Application of Subtractive Rapid Prototyping (SRP) For RSP Tooling

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Abstract

The work performed under this project was performed by Mr. Pratik E. Nikam as a part of his MSME program under the supervision of Dr. John L. Frater. Mr. Nikam's masters thesis makes up the body of this report and was approved by a faulty committee in the Fenn College of Engineering. This project demonstrates that Subtractive Rapid Prototyping (SRP) is a powerful tool reduce the time required to fabricate a forging die by the Rapid Solidification Process (RSP).

The RSP Tooling process facilitates the manufacture of a forging die within five days from the time that the die has been designed using a solid modeling computer program. There are two lengthy time constraints in this process. The first is the fabrication of a pattern of the die from the solid model. Historically this has been done using the steriolithography process and takes approximately two days. The second time constraint is the process is the a ceramic casting of the pattern that forms the target that the metal is spayed at.. This second process also takes about two days. This program addressed the first of these time

.The results of this program demonstrate that patterns can be fabricated using a low cost SRP device such as a desk top CNC milling machine. For this project a Roland MDX 15 machine was used; however, any SRP device could have been used. This machine cost $2995 which is well below the cost of a steriolithography machine. For a modeling material three different Ren Boards (Cured Polyurethane) were used; Ren Shape 450, Ren Shape 460 and Ren Shape 5003. The Ren Shape 150 was too porous, and did not result in a suitable die although this material was the easies to machine and resulted in the best surface finish. The Ren Shape 5003 was too hard, and the SRP machine could not machine it. Finally, the Ren Shape 460 resulted in a pattern with excellent surface finish and worked very will in the RSP tooling process.

As a result of this project, the patterns for the RSP Tooling process can be made in the engineering department itself, or an a related laboratory facility. There is no need to make costly steriolithography patterns in a service bureau. Most importantly, the patterns can be made in a matter of a few hours rather than two days..

APPLICATION OF SUBTRACTIVE RAPIDPROTOTYPING TO THE DESIGN AND MANUFACTURE OF RAPID SOLIDIFICATION PROCESS TOOLING

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APPLICATION OF SUBTRACTIVE RAPID PROTOTYPING TECHNOLOGY TO THE DESIGN AND MANUFACTURING OF RAPID SOLIDIFICATION PROCESS TOOLING

PRATIK E. NIKAM

ABSTRACT

Rapid Solidification Process (RSP) Tooling is a patented process that produces high volume production tooling in prototype timing. The process was invented and perfected by Dr. Kevin McHugh at the Idaho National Engineering and Environmental Laboratories (INEEL). A newly formed company, RSP Tooling, LLC licensed this technology for the purpose of tooling application. It is capable of producing 7”X7”X4” tools at the rate of one every three hours. Because of the speed, cost, and quality of this new process, new ways of thinking are required to maximize the benefits. A study of the RSP tooling process indicates that improvement greatly impacts time, from the point where a 3D CAD model exists in the computer to the point where a finished die is available.

Fabrication is currently being done using a Steriolithography (SLA) process that is costly and time consuming. The total process now takes approximately 5 days. Production of the SLA model takes up 33% of the time. The SLA also accounts for 40% of the cost of the initial tool. The purpose of this thesis is to reduce the time and cost involved in fabricating by applying the Subtractive Rapid Prototyping Process (SRP).

The Subtractive Rapid Prototyping Process (SRP) has the potential of providing the forger a faster, low cost methodology to fabricate patterns for the manufacture of RSP tooling forging dies. This thesis will provide a powerful tool to allow fabrication of the pattern in the office, engineering laboratory or a machine shop.

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CHAPTER I

Introduction

The purpose of this thesis is to reduce the time and cost required to produce dies, by using Rapid Solidification Process (RSP) tooling process. A study of the RSP tooling itself indicates that there are two steps in the process in which improvement could greatly impact time from the point where a 3D CAD model of a finished die exists in the computer and the point where a finished die is available.

Fabrication of the model

This process is currently being done using a Steriolithography (SLA) process that is costly and time consuming. The total RSP process now takes approximately 5 days. Production of the SLA model consumes two of those days or 33% of the time. The SLA also accounts 40% of the cost of the initial tool, as mentioned in Table I.

The fabrication of the ceramic target

While this task is the major time delay between having a solid model of a die and having the finish machined die, it is currently being addressed be the Idaho National Environmental Engineering Laboratory (INEEL) personnel who invented the RSP process. This process accounts for an additional 33% of the time but only 10% of the cost.

This thesis is directed toward the first of these opportunities. The Subtractive Rapid Prototyping Process (SRP) has the potential of providing the forger a faster, low cost methodology to fabricate patterns for the manufacture of RSP tooling forging dies. This project will provide a powerful tool to allow them to fabricate the pattern in the office or Engineering laboratory and reduce the time and cost of creating the model by as compared to the stereolithography approach.

SRP is the process that lets engineers and designers mill 3D prototypes quickly and inexpensively, thereby eliminating costly outsourcing. This process is the opposite of conventional rapid prototyping in which a 3D part is fabricated by slicing modeling material to build up the 3D prototype of the part. As the thickness of the slice decrease, the number of layers that must be printed increase. This result in a more accurate representation of the prototype to the CAD model at the expense of the time required making the prototype. Since many forge shops do not have a rapid prototyping capability, they must outsource this activity to service bureau to have the model made for RSP tooling application. This is costly and time consuming.

The SRP process is CNC milling process. As such, removing material makes the prototype. If SLA method is successfully replaced with better technique with similar surface finish, then 70% time of this process can be saved. This project will explain about how Subtractive Rapid Prototyping using milling machine can replace SLA method without affecting required finishes. To prove this, a simple part is built, which has drafts and curves. To build this part, Modela MDX-15 is used, a small desktop CNC machine that has RPM of 3000. For this project the model material that the pattern for the RSP tooling process will use are various qualities of Ren boards, a very commonly used modeling material. These Ren boards are low cost and easy to cut, styling boards.

The main concern while comparing results was the saving of time with less porosity and better surface finish in the part. Three different Ren board available with different hardness form highest to lowest were used. Hardness of these materials varies from 25 to 70. The time required for building the part, visual porosity level, and last but not the least the surface finish on the part is compared. After comparing all three types of material, these parts are supplied to RSP Tooling, LLC where they used these parts to build the tool. The goal of this project to determine if the dies can be fabricated from the model made with the SRP process are comparable to dies made by the SLA process.

CHAPTER II

RSP TOOLING

2.1 History

The Rapid Solidification Process (RSP) was developed at the Idaho National Engineering and Environmental Laboratories (INEEL) under grants from U.S. Department of Energy (DOE). The initial patent for the process was written in 1990 and had as its basis the invention or discovery that a liquid could be broke down into small droplets by use of the shearing effect of a flowing gas. There are a large number of possible applications of this invention.

An early application was the production of low-carbon steel strip, the industry's highest volume commodity. There are many advantages to producing strip by using RSP, with the most important from the point of view of the Department of Energy (DOE) being a significant reduction in energy accuracy, hot rolling unit operations could be eliminated, saving time, money and energy.

Work on the process resulted in another patent in 1995 which introduced the use of pressurized injection of liquid into a tube, thereby improving the operational flexibility of the device while producing a more uniform droplet size distribution in the spray. An additional benefit was the ability to control and increase the cooling rate of the droplets, which results in microstructure and material property improvements in the deposited metal.

Since the grain structure of the spray deposited metal was good, as was the ability of the spray deposited metal to replicate complex surface shapes, the idea of using the process to manufacture tools was developed. This resulted in two things: a new patent in 1997, and the terminology of RSP Tooling. Additional patent applications have been submitted which refine the actual process to produce tooling.

The initial issue is whether there is a need for a method to produce tools faster and for less cost. The process is so revolutionary these issues can only be addressed by examining different segments of industry and government operations.

The Department of Energy initially started, and continues, to support research into RSP because it is directly related to reducing costs of producing strip steel but the tooling applications also save energy. It has been shown that the rapid solidification process creates dies that are equal better than premium grade tool steel, but does it from the least expensive of the alloy cast ingots, broken tools or recycle works. Because of this all of the operations now preformed to create a high quality steel including Electro Slag Remelting and forgings can be eliminated.

The process also eliminates the need to heat treat the material. As sprayed H13 has a hardness of 56 to 58 Rockwell C, which is illustrated in Table 2, and has ability to be age hardened at low temperatures compared to standard heat treatment methods. This also means that there is no distortion and thus no need to remachine a tool after being heat-treated. The process is also very fast and can produce the same amount of tools as six CNC machines while using the same energy as two. All of these factors save a significant amount of energy.

The Defense Logistics Agency of the DOD views the method as a way to quickly bring low volume forgings into production at substantially reduced cost. This result in the ability to use forgings on new products gaining the advantage of less weight and higher quality while maintain a lower cost. It also helps in the production of replacement forgings when the original tooling is no longer available, reducing both cost and of more significant-time.

In the tool and die manufacturing area the benefits are more far-reaching and economical in nature. A significant number of tool and die shops have gone out of business in recent years because of competition. The reasons given for buying overseas are cost and timing. The RSP Tooling process can reduce the cost and timing for a complete moderately complex tool by 30%. This will in most cases surpass the abilities of the overseas competitor and allows the user to deal with local sources with all the associated added benefits. This is of significant benefit to maintain critical skills that could jeopardize safely if lost.

The tool user also benefits. Obviously the parts produce benefits from the lower price and faster timing of the purchased tooling. There is also significant evidence that using RSP can increase tool life of produced tools. This results from the better material properties obtained with the rapid solidification and also from the ability to use new material that are now too costly to machine.

Previous to the introduction of this process there were no rapid tooling methods that can produce high volume production tooling for such a variety of metals and processes.

2.2Process

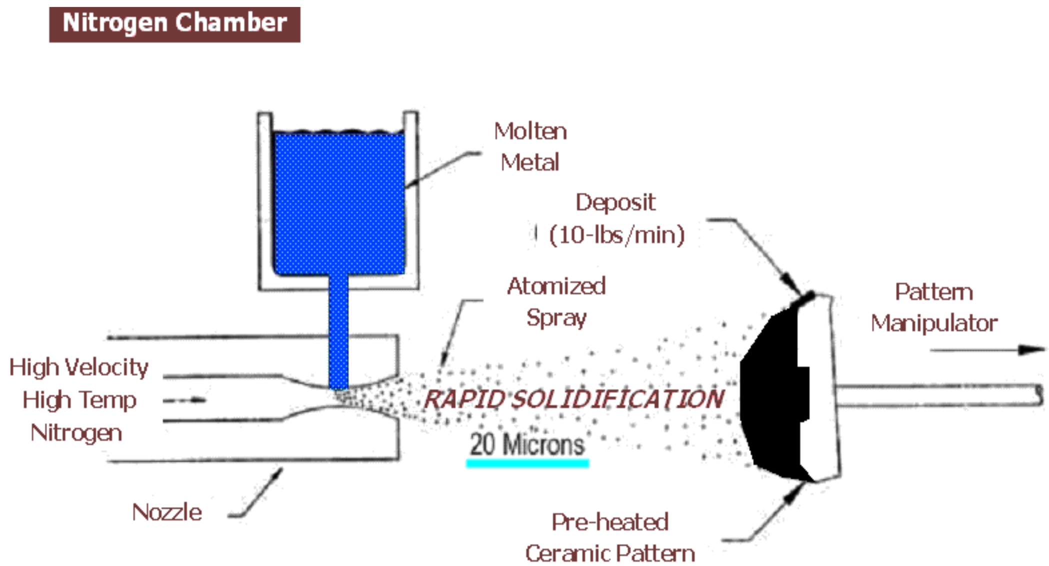


Figure 1: Schematic of the RSP Tooling Process

The RSP Tooling production process, which is illustrated in Figure 1, starts with a CAD model of the tool that is adjusted for shrink. A pattern is produced by stereolithography (or any other method that produces a rigid model). A ceramic cast is then poured and fired. This is placed in the RSP machine and sprayed with molten metal. The as sprayed tool is then "squared up" and fit into the die. A unique benefit of RSP is that the properties of many tool steels (including H13) can be tailored using relatively low temperature aging treatment, thereby eliminating distortion. H13, when age hardened, shows an increase in strength over conventionally heat-treated material, both at room and elevated temperatures, as per Figure 4.

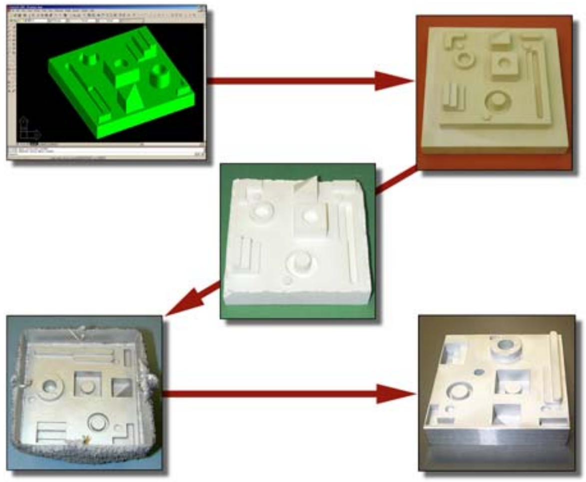


Figure 2: RSP Tooling Production Process

SLA model	2 days
Preparation of Cast Ceramic model	2 days
RSP Sprayed tool	2hrs
Finished tool	1 day

Table I: Process Time for RSP Tooling Process

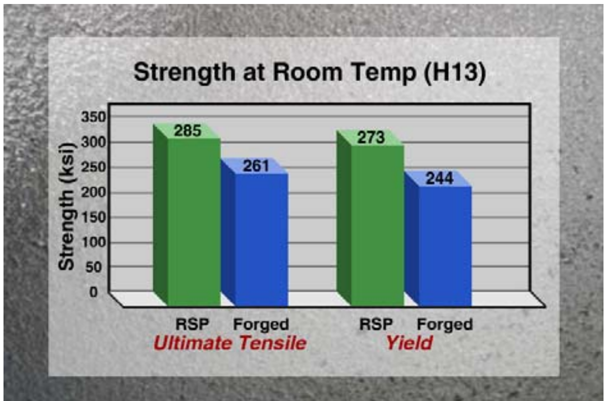
Machine Cycle time	3 hrs
Process Cycle time	5 days
Metals	All tool steels, copper, brass, gray iron, specialty Alloys
Dimensional (H13 data)	
Accuracy (ceramic pattern to tool)	+/- 0.00025 in
Accuracy (CAD to tool W/shrink)	+/- 0.002 in./in.
Repeatability (RTV to tool)	+/- 0.001 in.
Metallurgical (H13 data)	
Density	99.7%
Hardness	56 HRC to 62 HRC

Ultimate Tensile Strength	154 KSI to 285 KSI

Table II: RSP Process Capabilities

RSP Tooling, LLC, Located in Solon, Ohio is commercializing the process and has acquired an exclusive worldwide license for the Tooling Applications. The Beta production, which is machine that is shown in Figure 3, can produce a tool that is up to 7 inches, by 7 inches, by 4 inches thick. Although there are many tools in this size range going to a size of 15x15x10 substantially increases the revenue potential and the savings realized. To achieve the larger sizes substantial changes must be made to the machine design. Instead of spraying horizontally it would be required to spray vertically. There may also be the need to use multiple spray heads. Both of these concepts must be tested in laboratory conditions to assure there are no intrinsic difficulties before actually building the larger machine.

