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쾌속조형(Ceramic SLA)과 고속가공을 이용한 단납금형 개발에 대한 연구

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Case Study of Hybrid Tooling using High Speed Cutting and Ceramic SLA (StereoLithography Apparatuses) Technologies

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"Getting to market first" is extremely critical in this competitive business environment. The speed at which products are developed and released to market is tightly linked to profitability and market share. Many companies that have been very skeptical of Rapid Tooling (RT) technologies developed so far are working on Hybrid Tooling (HT) that can really meet the market standards. This paper describes the experimentation how HT process has been being successfully established and effectively applied with typical case study. Through the experimentation, Ceramic-filled HT was found to be aptly suited for the low grade mold, both in terms of the lead time, dimensional accuracy, and tooling cost.

Keywords : Hybrid Tooling, Rapid Tooling, Bridge Tooling, Mold, Ceramic-filled SLA

1. Introduction

During the past 10 years, Rapid Prototyping (RP) technologies have been explored for direct fabrication of injection molding tools using 3D CAD models [1, 3]. The challenge in RT is related to the fact "the requirements are tighter than that of RP". In order to meet the tighter requirements, the challenge lies in combining lead-time, strength, accuracy and surface quality. However, most of them have been found almost unviable due to their intrinsic properties of fabrication material and process while many RT technologies allegedly could meet the market requirements [1, 3].

Many RT technologies have been introduced based on 3D CAD/CAM standardization and database. A new product development process had been introduced in which production tooling starts after RT for reliability tests and bridge tooling. Key concept of this product development process is based on simultaneous engineering "using one CAD data base from product design to mass production." Unlike others, as shown on <Figure 1>, FDSolutions (Fast Delivery Solutions) is a total RT solution, which is encompasses from conceptual tooling to bridge tooling using hybrid approaches.

HT consists of three kinds of time-compression technologies to help expedite injection tooling within a week from customer's data receipt. This tooling concept with the conviction can be a reliable alternative for current RT technologies.

As soon as customer's product model data is transferred to RT division, basic tool design starts using tooling analysis derived from quotation stage that finished within only a day. In the next step, insert fabrication method or combination is se-

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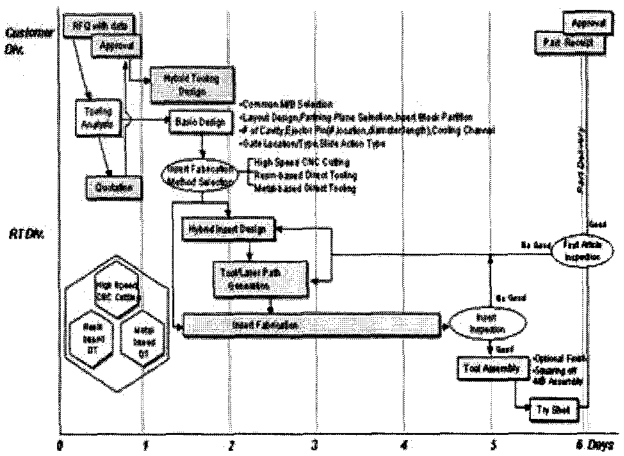
lected, and then Hybrid Tooling insert design begins along with early-phase insert fabrication based on basic design results. Along with Hybrid insert design, tool or laser paths are generated to fabricate inserts for feature details using 3 kinds of time-compression technologies.



<Figure 1> Basic concept of Hybrid Tooling (FDSolutions) process

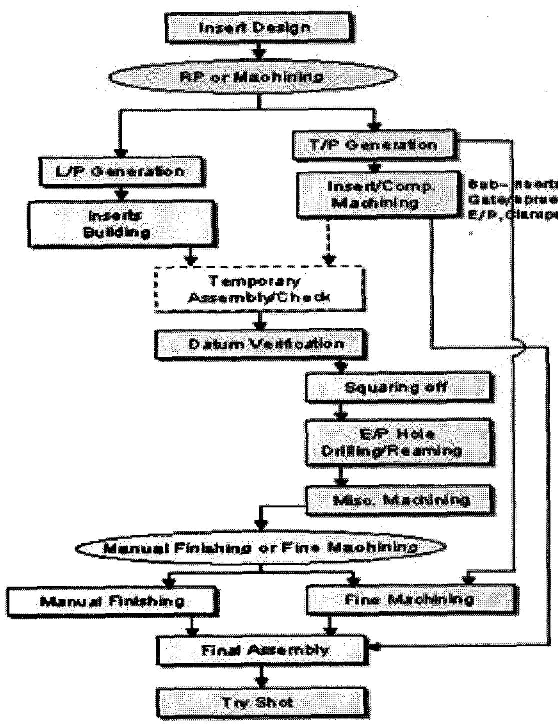
Once insert fabrication is finished, fabricated inserts should be inspected by CMM or other measuring instruments. If inspection result is good, inserts are assembled into a common mold base already selected. And then parts are sampled on the injection-molding machine using the fabricated inserts. The molded parts are delivered to the customer if they are checked well. The following sections evaluate how HT processes work, and presents current possibilities and limitations.

