Rapid Tooling for Injection Molding of Rubbers

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Abstract

Rapid tooling is known for molding of thermoplastics for years. Information about rapid tooling for rubber parts is quite rare. The different demands on tools for vulcanizing rubbers and some case studies will be shown. The emphasis is on cast resin tools, since this technique is cheap and can be used from everyone.

1 Introduction

In the past, several rapid tooling methods for injection molding of thermoplastics have been developed. However, there are no published examples concerning injection molding of elastomers. This paper illustrates the differences in the injection process, the demands on the tools and presents examples. These examples demonstrate the limitations and the needs for further development.

2 Different injection molding processes of thermoplastics and rubber - different demands on the tools

Overall, both processes are quite similar - molten material is injected with a screw into a cavity. Of course the particularities lead to different demands on the tools. Mainly the temperatures of the tools and the injected material differ.
Injection moulding of thermoplastics requires a high material temperature and a low mould temperature as the molten thermoplastic material will become solid if it cools. The production requires a transition from hot molten material to cold frozen material. Therefore the temperature of the mould is normally less than 80°C and the temperature of the injected material is between 200°C and 350°C. Rubbers vulcanise at high temperature (160°C – 200°C), thus the rubber is preheated to approx. 80°C or less to become soft enough to be injected into the hot tool. There, after a few seconds when the material warms up, vulcanisation starts. Depending on the material, the cycle time is about 100s. The part will be ejected at high temperature. Therefore the mould has a constant temperature of e.g. 180°C.

The rubber parts are of course very flexible so that the ejection forces are low. Thermoplastic parts have a reasonable stiffness, however due to shrinkage they can stick to the tool so high ejection forces are necessary. These forces often lead to a failure of the mold.
Tools for injection molding thermoplastics therefore need high strength at temperatures below 100 °C to withstand the clamping forces, (the forces during injection and ejection). Tools for producing rubber need to be stiff up to 200 °C. Since the tools are normally mounted at room temperature and then heated, the thermal expansion must also be considered.

3 Potential Process chains for manufacturing rubber parts

The constant tool temperature of 200 °C was the first criteria to reduce the number of process chains to be considered. The metal based process chains like the DMLS® from EOS, 3D-Keltool® or DTM's Rapid Steel are ideal. However, all of these materials contain copper which can be critical for the vulcanization with sulfur, thus coatings of the tools will be necessary and the compatibility with the rubber must be tested. These process chains are costly compared to others. The indirect ones are also time consuming, so that they may only be considered for very complex geometries. Cast resin tools, which have improved considerably during the last few years are well known from injection molding of themoplastics. Here the advantages are the low investment costs, the tools can be made before drafting and tool design is finished. These tasks may be done directly on the model. Working with thermoplastics, the problems are the low strength, so the tools may break either due to the injection or ejection forces. This will be a less of a problem when using rubbers, but most of the cast resins soften above 160 °C and have a reasonable thermal expansion. This causes accuracy problems.

4 Making experience with case studies

The first tool should only show the feasibility of the process chains. So a part was chosen which can be molded in two mold halves with a simple parting surface. One mold half was manufactured in steel by conventional turning to reduce the costs. Figure 1 shows a modified damping ring with gate.

4.1 3D-Keltool

A model of the tool was built with stereolithography to be copied with the Keltool process (Figure 3). Therefore it was scaled with an oversize of 0,6 % as recommended by the supplier, the cavity and parting surface was finished to the correct dimensions. It was then sent to 3D-Systems where it is converted into metal within 10 days. This part showed exactly the same surface quality as the stereolithography pattern but was 0,2 % too small. The parting surface was slightly rounded, so it had to be planed. To avoid problems with the copper, a coating of chrome was applied by electroplating.
It was then no problem to mount the mould in the injection machine. The first shots showed the need for some venting holes at the pins of the part, it was then simple to mould several parts with standard injection parameters.

