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Simulating HCR Injection Molding
Realistic mold filling

Simulations, long established in the injection molding of liquid silicone rubber, can now also be effectively applied to high-consistency rubber, yielding realistic results and potential process enhancements. This is shown by a comparative filling study involving an injection molding machine and simulation software.

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Today, computer-assisted simulation is indispensable when it comes to the injection molding of plastics. Thanks to commercial simulation programs, it is possible to optimize the entire development and production process of injection-molded plastic products in the virtual world. For many years, the industry has relied on the tried-and-tested SIGMASOFT® software to simulate the injection molding of liquid silicone rubbers (LSR) [1, 2, 3, 4]. The software is an invaluable aid for designing not only the desired part, but also the mold and processing of the silicone. Despite this, no reports have ever been published on the use of programs that simulate the injection molding of high-consistency silicone rubber (HCR).

Silicone manufacturers and simulation software providers are currently registering growing interest in HCR injection molding. Only a few years ago, there was a view that the injection molding of solid silicones was uneconomical, as the associated cycle times were usually long and there were no process engineering options that would enable automation. However, the recent availability of HCR characterized by relatively short curing times, coupled with advances in metering technology and machinery, have made silicone compounders reconsider that view. Thanks to these developments, continuous, automated and cost-effective injection molding of complex parts featuring filigree structures is now possible.

Silicone manufacturers clearly find this very attractive. But is it possible to make reliable predictions about the process, even when this involves manufacturing complex products from HCR silicones? In a recent study, Sigma Engineering GmbH and WACKER showed the example of a filigree silicone product to demonstrate that simulation can realistically depict the actual HCR injection molding process and that it can also reveal substantial optimization potential.

The solid silicone used

Known for their good mechanical properties after vulcanization [5], solid silicones lend themselves to applications where they are regularly exposed to high loads. The “Lemon Press 1” from Spanish consumer goods manufacturer Lékué S.A.U. serves as a good example of such a molded product (Fig. 1).

The press was made with WACKER's biomethanol-based solid silicone rubber grade SILMIX® eco R plus TS 40002. This ready-to-use, specialty solid silicone pre-colored compound is based on the commercial grade ELASTOSIL® R *plus* 4001/40 MH, which vulcanizes to an elastomer with a hardness of Shore A 40. Such cured rubbers achieve a tensile strength of 11.8 N/mm², a tear resistance of 38 N/mm, and an elongation at break of 930%.

The compound is vulcanized by a platinum-catalyzed addition reaction conducted at elevated temperature. Curing proceeds much faster than in the case of peroxide curing, a process widely used to vulcanize HCR compounds. Furthermore, as no by-products are formed during addition curing, the cured rubber is odorless [6]. WACKER offers an extensive product portfolio of these addition-curing solid silicone rubber grades.

Data accuracy is a must

The availability of valid data on the material properties of the silicone used is crucial for any realistic injection molding simulation. The more precise the data, the more realistic are the simulation results.

Data on the curing kinetics and rheological properties of the compound are particularly important. Information on the curing kinetics of the solid silicone used in this case study is presented in Fig. 2. The curves show how the curing degree of the silicone develops over time at four different temperatures.

Even small differences in temperature are enough to have a significant impact on the curing rate and therefore on the curing degree achieved after a certain period. Curing of the molded part will not be uniform if the temperature of the HCR compound injected into the heated cavity is not uniform throughout. As a result, a longer heating time will be required. If exact data on the curing kinetics are available, the injection molding simulation can visualize the curing reaction and helps with the identification of under-crosslinked areas. Quality issues or productivity losses resulting from under-curing can thus be eliminated from the beginning – even during the design phase itself.

Another critical parameter in the production of molded parts is the flow properties of the HCR compound, which can impact the filling of the cavities in the mold. Solid silicones are shear-thinning materials – the higher the shear rate, the lower is the viscosity of the compound. Additionally, solid silicones show a temperature dependent behavior of the rheology, i.e. the higher the temperature, the lower is the viscosity of the compound. For a realistic molding simulation, the data on the viscosities associated with the shear rates and temperatures during injection molding must be as accurate as possible.

