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쾌속조형기술과 고속가공을 이용한 하이브리드 금형 개발에 대한 사례연구

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Case Study for Hybrid Tooling Using High Speed Cutting and RP(Rapid Prototyping) Technologies

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The speed at which products are developed and released to market is tightly linked to profitability and market share. Hence, many companies are still in a desperate need of real Rapid Tooling (RT) technologies which can really help to expedite their prototype tooling and pre -production tooling for injection molding. Many other companies that have been very skeptical of RT technologies developed so far are working on Hybrid Tooling (HT) that can really meet the market standards. With the conviction that HT can be a reliable alternative for current RT technologies, this paper describes the experimentation how HT process has been being successfully established and effectively applied with typical case studies. Through the experimentation, Ceramic-filled SLA tooling was found to be aptly suited for the low grade mold, and Metal SLS tooling was found to be aptly suited for the medium volume mold both in terms of the lead time, dimensional accuracy, and tooling cost.

Keywords : Hybrid Tooling, Rapid Tooling, SLA, SLS

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[2, 3, 9]. 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 have been developed so far [2, 3, 9].

In our job shop facility, many RT technologies have been introduced based on 3D CAD/CAM standardization and database, while high speed CNC aluminum tooling has been mainly applied to reduce their new product development cycle. Recently, a new product development process had been introduced in which production tooling starts when RT for reliability tests and bridge tooling starts to reduce "time

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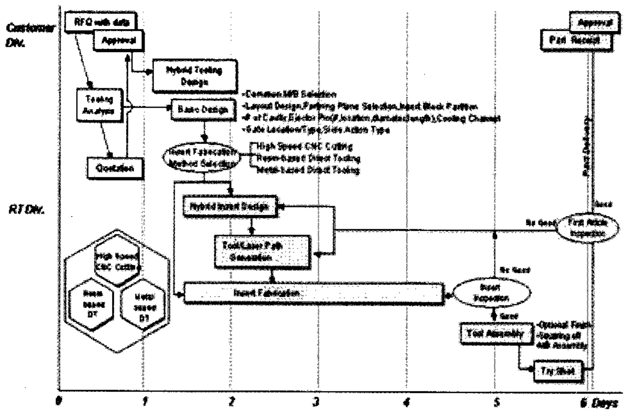
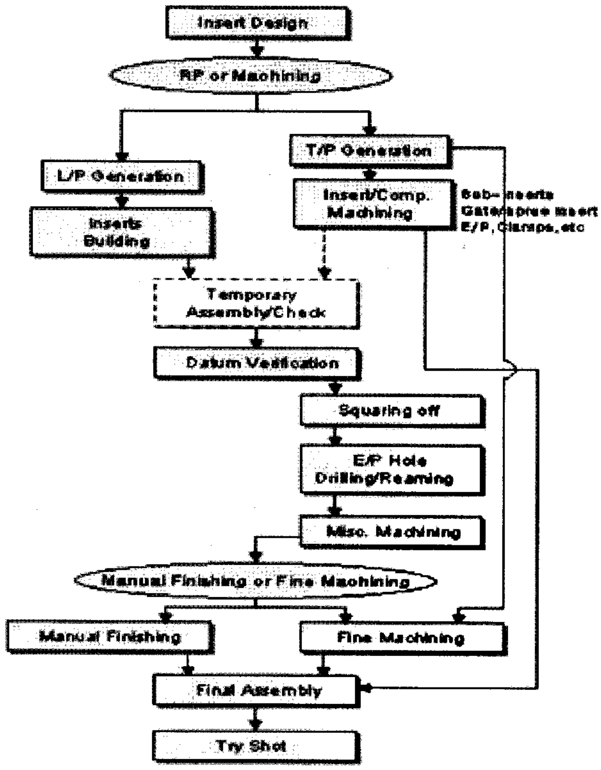


<Figure 1> Basic Concept of Hybrid Tooling Process

to market." 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 in <Figure 1>, HT solution encompasses from conceptual tooling to bridge tooling using hybrid approaches.

HT consists of three kinds of time-compression technologies that can help to expedite injection-molding tooling within a week from customer's data receipt. This tooling concept has established with the conviction that HT can be a reliable alternative for current RT technologies. <Figure 2> shows how fast RT division can respond to customer's request. 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 selected, 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 using 3 kinds of time-compression technologies. 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 injectionmolding machine using the fabricated inserts. The molded parts are delivered to the customer if they are checked well. The following section describes how HT processes are experimented, and presents current possibilities and limitations with two typical case studies.



