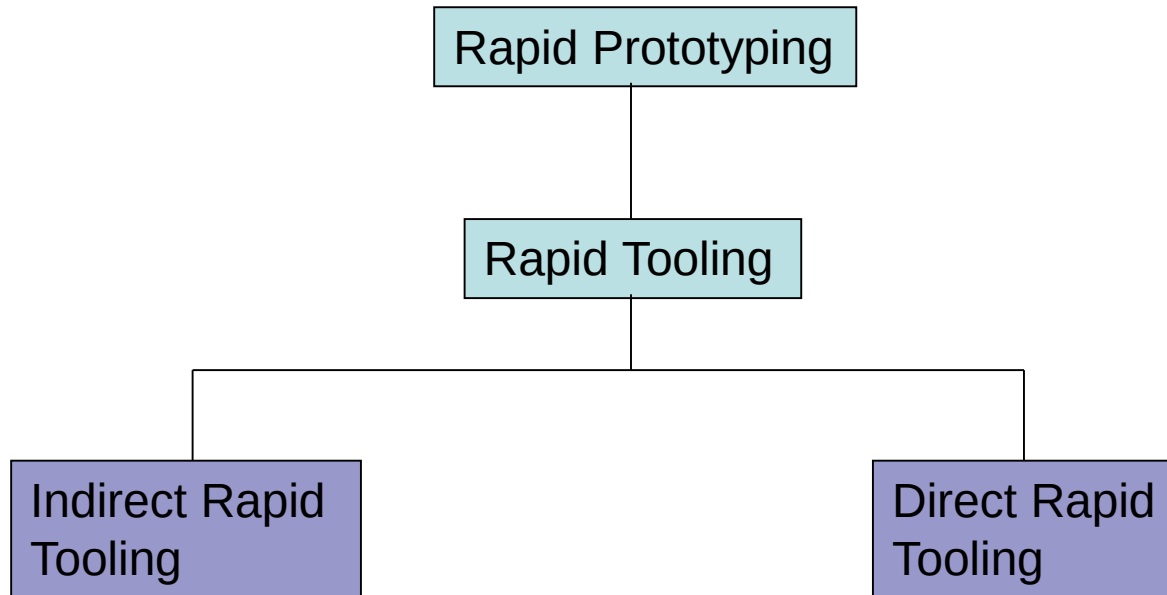


Rapid Tooling



Indirect Methods of Tool Production

Indirect Methods of Tool Production

- Reduction in delays inherent in re-iterations & fine tuning of products
- Rapid tooling – Rapid production
- Rapid production of 3D solid objects from designs generated on CAD
- RP parts – relatively limited range of build materials results in difference between mechanical / thermal properties of prototype & production part
- RP industry targeted tooling production to capitalise on RP technology

Indirect Methods of Tool Production

Rapid Prototyping

Rapid Tooling

Hard Tooling

Rapid tooling seeks to bridge the gap between RP & Hard tooling

Indirect Methods of Tool Production

- RT is a good alternative to traditional mould making techniques
- RT allows tool validation before changes become more expensive
- The broad range of RP/RT options makes selecting the optimum solution for a given application difficult
 - A good understanding of the processes is essential
 - Strengths
 - Weaknesses
 - Competitive merits of materials

Metal Deposition Tools

- Uses RP model with:
 - Good surface finish
 - Draft angles
 - Allowance for shrinkage (mould material)
- Pattern is embedded along its parting line into plasticine within a chase
- Sprue gates and ejector pins are added after a release agent has been applied
- A thin layer (2-3mm) of **low melting temp** metal is deposited over the exposed part of the mould
- The mould is back filled with an epoxy resin
 - Strength
 - Thermal expansion
 - Aluminium additives
- The mould is inverted, plasticine is removed then the process is repeated on the other side of the mould

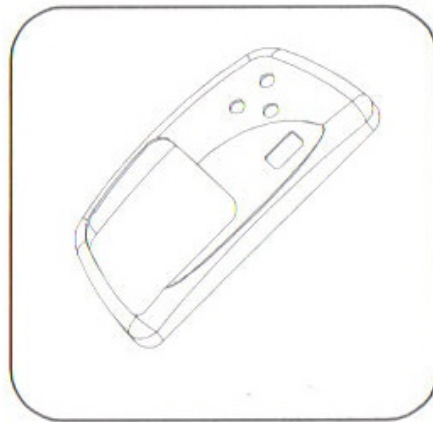
Metal Deposition Tools

- Not all deposition methods can be used. The most commonly used for RP replication are:
 - Spray metal deposition
 - Nickel electroforming
 - Nickel Vapour Deposition (NCD)

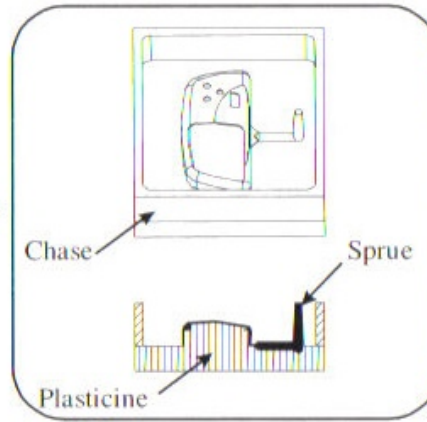
Spray Metal Deposition Tooling

- Approx 2000 parts per tool
- Tooling relatively inexpensive
- Tooling fast to produce
- Tooling can handle abrasive materials
- Parts moulded are accurate
- Parts can be moulded from exact production material
 - Sheet metal forming
 - Injection moulding
 - Blow moulding

