Using the simulation to reduce the risk of fatigue cracks in forging dies

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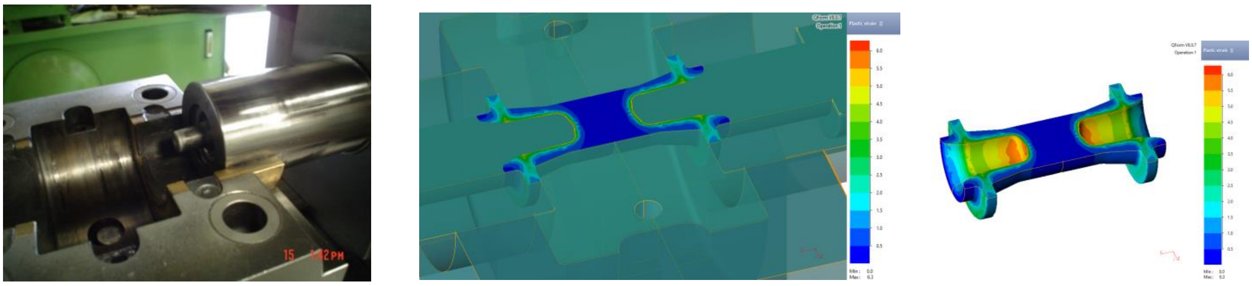
It has been estimated that the cost of the tools may be as much as 8–15% of the total production costs in closed die forging so it is clear that extending the life of tools may significantly reduce overall production expenses (Fig. 1). The main causes of premature die failure are brittle cracks, plastic deformation, abrasive die wear and fatigue. Brittle cracks and plastic deformation can be reduced by using high quality tool steels as well as through careful load monitoring and the use of simulation. Minimizing abrasive wear and fatigue cracks are another way of reducing premature die failure and here we present a new approach to predicting and minimizing the effect of fatigue in forging dies.



a. b. c.

Fig. 1. The photo of the tooling set arrangement (a), the forged part inside the tools (b) and the strain distribution in a forged part obtained in simulation by QForm 8 program.

Thermal fatigue failure or thermomechanical fatigue is the result of cyclic 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 that occur in the body due to applied cyclic external load from forged part.

Low cycle fatigue (LCF) in a hot forging die can be defined by a reduced number of cycles to failure (typically less than 10,000), as well as occurrence of cracks on the curved areas of the die. Another distinguishing feature is the pulsating character of die loading as opposed to the symmetric cycles traditionally considered in 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. This phenomenon is known as an elastic shakedown in continuum mechanics but actually it has no place in real hot forging dies.

In reality due to high temperature on the surface of the die we observe the so called “cyclic softening effect” in the thermomechanical fatigue. It depends on the temperature and cycles frequency. The effect of cyclic softening reduces yield stress and causes additional plastic deformations which results in the phenomenon of plastic shakedown. There is some evidence 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. Taking these mechanisms of cracking into consideration we have proposed a new complex model of die fatigue failure that is observed in hot forging [1]:

The proposed method is based on the following assumptions:

1. The process of cyclic die 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 are summarized 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 and 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 as schematically shown in Fig.2 where the plastic deformation in every cycle is gradually reducing.
8. The value of the yield stress reduction is proportional to the plastic deformation in a cycle.

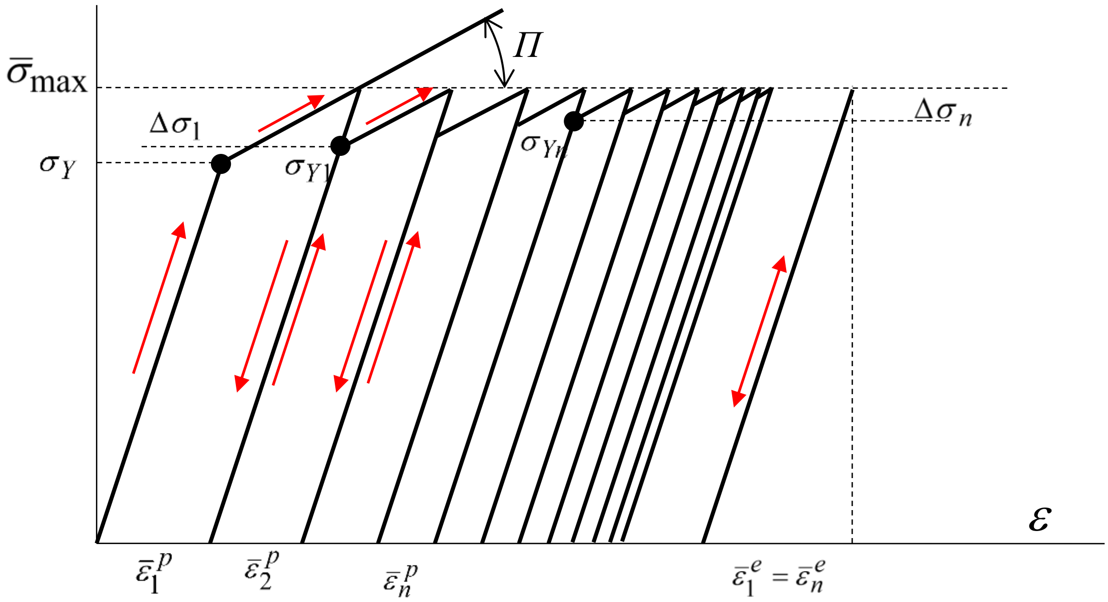


Fig. 2. The schematic stress-strain diagram of loading-unloading cycles in a forged die when the material reaches yield stress σ_Y and where Π is the module plastic hardening.