Figure 3: The Beta RSP Tooling Machine



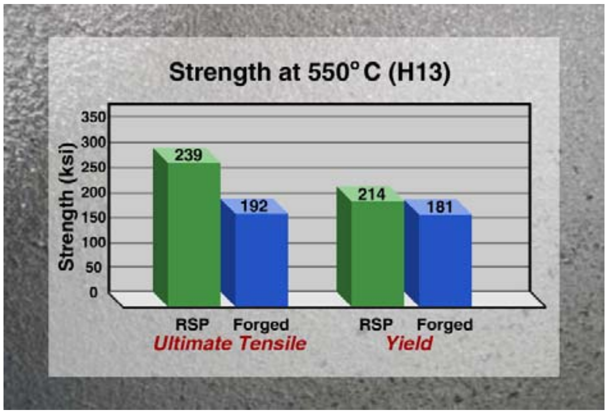


Figure 4: Comparison of Material Strength at Room Temperature And at 550ºC (1022ºF)

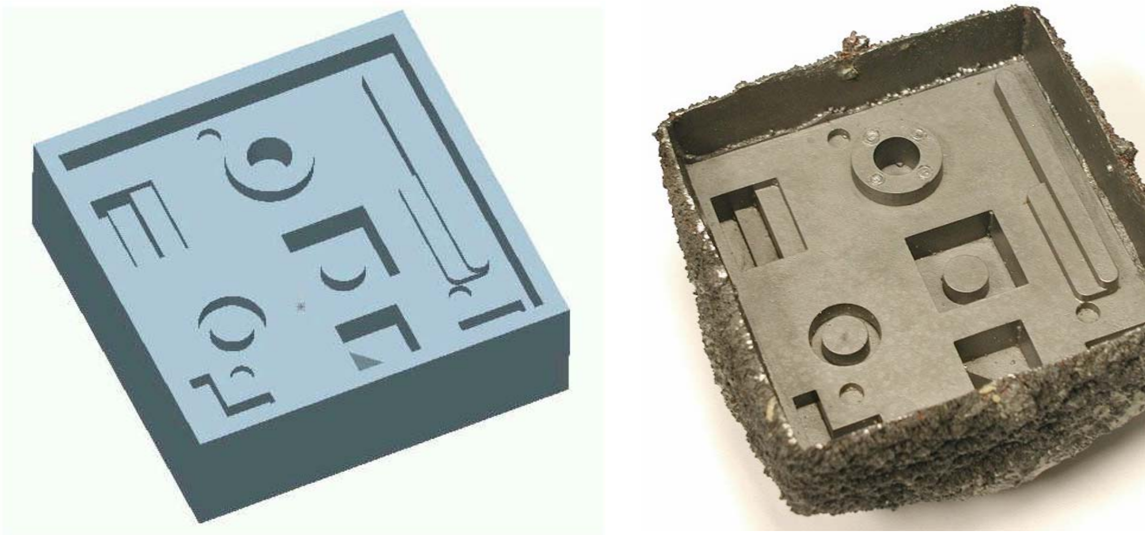


Figure 5: CAD Model of the Die and RSP Tooling Die

The finished CAD model of the die is then modeled in Solid Works. Figure 5 shows the finished model of the die and the die that was fabricated by the Rapid

Solidification Process.

2.3 Working Process of RSP Tooling

RSP tooling is a spray forming technology tailored for producing molds and dies. The approach combines rapid solidification processing as net shape materials processing in a single step. The concept involves converting a mold design described by CAD file to a tooling master using a suitable Rapid prototyping technology such as Steriolithography. This is followed by spray forming a thick deposit of tool steel on the pattern to capture the desired shape, surface texture and detail. The resultant metal block is cooled to room temperature, separated from the pattern and squared up to fit a standard holding block. The turn around time is approximately five days, which is significantly less than traditional tooling.

This process involves spraying layers of molten metal onto a 3-D pattern and building up the layers into full-sized die. This Rapid Solidification Process circumvents the majority of the fabrication steps in conventional methods. A high velocity jet of nitrogen sprays tiny droplets of molten metal onto ceramic pattern, depending on the alloy used. The surface area of the droplets is so great compared to their volume, the droplets cool somewhere between 100 to 100,000 degrees per second. Such a fast cooling rate results in unusual beneficial characteristics of the alloy. It produces a very uniform microstructure and allows the properties of many die steels to be tailored using 'artificial aging' instead of conventional heat treatment. Industry has demonstrated that artificial aging benefits many die steels. RSP dies last about 20% longer than conventional, machined dies.

Rapid solidification results in a combination of liquid, solid and "slushy" droplets coating the tool pattern. The slushiness allows the droplets to stick together as they hit the pattern, and may contribute to the level of detail RSP can achieve. The process does not avoid all post-fabrication steps, however. After depositing the spray on the mold or die, the pattern is removed; the deposit is trimmed to fit a standard mold base, and is heat-treated, if necessary. In prototype development, initial dies can be designed, created and tested within a few days. Changes to the die can be incorporated quickly and inexpensively. When the design is satisfactory, the prototype can be directly used for production without additional steps.

2.4 Benefits of RSP Tooling

RSP Tooling can produce a tool or insert within five days after the solid model has been defined in the computer. The advantages of this process are:

- The sprayed insert cavity requires little or no finishing machining, polishing, or engraving.
- Any commonly used tooling alloy can be used, and special steel materials can be tested as well.
- Timing to a production ready insert is no longer than most prototype processes and significantly less than other production ready processes.
- Tools made of H13 do not require heat treat .As Sprayed they are at Rockwell C 56 and can be age hardened to Rockwell C 62.

- Tools made of H13 appear to have a 25% increase in life expectancy over standard machine tools from high grade forged H13.
- The process is extremely repeatable and the cost for additional inserts is 50% of the cost of the initial one making it an ideal process for multi-cavity dies and replacement inserts because there is no need to repeat the Rapid Prototyping step.

It is believed that scrap tools can be melted and reused without loss of material properties.

2.5 Technology

RSP Tooling is a spray forming technology that was developed by Dr. Kevin McHugh at INEEL for producing molds and dies. The general concept involves converting a die design described by a CAD file to tooling master using a suitable rapid prototyping technology. A pattern transfer is made to a castable ceramic, typically alumina or fused silica. Spray forming a thick deposit of tool steel on the ceramic pattern to capture the desired shape, surface texture, and detail follows this. The deposit is built up to the desired thickness at a rate of about 500-lb/hr. Thus, the spray time for a 7"X 7" X 4" thick insert is only 8 minutes. The resultant metal block is cooled to room temperature and separated from the pattern. Typically, the deposit's exterior walls are machined using a wire EDM.

The turn round time for cavity or insert is unaffected by complexity. From receipt of a CAD solid model to shipment of the tool is about 5 days. Molds and dies produced in this way have been used for prototype and production runs in plastic injection molding, die casting, and forging process.

Generation of the physical model is straightforward. A number of rapid prototyping approaches are available commercially to accomplish this, but they differ widely in terms of cost, accuracy, and surface finish.

Ceramic patterns are made by slip casting or freeze casting ceramic slurry, typically made of alumina or fused silica on to the tool master. This involves mixing a ceramic powder with a liquid activator or binder, pouring the mixture into a mold, allowing it to set up, firing the ceramic in a furnace. Many ceramic formulations have been and are being evaluated for suitability in the process. Ease of casting, material cost, surface roughness, strength, thermal shock resistance, maximum use temperature, flatness, and dimensional accuracy are assessed. With the right equipment and procedures, very accurate and reproducible ceramics are easily made.

The spray-forming step is at the heart of the RSP Tooling process. Spray forming involves atomizing i.e. breaking up a molten metal stream into small droplets, using a high velocity gas jet. Aerodynamic forces overcome surface tension forces producing an array of droplet sizes that are entrained by the jet and deposited onto the pattern.

As the droplets traverse the distance separating the atomizer and ceramic tool pattern, they cool at very high rates that vary depending on size. As a result, a combination of liquid, solid, and droplets impact the ceramic, and weld together to form a coherent deposit.

The high cooling rate of the deposit greatly impedes atomic diffusion, so segregation is very limited to cast metal. It also minimizes the erosive interaction of the metal and ceramic tool pattern, allowing the deposited metal to accurately capture the surface details of the ceramic that would not be possible if the metal was cast onto the ceramic.

2.6 Accuracy

Dimensional accuracy and repeatability of all processing steps have been analyzed by Colorado State University personnel and industry partners using coordinate measuring machines (CMM). This has helped to identify suitable materials and processing conditions. Several conclusions have been drawn from the study.

Dies made from the same master but different ceramic patterns were essentially identical which is of major importance in multiple cavity dies or replacement inserts.

Most of the shrinkage in the ceramic comes from casting and firing the ceramic. Some ceramic formulations nearly eliminate the shrinkage. The shrinkage is consistent and reproducible which means that a computer program to predict shrink by feature will improve the process accuracy. The overall conclusion of the dimensional accuracy study is that the accuracy of molds made by the RSP Tooling method is comparable to the conventional practice of machining, polishing, and heat-treating.

2.7 Technical and Economical Benefits

The main benefits of RSP Tooling involve cost and turnaround time reductions without sacrificing quality and accuracy. When the atomized spray covers the surface of ceramic tool pattern, it replicates the features very accurately, regardless of the complexity. By doing so, it eliminates many steps in normal die-making practices such as milling, EDM, and polishing.

The cost for RSP tool is also constant except for the solid model cost and the material used. The master pattern varies depending on the method used, the size and the material. The cost of the second cavity does not have the cost of SLA since only one SLA is required.

2.8 Surface Finish

The surface finish that can be achieved by using RSP system is dependent on the ceramic and the initial model. The spray system replicates the ceramic with extreme accuracy and can pick up details as small as 0.0001”. Using the standard process now in use a surface finish of 45 micro inches can be achieved.

2.9 Limitations

There are limitations to the size of molds and dies that can be produced with current RSP Tooling equipment. Currently RSP Tooling, LLC can produce dies of the size of 7” X 7” X 4”. However, the process has no inherent size limitation, and the company is planning machines with lager capacity.

The second limitation is the aspect ratio for standing features of the die. Cavity features on the mold surface do not present problems. However, boss features on the mold surface do if their aspect ratio exceeds about 4:1, i.e., if the feature protruding from the surface of the die is more than 4 times as tall as it is wide. This is because, when spraying molten metal down into a cavity in the ceramic the metal will tend to bridge across the hole before it is entirely filled.

CHAPTER III

CONCEPT OF PROTOTYPING

A prototype is a physical representation of a product, which can be used to resolve one or more issues during product development. Prototyping communicates the visual layout and a product's look; experimental prototyping enables the exploration, optimization, and validation of the mechanical hardware. Prototypes help the design process in that they may be visually inspected, experienced, tested, modeled and simply observed as a 3-D entity. Two choices exist for modeling and simulating a product's performance: analytical models and physical models. During the pre-production phases of development, all models for a product cannot be solely analytical in nature. Unexpected effects are always discovered in the physical reality of a product. Many reasons exist for this realistic shortfall of analytical models, including accuracy, development time, and model intent. The effectiveness of physical models is pronounced for these situations. An extreme case of incomplete analytical modeling relates to the intent of a prototype. Hence a physical prototype construction and analysis is a critical aspect of product realization.

The term *rapid prototyping* (RP) refers to a class of technologies that can automatically construct physical models from Computer-Aided Design (CAD) data. These "three dimensional printers" allow us to quickly create tangible prototypes of our designs, rather than just two-dimensional pictures. Such models have numerous uses. They make excellent visual aids for communicating ideas with co-workers or customers. In addition, prototypes can be used for design testing. Designers have always utilized prototypes; RP allows them to be made faster and less expensively.

For small production runs and complicated objects, rapid prototyping is often the best manufacturing process available. Of course, "rapid" is a relative term. Most prototypes require from 3-72 hours building the part, depending on the size and complexity of the object. This may seem slow, but it is much faster than the weeks or months required to make a prototype by traditional means such as machining. These dramatic time-savings allow manufacturers to bring products to the market faster and less expensive.

Rapid prototyping is usually characterized by using ***additive methods***. Small fabrication primitives, such as drops or layers, are applied over and over until the part is completed.

Additive methods have the following key advantages:

1. The parts can have almost arbitrary geometric complexity.
2. The fabrication can be setup with little or no human preparation.

The following sections will look at several of the major rapid prototype technologies currently in use, characterize them by their additive increments, and describe their technology. At least six different rapid prototyping techniques are commercially available, each with unique characteristics. A software package "slices" the CAD model into a number of thin layers, which are then built up one atop another.

