STRESS CONCENTRATION FACTOR ON A CORROSION PIT

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Abstract. *Phenomenon of corrosion in structural materials is very important, because they very often yield to aggressive environment. Moreover, not inconsiderable effect of fatigue damage via cyclic loading of such engineering structures should be considered as well. Thus, the influence of a corrosion pit (of a circular segment shape) on the stress distribution in a rectangular specimen subjected to remote tensile stress range has been investigated via finite element method. Particularly the stress concentration factor has been calculated for various sizes of the corrosion pit and the results obtained have been discussed.*

Keywords

Corrosion pit, finite element simulations, stress concentration, high-strength steel (HSS).

1. Introduction

Steel constructions are very often besides the cyclic loading (fatigue) subjected to aggressive environment during their service life. Thus, when assessing their lifetime, this effect needs to be considered. Corrosion can cause both weakening the specimen/construction cross-section and formation of stress concentrators. These processes are undesirable and have significant effect on the lifetime period. Various protective arrangements are being searched (such as surface coatings and treatments that are more resistant to impact of moist environment). Nevertheless, the corrosion phenomenon is often unavoidable and therefore, it is necessary to investigate its influence on reliability assessment of structures subjected to corrosive environment, see e.g. [1] or [2]. There exist different kinds of corrosion. Some review works dealing with the probably most widespread *pitting* corrosion can be mentioned, such as [3], [4] or [5]. Moreover, a few papers are devoted directly to combination of corrosion and fatigue damage, see e.g. [6], [7], [8] or [9].

Also in this paper, combination of corrosion and fatigue mechanisms are studied. Particularly, stress concentration on a corrosion pit of various length and depth in a rectangular specimen under tensile cyclic loading is investigated and results obtained from numerical simulations are discussed.

2. Corroded specimen

Corrosion pits are created based on the particular conditions of each structure, i.e. their size and shape depend on corrosive environment (its aggressivity, period of its impact etc.), see Fig. 1. Thus, effect of the pit length and depth on the stress distribution was investigated. The dimensions of the specimen for numerical simulations were suggested according to real specimens prepared for fatigue tests under various corrosion levels, see. Fig. 2a. Although the real specimen is cylindrical, the finite element model was created as a two-dimensional rectangular cut of the middle part of the corroded specimen as indicated in Fig. 1. Plane strain conditions were considered to avoid the ring-shaped pit if axisymmetric condition would be applied. The corrosion pit shape is a circular segment considering the relation between its depth and length as $LC = 4 \times D$, see Fig. 2.

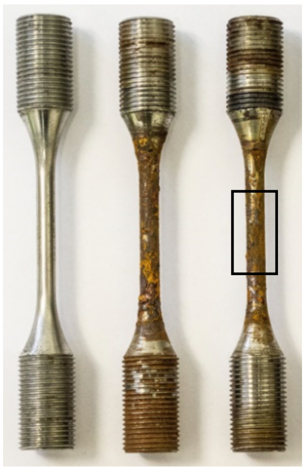

Fig. 1: Example of steel specimens for fatigue experiment without and with various level of corrosion.

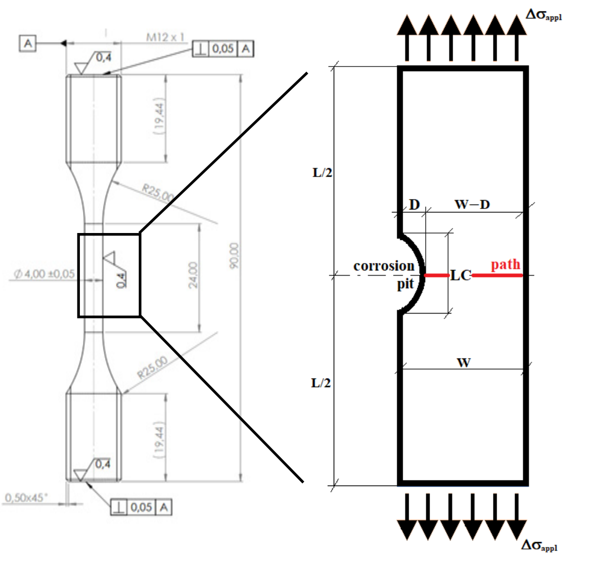

Fig. 2: Scheme of the real cylindrical specimen (a) and the analysed rectangular specimen with a corrosion pit subjected to remote tensile cyclic loading.

The values of the individual geometrical parameters were set as:

- specimen length, $L = 24$ mm;
- specimen width, $W = 4$ mm;
- corrosion pit depth, $D = 0.1$ to 1 mm;
- corrosion pit length, $LC = 0.4$ to 4 mm;
- corrosion pit radius, $RC = (LC^2+4D^2)/8D$.