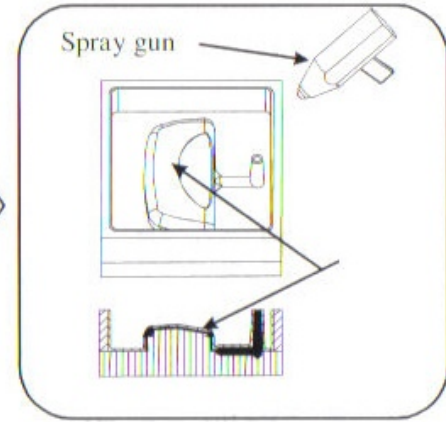
Spray Metal Deposition Tooling



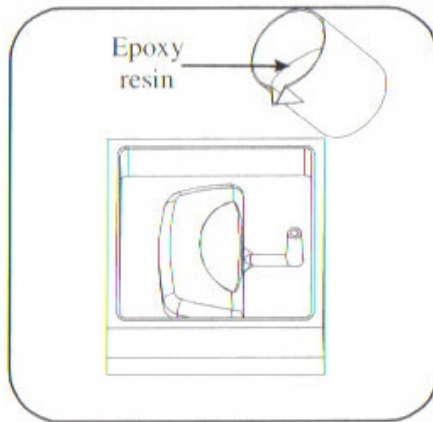
Master model



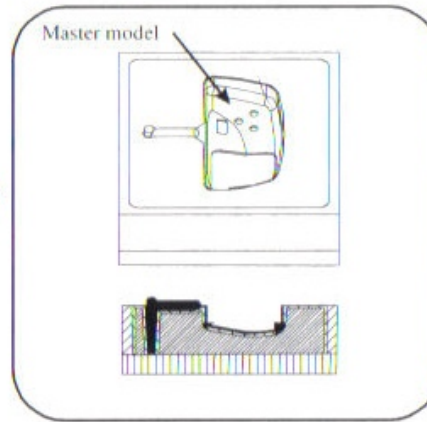
Embedding of the model along its parting line



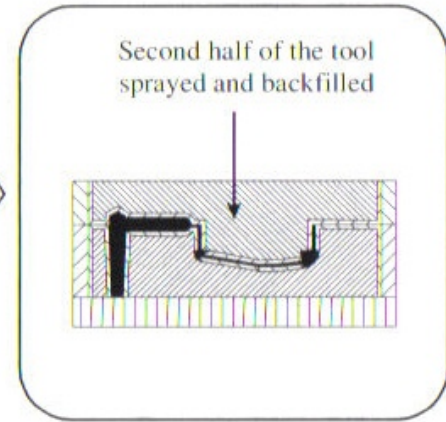
Spraying of the first half of the mould



Backfilling of the mould



Inversion of the first half of the mould



Spraying and backfilling of the second half of the mould

Spray Metal Deposition Tooling

- Gas metal spraying
 - Low melting point alloy
 - Lead/tin wire melted by jet of burning gas
 - Molten alloy is atomised & propelled onto substrate
 - Uses a nozzle similar to a paint sprayer
- Arc / Tafa metal spraying
 - Uses a gun in which an electric arc between two wires causes them to melt.
 - Aluminium or Zinc is most often used for the wires
 - The molten material is then atomised and deposited by compressed gas

Nickel Electroforming

- RP model is sprayed with electrically conductive paint
- Placed into an acid bath containing bags of nickel powder
- A voltage is applied & the nickel is attracted to the conductive part by electrolysis
- Can be used for a wide range of applications such as:
 - Injection mould cavities & cores
 - Embossing plates
 - Fine printing plates
 - Seamless belts

(3D Systems 1995)

Nickel Vapour Deposition (NVD)

- Based on growth of metal from gaseous vapour
- Pattern is heated (approx 100°C -190°C)
- Nickel carbonyl gas Ni(CO)_4 is passed over the pattern – pure nickel is deposited
- An exact duplicate of the patterns surface is produced
- Deposition rates of 0.005 & 0.8mm/h

RTV Tools

- Silicone rubber moulds
 - Tin based silicone – less expensive & more durable
 - Platinum based silicone
- Suitable for applications where a material which mimics the properties of the production material can be used:
 - Fit
 - Form
 - Physical testing (limited)
- Used to mould parts in
 - Wax
 - Polyurethane
 - Epoxy materials (limited)

RTV Tools

- Sequence for producing an RTV tool
 - 1) Producing a pattern (any RP method)
 - 2) Adding venting & gating to the pattern
 - 3) Setting-up the pattern in a mould box with parting line provided in plasticine
 - 4) Pouring silicone rubber to form one half of the mould
 - 5) Inverting the first half of the mould and removing the plasticine
 - 6) Pouring silicone rubber to produce the second half of the mould

