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Influence of environmental factors on corrosion of ship structures in marine atmosphere

C. Guedes Soares [a],*, Y. Garbatov [a], A. Zayed [a], G. Wang [b]

[a] *Centre for Marine Technology and Engineering, Technical University of Lisbon, Instituto Superior Técnico, Av. Rovisco Pais, 1049-001 Lisboa, Portugal*
[b] *American Bureau of Shipping, Technology ABS Plaza, 16855 Northchase Dr., Houston, Texas 77060-6006, USA*

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ABSTRACT

This paper deals with the modelling of the effects of relative humidity, chlorides, and temperature on the corrosion behaviour of ship steel structures subjected to marine atmospheres. A new corrosion wastage model is proposed based on a reference non-linear time-dependent corrosion model that is modified by the effect of different environmental factors contained in the marine atmosphere. The model assesses the corrosion degradation under stationary environmental conditions denoted as "short-term". The long-term corrosion degradation is predicted by considering the succession of the various environmental conditions that can be present in the marine atmosphere during a ship lifetime and adding the corrosion damage incurred during each of them. Corrosion records (depending only on time) are used to calibrate the reference model while the effect of environmental factors in increasing or decreasing the corrosion rate is based on data published by other authors. A numerical example of a representative application of the new corrosion model is presented, to demonstrate how to apply the model.

1. Introduction

Corrosion and corrosion-related problems are considered to be the most important factors leading to age-related structural degradation of ships and many other types of steel structures. Corrosion has a harmful consequence from the point of view of safety and can lead to thickness penetration, fatigue cracks, brittle fracture and unstable failure. These failures can imply a risk of loss of human lives and a risk of polluting the environment depending on the ship type.

At the ship design stage corrosion additions will increase the required net thickness of structural hull members to compensate for expected thickness reduction during the assumed ship life. After commissioning, ships are surveyed at regular intervals to investigate their condition, and any worn structural members are replaced, based on a wastage allowance. However, some ship owners even prefer to build ships with higher plate thicknesses to reduce the number of interruptions of ship operation during the ship life for material replacement.

The decision about the preferred level of safety and consequently of the plate thickness to be included in the ship is more often made on the basis of reliability studies that incorporate a model of corrosion growth. Guedes Soares and Garbatov [1] presented a time-variant formulation to model the degrading effect that corrosion has on the reliability of ships' hulls. They also considered one repair policy showing the effect of plate replacement when its thickness reached 75% of the as built thickness. Wirsching et al. [2] presented a reliability assessment relative to the ultimate strength failure of a ship hull experiencing structural degradation due to corrosion. Shama et al. [3] demonstrated the effects of deterioration by corrosion on the reliability of double hull tanker plates subjected to different loading conditions.

General corrosion, which is the most common form of corrosion, takes place over the entire surface of the metal and is the one addressed here. The general practice to monitor the growth of corrosion during ships life is to conduct thickness measurements at regular inspections for maintenance and classifications according to the requirements of IACS (International Association of Classification Societies) [4]. The ship hull periodical surveys are classified as annual, intermediate and class renewal survey, and other mandatory surveys may also be performed.

The thickness measurements indicate the amount of wastage as a function of the age of structural elements and this data is used to develop relations that predict how corrosion wastage grows with time.

Typically linear relations have been used in traditional models. However, more recently attention has been given to the detailed aspects of steel corrosion and models that explain the various corrosion mechanisms have been proposed mainly by Melchers [5], indicating that the initial phases of are of a very high corrosion growth, which tends to level off later.

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* Corresponding author. Tel.: +351 2184179607; fax: +351 218474015.
E-mail address: guedess@mar.ist.utl.pt (C. Guedes Soares).

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The ship owner associations and the Classification Societies collect data of ship plating thickness measurements and some databases are available worldwide as reported by TSCF (Tanker Structure Co-operative Forum) [6], Yamamoto and Ikegami [7] and Wang et al. [8]. These databases show that the historical data on corrosion wastage has a rapid growth in the initial years and tends to level off later.

As a result of this type of evidence a new set of models exhibiting this type of behaviour have been proposed by Guedes Soares and Garbatov [9,10], Paik et al. [11] and Qin and Cui [12]. These models have been calibrated with data from tankers [13] and from bulk carriers [11,14] showing a very good adjustment.

All of these models do not represent the succession of corrosion mechanisms described by Melchers [5], but they represent the overall trend that can be seen both in Melchers model as well as in ship historical data. Therefore, they are appropriate models to be used by Classification Societies and ship owners to predict the growth of corrosion in general and to plan inspections on that basis.

However, it has been shown that sister ships can experience different levels of corrosion, showing that the application of such models represent average situations but can have significant deviations when applied to one specific ship. Furthermore, experience has shown that even in the same ship corrosion rates vary significantly from location to location. The reason is that the environmental conditions that are present in the different ship spaces and which different ships are subjected are different.

A first approach to solve this question has been adopted by separating the corrosion thickness measurements in areas of relatively constant environmental conditions, such as deck, tanks, hull etc. However, the definitive way of dealing with this problem is to represent explicitly the effect that the various environmental factors have on corrosion.

