PC_{Pro} a novel technology for Rapid Prototyping and Rapid Manufacturing

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1 Abstract

PC_{Pro} stands for Precise Cast Prototyping, which is a combination of casting technologies and milling. This method was developed at Fraunhofer IWS in Dresden, Germany. It is patented in Germany [1] and is applied in the USA under US 10/794,936. The main goal for this development was to shorten the process chain for making plastic prototypes accompanied by higher quality. The casting technology was integrated in a machining center in order to enable a high degree of automation and to avoid an external casting system. This means that Rapid Manufacturing can be easily implemented using such an automated combination of casting and machining.

This article describes the PC_{Pro} method by means of the fabrication of sample parts. The advantages and the limitations in comparison to common Rapid Prototyping and Rapid Manufacturing process chains will be discussed. In addition, the manufacturing of a prototype machine is presented.

2 Introduction

Rapid Manufacturing is nowadays described as the direct production of finished goods using additive processes out of digital data [2]. Considering the objective "direct manufacturing of finished products", it can be applied to all manufacturing processes that enable this goal out of 3D-CAD data. Therefore subtractive-, forming-, shaping- and molding- procedures and their combinations should be considered, while fulfilling the requirements such as high flexibility.

The PC_{Pro} method is characterized by the application of CAD/CAM, CNC-milling and casting technologies. Thus, it embraces forming and subtractive technologies. Forming such as molding is a well known process for the fabrication of prototypes. The investigated integration of casting systems in CNC machining centers accompanied with a high degree of automation offers higher productivity, profitability and quality of the produced parts. PC_{Pro} includes data generation of the mold/part, casting of the outer contour and milling of the inner contour. This combination allows a flexible control adapted to the demands of the product development process. The automation of the entire process chain enables Rapid Manufacturing.

This paper will deal with the basics of the PC_{Pro} method as well as with advantages, limitations and the actual development of a prototype machine.

3 PC_{Pro} process chain

In the following, the basic process steps are explained using a typical cover part common for example in automotive or electronic industry. The process starts with the import of the CAD data of the part in a CAD/CAM system.

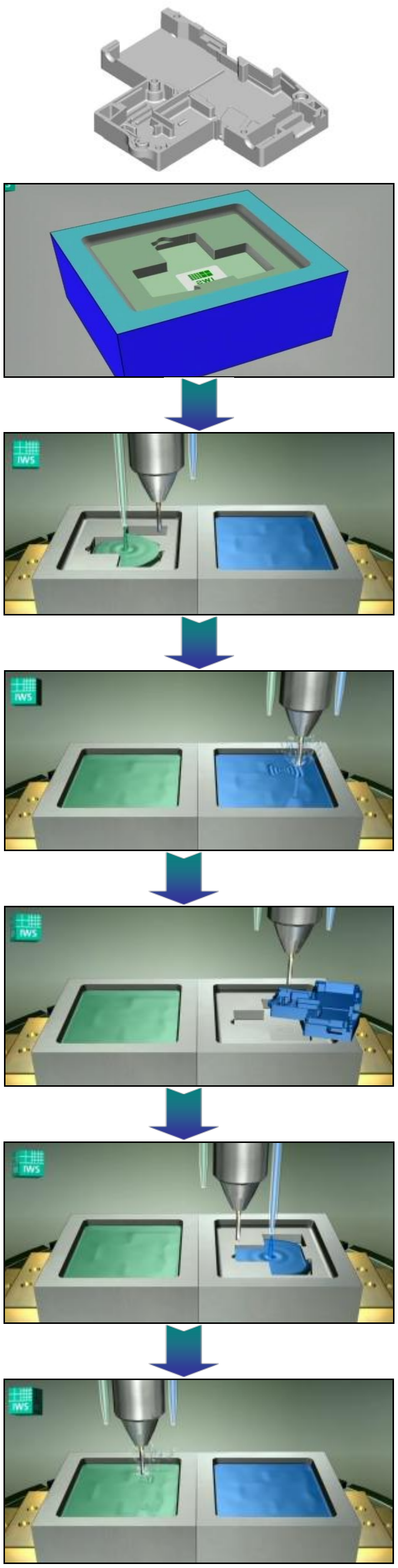
From this CAD data the lower mold is derived, which is easily done using a volume modeling CAD system. After the lower mold is generated as a three-dimensional CAD-representation, NC-programming and milling of the lower mold takes place. For this, the mold block is clamped in the combined milling/casting system. The finish machined mold will remain in the system for casting and part milling. As can be seen from Figure 1, in this case two molds (or parts) are manufactured simultaneously.