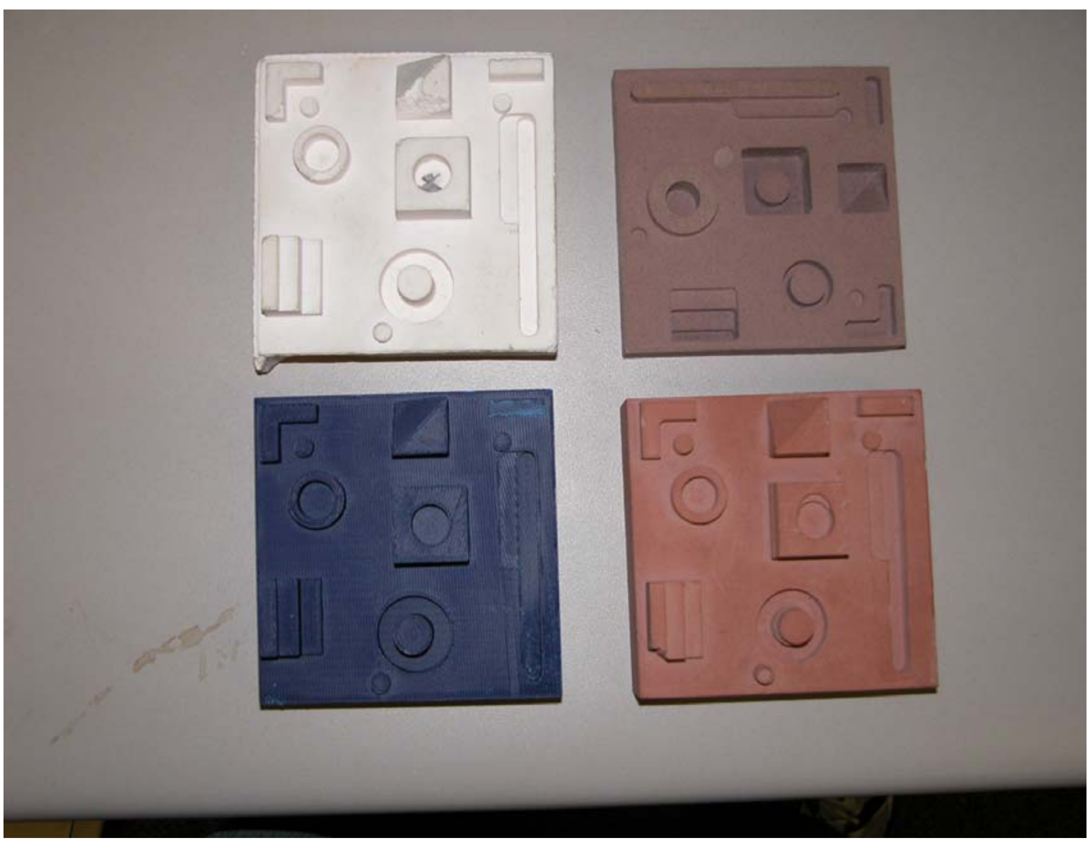


Figure 6: Broken Ceramic Part and Prototyped Parts

CHAPTER IV

RAPID PROTOTYPING

4.1 What is Rapid Prototyping?

Today it is very important to guide a new product from concept to market quickly and inexpensively. Rapid prototyping technology aids this process. Rapid prototyping automates the making of a prototype. It builds a prototype part from a 3-D CAD drawing.

Other terms used for rapid prototyping:

- Desktop manufacturing
- Automated fabrication
- Tool-less manufacturing
- Free-form fabrication

4.2 Why Rapid Prototyping?

To get a new product inexpensively to the market it has to be done quickly. One way to gain some time is to shorten the design process. A prototype is indispensable. Conventional prototyping takes weeks or even months, depending on the product and the method used. Rapid prototyping is a method to make these prototypes much more quicker and also more cost-effective. Furthermore rapid prototyping is capable of making parts with very small internal cavity and complex geometries. It is possible to see the real product in the early stage of the process of bringing a new product to the market.

4.2.1 How does rapid prototyping work?

Rapid prototyping was introduced in 1987. This technology was an additive process. An additive process builds an object by joining particles or layers of raw material. Other conventional processes are subtractive and compressive. Materials used for the additive process are photopolymer, thermoplastic, adhesives, powder, polymer and metals.

4.3 Overview of Rapid Prototyping

The term *rapid prototyping* (RP) refers to a class of technologies that can automatically construct physical models from CAD data. These "three dimensional printers" allow designers to quickly create tangible prototypes of their designs, rather than just two-dimensional pictures. Such models have numerous uses. They make excellent visual aids for communicating ideas with co-workers or customers. In addition, prototypes can be used for design testing. Designers have always utilized prototypes; Rapid Prototyping allows them to be made faster and less expensively.

In addition to prototypes, RP techniques can also be used to make tooling (referred to as *rapid tooling*) and even production-quality parts (*rapid manufacturing*). For small production runs and complicated objects, rapid prototyping is often the best manufacturing process available. This may seem slow, but it is much faster than the weeks or months required to make a prototype by traditional means such as machining. These dramatic time-savings allow manufacturers to bring products to market faster and more cheaply.

At least six different rapid prototyping techniques are commercially available, each with unique strengths. As RP technologies are being increasingly used in non-prototyping applications, the techniques are often collectively referred to as *solid free-form fabrication*; *computer automated manufacturing*, or *layered manufacturing*. The latter term is particularly descriptive of the manufacturing process used by all commercial techniques. A software package "slices" the CAD model into a number of thin layers, which are then built up one atop another. Rapid prototyping is an "additive" process, combining layers of paper, wax, or plastic to create a solid object. In contrast, most machining processes (milling, drilling, grinding, etc.) are "subtractive" processes that remove material from a solid block. RP's additive nature allows it to create objects with complicated internal features that cannot be manufactured by other means.

Of course, rapid prototyping is not perfect. Part volume is generally limited to 0.125 cubic meters or less, depending on the RP machine. For metal parts, large production runs, or simple objects, conventional manufacturing techniques are usually more economical. These limitations aside, rapid prototyping is a remarkable technology that is revolutionizing the manufacturing process.

4.4 Rapid Prototyping Techniques

Most commercially available rapid prototyping machines use one of six techniques. At present, trade restrictions severely limit the import/export of rapid prototyping machines, so this guide only covers systems available in the U.S.

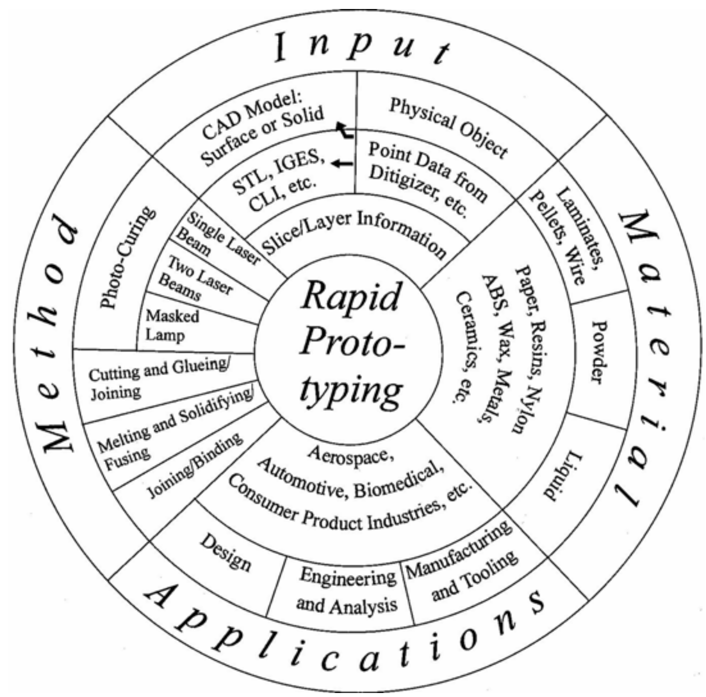


Figure 7: Rapid Prototyping Wheel

4.4.1 Stereolithography

Patented in 1986, stereolithography started the rapid prototyping revolution. The technique builds 3-D models from liquid photosensitive polymers that solidify when exposed to ultraviolet light. As shown in the Figure 8, the model is built upon a platform situated just below the surface in a vat of liquid epoxy or acrylate resin. A low-power highly focused UV LASER traces out the first layer, solidifying the model's cross section while leaving excess areas liquid.

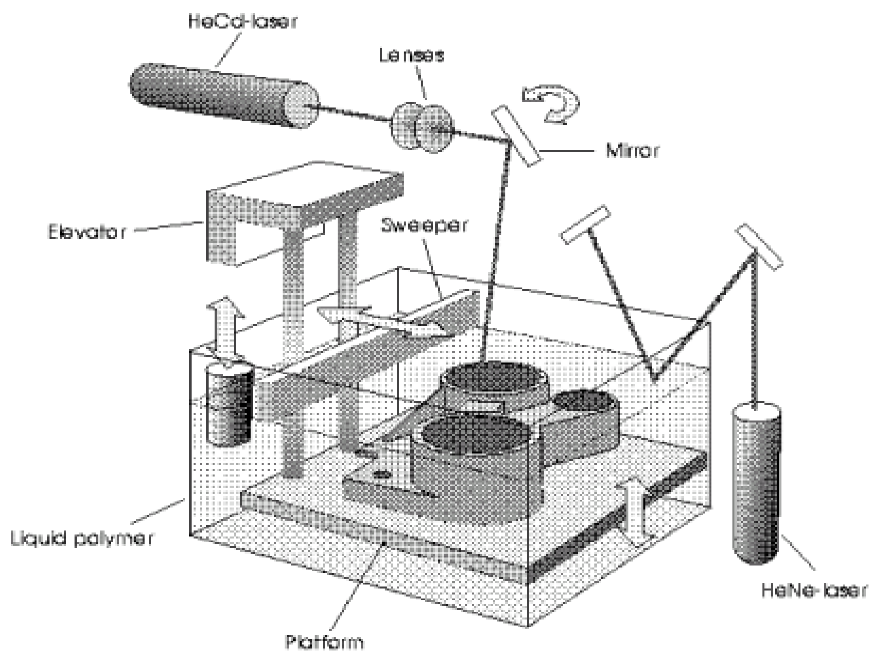


Figure 8: Schematic Diagram of Stereolithography

Next, an elevator incrementally lowers the platform into the liquid polymer. A sweeper re-coats the solidified layer with liquid, and the laser traces the second layer atop the first. This process is repeated until the prototype is complete. Afterwards, the solid part is removed from the vat and rinsed clean of excess liquid. Supports are broken off and the model is then placed in an ultraviolet oven for complete curing.

Stereolithography Apparatus (SLA) machines have been made since 1988 by 3D Systems of Valencia, CA. To this day, 3D Systems is the industry leader, selling more RP machines than any other company. Because it was the first technique, stereolithography is regarded as a benchmark by which other technologies are judged. Early stereolithography prototypes were fairly brittle and prone to curing-induced warp and distortion, but recent modifications have largely corrected these issues.

Figure 9: Stereolithography Product

4.4.2 Laminated Object Manufacturing

In this technique, developed by Helisys of Torrance, CA, layers of adhesive-coated sheet material are bonded together to form a prototype. The original material consists of paper laminated with heat-activated glue and rolled up on spools. As shown in the Figure 9, a feeder/collector mechanism advances the sheet over the build platform, where a base has been constructed from paper and double-sided foam tape. Next, a heated roller applies pressure to bond the paper to the base. A focused laser cuts the outline of the first layer into the paper and then cross-hatches the excess area (the negative space in the prototype). Cross-hatching breaks up the extra material, making it easier to remove during post-processing. During the build, the excess material provides excellent support for overhangs and thin-walled sections. After the first layer is cut, the platform lowers out of the way and fresh material is advanced. The platform rises to slightly below the previous height, the roller bonds the second layer to the first, and the laser cuts the second layer. This process is repeated as needed to build the part, which will have a wood-like texture. Since the models are made of paper, they must be sealed and finished with paint or varnish to prevent moisture damage.

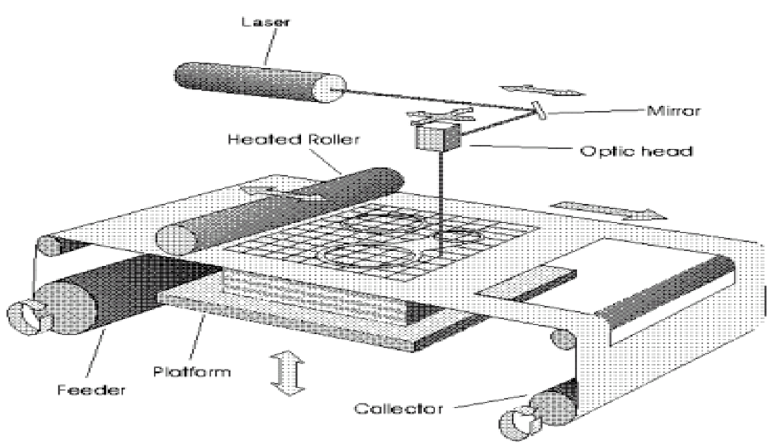


Figure 10: Schematic Diagram of Laminated Object Manufacturing

Figure 11: LOM Product

4.4.3 Selective Laser Sintering

Developed by Carl Deckard for his master's thesis at the University of Texas, selective laser sintering was patented in 1989. The technique, shown in Figure 12, uses a laser beam to selectively fuse powdered materials, such as nylon, elastomer, and metal, into a solid object. Parts are built upon a platform which sits just below the surface in a bin of the heat-fusable powder. A laser traces the pattern of the first layer, sintering it together. The platform is lowered by the height of the next layer and powder is reapplied. This process continues until the part is complete. Excess powder in each layer helps to support the part during the build.