This 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 due to low cycle fatigue when forging a double flange part (Fig. 1). The die stress distribution in the assembled die that corresponds to the highest load in a forging cycle is shown on Fig.3. We can see that there are definite areas where the effective stress reaches the yield limit.

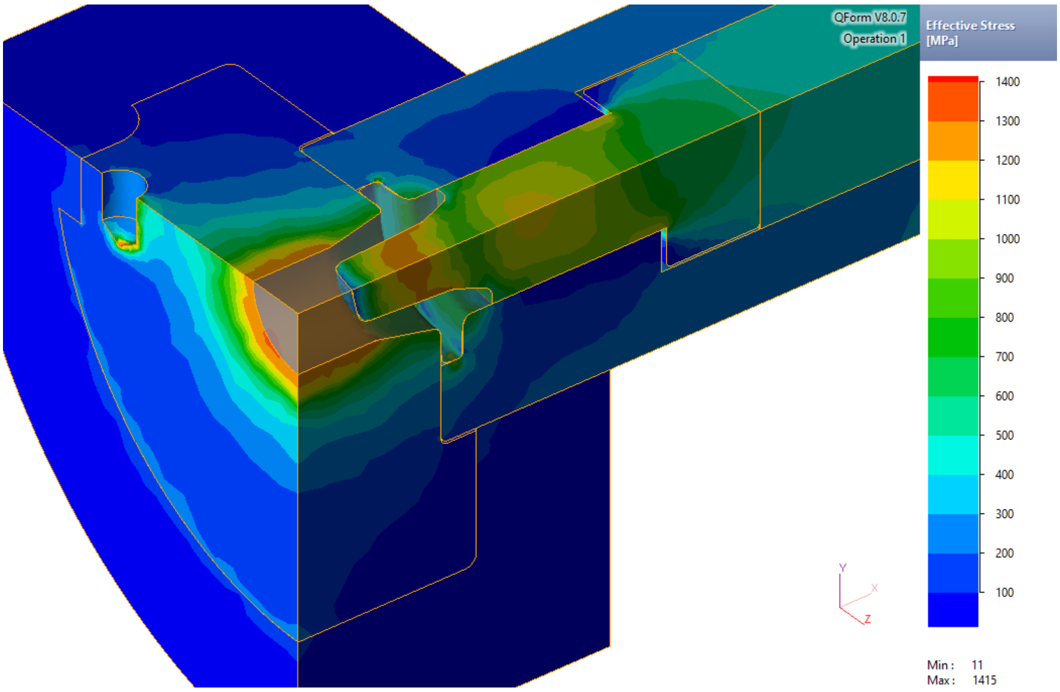
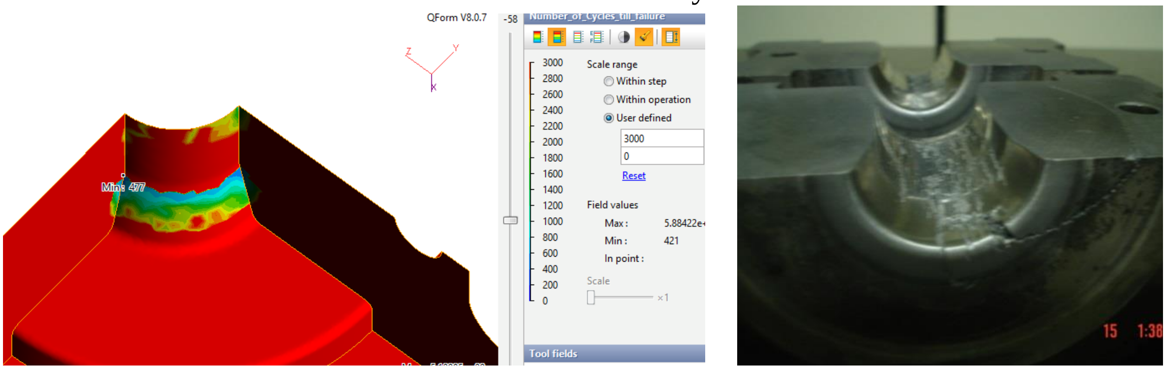


Fig. 3 Effective (equivalent) stress distribution in the assembled die during the forging in a crosscut view.

By implementing the developed model we get an estimate of the number of cycles until the die fractures due to thermo-mechanical low cycle fatigue. The simulation has shown that it is about 477 cycles and that corresponds very well to practical observations of 400-500 forged parts until die failure. As we can see from Fig. 4 the predicted location of the crack at the spread area of the die insert is the same in the simulation as it is in reality.



a. b.

Fig 4. The crack location predicted using proposed model and indication of the number of cycles till failure as 477 (a) and the actual crack in the die appeared in 400-500 cycles (b).

Having a numerical model to predict fatigue fracture allows us to test and modify die designs through simulation before making the actual production dies. In our opinion, this proposed die life prediction model is practical and can be very effective for developing forging die designs.

Further details regarding the implementation of developed die life prediction model can be obtained from the author. Please, send your enquiries to micas@qform3d.co.uk

References:

1. Vlasov A.V., Stebunov S.A, Biba N.V., Fatigue failure of the forging tool simulation in QForm.- Proceeding XII Conference “Blacksmith-2015”, Ryazan, Russia, 22-25 September 2015, pp.443-454 – in Russian