In the next process step, the cast material is poured in the mold. Possible materials are two-component fast-curing resins, typically used for vacuum casting or resin injection molding applications [3]. The mold block material can be similar. Other materials could be considered, such as metals.

Then the cast material hardens. After that, the inner contour is milled. NC-programming for the inner contour is done in the CAD/CAM system. For this, the CAD-file of the part is merged with the mold-data. For NC-programming, typical milling cycles or high speed cutting strategies can be used.

The final step is the mold removal. It can be done manually or automated. For a better removal, usually separator is applied before casting.

To increase the productivity for Rapid Manufacturing more than two molds can be placed in the PC_{Pro} system.



3D – CAD data
CAD data of the desired part is read in a CAD/CAM system.

CAD/CAM and milling lower mold
Derivation of the lower mold from the part CAD data. NC-programming and milling of the lower mold. Milling is done in the CNC- milling/casting system.

Casting left side
Pouring the cast material in the molds.
Remark: In this case, the process is shown using two cavities.

Milling of the right part
Milling of the already hardened material, to generate the inner contour (here right side).

Part removal right side
The finish machined part is removed. It can be done manually or automatically.

Casting right side
After part removal, the right mold is refilled. Meanwhile the left side has hardened, if using for example fast curing resins (10-15 minutes).

Milling of the left part
The left inner contour is milled. These process steps (starting again from part removal) are repeated until the job is finished.

Figure 1: PC_{Pro} manufacturing steps

3.1 Sample part fabrication

To prove the feasibility of this process, several plastic test parts have been produced. For the initial tests, the manufacturing of the sample parts was performed in a conventional machining system. For this, the model block was clamped onto the machine table and the mold was milled and prepared with separator. A standard two-component polyurethane system (RenCast™ FC52, [4]) with a low viscosity was manually mixed and poured in the cavity. Color and filler material were varied in these experiments (Figure 2).

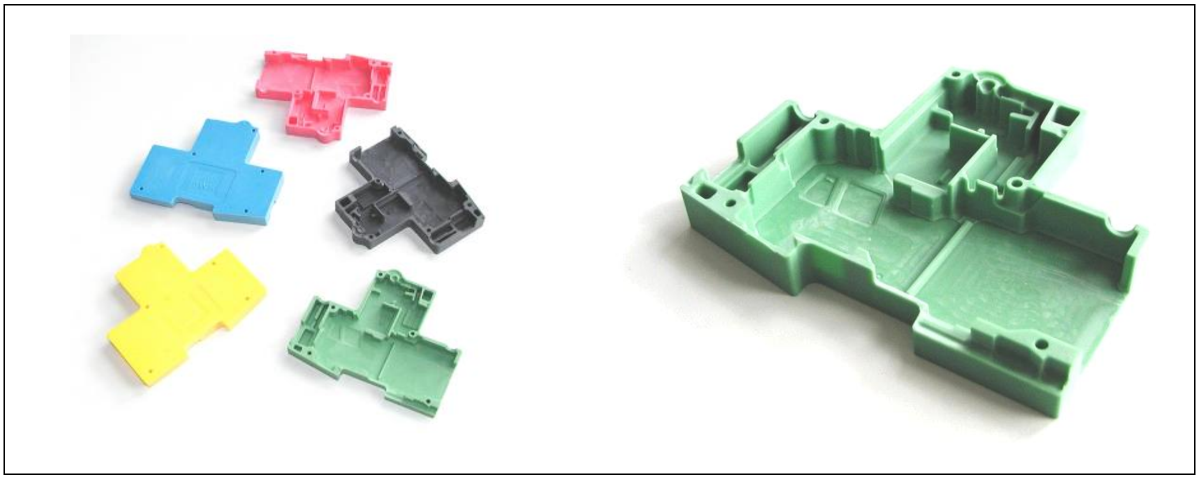


Figure 2: PC_{Pro} parts

The initial experiments have shown that the setup is useful to manufacture several parts with a complex geometry. The inner geometry of the part is easily changeable by changing the CAD/CAM stream of parametric systems. This is one of the big advantages that the upper mold only virtually exists. Hence the system is very flexible. Furthermore, less effort is necessary to build the tool.