Figure 12: SLS Product

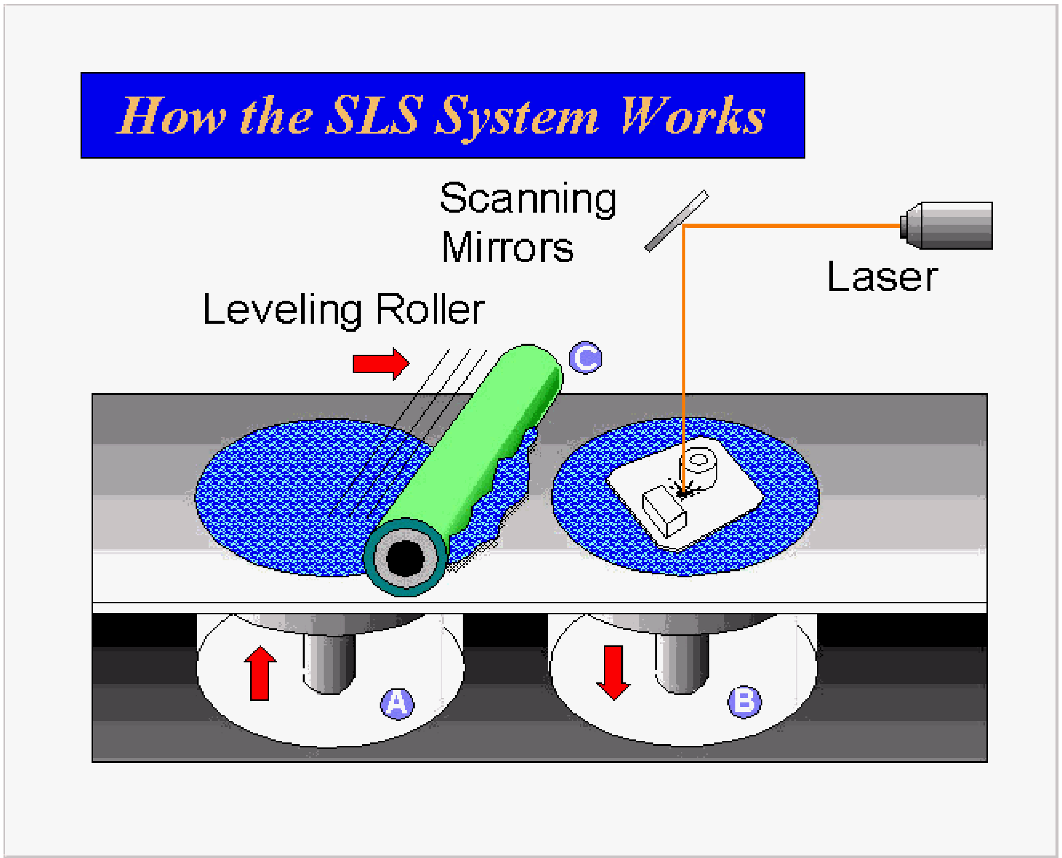


Figure 13: Schematic Diagram of Selective Laser Sintering

4.4.4 Fused Deposition Modeling

In this technique, filaments of heated thermoplastic are extruded from a tip that moves in the x-y plane. Like a baker decorating a cake, the controlled extrusion head deposits very thin beads of material onto the build platform to form the first layer. The platform is maintained at a lower temperature, so that the thermoplastic quickly hardens.

After the platform lowers, the extrusion head deposits a second layer upon the first. Supports are built along the way, fastened to the part either with a second, weaker material or with a perforated junction.

Stratasys makes a variety of FDM machines ranging from fast concept modelers to slower but high-precision machines. Materials include ABS (standard and medical grade), elastomer (96 durometer), polycarbonate, polyphenolsulfone, and investment casting wax.

Figure 14: Hand Lever Produced by FDM

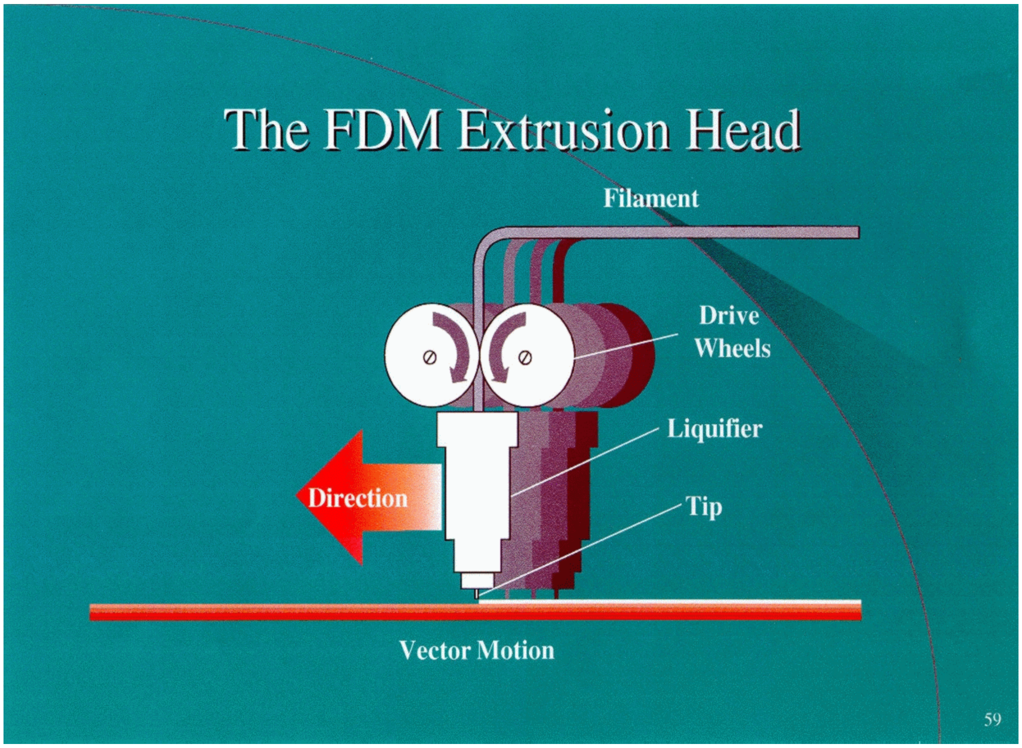


Figure 15: Schematic Diagram of Fused Deposition Modeling

4.5 Sources of Errors in Rapid Prototyping

Everybody knows that any manufacturing process is approximate. No part geometry can ever be produced exactly according to specifications. Typical additive processes are worse in this regard than are typical subtractive processes, so it is a good idea to be familiar with the sources of the approximation errors.

Resolution errors arise from a limitation on the total number of addressable points in the x-y-z coordinate system of the machine.

Accuracy errors arise from each individual device's location deviation in the object being fabricated from the geometry in the STL file.

Errors due to layer thickness come about because the layers act as "terraces" and the stair-steps give the surface a roughness it was not supposed to have. This is very similar to the familiar computer graphics aliasing problems. However, whereas aliasing artifacts can be fixed by blending in surrounding pixels, no analogous process exists for fabrication.

Post-processing errors arise from each RP technology's post-fabrication characteristics. For example, stereolithography parts might warp during the curing process or might sag if exposed to too much heat. LOM parts might change shape by absorbing moisture if not properly sealed.

Some errors occur due to the preparation of the STL file:

Insufficient triangulation happens when not enough triangles are used to approximate the curved surfaces. The control of the number of triangles is usually a parameter that is left to the discretion of the user. Too few triangles result in a model, whose curved surfaces feel crude, not smooth.

CHAPTER V

SUBTRACTIVE RAPID PRTOTYPING

5.1 What is SRP?

SRP (Subtractive Rapid Prototyping) is another process of transforming 3-D digital models content into physical objects. The term Subtractive suggests that taking away material during the process. This is precisely what CNC Rapid Prototyping does. The original source model can be of any 3-D content or software origin. Any CAD, CAM, or 3-D modeling or animation part(s) or model files can be machined. Any type of model can be machined such as polygon mesh models, nurbs surface & Solids models, point cloud models or scanned data files.

Subtractive Rapid Prototyping (SRP) is a low cost prototyping and parts manufacturing process. The digital model is recreated and transformed into a real world physical object that can be held in the hand. The final milled parts can be used for preproduction models ready for manufacturing, product prototypes, sales samples, proofs, displays, and concept development.

Many industries can benefit from and utilizing RP such as Computer Graphics, Toys, Medical & Dental, Machine Shops, Product Development, Inventors and prototyping companies.

5.2 Key Benefits

Application of Subtractive Rapid Prototyping provides many benefits some of them are as follows

- Increase productivity and save cost.
- Turn over parts in just a few days.
- No more wasted internal resources and man-hours.
- Wide variety of materials can be machined.
- Surface Quality Rivals any other RP system on the market.
- High tolerance machining

Any model regardless of the source software can be machined.

SRP Work Flow

1. 3D-CAD model creation
2. The model is imported into the CAM post processing or milling software
3. The model is programmed by creating progressive tool paths
4. The tool path data is sent to the CNC Machine and the part(s) are milled based on those tool paths
5. The model is cut from a solid stock block of raw material

CAD Model Creation

First, the object to be built is modeled using a 3D-CAD software package.

SolidWorks as solid modeler is being used for the project. It is also possible to create CAD file expressly for prototyping purposes by capturing the geometry of part.

Import into milling software

It is not necessary to save the 3D model into particular format such as STL as in RP. Whatever software is used, just the part file from that software is necessary. For SolidWorks just native SolidWorks part file (.sldprt) file is needed. If AutoCAD is being used, then just need (.dwg) file is needed. So SolidWorks file will open into the CAM software directly. For the project GibbsCAM software is used, as milling software, for creation of tool path and simulation of model.

Creating progressive tool paths

Once the model is in the GibbsCAM then tools and processes were decided for building the part. In accordance with that tool path was created so as to obtain an accurate model with better surface finish. The building simulation in GibbsCAM can be observed better before even the actual building process. Speed, depth of cut, and width of cut can be adjusted with GibbsCAM.

Send data to CNC Machine

Now the tool path for machining process is known. Then the software generates G and M code automatically so that the connected CNC machine can read the data. To achieve this just post processing is required and then save the file. Post processing will create G and M code for particular CNC machines. Once this saved file is sent to the CNC machine through a printer, the machine starts running.

<u>Cut solid stock block of raw material</u>

The raw material has to be mounted on the bed of CNC machine. The mounted block should be fixed and should not move throughout the machining process. With SRP being a subtractive process, the tool will remove the desired material from the solid block to obtain required shape. The tool will follow the tool path created by G and M codes to cut the stock block.

Subtractive processes have their own set of advantages:

1. Accuracy - Machine tools are more accurate than rapid prototyping layer-by-layer or drop-by-drop methods.
2. Finish - Machine tools can produce a very smooth finish.
3. Mass production - Machining methods are faster and cheaper for per-part production and thus are more appropriate in mass production.
4. More materials - Many different materials can be machined.
5. Larger pieces - Larger geometries can be machined than can be prototyped

CHAPTER VI

THE MACHINE: ROLAND MDX-15

For this project, a Roland MDX 15 was used which makes an attractive addition to desktop. It's low weight and compact size makes true desktop prototyping possible. All control electronic is integrated.

Its operation is by far the easiest of all available machines, it can be driven from the PC, and by just sending a file to the printer port, no extra software is needed. As the home position is fixed no controls on the machine are needed as well. The NC files needs to be in Roland format, which can be chosen in most CAM packages.

As a scanner the machine is driven from a PC by the included Picza software. This software enables setting of the area to be scanned, and the resolution (pitch) to be used, and the rest is done automatically. Output of the CAD geometry is possible in STL, DXF and VRML format.

CNC Machining

A large cutting tool is used to rough out the model and remove large quantities of unwanted material from the work. Subsequently tools of smaller diameter and end profile follow this, until the work is near completion. Finally a small tool is used to finish the surface to the required standard. Various size and shape cutters are used according to the materials and how fast they can work on. Foam is much faster to work on than steel for example. Some machines can automatically interchange tools as the work progresses.

The **number of axis** available can determine a machine's capability.

3 axis machines give the basic movements for 3D geometry x, y, and z. Usually the revolving cutter moves up and down (z -axis) and the work is clamped to a moving bed that travels from right to left (x-axis) and from forward to back (y -axis).

4 axis machines allow the cutter to revolve around the x-axis, this option can be fitted to a 3-axis machine usually requiring the work being clamped into a controlled revolving jig.

5 axis machines allows for the work to be simultaneously revolved around the z-axis. This broadens the potential further enabling work to be made that has undercuts.

Machine path verification

The more complicated the work, the machine and the machining needs, the more necessary it is to have verification software, that can predict and ensure that the form can be manufactured without damaging the work, or the machine.

Figure 16: Modela MDX 15

Features:

<u>Subtractive RP</u>

Subtractive Rapid Prototyping starting with a solid object and removing unwanted material - has several advantages over traditional rapid prototyping. Significantly less expensive than rapid prototyping machines with the same resolution, SRP machines mill a wider range of materials that cost less and do not require chemicals or post finishing work. Plus, they produce a superior finish.

<u>Scans Almost Anything</u>

The MDX-15 scans a wide range of objects that conventional contact scanners find very difficult. It can even scan glass, which is impossible using optical scanners because the light beams passes through the object without detecting it.

CHAPTER VII

THE MATERIAL: REN BOARD

Generally metals and alloys are used in CNC machines. But instead of metals, if other material is available to work with, which will be easier to machine, then that will be always be an added advantage. So considering all factors and machine's capability Ren shape boards are used to manufacture die.

Ren shape tooling and high-temperature work boards are designed and formulated to meet the wide scope of tooling, modeling, prototyping and fabricating applications found throughout industry.

Although the Ren Shapes consist of tooling boards for many types of applications, they all share a number of performance characteristics including: ease of machining, excellent dimensional stability, good edge definition, and low levels of residual particles for easy cleanup.

Ren Shape 450 is the standard by which all other modeling boards are measured. An ideal material for models and prototypes, master patterns, tooling aids, forming tools and proofing CNC programs, this material will produce very stable, dimensionally accurate tools with well-defined edges and surface detail when prepared, handled, and worked properly.

Ren Shape can be machined using standard woodworking tools and will not result in objectionable dust particles when planed, milled, sawed, or drilled. Ren Shape resists warping and can be easily painted and finished for appearance and prototype models.

Trade Name: Ren Shape 450

Chemical Family: Cured Polyurethane

The core product in the Ren Shape line is Ren Shape 450, an easy-to-machine; dimensionally stable material that was developed more than 10 years ago for use with computer-numerically-controlled machining equipment. This original board was based on an award-wining material Ciba developed for NASA / Rockwell specifications for machining master models of thousands of tiles for the thermal protection system.

Among these new-generation boards are products for building styling models, fixturing and duplicating aids, foundry patterns and hammer-form dies as well as metal-forming and vacuum-forming molds, and nickel electroplating mandrels.

Ren Shape mold in half the time needed to machine metal. The board helps significantly reduce delivery times and costs on initial parts while hard tooling is being made.

