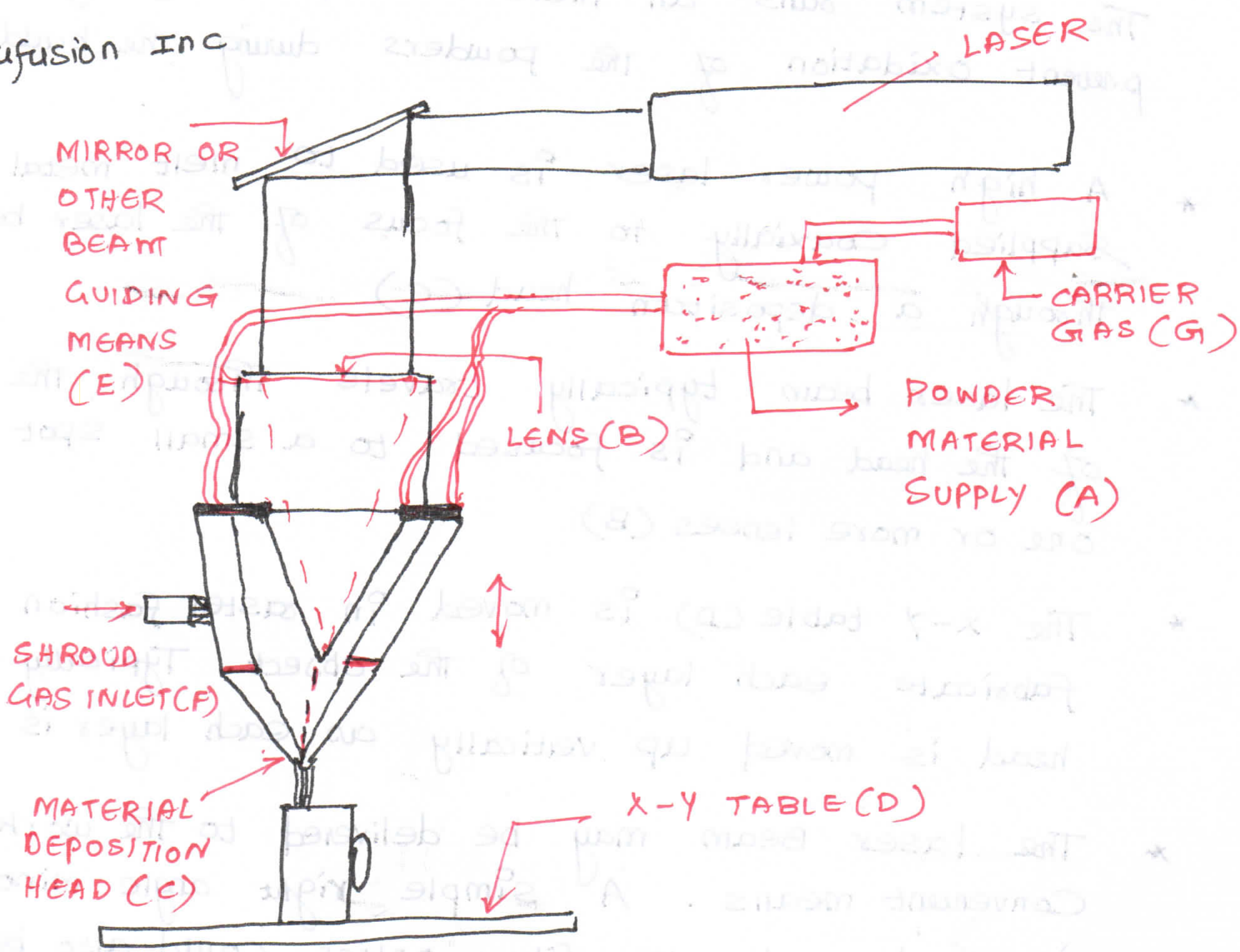
LASER ENGINEERED NET SHAPING (LENS)

Laser powder Forming (LPF) Such as Laser Engineered Net shaping [LENS] are gaining importance. The strength of these technologies lies in their ability to fabricate fully dense metal parts with good metallugical properties at reasonable speeds. The method is also referred as Laser fusing.

The figure below shows the approach adopted by Sandia National Labs and Commercialized by Optomec, Accufusion Inc



BUILD MATERIALS :

Current Build materials include Stainless steel 316 (SS316) Tooling steel (H13) and Titanium with 6% Aluminium and 4% Vanadium (Ti-6-4).

