INJECTION MOLDING WITH COMPOSITE STEREOLITHOGRAPHY RESINS

By Jim Williams, Paramount Industries, Inc. President and CEO

INTRODUCTION:

For several years rapid tools made using stereolithography (SL) technology have been tried for injection molding thermoplastic parts. Success has been very limited due to low strength, inadequate temperature resistance, and poor dimensional stability of SL resins. A new class of stereolithography materials, composite resins, coupled with high resolution SL technology, shows signs of breaking the mold. Molds made of these resins have been used to make hundreds of injection-molded parts out of plastic materials such as ABS, polypropylene (PP), polyethylene (PE), polycarbonate (PC), thermoplastic elastomeric (TPE), and 33% glass-filled nylon. Depending upon part geometry, the use of these molds can provide time savings, cost savings, or both when compared to machining metal molds.

Paramount's venture into non-machining type tools began in the late seventies with spray metal, epoxy composites, and 3M's Tartan tool process. Although ahead of their time, these systems were vain attempts to reduce cost and lead time. How much has changed? In '94 DTM Corporation introduced RapidSteel®, the first true commercial tooling system using rapid prototyping laser technology directly to grow a mold insert. It was not long after that a plethora of rapid tooling processes were being marketed and getting press. It seemed that a new RT system was introduced monthly. The synthesis of the process offerings boiled down to direct and indirect, rapid tooling processes.

The winner of the RT gold cup was not a product of rapid prototyping (RP) machines but of CNC machining technology. Without a doubt high-speed machining technologies have out performed every indirect and direct RP based tooling process ever conceived - second to none in terms of part quality and predictability. So why re-visit rapid prototyping based rapid tooling?

The answer lies in what intrigued me when Charlie Kaufmann from DSM Somos paid us a visit. I am to rapid tooling like a gambler is to the gaming tables. Show me the possibility of a good hand, and I'll wager a bet. Two new cards were played- the promise of resilient SL resin materials matched with reliable machine accuracy. Suitable materials and RP machine accuracy were two essential ingredients missing from prior RT art. Two critical components, 3D Systems Viper with its repeatability and reliable accuracy in and DSM Somos ceramic filled SL material were in my hand. Playing this hand seemed like a sure bet.

The stakes are high! -- *our customer's success!*

Ten months ago Charlie shared with me his vision to apply DSM Prototool 20L™ to make injection molds. The clincher for me was this material's heat deflection temperature. While I am certainly no materials expert, I know what the issues were with prior attempts to use SL resins for cavities and cores.   As a product developer and prototype house we are very aware of the gaps in rapid tooling.   Even in my own shop, schedule loading (queue time) is the leading determinant of providing a rapid delivery to every new opportunity.

Ironically, all of Paramount's past RT experience was with everything but SL resins. Today High Speed (HS) CNC machining is our rapid tooling standard. During the last 30 years we have developed products using cast epoxy composites, cast aluminum, cast S7, spray-metal, cast beryllium, KelTool, SLS RapidSteel™, and machined tools.

After considering how I would communicate our experiences, I realized the SL RT story would not be fully appreciated without a technical understanding of DSM's ceramic SL resin. After all, Paramount's expertise is in applying technologies and materials, not material chemistry. I asked Charlie if DSM would co-author this paper by contributing a technical section on DSM Somos ceramic materials in conjunction with Paramount's design-build experience and customer case studies. This paper is the result of ten months of partnering and collaboration between Paramount and DSM Somos.

The following technical section on DSM materials was authored by Charlie Kauffman of DSM Somos:

COMPOSITE STEREOLITHOGRAPHY RESINS:

By Charles Kaufmann, DSM Somos, Senior Account Manager

INTRODUCTION

As Jim described earlier, many rapid tooling processes have been used to make injection molds, and all of these have met with very limited success. Stereolithography is no exception. Until recently there were no SL resins that offered the accuracy, durability, and temperature resistance required for injection molding. Now, a new composite SL resin, DSM Somos ProtoTool 20L, promises to change the game.

Before discussing the detailed property differences between composite resins and unreinforced resins, let's examine the meaning of the term composite. A composite is usually defined as the combination of a matrix material and a reinforcing material to create a product that has properties that are better than those of either component by itself. The key to the improved properties is a strong bond between the two components. By varying the ratio of components, composite properties can be tailored for specific applications.

A common example of a composite is fiberglass that is used in construction materials, boats, cars, and sporting goods. More expensive, but higher performing graphite/epoxy composites are used in aircraft and high-end sporting equipment.

In stereolithography, the combination of a high performance resin blend and a ceramic reinforcement has been used to produce a composite material, DSM Somos ProtoTool 20L, that has excellent properties for use in injection molds. These properties include high strength, modulus, heat deflection temperature, and accuracy, as well as excellent dimensional stability when compared to neat SL resins. Now let's examine these properties individually.

MECHANICAL PROPERTIES

To begin the analysis of the differences between ProtoTool 20L and unreinforced SL resins let's look at Figure 1. This chart plots flexural modulus against elongation at break. These variables were chosen because they are among the most meaningful when considering how SL functional parts are used. As with most material families, as modulus increases, elongation decreases and vice versa.

