Status quo of stress simulation for hot and warm work piece temperatures in forging

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Abstract

Hot forging dies are subjected to high mechanical, thermal and chemical loads. These loads can lead to die failure and therefore are one of the main cost factors in forging industry. The billet temperature is the process parameter mainly influencing the loads in forging processes. In warm forging the billet temperature is much lower than in hot forging. Warm forging becomes more and more important due to the advantages against hot and cold forging. This paper describes an analysis of FE-simulations of the change in loads on forging dies and the effect on the die life time by changing from hot to warm forging processes. Furthermore a method is presented which enables a calculation of thermal stresses in forging processes.

1 Introduction

Forging is a manufacturing process enabling a near net shape production of complex high duty parts [1]. Hot forging of steel is performed at temperatures between 900 and 1250 °C to enable extensive plastic deformation. Due to the high temperatures the forces needed for hot forging are low compared to cold forging. One main disadvantage of hot forging is a low surface quality of the forgings.

Increasing quality requirements for forged parts lead to a wide use of enhanced forging processes like warm forging instead of hot forging. Warm forging takes place at temperatures between 600 and 900 °C and combines some advantages from hot and cold forging. Warm forged parts have a good surface quality and smaller tolerances than hot forged parts while at the same time the required forming forces are much lower than in cold forging [2].

These advantages have the potential to increase the profitability of forging processes. A main obstacle preventing a wider use of warm forging is the die life time. At current state it is postulated that in warm forging the die life time is much shorter than in hot forging. However, the processes leading to die failure in warm forging have not been investigated extensively yet.

2 Die Life Time

One major factor of manufacturing costs in forging are the die costs, which are mainly determined by the die life time. In forging the die life time is limited by severe failure mechanisms occurring from a variety of mechanical, chemical and thermal loads [3, 4, 5]. The most common die failure mechanisms are cracking, thermal and mechanical micro cracks, plastic deformation and abrasion wear. The influence/impact of loads on failure mechanisms is shown in the following table.

Table 1: Influence of loads on damages limiting die life time of forging dies

	Cracking	Micro Cracks	Plastic Deformation	Abrasion wear
Mechanical Loads	●	◖	●	●
Thermal Loads	○	●	◖	Unknown
Chemical Loads	unknown	Unknown	Unknown	Unknown

● High Influence ◖ semi Influence ○ no Influence

The influence of mechanical loads on die failure mechanisms is well known. Cracking occurs when the mechanical stresses in the die exceed the tensile stress of the die material. Thermal loads have no significant effect on cracking. The influence of chemical loads is unknown. Micro cracks on the other hand occur from alternating tensile and compressive stresses on the die surface. The alternating stresses come up due to temperature exchange and forming forces. Internal processes in the die material can lead to softening of the die material. Therefore chemical loads also have an influence on the die life time. Plastic deformation occurs when the stresses in the die exceed the yield strength of the die. Therefore the mechanical loads have a high influence on the failure mechanism plastic deformation. The thermal loads have an influence on this failure mechanism due to the lowering of the yield strength on higher temperatures. The abrasion wear is mainly determined by the contact pressure and velocity between billet and die (mechanical loads) which nowadays is calculated by the archard equation [6]. The archard equation has been modified in several works for example by considering not only the adhesive abrasive wear but as well wear mechanisms such as abrasive wear and oxidation wear [7]. The exact influence of chemical loads is unknown yet.

The process parameters mainly influencing the loads in forging processes are:

- The geometry of billet and dies
- The material of billet and dies
- Lubricants in use
- Movement of die
- Temperature of billet and dies

To identify the change of loads between hot and warm forging the loads in warm forging in comparison to hot forging can be easily compared by varying the billet temperature for an otherwise unchanged process.

