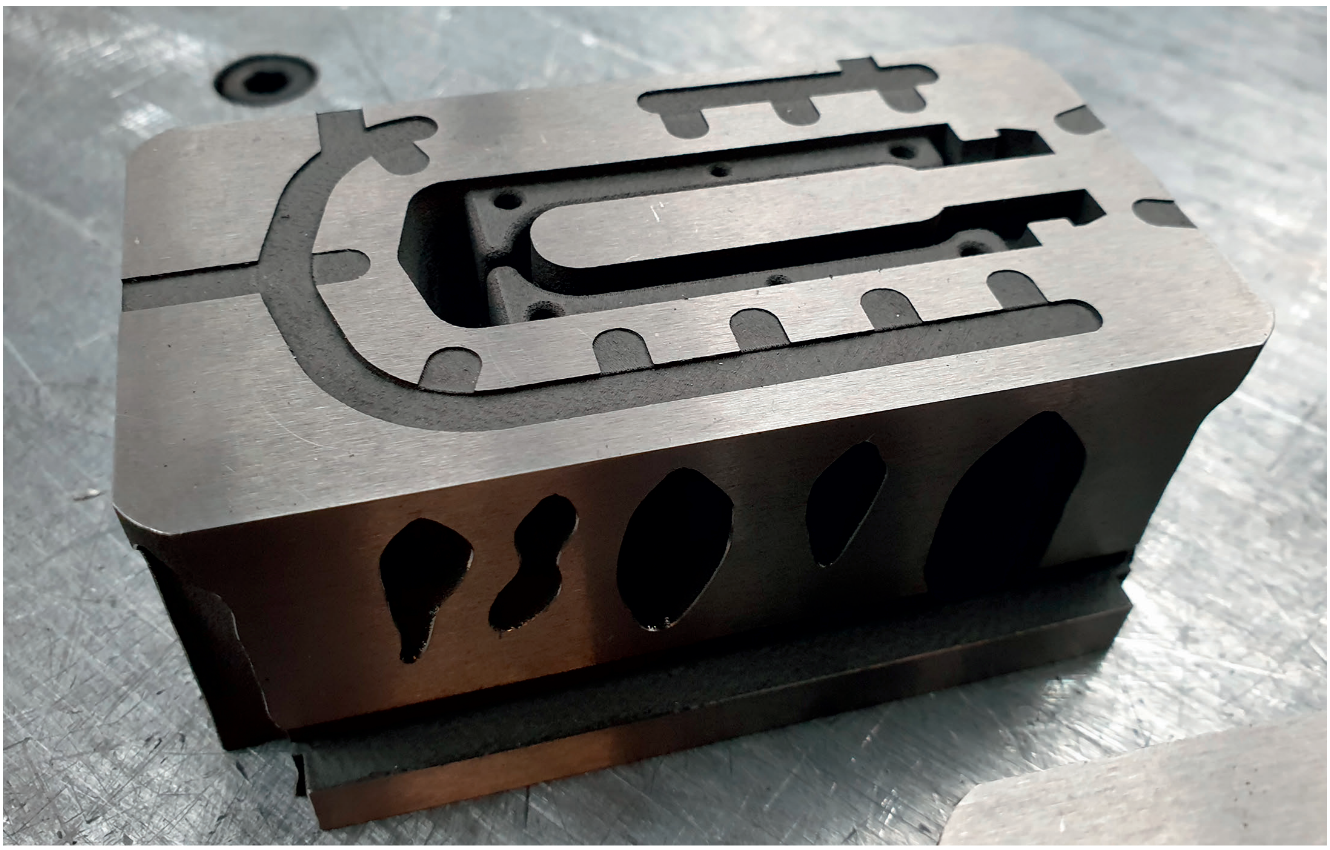
The Potential of Redesign and Part Consolidation

Additive Manufacturing and Hybrid Molds in Combination with Conventional Machining

Hybrid production chains have been increasingly in the spotlight in recent years. This also applies to the combination of conventional manufacturing and additive processes in tool construction. With the example of an injection molding tool, it is shown how mold inserts produced by additive manufacturing can greatly shorten cycle times, and thereby significantly reduce unit costs. The important thing is to find a suitable combination of processes from the variety available.