<Figure 2> Core Procedure of HT Process

2. Experimental Work

2.1 Experimental Procedure

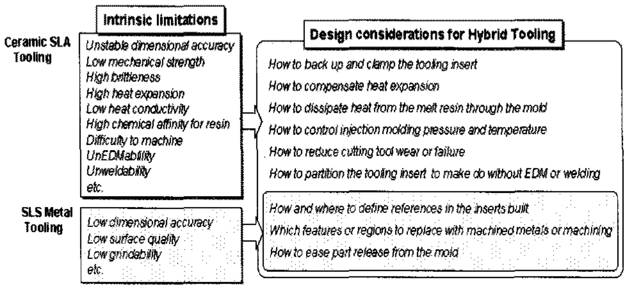
In this research, two kinds of HT processes have been explored : (1) metal SLS (Selective Laser Sintering) tooling with HSC (High Speed Cutting), (2) ceramic-filled SLA (Stereo Lithography Apparatuses) Tooling with HSC. Basic procedures for this experiment are followed. At first, mold inserts with sub-inserts 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 fabricating mold inserts and sub-inserts.

Along with the flow chart on <Figure 2>, one set of SLA mold inserts and one set of SLS 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, and SLS metal mold inserts on Vanguard (3D Systems) using Laser Form (ST-200). 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. 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.

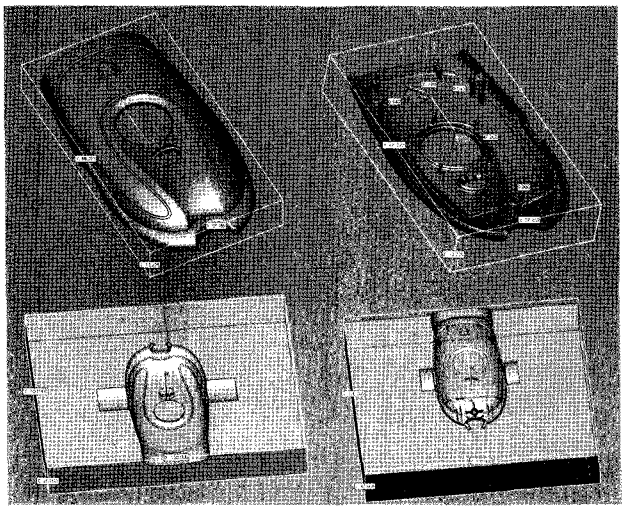
2.2 Insert Design Considerations

Metal SLS tooling and ceramic SLA tooling have many intrinsic limitations, there should be so many things to be intensively considered at design stage as shown in <Figure 3> [5, 7, 11].

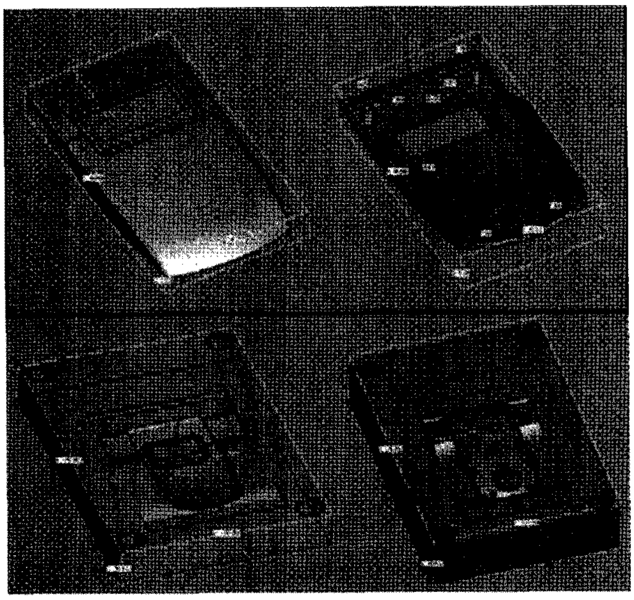


<Figure 3> Basic Design Considerations for Hybrid Tooling.

