Induction reheating of preforms and flash reduced forging of crankshafts

Author(s) Name(s) and Affiliations(s)
M. Stonis, J. Langner, T. Blohm, IPH – Institut für Integrierte Produktion Hannover gGmbH, Hollerithallee 6, 30419 Hannover

Contact data
M. Stonis
IPH – Institut für Integrierte Produktion Hannover gGmbH, Hollerithallee 6, 30419 Hannover, +49511-27976336, +49511-27976888, stonis@iph-hannover.de

Summary
The more complicated a forging geometry is, the more flash is necessary to achieve a form filling and a part free of defects. Most small and medium sized enterprises (SME) forge many different parts in small and medium batch sizes and cannot afford the high effort to design more efficient forging processes. In the following paper the development of a resource efficient forging process chain for crankshafts is summarized.

The forging sequence consists of flashless preforming steps and a flash reduced final forging. The tools were designed to work on industrially used fast moving mechanical presses. The last of the four flashless preforming steps is a multidirectional forming of the crank webs and a pin offset. To keep the forging forces on a low level and enable a stable forging process, an induction reheating of the preform before multidirectional forging was designed. The crankshaft was successfully forged with a reduced flash ratio of less than 10%.

Key Words
forging, flash, induction heating, preform, crankshaft

Introduction
Forging parts are used if high dynamic loads are to be withstood. Typical parts are used in combustion engines or powertrains in automobiles or commercial vehicles. Examples for such parts are shafts, connecting rods or crankshafts. The most common forging process is closed die forging with flash [1]. Flash is a surplus of material, which is used to ensure the filling of the cavity in a forging process. The flash itself has to be clamped from the part and disposed afterwards. The flash ratios of forged parts vary between a few and more than 50%, depending on the geometric properties of the forged part [2]. As material costs represent a major cost factor in the forging industry, there is a high potential to save material and production costs by reduction of the flash ratio.

In this paper, the research for the design of a flash-reduced forging sequence including an induction reheating of the preforms for a geometrically complicated part – an industrial two-cylinder crankshaft – is described.

In the collaborative research centre (SFB 489) “Process chain of producing precision forged high duty parts” precision forging technologies to produce complicated long pieces completely flashless were developed [3]. Such a design of the forging sequence has been done exemplarily for a simplified two-cylinder crankshaft [4]. However, the development of this forging sequence was very time-consuming, since flash and folds had to be avoided at all stages, which is especially challenging in flashless forming processes for complicated geometries. Moreover, close tolerances of the billets and the dimensions of the tools were required, which made them disproportionately expensive. The result of this development was a set of forging tools able to produce a flashless crankshaft. But the forging force in the final forging tool was so high [5] that the tool wore off after a few strokes.

2. Simulation of forging sequences for an industrial two-cylinder crankshaft
Based on these results the process chain has been adapted to a serial production of a two-cylinder crankshaft within the project “Resource efficient forging of complicated high duty parts” (REForCh). Industrial SME partners and research centers from Germany, Romania, Spain and Turkey were working together in this project supported by funding under the Seventh Framework Programme of the European Union [6]. The idea for the new process chain is based on the aspects of very high die wear in final forging and the need for flash reduction. To combine these aspects, flashless preforming operations and a flash reduced conventional final forging was investigated. Feasible simulation parameters for the boundary conditions of the forging environment have been investigated [7]. With these parameters the forecast quality of the new flash reduced forging sequence design by Finite-Element simulations can be increased and the number of iteration loops for a die design can be decreased in the future.

The material of the two-cylinder crankshaft is the micro-alloyed steel 38MnVS6. The conventional
forging sequence consists of five forging steps (see upper part of Figure 1).

The sequence starts with an upsetting operation, in which the raw billet gets bulged. To achieve a better mass distribution, the next two preforming steps are used to obtain more material in the areas of the crank web and the crank pin. This 1st and 2nd preforming operation is performed in the same open die by turning the part by 90° along the longitudinal axis. With a 3rd preforming and a final forging step in closed dies the crankshaft is forged with about 54 % flash ratio.

3. Development of induction reheating

Before the multidirectional forming a reheating is performed to redistribute the temperature in the part homogeneously in order to lower the required press forces in the multidirectional forging stage. For the reheating process a new induction heater had to be developed (see Figure 2), which is able to reheat billets with a varying mass distribution along its longitudinal axis by different coil diameters [8]. This development was conducted by EMA-TEC GmbH with the help of Institute for Electrothermal Processes, Leibniz Universität Hannover.

The induction coils have been designed in two sections so that an easy and quick loading and unloading of the induction reheating system can be realized. Therefore different requirements had to be taken into account. On the one hand a contour fitting shape of the coils had to be realized to achieve the required temperature distribution in the preformed work piece without overheating it. On the other hand it was essential to design the reheating system reasonable in order to fit the requirements of a stable, reliable and economic production procedure.

4. Development of flash reduced forging tools

4.1. Preforming tools

The concept of the forging tools for 1st and 2nd flashless preforming are similar. To achieve a completely flashless preformed part the forging is realized in dies with completely enclosed gravures (see Figure 3). The lower die is built up of one monoblock part, like a conventional forging die, except that there is no flash gap. The upper die is built up of two elements, the die itself and the punch. The parts of the upper die are assembled at the upper plate, which is directly connected to the ram of the press. With the downward movement of the ram the upper die is getting into contact with the lower die first and is closing the die without performing any forming operation. With the ongoing movement of the stroke the punch is moving into the upper die and is performing the forming. To keep the dies closed while the relative movement of punch and upper die, springs with a guiding are assembled between the upper plate and the upper die.