Ren Shape 450 Modeling Board - A medium-density polyurethane modeling board that holds tight tolerances, maintains outstanding dimensional stability after exposure to temperature and humidity extremes, and holds solid, well-defined edges. This has hardness of 45-50 Rockwell C.

Figure 17: Ren Board 450

Ren Shape 5003 Modeling Board - A higher-density epoxy board are used for production of models that can withstand exposure to temperatures up to 140°F (60°C). Holds close tolerances, well-defined edges and exhibits good tensile and compressive strength. This has hardness of 65-70 Rockwell C.

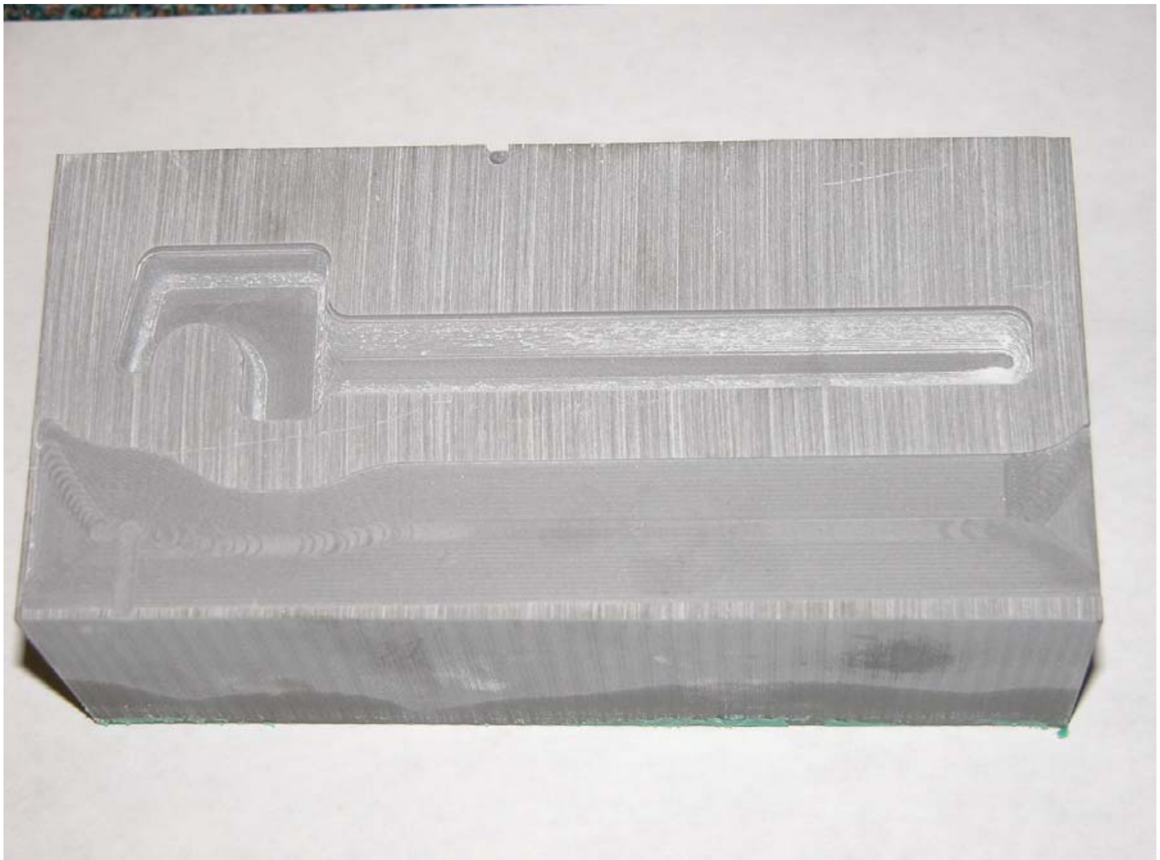


Figure 18: Ren Board 5003

Ren Shape 460 Modeling Board - A low- density precision modeling board, the material also exhibits lower coefficient of thermal expansion than other modeling materials for enhanced dimensional stability over a broader temperature range. Exhibits excellent accuracy and edge definition. This has hardness of 30-35 Rockwell C.

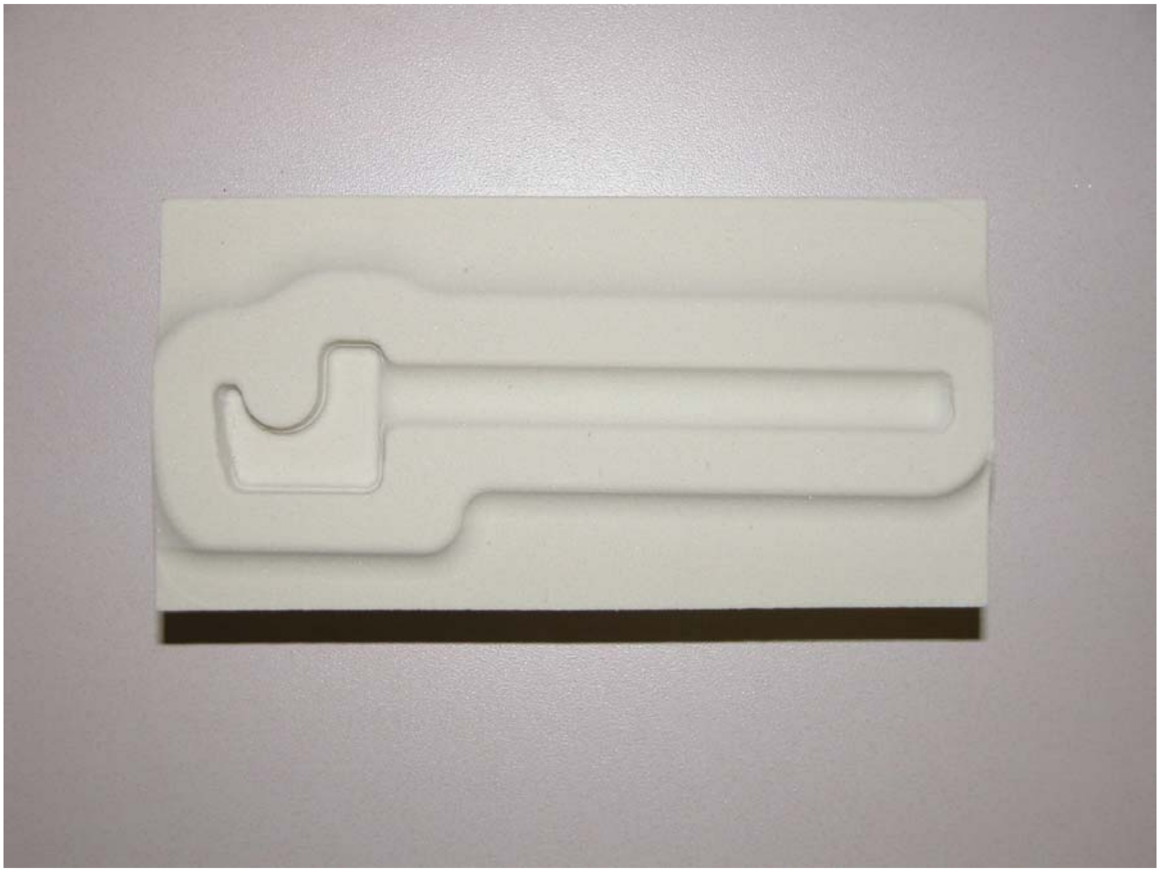


Figure 19: Ren Board 460

Figure 20: Different types of Ren Boards; A: Ren Board 5003,

B: Ren Board 460, C: Ren Board 450

CHAPTER VIII

COMPARISON STUDY

8.1 Comparison of SRP and RP

In Cleveland State University, facilities for creating easy as well as complicated dies are available. To illustrate, as a practical example, a comparison study of all three facilities for the following die was performed.

Figure 21: Part to be Studied

nology	FDM	3DP	SLA	SRP
terial	ABS	Plaster	Epoxy	Polyurethane
y(inches)	0.01	0.001	0.006	0.002
d Size	8x8x12	20x24x16	20x20x24	6x4x2 3/8

Table III: Comparison of Machines

These facilities are compared for

- Accuracy (layer thickness)
- Maintenance
- Machining time

8.1.1 Accuracy

Stair-stepping

Since rapid prototyping builds objects in layers, there is inevitably a "stair-stepping" effect produced because the layers have a finite thickness. Those methods that produce the thinnest layers have less stair-stepping than others, but it's almost always visible. The machines that can build each layer flat after its deposition and as little as 0.0005 inches of material can be left as a layer thickness. Of course, that makes the building process very slow. Variable layer thickness can however, be used at times to speed things up. Steriolithography can also produce thin layers, although not quite at that level and this feature is mainly used to make small parts in the several inches or less range. Everything else produces more pronounced stair stepping. Obviously methods based on one or another form of laminated object manufacturing (LOM) will be limited in what can be accomplished because of the raw material thickness. Methods based on powders, for example selective laser sintering (SLS) or three dimensional printing (3DP), have the finite size of the powder as a lower limit. Layer thickness will almost always be greater than the minimum particle size. One cannot indefinitely grind a powder smaller since at some point it starts to acquire a static self-charge that makes it difficult to spread evenly. In some experimental methods of LOM, variable layer thickness is used and cutting means may be employed that shape edges so that less stair-stepping is visible.

Stair-stepping is one type of inaccuracy, as well as a visual appearance artifact, that differentiates RP from all subtractive methods. Absolute accuracy can be defined as the difference between an intended final dimension and the actual dimension as determined by a physical measurement. In addition to those for linear dimensions, there are accuracy specifications for such features as hole sizes and flatness. In a few fields absolute accuracy isn't very important, but in most areas it's a critical issue. A number of studies have been done comparing rapid prototyping technologies with one another and with standards over the years. Enormous strides have been made, and while tolerances are still not quite at the level of CNC, they come close over most measurements for many RP technologies. However, one cannot say with any certainty that one method of RP is always more accurate than another, or that a particular method always produces a certain tolerance. That's because unlike CNC, where the position of the cutting tool can be easily and precisely determined as a reference point, and which operates on the work in a very direct way, all methods of RP involve multiple operations, intervening energy exchange and/or complex chemistry.

8.1.2 Maintenance

Removing of support structure:

The major problem with rapid prototyping is the removing of support structure. Support structure is the material, which can be easily removed, melted, or dissolved. This is used to build up the main part of the die. This just provides support and fills up the gap. Powder-based methods of rapid prototyping are self-supporting for features such as overhangs and undercuts, the excess powder is simply shaken off or vacuumed away. All other methods require a support structure of some kind, which is fabricated right along with the part. This must subsequently be removed in a secondary operation, which may require considerable effort and time. For SRP, there is no need to worry about support structure. The SRP technique does not involve the support structure as it cuts the part out of the block. So only thing to worry about is the burr but merely a brushing up solves the problem.

8.1.3 Speed

All RP technologies are fairly slow taking from hours to even days to output a part. It is not unusual with some complex parts to save literally weeks of machining time.

3D Printing is the speediest- quicker than stereolithography and far faster than some inkjets or FDM. Considering the time required to build up the impression die, it can be easily concluded that SRP is the least expensive and fastest technique of all. The time required to build the die in 3D Printer is 2 hrs and 17 minutes, in Stratasys it requires 5 hrs and 47 minutes but with the SRP technique which uses CNC machining it requires around 5hrs for the same part with more accuracy.

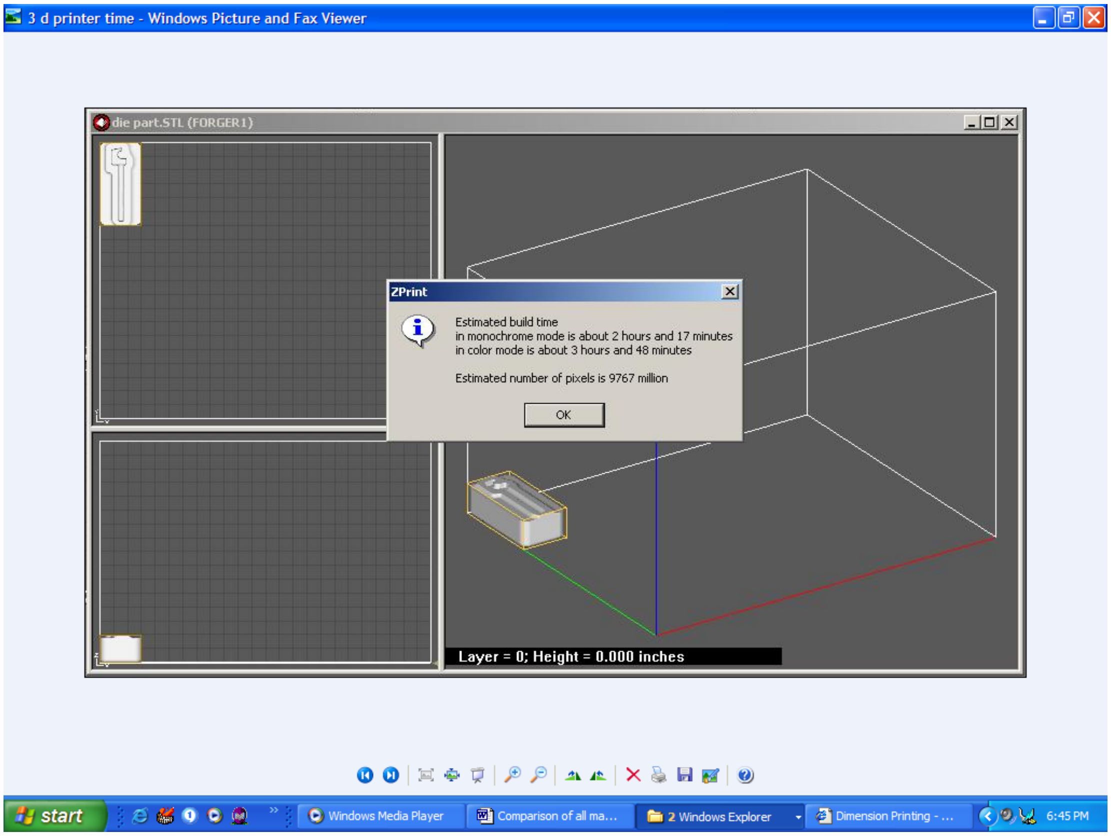
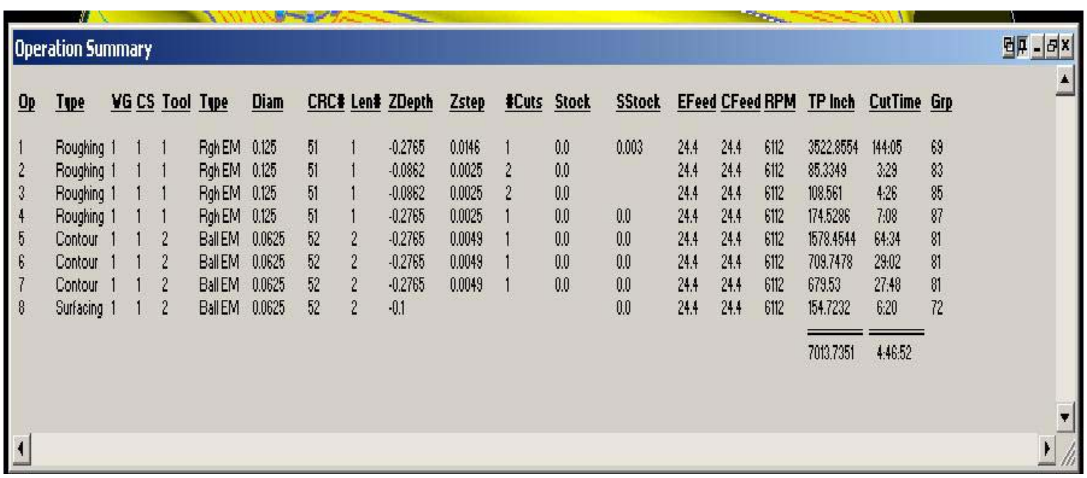