Using just one mold and considering the curing time of the resin, plus ~5 minutes for machining, about 2-3 parts can be made per hour. Working simultaneously with two molds the production numbers are doubled. Depending on the available work platform, more molds can be prepared.

4 Manufacturing of the prototype machine

For the desired high degree of automation, several tasks must be considered. Examples of automation:

- Taking a mixer unit from the pick-up station.
- Moving to the desired cavity and casting a designed amount of resin.
- Mixer release at the drop-off station, since it will be cured soon.
- Collision avoiding of mixer and machining spindle.

The construction, manufacturing and testing of a prototype system was carried out at Fraunhofer IWS. The system is capable to generate prototypes automatically. At first, the mold removal will be done manually.

The prototype machine that can be seen in Figure 3 was presented at the Fraunhofer IWS workshop “Rapid Technologies” (November 2004) in Dresden [5] and shown at the Euromold tradeshow in Frankfurt, Germany (December 2004). As a result, a positive industry feedback can be stated.

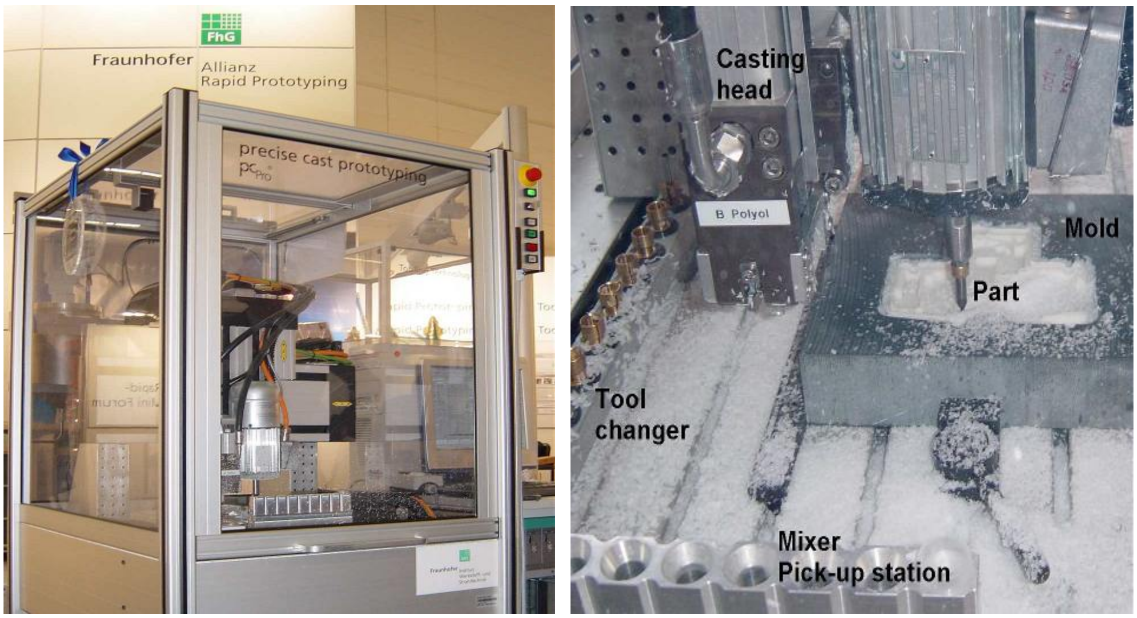


Figure 3: PC_{Pro} system at Euromold 2004

5 Advantages and Limitations

The PC_{Pro} method entails several advantages compared to common process chains such as Rapid Prototyping/vacuum casting. In this chapter the main benefits and limitations of the process will be outlined.

5.1 Quality

- During the casting process, air bubbles can escape freely, since there is no second mold half. Thus, completely dense parts can be manufactured.
- PC_{Pro} is a simple casting procedure without any gate system. Mold turbulence and thus air bubbles cannot occur.
- The wear of the lower mold half can be easily repaired by shifting the NC-programs and overhauling this tool half. It is not necessary to build a new tool.
- Complicated features (for example threads) that cannot be made by casting procedures are easy to manufacture using the integrated CNC-machining.

5.2 Precision

- Finish machining takes place after curing and shrinkage of the casting materials. Thus, the parts have a higher precision compared to other casting technologies. Narrow tolerances can be obtained.

- The complete machining is done in one set-up, therefore no inaccuracy results between inner and outer contour. There is no misalignment between lower and upper mold. Additional clamping for finish machining is avoided.