3 Simulation Modell

Two different simulation schemes have been used to compare the mechanical and the thermal loads. Chemical loads will not be covered in this paper. Calculating the mechanical loads has been performed with Forge3 version 2012 while for calculating the thermal loads Ansys mechanical has been used. The forging dies have been modelled as deformable dies. For the dies and the billet tetrahedral elements were used with elasto-plastic material behaviour. The geometry is shown in Figure 1.

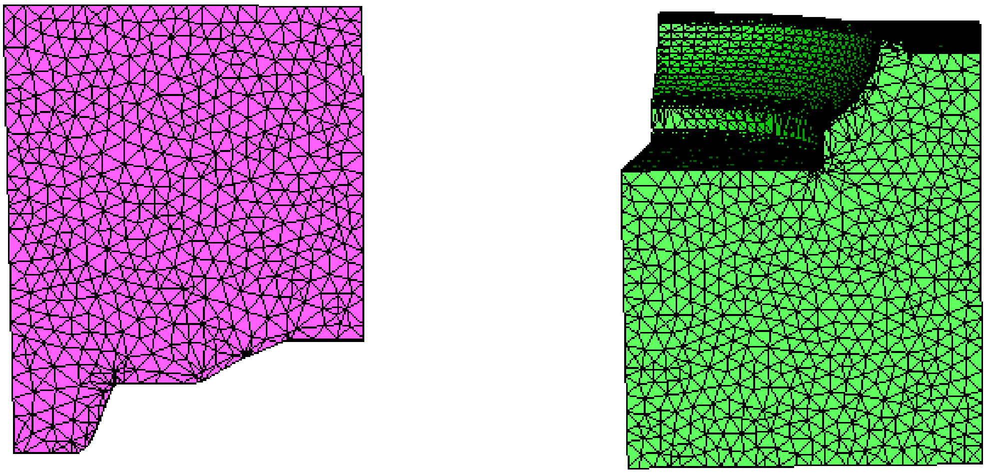

Figure 1: Upper Die (left) and lower die (right)

For the analysis of loads on forging dies in hot and warm forging the billet temperature has been varied between 600 and 1200 °C. The work piece temperature covers hot and warm forging temperatures and influences the loads due to the temperature dependent flow stress of the billet material. The chosen die temperatures represent distinctive die temperatures in industrial forging processes. Die failure due to thermal loads occurs because of thermal residual stresses. During the batch production of forged parts temperature fluctuations on the die surface occur. Areas with long contact time betw een billet and die are heating up faster than areas with shorter contact time. The surface of the dies can reach up to 700 °C directly after the forging process [8, 9] (see Figure 2). During the time between two forging strokes this leads to thermal stresses.

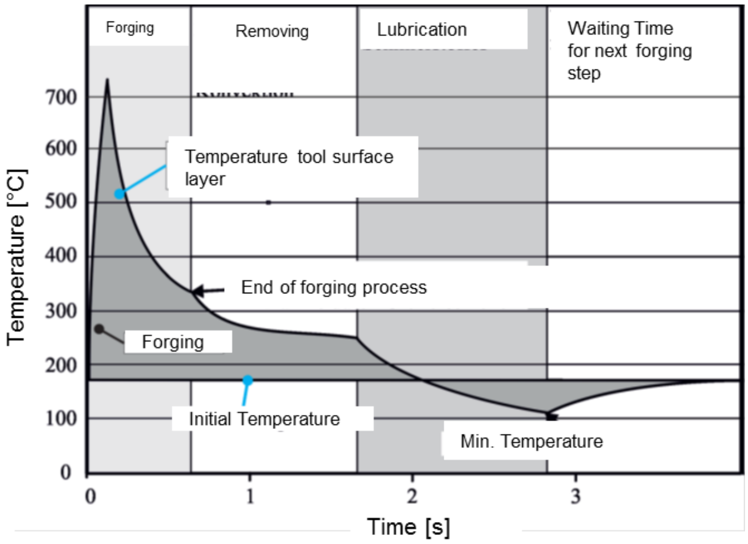

Figure 2: Temperature development of die surface [09]

Since the thermal cracking of hot forging dies does not appear after the first forging stroke it is necessary to calculate the thermal stresses with the temperature distribution after a certain number of forging strokes [10]. To do so, the simulation scheme shown in Figure 3 was used.