Cyclic loading value and properties of the linear elastic material model representing the properties of very popular high-strength steels (HSS) were assumed to be: tensile stress range, $\Delta\sigma_{appl} = 100$ MPa; Young's modulus, $E = 210$ GPa; Poisson's ratio, $\nu = 0.3$.

Numerical model was created as two-dimensional adopting the plane strain conditions. Due to the symmetry, only the upper half of the specimen was modelled. Elements used in ANSYS computational software for creation of the specimen were quadratic ones, denoted as PLANE183. The size of the smallest element used at the corrosion pit surface as well as in its closest vicinity was 0.001 mm in all configurations under the study. Thus, it was possible to obtain comparable values of the maximum stress at the bottom point of the corrosion pit.

The stress distribution at the corrosion pit surface was investigated to find the location of the maximum stress concentration. Further, the stress concentration at the corrosion pit was expressed via the stress concentration factor K_t defined as, see [10]:

$$K_t = \frac{\sigma_{max}}{\sigma_{avg}}, \quad (1)$$

where σ_{max} represents the maximum stress value (occurring at the corrosion pit bottom) and σ_{avg} represents the average stress value (along the ligament of the cross-section ahead of the corrosion pit, as it is indicated by the red "path" in Fig. 2b). Particularly, the von Mises stress values were assessed.

3. Results

In the following section, results and their discussion can be found. Particularly, the von Mises stress distribution along the (half of the) corrosion pit obtained from ANSYS computational software can be seen in Fig. 3 and it is obvious that the maximum occurs at the bottom of the corrosion pit (symmetry axis) and the rest of the values decrease towards the edge of the corrosion pit.

Additionally, the distribution of selected stress components was investigated ahead of the corrosion pit through the specimen width. The dependences of the σ_{xx}, σ_{yy} and σ_{vM} (von Mises) stresses for various corrosion pit depths (D between 0.1 and 1.0 mm) can be found in Fig. 4. The results are plotted as a function of the relative distance from the corrosion pit x related to the ligament W-D.

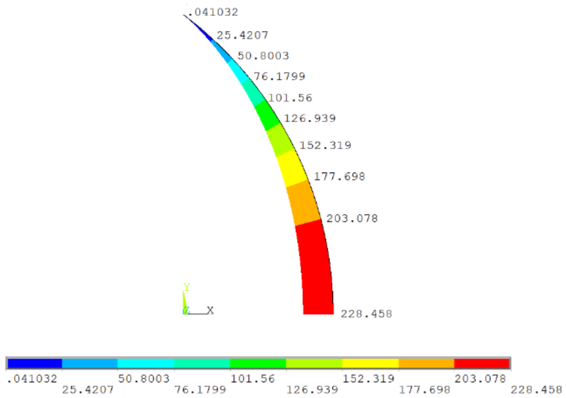

Fig. 3: Von Mises stress (in MPa) distribution along the upper half of the corrosion pit for the specimen with the corrosion pit 0.5 mm deep and 2 mm long.

The last set of results is presented via Tab. 1, where the values of the maximum and average von Mises stress is presented together with the corresponding stress concentration factor and its percentual difference for increasing corrosion pit size.

Tab.1: Values of the maximum and average von Mises stress together with the corresponding stress concentration factor and its percentual difference for increasing corrosion pit depth ($D = 0.1$ to 1.0 mm).

D [mm]	σ_{max} [MPa]	σ_{avg} [MPa]	K_t [-]	$(K_t-K_{t,D=0.1mm})/K_{t,D=0.1mm}$ [%]
0.1	202.47	88.84	2.28	-
0.2	204.71	89.18	2.30	0.72
0.3	210.72	89.97	2.34	2.76
0.4	217.67	91.11	2.39	4.83
0.5	228.46	92.74	2.46	7.89
0.6	238.11	94.47	2.52	10.59
0.7	251.55	96.68	2.60	14.17
0.8	266.68	99.16	2.69	18.00
0.9	284.70	102.02	2.79	22.44
1.0	304.92	105.14	2.90	27.25