Figure22: Estimated Time in 3D Printer


Operation Summary

Op	Type	VG	CS	Tool	Type	Diam	CRC#	Len#	ZDepth	Zstep	#Cuts	Stock	SStock	EFeed	CFeed	RPM	TP Inch	CutTime	Grp
1	Roughing	1	1	1	Rgh EM	0.125	51	1	-0.2765	0.0146	1	0.0	0.003	24.4	24.4	6112	3522.8554	144:05	69
2	Roughing	1	1	1	Rgh EM	0.125	51	1	-0.0862	0.0025	2	0.0		24.4	24.4	6112	85.3349	3:29	83
3	Roughing	1	1	1	Rgh EM	0.125	51	1	-0.0862	0.0025	2	0.0		24.4	24.4	6112	108.561	4:26	85
4	Roughing	1	1	1	Rgh EM	0.125	51	1	-0.2765	0.0025	1	0.0	0.0	24.4	24.4	6112	174.5286	7:08	87
5	Contour	1	1	2	Ball EM	0.0625	52	2	-0.2765	0.0049	1	0.0	0.0	24.4	24.4	6112	1578.4544	64:34	81
6	Contour	1	1	2	Ball EM	0.0625	52	2	-0.2765	0.0049	1	0.0	0.0	24.4	24.4	6112	709.7478	29:02	81
7	Contour	1	1	2	Ball EM	0.0625	52	2	-0.2765	0.0049	1	0.0	0.0	24.4	24.4	6112	679.53	27:48	81
8	Surfacing	1	1	2	Ball EM	0.0625	52	2	-0.1				0.0	24.4	24.4	6112	154.7232	6:20	72
																	7013.7351	4:46:52	

Figure 23: Estimated Time in Modela MDX 15

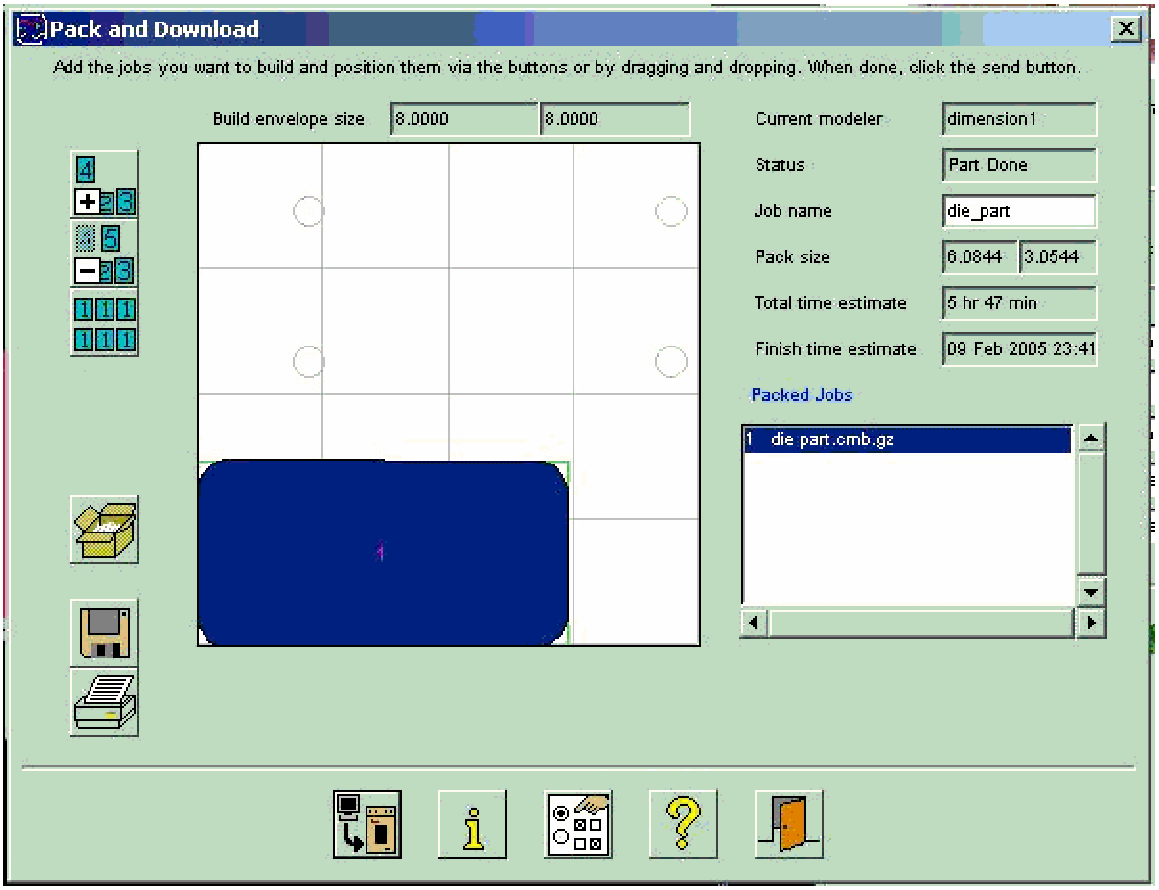


Figure24: Estimated Time in Stratasys

8.2 Comparison of Technologies

These are the pros and cons of Subtractive Rapid Prototyping (SRP) and make some general comparisons to other technologies available in the market. With significant developments having being made in both technologies both types of systems have their inherent advantages and disadvantages. The dilemma to use one system over the other would most likely be determined by several factors such as the part or model itself, time, costs, material selection, the degree of accuracy, secondary operations such as work involved in clean up and or finish, as well as final use for the finished prototype.

Rapid Prototyping can be considered for any type of the available technologies. Rapid Prototyping would refer most likely to SLA, LOM, and FDM technologies. These types of technologies are all typically build-up processes, where the software examines the surface model data and creates cross-section of the model's shape. The software divides it into hundreds or thousands of individual layers. Each layer is progressively built up to form the net shape of the part.

Subtractive Rapid Prototyping, as it implies is a removal process; the process of CNC machining from a raw stock block of material. Where the machine tool cuts or removes material from the stock in a progressive fashion until the net shape is achieved. The path of the cutters is generated in a post processing software (CAM machining software).

Typically with other RP technologies such as SLA & FDM there are greater capabilities of producing almost all of the details in the part, but by nature of the process, 3 to 4 times the amount of hand clean- up work is needed. The amount of clean-up work to polish off a SRP part will most likely be much less than a RP part.

- ***Materials***

CNC: Nearly unlimited

Machining centers are capable of milling almost every material imaginable.

The following materials can be machined. Compared to any other RP technology SRP offers an almost endless variety of materials

FOAM BOARDS: Expanded poly-styrene, urethane foam tooling board, and green foam

WOOD: MDF, partial board, misc. woods, cork board

PATTERN LUMBER: White pine, mahogany, cherry, hard maple, and poplar

TOOLING BOARD: Ren-Shape, chemical wood

PLASTICS: acrylic, ABS, styrene, polycarbonate, 2 Color engraving stock, engraving blanks, delran, polyethylene, polyacetal, celtec, and other plastics

URETHANES: ridged urethane **r**esin (fast cast), misc. ridged and simi ridged urethanes

EPOXY RESINS: misc. epoxy resin systems

COMPOSITES: bondo, filled urethanes

WAX: freeman machine-able Wax, sculpting wax (barbie toy sculpting wax), jewelers wax, paraffin wax

GYPSUM PRODUCTS: plaster, ultra cal 30, pottery plaster

METALS: non-ferrous metals such as brass, aluminum, copper, bronze

FOODS: chocolate, hard candy, solid sugar, and misc. goodies

RP: Limited

Material development has come a long way. A broader range of materials and material properties are available. These now include metals, plastics, ceramics, and composites. Yet, the selection is still very limited. And in most cases, properties do not exactly match those of machinable, moldable, or castable materials.

- ***Maximum Part Size***

CNC: Large enough to handle aerospace parts

From small desktop units to large systems, CNC machining can fabricate parts and molds of virtually any size. Size is only limited by the capacity of the available machine tools.

RP: 24″ x 36″ x 20″

Although commercially available units may not be able to handle an instrument panel or bumper, the available build envelopes are suitable for the majority of consumer and industrial products. Should a part be too large for the system, it can be constructed in sections and glued. An important consideration is the impact of size on time. Larger parts take longer to build.

- ***Part Complexity***

CNC: Limited

CNC machining must deal with every feature in a part, and this can add time and cost. As the complexity of the part rises, so do the number of setups and tool changes. High aspect ratio features, deep slots and holes and square corners can challenge the most expensive CNC milling machine. While a five-axis mill and some ingenuity can overcome challenging features, something as simple as an undercut can produce problems.

RP: Unlimited

If a prototype can be modeled with design software, it is possible to build it with little impact on time or cost. The ability to quickly and cost-effectively produce complex parts is one of RP's biggest benefits.

- ***Feature Detail***

CNC: Varies

For many features, CNC has the advantage over RP. Sharp edges, smooth blends, and clean chamfers are among the details where CNC excels. This is especially true when evaluating detail in terms of accuracy and surface finish.

RP: Varies

There are situations in which RP can produce features that CNC cannot. For example, RP can produce sharp inside corners and features with high aspect ratios, such as deep, narrow channels or tall, thin walls, ribs and posts.

- ***Accuracy***

CNC: 0.0002″ to 0.005″

With the right equipment, it is possible to machine at high precision. While CNC in general is more accurate than RP, precision is usually related to the cost of the machine.

RP: 0.005″ to 0.030″

While it is possible to achieve dimensional accuracy better than 0.005” on individual dimensions, 0.005” to 0.030” is the typical range of deviation. Accuracy is a function of the RP system and the size of the dimension. As a dimension increases, so does the inaccuracy.

- ***Repeatability***

CNC: High

CNC is much more repeatable than RP. If the tool-path, tool, and materials are unchanged, the output is highly repeatable.

However, environmental conditions and the human factor can affect results. Temperature and humidity, for some materials, can alter the outcome as can the accuracy of the machinist's setup.

<u>**RP:** Low</u>

Build any part on two different days and the results may vary. RP is sensitive to many factors that affect the quality of the prototype. Temperature, humidity, orientation and placement are just a few of the parameters that can affect the repeatability of the output.

- ***<u>Surface Finish</u>***

<u>**CNC:** Ra 20 to 200 (0.5 to 5 microns)</u>

Unlike RP, CNC machining can produce surface finishes suitable for prototypes, patterns and tooling. As with RP, secondary operations (sanding, polishing) can further improve the surface finish, but they may adversely affect accuracy, time and cost.

RP: Ra 100 to 600 (2.5 to 15 microns)

Without any secondary operations, some, if not all, surfaces will be rough. While RP has progressed to layer thickness of 0.0005” to 0.001” for some technologies, the layer striations and stair-stepping still affect surface finish. If desired, secondary operations can improve the smoothness to any level, but this can alter the dimensional accuracy of the part. Also, these operations can add time and cost to the project.

- ***Reliability***

CNC: Moderate to high

With more than 30 years of research and development, CNC is a mature technology that is dependable and reliable. Over the years, continuous improvement has eliminated system elements that diminish reliability.

RP: Moderate

For most technologies, reliability increases as the product matures. The age of RP technologies ranges from 1-15 years, which means that varying degrees of reliability is expected. With less time and fewer resources, some of the RP manufacturers have not had sufficient time to refine the components of the systems to improve reliability.

- ***Staffing***

CNC: Significant

CAM software applications have improved, but in most cases, they have not eliminated the need for human intervention. Machine setup and operation require an experienced machinist and it is not common to make prototypes in a lights-out mode.

RP: Minimal

With the exception of secondary operations (benching), RP requires little labor. Within a few minutes, it is possible to prepare files for part production and start the build. During the build, there is little or no operator attendance.

- ***Skilled Labor***

CNC: Moderate to high

Machining takes skill, creativity and problem-solving abilities. From designing tool paths and machining strategies to operating and monitoring the cutting, machining is the work of experienced craftsmen. With organizations getting leaner and the availability of machinists declining, there could be a lack of available resources for prototyping work.

RP: Minimal

The technology is certainly not a minimum wage position, but when compared to machining, the demand for highly skilled talent is much less. This is true in part because less labor is required.

Additionally, RP has improved in ways that take the art out of the process.

- ***Lead-time***

CNC: Moderate

A lot goes into machining. Labor, tool paths, fixturing, machine time and materials are required. The result is that many jobs will take longer than those done in RP. However, CNC can be faster when the design is simple and straightforward, and when high spindle speeds and feed rates are an option.