The flow properties under shearing at different temperatures are therefore determined in the absence of curing by conducting the viscosity measurements on addition-curing silicones without the platinum catalyst. The presence of the catalyst would induce curing and thus falsify the readings. In practice, the rheological properties of a solid silicone compound are measured with either a rotational viscometer or a high-pressure capillary viscometer. The latter method is more time-consuming and requires more material.

Comparison of the data for actual and simulated filling studies performed on a test part verified that the values were suitable for use in simulations. WACKER conducts such tests on its own injection molding machines at its Process Technology Center in Burghausen (see insert). The comparison of the simulations with the actual test parts made from solid silicone grade SILMIX® eco R *plus* TS 40002 shows that reality can be simulated very accurately with the aid of the rheological data.

Simulated injection molding of a lemon press

The first step in the simulation of an actual part was to produce the lemon press by an automated injection molding process. The solid silicone was processed in a Flexseal 300 injection molding machine from Engel Austria GmbH, which was equipped with the Rotofeeder rotary conveyor system. The mold was provided by Nexus Elastomer Molds GmbH. Sigma Engineering simulated the entire injection molding process using its Sigmasoft® Virtual Molding software. Part of the simulation involved a virtual filling study, for a visual comparison of the calculated predictions with actual partially filled parts.

As in reality, the simulation consisted in heating the mold first and then running it through several complete molding cycles until a steady thermal state was achieved. This required a heating time of 30 minutes, followed by eleven cycles. The simulation replicates the entire mold-filling process in detail. For example, it can map the development of the temperature distribution and the cavity pressure over time.

The simulation showed that the temperature distribution inside the cured molded part was not uniform. This has an impact on the curing performance. Areas close to the gate and thick-walled areas of the processed lemon press (Fig. 3) are comparatively cold, because the material is cooled until it reaches the injection nozzle in the machine.

The rate of curing in these cooler regions is slower. In contrast to the warmer areas, it takes longer to attain the specified curing degree there. Figure 4 (left) shows areas that are cured less than 90% at a specific point in time – in this case, after a process time of one minute and 14 seconds. Slow-curing areas determine the heating time and thus also the cycle time.

The simulation also revealed why curing was not uniform. This is shown in Fig. 5, which identifies a point in time (t = 8.76 s) at which the silicone has filled the cavity to around four-fifths of its volume (86.01% to be precise) and compares the curing degree at this point (left image) with the simulated temperature distribution (right image).

At this point, the silicone is therefore still not crosslinked. The temperature distribution in the core of the mold (central section of the right image) is not uniform. On the ejector side of the mold, the temperature in the core is around 160 °C; near the gate, it drops to around 130 °C as a result of thermal contact with the cooler HCR compound that is injected. Evidently, heat transfer through the core in the direction of the gate is inadequate.

Various options aimed at improving the heat transfer were therefore simulated. It was subsequently decided to insert a copper sleeve into the mold and over the steel core. This was done by Nexus Elastomer Molds GmbH in order to make use of the superior thermal conductivity of copper.

The simulation indicated that this modification would raise the core temperature near the gate by around 10 Kelvin (Fig. 6). As a result, the silicone in the critical areas would crosslink faster compared with the original mold design. This would slash the heating time and, with it, the cycle time (Fig. 4, right). According to the simulation, the cycle time would fall from 93 to 76 seconds, corresponding to a time saving of 17 seconds (Fig. 7). Indeed, the new mold design's predicted outcome was confirmed during the actual test on the injection molding machine. The cycle time dropped to 78 seconds without any additional process changes.

Comparison of actual and simulated filling

A filling study provided a further opportunity to compare the simulation with the actual injection molding process. The filling simulation was part of the overall simulation project. Under real conditions, different partial fillings were created on the injection molding machine; the injected volume of HCR compound was increased from shot to shot in four-percent increments from 48% to 100%. The resulting incomplete molded parts were then photographed from several angles.

Figure 8 compares the simulated models with the photos of the incomplete molded parts for three filling levels – 48%, 68% and 88%. The partial fills are shown on the left and the corresponding simulations on the right. The latter show the spatial distribution of filling after each shot.

This approach also enables us to assess the risk of the formation of trapped air. The simulated partial fills allow of the conclusion that the overflows provided for in the mold design are correctly positioned to prevent the formation of air. A visual comparison of the photos with the simulation images shows little or no discrepancy between simulated and actual outcomes.