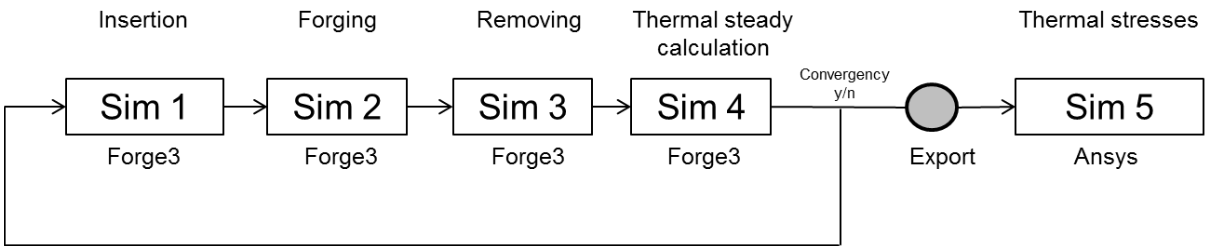

Figure 3: Simulation chain used to determine thermal residual stresses

The first step is to build up a simulation chain containing every process step (insertion, forging, removing). For the insertion of the billet a waiting of 1s in the die was assumed. Afterwards the forging stroke itself is calculated. The billet temperature and stroke velocity are the most important parameters for this simulation. After the forming process the billet has to be removed from the die. It was assumed that this process would take 1s. These simulations are the input parameters for the thermal steady calculation in Forge3 (see Figure 3). The forging process cycle is repeated as long as a temperature convergency from 2.5 °C is reached within the thermal steady state calculation. Afterwards the result of the thermal steady state calculation was used in a thermal stresses simulation. To enable a calculation of thermal residual stresses in Ansys the results from the thermal steady state calculation have been exported from Forge3 and after a conversion to a suitable format imported in Ansys. In Ansys a transient analysis has been performed with the temperature distribution as initial load. According to [10] the mirror planes have been fixed as boundary conditions. Furthermore one point in the direction of the cutting planes has been fixed in space.

4 Analysis of mechanical and thermal loads

The analysis of mechanical loads of forging dies revealed a decreasing mechanical load when increasing the billet temperature (see figure 4).