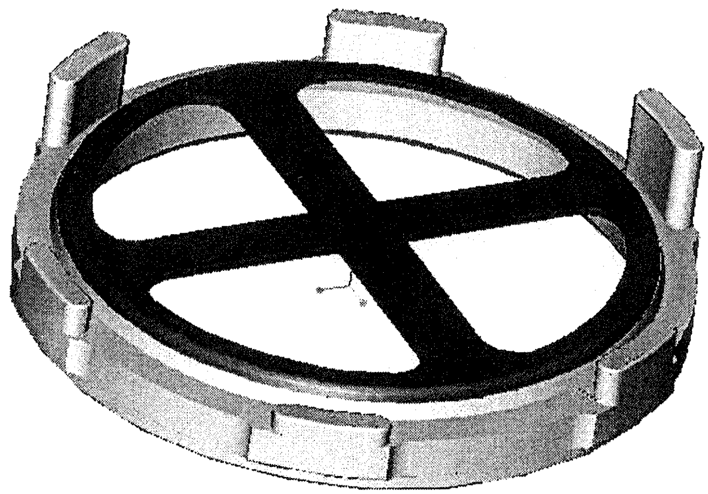

Figure 1: CAD-design of the test part with gate

4.2 Cast resin tool with Cubital's Solid Ground Curing SGC

Since the SGC has its advantages for big parts, the negative of the tool was designed in CAD and built. Cast resin was poured directly on the finished negative and pre-hardened to form the tool. The negative can be removed easily since it is mainly wax and the tool can be completely hardened. All these steps take about 5 days. As casting material, an epoxy resin from HEK was chosen, which is a standard material for casting tools for injection molding of thermoplastics. The tool was made as a insert in a mother mould. Since the resin has a reasonable thermal expansion ($\alpha = 3*10^{-5}\ K^{-1}$ at 50 °C, $\alpha=6*10^{-5}$ at 190 °C, a total of 0,4 % from 30-190 °C), it was cut to a smaller diameter than the mother mold to allow enough room for expansion. It was then mounted on the injection molding machine and slowly heated to 180 °C. During the molding process with different pressures, no problems occurred. However, some small deformation could be seen on the holes forming the pins of the part, this can be explained by the thermal expansion coupled with the softening of the material.

4.3 Cast resin tool with stereolithography model

This process chain starts directly with the part itself. It is built in the stereolithography machine (together with the gate), then it is accurately finished, also the stair stepping is removed. Here also some painting may be useful. Draft angles may be added by sanding, this is necessary to enable subsequent removal of the pattern from cast resin. Normally, the parting surface can be carved in wood or plastic material. In our case the other half of the tool already existed in steel. The part is then glued to the parting surface and coated with release agent. The first half of the tool can be casted with epoxy filled material. When this half is cured it serves together with the part to cast the second half (which was not necessary in our case). The injection molding took place as described above with out problems. It must be noted that the molded parts from this mould had excellent surface quality, the best of all the process chains tested.

Here two tools were tested from a commercial resin (HEK EP 250) and a highly filled mixture developed at IKP (Figure 3). This was done because most of the cast resins available for rapid tooling showed softening below 200°C in previous material tests. A measurement showing this behaviour is shown Figure 2.