Conclusion

Simulating the injection molding process allows us to support product, mold and process development and to run through various optimization options from the very beginning. This principle also holds true when it comes to processing high-consistency silicone rubber. Silicone parts producer and tool manufacturers stand to benefit from significant time and cost savings. Time-consuming and costly development projects are eliminated and the changes to the design of the intended molded part can be tested at any time with the software. This allows optimization of the injection molding process with relatively little effort. Moreover, silicone compounders are able to estimate cycle times and, consequently, the manufacturing costs in advance which is clearly a plus when it comes to calculation of costs at a project.

The lemon press is also a good example of the fact that it is even possible to simulate the HCR injection molding process of complex parts. However, that is contingent on a knowledge of the behavior of the solid silicone rubber compound intended for processing under injection molding conditions. Property data based on reliable measurements are crucial in this context. Thus, the flow properties of the compound must be measured in the absence of curing by the best-suited measuring procedures.

Acknowledgments:

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Insert 1 – WACKER

Process Technology Center of Silicone Elastomers

The Process Technology Center of Silicone Elastomers operated by WACKER at its Burghausen site is entrusted with supporting all departments and divisions worldwide that are involved in liquid and solid silicone rubbers. The chemical company uses equipment and machinery similar to those deployed by silicone compounders to study the behavior of its silicone products during processing. The tech center thus plays an important role not only in the development of new silicone products and innovative technologies but also in supporting customers with specific issues relating to silicone processing or the implementation of new projects. The Process Technology Center is equipped with extruders, vulcanization tunnels, injection molding machines and a range of metering equipment. WACKER maintains close contact with reputable machinery and tool makers with the aim of acquiring new equipment lines and keeping up with the latest technological developments. The tech center is also capable of processing liquid silicone rubbers and thermoplastics together in a two-component injection molding process.

Insert 2 – Sigmasoft

SIGMASOFT® Virtual Molding

SIGMASOFT® Virtual Molding simulation software has matured over a period of more than 25 years. The vast know-how accumulated by Sigma Engineering’s experts is passed on to its customers via its virtual molding technology. The simulation software not only creates a digital twin, but also facilitates simulated operation across many production cycles. Key to the virtual molding principle is holistic 3D simulation of flows, heat flux, and material properties in injection molding, as well as the complete mold with all its details. The range of applications across the various industries is just as diverse as the applications related to the process itself. The software can be used for designing and optimizing injection molds and injection molding processes as well as for the design, layout and dimensioning of plastic parts.

Illustrations

Fig. 1: The “Lemon Press 1” from Lékué S.A.U. is a good example of a silicone product featuring filigree and thick-walled areas. (Photo: WACKER).

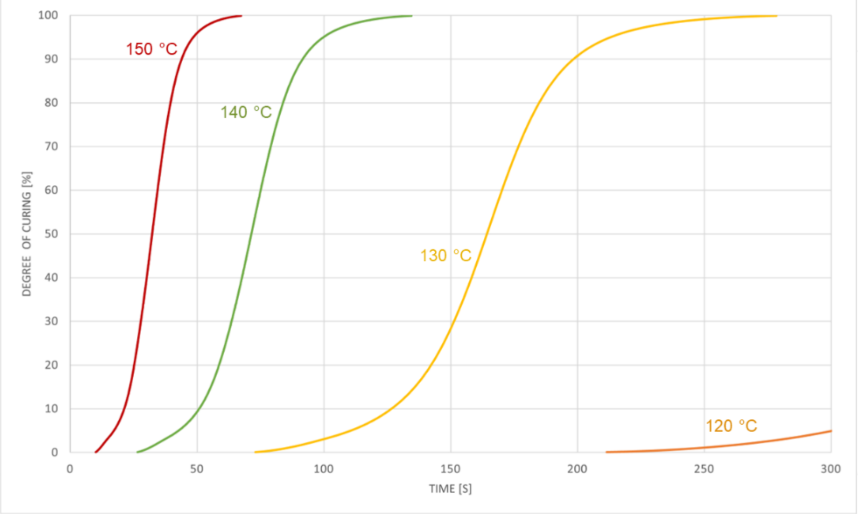


Fig. 2: Curing kinetics of the HCR compound used. The graph shows the curing degree as a function of time at different temperatures.
(Chart: WACKER)