RTV Tools

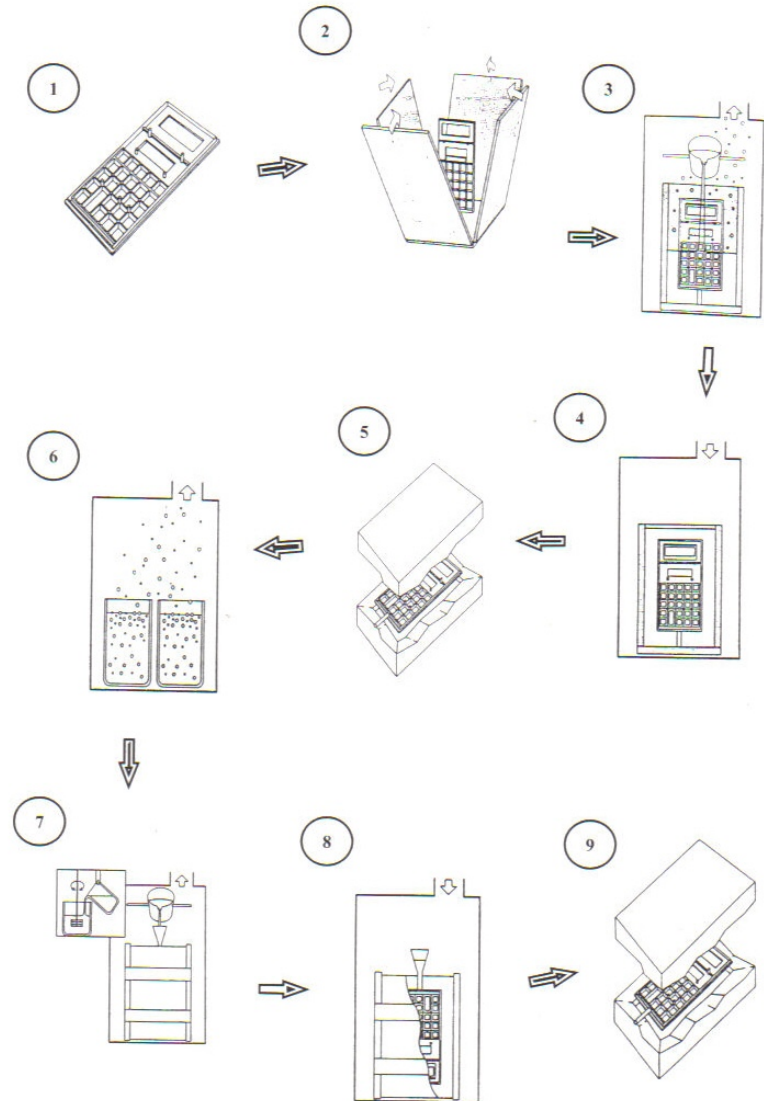
- Vacuum Casting
 - Parts with fine detail can be cast
 - Parts with very thin wall thicknesses can be produced
 - Tools can be made very accurately
 - A vacuum casting chamber has two sections:

Chamber 1 – mixing the 2 part resin

Chamber 2 – casting the resin into the mould

Vacuum Casting Process

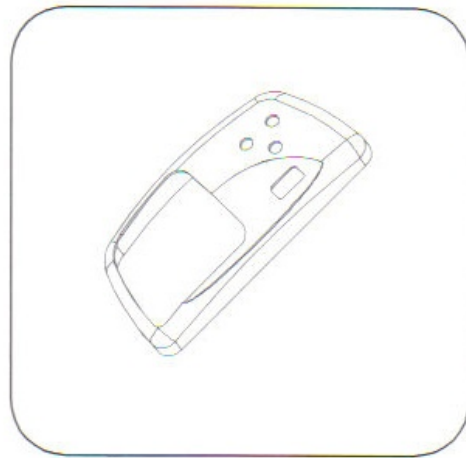
1. Pattern using RP process (SLA, SLS, FDM etc.)
2. Pattern is fitted with a casting gate, set up on the parting line & then suspended in a mould casting frame
3. Once the two-part silicone-rubber is de-aerated & then mixed it is poured into the mould casting frame around the pattern
4. The mould is cured inside a heating chamber
5. The pattern is removed from the silicone mould by cutting along the parting line
6. The urethane resin is measured, dye is added for coloured components & casting funnels placed. Then the mould is closed & sealed
7. Computer controlled equipment mixes & pours the resin inside the vacuum chamber. Because this takes place in a vacuum, the mould is filled completely (no air bubbles or voids)
8. After casting the resin the mould is moved to the heating chamber for 2 to 4 hrs to cure the urethane part
9. After hardening, the casting is removed from the silicone mould. The gate and risers are cut off to make an exact copy of the pattern. If required the component can be painted or plated.



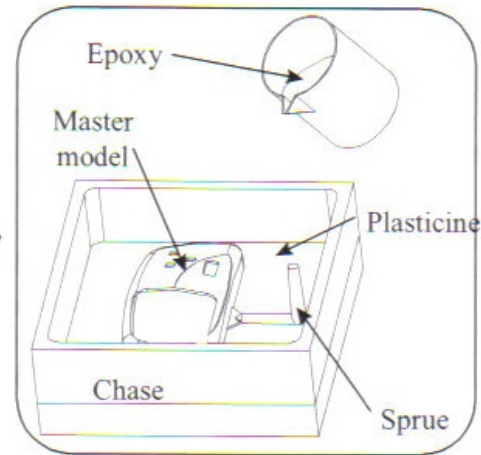
Epoxy Tools

- Used to manufacture prototype parts or limited runs of production parts
 - A frame is constructed around the parting line of the RP model
 - Sprue gates & runners can be added or cut once the mould is finished
 - The exposed surface of the model is coated with a release agent & epoxy is poured over the model
 - Aluminium powder & copper cooling hose lines added to epoxy – thermal conductivity
 - Once the epoxy has cured the assembly is inverted & the parting line block is removed leaving the pattern embedded in the side of the tool just cast
 - Another frame is constructed the second side of the tool is poured & cured
 - The two parts of the tool are separated and the pattern is removed