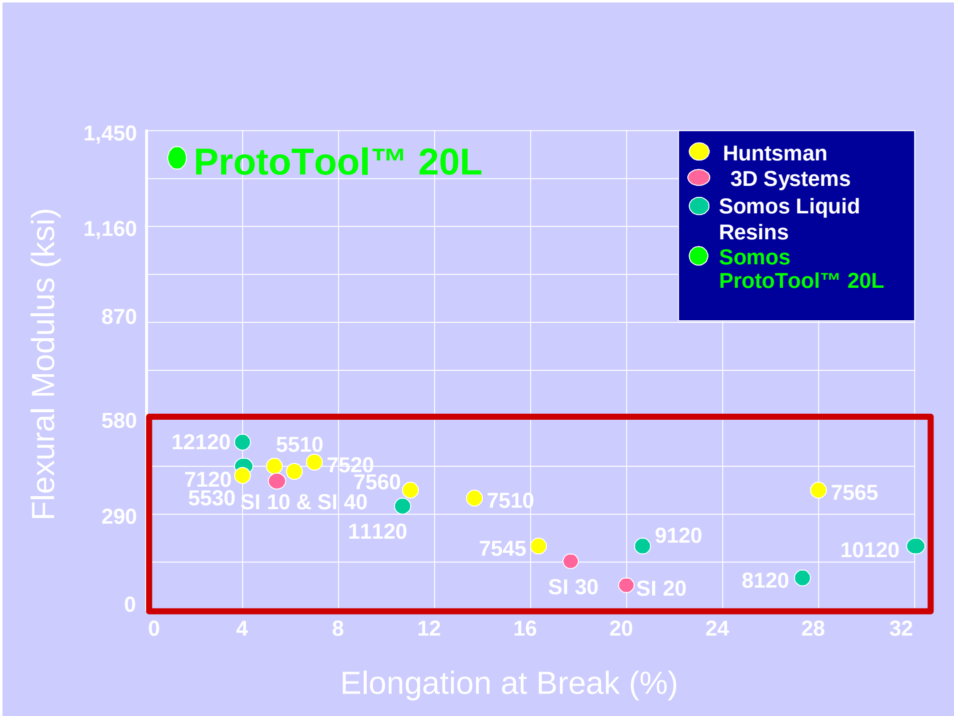

Figure 1 – Flexural Modulus and Elongation of ProtoTool 20L & Unreinforced SL Resins

The bottom third of the chart shows data points for most of the unreinforced solid-state SL resins in common use today. A box has been drawn around the data that fairly well defines the limits of performance of these products. Because all of the resin producers use variations of the same chemistries, all of the current products are subject to these limits. In fact, a pretty nice straight line could be drawn through the data to approximate performance capabilities of these resins.

In the upper left corner of the chart there is a data point for ProtoTool. This shows that the material has an extremely high flexural modulus, and a correspondingly reduced elongation at break. This material is truly "outside the box". The low elongation has not been a negative factor in most applications, including injection molding, because the high modulus makes the material extremely hard to break. Other important mechanical properties of ProtoTool 20L are compared to those properties of typical unreinforced SL resins in Figure 2.

Property	***Typical Unreinforced SL Resins (UV cure only)***	**ProtoTool 20L Composite Resin (UV cure only)**
Tensile strength (psi)	4,500-8,000	10,400-11,400
Modulus of elasticity (psi)	100,000-500,000	1,464,900-1,624,400
Elongation at break (%)	4-30	1.2-1.3
Flexural strength (psi)	6,000-15,000	17,100-17,800
Flexural modulus (psi)	100,000-500,000	1,340,200-1,392,400
Compressive strength (psi)	N/A	22,200
Compressive modulus (psi)	N/A	1,470,000
Hardness (Shore D)	80-85	92.9-94.7
Izod notched impact (ft-lb/in)	0.2-1.0	0.3

Figure 2 – Mechanical Properties of ProtoTool 20L & Unreinforced SL Resins

From the table it can be seen that the mechanical property differences are significant. The higher strengths and moduli enable molds made of ProtoTool 20L to withstand high injection pressures. Compressive properties are not normally measured for unreinforced resins, but the high compressive strength and modulus of ProtoTool 20L enable molds made of this material to withstand the clamping pressures of an injection molding machine.

The high ceramic content of ProtoTool 20L increases the hardness above the normal range. This provides abrasion resistance and durability during the molding process.

Impact resistance for most SL resins is low due to the highly cross-linked polymers that are used. The impact resistance of ProtoTool 20L is at the low end of the normal range for SL resins, so care should be taken in handling molds made of this material.

THERMAL PROPERTIES

A major reason for previous failures of unreinforced SL resins in injection molding is their inability to withstand elevated temperatures. Heat deflection temperature (HDT) is a property that is commonly used to predict elevated temperature performance. HDT data for ProtoTool 20L and a typical unreinforced resin is presented in Figure 3.