Tool insert for a spacer of a glass fiber-reinforced PA66. The example shows that hybrid manufacturing is suitable and provides added value, even with comparatively simple parts © Eisenhuth

Over recent years, additive manufacturing processes have greatly improved in terms of their performance, reliability and the range of materials available. There are many industrial applications now available and new ones are emerging all the time – as is shown by the examples during the Corona crisis. However, it is also becoming clear that approval or certification is a stumbling block for rapid implementation in industrial series production. Especially where series production is concerned, not all processes are completely certified, or not all materials are available. This is because of the principle of layer build-up.

If 3D printing and conventional machining processes are combined with tool and mold making – the prerequisite is always adequate equipment and the corresponding expertise – then the disadvan-

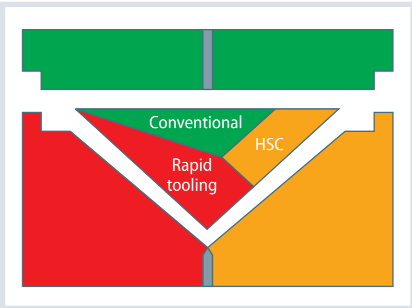


Fig. 1. Apart from conventional tool building, hybrid molding also includes additively manufactured mold inserts and HSC milling

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tages of part production in a hybrid production chain can be transformed into advantages by means of tool making.

Tools for injection molding elastomers, thermoplastics and thermosets have always been manufactured by the familiar material removal processes, such as lathe turning, milling and electrical discharge machining. Molds and mold inserts – which are for the most part subsequently hardened – have high surface quality, hardness and fatigue limit. The success here depends on many years of experience in the use of the tools. For example, with a long tool life, parts and components can be produced in uniformly high quality.

The Process Chain is Becoming More Challenging

For many years, a switch toward smaller batch sizes and shorter availabilities has been apparent – with a uniformly high quality always being required. This results in a dilemma for mold makers, since tools manufactured faster (e.g. from materials that are easier to machine) offer a shorter lifetime. To compensate for this, new solutions, often more technically complex, are required. It is also necessary to call on new processes to find solutions that meet these challenging conditions.

Additive manufacturing (AM) – in particular metal layering processes – if correctly applied, offer many advantages for manufacturing tools, and allow unique features and functions to be realized, which were not conceivable until now (using conventional methods). However, these processes also have disadvantages in surface quality and in speed of manufacturing. Additive manufacturing proves to be a promising addition to conventional methods, particularly if it is combined with conventional methods such as HSC (high speed cutting), which, as is known, is suitable for rapid machining of surfaces. With this procedure, it is important to realize that, due to the combination of processes, the process chain is extended with an additional factor, but also becomes more challenging.

It is already becoming clear that there is no moldmaking process for rapid manufacturing of injection molds that could really satisfy all the demands. The conditions applying to machining only allow high-speed operation to a limited extent. 3D printing, by contrast, offers advantages that can be exploited if the correct process parameters and chains are chosen and can significantly improve the efficiency, despite process-dependent disadvantages in the surface structure and fatigue limit.

The Combination: Hybrid Molding

Given the aforementioned problems, Eisenhuth GmbH & Co. KG, Osterode, Germany, as part of the "KitkAdd" project, publicly sponsored by the BMBF (German Federal Ministry of Education and Research), after a great deal of creativity and empirical work, succeeded in developing the combination of mechanical tool manufacture and metal 3D printing into so-called "hybrid molding." This approach essentially makes use of additively manufactured mold inserts, steel inserts manufactured by HSC, milled graphite electrodes and moldmaking standards, such as master molds, guide pillars and bushes (**Fig. 1**).

Each of these elements has positive material and manufacturing properties as a result of the process, which not only determine the injection mold but also its design [1] and construction. It is thus essential to combine the corresponding properties of the individual components and processes with one another. Combining the advantages of all manufacturing processes results in very efficient tools with their own unique features [2].

First the particular application must be described accurately. Based on their advantages and disadvantages, a strategy for utilizing the processes is created well before the design work is performed. The designer decides which parts are manufactured using which process, and which processes can be used. After the single part design has been completed, ready for manufacturing, the individual manufacturing steps are started simultaneously, even combining the individual manufacturing and secondary finishing processes. It is necessary to exercise especial care when planning and implementing this process. At the end, the parts are combined with one another and are available for production in a mold insert [3].

Designing for AM

For all manufacturing technologies, the production parameters must be observed. For example, with HSC, the absolute material removal rates are relatively low, but very high strength materials can be machined. 3D printing offers advantages for complex structures and great geometrical freedom and flexibility, though, here too, the pitfalls lie in the details. Low build-up rates, and therefore a high price per built-up volume require the design to be adapted to AM in the early stages for the least possible material consumption.