2. Experimental Work

2.1 Experimental Procedure

In this research, ceramic filled SLA Tooling with High Speed Cutting (HSC) has been explored. Basic procedure for this experiment followed the flow chart shown in <Figure 2>. At first, mold inserts with sub-inserts were designed by semi-automatic mold design program. And then some value analysis followed in order to decide which fabrication method to be taken for mold inserts and sub-inserts.

Along with the flow chart, one set of SLA mold inserts were made, and other inserts were machined on CNC milling machine. Ceramic-filled SLA mold inserts were built on SCS-8000 (Sony/D-MEC) using SCR-802 resin. So all inserts with sub-inserts underwent a proper process decided by value analysis. After that, mold inserts and sub-inserts built on each RP machine underwent intensive machining procedures for squaring off, drilling, and EDM with other miscellaneous machining.



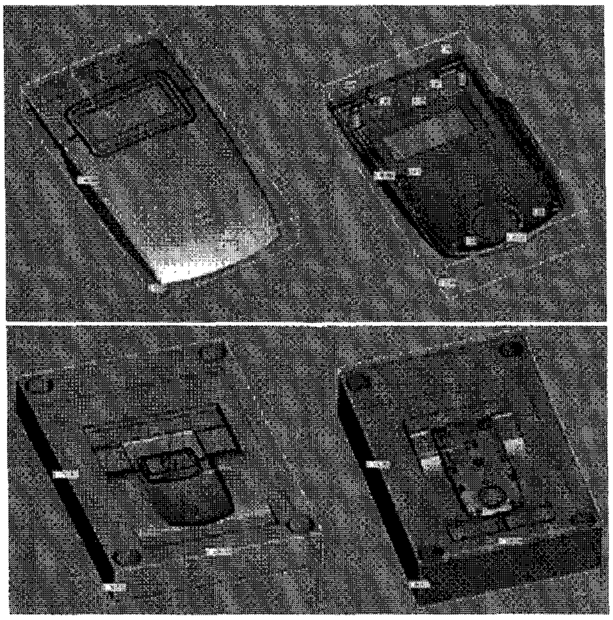
<Figure 2> Core procedure of HT process

All inserts and components were assembled and fitted into mold bases after finishing. Finally, injection molding for try shot was done on an ordinary injection molding machine. All of these procedures have been adopted as a standard core procedure of Hybrid Tooling process. A detail experimental process is described on the following sections.

2.2 Insert Design Considerations

In purpose of the case studies, the part in <Figure 3>(a) was applied. There are four small pillars with a diameter of 1.5, and 1.6mm on the part. These pillars are also assembled into the other side of part, and loose cores are applied in order to build these shapes. The part also contains two square features with a length of the sides of 8.6 and 7.7mm, which are also assembled into the other side of part. The part in <Figure 3>(a) contains three undercuts. Two undercuts are symmetric into Y-axis, and the last one is unsymmetrical into the others. In order to build these kinds of undercuts, insert slides are applied in general tooling process.

The design of a mold block in <Figure 3>(b) is a little different than that of the mold block made with the metal RT. Ceramic-filled RT process uses a kind of ceramic material that is based on the photo curing resin. Generally, the ceramic material is difficult for the cutting process due to its brittleness[2, 4]. Most features (weak to the machining during the post process) are removed on the mold design. The clear holes (required for an eject pin,) are already designed on the core block shown in <Figure 3>(b). The ceramic material is also week to the injection pressure. Some of features, that are weak to the pressure, are removed. In orderto build these kinds of the weak section, loose cores based on metal are assembled into the core block in <Figure 3>(b). There are four elliptical shapes on each corner of the mold, which function is rigidly to bolt the mold into the mold base with the screw. These shapes are also used to align the halves of the tool into the mold base.



<Figure 3> Part and Mold design applied into RHT : (a) Applied part and (b) Mold block

The mold design was conducted with Unigraphics (3D CAD software), and then converted into STL file. Magics Tooling (3D CAD software) is also used to handle, and to manage the STL file [5]. Due to the instability of current Rapid Tooling (RT) process, usually, artificial feature are attached on the mold block in purpose of HT. The artificial feature is then used into the base line or point of the post process. In this case study, however, there is no artificial feature on the part as shown in <Figure 3>(b).