5.3 Time and costs savings

- The second mold half exists only in the form of NC-programs. That means geometric modifications can be done very quickly by changing the 3D-CAD geometry (parametric CAD/CAM systems).

- A physical master model is not necessary, thus the costly and time-consuming model-making process with expensive Rapid Prototyping equipment and materials is avoided. Moreover, the model preparation for the usage as a master is omitted.

- The expense for mold making is reduced, because only one mold half is manufactured. Construction of the second tool half including gating system, risers, mold venting and mold parting is avoided. Less experience of mold making is required.

- 3D-CAD effort is reduced. Construction of mold release slopes and fillets for inner contours are not necessary.

- Preparation of the mold is reduced, since only one half has to be cleaned. There are no mold venting holes that have to be prepared for casting. Separating of gating systems, risers and finish machining of the cast-part is omitted.

- If the lower mold is made of tool steel, it could be used for the following mass production.

- Cycle time depends on the number of molds used in the machining system.

- Automation of the entire process chain by the usage of exchangeable modules or transfer lines makes this process capable of Rapid Manufacturing.

- Integration in existing machining centers is possible.

5.4 Limitations

- Highly complicated geometries are difficult to manufacture. Typical application fields are parts with high demand on surface finish quality for the outer contour and with close tolerances for inner features.
- Undercuts in the inner contour could be made by 4 or 5 axes milling. Undercuts in the outer contour can be removed from the mold using mold inserts or silicone parts.

5.5 Process chain of PC_{Pro} in comparison to vacuum casting

As can be seen from Figure 4, the process chain to manufacture prototypes is shortened, which contributes to time and cost savings. It is mainly reduced because of the lower effort to build the mold and an easier casting technique.

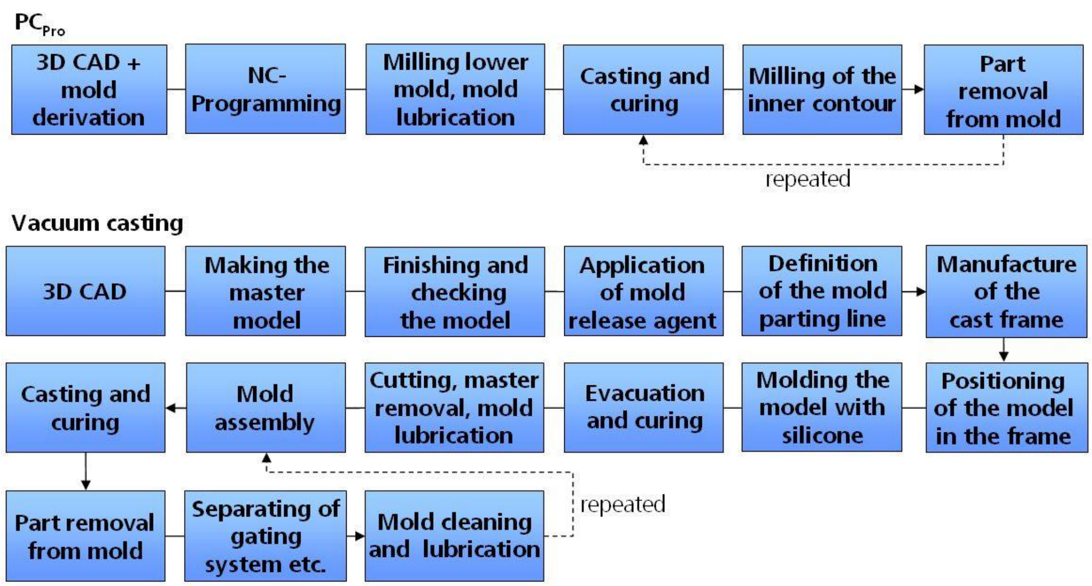


Figure 4: Comparison of RP process chains

6 Summary

For the generation of plastic prototypes a unique technology was developed. The system consists of a combination of forming and subtractive manufacturing methods. The solution is a low cost system that enables the generation of parts with high precision. The process chain to generate prototypes is highly shortened, accompanied with the possibility of quick geometrical changes. PC_{Pro} can be described as a fully automated process chain for mold making, casting and mold removal of the part. Because this system enables high part quality (close tolerances and high surface quality) and thus minimized finish machining, it is a true Rapid Manufacturing System.

Moreover, the high flexibility concerning geometry changes for the inner and outer contour allows Rapid Prototyping and Rapid Manufacturing. Geometric changes during serial production are easily to realize without a big effort for mold making.

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