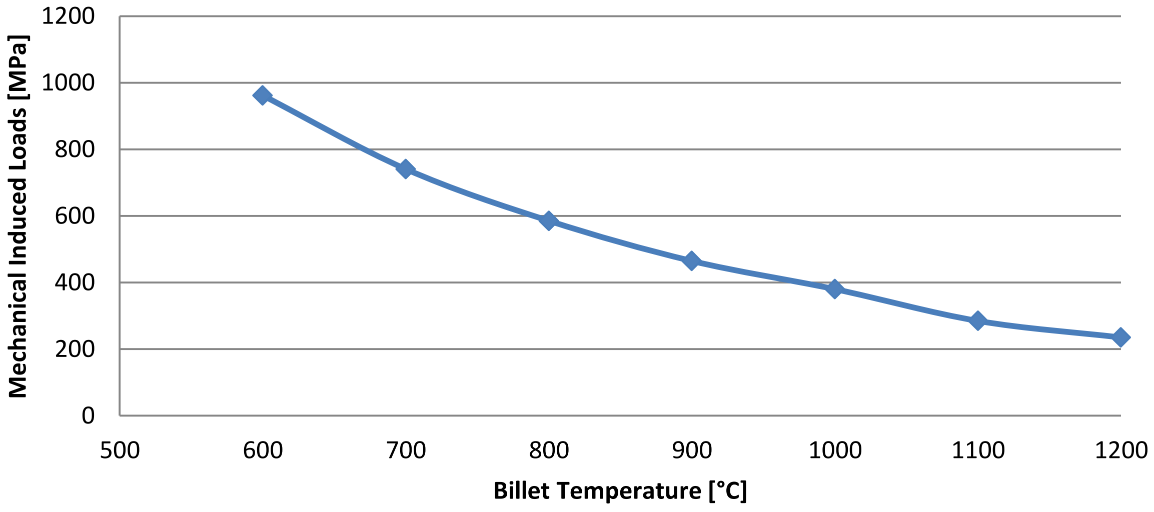

Figure 4: Mechanical Loads in dependency of billet temperature

An increasing billet temperature leads to an increasing heat input into the dies. This leads to higher thermal stresses, which were analyzed afterwards. The thermal stresses were analyzed based on the assumption of a starting die temperature of 100 °C. The results of the thermal steady state calculation are shown in Figure 5. These results are the basis for the calculation of the thermal stresses. Increasing billet temperature from 600 °C to 1200 °C elevates the maximum die temperature from 442 °C to 740 °C. Only the parts of the die which are in direct contact with the billet during the forging process are heated up.

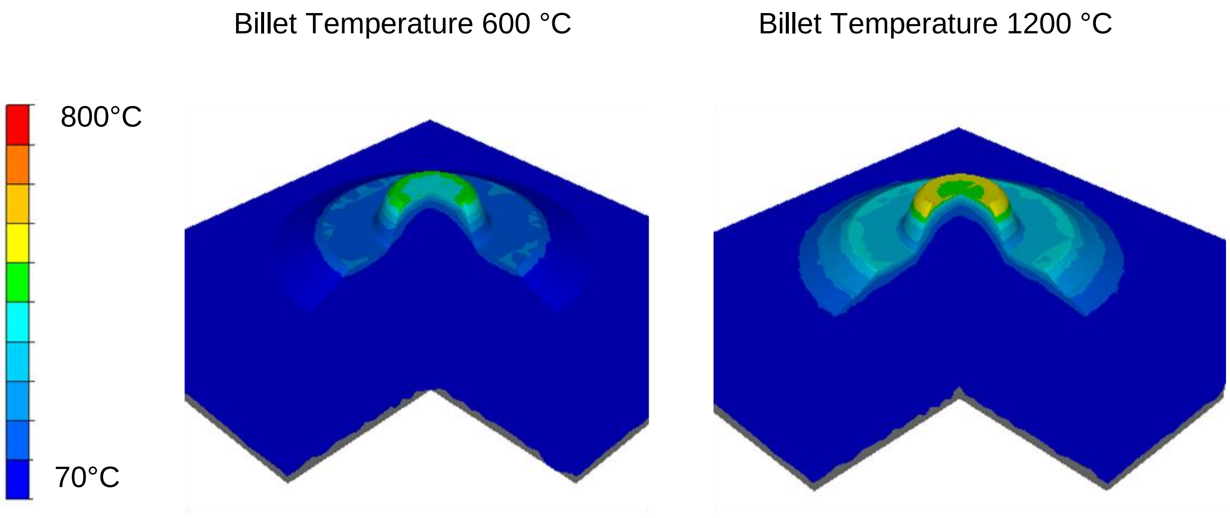

Figure 5: Temperature distribution field of the forging dies depending from the billet temperature

The distribution of the thermal stresses is equally distributed on the surface of the die. Differences can be obtained in the maxima of the thermal stresses. The maximum thermal stresses are the critical points for die failure due to thermal loads.

Therefore Figure 6 shows the maximum thermal stresses in the upper die in dependency of the billet temperature. It can be seen that an increasing billet temperature from 600 to 1200 °C leads to an increase of thermal stresses of approximately 300 MPa. This corresponds to an increase of thermal loads of about 40 %. The determined stresses due to thermal loads have the potential to damage the die heavily.

