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Realistic Simulation of the Combustion of Exothermic Feeders

Exothermic feeder sleeves are increasingly being used in iron casting, and a new model helps metalcasters design feeder systems more efficiently using the sleeves. MALTE LEONHARD, MATTHIAS TODTE, FLOW-3D CAST AND JÖRG SCHÄFER, GTP SCHÄFER

The use of feeders is generally unavoidable in gravity casting, but often represents a conflict for designers: the dimensions and number of feeders should be large enough to reliably prevent shrinkage cavities, but the feeder weight should be minimized to reduce energy and processing costs, as well as recycled material, as far as possible. The rising complexity of castings further increases development demands. Highly exothermic feeder systems have become increasingly important because they are more space-saving and efficient than traditional natural sand feeders.

Fig 1. Test setup to examine the burning behavior of exothermic feeder materials.

Feeder systems can be divided into two types: with insulating or exothermic feeder materials. In the case of insulation feeders, the solidification time of the melt in the feeder is lengthened by means of a feeder body whose thermal conductivity is considerably lower than that of the mold material. The melt thus remains liquid for longer and is available to the junction to compensate for shrinkage. Reduction of the size of the feeder can be achieved by using an exothermic cap material. As a result, there is an exothermic reaction of the cap material when the ignition temperature has been exceeded. The melt is warmed by the heat that is released and thus remains liquid for longer. Exothermic feeder systems are therefore very efficient and can supply the casting with liquid melt for longer with less volume.

While the simple formulae of geometric modulus calculations were used in the past, metalcasters can now exploit casting simulations that can

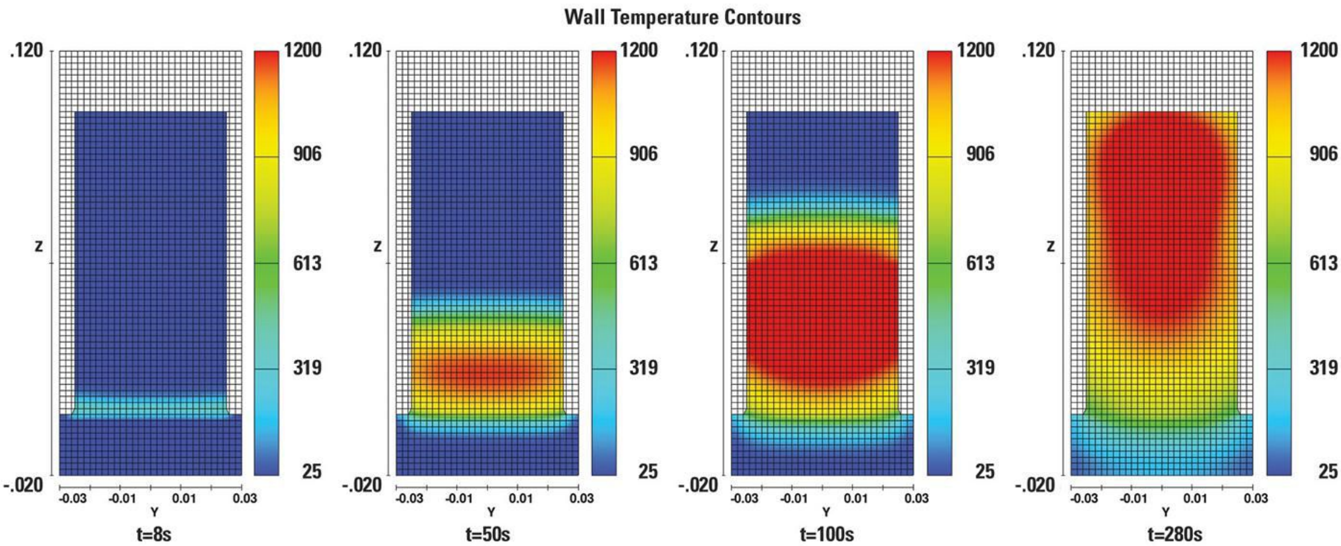

Fig 2. Simulation of the burning behavior of exothermic test bodies.

predict the thermic module and solidification morphology, among other things, and are thus helpful for feeder design. Simulations are an effective tool for finding efficient solutions, particularly regarding the selection and dimensioning of appropriate feeders. The growing demands from digital design and the use of casting simulations have been addressed again and again; meanwhile, the methods have become a fixed component of most development processes in foundries. The numerical description of natural and insulating feeder systems is accurate, and dependable results can be achieved. The models for using exothermic feeder systems, however, have so far been unable to predict processes accurately enough, leading to over-dimensioning of the feeder in practice—and thus to uneconomical solutions. The motivation to depict the burning behavior of exothermic feeder materials as accurately as possible in simulation programs is high because exothermic feeders are now the most commonly used feeder variant in iron casting.