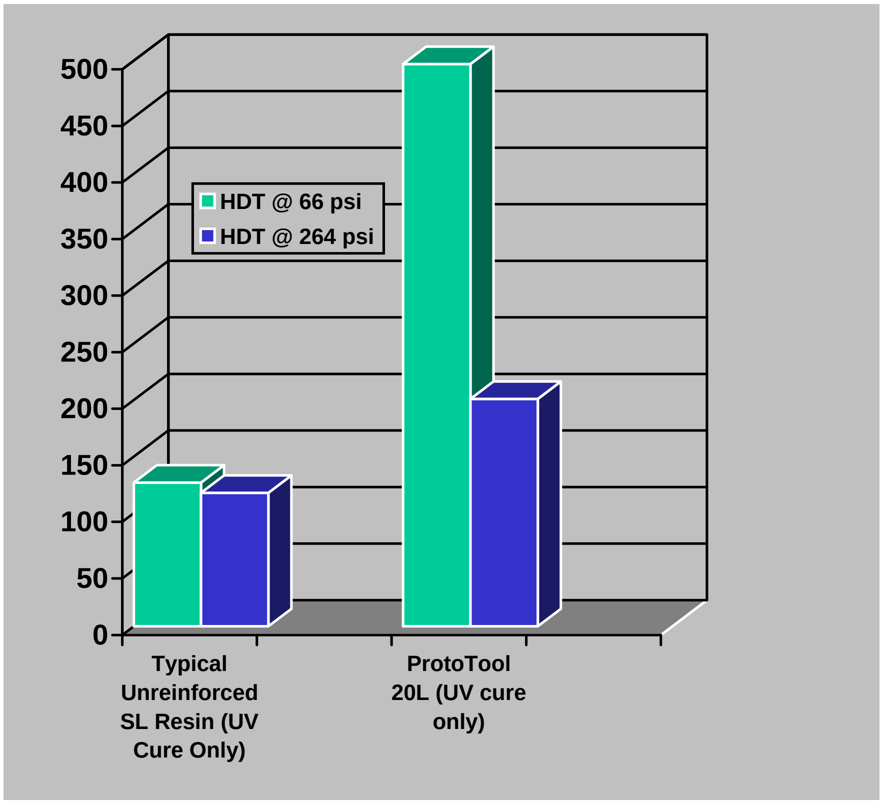

Figure 3 – HDT^{o}F of ProtoTool 20L and a typical unreinforced SL resin

It is obvious that ProtoTool 20L has superior temperature resistance. The low pressure HDT is almost 500ºF, a temperature that exceeds the processing temperatures of many commonly molded engineering thermoplastics. It is worth noting that the ASTM HDT test uses a thin strip of material that deflects under relatively low loads. From experience, it appears that ProtoTool 20L molds are able to withstand much higher pressures at elevated temperature, indicating a significant increase in bulk properties.

ACCURACY

In injection molding, accuracy is extremely important. The accuracy of the molded parts is highly dependent on the accuracy of the mold. For stereolithography molds, accuracy is really comprised of three factors:

1. Accuracy of building the mold.

2. Change in dimensions due to moisture absorption
3. Change in dimensions due to thermal expansion

Figure 4 summarizes the properties that affect accuracy.

Property	***Typical Unreinforced SL Resins (UV cure only)***	**ProtoTool 20L Composite Resin (UV cure only)**
Cure-related shrinkage (%)	0.24-0.50	0.00
Water absorption (%)	1.0-1.25	0.24-0.30
Coefficient of thermal expansion from 212-302°F (μin/in-°F)	75-105	45-51

Figure 4 – Properties that Affect Accuracy

All unreinforced SL resins experience shrinkage as they cure, so the stereolithography machines are set up to compensate for this by applying shrink factors into the build program. The shrink factor for each resin must be established before accurate parts can be built. The high loading of ceramic particles in ProtoTool 20L results in a shrink factor of 0.00, making it easier to produce accurate parts.

Moisture absorption from the air can occur quite quickly in parts made of many conventional SL resins. As parts absorb moisture they gain weight and they grow dimensionally. Sometimes the growth is significant enough that parts will no longer be in tolerance. From the data above, it can be seen that ProtoTool 20L has very low moisture absorption compared to unreinforced SL resins. For tooling this can be extremely important.

Figure 4 also shows that ProtoTool 20L also has a lower coefficient of thermal expansion (CTE) at elevated temperature than conventional resins. Although the ProtoTool 20L CTE is not as low as those of steel and aluminum molds, experience has shown that is not a problem; tolerances of molded parts are easily maintained using ProtoTool 20L molds. Also, the ProtoTool 20L CTE is close enough to those of the metal mold frames that stress build-up in the mold has not been a problem.

BUILDING AND FINISHING PROTOTOOL 20L MOLDS:

Although ProtoTool 20L is a composite resin with a high loading of ceramic reinforcing particles, it can be used in most commercial stereolithography machines. It requires periodic mixing to maintain homogeneity, but users of the material have learned how to do this efficiently.

Also, the photo-speed of ProtoTool is comparable to most unreinforced SL resins on the market today. As with conventional resins, total production time can be minimized by balancing layer thickness and build orientation against sanding and polishing time. The proper mix will be geometry dependent.

Finishing of the molds can be accomplished using conventional methods. ProtoTool 20L can be machined, ground or hand sanded (wet or dry). If significant amounts of machining are required, carbide tools are recommended. A mixture of dishwashing soap and water works well as a cutting fluid. For accuracy, it is recommended that holes for ejector pins, core pins, etc. be built slightly undersized and then reamed for a perfect fit.

While care should always be taken to avoid breathing dust during part finishing, composite materials may warrant extra care. Most composite resins use silica as the reinforcing ceramic. DSM Somos has avoided the use of the crystalline silica as a corporate philosophy due to the known hazard of airborne particles relative to cancer and silicosis. The ceramic reinforcing material in ProtoTool 20L is amorphous silica, which is not known to have the same hazards as the crystalline variety.

In summary, ProtoTool 20L has unique properties that can make it an excellent choice for injection molds. Now Jim will continue the story by discussing some real jobs that were completed using this material for injection molding.

SL RT – FUNDAMENTALS:

With Charlie's insight we now have an understanding of DSM's composite SL resin. Let's take a look at the application of DSM's ceramic resin system. Success to using any mold making process requires certain acquired knowledge and hands-on experience. In many ways machined tools are easier in that they are risk free relative to predictability. Thermal management of the tool is key to achieving proper polymerization and part fill.

There are seven key elements to consider if the application of SL resin for making direct cavity and core inserts is going to be successful. These elements are dependent on having the right stuff: knowledge, technology, materials, and experience. How these key elements measure up relative to injection molding may determine your project's level of success.

1. SL resin… Does the material have the necessary performance characteristics required for injection molding.
    - Resin stability: Some SL resins can absorb moisture, possibly causing the insert to grow over time. The cavity and core insert set have been produced with precision. Any dimensional change could cause the insert to warp, possibly causing the tool to crack or flash under compression and injection pressures.
    - Shrink factor: Does the material shrink? If shrinkage is a factor, is it predictable? Does it shrink uniformly in all directions?
    - Dimensional accuracy: Considering the various process phases the insert will go through and the time element, how dimensionally accurate does the SL resin remain?
    - Strength characteristics: Understanding the demands of high pressure injection molding when designing an SL tool and the material strength limits is very important. Compression loads, tensile and shear forces are put to the task in the plastic injection molding environment.