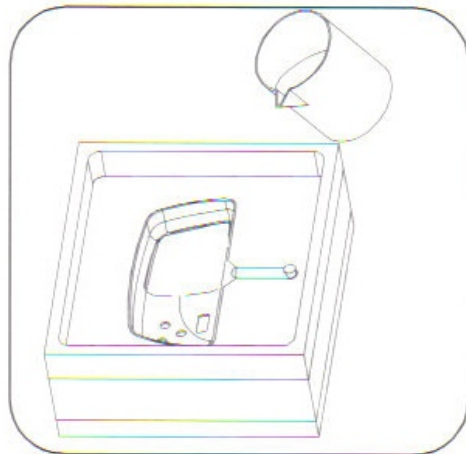
Epoxy Tools



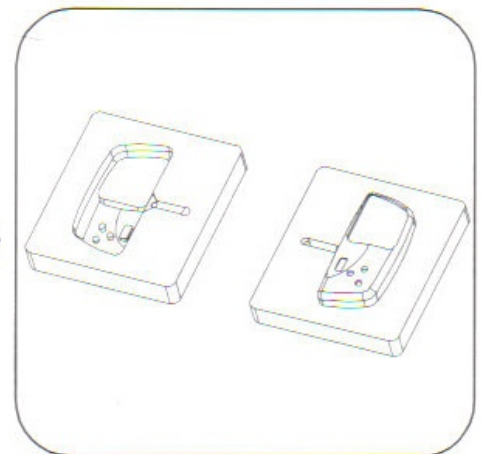
Master model



Embedding of the model along its parting line and backfilling with epoxy resin

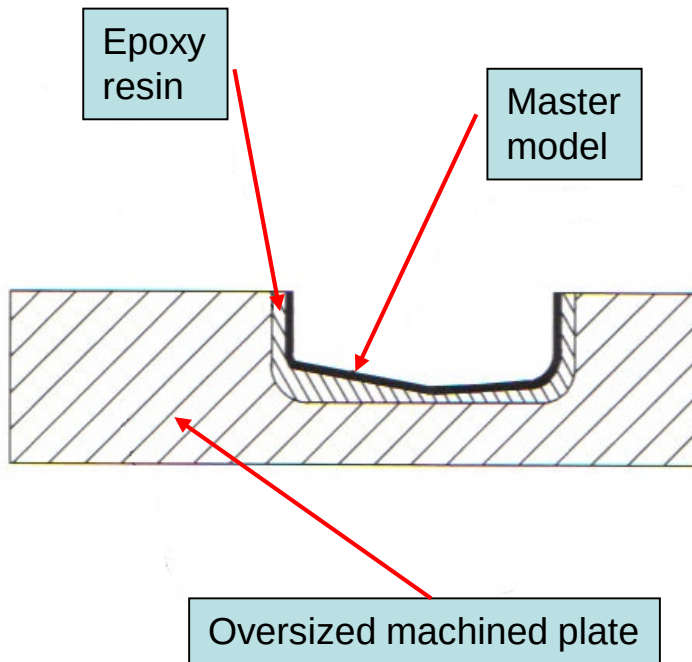


Inversion of the first half of the mould and backfilling



Epoxy injection moulding inserts

Epoxy Tools



- Soft Surface Tooling
 - Improved thermal conductivity
 - Often has a longer tool manufacture time than normal epoxy tooling due to extra machining time

Epoxy Tools

- Limitations
 - Limited tool life
 - Poor thermal transfer
 - Tolerance dependent on master patterns
 - Aluminium-filled epoxy has low tensile strength

Epoxy Tools

Approx Aluminium-epoxy tool life (3D Systems 1995)	
Material	Too Life (shots)
ABS	200-300
Acetal	100-1000
Nylon	250-3000
Nylon (glass filled)	50-200
PBT	100-500
PC/ABS Blends	100-1000
Polycarbonate	100-1000
Polyethylene	500-5000
Polypropylene	500-5000
Polystyrene	500-5000

Ceramic Tools

- Instead of using epoxy, plaster ceramics can be cast around a master to produce a tool cavity
- Ceramic tools can be employed for:
 - Plastics processing
 - Metal forming
 - Metal casting
- Water content of ceramic plaster is critical & needs to be controlled

Ceramic Tools

- The production of a ceramic tool differs from that of an epoxy tool in the following ways:
 - Ceramics only generate a small amount of heat while curing (approx 50°C) – no damage to master RP pattern
 - The ceramic must be poured in a vacuum to avoid air bubbles
 - A vibration table is often used to 'pack' the material

Ceramic Tools

- Ceramics are porous materials
 - This is undesirable when casting adhesive polymers
 - Surface treatments can be used to reduce the porosity
 - Dry film lubricant
 - Release agents
 - Silicone
 - PTFE
- Ceramic tools are brittle
 - They must be handled with care
 - Finely chopped fibres are often added to enhance fracture toughness & tensile strength
 - Aluminium fillers are often added to enhance thermal conductivity

Ceramic Tools

- A tool can produce approx 300-800 injection moulded parts
- Injection moulding cycle times of 30 seconds can be achieved
- Ceramics are relatively low cost materials
- Some ceramics have a curing time of a few hours
 - An injection moulding tool can be created in one day after obtaining an RP model