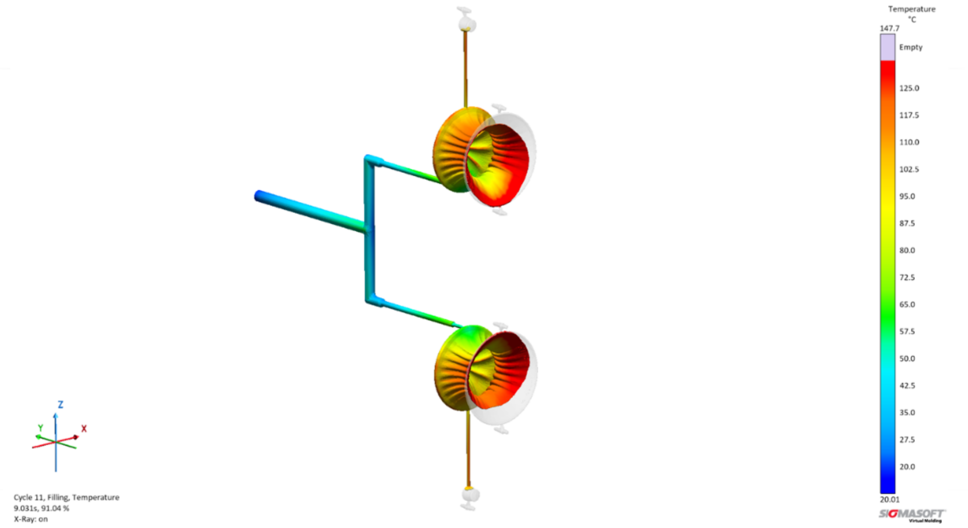


Fig. 3: Temperature of the HCR compound in cold runners and mold cavities, simulated at 9.031 seconds after the start of the injection molding cycle. (Chart: SIGMASOFT®)

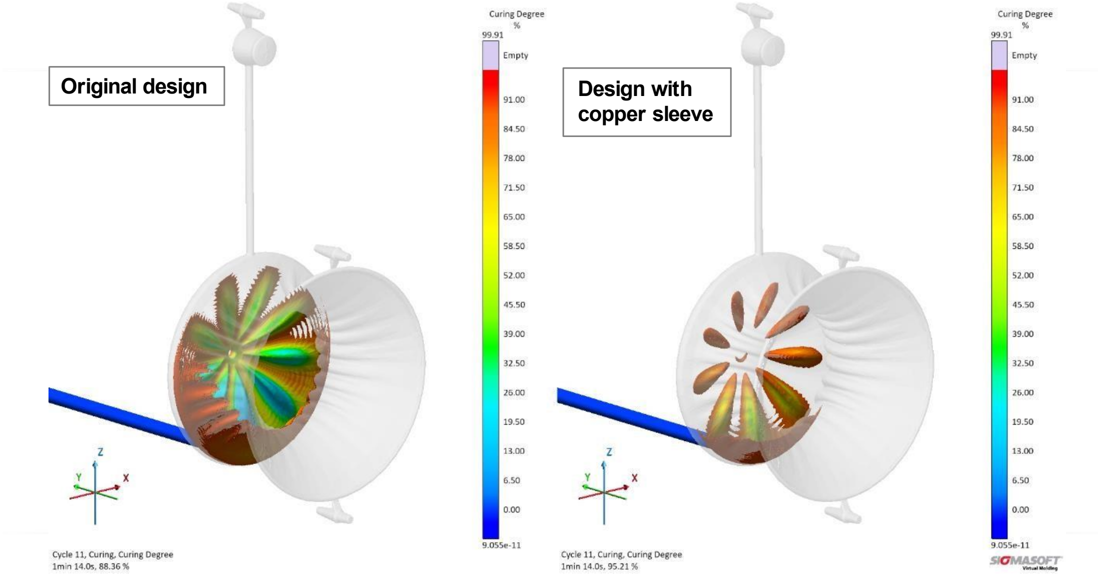
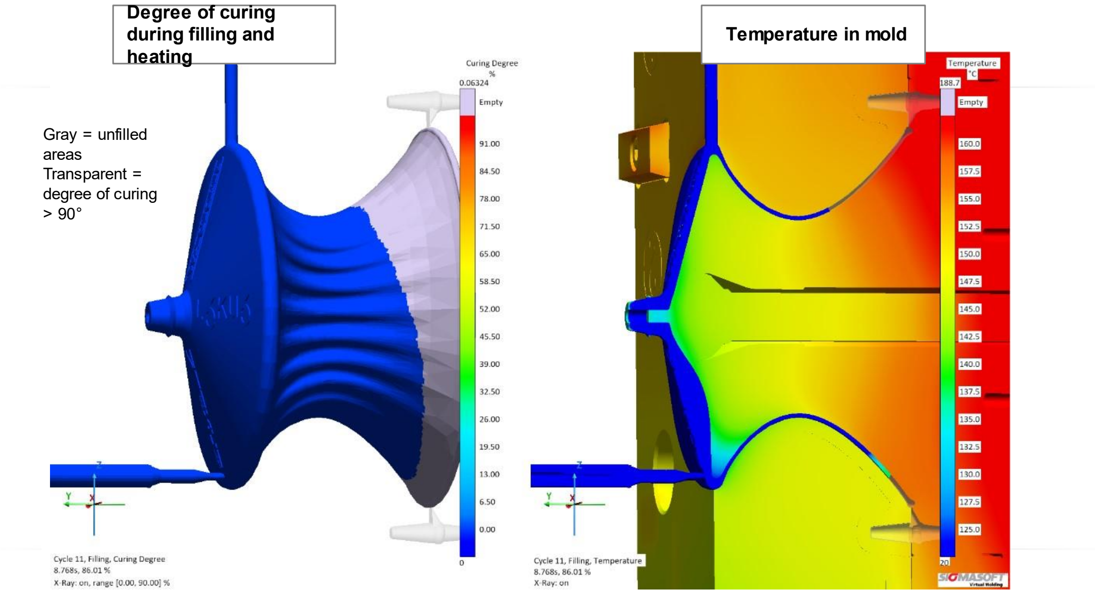