2. RP equipment...
    - Delivered accuracy: Does the part dimensional accuracy, as measured by Plastic Injection Molding industry standards, meet or exceed your internal quality management procedures, or more importantly your customer's needs ?
    - Repeatable: Is the technology reliable and repeatable across all part sizes?

3. Part size constraints… There are practical size limits to consider when deciding the feasibility of SL inserts. These are practical considerations, not necessarily absolute technical limitations.
    - Cost factor: Machine build time is measured in hours. There are associated hourly costs regardless of your business's financial cost accounting procedures. Quantity of SL resin needed to build inserts is measured at a cost per kilogram. Smaller inserts may be desirable. Shelling the backside of the inserts may be applied with two possible benefits. First is thermal heat dissipation. Second is SL resin cost reduction. With regard to saving money on materials it does not seem the return on investment would be feasible considering a reinvestment of labor cost (time) and replacement materials to add a back-filler. The benefits of using a Eutectic type metal, or other composite fillers, to dissipate heat may not yield the desired results compared to the investment of time. Further, I would be concerned about the filler material distorting the shelled insert. If your success is not measured by cost then back-filling may offer some benefits.
    - Size factor: The greater the part projected area, the greater the required press clamp force. Molding resin viscosity, as measured by melt-flow, plays a big part in determining required press clamp force. Tool cavity and core inserts are designed to shut-off, or kiss, to avoid part flash. To avoid flash the press clamp force is increased proportionate to both the injection pressure necessary to completely fill the cavity and the physical size of the part. The press technician finds a balance between part flashing and clamp force. The compressive strength of the SL resin is extremely impressive but under severe compression loads you should consider designing the tool so there is 0.005"-0.001" offset between the ProtoTool and the surrounding metal mold frame. This requires sound machining skills and exact machining tolerances.

4. Part and feature complexity… Are there any practical limitations to apply? No rules govern what is, or is not, feasible based on what has been learned to date.
    - Standing features like bosses and ribs may be affected by the force exerted against them. There has not been enough molding experience yet to accurately define aspect ratio limitations. Tall, thin protrusions can be replaced by metal parts if necessary.
    - Side actions such as cams and slides, should be considered a practical application for SL ceramic tools. Most likely they will be manual hand-loaded loose pieces. Complicated inserts can often be more efficiently produced by stereolithography than by machining.

- Part designs having molded-in inserts would be ideal for prototyping. The SL mold will have a longer cycle time so there's plenty of time to place inserts.

5. Mold making experience… Mold building knowledge and mold-making skills are crucial to achieving your objectives rapidly. Today's mold-maker can add value from the tool design process to the press. Creating a tool design is a collaboration of mold-maker's machining skills, tool design, and years of experience. Smart software helps automate tool design, but the creative thinking and planning to use SL resin inserts is best done with the help, or oversight, of an experienced mold-maker.

6. Molding resin… Probably the most important decision you will make is deciding if the specified molding resin can be run in the SL tool. No other key element has the variability or as many influencing characteristics as does molding resin. Injection pressures can range from 0.5 ksi to 40 ksi (500 psi – 40,000 psi). Resin processing temperatures can range from 190^{o}F upwards of 700^{o}F. Thermal management, that is the ability to sustain a uniform temperature throughout the mold fill cycle is a critical factor required to achieve parts with acceptable quality. Recommended cavity temperatures can be cool to the touch, or range in excess of 425^{o}F. We used a chiller air gun to cool the insert surfaces during the mold open cycle while taking surface temperature readings.

7. Plastic injection molding processing experience… I cannot emphasize the importance of partnering with an experienced press technician. Experience, creativeness, and patience are key to processing SL tools. A good technician is an invaluable asset if you are going to run an SL tool successfully.

MAKING THE BUSINESS CASE – TIME, QUALITY AND COST:

In addition to the seven key elements discussed above, there are customer and business considerations.

Efforts to compress tooling time are driven by several factors. Foremost, our customer's needs should drive what is acceptable quality, not the RT process. Often this simple truth can challenge and escape the best RT solutions supplier. As a product developer it's been my experience that altering the part design to suit the RT process is like the tail wagging the dog. While some customers need design assistance, their design intent and part integrity should never be compromised by the deficiencies of the applied rapid tooling process and/or the business model of the company providing the solution. In the

RT world equality of cost, time and quality can never truly be achieved because the customer is always raising the rapid bar. So how do cost, time, and quality weigh in using ceramic-reinforced SL resin?

My baseline for comparison is High Speed CNC machined aluminum tools. With today's HS machining knowledge and technology mold shops are using 3D solid model geometry with absolutely no 2D drawing intervention. Everything is digital. Machined tooling is predictable and reliable. Predictability and reliability are key to a successful rapid tooling program.

Cost models can vary immensely. If an OEM has in-house SL machines and tool-making expertise, their cost burden and overhead can be anywhere from consumed material costs only to mold shop and service bureau hourly billing rates. There are five basic steps that go into building a tool.

- Tool Design
- Programming
- Net Shape Machining
- Bench-work
- Tool Try-out and First Article

Machining net-shape is replaced by SL machine build. Bench-work would typically include: mold base preparation, precise sizing of cavity and core insert blocks to fit into the mold base, securing insert into mold base, reaming ejector pin and core pin through holes, adding gates and runners, bluing parting lines and shut-offs, removing stair-stepping from part exterior surfaces and all drafted surfaces, etc.

SL build style and insert (part) orientation determine machine build time. One of the largest tools we produced to date using Prototool 20L™ measured 8.2" x 4.3" x 1.9". To minimize stair-steps: cavity and core were placed with the 4" dimension in the Z axis angled at 20^{o} off vertical. The build time for the mold inserts in a 3D Systems Viper SL machine was approximately 75 hours. This was not a trivial cost component. The good news is that we learned from the experience and improved the process to cost-reduce the SL insert build machine hours. There will be more about this later.

