important to classify the different spaces surrounding the ship structure based on their physical and chemical characteristics. Based on this classification, it is necessary to develop a corrosion model and to define the most important factors affecting the corrosion degradation for each ship space.

3. Corrosion modelling

Usually, the available corrosion data represents thickness reduction measurements taken during periodical surveys at different ship lives. This reduction represents the corrosion degradation from both sides of the structural members. Previous studies, reported in (Garbatov et al., 2007; Garbatov and Guedes Soares, 2008, 2009) already performed regression analyses and fitted several data sets for tankers and bulk carriers to the nonlinear function of time corrosion model (Guedes Soares and Garbatov, 1999):

$$d(t) = \begin{cases} d_\infty\left(1 - e^{-(t-\tau_c)/\tau_t}\right) & t > \tau_c \\ 0 & t \le \tau_c \end{cases} \tag{1}$$

This model is governed by three parameters and represents the long-term description of corrosion deterioration under average environmental conditions. τ_t is the transition time, τ_c is the coating life and d_∞ is the long-term corrosion depth.

Long-term corrosion depth d_∞ is the maximum steady corrosion depth expected after a long period of time. As the corrosion process progresses, corrosion products (rust) are accumulated on the surface of the metal. If this layer of rust did not flake out and depending on its porous characteristics, it can reach to a thickness enough to isolate the substrate from the corrosive agents and then corrosion process stops. d_∞ is estimated based on the regression analysis and fitting of corrosion depth measurements taken through the ship life for each ship space that has certain environmental and operational characteristics.

The corrosion degradation model descriptors that are used in the present study are based on two sets of corrosion data for deck plates of ballast and cargo tanks of tankers. These data sets were provided by ABS (2002) and are analysed in (Garbatov et al., 2007). The first set includes 1168 measurements of deck plates from ballast tanks with