2.3 Evaluation Criteria

In RT industry, the difference between precision and accuracy has been discussed a lot. Precision is related with the ability to make fine detail, that is, the standard deviation of the data. On the other hand, accuracy relates to the correctness of dimensions, that is, an indication of how close a measurement is to the true value. The cornerstone in RT process is accuracy. The accuracy of a part depends on its application and geometry.

2.3.1 Dimensional Accuracy

To evaluate the dimensional accuracy of each process, 3D scanner was used to collect the measurement data of each experimental part. The scanned data are then compared with 3D CAD data in order to assess the dimensional accuracy. The output data are classified into two categories that are a mold block (core, and cavity), and a molded part.

2.3.2 Mold block

- 3D image of fitting the scanned data into 3D CAD data of the mold block
- Flatness of the parting line
- Vertical tolerance of the parting line into the Z-axis
- Measurement and location tolerance of the assembled section

2.3.3 Molded part

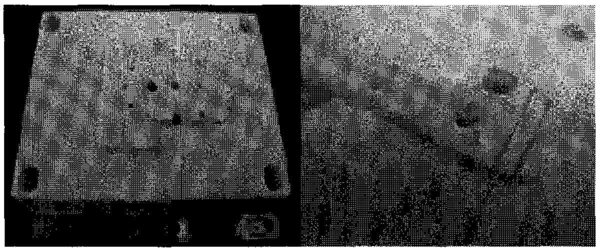
- 3D image of fitting the scanned data into 3D data of the molded part
- Flatness of the parting line
- Measurement and location tolerance of the assembled section

2.3.4 Tooling Lead time

Since the end user wants to receive the parts quickly, total manufacturing time including part finishing is the first priority. In order to be applied into the injection molding process, each mold block fabricated by RT process was handled with the machining process. The machining process was done using conventional techniques. For the experimental investigation, the machining time and condition were measured and collected during the post process.

3. Experimental Work

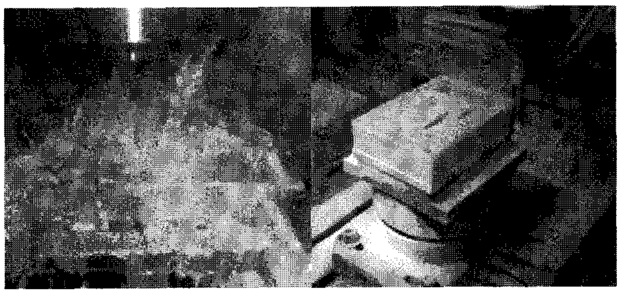
Comparing to the metal-based rapid tooling, the resin-based rapid tooling has better dimensional accuracy and precision. The post process is required to be used in the injection molding process due to the stair effect and the deformation shown in <Figure 4>(b) and <Figure 5>(b). For our experiment, only four steps were conducted for the molded part to be produced in the injection molding process.



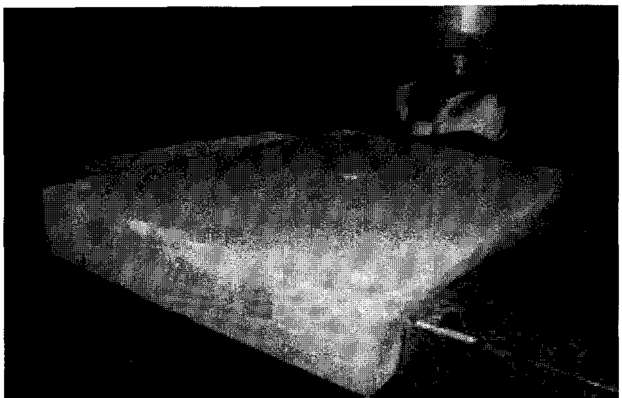
<Figure 4> Mold block fabricated by Sony : (a) Core block, and (b) Close up view of a section

<Figure 5> Mold block fabricated by Sony : (a) Cavity block, and (b) Close-up view of a section