BUILD PROCESS:

Like most RP Process, LENS system uses a layered approach to manufacturing components, in which an STL file is sliced into horizontal cross sections, which are then downloaded to the machine from the bottom slice upwards.

DEPOSITION HEAD

Metal powder is injected from 4 feeder tubes into the focal point of a high-powered laser, a 700 W Nd:Yag. The system runs an inert atmosphere of argon to prevent oxidation of the powders during the build process.

* A high power laser is used to melt metal powder supplied coaxially to the focus of the laser beam through a deposition head (C)
* The laser beam typically travels through the center of the head and is focused to a small spot by one or more lenses (B)
* The X-Y table (D) is moved in raster fashion to fabricate each layer of the object. Typically the head is moved up vertically as each layer is completed
* The laser Beam may be delivered to the work by any convenient means. A simple right angle mirror (E) is used, and even fiber optics could also be used.
* Metal powders (A) are delivered and distributed around the circumference of the head either by gravity, or by using an inert, pressurized carrier Gas (G).
* Even in cases, where it's not required for feeding, ... gas (G) is typically used to shield

the melt pool from atmospheric oxygen for better control of properties, and to promote layer to layer adhesion by providing better surface wetting.

* The fabrication process takes place in a low-pressure argon chamber for oxygen-free operation in the melting zone, ensuring good adhesion.

PRINCIPLE OF LENS :

(i). A high powered Nd:YAG laser focused onto a metal substrate creates a molten puddle on the substrate surface. Powder is then injected into the molten puddle to increase material volume.

(ii). A 'printing' motion system moves a platform horizontally and laterally as the LASER beam traces the cross section of the part being produced. After formation of a layer of the part, the machine's powder delivery nozzle moves upwards prior to building next layer.

STRENGTHS :-

1) LENS process is capable of producing fully dense metal parts. Metal parts produced can also include embedded structures and superior mechanical properties. Microstructure produced is also relatively good.

2) Functional metal parts with complex features can be produced.

3) Post processing is minimized thus reducing cycle time

LIMITATIONS :

1) ~~Limited~~ The process is currently focussed to produce only metal parts.
2) A relatively large area is required for the unit.
3) Power Consumption of the laser is high.

APPLICATIONS

The LENS technology can be used in the following areas.

a) Building mold and die inserts.
b) Producing Titanium parts in the race car industry.
c) Fabricating Titanium components for biological implants.
d) Producing functionally gradient structures
e) Component repairs.
f) Producing Titanium for aerospace components.
g) Manufacturing cermets and carbon nanotube - reinforced Nickel.

1 KSi = 6894.757 kilopascals.

MATERIAL PROPERTIES OF LENS_FABRICATED TEST SPECIMENS :

	UTS (KSi) (kilopound per square inch)	YTS (KSi)	Elongation (% per inch)
1) LENS 316SS	115	72	50.
2) LENS INCONEL 625	135	84	38
3) LENS Ti-6Al-4V	170	155	11.

* LENS system holds a dimensional accuracy of + 0.020 inches with a repeatability of about +0.005 inches in -X Y-Y plane and +0.020 inches in -Z layer.
* Layer thickness can be varied from 0.001 inches to 0.040 inches.

INDIRECT RAPID TOOLING :

Rapid Tooling is a term used to describe a process which either uses a rapid prototyping model as a pattern to create a mould quickly or uses the rapid prototyping process directly to fabricate a tool for a limited volume of prototypes.

Rapid Tooling is making Tools using RP process to

a) Minimize the cost
b) Increase the productivity
c) Increase Dimensional accuracy.
d) Decrease Total time.

How it is different from conventional Tooling :

→ Tooling time is much shorter than for a conventional tool (almost below 1/5th that of conventional tooling)

→ Tooling cost is much less than for a conventional Tooling. cost can be below five percent of conventional tooling cost.

→ Tooling life is considerably less than for a conventional tool.

→ Tolerances are wider than for a conventional Tool.