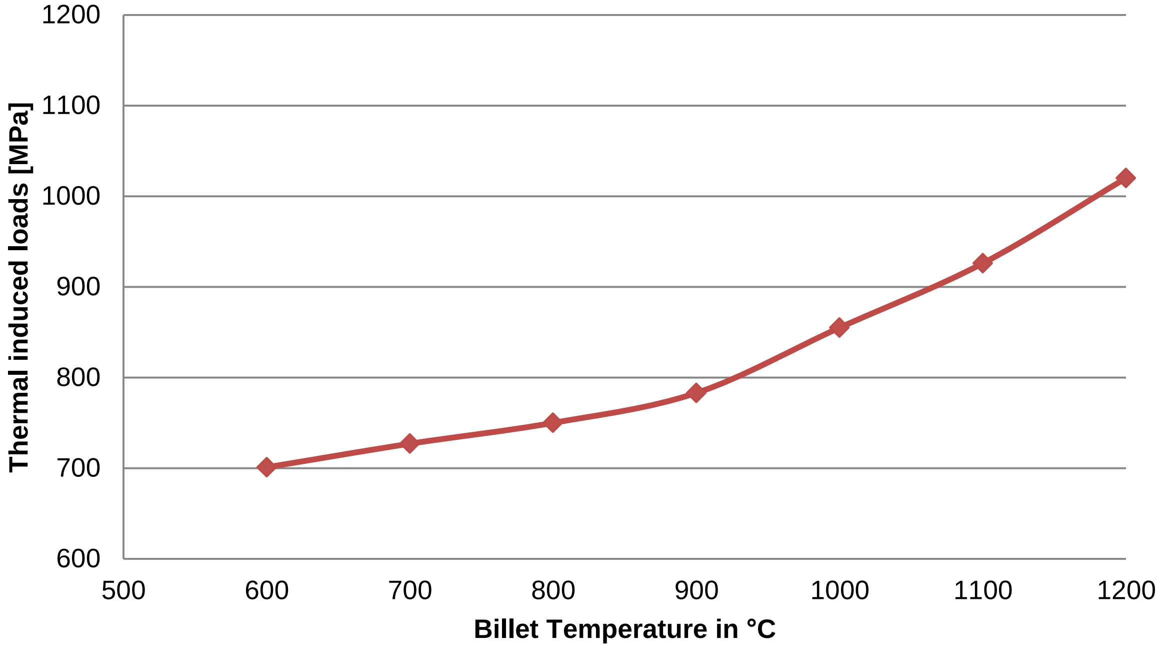

Figure 6: Course of the thermal stresses in dependency from the billet temperature

Plotting the calculated thermal loads and the mechanical loads of the upper die in one diagram in dependency of the billet temperature it can be shown that the course of the thermal and mechanical loads is contradictory (see Figure 7). The thermal stresses are increasing with increased billet temperature. At about 900 °C the gradient of the curve is increasing even more. The curve is nonlinear. In contrast to the thermal loads the calculated mechanical loads are decreasing with increasing billet temperature. Here it is also a non-linear course.