Cast Metal Tools

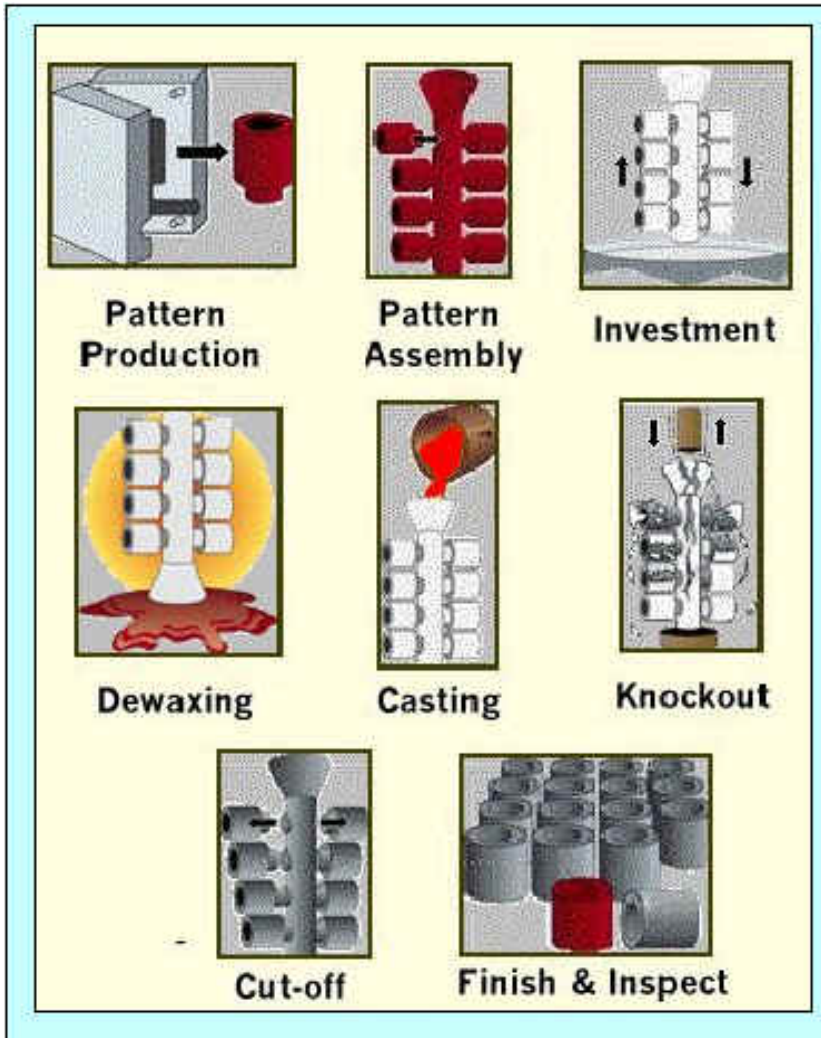
- Metal moulds are generally expensive & time consuming to machine
- By combining RP techniques, some Zinc or Aluminium alloy moulds can be made 'rapidly'

Cast Metal Tools

- Investment Casting
 - Any RP process can be used to create sacrificial models for investment casting utilising special build materials
 - Another technique is to build the ceramic shell that will be used for investment casting

Cast Metal Tools

Investment Casting Process



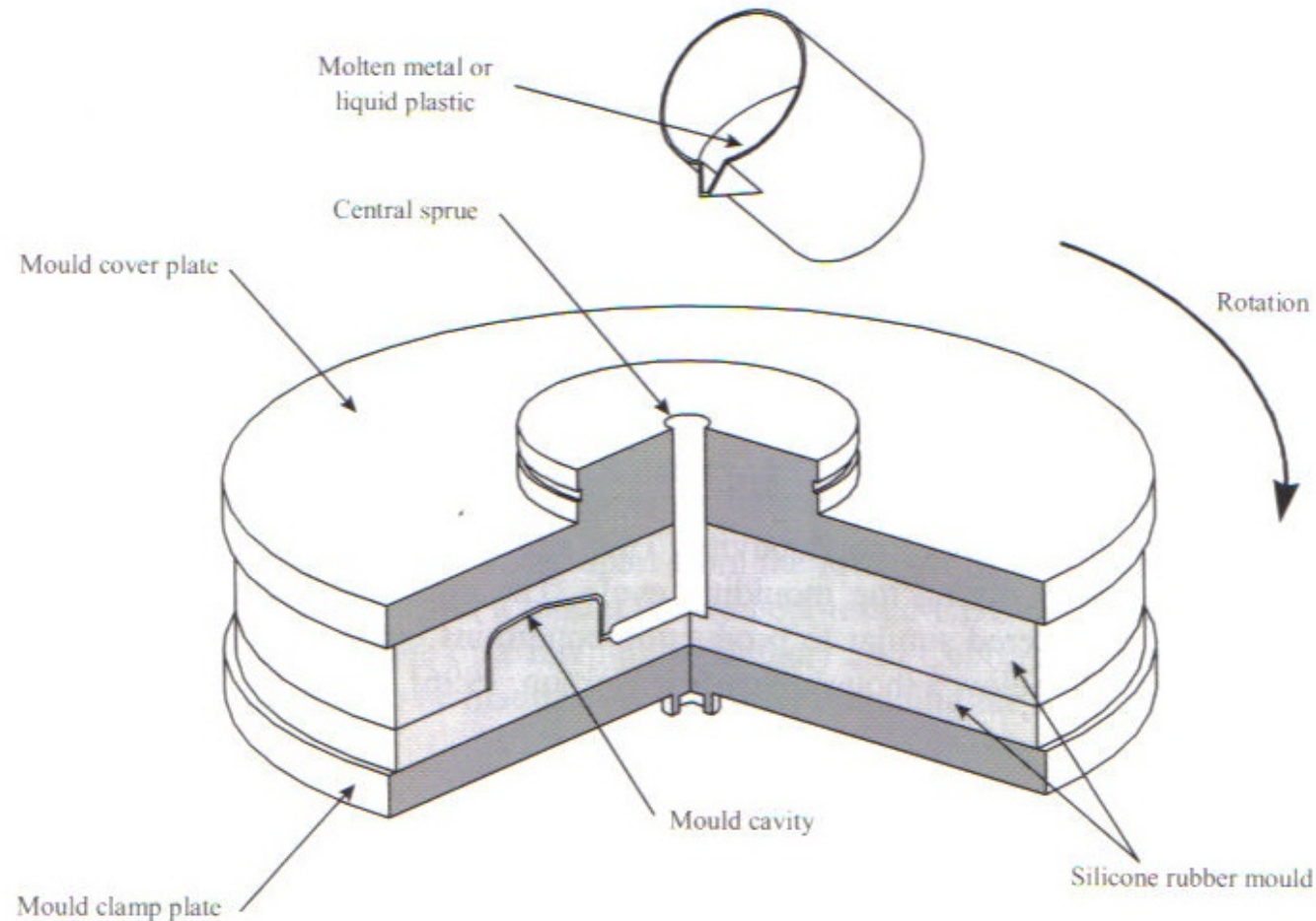
- Pattern Produced
- Pattern-tree assembled
- Pattern tree investment coated
- Pattern material melted out of the mould
- Molten, casting material poured into the mould
- Investment moulding material broken off the casting
- Individual castings cut off the casting tree and finished

