Numerical simulation of flow and compression of green sand

The focus of the industrial PhD project was concentrated on the production of the sand mold (green sand) which gives the cast component its final geometrical shape. In order to ensure a high quality of the cast component, it is important to control the manufacturing process of the mold itself so that it is homogeneous and stable. Therefore gaining a basic understanding of how the flow and deposition of green sand should be characterized and modeled was important, so that it could be used for simulation of the manufacturing process of the sand mold.

The flowability of the green sand is important when the sand flows down through the hopper filling the chamber with sand during the sand shot. The flowability of green sand is mostly governed by the amount of water and bentonite which both decrease it. The flowability and the internal forces thus control how well you can fill a complex mold geometry in which shadowing from ribs and other geometric obstacles may be present. If the flow stops prematurely it might hinder the mold from being completely filled or result in too high variation in the material density which could influence the final surface of the cast part. The wet bridges created by the bentonite makes the sand grains stick together where the bentonite and water make the green sand very cohesive and by squeezing the mixture it obtains mechanical properties that stabilizes the mold to acquire a strong mold for the casting process. Therefore the green sand flowability is important during the sand shot for a proper filling of the chamber, and subsequently the solid mechanical properties during the squeezing process are important for the final strength of the mold. This is problematic since these mechanical behaviours have an inverse relationship, e.g. if the green sand is too dry then the green sand flowability will be very high and the strength of the mold will be low and vice versa at least for the wet green sand up to a certain water content level. Therefore, obtaining the correct green sand condition and improving the filling of the mold during the sand shot are of great importance.

The Discrete Element Method (DEM) was chosen as the numerical model since the discrete nature of the method simulates the granular structure of the green sand with good agreement. The DEM model uses a rolling resistance model to emulate the non-spherical quartz sand particles’ resistance to rolling as well as a cohesive model to emulate the binding of the quartz sand particles from the bentonite.

The green sand was characterized with a ring shear tester where the yield locus was found and a new way to define the flowability was suggested. The ring shear tester was used to obtain the static friction coefficients for the DEM model. A sand pile experiment was used to investigate the simple mechanical behaviour of green sand from the measured height. From this height the DEM model was also calibrated with respect to obtaining the values of the rolling resistance and obtaining the parameter in cohesive model.

The project dealt with the flow of the sand particles and the deposition of sand during the production of sand molds using the sand shot in the DISAMATIC process. The deposition of the green sand in the chamber was investigated with a special cavity design where air vents were placed inside the cavities. The air vents are used to transport the green sand with an airflow during the sand shot. By changing the air vents settings in the chamber and in the cavities it was possible to improve the filling in the narrow passages in the cavity design, thereby improving the final sand mold as well. The sand shot with the cavity design was simulated by the discrete element method (DEM) modelling the flow of the green sand combined with classical computational fluid dynamics (CFD) for modelling the airflow in the chamber and the airflow through the air vents. These experiments and simulations gave beneficial insights to the DISAMATIC process and how to improve it. Additionally fluidization properties of green sand were investigated with a fluidized bed and the newly developed Anton Paar Powder Cell was used to obtain the fluidized viscosity.

Commercial aspects

Knowledge was acquired about the filling of the mold chamber with green sand in a special designed cavity geometry. The settings of the air vents together with the air pressure initially applied in the air tank gave valuable ideas for improving the filling in the cavities thereby improving the final mold. Furthermore, it was possible to apply the commercial software of STAR-CCM+ using the combined CFD-DEM model to simulate the process with a 3-D slice representation of the geometry successfully. This makes it more feasible to develop a stand-alone code in the future for simulating the DISAMATIC process. The sand shot in the DISAMATIC process might also be modelled with a continuum model where the ring shear tester could give indications of the solid mechanical behaviour of the green sand and the Anton Paar Powder Cell could be used for obtaining the fluidized viscosities of the green sand.