Time, or the lack of time, is the most ardent justification for considering SL RT. Where time is not a major consideration for the customer, HS CNC machining may be the correct choice. Here again if your cost to produce the SL tool is lower than a machined tool, and you have all the necessary key elements within you reach, then SL may be your best choice.

Quality is not ambiguous, nor should it be arbitrary, but it can be a huge variable from customer to customer and application to application. There are many different reasons that customers need parts. All are application or purpose driven. Two of the client case studies presented in this paper had very different reasons to justify using SL tools. Customer application is an important variable to understand when selecting the correct RT process.

Part quality is measured on three points: visual, dimensional and structural. The customer may require all points be acceptable, or may forego any one for the benefit of reduced time and/or cost, subject to any existing RT process limitations. Visual quality typically refers to part surface finish, flash, gate vestige, sinks, splay, cold knits and other conditions causing cosmetic and/or structural irregularities. The structural integrity of a part can be compromised if the resin is not processed according to manufacturer recommendations. As an example, cold knits around bosses are not an unusual problem even with metal tools. This problem can be exacerbated with resin based tools due to the inability to optimize all molding resin processing parameters.

CASE STUDY #1 AND SL RAPID TOOL #1:

Two factors that we considered when deciding to experiment with DSM's ceramic filled resin for SL RT: A challenging part and a willing customer.   If successful, our business plan was to adopt SL RT as an alternative solution, in addition to Paramount's standard -- HS CNC rapid tools.   Our business goals were clear – *less than a week from art-to-part and much less expensive compared to machined metal tools!*

The first thing essential to our discovery was to test Prototool 20L™ for elevated HDT (heat deflection temperature). Based on prior art, low HDT was a leading cause of failure with resin based rapid tool inserts. 145°F HDT was typical of SL resins. Surely, if this obstacle could be overcome, it would open the door to 75%, or more, of the engineering grade molding resins used in most products. Possible exceptions could be polyether, polysulfone and similar resin classes having processing temperatures above 600°F. Many of these engineering resins require secondary sources of heat to manage elevated mold temperatures. DSM's published material properties sheet states Prototool 20L™ can attain 495°F (258°C) HDT .

Second was to find a customer willing to give us an assignment that was a real live-fire test. The desired outcome would be both time and technically challenged using SL resin inserts.

We had been working with a product development team for nearly a year at a division of Ingersoll Rand (IR) developing a new line of high-speed, hand-held air grinders. This new product line was being engineered to transition their traditional product manufacturing processes from machined metal components to lower cost injection molded thermo-plastics. The results of their design efforts were vastly improved product design and technical leadership in this tool category.

The predominant resin used was a type 6 Nylon, with 33% glass filler (BASF Capron 8333G-HI). This material is typical for robust and abusive industrial environments. Recommended injection pressure for this grade was relatively low: 0.5 ksi -1.8 ksi (500 psi-1,800 psi). Processing temperature was 520-560^{o}F and mold temperature was 180-200^{o}F.

The production tooling was near completion and first articles were beginning to arrive from IR's China supplier. The main body housing is cylindrical with compound surface geometry on the exterior surfaces. The surface geometry was interpreted incorrectly based on the 3D CAD data sent to their supplier. This error translated to the inside of the body housing. Considering the options, the IR engineering team discovered they might be able to modify an internal part called a Cage to compensate for the error. The theory needed to be tested. They could request the vendor to correct the body housing but this decision would put them 4-5 weeks behind schedule. Testing this part using RP materials, or cast urethane, was not an option. Using anything but Capron wouldn't work. Motor speeds of 30,000 rpm and accelerated air velocities can create temperatures that can challenge most thermoplastics.

The team needed at least two parts molded in Capron to verify their design concept. If this worked, they would have their China vendor change the Cage tool. Choosing this option would allow them to begin assembly 2-3 weeks sooner. Unfortunately, they would still be 2-3 weeks later then planned. Paramount delivered molded parts in just under 2 weeks.

The tool (photo image 1) was designed with a tunnel gate. This required adding a machined metal insert (photo image 2). Another justification to add the metal insert was to counter the abrasiveness of the glass filler. Glass would have quickly deteriorated the SL resin in this high pressure, high flow area.