Not all structures can be manufactured additively, so that, for example, small bridges, deep grooves or delicate structures can present difficulties. Since this is still dependent on the orientation of the part in the build chamber of the AM machine, the designer faces a particular challenge to produce designs suitable for manufacturing. »

Fig. 2. The part is used during painting to keep the engine hood at a defined distance

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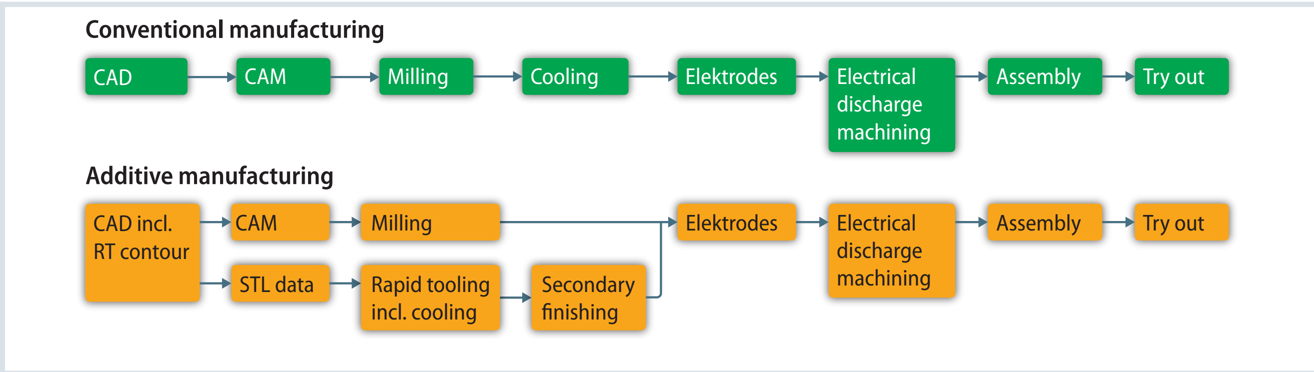

Fig. 3. Graphic of the conventional, hybrid and additive process chains: the mold inserts for the tool for injection molding the spacer were manufactured by selective laser melting Source: Eisenhuth, © graphic: Hanser

The advantage of the generative build-up of the metal tool components, namely the possibility of manufacturing extremely complex shapes, can also be utilized for combined application in electrical discharge machining. Thus, additively manufactured copper electrodes open up new machining possibilities here, and can supplement the graphite electrodes manufactured by HSC in the case of particularly difficult geometries.

Spacer as a Practical Example

In previous years, Eisenhuth gained a lot of experience in various industries with customer parts. The example of an injection mold for a simple part (**Title figure**) is used here to illustrate a suitable combination of processes from conventional and additive manufacturing. The part that is manufactured here is a spacer (**Fig. 2**) of a high temperature resistant, glass fiber-reinforced "triple-six polyamide" (PA6T/66, type: Grivory HT2V-3H, manufacturer: Ems-Chemie AG, Domat/Ems, Switzerland).

The aim of the project performed with this material is to examine what advantages can be achieved with AM parts, and how much influence additive manufacturing has on the cycle time, and therefore on the costs of the injection-molded part. And also to show that hybrid manufacturing is suitable and provides added value, even with comparatively simple parts [4].

The original approach was only to optimize the costs for the final serial part. However, since the spacer had already been optimized for series production (i.e. finalized) and could not be manufactured from the specified series material with the required strength, the workaround was chosen to optimize the tool in favor of shorter injection molding cycles. This was achieved using a temperature-control system with conformal cooling. It was also possible to reduce material consumption and therefore the costs for tool manufacture by means of a so-called "bionic design" [5].

Optimizing the Tool by a Bionic Design

The design of the mold insert is initially based on the target geometry, i.e. the original data set [5]. Implementation in 3D printing required one thing in particular: observation of the AM-specific design rules [1]. The ultimate design satisfied the loading, manufacturing and secondary finishing requirements for a mold insert that was produced by selective laser melting.

Due to the layer-by-layer manufacturing process, the design could be optimized during CAD, such that the mold inserts could be produced with approximately 35 % lower material consumption. As a result, the process time in the AM machine – generally the cost driver [6] – was also reduced, so that the manufacturing of the inserts was accomplished in less than two thirds of the time [5]. In addition, the hybrid-molding design was chose so as to keep the effort for secondary finishing as low as possible.

