Overcoming Limits - Die Forging of Cast Preforms

Grenzen überwinden - Gesenkschmieden gegossener Vorformen

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Abstract. Casting and forging are among the technologies with the highest material and energy requirements. Many efforts have been made to minimise the expenditures involved, but in most cases they have been limited to the individual application case. While the combination of casting and forming processes has been described and applied extensively for aluminium components, this approach has been far less investigated and advanced for steel components.

The latest developments in the software with a direct interface between casting and forming simulation enabled the creation of a continuous simulation from the casting to the finished forged part. The match between the simulation and the real component was verified on the basis of manufactured sample parts.

Currently ongoing investigations focus on the formation of the microstructure in the component. At the same time, the process chain casting - forging is being developed and evaluated for a further component.

This approach overcomes existing limits and opens up new possibilities for component design by linking simulations of casting and forging technologies into an integrated continuous process chain simulation.

Keywords: cast preforms, die forging, continuous process chain simulation

Abstract. Während für Aluminiumbauteile die Kombination von Ur- und Umformprozess bereits näher beschrieben und umgesetzt wurde, ist für Bauteile aus Stahl eine solche Vorgehensweise bisher kaum untersucht worden.

Die neusten Entwicklungen von Schnittstellen zwischen Gieß- und Schmiedesimulation im Softwarebereich erlauben den Aufbau einer durchgängigen Simulation vom Abguss bis zum Schmiedeteil, welche am Beispiel einer Schaltgabel nachvollzogen wurde. Die Verifizierung der Simulationsergebnisse erfolgte anhand eines real gefertigten Bauteiles.

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Die derzeit laufenden Untersuchungen konzentrieren sich auf die Abbildung der Mikrostruktur im Bauteil sowie den Aufbau der Prozesskette Gießen - Schmieden für ein weiteres Bauteil.

Keywords: Gussvorformen, Gesenkschmieden, kontinuierliche Prozessketten-simulationen

1 Motivation

In the search for new production concepts for complex steel components, the combination of casting and forging is once again moving into the focus of investigations. As early as the middle of the last century, the first attempts were made to combine the casting and forming processes [1]. These investigations and current ones have in common the goal for minimising the material use. A further positive aspect of combining these two processes is the possibility of eliminating defects such as cavities or pores resulting from the casting process with the subsequent forging operation. In most cases, these investigations are limited to the manufacture of semi-finished products [2-5]. In this product stage, casting defects are easier to eliminate, as it can generally be assumed that the forming directions are frequently changing.
Forged components made from cast preforms are generally not subject to these high levels of deformation but are optimally formed in one step and in one direction. Components produced in this way can combine the advantages of these two manufacturing processes, a high degree of flexibility with regard to geometry and areas of higher strength as a result of forming. Werke et al. [6, 7] describe the advantages of components produced by combined manufacturing. Applying the combination of casting and forging processes, components can be produced which can have different properties in different component areas and which overcome the boundaries between casting and forming.

2 Approach and Preliminary Studies

2.1 Demonstration Part

The feasibility of the process combination casting - forging was established as result of a benchmark for shift fork manufacturing routes in preliminary studies. Compared to a complete forging chain, there is a significant reduction in the number of process steps in such a combined process chain, which led to considerations as to how such a production process could be simulated and implemented.

Fig. 1. The demonstration part selected for simulation and manufacturing

Alternative manufacturing routes included, for instance, multiple forming stages coupled with bending and joining operations, or a complex joining process consisting of joining operations of separate component elements. The manufacture of a cast preform appeared to be a promising approach not only with regard to the utilisation of material but also with regard to the required component properties.

2.2 Software for Simulation

The initial task in developing the process chain for the component shown in Figure 1 was to develop the forging process and the corresponding forging dies for pre- and final forming. Using the FORGE® simulation software, a two-stage forging process was designed and optimized with regard to material flow and die filling. The result of the forging simulation is used as the base for the design of a casting model for sand casting (Fig. 2), which was developed in cooperation with the Gießerei-Institut, TU Freiberg. Figure 3 shows the derived model for the production of the casting moulds.