Fig. 4: Silicone sections that have attained a curing degree of <90% after a certain process time (74 s) has elapsed. The left image shows the simulation for the original mold design, while the right image shows the simulation for the improved design. The colors represent the curing degree. (Images: SIGMASOFT®)

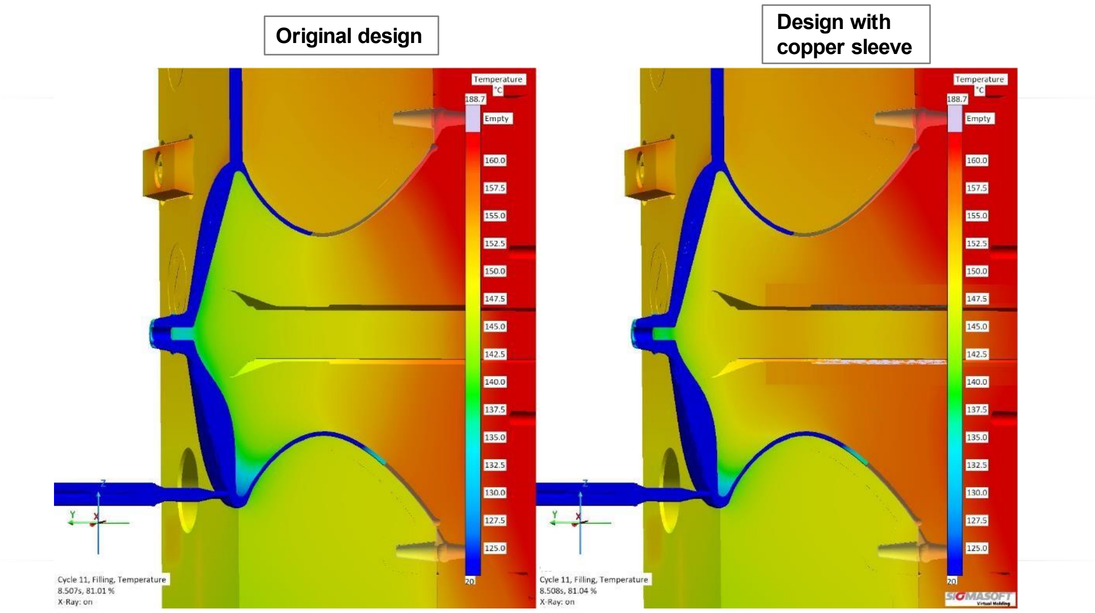


Degree of curing during filling and heating

Gray = unfilled areas
Transparent = degree of curing > 90°

Temperature in mold

Fig. 5: Curing degree (left) and temperature in the injected silicone and in the core of the mold (right), simulated at 8.76 s after the start of the process. (Images: SIGMASOFT®)