As shown in <Figure 4> and <Figure 5>, the two different parts were used for the purpose of case studies. The part in <Figure 4> (a) was applied into metal SLS tooling. It contains three small pillars with a diameter of 0.54, and 0.88 mm. These pillars were designed to be fitted together with the other part. Due to slenderness of these pillars, it was a bit difficult directly to use a micro-tool on this mold inserts



<Figure 4> Part and Mold Inserts Designed for Metal SLS Tooling : (a) Part, and (b) Mold Inserts



<Figure 5> Part and Mold Inserts Designed for Ceramic SLA Tooling : (a) Part and (b) Mold Inserts

made of metal. In order to build these kinds of features, micro drilling with reaming or EDM is applied in a general tooling process. As shown in <Figure 4> (a), the most difficult features are five small vertical bosses that are much smaller than the pillars. EDM process is generally applied in a tooling process for building this kind of shape.

As shown in <Figure 4> (b), the mold inserts were designed for metal SLS tooling. The mold design was conducted with Magic Tooling [8]. It was easy to design mold inserts using STL for parts that have relatively less complicated parting surfaces. Due to the dimensional instability of current RT processes, usually, dummy feature are attached to the mold inserts designed. The dummy feature is then used as global or local references for post-process. In this case study, however, there is no dummy feature on the part as shown in <Figure 4> (b).

For ceramic SLA tooling process, the part in <Figure 5> (a) was applied. There are four small pillars with a diameter of 1.5, and 1.6mm on the part. These pillars are also to be fitted together with the other part. As mentioned above, metal pins machined were applied in order to make these features. The part also contains two square rib features with a length of the sides of 8.6 and 7.7mm, which are to be fitted together with the other part.

The part in <Figure 5> contains three undercuts. Two undercuts are symmetric into Y-axis, and the last one is unsymmetrical into the others. In order to make these kinds of undercuts, mechanical or manual slides are applied in a general tool making process. The design of a mold insert in <Figure 5> (b) is a little different from that of the mold insert in <Figure 4>.

The ceramic SLA tooling uses a kind of photo polymer that is filled with ceramic additives. Generally, the ceramiclike material is difficult to machine due to its brittleness. Some features, which are too weak to machine were removed from the mold design [4]. The through holes, which were employed for ejector pins, were already designed on the core insert shown in <Figure 5> (b). The ceramic-like material is also week against high injection pressure. Some features were removed from the mold design. In order to make these kinds of the weak features, sub-inserts made of metals could be replaced with.

There were four elliptical features on each corner of the mold inserts, which were used for mold insert to be bolted onto the mold base with screw bolts. These features were also used to align the halves of the mold insert with the mold base.

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.

• *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.

■ 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

■ 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

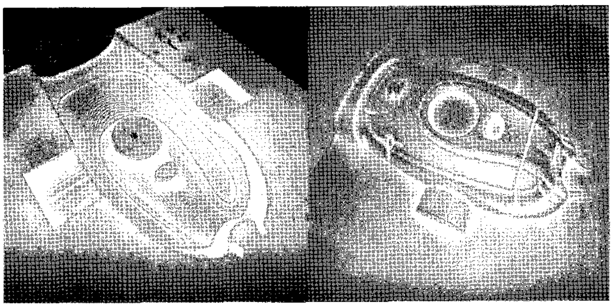
■ *Tooling Lead time*

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.

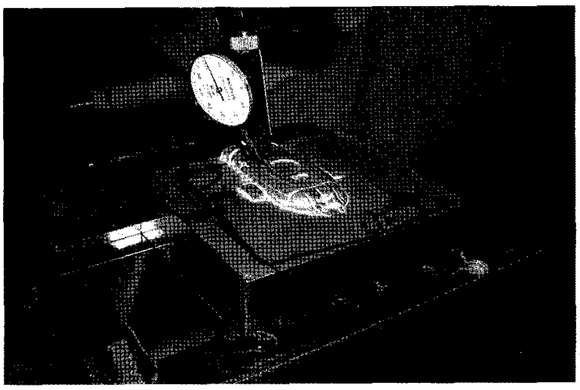
3. Experimental Work

3.1 HT using metal SLS tooling

Due to the stair effect and the deformation of the parts (in <Figure 6>) fabricated by RT process, machining is required to be used in the injection molding process. By utiliz-



<Figure 6> The Mold Block Fabricated by DTM Process : (a) Cavity Block and (b) Core Block



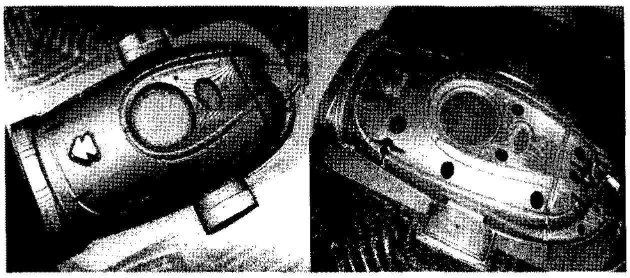
<Figure 7> Showing the Sep for Checking the base Line and Point

ing five-axis profile cutting, some stair stepping can be eliminated. It is not always required in the injection molding process to remove most of the stair steps. To conduct the post process, several steps are needed, which may depend on the user's requirement. For our experiment, four steps were conducted for the molded part to be produced in the injection molding process.

