Numerical analysis of lateral forces in a die for turbine blade forging

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There are various processes for production of turbine blades. Hot forging has been the most common, especially for automotive, marine and industrial turbochargers or aero-engines turbines. Advanced computer modelling has become a powerful tool for process planning and tool design in order to get near-net shape blades in hot forging. This paper presents the effect of die cavity positioning on metal flow and distribution of lateral forces in the die during aero-engine turbine blade hot forging. An influence of torsional moment on dies offsetting introduced by these lateral forces has also been pointed out.

Keywords: turbine blade, forging, lateral forces, torsional moment, computer modelling

1. Introduction

Analysis of lateral forces in the dies for turbine blade forging has been the main aim of this paper. Small lot production is rather typical for turbine blades what could be regarded as not suitable for hot forging because of high cost of tools. However, forgings are characterized by very advantageous distribution of grains and relatively high strength what has usually been regarded as more important than relatively high cost per piece. There is a growing demand to produce turbine blades in near net-shape geometry. This demand requires special design of dies and special control of forging process. Numerical simulation of blade forging process is difficult due to three-dimensional twisted shape of the blade, non-steady state contact between the die surface and the workpiece, and thermo-mechanical loads. Hence numerous works have been done to develop 3D FEM simulation in order to get deformed configurations on the forging stages and to find the optimized die and preform shapes [1, 2, 7]. Also, minimization of the forging errors with the inclusion of press and die deflections has also been performed [3, 4].

One of the ways to minimize tolerances and allowances is limitation of lateral forces which are present in the dies during forging process. They would cause offsetting of upper and lower dies what results in unacceptable geometrical errors of the forgings. Lateral forces depend mainly on arrangement of die cavity in the die block and positioning of the parting surface [5, 6]. As for industrial practice, finding an optimized die design with low
lateral forces usually requires some number of tool sets to be tested. This way is very expensive. On the other hand, computer modelling provides a possibility to carry out virtual test with different sets of tools what considerably decreases cost of trials [8].

As for this paper, computer modelling of turbine blade forging has been carried out by means of SuperForge software based on finite volume method FVM. Analysis of numerical results has provided data on die loading including lateral forces as well as on an appropriate filling of die cavity in order to limit material folding and fracture. This opens the possibility to counteract the lateral thrust by a proper die design and machining counterlocks into the parting surfaces of the dies.

2. Turbine blade forging

Square bar made of alloyed structural steel PN 18H2N4WA (0.18% C, 1.4% Cr, 4.2% Ni, 1% W), equivalent to DIN 1.5919, has been used to prepare a preform for forging of turbine blade in industrial process. Preform was heated to 1150 °C. Slight upsetting of the preform was used to remove scale from the surface. Next, the preform was forged just in one die cavity. After trimming the flesh, the forging was subjected to drop sizing. Figure 1 presents photos of industrial dies and the final forging.

![Industrial dies (a) and the final forging – turbine blade (b)](image)

Fig. 1. Industrial dies (a) and the final forging – turbine blade (b)

3. Computer modelling

There were taken into account two cases in computer modelling of turbine blade forging. Case I was related directly with the industrial forging. As for case II, two forgings were made simultaneously at the same stroke of hammer. There were two cavities in one die block. The cavities were positioned in opposite directions as regarding the shape of turbine blade, see Figure 2. Computer models of the dies were prepared by using Unigraphics files on detailed die design.
Dies were preheated before forging to 300 °C. Friction conditions between lubricated die surface and deformed material were described by friction factor \( m = 0.2 \). Forging parameters were defined according to crank forging press LKM1600. Thermo-mechanical numerical analysis took into account temperature dependent changes of material properties during forging. Tools were modelled as elastic bodies and heat transfer was taken into account. A shape of forging obtained by means of computer modelling is shown in Figure 3. This shape corresponded very well with the shape of industrial forging and was the same for cases I and II.

\[ \text{Fig. 2. Computer models of upper and lower dies for turbine blade forging; case I – industrial dies (a), case II – dies with doubled cavities (b)} \]

\[ \text{Fig. 3. Turbine blade with a flesh (computer modelling)} \]

### 4. Numerical results

Figures 4 and 5 present changes in \( X \) and \( Y \) lateral forces acting on die cavity for case I and case II. The direction of \( x \) and \( y \) axis are shown in Figure 2. Forces had opposite directions for upper and lower dies, Figure 4. Generally lateral force \( X \) is much
bigger than lateral force $Y$. Maximum values of lateral forces $X$ were equal to about 5% of forging force $Z$. These relatively high values would cause offsetting of the upper and lower dies.

Fig. 4. Changes in $X$ and $Y$ lateral forces for case I (industrial die)

Fig. 5. Changes in $X$ and $Y$ lateral forces for case II (dies with doubled cavities)

To minimize an influence of lateral forces on accuracy of forgings, a die design with doubled cavities was proposed. The arrangement of the cavities in opposite directions was supposed to counterbalance $X$ lateral forces for each die cavity. It has really been observed – summary of the forces was a few times lower than the force in case I. Origins and values of lateral forces vectors are shown in Figure 6. Though the directions of $X$ lateral forces are opposite for each cavity and the summary of the lateral forces is minimized, some torsional moment and tensile stresses in the upper die appeared. Torsional moment should be counterbalanced by special counterlocks.
Tensile stresses are dangerous for hard tool material and would increase a sensitivity to crack initiation in the die.

5. Conclusions

1. Numerical modelling of turbine blade forging revealed considerably high lateral forces in die cavities which would cause offsetting of the lower and upper dies leading to geometrical inaccuracies of the forgings.

2. Doubling die cavities for the same stroke resulted in a considerable decrease in values of \( X \) lateral forces. However, some new undesirable phenomena appeared – torsional moment between upper and lower dies and tensile stresses in the upper die.

3. An analysis of causes of upper and lower dies offsetting should take into account not only lateral forces but torsional moments as well. Then appropriate counterlocks could be carefully designed for the near net-shape forging dies.

References


Analiza numeryczna sił bocznych w matrycy do kucia łopatki turbiny

Wiele jest sposobów produkcji łopatek turbin, a kucie na gorąco zaliczane jest do klasycznych. Poprzez kucie produkuje się łopatki do sprężarek różnych silników samochodowych, okrętowych, przemysłowych itd. Zaawansowane modelowanie komputerowe stało się poważnym narzędziem w opracowaniu procesów technologicznych i konstrukcji narzędzi do kucia łopatek prawie na gotowo. W referacie przedstawiono wpływ umiejscowienia wykrojów w matrycy na płynięciu metalu i zmiany sił bocznych działających na wykrój matrycy w trakcie procesu kucia łopatki. Wskazano również, że powstaje moment skręcający matryce dolne i górne, prowadzący do błędów wynikających z przesadzenia matryc.