Original design

Design with copper sleeve

Fig. 6: Simulated distribution of temperature in the core of the mold and in the injected silicone, recorded after 8.507 s. Simulation for the original mold design (left) and for the improved design (right). (Images: SIGMASOFT®)

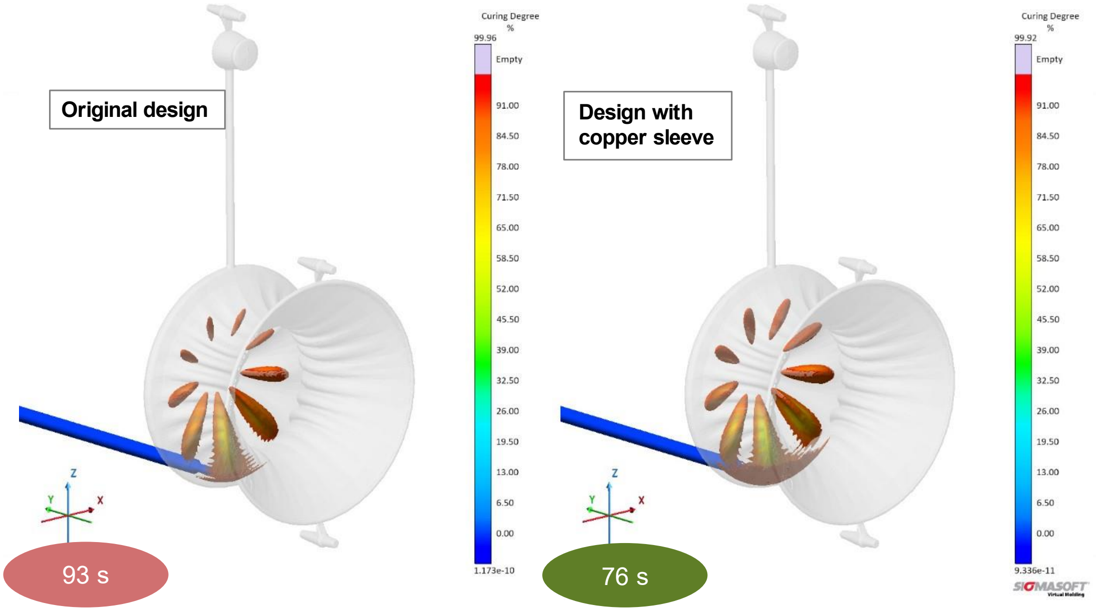
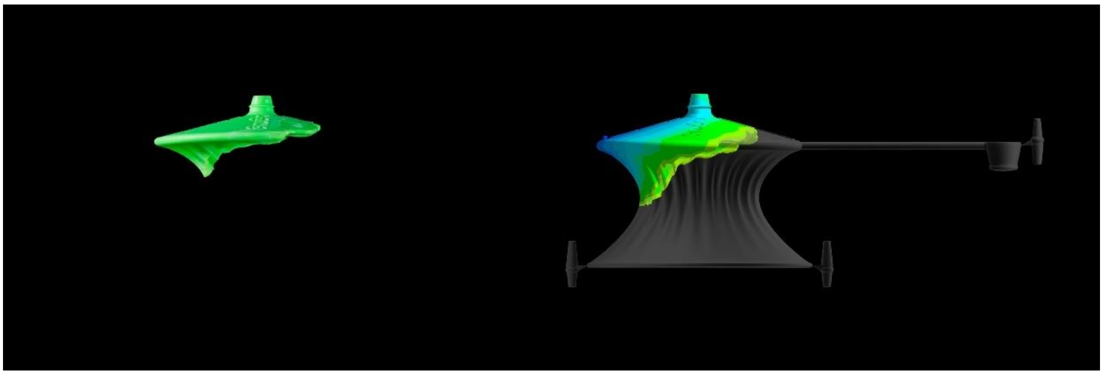
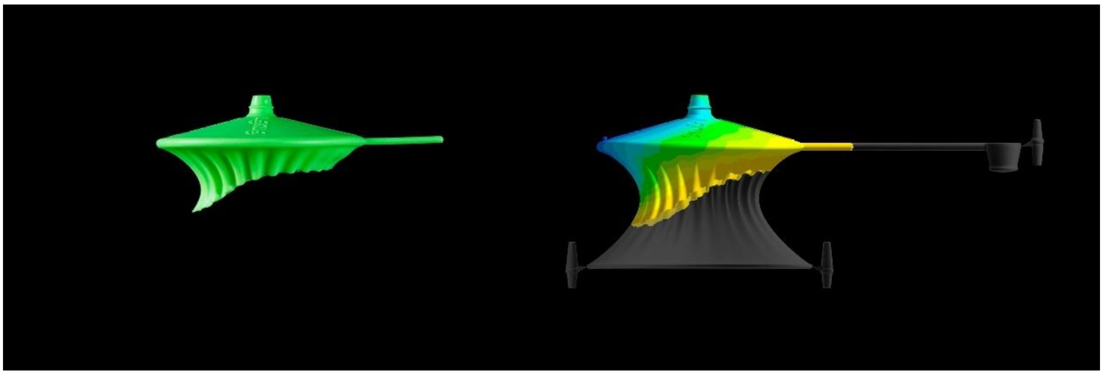