Fig. 2. Modified model for casting simulation (left: forging part, centre: the new injection system, right: cast model)

Fig. 3. Derived model for mould making (left: upper part, right: lower part)

No casting optimisation of the component was carried out, since the focus of the investigation lay on simulation and verification of the process combination.

The next challenge was the selection of a suitable material. Historically, not only the casting and forging technologies have developed independently of each other, but the materials available have also been adapted to the respective application and the associated technologies [8]. The 42CrMo4 steel grade data from the data base JMatPro was used for initial tests.

The quality of the components produced by a combination of casting and forging is considerably dependent on the casting process. New materials with improved casting properties for similar applications were developed at Gesenkschmiede Schneider GmbH Aalen [9, 10]. Due to the limited availability of suitable materials, it is necessary to determine the relevant material properties as a basis for a combined simulation of the two methods. Krüger et al. [11] describe a possible procedure for such a case.

MAGMASOFT® is the most commonly used simulation software for casting processes in Germany. For the purpose of this project, it is necessary to transfer the simulation results from the casting to the subsequent forming simulation. MAGMASOFT® transfer and interface possibilities are limited at the current state. Therefore, the THERCAST® system, which has so far not been well-known in Germany, was used, as this system allowed a direct transfer of results to the forming simulation software FORGE®. Both THERCAST® and FORGE® were provided by the French manufacturer Transvalor S.A. This company has developed an interface for data transfer without loss of model parameters.

3 Investigation Results

The main focus of the described work was the realisation of a combined simulation of a casting process and a forging process. Therefore, a detailed evaluation of the individual processes was not carried out at this point. A distinction was not made between solidification and gas porosity, as is the case with non-ferrous metals in particular. Moreover, the influence of friction conditions in the forging dies was not considered either. The term risk of porosity is used in the context of component defects resulting from the solidification of the casting material.

Studies are currently underway to evaluate and compare the microstructures in the component, taking into account the respective manufacturing process. Special attention is given to the estimation of the size up to which internal and external defects can be closed and whether this is a compaction or a fusion of the grain boundaries.

3.1 First Simulation - Casting

The casting simulation was set up as a sand casting process according to the conditions of actual implementation for real components with a casting time of 12 seconds at a casting temperature of 1650°C. To shorten the calculation time, the symmetrical model was modified and only a quarter was calculated. The cooling time in the sand mould was assumed to be 10 hours.

The blowholes and porosity of the model generated in this way were essentially evaluated according to three criteria:

- Porosity_Transfer_of Parameters_(Niyama)
- Porosity_Transfer_of Parameters_(Shrinkage) and
- Porosity_Transfer_of Parameters_(Yamanaka).

A distinction of several parameters is necessary to describe the porosity in order to consider both thermal (Niyama) and mechanical (Yamanaka) aspects. In addition, the parameters refer to either the elements (shrinkage) or the nodes (Niyama) of the mesh in the simulation model.

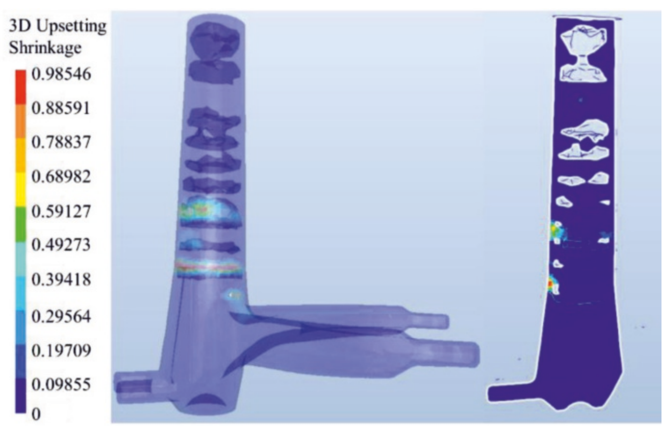

Fig. 4. Distribution of cavities on the casting (left: transparent, right: in cross-section)

The shrinkage parameter is used in the two process steps to represent internal defects. Due to the solidification of the liquid metal, shrinkage occurs in individual component areas. The expected distribution of blowholes is shown in Figure 4.