All these measures – especially the conformal cooling – increase the part complexity significantly. This highlights the big advantage of additive methods since, unlike conventional machining, the complexity here has only a very small influence on the costs ("complexity for free") [4].

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Service

References & Digital Version

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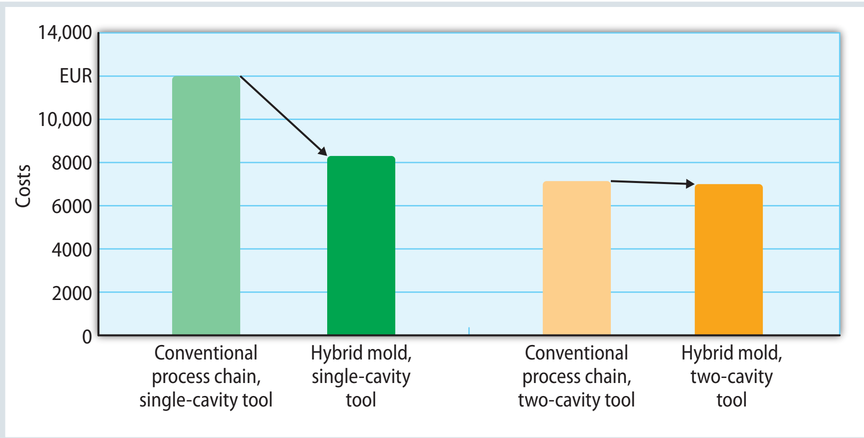

Fig. 4. Production costs for 100,000 plastic parts in each case with a one- and two-cavity tool. The hybrid process chain has the advantage Source: Eisenhuth, © graphic: Hanser

Comparison of Process Chains: Complexity Has no Extra Costs

Within the publicly sponsored "KitkAdd" project [7], Eisenhuth, together with one of the project partners, the Institute of Production Technology at the Karlsruhe Institute of Technology (KIT), developed a calculation tool for determining the manufacturing costs and times in production. The starting data can now be changed at any time, and since it can be almost precisely predicted how the changes each influence the result, the effectiveness of a measure can be derived.

The calculation tool is based on a detailed analysis of the different process chains (**Fig. 3**). This can be used to determine all the data and parameters that influence the mold and injection molded part costs, as well as the production times. From the result, the three possible variants – conventional, hybrid and additive process chains – can now be compared.

In this context, hybrid means a combination of a conventional tool with additively manufactured mold inserts. In the scope of the project tool, the project partner KIT also determined what costs are generated by a purely additive tool. Here it was found that there is no break-even, i.e. the 100 % additively manufactured tool is more economical than a conventional tool.

In a detailed analysis of the process chains, the tool costs for the two variants, the one- and two-cavity tool, are considered and this information is also incorporated into the calculation tool. As a result, it is found that the hybrid tools are about 35 % more expensive than the tools manufactured conventionally. This is primarily because of the increased manufacturing and secondary finishing costs of the additively manufactured inserts.

However the crucial factor is that the pure consideration of tool costs only covers part of the process chain, since with the use of hybrid tools, the production costs of the final parts are reduced. Consequently, after the tool costs, it is also necessary to determine the part costs for the two tool variants. The developed cost model not only supplies the pure costs for the basic tool and mold inserts, all the cost factors, such as the cycle time, are also considered.

This is also found in practice: In the case of additively manufactured mold inserts, the cycle time is shortened significantly (25 s instead of 38 s) due to the conformal cooling in contrast to mold inserts manufactured conventionally. This leads to a significantly higher utilization of the machines and increases the capacities: thus, e.g., for 100,000 parts, the break-even is reached even earlier (**Fig. 4**). Consequently, the part costs of the hybrid AM production chain for this two-cavity tool are reduced by about 2.5 % compared to a tool manufactured conventionally.

Summary

The example shows that despite the higher tool costs and the necessary secondary finishing work, the productivity for using hybrid tools is increased significantly while the part costs are simultaneously reduced. The prerequisites for this, however, are, first, a greater design effort and the necessity for comprehensive process knowledge of the – very different – methods used. In summary, it can be stated that the additive manufacturing of tools and tool inserts leads to significant technical and economic advantages for producers who are open to new ways of thinking and are not afraid of the effort. ■