

# FRACTURE PARAMETERS OF A PERPENDICULAR CRACK WITH ITS TIP CLOSE TO A CORROSION PIT

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**Abstract.** Pitting corrosion is an important kind of damage of metal specimens. Therefore, this paper is devoted to investigation of mutual interaction of a corrosion pit and a fatigue perpendicular crack. A rectangular specimen subjected to remote tensile loading was modelled via finite elements and basic fracture parameters were calculated for various distances of the pit from the crack. Based on the obtained dependences of  $\Delta K_I$ ,  $\Delta K_{II}$  (stress intensity factors for normal and shear modes) and  $B$  (parameter biaxiality) on the relative crack lengths ( $a/W$ ), it can be summarized that the corrosion dimple is significant for the crack propagation only if the relative crack length is very short in comparison with the corrosion pit. Then, the corrosion pit can affect as a protection against the crack propagation.

## Keywords

*Corrosion pit, finite element method, fracture parameters, perpendicular crack, high strength steel.*

## 1. Introduction

High strength steels have been used in civil engineering area for structural elements of constructions relatively lately, 20 to 25 years. Besides the traditional use for guardrails and handrails, it is more and more often utilized in load-bearing structures of deck or suspension systems, as well as in anchorage components. Significant technological advances in the use of high strength steel in construction are described for the design and assessment of reliability for instance in Eurocode 3 [1], [2]. The main advantage of the high strength steels is its high strength and high ductility. On the other hand, also this material is subjected to long-time influence of the environment and

various kinds of loading and because of its relative novelty, its response to the mentioned phenomena is not described satisfactorily yet.

The failures can primarily occur due to initiation of cracks through stress cracking followed by fatigue crack growth requiring a certain stress range and a sufficiently large number of cycles until final failure ensued through sudden and instable fracture after fatigue growth to a critical crack size. The state-of-the-art review of metal fatigue has been published, for example in [3], [4] and [5]. Numerous methods have been proposed for the evaluation of the remaining fatigue life of load carrying steel structures and steel bridges [6], [7].

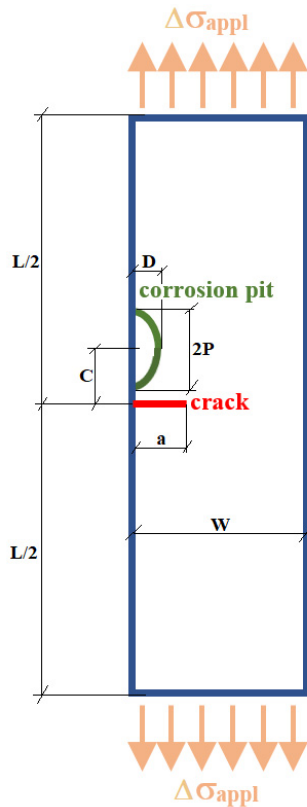
Additionally, pitting corrosion is an important kind of damage of metal specimens. It causes crucial changes in the surface morphology, which is often connected to local stress concentrations, reduction of the cross section, etc. The mentioned effects can significantly decrease the lifetime of specimens made of various metal materials. Studies on behaviour of specimens with corrosion pits can be found for instance in [8], [9], [10], [11], [12], [13] and [14].

In this paper, an effect of a corrosion pit on the propagation of a perpendicular near crack is investigated via linear elastic fracture mechanics principles. The analysis presented is performed via finite element method and the influence of the mutual distance of the pit and the crack on the stress intensity factors is investigated.

## 2. Theoretical Description

Generally, two cases can occur: either the crack can develop directly from the corrosion pit (then LEFM cannot be applied, but the solution via the stress concentration factor  $K_t$  related to the notch root radii is necessary, see e.g. [15]) or it can exist in its vicinity due to some mechanical

or inhomogeneity penetration. The former case is rather more typical but the latter one is studied more occasionally, although the crack can develop as a consequence of various surface defects/damages. The paper is devoted to analysis of the fracture behaviour of a perpendicular crack existing *near* a corrosion pit in a rectangular bar loaded by pure tensile stress, see the scheme in Fig. 1.