Figure 3: CAD-model of preforming dies on table mounting plates

4.2. Multidirectional forming tool

Tools for a multidirectional forging of crankshafts have already been used in the SFB 489. But they were only used in laboratory conditions on a slow working hydraulic press [3]. Within this new development the tools had to be developed to be used in an industrial environment at fast moving mechanical presses. The upsetting is comparable to the conventional process. But the first two preforming operations are performed in completely closed dies. For a precise flashless forging process it was important, that the guiding for these processes work properly, thus big guiding mechanisms with a
diameter of 50 mm and more have been used. But the main aspect which is necessary to allow for a flash reduced crankshaft, is the design of the multidirectional working segments. In multidirectional forming the vertical movement of the press ram is redirected by wedges that distributes and deflects the force of the forging press to horizontal directions (Figure 4). For the multidirectional forging the preformed part is inserted in the tool. When the ram moves downwards, the upper and the lower die close, thus they enclose the work piece allowing the flashless preforming. A constant pressure is kept between the upper and the lower die by use of disc springs. As the ram moves further, the actual forming takes place. The die segments 1 and 5 are moving in opposite direction, against each other. This movement shortens the part for about 50 mm. It also decreases the thickness of the crank arms from 34 mm to 16 mm, by pressing the material at the dies 2 and 4. Additionally die segments 2 and 4 are driven in a horizontally orthogonal direction, realizing the offset of the journals of 20 mm. When the forming operation is finished, the multidirectional dies open and the individual dies are set back to their initial position by additional springs.

For the final forging the same die as in the conventional process has been used.

5. Forging trials
The forging trials of the conventional press were made in industrial conditions at the workshop of the Turkish forging company. For the first three preforming operations a mechanical forging press RAVNE 630 was used with a maximum available press force of 6300 kN. The 3rd closed die preforming (see Figure 1) and final forging were performed on a mechanical press MAXIPRESS 4000 with a maximum available press force of 50000 kN. The billet was heated up in an induction heater to 1250 °C. The dies were initially preheated up to 150 °C. Figure 5 shows the results of the conventional forging process.

After the simulative development of the new forging process was finished, the new process chain was set up in an industrial environment. The preforming tools were mounted on the mechanical press with a press force of 6300 kN. The multidirectional forming tool and the unchanged final forging tool were mounted on an eccentric press with a maximum force of 40000 kN. The initial heating of the billet, which has a weight of approximately 8.0 kg at a diameter of 60 mm and a length of 280 mm, was done by a standard induction heater to a temperature of 1250 °C. Afterwards the billet was inserted manually in the upsetting process and afterwards in the first and second preforming operation. Between forging operations, a lubricant was brushed manually onto the die. After the second preforming the induction reheating was done for about 35 seconds. After the induction reheating, the multidirectional forming was performed with the reheated billet which had again an almost homogenously distributed temperature of 1250 °C. Afterwards the final forging was done by use of the standard final forging die, which remained unchanged. All the operations were performed with the typical fast working speed of the forging presses. In Figure 6 the results of the process chain are shown.

The billet is upset first. Next, the closed die preforming operations are shown in which the mass allocations in the areas of the crank arms can be seen. In these operations, no flash occurs. The cavity is also not completely filled, which is a precaution in flashless forging operations. If the cavity should be completely filled, there is a high risk to overload the
die, which would result in crack of the die, which has
to be avoided at all costs. Afterwards, the preformed
crankshaft after the multidirectional forging is shown.
It is obvious that the total length of the crankshaft
gets reduced, as well as the thickness of the cranks
arms. Additionally, the offset of the journals can be
seen clearly. In the multidirectional forging, a small
amount of flash occurred. This happened due to the
manually handling of the parts and fluctuations in the
raw billet. This issue will be dealt with in the future by
adjustments of the preforming tools. The final
 crankshaft with the small amount of flash is the result
of the process chain.

6. Economic significance
The decreased weight of the billet (reduction of 3 kg)
enables a significant reduction in energy
consumption of the initial induction heating process.
Even with the reheating process between the third
preforming and the multidirectional forging, the
energy consumption of the new developed process is
decreased by about 24 %, which equals to 1.58 kWh
per part.
The results will help the industrial SME partners to
strengthen and enlarge the consisting international
partnership for research and marketing. Against the
background of low labor costs in big forging markets
like Asia and South America, European forging
companies with high labor costs can only compete
with latest forging technologies when they are forging
complicated forging geometries like crankshafts.
Consequently, the results will help them to secure the
European steel application market.

Conclusion
Rising prices for energy and steel force the
manufacturers of forgings to reduce their costs. This
is even more important for metal forming industry, in
which the material costs represent up to 50 % of the
total production costs. A reduction of the material
used is a viable approach in metal forming industry to
achieve this reduction. To reach this goal, an
innovative forging process chain with flashless
preforming operations and induction reheating for a
two cylinder crankshaft was developed. Forging trials
in an industrial environment were used to show the
feasibility of this new process chain in batch
production. The flash ratio of the conventional
process chain of 54 % was reduced to less than 10 %
by achieving a better mass distribution in the
preforming steps of the new forging sequence. In the
future, the developed concept will be improved
further, to allow for a stable serial process without
fluctuations. Furthermore, the concept of the process
chain will be designed to work in processes with four-
cylinder crankshafts. The multidirectional forging
technology will also be used to improve other forging
process, e.g. to allow for undercuts in forging
industry.

Abbreviations
CAD: Computer Aided Design
FE: Finite-Element
REForCh: Resource efficient forging of complicated
high duty parts
SFB: Sonderforschungsbereich (engl. collaborative
research centre)
SME: small and medium sized enterprises

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