Base line and point: Before starting the machining, the base line and point should be figured out due to the deformation of the fabricated part. As shown in <Figure 7>, dial gauge is used in order to check the direction of X-axis and Y-axis, and the center point of the mold block. Ideally the shut-off faces (Parting plan) should be flat, and vertical to the Z-axis.

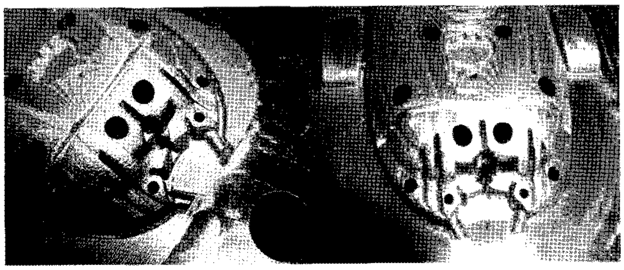
<Figure 8> Showing the Machining the Mold Blocks

Machining process : Shut-off faces are particularly important in tooling, which constrain the part being produced. The two halves of tool are touched on the shut-off faces during the injection process. To make the shut-off faces flat, machining is conducted on the mold block shown in <Figure 8>. The side and back surfaces of the mold block are also machined to fit into the mold base. After machining the surfaces of the mold block, micro tool is used into the features of the part during the fine finishing.



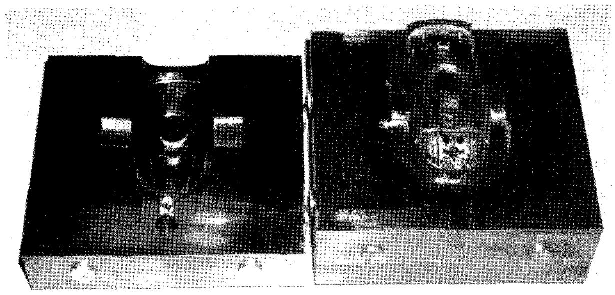
<Figure 9> Showing the Core Block : (a) After Machining, and (b) After Drilling

Drilling : In order to eject the molded part during the injection process, the ejecting holes should be drilled on the core block shown in <Figure 9> (b). Through the holes, the ejecting pins are functioned during the injection process. The dimensional accuracy of three pillars cycled in <Figure 9> (a) is not acceptable due to the capability of RT process. Loose cores should be replaced instead of the pillars that were removed during the drilling shown in <Figure 9> (b).

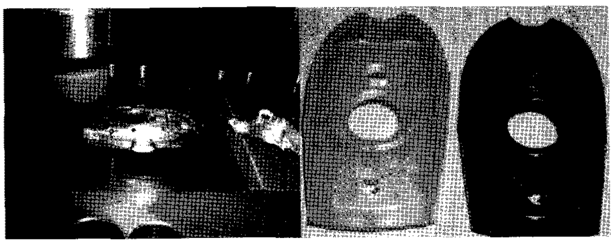


<Figure 10> Showing the core Block : (a) After Drilling, and (b) After EDM & Polishing

EDM and Polishing : as shown in <Figure 10> (a), very small size of holes was not fabricated precisely by RT process. To make this size of the holes in <Figure 10> (b), EDM is conducted instead of drilling that may be difficult to produce the very small size of the holes. During the injection process, the molded part is stocked into the core block. A problem is occurred due to the semi polishing the side surface of bosses. In order to prevent this kind of problems, the side surface in the bosses should be fine polished as shown in <Figure 10> (b).



