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MODELLING OF FATIGUE FAILURE OF GEARS WITH THIN RIM

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Abstract: *This work is focused on a fracture mechanics analysis of a spur gear with thin rim. The fatigue crack propagation is numerically studied using special routine implemented in the numerical model. Two criteria for crack kinking are considered: MTS criterion and modified MTS criterion which takes constraint effect into account. Sensitivity analysis of the crack increment size is present. It was found that for the same crack path obtained numerically the MTS criterion requires smaller crack increment in comparison with modified MTS criterion.*

Keywords: ***crack, fatigue fracture, gear, thin-rim***

Crack propagation in a non-homogenous stress field generally displays a complicated trajectory. Accurate estimation of the crack path can aid the prediction of unexpected failures in engineering structures. The usual assessment of the crack trajectory and crack propagation rates is based on a phenomenological approach. According to classical linear elastic fracture mechanics two cracks display similar behaviour if the stress intensity factors are equivalent (Anderson, 1995). Recently it has been shown that in some cases two-parameter fracture mechanics, which take into account the constraint effect, can describe the crack tip stress field more accurately. Consequently, the criteria used for estimation of the fatigue crack trajectory were also modified (Ayatollahi & Aliha, 2008).

For the work presented the commonly known (Maximum Tangential Stress) MTS criterion was used for an estimation of the crack path. As a practical application, the numerical estimation of the gear with a thin rim failure is shown. An advantage of this kind of gear is important weight reduction in comparison to classical gear designs. The disadvantage of this type of gear is higher susceptibility to fracture failure originating from the tooth foot. The crack propagating below the tooth causes only fracture of the tooth. The aim of this research is attempt at clarification of discrepancies found in the current literature (Lewicki & Ballarini, 1997) and to introduce a constraint based methodology for estimation of the crack behaviour.

Minimal gear rim thickness refers to the thickness in which the crack is still growing below the tooth. From a practical perspective, this represents the state where the function of the gear is endangered but a degree of survival probability remains. For this reason knowledge of the minimal gear rim thickness is necessary in many engineering applications. The crack growth is modeled by an incremental method similar to the one published by (Španiel, Jurenka & Kuželka, 2009). All cracks start in the tooth root with an initial length of 0.25mm. The position of the initial defect was found using numerical analysis of the gear without the crack where highest tensile stresses occurred and corresponds with the location of the initial defect based on experience with gear failure (Kramberger et al., 2004a; Kramberger et al., 2004b). The gear studied was a spur gear with 25 teeth and involute tooth profile. Parameters of the gear studied were: normal modulus $m = 4$ and tooth width $b_w = 30$ mm.

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All simulations were performed as a 2D model under plane strain condition. The contact between the gears was substituted by a contact force which acts at the highest point of the active tooth flank. The numerical model is shown in Fig. 1.

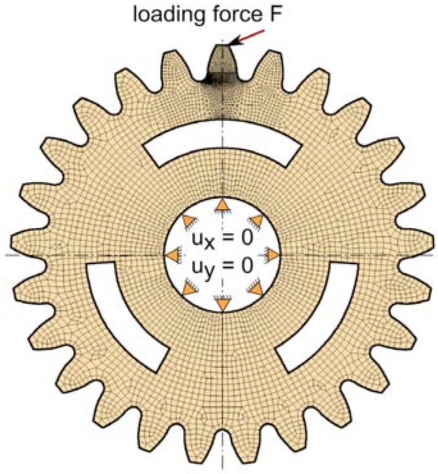

Fig. 1: Finite element model of the gear studied with boundary conditions and applied load

LEFM approach used in (Lewicki & Ballarini, 1997) was not able to predict correctly the crack path for a gear of this kind. In the present work two-parameter linear elastic fracture mechanics is used for simulation of the crack propagation in the same gear as in paper (Lewicki & Ballarini, 1997). The two-parameter LEFM estimated well the type of the gear failure in the case studied in comparison to classical LEFM where the prediction led to a non-conservative estimation of the crack path.

To support the obtained conclusions, a fracture mechanics analysis of a special specimen with high level of constraint (modified CT specimen) was used to prove experimentally numerical predictions for the crack path calculated on the basis of classical and modified MTS criterion (two-parameter crack description). The accuracy of the numerical estimations was dependent more on the crack increment size than on the criteria used. Smaller crack increment leads to better accuracy of prediction for both. It can be concluded that the use of two-parameter description for numerical predictions of crack path approximates experimental results more sufficiently with less crack increments than the crack path predicted on the base of stress intensity factor only.

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