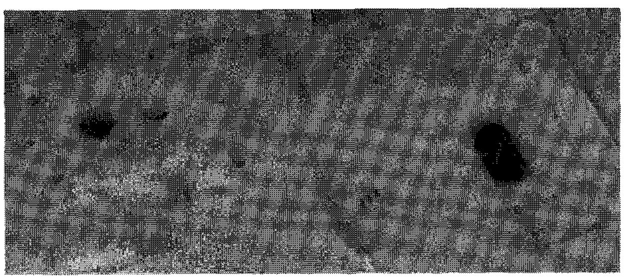
- Base line and point : In order to figure out the base line and point, the same process applied in the metal-based rapid tooling was conducted on the resin-based mold block. Dial gauge is used in order to check the direction of X-axis and Y-axis, and the center point of the mold block.
- Machining process : During the injection process, the two halves of tool are touched on the shut-off faces. Even though the resin-based mold block has better dimensional accuracy, machining is conducted in order to make the shut-off faces flat as shown in <Figure 6>. The side and back surfaces are also machined to fit into the mold base flat as shown in <Figure 6>(b). After machining the surfaces, micro tool is used into the features of the part for the fine finishing. During machining the backside of the mold block, a lot of dust is generated as shown in <Figure 6>(b) and <Figure 7>. The dust is mainly generated because of the components (ceramic powder) of the resin-based mold. The raised dust may also reduce an efficiency of machining. <Figure 7> shown another effect of the rough milling during machining. The fragments on the block edge are occurred due to the brittleness of the ceramic material.
- Drilling and EDM : As shown in Figure 4 (a), the ejecting holes and the places for the insert cores are already made on the core block. Drilling for these features is not required for the resin-based mold block. Due to the property of the ceramic material and the better dimensional accuracy, EDM cannot be applied on the resin-based mold block.
- Polishing : The molded part is stocked into the core block or fractures some features during the injection process. The problems might be occurred due to the semi polishing of the side surface. In order to prevent this kind of problems, the side surface of the weak features should be fine polished as shown in <Figure 8>.



<Figure 6> Showing the machining of the mold block fabricated by Sony process : (a) Cavity block, and (b) Core block

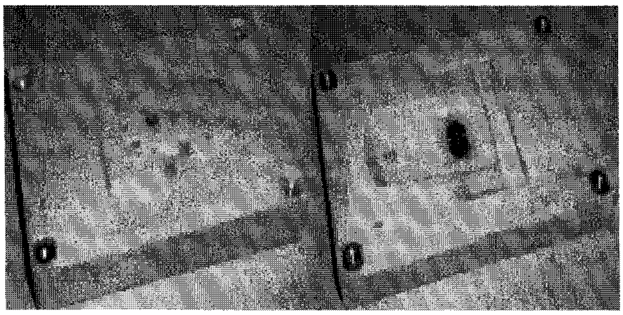


<Figure 7> Showing the effect of rough milling

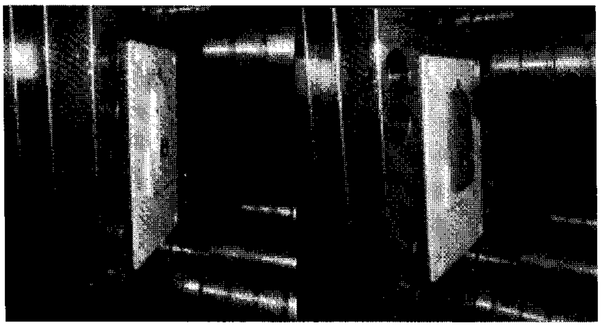


<Figure 8> Showing the mold block after machining and polishing : (a) Core block, and (b) Cavity block

As shown in <Figure 9>, the mold block is ready to fit into the mold base after the post process. Four screws are inserted on each mold block in order to firmly attachéinto the mold base. The detail numerical results are described on the next section. After trying several experiments, parts are molded as shown in <Figure 10>. The detail numerical results are described on the next section.



<Figure 9> Showing the mold block fabricated by Sony process after the post process



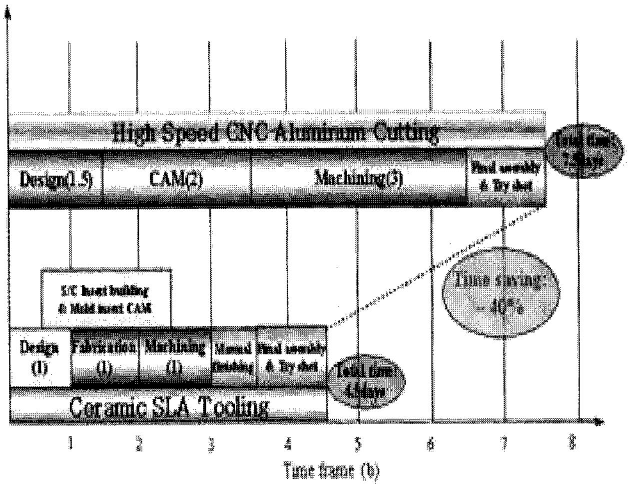
<Figure 10> Showing molding process with the different material