<Figure 11> Showing the Mold Block After the Post Process



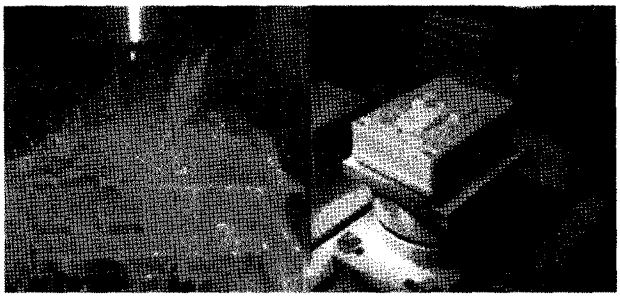
<Figure 12> Showing (a) Molding Process and (b) Molded Parts with the Different Material.

As shown in <Figure 11>, the mold block is ready to fit into the mold base after the post process. Two pins are inserted on each side of the mold base in order to fit into the mold base. In <Figure 12> (a), the block is fitted into a mold base and ready to mold the parts. After trying several experiments, parts are molded as shown in <Figure 12> (b). The detail numerical results are described on the next section.

3.2 HT using ceramic SLA tooling

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. For our experiment, only four steps were conducted for the molded part to be produced in the injection molding process.

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.

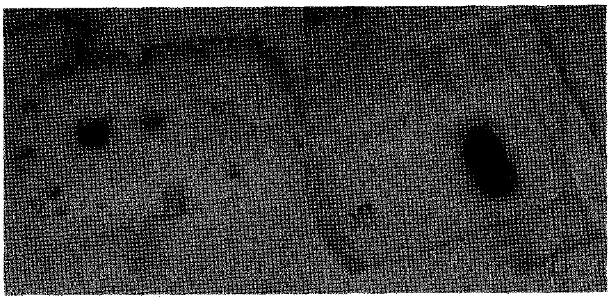


<Figure 13> Showing the Machining of the Mold Block Fabricated by Sony Process : (a) Cavity Block, and (b) Core Block

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 13>. The side and back surfaces are also machined to fit into the mold base flat as shown in <Figure 13> (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 13> (b) and <Figure 14>. 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 14> 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.

<Figure 14> Showing the Effect of Rough Milling

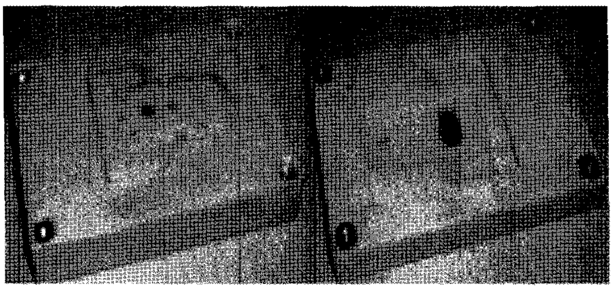
Drilling and EDM : Comparing to the metal-based rapid tooling, the ejecting holes and the places for the insert cores are already made on the core block. Drilling for these features is not required for the resin-based mold block. Due to the property of the ceramic material and the better dimensional accuracy, EDM cannot be applied on the resin-based mold block.



<Figure 15> Showing the Mold Bock after Machining and Polishing : (a) Core Block, and (b) Cavity 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 15>.

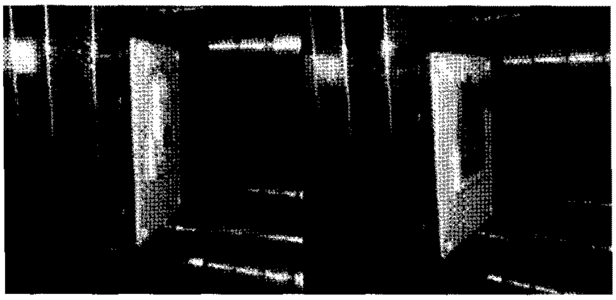
In <Figure 16>, the mold block is ready to fit into the mold base after the post process. Four screws are inserted on each mold block in order to firmly attachéinto the mold base. After trying several experiments, parts are molded as shown in <Figure 17>. The detail numerical results are described on the next section.



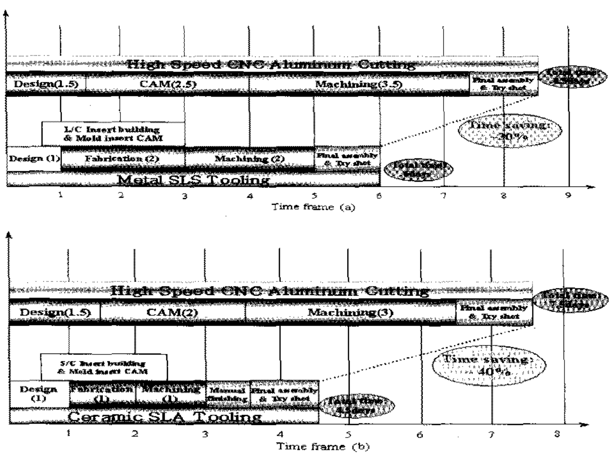
<Figure 16> Showing the Mold Block Fabricated by Sony Process After the Post Process.