The model now makes it possible to accurately describe the burning behavior of the feeder cap, i.e. the chronological and spatial course of the release of energy in the cap.

State of the Art

Exothermic feeder materials contain, among other things, aluminum and iron oxide. These react strongly exothermically because the aluminum has a higher affinity to oxygen than iron does.

Aluminum oxide and iron are produced when iron oxide and aluminum react, generating a lot of heat (aluminothermy, or the Goldschmidt Process).

$$Fe_2O_3 + 2Al \rightarrow Al_2O_3 + 2Fe \quad (1)$$

This reaction only gets going above a particular ignition temperature—which the feeder material reaches as a result of the melt filling the mold. In most feeder systems the exothermic

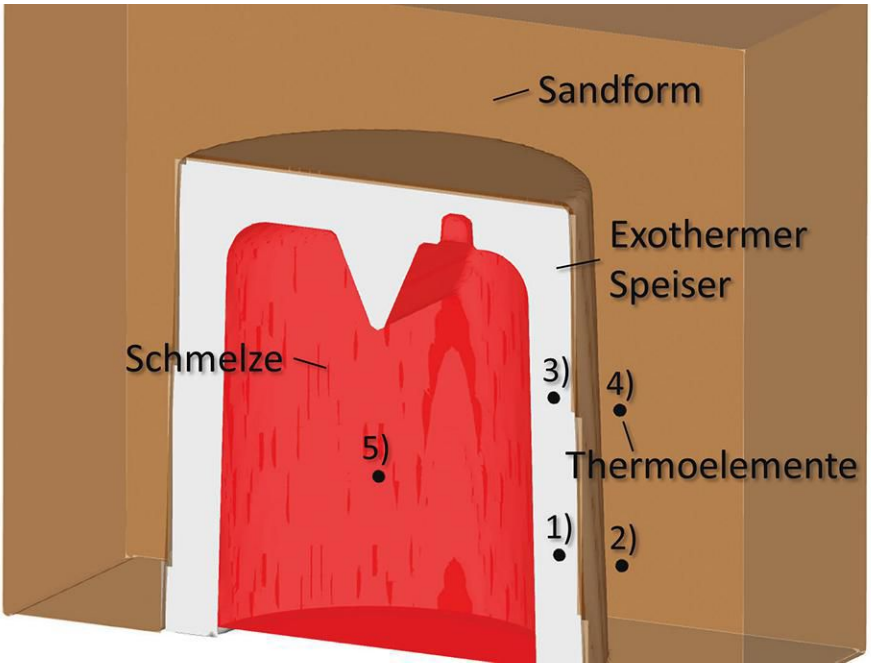

Fig 3. Thermocouples were positioned in five separate areas in the real casting trials.