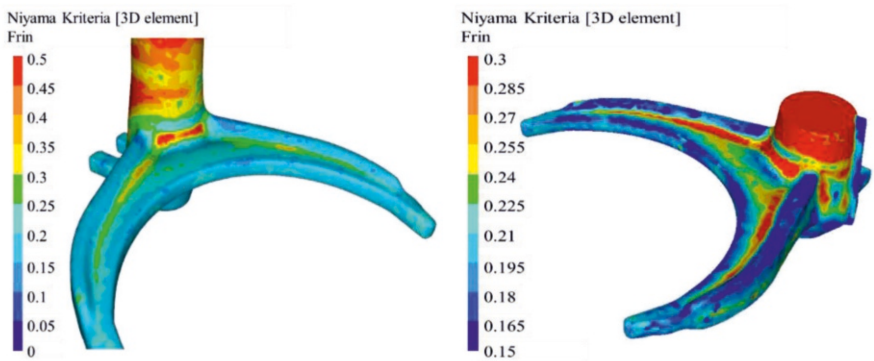

Fig. 5. Distribution of porosity on the casting (left: after casting simulation, right: in preparation of forging simulation)

The Niyama parameter is used to evaluate the surface porosity and indicates the areas with increased tendency to form pores. The expected distribution of porosity (Niyama criteria) is shown in Figure 5.

3.2 Second Simulation - Forging

In order to transfer the results of the casting simulation to the forging simulation, the feeder system of the casting model was removed with a trim operation. A similar approach is used in actual component manufacture, where critical areas with porosities or blowholes are placed in such a way that they are removed during subsequent machining. Starting from the model of the casting simulation after cooling down, the forging model is initiated with a heating phase in a first step. A comparison of the thermal expansion during heating and the shrinkage during cooling in the previous process shows a very close conformity.

Due to the near-net-shape cast preform, the forging simulation uses only the final die cavity of the initially developed tool. For the design of a continuous process simulation it is sufficient to define the tools as rigid. The current focus of the investigation does not lie on the optimised technology for manufacturing a component, but on the possibility of linking different simulation models with each other without loss of information in order to be able to realise new manufacturing paths.

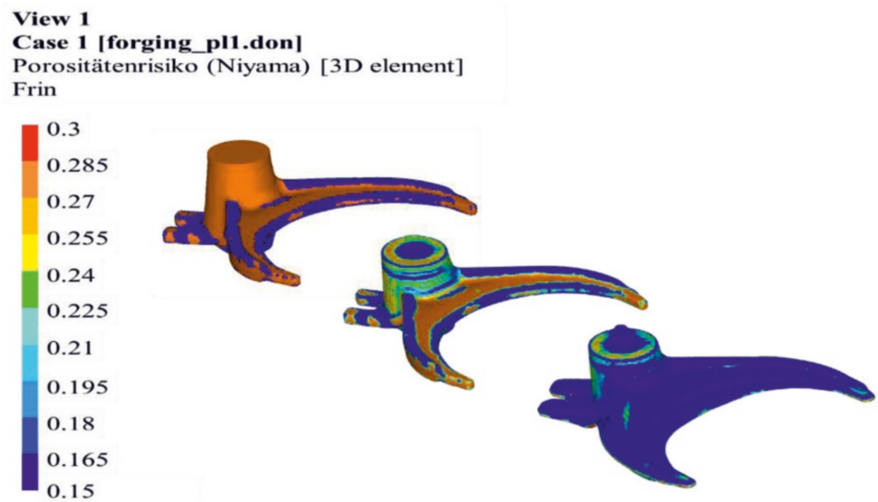

Fig. 6. Risk of porosity (orange - high; blue - small; left: after casting simulation, centre: during forging simulation, right: after forging simulation)

Conventional forming models and simulations do not contain any parameters regarding the porosity distribution. Porosity parameters were taken from the casting simulation and assigned to the component as user variables. This procedure enables the evaluation of porosities in the forming simulation, thus allowing for a statement on the extent to which the forming process affects the properties of the cast model.