**Fig. 1:** Scheme and dimensions of the cracked bar with a corrosion pit subjected to remote tensile loading.

Thus, the classical linear elastic fracture mechanics concept was applied in order to obtain the dependence of the stress intensity factors range on the crack length for various geometrical configurations, i.e. for various mutual distances between the crack and the pit. Because of the orientation of the crack, mode I of loading is dominant and significantly higher values of mode I stress intensity factor range needs to be expected. Nevertheless, also the values of mode II stress intensity factor range are non-zero because of the presence of the corrosion dimple and they were therefore investigated as well. Moreover, the  $T$ -stress as the second (non-singular) parameter of the Williams expansion [16] derived for approximation of the crack-tip stress/displacement field were also investigated. To be more accurate, the dependences of the dimensionless biaxiality ratio  $B$  on the relative crack length can be found in the section Results, where  $B$  is defined as:

$$B = \frac{T\sqrt{\pi a}}{\Delta K_I}, \quad (1)$$

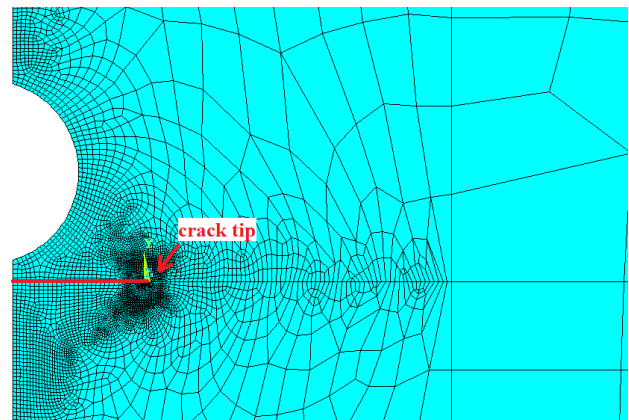
where  $T$  represents the  $T$ -stress,  $a$  is the crack length and  $\Delta K_I$  is the mode I stress intensity factor range.

## 2.1. Dimensions

The dimensions of the cracked specimen as well as the corrosion pit are schematically introduced in Fig. 1. Particularly, the following values have been used: the specimen length  $L = 100$  mm, the specimen width  $W = 10$  mm, length of the corrosion pit  $2P = 0.4$  mm, depth of the corrosion pit  $D = 0.15$  mm, applied tension  $\Delta\sigma_{\text{appl}} = 300$  MPa. The dimensions of the corrosion pit were chosen based on values published in recent research papers dealing with corresponding topics, see e.g. [9], [10] and [14] etc. The last two parameters varied in the defined range: crack length  $a$  between 0.05 and 0.7 mm (with the step of 0.05 mm) and the distance of the middle of the corrosion dip from the crack  $C$  between 0.25 and 0.5 mm (with the step of 0.025 mm). In total, 154 various configurations have been simulated and the corresponding fracture parameters calculated.

## 3. Numerical Model

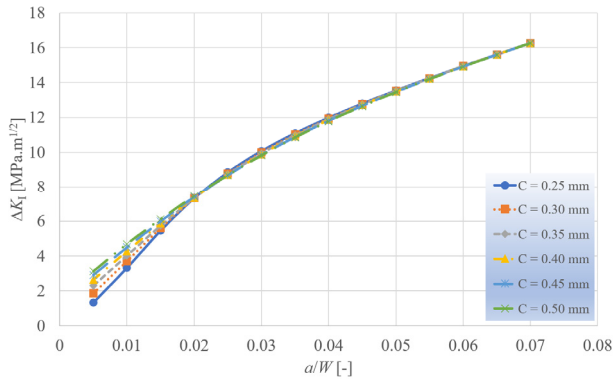
For purposes of the study, a simplified 2D numerical model was created. Finite element (FE) mesh was finer in the vicinity of the studied crack as well as on the surface of the corrosion dip, as can be seen in Fig. 2. Quadrilateral 2D elements (called PLANE183) were chosen. Material properties of the specimen were defined by the Poisson's ratio of 0.3 and by the Young's modulus of 210 GPa, as are typical for lots of steel grades. The special configuration of the first row of elements around the crack tip was utilized – their mid-side nodes were shifted to  $1/4$  of the length of the element toward to the crack tip. Thus, the well-known  $r^{-1/2}$  crack-tip singularity for the singular stress field near the crack is ensured. The corresponding stress intensity factor ranges for all modelled configurations were then calculated via CINT command implemented in ANSYS commercial FE software [17]. This procedure the contour integral calculation to obtain requested fracture parameters.