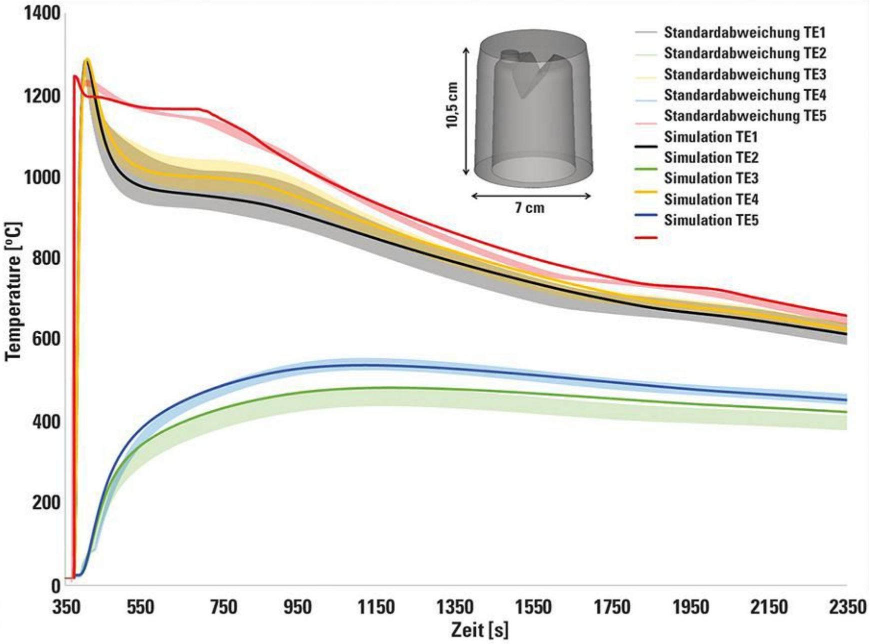

Fig 4. Comparison of measured temperature curves with the simulation results.

material burns radially outward from within the feeder. The burning time depends on the feeder sleeve geometry and the specific combustion speed of the material.

Industry constantly develops further variants and combinations of feeders, for example hybrid feeders that consist of a combination of insulating and exothermic materials.

Exothermic feeder systems have, up to now, only been simply depicted in simulation programs, with the entire sleeve volume being assigned an energy content that is constantly released during a defined burning time. It is already difficult enough for users to determine the energy content, but it is even more difficult to define a burning time because this depends on the feeder geometry.

This simplified form of modeling can potentially lead to major deviations of the simulation results from reality—and consequently to over-dimensioning of the feeder. The fact that the material properties also vary in the unburnt and burnt states has hitherto not been taken into account in foundry simulations.

Experimental investigations started by carrying out measurements of the thermophysical properties in order to obtain data on exothermic feeder materials. A sample with a defined energy-per-time unit was heated and the material properties continuously determined. One difficulty during these measurements was the high level of dynamism caused by the exothermic reaction. As soon as the ignition temperature is reached, the material burns up autonomously—and no longer follows the temperature of the measurement system. So, it was only possible to reliably determine the material properties in the unburnt state during these experiments. Therefore, the combustion behavior and material properties during and after burning were initially inaccurate or unknown.

It was necessary to examine the burning behavior with more precision.

For this purpose, an experiment was set up to test the exothermic materials (Figure 1). Two test pieces (D = 50 mm, H = 50 mm) were made for the experiment using exothermic material, and one was placed on top of the other. The lower test piece was ignited and the burning behavior of the two samples investigated. This setup allowed good observation and understanding of the progress of the combustion process. Then the chronological and spatial course of the burning behavior was compared with the simulation model (Figure 2).

Real casting trials in furan sand molds were carried out after the investigation of the burning behavior of the test bodies. During the casting experiments, exothermic feeder sleeves in a furan sand mold were filled with melt and the temperature curves were determined. For this purpose, separate thermocouples were positioned in the exothermic material, the molding sand and the melt to determine the temperature changes.

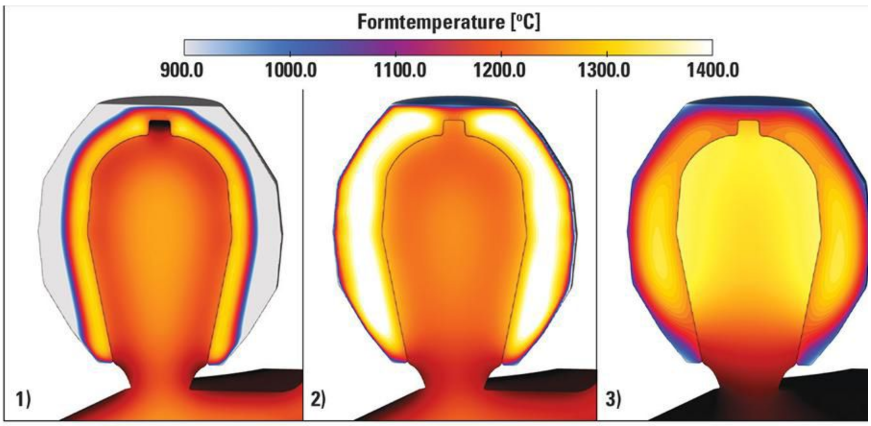

Fig 5. The burning behavior of exothermic feeder sleeves is represented. Left: Start of the exothermic reaction. Middle: Combustion of the exothermic feeder. Right: “Afterglow” of the feeder material.