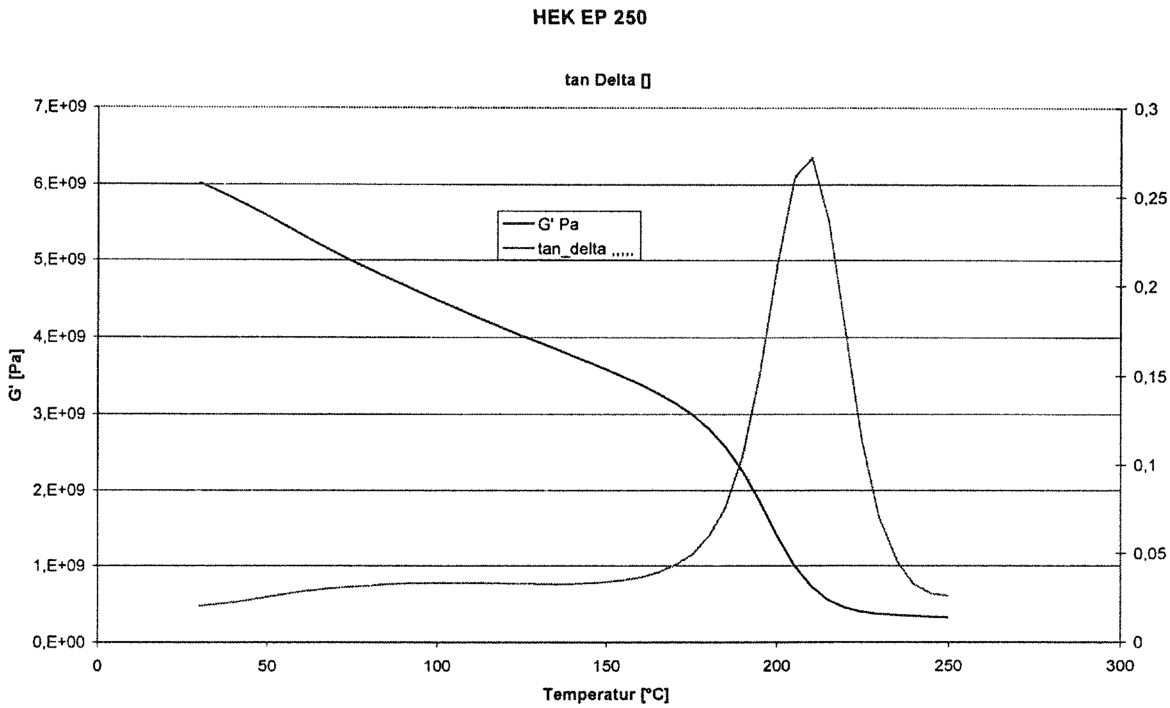

Figure 2: Thermo dynamic mechanical analysis of a cast resin

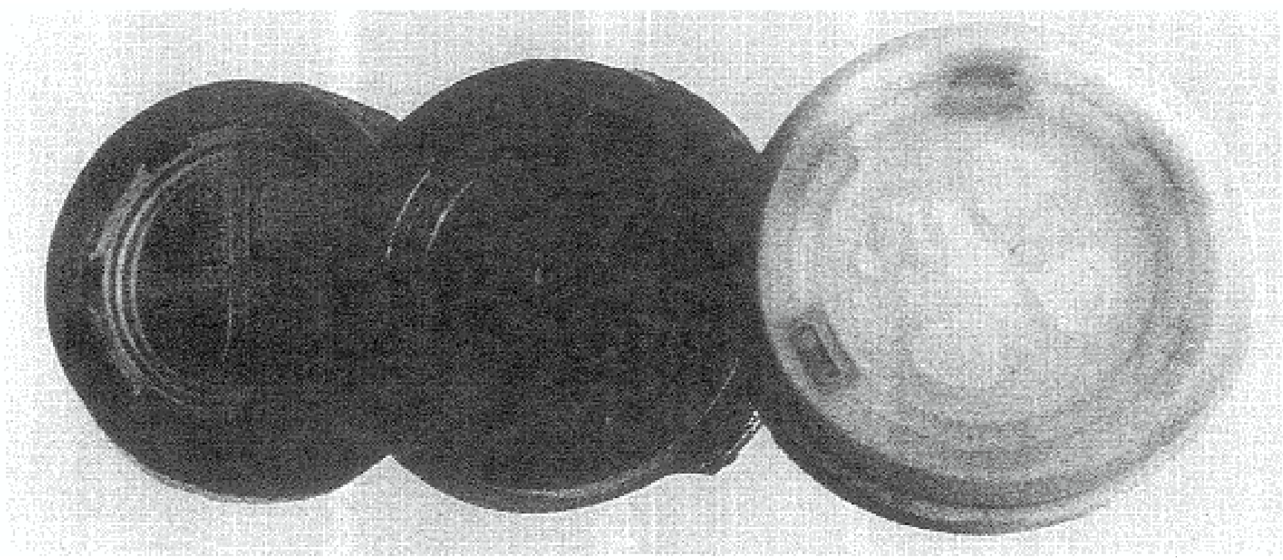

Figure 3: Tools made in Keltool, Cast resin, Stereolithography pattern

4.4 Tool made with metal spraying

The process chain for metal sprayed tools is similar to the cast resin process chain. The first step is the SLA master pattern which is mounted on a plate with the required parting surface. In the next step a low melting alloy has to be sprayed and the generated thin metal shell has to be backed with cast resin. The advantage of this technique compared to cast resin tools is the improved mould surface. The surface is less brittle then a cast resin surface and is generated within a short time. Of course the equipment for spraying metals is not available for everybody. It is also not possible to generate every shape, since the material is sprayed and for example holes cannot be reached.

4.5 Conclusion of case studies

With all of the mentioned process chains, it was possible to manufacture dozens of rubber parts. All tool materials where compatible with the used rubbers (FPM, ACM, NBR). Of course the metal tools appeared identical after the last shot to that at the beginning whereas some of the cast resin tools had small deformations. The accuracy of all tools is comparable and within the tolerances of usual rubber applications. To manufacture high precision parts, for example sealings which require to be accurate within some hundredths of a millimeter, these process chains are not suitable. With this simple part where the feasibility had to be shown, the tested process chains were more time and cost consuming than the conventional route (milling, eroding) so that the next comparison has to be made with a more complex geometry.
The cast resin, which was chosen carefully after mechanical tests at 200 °C, did not fulfill the demands completely. Other materials have to be found with improved thermal properties (thermal expansion, thermal conductivity) and most importantly, mechanical properties.