Literature reviews by Melchers [5], Zayed et al. [15] and Panayotova et al. [16] have identified the main corrosion mechanisms that can be found in ship structures and the main environmental factors that affect them.

Corrosion of deck plating is affected by green water, rain and service water accumulation, in addition to the high humidity and the aggressive marine atmosphere. Side shell plating is subjected to three different environments. The upper part of it is subjected to the aggressive atmospheric environment, rich in high chloride content, oxygen and other corrosive minerals, in addition to the seawater spray arising from the ship motion and wave effects. This region is also subjected to high relative humidity. Salts may be detected, which may result from salt spray blown by wind. The variations in relative air humidity cause either the evaporation or condensation of water. The gases contained in the air may have carbon dioxide (CO_2), hydrogen sulphide (H_2S), sulphur dioxide (SO_2), or sulphur trioxide (SO_3). They activate the thin layer of electrolyte and accelerate the rate of corrosion even more, since this process takes place in an oxygen-rich atmosphere. The effect of temperature and the different environmental factors on the atmospheric corrosion behaviour was illustrated by various studies such as Ambler and Bain [17], Ailor [18], Grossman [19] and Vernon [20].

The lower part of the side shell of ship hull is completely immersed in seawater. Water properties such as salinity, temperature, oxygen content, pH level and chemical composition can vary according to location and water depth. These properties actually affect the corrosion degradation in that part of the ship as indicated, for example, by Mercer and Lumbard [21], LaQue [22], Dexter [23] and Melchers [5,24,25]. The flow of water contributes to accelerated corrosion as studied by LaQue [26] and Melchers and Jeffrey [27].

Between the immersed and the atmospheric part of the side of ship hulls, the side shell plating is subjected to a more aggressive environment. This zone is a very aerated area due to the turbulence of the sea surface around the ship hull. These actions increase the oxygen content of this layer, in addition to the wear effects arising from the motion of the sea surface against the side shell and the wet and dry effect making this region a highly corroded zone. The extent of the maximum corrosion in the still waterline zone is determined by the sea state conditions and the atmospheric temperature. The maximum rate of attack in colder climates would be smaller, while with more intensive wave action in warmer climates it would be greater [22].

Inside ship cargo tanks, different corrosive environments also exist. The lower part is in contact with the cargo. The ceiling and the upper part of the tank are in contact mainly with gaseous atmospheres [28]. Between the previous parts, there is an area that sometimes is in contact with cargo and others with gaseous atmosphere depending on the level of cargo in the tank. Yasunaga et al. [29] studied the corrosion degradation of the upper deck of cargo oil tank of an oil tanker, while Katoh et al. [30] investigated localized corrosion of cargo oil tank bottom plate of an oil tanker.

As these situations involve different types of environments that will induce corresponding types of corrosion, the approach adopted has been to develop a specific model for each. Gardiner and Melchers [28] proposed a model for enclosed atmospheric corrosion within ship spaces based on temperature, salt deposition and time of wetness. Guedes Soares et al. [31] have suggested how to deal with corrosion in the immersed part of ship hulls while Guedes Soares et al. [32] proposed a model to represent the effect of environmental factors inside cargo tanks. This paper complements those by dealing with atmospheric corrosion, and adopting a similar general approach.

Corrosion involves the interaction between metal or alloy and its environment and is affected by the properties of both the material or alloy and the environment. Atmospheric corrosion occurs on a steel surface in contact with the atmosphere and thus is not immersed in water. However, for corrosion to occur, a thin wet film needs to be created by the humidity in the air in combination with impurities.

Atmospheric environments vary depending on the chemical constituents. Some major chemical constituents of the atmospheric marine environment are relatively constant worldwide. However, the minor constituents vary from site to site and with season and storms. The variations in the chemistry of open ocean atmosphere tend to take place slowly and over horizontal and vertical scales that are large in comparison with the dimensions of most marine structures. Such gradual changes may produce an equally gradual change in the corrosion rate of structural materials with season and location, but they are unlikely to produce sharp changes in either corrosion mechanism or rate.

A number of studies related to corrosion evaluation under marine atmospheric conditions have been reported in the specialized literature. Grossman [19] showed the corrosion rate per day of wetness and demonstrated the accelerating effect of temperature on corrosion rate at six test sites. Sodium chloride is a chief contaminant, and salt spray is principally responsible for metal corrosion in ocean environments. Ambler and Bain [17] performed a series of tests in Nigeria to illustrate these effects. Specimens of steel were exposed to the atmosphere at distances from the ocean ranging from a few yards to over 100 miles. The amount of sea salts measured off the coast of Nigeria illustrate this relationship between the salinity and the corrosion rate. Ailor [18] studied the effect of SO_2 levels on the corrosion rate of carbon steel, using data from three Norwegian test sites. The data shows that as SO_2 concentrations are increased, the corrosion rate, measured as weight loss, increases. For atmospheric corrosion, the presence of moisture, as determined by the time of wetness, is probably the most important effect [33]. Gardiner and Melchers [28] investigated