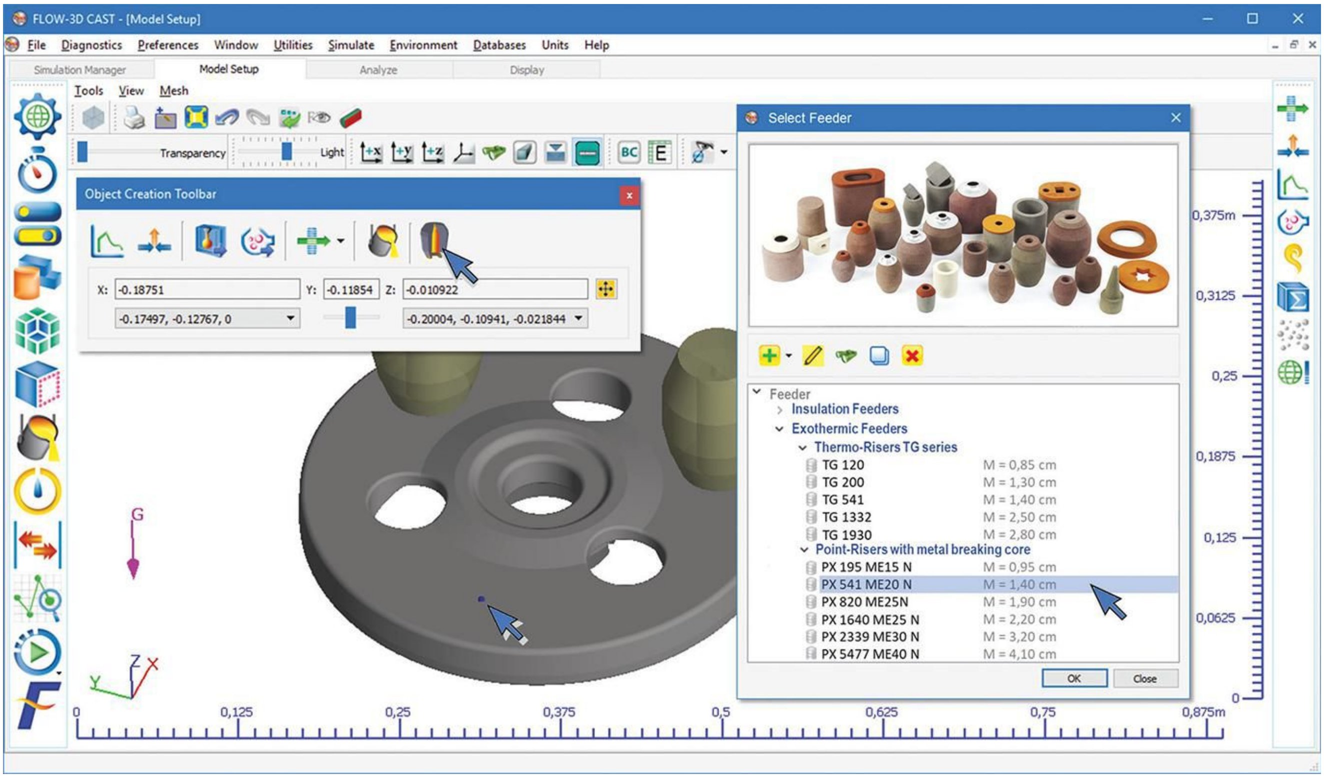

Fig 6. GTP Schäfer feeder database within the FLOW-3D CAST software.

One thermocouple was placed within the melt in the feeder. Two more were located in the sleeve, and two in the molding sand (Figure 3). The sleeve was filled with molten GJS 400 iron for the measurements.

The measurements were carried out repeatedly to provide high reproducibility and temperature curves that would be as conclusive as possible. The tests were repeated with three different cap sizes with a thermal module of 0.95 cm, 1.5 cm and 2.7 cm. They were intended to include as many different factors as possible (e.g. differing measurement positions, materials or densities) and the simulation model was examined with a large geometric bandwidth. Standard deviations were calculated from the recorded temperature curves and compared with the measurement values of the simulation results (Figure 4).