RP: Short to moderate

With less labor, fewer steps and an insensitivity to design complexity, RP reduces lead times not only for the physical build, but also for the entire process. Overall, the RP process is more efficient in both time and labor. With RP, data can be received at late evening and parts delivered the next morning; unthinkable for CNC machining unless there is more than one shift. Yet, this does not mean that RP is the fastest for all parts.

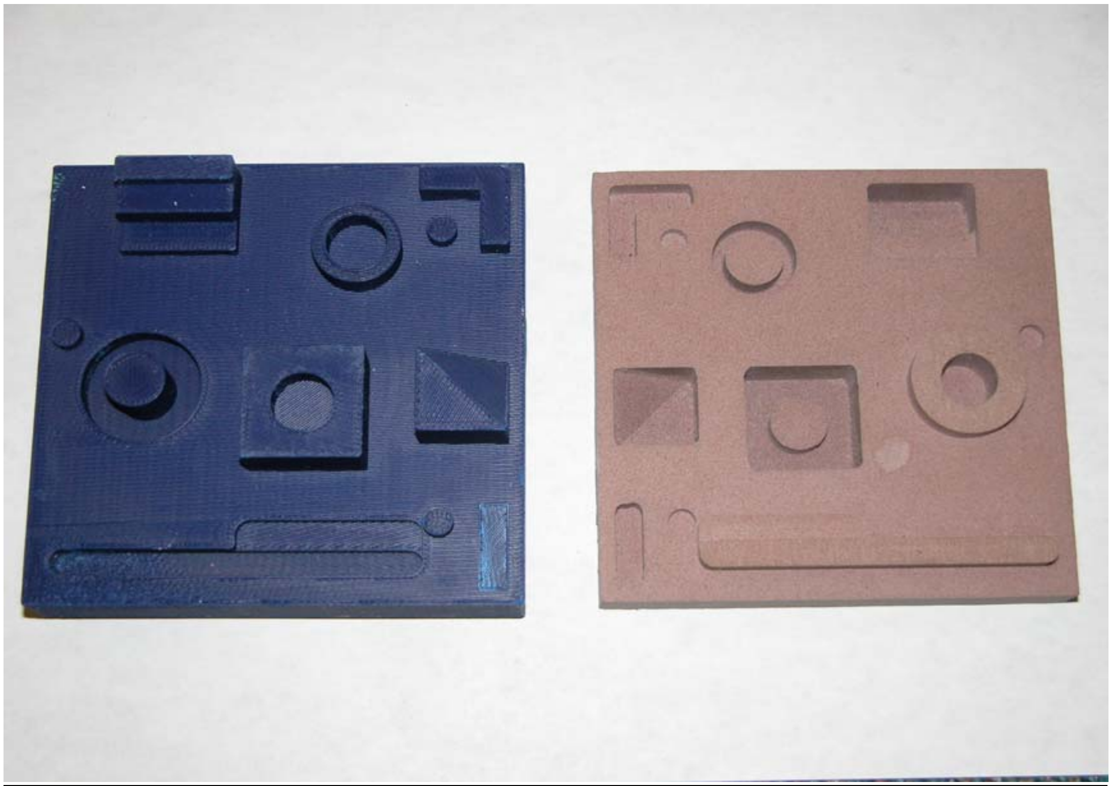


Figure 25: Parts using Additive and Subtractive Methods

CHAPTER IX

RESULTS

Comparing the result of different types of Ren boards that were used to build, rather cut the die, then is observed that the softer Ren board took less time than others. But Ren board 450 is the best option, considering the machinability, porosity and hardness.

Die with Ren board 460:

As this material has very low hardness, it took just 3 hr to complete the whole part. The product got very good surface finish. But the only and most important problem with this is the porosity. As the material is porous, it is very hard to get required ceramic part done. Attempt to make the ceramic part out of it failed, even with better part. So the idea of using this board was dropped.

Figure 26: Broken Ceramic Part

Die with Ren board 5003:

As the material has very high hardness, the part could not be completed. With the types of tools used, it is not at all practical to manufacture such parts with the Roland MDX-15. The hardness will eventually result in breaking the tools.

Die with Ren board 450:

As the material is machinable, it took little more time as compared to Ren board 460 but this is the best result that could be obtained. Surface finish is quite comparable to Ren board 450. Even the porosity is very less.

Figure 27: Preparation of Ceramic Part

Even with good surface finish, good ceramic part could not be obtained from any of the above material. So it was decided to build part with more finish. The number of cuts was increased from 20 to 45. And instead of doing ceramic part directly, RTV was made first and then ceramic was poured into it. Better results were obtained this time.

Figure 28: Ceramic Part (Second Attempt)

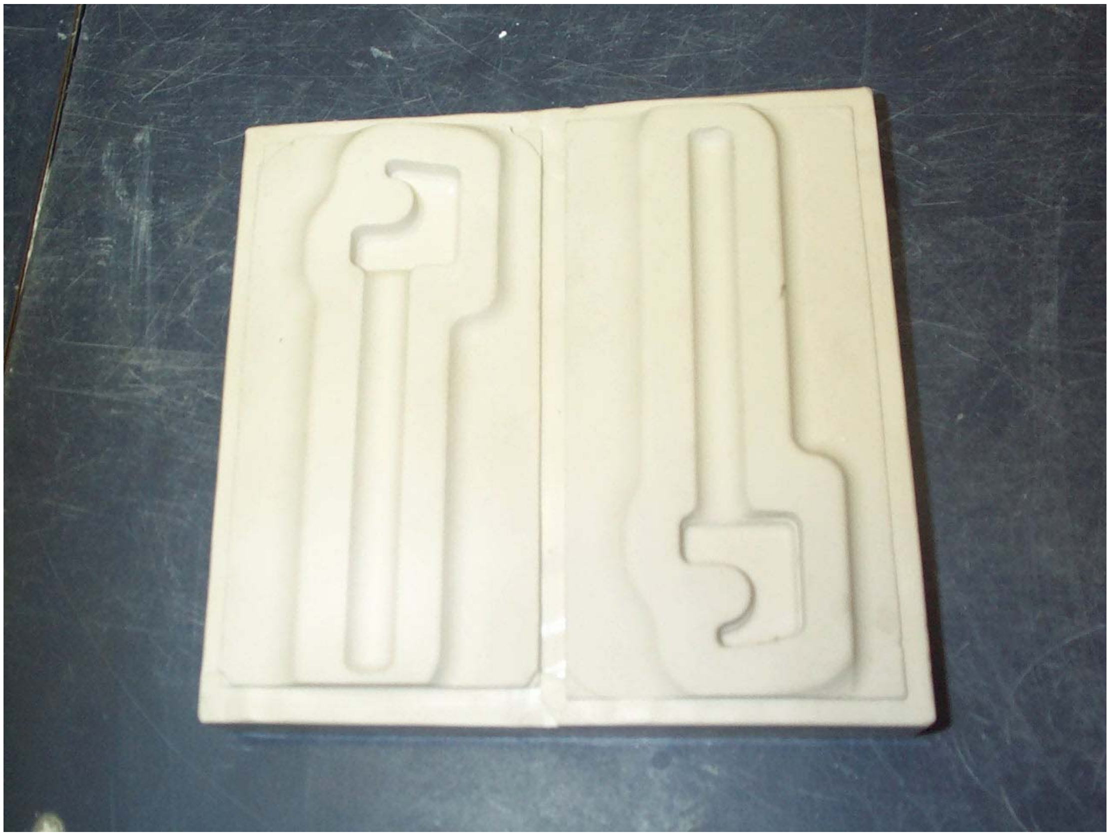


Figure 29: RTV Made from the Die

But when the tool was sprayed on ceramic, results were not good. The unevenness of the die was prominently visible on the sprayed tool. Only possible reason was poor surface finish on the die.

Again Dies were built with better surface finish. While doing so, building time of the die was increased. Time required to build the same die, using SLA is 12-15 hrs and after that finishing time of 12-15 more hrs. So it takes about 24 hrs to get finish part.

After adding some more detailed programming good parts were made out of Ren board 450. It took around 5 hrs to build the part. Visually the part has the better surface finish than any other prototyping technique. So using SRP, Modela MDX-15, Ren Boards and Gibbs CAM can save around 70% of time and money.

Figure 30: Sprayed Tool

Figure 31: Finished Tool

CHAPTER X

CONCLUSION

This study evaluated Subtractive Rapid Prototyping technique to replace SLA method used in RSP tooling process. The use of SRP technique significantly reduces time required to build the die as compared to SLA method. It is efficient approach to reduce the product development cycle and ensure product quality in relation with the manufacturing of product even with complex surfaces. Looking at the comparison of all the technologies in prototyping field, SRP is the least expensive, fastest, accurate, and the best technology to replace SLA in RSP tooling process. This is because it takes less space, less investment, and less maintenance, gives us more accuracy, good surface finish and significant timesaving.

If Subtractive Rapid Prototyping method is used to replace SLA, then almost 70% of time can be saved in that process. Using Modela MDX-15 for SRP process is the best option for the small and less complicated parts because MDX-15 can be used on desktop of offices or small lab, and that’s why it is also called “Desktop Manufacturing”.

Rapid prototyping machines are still slow by some standards. By using faster computers, more complex control systems, and improved materials, RP manufacturers are dramatically reducing cut or build time. Continued reductions in cut time or build time will make rapid manufacturing economical for a wider variety of products.

The rise of rapid prototyping has spurred progress in traditional subtractive method. Advances in computerized path planning, numeric control, and machine dynamics are increasing the speed and accuracy of machining. Modern CNC machining centers can have spindle speeds of up to 100,000 RPM, with correspondingly fast feed rates. Such high material removal rates translate into short build times. Another future development is improved accuracy and surface finish. Today's commercially available machines are accurate to ~0.001 millimeters in the x-y plane, but less in the z (vertical) direction. Improvements in laser optics and motor control should increase accuracy in all three directions.

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APPENDIX

GIBBS CAM SOFTWARE PROCEDURE

GibbsCAM software is easy to use. A quick overview of this process from part creation to completion is provided here. While there is no set sequence to creating a part, such as following Steps 1, 2, 3 there are some things that need to be done before others. For example, before making a part the file to work on is needed or have a tool list defined before generating G-code. However, once something is in the system, it is easy to change any parameter such as a tool or stock condition, and effortlessly update the entire part. On the following pages is a general guideline to the process of creating a part.

1. Create or Open a File 

The first thing that needs to be done is to have a file to work on. Either a new part file needs to be created or an existing model needs to be opened.

Create or capture the geometry so as to obtain 3D CAD model in SolidWorks.

Open GibbsCAM software and open the part file from solid works to GibbsCAM

- **Select machine type…3-axis vertical mill**
- **Select suitable units (inch or mm)**
- **Select solidify**
- **Select remove unneeded topology**
- **Select simplify**
- **OK**

Now 3D model into CAM software can be seen.

<u>Adjustment of origin:</u>

CNC machine will take that as an origin of the 3D CAD model. This means that the origin of CNC machine cannot be changed. It is always left front corner. But CAD model's origin can be adjusted according to the CNC machine origin. It is always a good practice to bring CAD model origin to left front corner. New coordinate system can be created.

- **Go to Modify**
- **Move part origin**
- **Select X/Y/Z**
- **Press ALT and click where the origin will be moved to**
- **Press Do It**

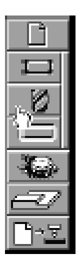
2. Create Operations 

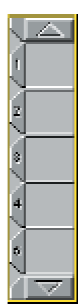
Once a model is created, machining functions need to be applied to the part. This includes setting the available tools, defining processes and creating operations. Creating tools may be done at any time, so long as a part file is open. Processes and Operations may be created after tools are defined. There are three lists in the system. These are the Tool List, the Process List and the Operations List. These lists hold tiles. Each tile is used to describe an individual tool, process or operation. A list can hold many items. To scroll through a list, click on the arrow at the top or bottom of a list. This will move the list up or down one item at a time.

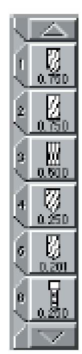
<u>Tool creation:</u>

The Tool List is used to define the tools used to cut a part. By double-clicking on an empty tile a new tool is created and a Tool dialog opens. A tool is then fully defined within the tool window. This includes the type of tool and its size. Only one Tool window may be open at a time. Tool tiles display a graphic of the tool type and the size of the tool. This instantly changes with any modifications to the tool.

Click Tools and double click in the first window to create first tool.

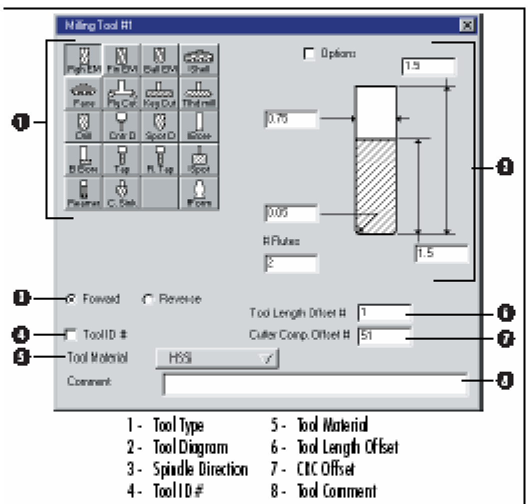






Defining a Tool is easy. Simply follow these steps.

- **Double-click on a tile in the Tool List.**
- **Select the Tool type from the matrix of buttons.**
- **Define the tool's size through text entry or pull-down menus.**
- **Close the dialog or double click on another tile (empty or full) to save the tool.**



We can very well select type and parameters of the tool. By clicking in the second window second tool can be created the same way.

Depressing the Tool List button in the top-level palette will bring up the Tool List. Double-clicking on a tile will bring up a Tool Creation dialog. This dialog is used to create and modify tools. Once the tool information has been entered and the dialog closed, a Tool tile will be created which displays the tool type and tool diameter. To create more tools, click on a new, empty tile. Clicking on another tile while a tool dialog is open will close the current tool dialog, saving your changes.