Cast Metal Tools

- Spin-Casting
- Material is injected through a central sprue into a mould that is rotated at high speed
- Spin casting moulds for metals are made from heat vulcanised silicone
- The heat given out during the fabrication of such moulds is too high for usual RP patterns
 - An RTV rubber mould is made from the RP pattern
 - From the RTV mould a tin based metal alloy part is cast
 - The tin alloy part is then used to fabricate the vulcanised silicone mould
- The final mould can spin-cast zinc alloy parts which have similar properties to die cast aluminium parts

Cast Metal Tools

Spin Casting

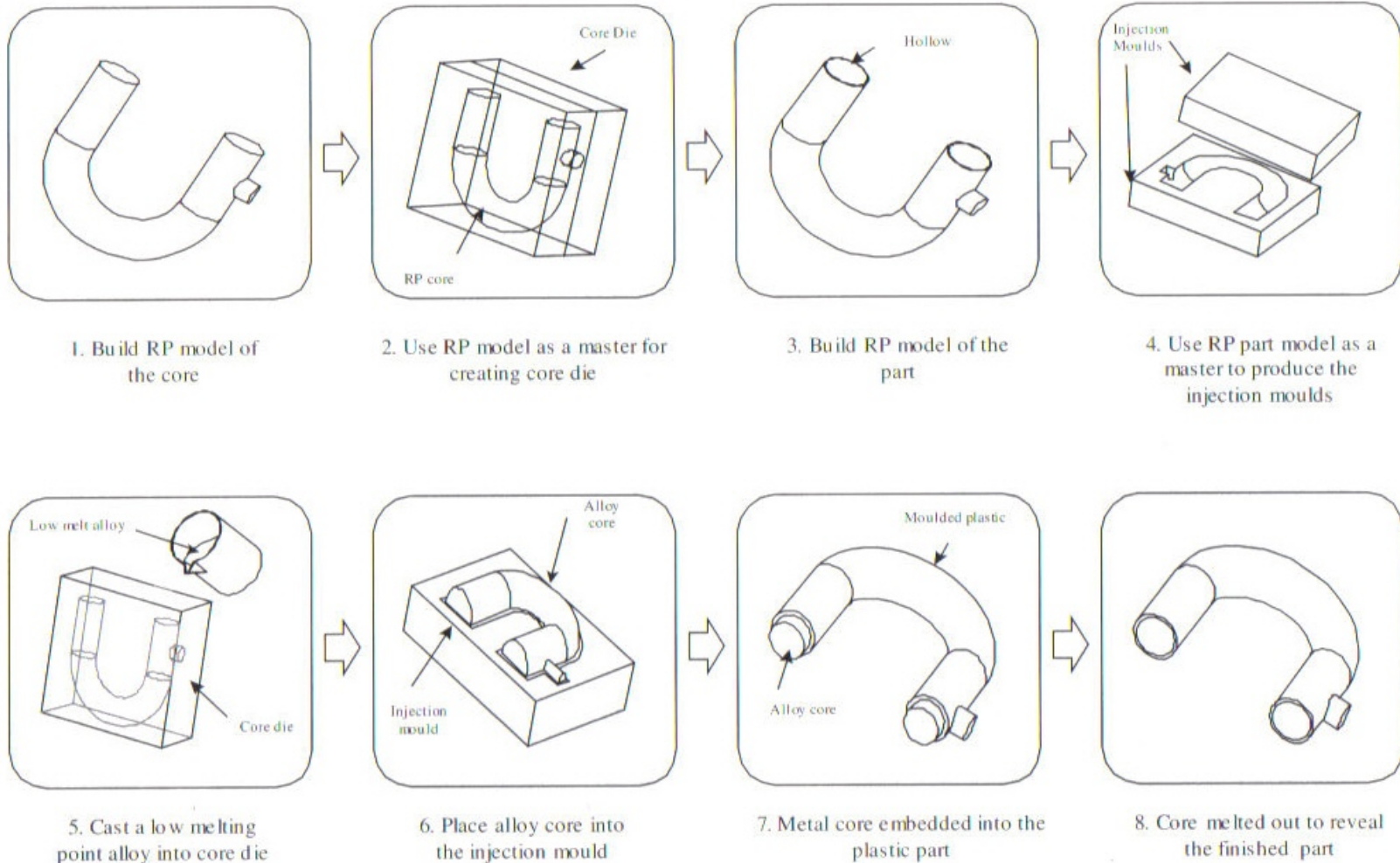


Cast Metal Tools

- Fusible Metallic Core
 - Relatively new technology
 - Forms complex hollow one-piece plastic components
 - A variation of investment casting
 - Low melting point alloys are used for sacrificial patterns instead of wax
 - RP techniques are employed to build the part & core models