4. Result

As mentioned before, precision is related with the ability to make fine detail. On the other hand, accuracy relates to the correctness of dimensions. The cornerstone in RT process is accuracy that depends on application and geometry of the part.



<Figure 17> Showing Molding Process with the Different Material



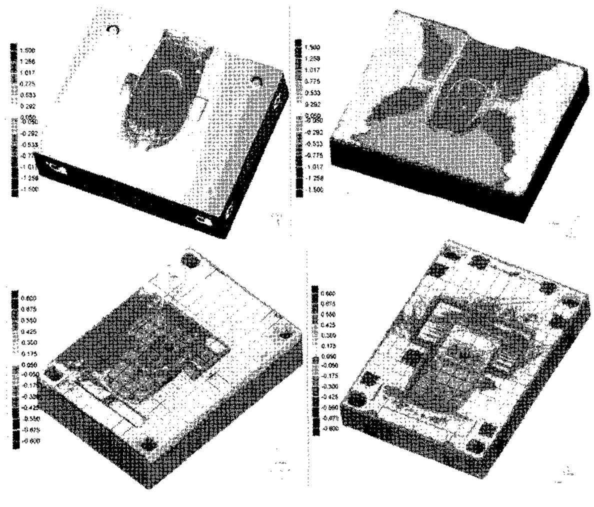
<Figure 18> Experimental Comparison of Tooling Leadtime : (a) Metal SLS, and (b) Ceramic SLA

4.1 Tooling Lead-Time

The information related to the fabrication time, condition, and material was provided from each participant. As mentioned on the previous section, the machining process was done using conventional techniques. As shown in <Figure 14>, 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 cases by 30% or 40% comparing to High Speed CNC tooling approach. However, it should be noted that tooling lead times can be reduced by over 30% in average, though they might be varied depending on the tooling project type.

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.



<Figure 19> Scanned data of the Mold Insert before Machining (a) Metal SLS Insert, and (b) Ceramic SLA Insert

The mold inserts fabricated by HT approaches were scanned, and then fitted into the original CAD data as shown in <Figure 19>. As detailed in <Table I>, the dimensional accuracy of metal SLS inserts are described, but this does not mean that metal SLS inserts are worse because metal SLS inserts are machined with High Speed CNC in order to fit into the mold base as described on section 3. Each part shown in <Figure 20> (a) was sampled through the injection molding process. The brief conditions of the molding process are described in <Table II>.

<Table I> Dimensional Accuracy of Mold Inserts

	Overall accuracy	Feature accuracy
Metal SLS inerts	+ 0.25mm	+ 0.15mm
Ceramic SLA inserts	+ 0.15mm	+ 0.10mm

<Table II> Molding Condition of Molded Parts

Part name	MS cover	MP cover
Resin	PC	PC
Cycle time	40sec	160sec
Max. shot #	20K(real)	118(real)

The molded part were scanned, and then fitted into the original 3D CAD data as shown in <Figure 20> (b). The overall dimensional accuracy of the molded parts lies within the normal tolerance (~+0.15mm) in <Figure 20>.

5. Conclusion

The use of Hybrid Tooling process has proven as a method in the injection molding process to be a valuable and effective tool in time and cost saving for the tool manufacturing. According to other case studies[1, 5, 6, 10], they also had very much similar results comparing with our results. There is no one answer to which RT technologies you should use. The selecting process will be inevitably varied according to customer's needs, the desired product, or the geometry of the complicated part. Based on the results of the case studies, the following conclusion can be made :

■ Although surface roughness and dimensional accuracy of the mold insert fabricated by RT technologies were not acceptable directly to be applied in the injection molding process, RT technologies has shown the potential benefit for the tool manufacturing with some minor finishing and fitting.

■ For the short lead-time and small products(~<200shots) with complicated shapes, it might be better to use CNC aluminum tooling. On the other hand, metal - based RT might be better for large products(1000shots<~) with simple shapes.

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