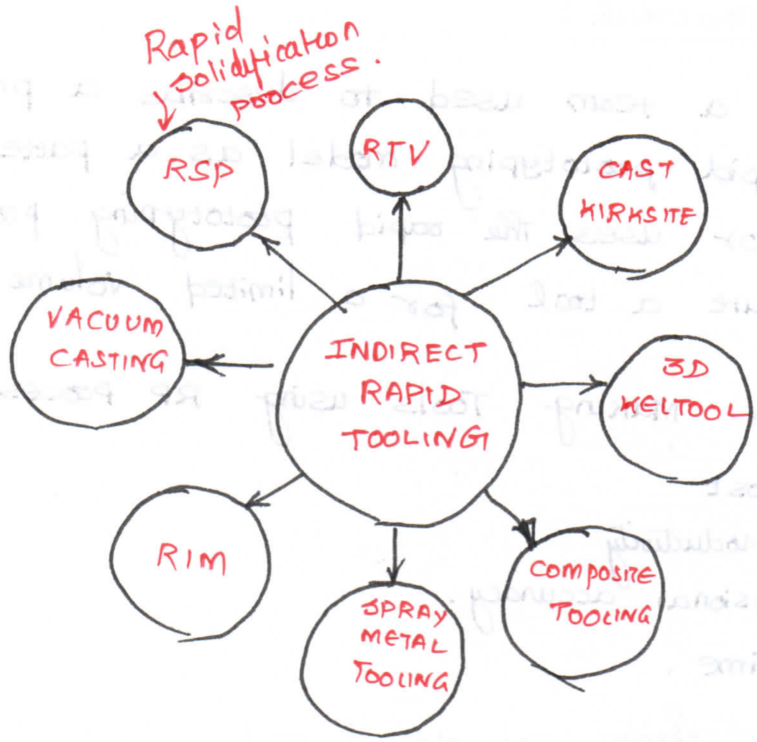
Types of Rapid Tooling :

Rapid Tooling can be broadly classified as

1) Indirect Tooling 2) Direct Tooling.

* Indirect Tooling methods used RP inserts to produce moulds.
* Direct Rapid Tooling methods allow injection moulding and die casting inserts to build directly from 3D CAD models.

→ Indirect or pattern based Tooling : Approaches use master patterns to produce a mould or die, Indirect methods are intended as prototyping or pre production tooling processes and not production methods.



SILICON RUBBER TOOLING:

→ Rapid Prototyped model is used as a pattern for a silicone Rubber mold, which can then in turn be injected several times.

→ One of the most popular tooling applications for RP is the production of room temperature vulcanizing (RTV) silicone Rubber Tooling.

→ The purpose of RTV tools is to create urethane or epoxy prototypes, often under vacuum (therefore termed Vacuum casting)

The Process of making a Rubber mould consists of:

a) Making a master pattern, usually on an RP machine.
b) Finishing the pattern to the desired appearance.
c) Casting RTV silicone rubber around the pattern to form the mould, and then injecting the mould with two-part thermoset materials to create moulded plastic parts

→ Silicone Rubber Tooling provides fast, inexpensive moulds, excellent part Cosmetics, and the option of using multiple materials. The process is suitable for small or medium sized parts.

→ Another benefit of Silicone Rubber Tooling is the Negative draft (undercuts) that can be achieved due to flexibility of the mould material.

ALUMINIUM FILLED EPOXY TOOLING :

* Also known as Composite Tooling.
* Requires a Master pattern. The pattern is created by RP process. The pattern is finished and then embedded in a parting line block to create the parting line of the mould.
* Metal inserts are placed in areas where the epoxy is unlikely to withstand the pressures of the injection-moulding process.
* Epoxy is then cast against the pattern and parting line block combination to create the first side of the tool. Once the epoxy is cured, the assembly is inverted and the parting line is removed, leaving the pattern embedded in the first side of the Tool.
* The second side of the tool is then cast against the first.

TIME : Composite Tooling generates injection moulded parts in 2 to 6 weeks.

PRODUCTION RATE : The moulding process will have a cycle time of 5 to 15 minutes.

- ACCURACY : Accuracy is dependent on the SLA model. Typically about +/- 0.005" to +/- 0.015"

COST : Dependent upon the cost of the master pattern, and overall size of the part. An SLA master pattern can cost between $300 to $1000 on average

CAST KIRKSITE :-

* Kirksite is a Zinc - Aluminum alloy with excellent wear resistance. (94 % Zn; 6 % Al) with a melting point of 385°C.

* The process for making Cast kirkisite Tooling begins much like the process for epoxy based composite tooling,

* First, a shrink - Compensated Master pattern of the part is produced, typically using an RP Process. A rubber or Urethane material is then cast against the part master to Create the patterns for the core and cavity set, which will be cast in kirksite.