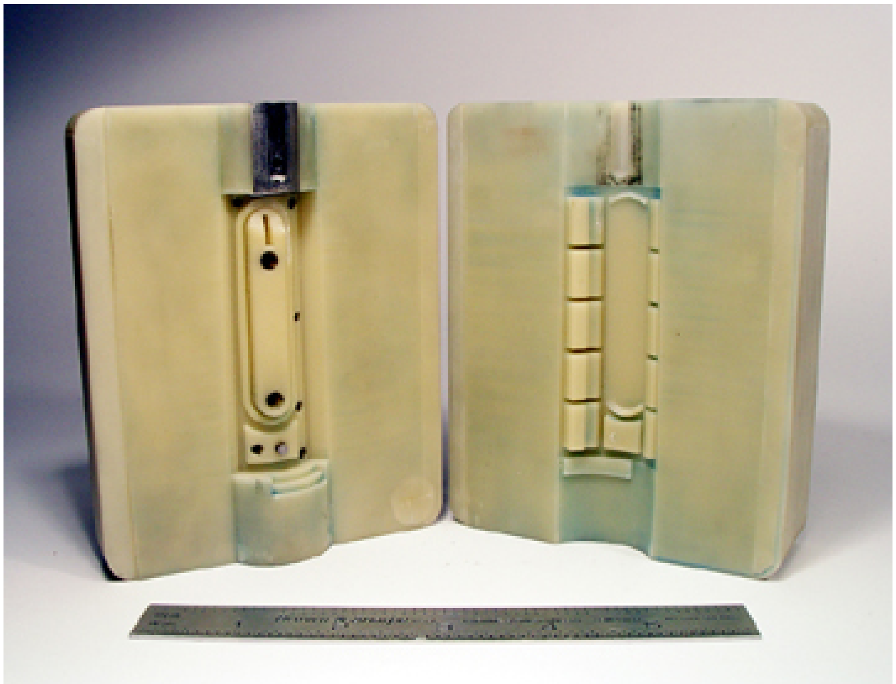

Photo Image 1 – SL ceramic composite resin mold insert set

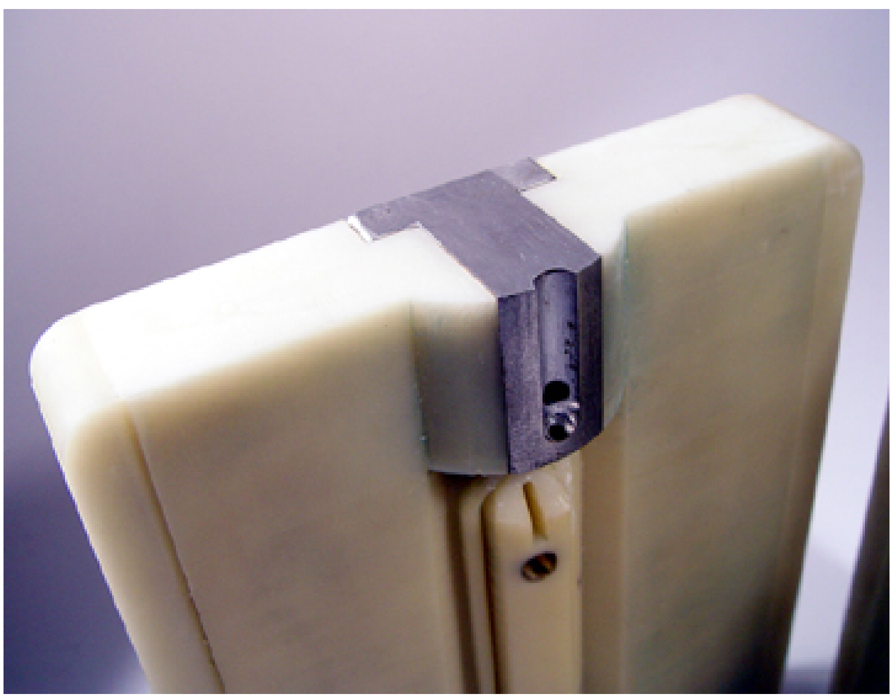

Photo Image 2 – Steel insert for tunnel gate in SL resin injection mold

We first ran the tool in ABS simply to gain confidence in the tool and establish shot size. After all, it was our first SL tool. The cavity filled out very well and the part ejected without incident. We shot about two dozen parts before switching over to Capron. We ran off 16 Capron parts before shutting down. After two shots we began to notice the tool degradation on a standing wall on the B side (core) directly adjacent to the tunnel gate. What we believe happened was the pressure at the gate was too high, and literally undermined the SL ceramic filled resin, breaking off a piece adjacent to the gate. Another possibility could have been the abrasiveness of the glass filler. The degradation was localized at the feature and not systemic.

So, what did we learn and what we would do differently? From a tool design viewpoint this was the ideal place to locate the gate. With this part design the feature resembles an oval race track that runs completely around the part on the B side. The only alternative would have been to machine another insert and place in it the area opposite the gate to counter the material force.

Overall our customer was able to use the two parts for their engineering pilot performance evaluation. Parts measured well within nominal manufacturing tolerance for injection molding ($^{+}$/- .005 In/in). Prototool 20L™ was processed in high-resolution (.002 inch layers) using a Viper SL machine. Molded parts were delivered within two weeks from first receiving 3D data. When queried with regard to the usefulness of the parts our customer said “the parts were quite functional”. In fact they were being used in an engineering pilot build along with other production molded components.

CASE STUDY #2 – SL RT #3:

As with all the SL tools that have been produced since we started experimenting in 2004, each has taught us lessons and helped us refine our process. This client having made one SL tool with us (actually our 2nd SL RT#2 and largest to date), wanted to do another tool and internally benchmark it against a machined aluminum tool. The machined tool was not contracted with Paramount. Our client requested that the parts be received ahead of the molded parts from the aluminum tool vendor. 700 parts were ordered. (photo image 3)

The table (figure 5) was copied from the Gantt schedule supplied to the client. During this experimental period Paramount was not processing Prototool 20L™ in-house. The elapsed time to produce the SL ceramic inserts was nearly double what we would plan running the ceramic in-house today. In our first few tools as a general rule of thumb we added an inch per side of the part. Our findings proved that this added no value to the tool performance and only added more cost to grow the SL insert.

Task Description	Duration	Start	Finish
Tool design	1 day	09/23/04	09/23/04
Build SLcavity/core inserts	3 days	09/24/04	09/28/04
Ship inserts to Paramount	1 day	09/28/04	09/29/04
Bench-work	4 days	09/29/04	10/05/04
Tool try-out & mold 700 pcs	3 days	10/07/04	10/11/04

Figure 5 – Development schedule for SL rapid tool

Photo Image 3 – Styrene molded parts using DSM Somos ProtoTool SL mold

During the molding process, after approximately 500 parts had been produced, the tool cavity split in half. Notice the four bolts holding the cavity halves together (photo image 4). The mold cavity parts were glued back together and we were back in the press within a couple of hours (photo image 5). Our conclusion was that the insert blocks were probably undersized 0.001"- 0.002" when fitted into the mold insert pocket. This minute space may have, after 500 injection pressure cycles, caused the tool to split. The sides of the part have approximately 2-3 square inches of surface. Injection pressure for the styrene that we used was specified between 10 ksi –15 ksi (10,000-15,000 psi).

Amazingly, after gluing the two halves together and smoothing the joint, there were no traces of a bond line on the molded parts.