4. Result

As previously mentioned, the challenge in RT or HT lies in how to combine lead-time and dimensional accuracy which can be acceptable in this industry, and so we firmly believe Hybrid Tooling approach in which RT can be aided by high speed CNC machining is a reliable alternative. Based on our 2 case studies, we can summarize what we found as follows;

4.1 Tooling Lead-Time

Since customers want to receive their parts quickly, total tooling lead-time including part finishing is the top priority. Each machine manufacturer provided the information related to fabrication time, condition, and material. As mentioned in the previous section, the machining process was done using conventional techniques. As shown in <Figure 11>, the lead-time of each process in each case was measured during the experimental investigation. The use of Hybrid Tooling process reduced the tooling lead-time on either case by 40% comparing to High Speed CNC tooling approach. However, it should be noted that tooling lead times can be reduced though they might be varied depending on the tooling project type.



<Figure 11> Experimental comparison of tooling lead-time: HSC and Ceramic SLA HT

4.2 Dimensional Accuracy

To evaluate the dimensional accuracy of each process, 3D optical scanner (COMET VZ100, Steinbichler) was used to inspect mold inserts built and part molded from them. The scanned data are then compared with original 3D CAD data in order to assess the dimensional accuracy. The output data are classified into two categories, one is for the mold insert, and the other is for a part molded.

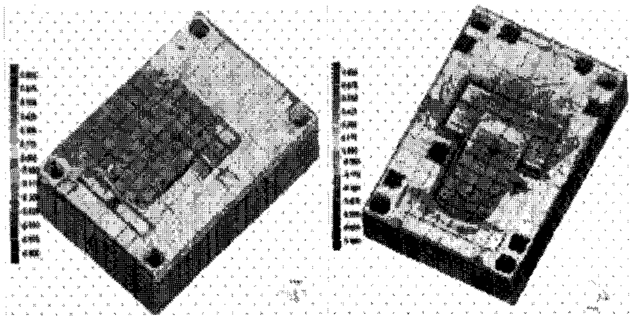
<Table 1> Dimensional accuracy of mold inserts

	Overall accuracy	Feature accuracy
SLA tooling	+ 0.15mm	+ 0.10mm

The mold inserts fabricated by HT approaches were scanned, and then fitted into the original CAD data as shown in <Figure 12>. Each part shown in <Figure13>(a) was sampled through the injection molding process. The brief conditions of the molding process are described in <Table 2>.

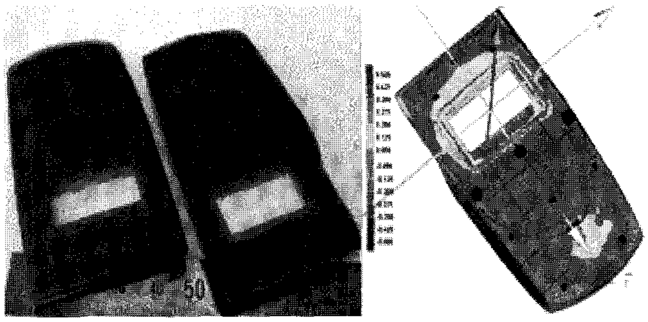
<Table 2> Molding condition of molded parts

Part name	MP cover
Resin	PC
Cycle time	160sec
Max. shot #	118(real)



<Figure 12> Scanned data of the mold insert before machining Ceramic SLA insert

The molded part were scanned, and then fitted into the original 3D CAD data as shown in <Figure 13>. The overall dimensional accuracy of the molded parts lies within the normal tolerance (~± 0.15mm) in <Figure 13>.



<Figure 13> Molded parts and scanned data for Ceramic SLA HT

5. Conclusion

This research has shown us how Hybrid Tooling process can be a relatively reliable RT approach and what kind of impact it can give to this tooling industry, though there are many intrinsic limitations still left to be improved further in the future; dimensional instability, low mechanical properties, and low surface integrity, etc. Based on the results from two case studies, the following conclusions can be made :

- Hybrid Tooling process has proven as a reliable and effective method with reasonable quality for time-saving over 30% in tool-making process; So we can suggest that ceramic SLA tooling approach can be cost-effectively used for conceptual/disposable tooling (under 200 shots),
- If general design rules for HT can be fully established, HT can hopefully be a general tooling solution any one can use with ease, though each RT has many intrinsic limitations.

References

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