It was possible to show that the temperature curves of the simulation results mostly lay within the calculated standard deviations. It could therefore be derived that the deviations of the temperature curves between the simulation and the experimental results were within the measurement accuracies and, furthermore, that the implemented model of exothermic feeder sleeve behavior was accurately represented.

The New Model

The new model is intended to reflect reality as precisely as possible. The feeder is not treated as a complete exothermic volume that behaves identically everywhere, but instead each cell of the computational grid is treated separately. The exothermic reaction is triggered as soon as a grid cell of the feeder reaches the ignition temperature, and heat is released according to a calculated function. The temperature of the cells increases and heats the neighboring cells as in a chain reaction, so they also reach their ignition temperature. In this way, a realistic combustion behavior is shown within the feeder sleeve. After the exothermic reaction has taken place, the properties of the feeder material change and there is an insulating effect. The material properties of the feeder sleeves for each cell were also adapted to the level of combustion in the simulation. Thus, the thermo-physical properties of the unburnt and burnt material vary, having a further effect on temperature distribution during the combustion of the exothermic material. The different stages of the combustion process are shown in Figure 5. The feeder insert starts the exothermic reaction when the melt has raised the material to above the ignition temperature. Then the material burns autonomously and releases heat that warms the melt.

After the exothermic reaction has finished, there is an 'afterglow' as a result of the insulating properties. The high temperature of the exothermic reaction can therefore be retained, and the feeder can supply liquid melt to the casting for a long time.

A major added value compared to previous definitions is that a material, all of whose parameters are known, can be laid down in the database with general validity. Unknown values, such as the burning time of the entire sleeve, come up autonomously during simulation. A feeder database has been implemented in the software (Figure 6). The database contains feeder data on exothermic and insulating feeder sleeves. The correct feeder for a casting can be selected rapidly and efficiently on the basis of a modulus calculation, and its effect examined.

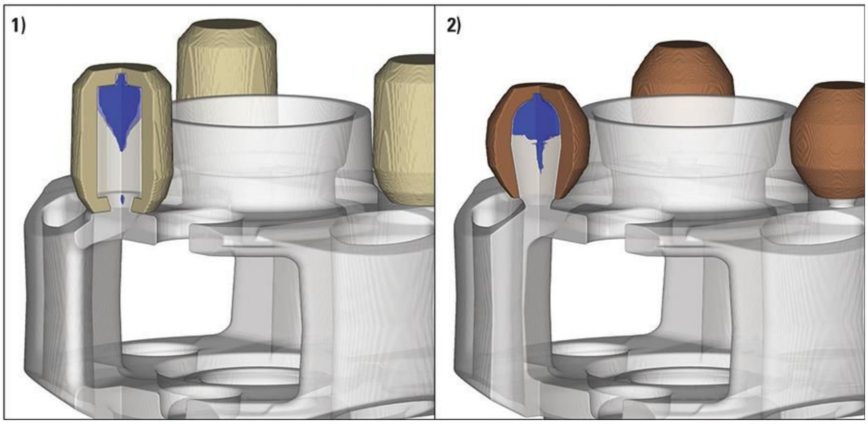

Fig 7. Casting clusters with different feeder sleeves are shown with insulating feeder material (left) and exothermic feeder material (right).

Validation

A case study in which an insulating feeder is used is shown in Figure 7. A porosity analysis shows that the feeder can only just compensate for the shrinkage of the component. As a result of the high solidification time, insulating feeders cannot maintain the melt at a high temperature sufficiently long, and a critical secondary cavity forms in the gate area. Although the defect is located within the feeder, it is nevertheless very unstable, as fluctuations in the process parameters (such as the chemical composition of the casting material, or the casting temperature) lead to shifts in the porosities in the component and thus to rejection. There are some defective components despite the process parameters being within the tolerances. Exothermic feeders were selected and dimensioned using the new simulation model to find a robust and efficient solution. No formation of secondary cavities is seen; the liquid melt is sufficient to compactly fill the component before solidification is complete. As a result of the more efficient mode of action, a smaller feeder body—with 30 % less melt volume—can be selected, preventing unnecessary recycling material. It was possible to achieve a robust solution with the feeders used because they do not behave sensitively to process-related fluctuations and reliably prevent imperfections within the component. MC

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