* plaster is then cast against the Core and cavity patterns to create moulds into which kirk site is cast.

* Once the kirksite is cast into the plaster moulds, the plaster is broken away, and the kirksite Core and Cavity are fit into a mould base.

* Originally developed for sheet metal forming tools in the automotive industry. Kirksite material is a Zinc/Aluminium alloy (94 %.Zn; 6 %. Al) with a melting point of 725°F.

* Due to vapour pressure of the zinc, the material is almost immune to the gas porosity encountered with other alloy systems and the shrinkage is approximately half that of aluminium, resulting in great cast mold accuracy and repeatability.

* Kirkisite is Machinable and weldable, making on the design consideration possible. One of the main benefits to this process is the ability to make geometric changes quickly and cheaply.

Tool life is dependent on many factors; particularly geometric Complexity and the nature of material to be molded.

* Kirksite is a Moderate strength Zinc-base alloy that was developed primarily as a forming tool alloy. Dies cast from kirksite provide low-cost tooling because the alloy can be accurately cast, requiring a minimum of finishing.
* In addition, kirksite has been used as a general purpose casting alloy for non-stressed components.

Nominal Composition : Zn-94 ; Al-3 ; Cu-0.03 Mg .

Typical uses :-

(i). press dies and punches for sheet metal forming
(ii). Molds for ceramics and rubber.
(iii). Injection moulding and compression molding dies.
(iv). Tube bending dies.
(v). Mandrels for metal spinning.
(vi). Low stressed Non-sparking tools and repair parts.

3D KELTOOL :

* 3D keltool is a powder metal process used to make injection mould inserts and other durable tooling from master patterns.
* Keltool was originally developed by 3M in 1976, was sold and further developed by keltool inc. In 1996, 3D systems purchased the technology from keltool Inc and renamed it 3D keltool.
* The word "keltool" refers to the proprietary powder metal sintering process, which involves infiltrating a fused metal part with copper alloy.
* This alloy fills in the voids in the otherwise porous material, producing a surface with the finish and hardness necessary for an injection mould.

PROCESS CHAIN OF 3D KELTOOL :

a) Master pattern.
b) Silicone casting
c) Casting with a Tool steel / Tungsten carbide / epoxy mixture.
d) Burn-out of Binder, sintering and infiltration with copper in an oven.
e) Tool insert ready for production.

→ Fabricating master pattern of the core and cavity
→ producing RTV silicone Rubber moulds from the patterns.
→ Filling the Silicone Rubber moulds with a metal mixture (powdered steel, Tungsten carbide, polymer binder with particle sizes of around 5 μm) to produce green parts. (powdered metal held together by the polymer binder) duplicating the masters.
→ Firing the 'green' parts in a furnace to remove the plastic binder and sintering the metal particles together.

→ Infiltrating the sintered parts (70% dense inserts) with Copper in a second furnace cycle to fill the 30% void space