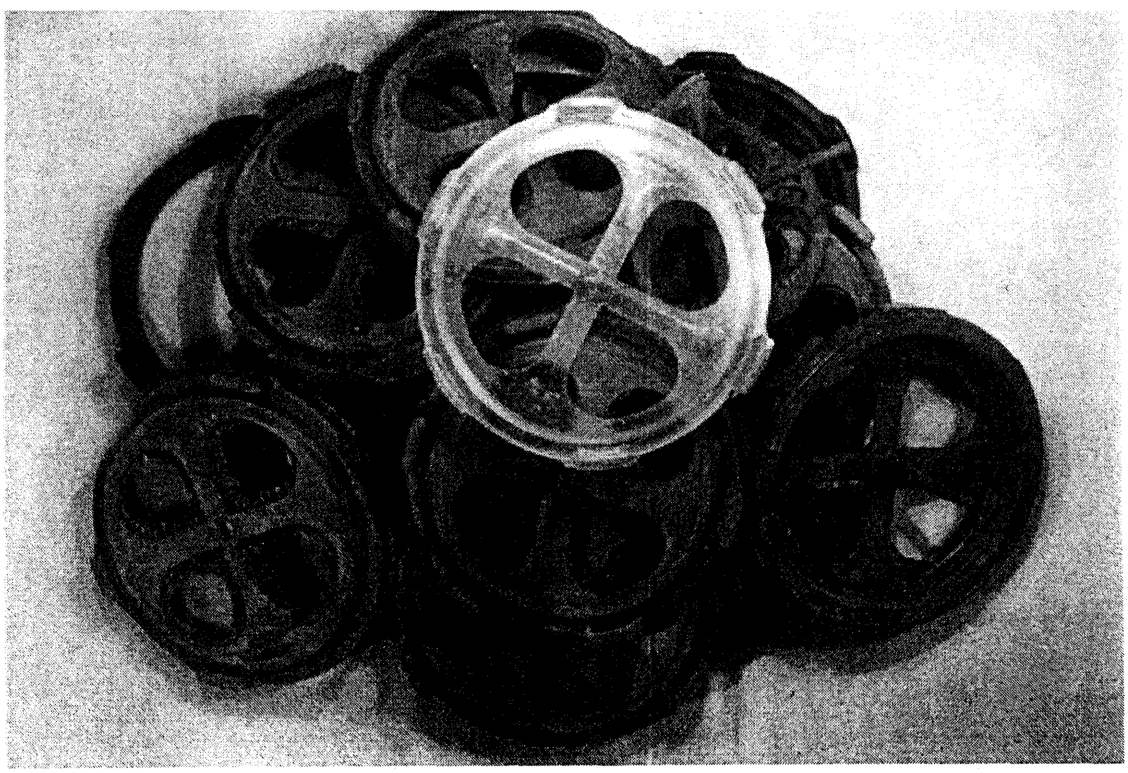

Figure 4: rubber parts in different materials from various tools, stereolithography part

5 Improved resins for casting tools

Since cast resin tools have several advantages, this process chain, mainly the material, is worthy of further improvement. A cast resin tool can be made in parallel to the tools design starting with the part. The parting line, drafting and the gate are designed manually by the tool maker. The molds also close properly. Finishing of the parting surfaces is not required. This step often takes a lot of time when using other tooling techniques.
The demands on cast resins for making tools can be defined as shown in Table 1.

Processing	Properties of cured material
• Compatibility with stereolithogaphy patterns (i.e. hardening below 70 °C) • Negligible shrinkage • Good surface quality • Good flow properties • Wetability (reinforcement) • Reaction not affected by humidity, fillers or reinforcement	• Stiffness and strength at room and tool temperature (200 °C) • Cutable with normal cutting tools • Low thermal expansion • High thermal conductivity • High density and heat capacity • Compatibility with rubbers (some materials disturb the vulcanization)

Table 1: Demands on Cast resins for tooling (rubbers)

These demands have to be considered either when selecting commercial resins or when searching for new cast resins or new filling materials. For example, most of the commercial tooling resins are filled with aluminum. However considering the thermal expansion, heat capacity, density or the thermal conductivity there are more suitable metals. On the one hand aluminum powder possesses a very good thermal conductivity, but on the other hand the thermal expansion is rather high. Since the tool temperature is high (200°C), it is important to use a cast resin with a low thermal expansion, therefore aluminum isn't a suitable filler. The IKP developed a cast resin tooling technique which allows use of reinforcement fibers on critical features and allows a fillerloading of about 5% in volume more than commercial cast resins. The combination of a high fillerloading and a suitable filler gives high stiffness and enables cast resin tooling even at 200 °C.

Figure 5 shows a rubber part together with metal inserts which are surrounded by rubber. It was manufactured in a tool with two mold halves and three slides made of new cast resin composition developed at the IKP.

6 Summary

The feasibility to produce rubber parts with rapid tooling techniques was shown. Of course all of the tested process chains show some problems to be improved. Cast resin tooling as a very affordable technique has a high potential to be improved in future.

Figure 5: Rubber part vulcanized in a cast resin tool, inserts to be inmolded

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