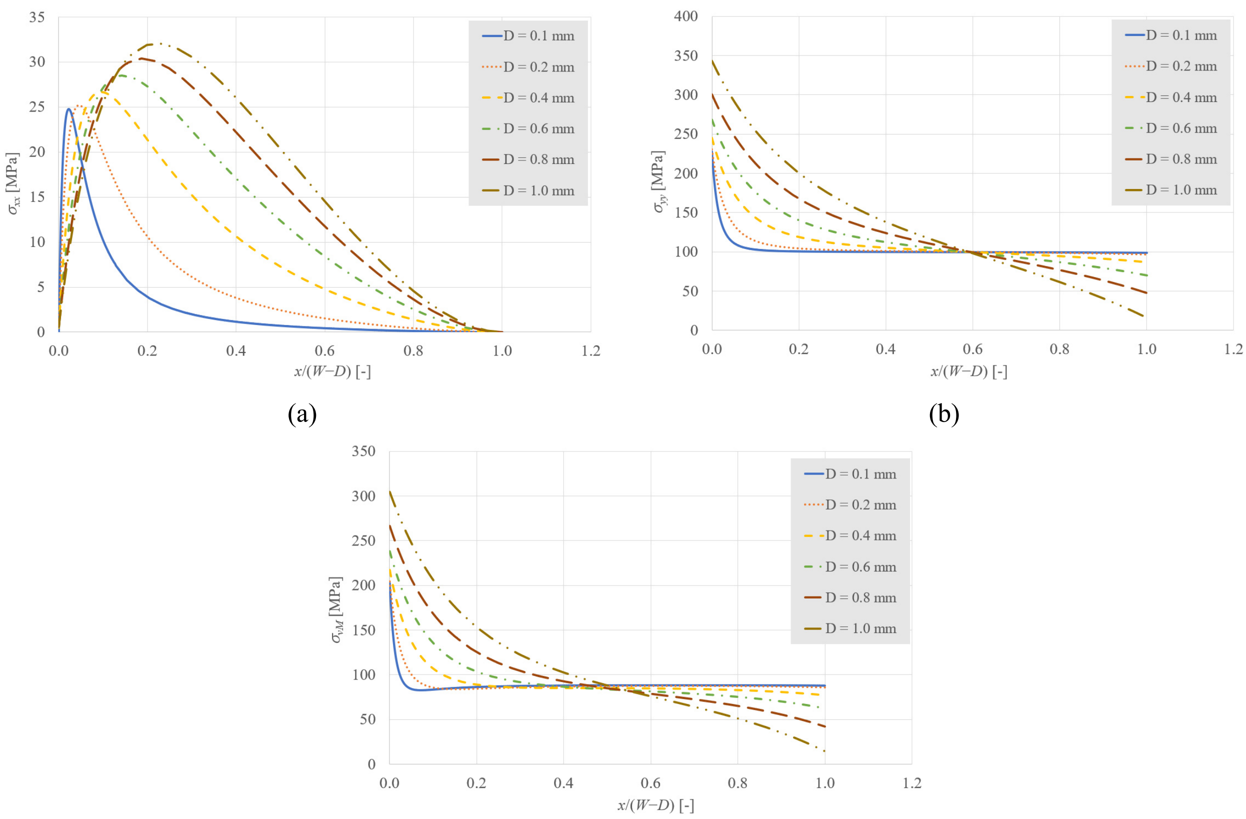

Fig. 4: Selected results of the stress distribution along the path overlapping the specimen width ahead of the corrosion pit for various corrosion pit depths (*D* between 0.1 and 1.0 mm): (a) σ_{xx}; (b) σ_{yy}; (c) σ_{vM}.

From the results obtained, the following points can be highlighted:

- The stress distribution of σ_{yy} component (Fig. 4b) shows the typical singular behaviour when the specimen is loaded via 100 MPa of tension. The stress growth at the corrosion pit is rather gentle when the pit is deeper.
- The deeper the corrosion pit, the higher the investigated stress values ahead of the pit.
- The previous statement is valid both for maximum and average values of the selected stress components.
- Moreover, also the ratio between the maximum and average value (referred to as stress concentration factor, K_t) calculated for von Mises stresses increases with increasing corrosion pit depth.
- An increase of about 27 % has been observed when the corrosion pit is ten times larger ($D = 1.0$ mm vs. $D = 0.1$ mm)
- It means that the level of the corrosion (directly influencing the corrosion pits size) affects the stress distribution/concentration in the specimen and/or structure and consequently can also influence its lifetime.
- Comparison with experimental results on corroded specimens is intended to compare the results qualitatively and quantitatively.

4. Conclusion

Influence of the presence of a circular-segment-shaped corrosion pit in a rectangular specimen subjected to remote cyclic tensile loading on the stress distribution has been investigated via finite element method for various corrosion pit geometries. Various stress components dependences on the distance from the corrosion pit have been analysed and stress concentration factors for von Mises stress calculated. The results show that depending on the level of the corrosion (corresponding to the corrosion pit size), the stress concentration increases. Particularly, when the corrosion pit is ten times larger ($D = 1.0$ mm in comparison to $D = 0.1$ mm), the stress concentration is higher about ca. 27 %. Experimental campaign on corroded specimens is running to be able to compare the results obtained. Then, the numerical simulations will probably enable to predict the lifetime of corroded specimens quickly and reliably.

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