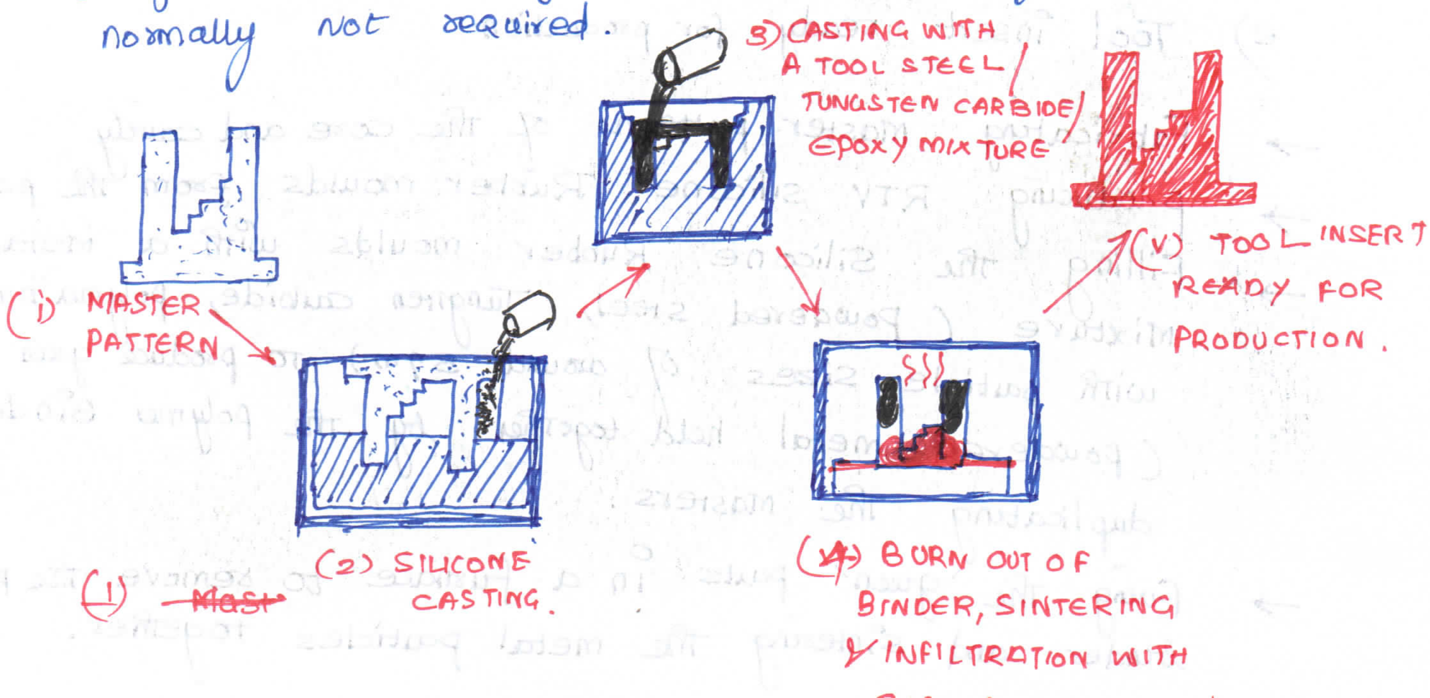
→ Finishing the core and cavity.

(*); 3D Keltool inserts can be built in two materials, Stellite or A-6 Composite tool steel. The material properties allow the inserts produced using this process to withstand more than 1,000,000 moulding cycles.

(*). The finished keltool part has the hardness of A6 Tool steel and can be machined like a traditional hard tool.

KELTOOL PROCESS :

- Keltool process starts by rapid prototyping a rubber mould which is then used to cast a steel powder and polymer binder mixture which is left to cure into a green state.
- Once cured, it is then fired, and copper is infiltrated into the mould, resulting in a tool consisting of approximately 70% steel and 30% copper.
- This mould can then be polished or machined to increase surface finish and good tolerances although finishing is normally not required.



SPRAY METAL TOOLING :

PROCESS :

→ This process uses a high velocity electric arc metal spray generating system to deposit finely atomized particles of molten metal onto a model surface to create a metal shell mould.

→ The metal is usually a low melting point metal or alloy of zinc, Nickel, copper and Aluminium. Kirksite is one of the most widely used alloys for metal spraying process.

→ The metal wire is supplied from a spool and melted by an arc produced in a spray gun. The molten metal is propelled by a jet of compressed air, causing it to break up into fine particles which are deposited on the model surface.

→ The model is coated with a release agent to anchor the initial spray coat provide adequate temperature resistance and enable good detail besides facilitating separation of the metal shell from the model.