Lesson learned: no room for any gap between insert block and mold pocket. There must be an extremely tight fit. Plans are in the works to develop a universal mold base system.   As we have learned, mold insert size flexibility is essential to keeping our SL build time at a minimum. Using the metal mold pocket to bolster the SL resin tool is critical. Tight pocket fits cannot be compromised. This mold set has produced well in excess of our client's 700 piece request.

In quoting our client he said *"The general reaction I have found regarding this part is that it came out better than people were expecting given the time frame and limitations of the ProtoTool material. Well done."*

Photo Image 4 -- ProtoTool cavity and core injection mold insert set

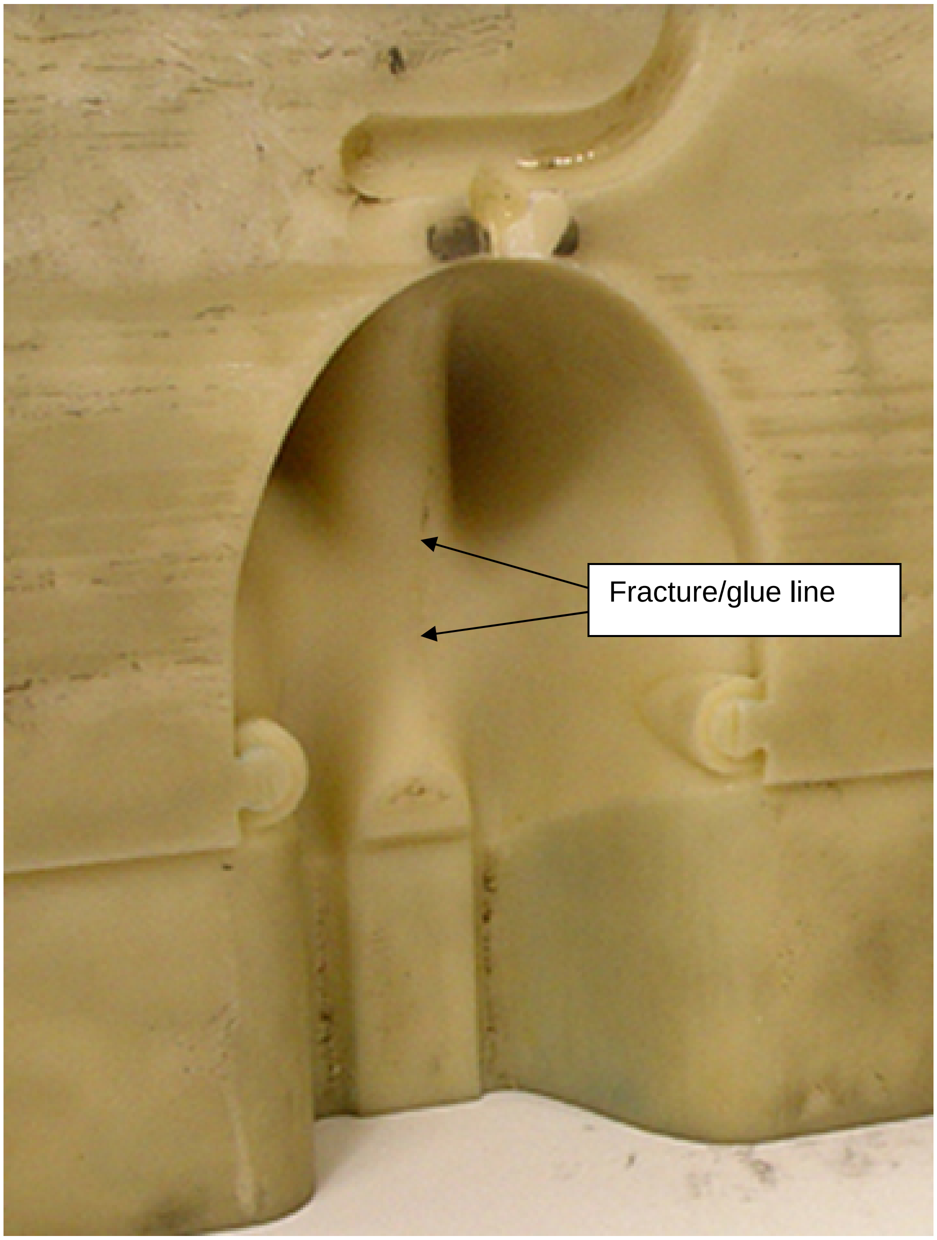

Photo Image 5 -- Image faintly shows split line that was successfully bonded together

CASE STUDY #3 – SL RT #5:

Lutron designs and manufactures home and commercial lighting controls. The part, called a Dome (photo image 6), had a custom sonic-weld assembly design that Lutron needed to test. The program engineer needed 5-10 parts molded in PC (polycarbonate) as quickly as possible. The part was not particularly complex. It would have been a rather simple tool to machine, except for several small standing ribs. The ribs most likely would have been added using EDM (electrical discharge machining) . Additionally, it came at a time our HS CNC tool queue was maxed out. The engineer was not particular about cosmetic surface appearance, but was adamant about reproducing the sonic-weld feature and overall part accuracy to his design and specified dimensional tolerances.

What is interesting about this SL insert is that the internal SL core ring (photo image 7) completely separated after 5 shots. Fortunately, we were able to recover the broken piece, glue it back on the core and continue running with only an hour lost. It separated again after 33 shots so we called it a day. Thirty-three (33) molded parts were delivered on the sixth day after receiving the order. All design features were intact and the dimensional inspection indicated all points were within 0.002 in.

Notice in image 7 the use of a machined aluminum center core. Creating hybrid tools that combine SL and aluminum can optimize time and outcome. In this application we would have had to get down between the inside diameter of the ring, and the OD of the center plug, and remove, by sanding, any stair stepping on the drafted surfaces. By machining the aluminum plug we could get access to both surfaces without much effort.

