Engineering Structures 152 (2017) 70–86

Contents lists available at ScienceDirect

Engineering Structures

journal homepage: www.elsevier.com/locate/engstruct

Experimental analysis of residual ultimate strength of stiffened panels with pitting corrosion under compression

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A R T I C L E I N F O

Article history:
Received 22 December 2016
Revised 25 August 2017
Accepted 30 August 2017

Keywords:
Experiment
Pitting corrosion
Stiffened plate
Ultimate strength

A B S T R A C T

The collapse mechanics and ultimate strength of a stiffened plate with pitting damage are investigated experimentally with specimens with circular shaped holes representing the pits in the plate. A series of compressive tests has been conducted to investigate the effect of pitting corrosion, including the initial imperfections. The pit location, pit diameter and pit depth are examined to determine the influence of the pitting on the ultimate strength. The experimental results of load-displacement relationship, the strain response and the ultimate strength under compressive loads are analysed. The ultimate strength reduction is related with the degree of pitting or volume loss.

1. Introduction

The marine environment leads to corrosion in marine structures. Corrosion damage is usually evenly spread over the metal surface in corrosive environment and will bring about reduction of structure thickness. It may be one of the primary causes that reduce the residual strength of stiffened panels, which are basic components of ship hulls and other offshore structures, in which corrosion wastage appearance will have significant influence on the ultimate strength and safety. Guedes Soares et al. [1] presented some corrosion models and identified environmental factors influencing corrosion of ship structures in contact with marine atmospheres. Other areas of the ship such as the immersed parts [2] and the oil tanks [3] are also subjected to corrosion that can be as intense of even more.

General corrosion and pit corrosion are two typical types of corrosion wastage in marine structures [4]. These two modes of corrosion can be found over the entire ship surface in aged marine structures. Actually, pit corrosion may be as common as the general corrosion. Extreme value models of the pit depths and corrosion wastage have been proposed by discussing the microbiological and abiotic processes for pit corrosion in different waters [5].

Bhandari et al. [6] reviewed and discussed the mechanisms and characteristics of pit corrosion and all possible factors studied by the researchers during the last decade. The pit corrosion processes is revealed into four phases with different corrosion rates influenced by some critical factors as temperature, PH among others [7]. Pitting corrosion is described by the pit depth, which is acknowledged as a critical factor. The uncertainties of the maximum pit depth were investigated by Melchers [8], who described it by the generalized extreme value distribution. The pitting depth is then assessed using Frechet extreme value distribution for long-term exposures of steel to seawater. The corrosion level is measured by the yearly corrosion rate [5], which is affected by the plate bending conditions [9]. The reliability of pit corroded pipelines shows strong sensitivity to the uncertainty of pit depth [10]. Paik et al. [11,12] introduced a Weibull probability model of corrosion thickness loss for the longitudinals and ballast tank of bulk carriers, including local corrosion as well as general corrosion. The effect on ultimate strength of pit depth t_c, which may be a key factor for pit corrosion characterization, will be investigated.

Corrosion wastage in structures may reduce their ultimate strength in different ways for different corrosion types. The thickness of structural elements is reduced uniformly for general (uniform) corrosion. The ultimate strength calculations are typically carried out by excluding the thickness loss, which will result in the decrease of the plate slenderness and column slenderness. Some studies about the ultimate strength with uniform corrosion are performed using empirical formulas, IACS rules and finite element method (FEM) [13].

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http://dx.doi.org/10.1016/j.engstruct.2017.08.069
0141-0296/

As general corrosion, is a much idealized situation, some researchers tried to improve the model, making it more realistic. Taking account in the different thickness for different location in one plate due to the corrosion, Teixeira et al. [14] proposed an approach to calculate the sensitivity of the ultimate strength to the randomness of the material properties, geometric size, corroded depth and initial imperfections by semi-empirical design equations or non-linear finite element analysis for non-uniformly corroded plates. The collapse of both-side randomly corroded steel plate are predicted by introducing an expression based on the equivalent thickness induced using elastic large deformation theory and rigid-perfectly plastic mechanism and FEM as the plate meshed into small element with different thickness caused by non-uniform corrosion [15]. It may be a good method for study the influence of the stochastic corroded depth but will cost much due to the small mesh size, whose results need to be validated by experimental results. It may be impossible for large structure to do the nonlinear finite element analysis (FEA).

For localized corrosion such as grooving, the strength capacity calculation procedure will be more complex due to stress concentration near the grooving. Grooving corrosion, which is one form of local corrosion is investigated for the ultimate strength of stiffened plates by the finite element method [16]. Grooving corrosion often occurs in large marine and offshore structure, with a localized line of material deterioration normally adjacent to welding joints along welded stiffeners or at plate butts or seams. The corrosion in welded joints of the stiffener and plate on the bulk carrier may result in severe degradation of ultimate strength. This type of corrosion may influence small area of the structure, however much larger than the surface of on pit of corrosion.