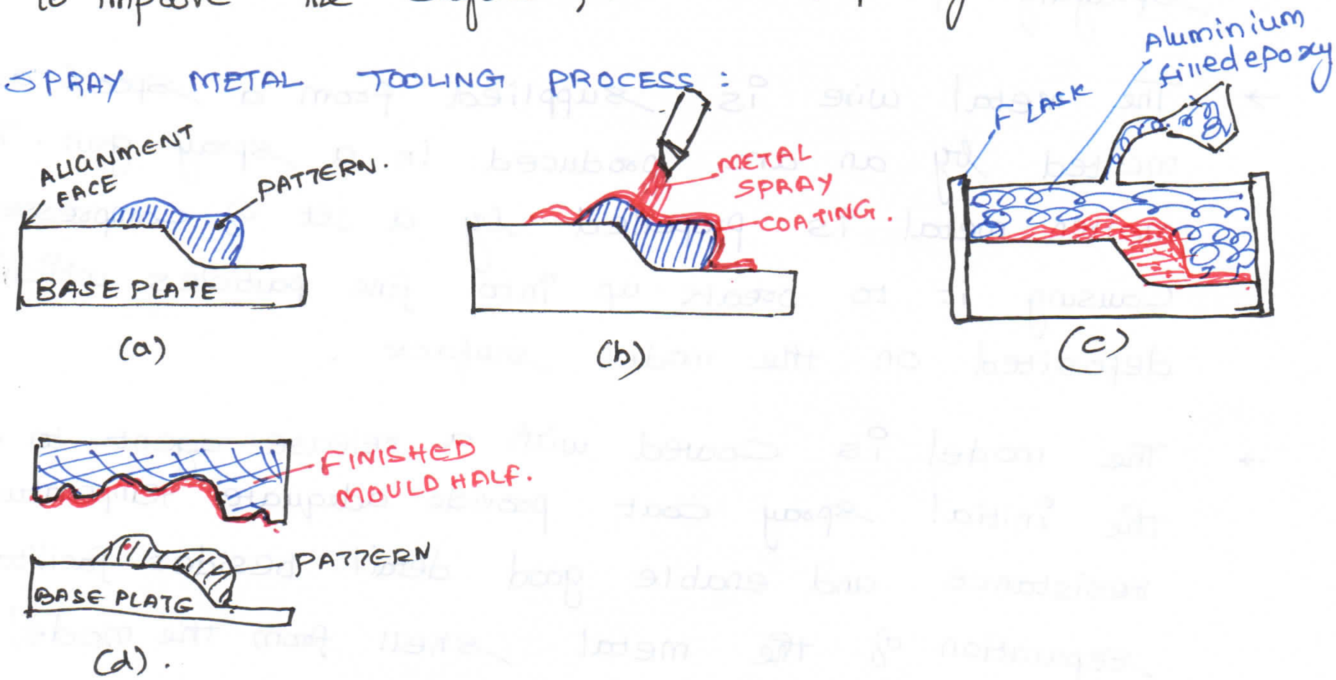
→ The compressed air, arc power and metal feed rates are carefully optimized to produce a spray, which is cool (less than 100°c) compared to the melting point of the metals involved.

→ The metal shell thus produced which is about 1 to 2mm thick can be reinforced by either layers or a solid mass of resin. The opposite sides of the part model can be sprayed to produce the two halves of the mold, which after reinforcement can be used for Thermoforming, plastic injection molding, Blow moulding, Sheet metal forming and vacuum Casting.

→ For metal spray method, Size is no limitation and the process has been successfully used for producing the Tooling for sheet metal forming of automobile body parts.

→ The porosity and low strength of sprayed metal molds however results in a shorter life compared to tool steel molds. Specially developed copper and Nickel plating techniques have been suggested for Zinc sprayed tooling to improve the surface finish and prolong the Tool life.

SPRAY METAL TOOLING PROCESS :



(Fig) Production of Tooling for injection molding by the sprayed-metal tooling process.

(a): A pattern and base plate are prepared through rapid prototyping operation

(b): Zinc - Aluminium alloy is sprayed onto the pattern.

(c): The coated base plate and pattern assembly is placed in a flask and back-filled with Aluminium impregnated epoxy.

d): After curing, the base plate is removed from the finished mold

DIRECT AIM (ACES INJECTION MOULDING)

→ ACES stands for "Accurate Clear Epoxy solid"

→ IS a new and vitally important rapid Tooling process to quickly and inexpensively build prototype parts using a variety of engineering thermoplastics in a very short time without the need for production Tooling.

→ The process involves growing the mold on a SLA system using ACES build style, That is shelled out on the bottom side. This leaves a cavity in the mold halves That have can be backfilled with various materials.

→ The materials include Aluminium-filled epoxy, ceramics and low-melting metals. The backfilling process provides a thermal conduit for the heat exchange system, as well as integrate the cooling system That may be put into mould halves.

→ The mould halves are mated and aligned, and the part surfaces are finished for surface quality. Using extended cycle times and release agent, Numerous parts can be made by directly injecting the final thermoplastics into ACES mold core and cavity halves using a standard injection molding machine.

COPPER POLYAMIDE TOOLING:

* The process uses the essence of SLS
  Copper polyamide powder matrix is used.
  Copper polyamide is a new metal plastic composite designed for short tooling applications.

* Tooling inserts are produced directly in the SLS machine with a layer thickness of 75 µm. Subsequent finishing is necessary before their integration in the tool base.

* During the CAD stage, Copper polyamide inserts are shelled, cooling lines, ejector pin guides, gates and runners are included in the design and built directly during the SLS process.