Figure 6 shows the changes of the porosity distribution from casting to forming. A large number of surface pores are present on the surface of the casting, which are obviously closed during subsequent forging. The improvement of the surface shown in the simulation has also been demonstrated on real components, Figure 7.

Fig. 7. Porosity on the casting (left) and after forging (right)

External defects and porosities of the corresponding production stages can be compared by marking the components. The evaluation of sections and microstructures is only possible by comparison on different parts.

In local areas with a high effective strain of forming, blowholes up to a size of 5 mm, as shown in Figure 4, were almost closed during the forming simulation.

In comparison, the real cast part exhibits shrinkage cavities and segregation zones, especially in the large cross-section of the section plane 1. The forged part is free of cavities. The formation of folds, oxide inclusions or slags must be investigated in more detail. Figure 8 shows the sections of investigation.

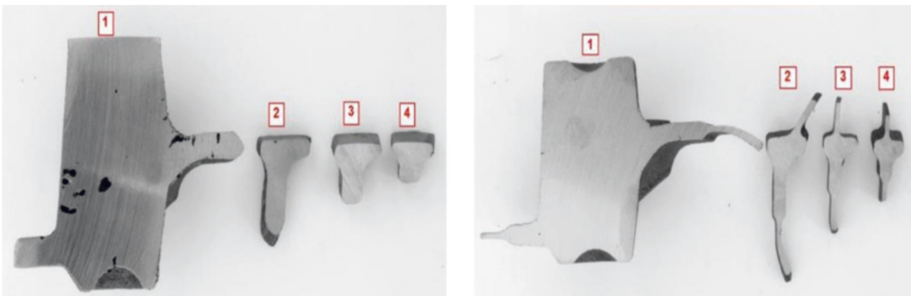

Fig. 8. Representation of the section planes for metallographic investigations (left: cast part, right: forged part)

4 Conclusion and Outlook

A simulation was set up for a steel component with a complex geometry that combines the casting and forging process steps. The development of the software enables a transfer of the simulation data from one process to another without loss of information. Therefore, it is no longer necessary to treat the simulation of each process separately for the production of steel components. For useful results, however, it is essential that each process is individually well understood and implemented in the simulation.

Results of the simulation regarding the distribution of porosities or the formation of blowholes were basically confirmed on actually manufactured components. First examinations of the component microstructure show the expected mixed structure as a result of forming of the cast microstructure. More specific results on the relationship between the degree of deformation and the change in microstructure cannot be made at the current state of investigation.

The use of the casting - forging process combination for this component led to a reduction of approx. 20% regarding burr formation. Since almost no optimization of the individual processes was carried out during the study, further increase in the savings potential can be assumed.

Currently running experiments are intended to analyse possible forging defects. In particular, the closing of larger pores or surface defects must be viewed critically in order to avoid the formation of wrinkles or the forging in of scale.

Future investigations are planned to include an enhanced coupling of the combined casting and forging simulation with a prediction of the expected microstructure. In order to make the presented process simulation available to a broader circle of users, a comparison is intended with the MAGMASOFT® - Simufact.forming® software systems which are widely used in Germany. Currently another lightweight complex component is being investigated to show the potential of the presented approach. Initial results indicate that there will be significant material savings for this component as well.

The combination of primary and secondary forming technologies combines the design freedom of casting with the strength-enhancing properties of forming technology in a single process chain. The presented materials and the associated developed manufacturing technology provide the end user with completely new tools with which it is possible to develop components in a new manner. Thus, a highly inhomogeneous property level can be defined and also implemented in terms of production technology. This process chain opens up completely new possibilities for lightweight construction and makes a considerable contribution to the conservation of resources along the entire processing route.

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