Cast Metal Tools

Fusible Metallic Core

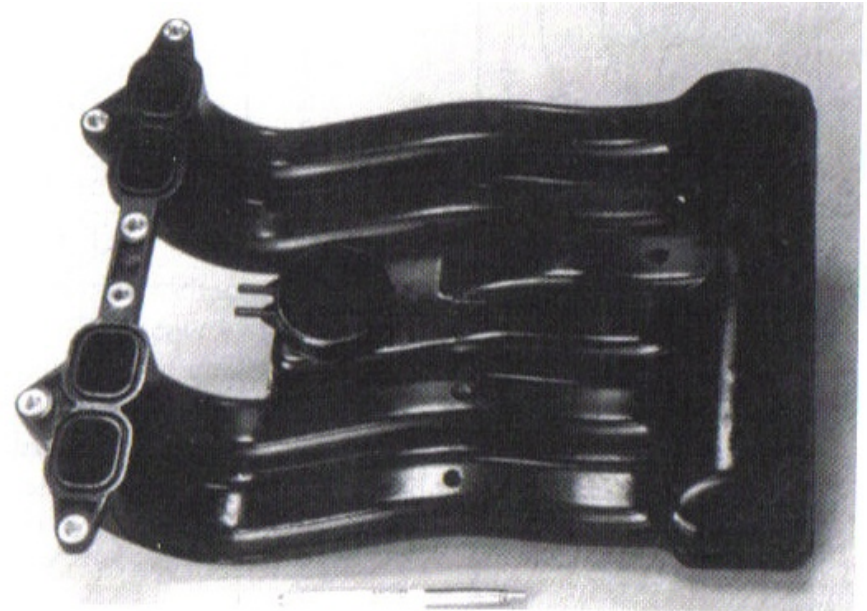


Cast Metal Tools

Fusible Metallic Core



Core encapsulation with
thermoplastic



Finished inlet manifold

Sand Casting

- Employed for the production of relatively large metal parts with low requirements for surface finish
- RP techniques can be used to create the master pattern
- When using RP techniques, shrinkage compensation & additional material for areas requiring post process machining can be easily included
- Other benefits from using an RP master pattern include reduced lead-times & greatly improved pattern accuracy

Direct Methods for Rapid Tool Production

Direct Rapid Tooling

- **Indirect rapid tooling** always has at least 1 intermediate replication process causing potential inaccuracies & increasing the tool build time
- To overcome these drawbacks RP apparatus manufactures proposed & developed new **direct rapid tooling** production methods
- Direct rapid tooling is build directly from a 3D CAD model

Direct Rapid Tooling

- Parts created from direct rapid tooling range from approx 1 to 100,000
- Durability & life expectancy of tooling depends on
 - Material of tool
 - RT method employed
- This allows for a wide application area of direct rapid tooling:
 - Prototype
 - Pre-production
 - Production

Direct Rapid Tooling

Direct rapid tooling processes can be separated into 2 groups

1) Direct Rapid Firm Tooling

- Less expensive methods
- Shorter lead times
- Appropriate for tool validation before changes become costly
- AKA 'firm tooling' or 'bridge tooling' filling the gap between 'soft' & 'hard tooling'

2) Direct Rapid Hard Tooling

- RT methods which allow pre-production & production tools to be built
- Marketed as 'hard tooling' solutions
- Parts are fabricated using sintered steel, iron & copper inserts infiltrated with copper or bronze

Direct Rapid Tooling

Direct Methods for Rapid Tool Production

Firm Tooling

Direct AIM
20-200 parts 1 week
(Dacell and Barritt, 1996)

DTM Copper PA Tooling
20-250 parts, 1 week (DTM, 1998)

DTM SandForm Tooling
1 part 1-3 days (DTM, 1998)

EOS Direct Croning Process
1 Part 1-3 days (Fritz,1998)

LOM Tooling in Polymer
(Data not available)

3DP Ceramic Shells
1-10 parts, 2-4 days (MIT,1999)

Hard Tooling

EOS Direct Tool
200-20,000 parts
1-3 weeks (EOS,1997)

DTM RapidTool Process
250-100,000 parts,
2-4 weeks (DTM, 1998)

LOM Tooling in Ceramic
(Data not available)

3DP Direct Metal Tooling
250-100,000
2-4 weeks (MIT, 1999)

Direct Rapid Tooling

- Direct ACES (Accurate Clear Epoxy solid) Injection Moulds (AIM)
 - Stereolithography used to produce epoxy inserts for injection mould tools for thermoplastic parts
 - Thermal conductivity of the mould is 300 times lower than that of one made from steel
 - Copper water cooling lines are inserted into the moulds body
 - Compressed air is blown onto the surfaces of the mould cavity after every injection moulding operation
 - An experienced operator will know when to suspend production to allow for more cooling
 - Aluminium powder is added to the back fill epoxy
 - Cycle time is long compared with production injection moulding (3-5 mins compared with 5 – 15 secs)
 - Tools made this way can produce up to 100 parts