Photo Image 6 – Lutron Dome part, viewed from inside part showing core side details

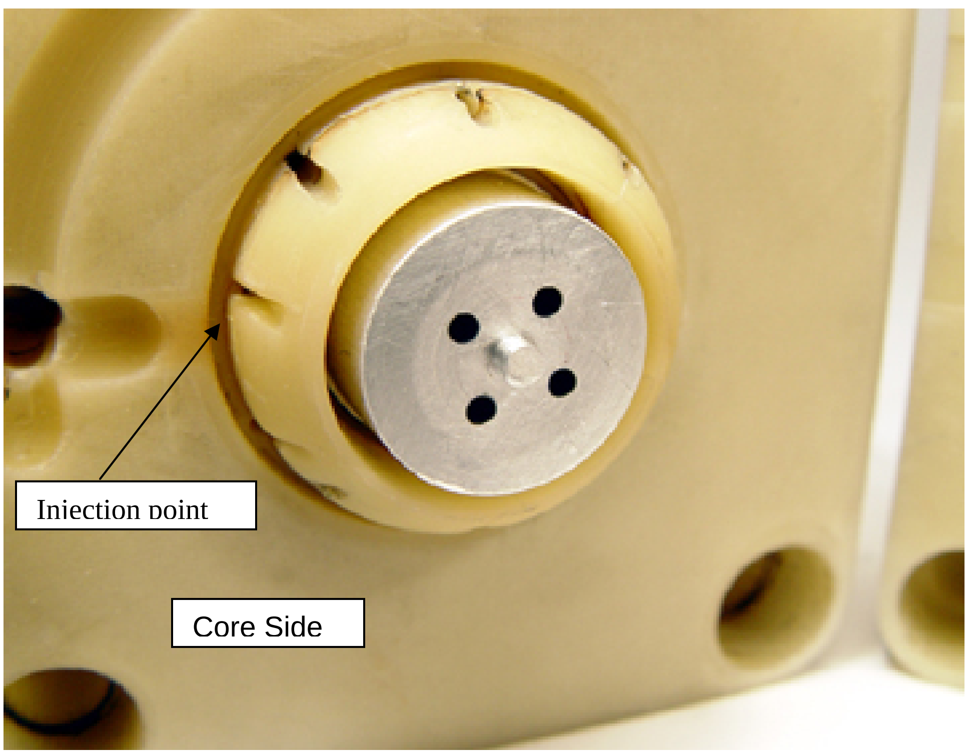

Photo Image 7 – Ceramic SL insert - core side showing machined aluminum insert

Since building our first SL tool several improvements have been recommended and adopted. The following table (figure 7) is a sampling of five SL tools made to date using Prototool 20L™.

Figure 7 - Table of Case Studies:

Tool#	**Customer**	**Tool size (inch)** A Side (cavity) B Side (core)	**Molding Resin**	**Processing Temp. °F**	**Cycle Time** (min/pc)	**Qty of Parts Molded**
1	Ingersoll-Rand	A - 4 x 5 x 1.4 B - 4 x 5 x 1.0	Capron 8333	530	2.0	16[1] (2)[2]
2	X	A - 8.1 x 4.3 x 1.9 B - 8.1 x 4.3 x 1.9	PP	410	2.3	>1000[1,2]
3	X	A - 5 x 5 x 2.4 B - 5 x 5 x 2.7	Styrene	410	1.2	>800[1,2]
4	DSM Somos	A –2.3 x 2.3 x 0.7 B - 2.3 x 2.3 x 0.7	ABS	437	0.9	~1700[1,2]
5	Lutron	A – 2.5 x 2.5 x 1 B - 2.5 x 2.5 x 1	PC	525	1.9	33[1,2]

[1] – total shots
[2] – delivered acceptable parts

The following table (figure 8) offers some insight to cost of SL RT verses HS CNC aluminum. These are only two examples. Both of these examples if produced again in SL would show cost and time savings.

Figure 8 -- SL RT Cost v. HS Aluminum

	Cage SL RT#1		**SL RT#2**	
Phase Description	**PT20L**	**HSM AL**	**PT20L**	**HSM AL**
	Hrs	**Hrs**	**Hrs**	**Hrs**
Tool design	4	4	12	12
CAM Programming	-	8	-	13
Net Shape	28	24	75	36
Bench-work	50	40	36	37
Sample tool	8	8	8	8
Labor & Machine Hrs:	90	84	131	106
SL Resin Cost	$ 450	$ -	$ 1,050	$ -
Purchased Materials:	$ 250	$ 250	$ 350	$ 485
Lead time	1.5 weeks	3 weeks	1.5 weeks	3 weeks

CONCLUSION:

From the beginning if the application of ceramic composite SL resins for rapid tooling were going to be considered a success, Paramount's goals would have to be met.: cost and time savings relative to machined tools without yielding our customer's part integrity. The customer would benefit in that they could get injection molded parts molded in their specified resin, without compromising their design intent or dimensional accuracy.

In the last ten months our research did not discover any caveats or extraordinary limitations to using ceramic composite SL resin for producing cavity and core inserts. On the first several tools the inserts were grown in high resolution on the Viper. Beginning with the Lutron dome part we found that normal resolution was adequate. Part accuracy was not jeopardized. This resulted in a $1,000 savings on growing the inserts plus time was saved.

Tool life expectancy has always been one of the criteria for building injection molds. Why else would you build a tool if not to produce multiple parts? The quantity, or tool yield, has also become a measurement used to gauge the level of success of a rapid tool process. Paramount's objectives in applying SL ceramic composites for making mold inserts are prioritized starting with part quality and specified engineering molding resin. The ability to manufacture injection molded parts rapidly without giving up design intent is foremost, and tool life should be secondary. Our investigations have clearly shown that quality and quantity are possible using these advanced composite SL materials.