Many researchers tried to introduce and improve the numerical method for the ultimate strength of the pitted structures. Ultimate strength and collapse of plates and stiffened panels with localized corrosion has been investigated using FEM [17,18]. The initial imperfections as geometric deformation and residual stress are included in these models. The plate subjected to local corrosion is divided into some sub-sections with rectangular shape to improve the mesh [17]. The general corrosion is assumed to happen in each sub-section. Using this simplified localized corrosion model, as a simplified model of pit corrosion, an expression for predicting ultimate strength of plates with pit corrosion was presented and the empirical formulae of strength reduction was derived using artificial neural networks [19].

Another proposed pitting corrosion model was with cylindrical, semi-spherical and conical pit shapes on the surface of the structure. Some small basic elements like web plate with pit were studied. The effect of pit corrosion on the residual strength of web plate under patch loading is studied by experiments and numerical simulations. Here, the welding residual stress is taken into account and pit corrosion is made on the web plate of the tested structural models by drilling with circular cone. The results show that the pit distribution and the pit shapes on the web can affect remarkably on the ultimate load and deformation behaviour of the web plate. The different corrosion model as general or pitting may have little influence on the ultimate strength if the corroded mass is the same [20]. Further researches about shear buckling failure mode and strength of the pit corroded web plate are reported in [21].

Another basic element of the flat plate with pit was focused to investigate the ultimate strength by numerical method. The formula between the ultimate strength and corroded volume loss of plate is deduced by a series FEM analysis of plate with pitting corrosion [22]. It was found that the pit shape has little influence on the reduction of ultimate strength if they have the same corroded volume loss. By performing many FEAs, the authors concluded that the volume loss is the most important factor that reduces the ultimate strength of corroded plates. Some other parameters that will have influence on the ultimate strength for corroded stiffened plates are investigated, such as the corrosion severity, plate slenderness and corrosion location [23]. The compressive strength of plates and stiffened panels are also studied to discuss randomly distributed pit corrosion. However, the effect on ultimate strength of the plate and panel of the randomness of pit location, corrosion severity and geometric size has not been discussed. Jiang and Guedes Soares [24], investigated the ultimate strength of a rectangular plate subjected to pit corrosion. The ultimate strength of a plate with a random localized corrosion degradation was studied in [25,26], and the probabilistic assessment was addressed in [14,27].

Some other researchers were focused on the ultimate strength of a big box structure with corrosion. Corrosion was formed by placing the box girders in sea water. Saad et al. [28,29] investigated the ultimate bending moment of a corroded hull box girder experiments by FEA. New stress–strain relations have been proposed to accounting for the effect of local corrosion on the flexural rigidity [30], in which the corrosion model and moment-curvature relationship are determined from the test results. Different corrosion severity cases as initial, moderate and severe corrosions are discussed in [31]. Some parameters as the initial deformation of plate, corrosion loss are studied [32]. Corroded test specimens were cut from a box girder that was initially corroded in real sea water conditions. The dimensional theory is discussed for scaling the experimental results [33]. It has been reported that several FEA of the ultimate strength for pit corroded structures have been conducted, but it is essential to have experimental results available so that the numerical results can be validated. Experimental studies of the ultimate strength of the pit corroded plate are much fewer than numerical results. Paik et al. [34] conducted experiments using pits made in the same way as in the present experiments. The set-up is shown in Fig. 1. There are 42 pits in one-side plate each with diameter of 30 mm. The pit thickness is equal to the plate thickness, as they are through thickness. Using the results of the experiment, the relationship of the residual ultimate strength was derived in a simple formula. Other researchers also did experiment ultimate analysis for the pit corroded ship structure.

Similar to this work Zhang et al. [35] performed experiments of the ultimate strength of a pit corroded plate with simple-supported lateral boundary condition. Ahmmad and Sumi [36] performed a series experiments to investigate the tensile strength of plates including the intact, uniform corroded and pit corroded

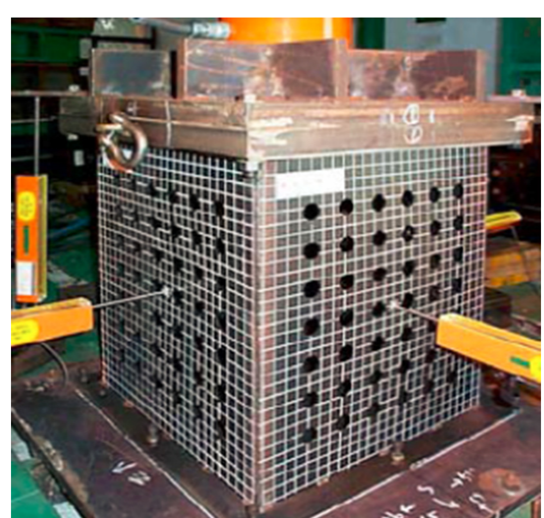

Fig. 1. Set-up of experiment by Paik [34].