To index through the various tools that have been created, click on the scroll arrows located at the top and bottom of the Tool List. Tools can be reorganized in the list at any time, even after operations have been created, without reprocessing the operations. To reorganize the order of tools, click once on the Tool tile to be moved and drag it to an insertion point. The system will automatically adjust the operations to reflect the change in tool order and number. Tool specifications can be modified at any point during part creation. However, if operations have been created using the tool, those operations must be reprocessed. To reprocess an operation, double-click on the Operation tile in the Operation List, and click on the *Redo* button. The new tool specifications will be incorporated into the new operation toolpath.

Process creation:

The Process List is used to define toolpath and create operations. A process consists of a single tool from the Tool List and a machining function from the Machining palette. When one of each of these items is dropped onto a Process tile, a process is created. Clearances, cut depth, speeds and a number of other items are filled out in the Process dialog. In most cases geometry or a solid is then selected to generate toolpath by clicking on the *Do It* button in the Machining palette. Once toolpath is generated, one or more operations are created for each process. Once operations are created the processes may be thrown away. Processes are temporary items whose information is stored in Operations. Please note that multiple processes can be created in the same list. This will cause multiple grouped operations to be performed on the same geometry or surface.

A single operation consists of toolpath, clearances, tool information, feeds &

speeds, and coolant choices. It is a visualization of G-code and will be used as the source of the G-code sent to a CNC. Operations are made from processes. A process is the combination of a tool and a machining function (roughing, contouring, drilling) applied to geometry or solids. A process is the core of an operation and is used to specify all of the operation's settings. The following image displays the components of an operation or set of operations including the components needed to make the operations.

The first step to making operations is to have the part model defined and a list of tools to cut the part.

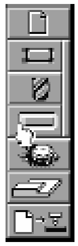
The second step is to click on the Machining button in the Top Level palette to open the Machining palette, Process List and Operation List.

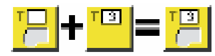
The third step is to combine a Tool tile with a Function tile in the Process List. This will open a window to set the operation's parameters.

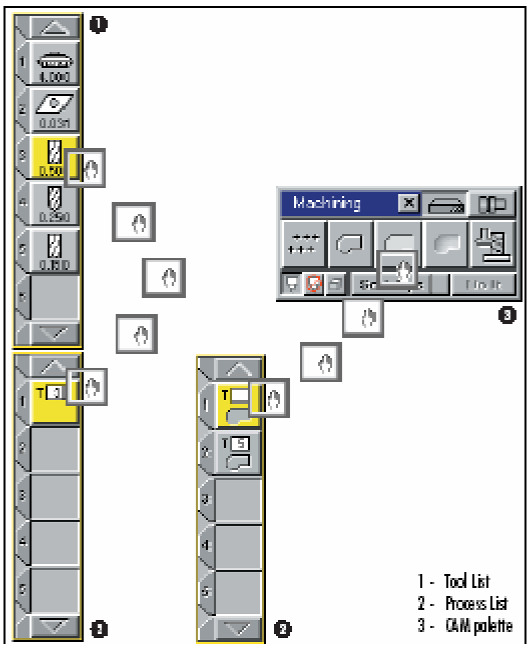
The fourth step is to select the geometry or solid that is to be machined and click on *Do It* in the Machining palette. This will create the toolpath for an operation. Repeat this process until the part is complete.

Click machining and drag the required process to the process palette. Then drag the required and created tool from tool window then new window will open.

- **A model must be present and tools must be defined.**
- **Click on the Machining button.**
- **Combine a tool tile with a machining function in the Process List.**
- **Select the geometry or solid to be machined and click on *Do It* to generate toolpath.**
- **Repeat as needed**



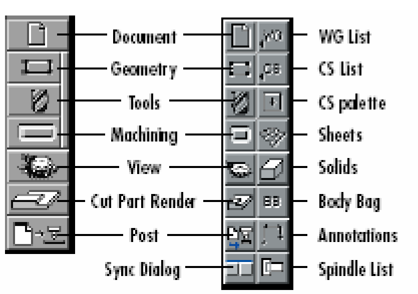


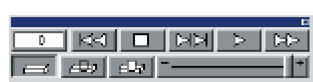


Operations are created from processes. Operations store the toolpath (all movement of a tool) and the information defined by a process. There will be at least one operation for each process. The data contained in operations is what will be sent to the CNC machine. Operations contain finished toolpath. The toolpath consists of the actual moves the tool will make to cut a part, a visualization of the G-code to be output. Double-clicking an operation in the Operation List will recreate the Process tiles that were in the Process List when the operation was created. This allows for the modification of an operation. The *Do It* button in the Machining palette will change to the *Redo* button. To create a new operation, be sure to deselect the current operation so the *Redo* button changes to the *Do It* button. Whenever new operations are made, the previous set of operations should be deselected. If they are not deselected, they will be overwritten. Operation tiles cannot be moved away from the Operation List. They can be sorted and reordered. To edit an operation's process information, double-click on the operation and it will be loaded back to the Process List. Clicking the *Redo* button will update the changes.

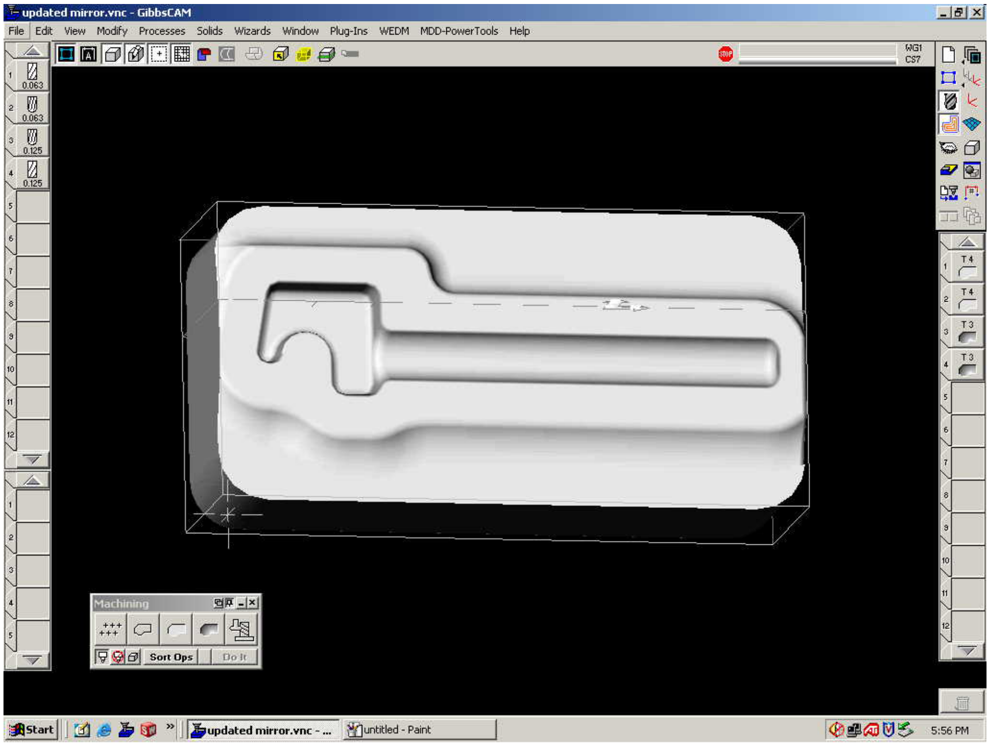
3. Render the Part 

Once operations have been defined for machining a part, Cut Part Rendering should be run. This provides a visual check of the part to ensure that the results are as expected. Many errors can be caught using Cut Part Rendering. After the simulation, if everything seems to be working perfectly, then these files have to send to the CNC machine. But for this G and M code have to be created so as the CNC machine can read and understand it.





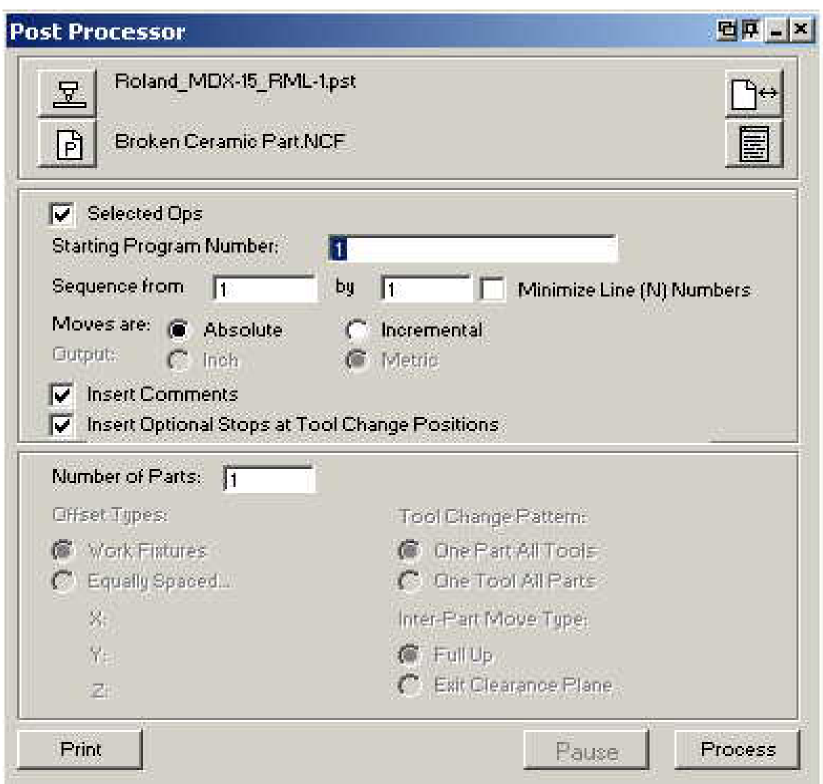
We can see the simulation by clicking on simulation.



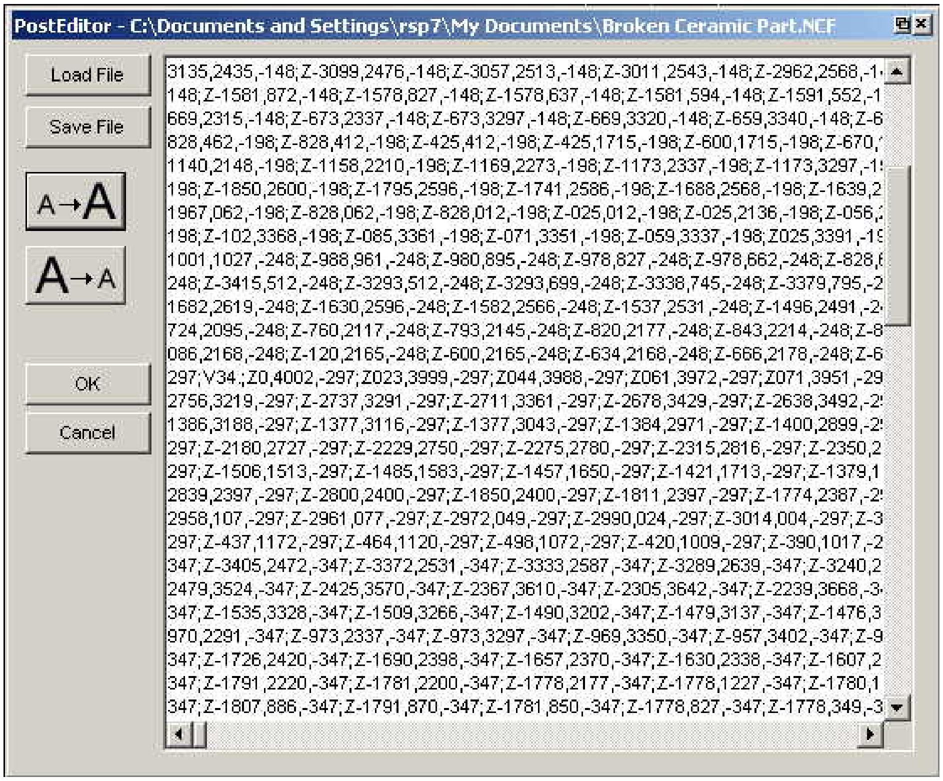
4. Post the Part

Once the operations to machine the part have been created and checked, the file needs to be post processed. Post Processing creates a text file (NC Program) that can be transferred to the machine control, from a part file (a VNC file). Post Processors specific to particular machine controls are used to create the text file from the VNC file. This is all accomplished in the Post Processor dialog. Clicking on the Post Processor button in the Top Level palette accesses the Post Processor dialog.

- **Click Post processor**
- **Select post file**
- **Select and save output file**
- **Selected ops if needed (this option gives us a facility to select the particular process from many processes)**
- **Process**
- **Output file will be saved automatically**



This file will be saved as .NCF file and this file is saved where our Roland printer is installed.



The following set of instructions

Select a post processor

Clicking on the Post Processor Selection button will bring up an Open dialog. Navigate to where the Post Processors is located, select the file and click on *Open*. That sets the post selection for the part.

Name the program

Clicking on the Program Name button will bring up a Save dialog. Navigate to where the posted output files are located, name the file and click on *Save*. That creates a NCF file for the code that is to be generated.

Set any desired options or parameters

There are a number of options that may be set in the Output and Multiple Parts sections of the Post Processor dialog. The number of parts being created can be specified, use work fixture offsets or a specific spacing as well as post only certain operations, output or suppress comments and insert optional stops.

Open the Text window

If a Post Editor to be used is not specified for the output from the *Plug-Ins* menu and wish to view the code, open the Text window by clicking on the Text window button. This is only to view the posted code as it is being generated. If selected a Post Editor is not selected or do not wish to view the code as it is being generated.

Click on *Process*

Clicking on *Process* will generate the code to be sent to the control. If Post Editor to use is selected from the *Plug-Ins* menu, the code will be displayed in the application after it is generated.

Save the file

Once the code is generated, save the file by clicking on *Save* or use the *Save* option from the *File* menu of selected Post Editor application.

<u>Sending the file to machine:</u>

Now adjust the tool position such that it should just touch the block. And that will be our origin for the CNC machine, which is always left front corner.

Now everything is ready and just has to give print command. But be sure that stock is fixed, it should not move during the machining. Otherwise process has to be started over again.

- **Go to start menu…**
- **Run**
- **Type command**
- **Ok**
- **Open Roland print**
- **Type Roland print "filename" .ncf**

Machine should start running.