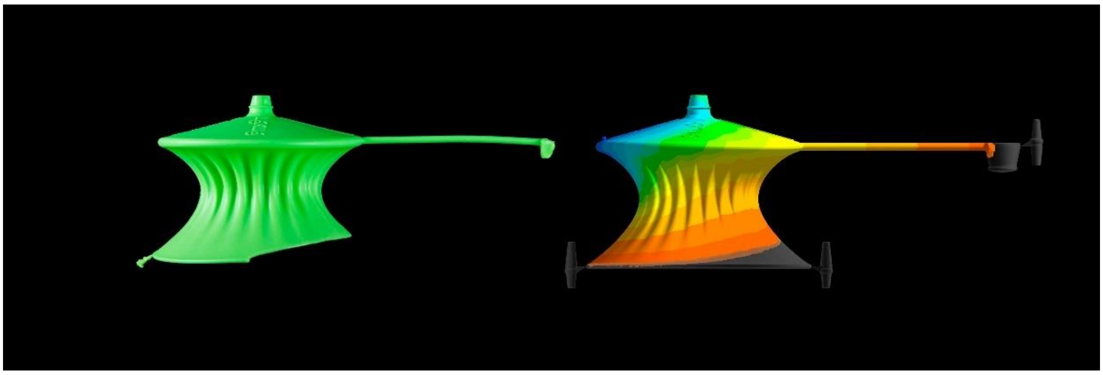
Fig. 7: Simulated cycle time for injection molding with the original mold design (left) and the improved design (right). The simulation predicts a cycle time reduction of 17 s. (Images: SIGMASOFT®)



48% filled



68% filled



88% filled

Fig. 8: The left image shows the sample from the injection molding machine. The right image shows the simulation when 48% (top), 68% (middle), and 88% (bottom) is filled. The different colors represent the cavity pressure. (Photos left: WACKER; images right: SIGMASOFT®)

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The Company in Brief:

WACKER is a global company with state-of-the-art specialty chemical products found in countless everyday items, with applications ranging from tile adhesives to computer chips. It has a worldwide network of 27 production sites, 22 technical competence centers and 48 sales offices with some 16,400 employees and annual sales of around €6.4 billion (2023).

WACKER operates through four business divisions. The chemical divisions WACKER SILICONES and WACKER POLYMERS supply products (silicones, polymeric binders) for the automotive, construction, chemical, consumer goods and medical technology industries. WACKER BIOSOLUTIONS, the life sciences division, specializes in bioengineered products such as biopharmaceuticals and food additives. WACKER POLYSILICON produces hyperpure polysilicon for the semiconductor and photovoltaic industries.