The method of elastic-plastic thermo-mechanical fatigue simulation and its implementation to hot forging dies life time prediction

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Durability of dies is one of the most important factors affecting the cost of hot forging products. The main reasons of premature die failure are abrasive wear, fatigue and plastic deformation. In this study focus is on a fatigue mechanism of dies failure that in hot forging is a thermomechanical process.

Thermal fatigue failure or thermomechanical fatigue is the result of cyclical heating and cooling of the surface of the die at a temperature of 30-40% of the absolute melting point of the dies material. In addition these thermal stresses are superimposed by the stresses occurring in the body due to applied cyclic external load from forged part.

Reduced number of cycles to failure (typically less than 10,000), as well as occurrence of cracks on the curved areas of the die show that actually a low cycle fatigue (LCF) takes place in hot forging. Another distinguishing feature is pulsating character of die loading on the contrary to symmetric cycles traditionally considered in the technical literature. The die stresses at each cycle vary from zero to a maximum and back to zero so the load of opposite sign does not occur. Moreover the peak loads can be considered as constant. Within such circumstances only the first cycle is to be with plastic deformation while all remaining cycles would have to remain within the elastic limit due to metal hardening phenomenon. This phenomenon is known as elastic shakedown in continuum mechanics. Meanwhile this conclusion is valid only if we assume isotropic hardening. Plastic deformations can be accumulated under kinematic or mixed hardening conditions.

Moreover it has been shown that cyclic softening effect may also be observed in the thermomechanical fatigue. It depends on the temperature and frequency. The effect of cyclic softening reduces yield stress and causes additional plastic deformations, which results into the phenomenon of plastic shakedown. There are some evidences that softening of die steels reaches its maximum at the beginning and then softening intensity decreases thus this effect is also to be taken into account.

The proposed method is based on the following assumptions:

1. The process of dies cyclic loading is considered as a combination of two stages, i.e. firstly, the elastic-plastic loading accompanied by the accumulation of plastic deformations in areas of stress concentration, and then at the second stage a purely elastic loading.
2. The accumulation of damages caused by plastic and elastic deformations is considered in accordance with the strain-kinetic failure criterion.
3. The plastic deformation damage is based on damage accumulation theory.
4. Damage caused by the elastic deformation is determined by the elastic component of the equation of Manson-Coffin-Basquin.
5. The maximum stresses in the locations of stress concentration are constant and determined by the load at the first cycle.
6. The process of plastic deformation accumulation is determined by the mechanism of thermo cyclic softening.
7. The material is linear hardening. Softening reduces the yield stress. Hardening modulus remains constant.
8. The value of the yield stress reduction is proportional to the plastic deformation in a cycle.

The model has been realized as a user's subroutine written in LUA language for embedded applications and was used in post-processor mode in QForm 8 metal forming simulation software. Its implementation has been illustrated by an example of calculating of the number of cycles till the die failure when forging of a gear in hot state (Fig. 1).

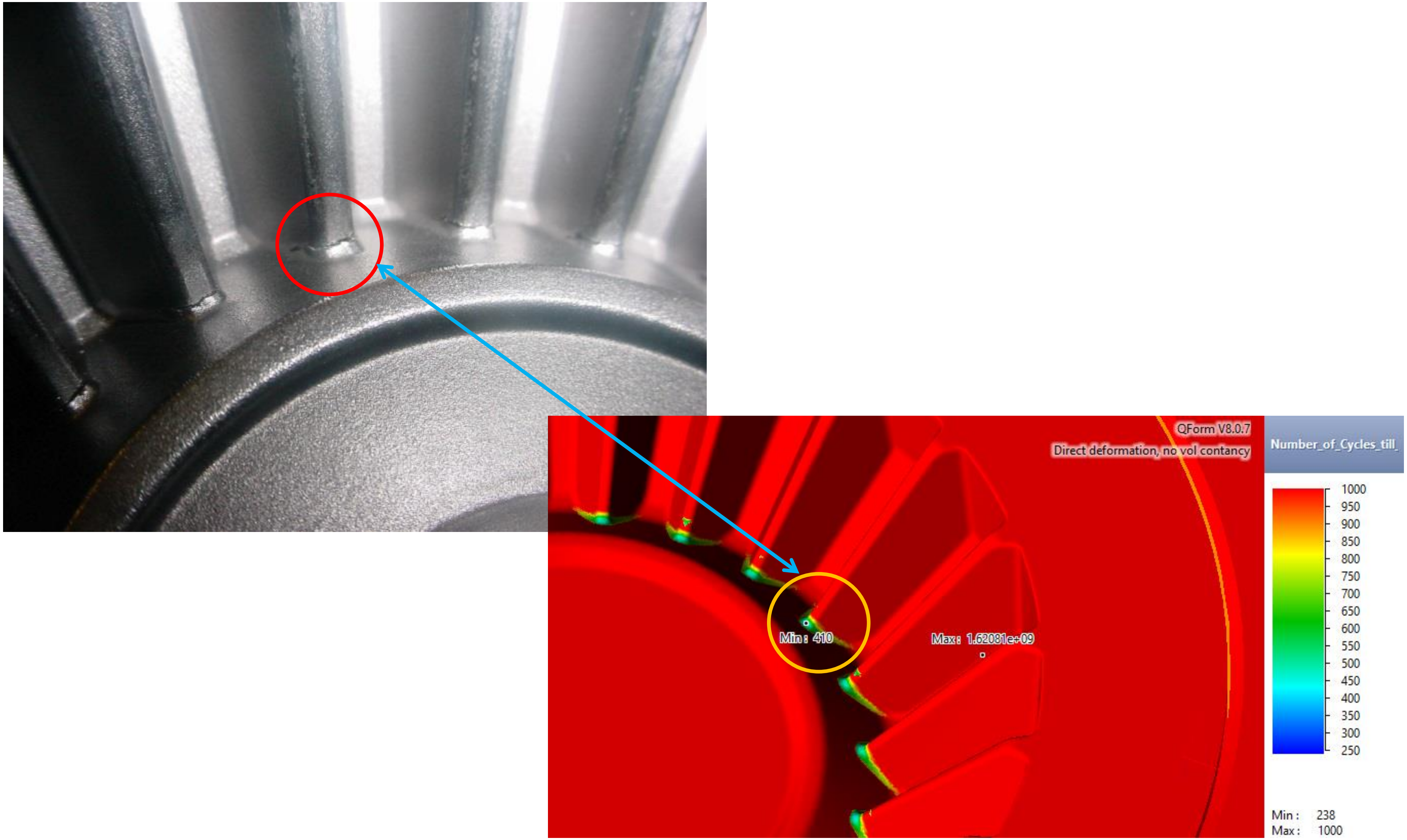

Fig 1. The crack in the die appeared in 400-500 cycles and its location predicted using proposed model with indication of the number of cycles till failure as 410.