* Then the insert surface are sealed with epoxy and finished with sand paper and finally the shell inserts are packed up with a metal alloy.

Advantages:

→ Inserts produced from copper polyamide are easy to machine and finish.

→ Heat resistant and thermal conductivity are better in most plastic tooling materials.

→ The cycle times of moulds employing copper polyamide inserts are similar to those of metal tooling.

RAPID STEEL 1.0 :

→ The first product, Rapid steel 1.0 powder is made up of low carbon steel particles with a mean diameter of 55 μm. The particles are coated with a thermoplastic binder.

→ The processing can be broken down into three stages.

a) GREEN PART MANUFACTURE (SLS PROCESSING)

* The low melting point binder allows the material to be processed in the SLS machine without heating the feed and part bed. Tooling inserts in the 'green' stage are built layer by layer through fusion of the binder.

b) CROSS LINKING :

* During the subsequent furnace cycle, thermoset binder coating would melt and would behave as a lubricant between the steel particles.

* To prevent distortion being caused in this way during the low temperature portion of the furnace cycle, the green part is infiltrated with an aqueous acrylic emulsion and dried in an oven at about 60°c.

* The acrylic emulsion acts as a ~~emulsion~~ binding agent and dried in an oven at about 60°c.
  It provides strength to the green part when the polymer is burnt away in the furnace.

* The drying time is dependent upon the part size, for large parts, it can take up to 48 h.

c) FURNACE PROCESSING :

* In this part, the green part is converted into a fully dense metal part by infiltration with molten copper.

* To remove oxides from steel surface, a mixture of hydrogen and Nitrogen is used during the furnace cycle.

* Between 350 – 450°C, the polymer evaporates. Then the temperature is increased to 1000°C to allow the sintering of the steel powder.
* Finally the part is heated up to 1120°C where Copper infiltration occurs drawn by capillary action.
* The final Rapid steel 1.0 parts are 60% steel, 40% copper fully dense parts which can be finished by any technique including surface grinding, milling, drilling, wire erosion, EDM, polishing and surface plating.

Rapid Tool process imposes a number of constraints.

a) Excess material has to be added on the parting surfaces, shut offs and sides of the inserts and machined afterwards for a good surface match.

b) The process requires a flat base for proper infiltration.

c) Features that require a very high positioning accuracy or tight tolerances and that are easy to machine (eg) hole or that can be easily added (eg). certain features like bosses have to be removed from the CAD model before SLS process.

d) In the furnace, between the debinding and sintering stages, the part shape is maintained only by friction between the steel particles.

- Features such as hole across the whole part or cooling lines have to be avoided because they can weaken it, causing it to distort and even to collapse. During each of the Rapid tool process steps, parts are subjected to size variations.

RAPID STEEL 2.0 :

→ Rapid steel 2.0 offers a number of modifications over rapid steel 1.0.

* The Base metal has been changed from carbon steel to 316 stainless steel.

* Bronze has replaced copper as the infiltrant

* The thermoplastic binder material has been substituted by a Thermoset binder.

Processing of RAPID STEEL 2.0 differs from RAPID STEEL 1.0.

1) Green part Manufacture ('SLS' processing): The part bed is heated to a temperature of about 100°c for SLS processing.

2) Brown part manufacture (Furnace debinding and sintering cycle) The temperature is raised to 1120°c held for 3 hours and decreased to room temperature in a controlled atmosphere.

3) Part infiltration : The temperature is raised to 1050°c held for 2 hours and decreased to room temperature in a controlled atmosphere.

Physical properties:-

Average particle size. (μm) :- As per ASTM D 792 ;

For Rapid steel 1.0 → 50 μm.
For Rapid steel 2.0 → 34 μm.

→ From initial observation, it is possible to interpret that the decrease of the average particle size from 55 μm to 34 μm allows parts to be built with a smaller layer of thickness.

→ This leads to smoother surfaces through a reduction of stair stepping effects and consequently shortens the time

* The particle size reduction also increases the part resolution by allowing the formation of sharper edges.

* However, the minimum feature size still remains in the order of 1mm. The reason for this is that, although the laser beam diameter is small, the thermal conductivity of the steel powder causes the beam to sinter an area wider than its diameter.

* The properties of bronze make the part easier to polish and gives better friction characteristics to the mould inserts. In addition, the change of the metal base from carbon steel to 316 stainless steel should increase the mould wear resistance.