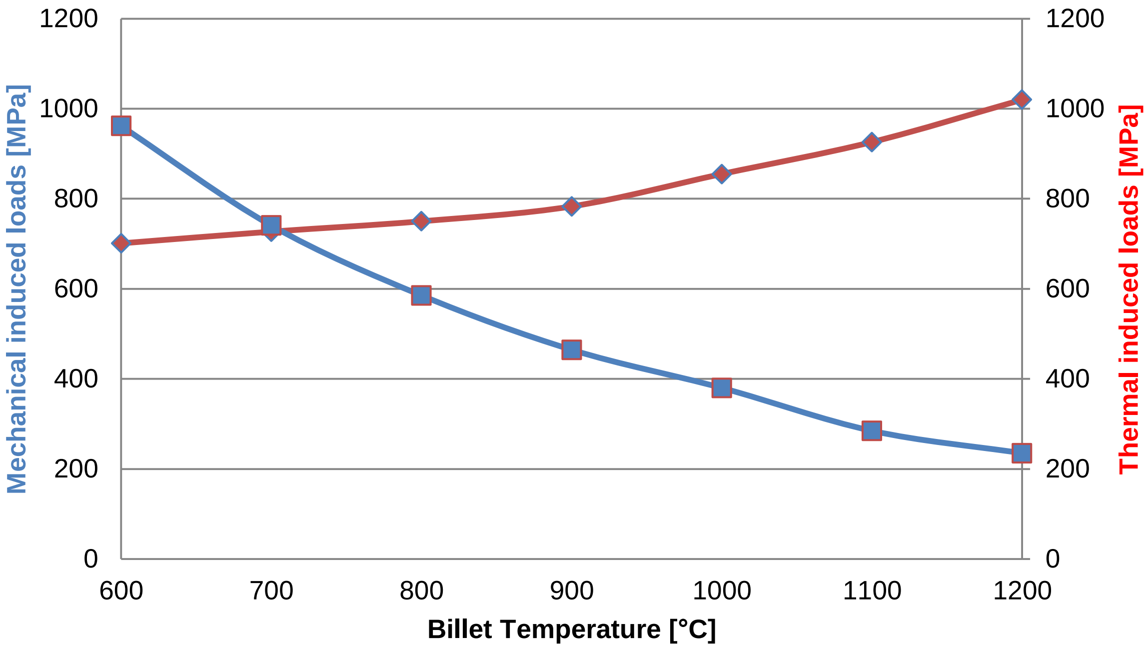

Figure 7: Course of the thermal and mechanical stresses in dependency of the billet temperature

The results of the investigations show the contradictory influence of the billet temperature on the mechanical and thermal loads. The change in loads affects the die life. The risk for cracks is increasing with decreasing billet temperature due to the increasing mechanical loads on the dies. The change in thermal loads does not affect the risk of cracks. For micro cracks a clear statement is not possible. The lower thermal loads in warm forging lead to a decreasing risk of micro cracks whereas the higher mechanical loads lead to an increasing risk. The influence of mechanical and thermal loads on the risk of micro cracks has to be evaluated in experimental tests. The same applies for the risk of plastic deformation, the increasing mechanical loads may lead to a loss of die life time due to plastic deformation but the lower thermal loads decrease the risk of plastic formation. The exact impact on the risk of failure due to plastic deformation has to be evaluated in experimental tests. Abrasion wear occurs due to high contact pressure in combination with material movement between billet and die. The increasing mechanical loads in warm forging increase the mechanical loads and therefore the risk of die failure due to abrasion wear is higher than in hot forging. On the other hand the thermal loads lead to crack initiation on the die surface in hot forging. Whether these cracks have to be obtained in calculating the abrasive wear will be examined in future investigations.

5 Summary and Outlook

The results of the investigation have shown that the billet temperature has a contradictory influence on the mechanical and thermal loads. The results show that it is necessary to take the thermal loads into account when looking for the best process temperatures regarding the die life time. For this purpose the simulation results for the mechanical loads were compared with the calculated thermal stresses of an upper die based on the thermal steady state calculation of Forge3. The thermal steady state calculation was based on a process chain consisting of a waiting time of the billet in the die, the forging process and a removing step. The thermal stresses have been calculated with a transient mechanical analysis in Ansys with the calculated temperature distribution as initial loads. In further studies the calculated thermal stresses have to be validated in experimental tests. Furthermore the process setup of the experimental tests can help to gain better knowledge about the boundary conditions in forging processes to calculate the influence of thermal loads on die life time.

Acknowledgments

The ZIM-Project (KU2098704US3) was funded by the AIF under the program "Zentrales Innovationsprogramm Mittelstand" by the German Federal Ministry for Economic Affairs and Energy in cooperation with Dr.Bergfeld GmbH following a decision of the German Bundestag

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