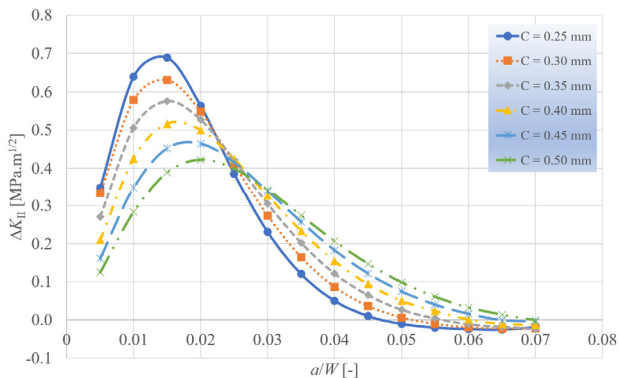
**Fig. 2:** Detail of the finite element mesh near the crack tip used for numerical modelling of the problem.

## 4. Results

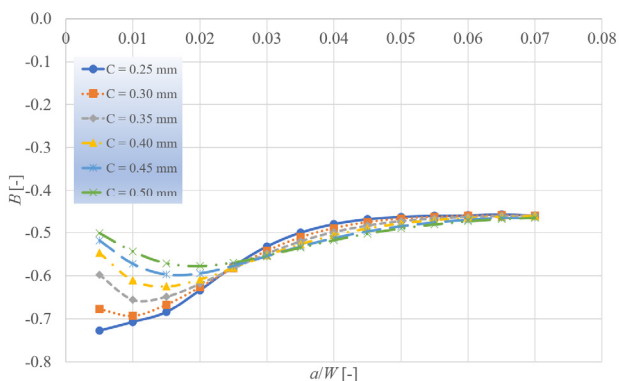
The stress intensity factors ranges and  $T$ -stress/biaxiality factor ( $B$ ) were investigated in dependence on the (relative) crack length for various mutual distances of the crack and the corrosion pit in a rectangular specimen under pure tension. The results for  $\Delta K_I$ ,  $\Delta K_{II}$  and  $B$  can be seen in Figs. 3, 4 and 5.



**Fig. 3:** Mode I stress intensity factor range as a function of the relative crack length for various mutual distances of the crack and the corrosion pit in the rectangular specimen subjected to pure tensile loading.



**Fig. 4:** Mode II stress intensity factor range as a function of the relative crack length for various mutual distances of the crack and the corrosion pit in the rectangular specimen subjected to pure tensile loading.



**Fig. 5:** Biaxiality ratio as a function of the relative crack length for various mutual distances of the crack and the corrosion pit in the rectangular specimen subjected to pure tensile loading.

## 5. Discussion

Based on the results obtained several general statements can be summarised:

- The presence of the corrosion pit near the crack influences the fracture parameters only in the case of very short cracks.
- For relative longer cracks, the stress intensity factors ranges as well as biaxiality ratio are stabilized and independent on the mutual position between the crack and the pit.
- $\Delta K_I$  is influenced by the pit if the crack is smaller than 0.2 mm,  $\Delta K_{II}$  and  $B$  if the crack is smaller than 0.7 mm.
- Existence of the corrosion pit near the crack tip causes light decrease of the  $\Delta K_I$  values and increase of  $\Delta K_{II}$  values. It means, that the corrosion pit leads to development of weak mixed-mode conditions for crack propagation (contrary to the specimen without the pit, where only mode I crack propagation occurs).
- Although the  $\Delta K_{II}$  values are not very high, for a very short crack it can lead to its deflection from the original perpendicular propagation direction. Thus, the crack could stop at the corrosion pit, which would positively affect the lifetime of the specimen.

To conclude, it has been found out that the corrosion pit influences the crack behaviour only if the specimen contains very short cracks. When the crack is long enough, it behaves independently on the presence of the corrosion pit.

## 6. Conclusion

In the paper, the mutual interaction of a perpendicular crack and a corrosion pit in a rectangular specimen subjected to pure tension is investigated. The basic fracture parameters describing the fatigue crack growth were calculated via finite element method. It has been found out that the corrosion pit influences the crack behaviour only for very short cracks. Such a configuration leads to development of I+II mixed-mode conditions of the crack propagation and can cause deflection of the perpendicular crack from its original direction and consequently its stopping at the corrosion pit. It can be concluded that further extension of the study presented can be helpful for assessment of lifetime of cracked specimen/structures under corrosion. Mutual interconnection of numerical simulations and experimental observation is desirable in additional assessment processes.

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Financial support from the Czech Science Foundation (project No. 21-14886S - Influence of material properties of high strength steels on durability of engineering structures and bridges) and from the Faculty of Civil Engineering, Brno University of Technology (project No. FAST-S-22-7881- Numerical support during initiation and propagation of a crack in high-strength steels under corrosion) is gratefully acknowledged.

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