Direct Rapid Tooling

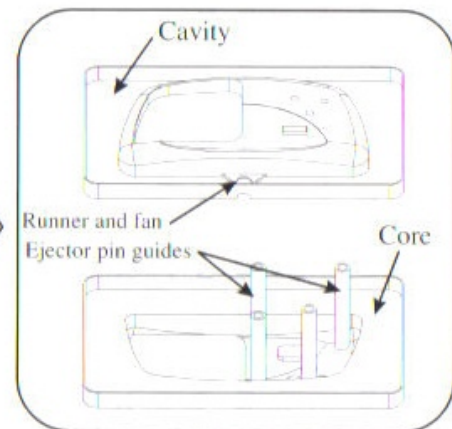
Direct AIM Injection Mould



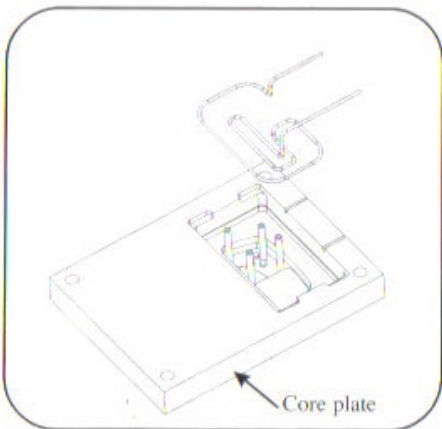
3D mould design



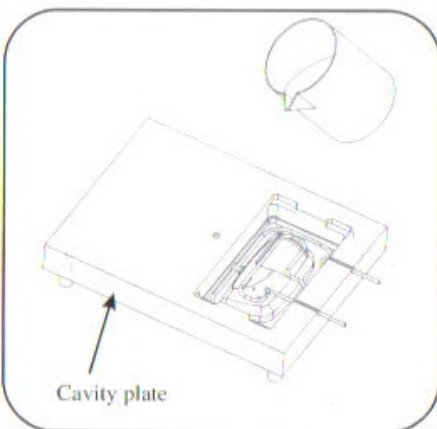
Manufacturing of the Direct AIM™ inserts



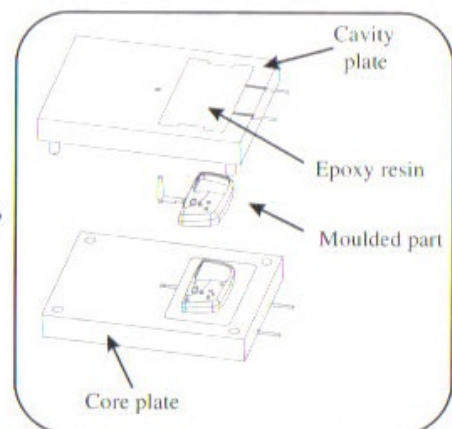
Stereolithography inserts



Integration of the inserts into the mould base.
Addition of cooling lines.



Backfilling of the mould with epoxy resin



Injection moulding

DTM Rapid Tool Process

- SLS based tooling system marketed as The RapidTool process
- 3 materials available
 - RapidSteel 1.0
 - RapidSteel 2.0
 - Copper Polyamide
- This is the most widely used RT method in production today

DTM Rapid Tool Process

Rapid Steel



1- 3D CAD
mould design



2- SLS processing



3- Polymer
infiltration
& drying



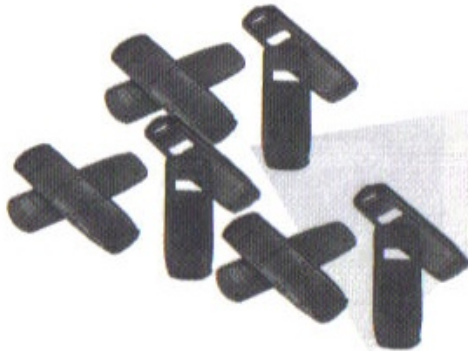
4- Debinding,
sintering & copper
infiltration



5- Inserts finishing



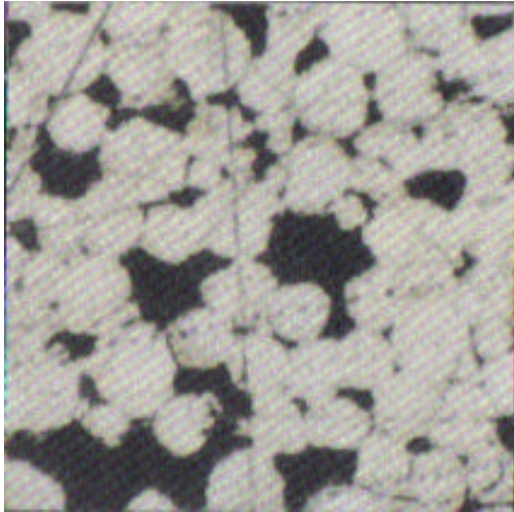
6- Plastic injection moulding



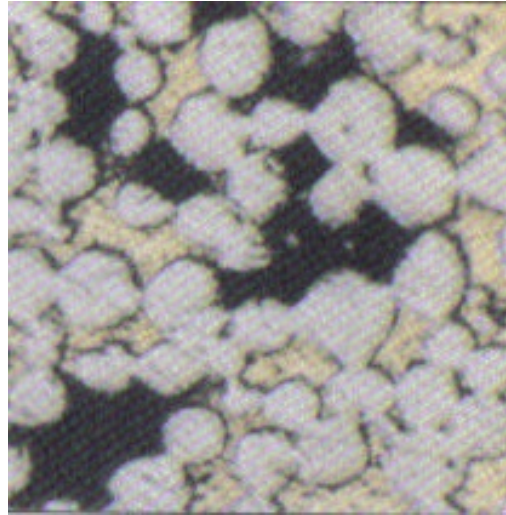
DTM Rapid Tool Process

Rapid Steel

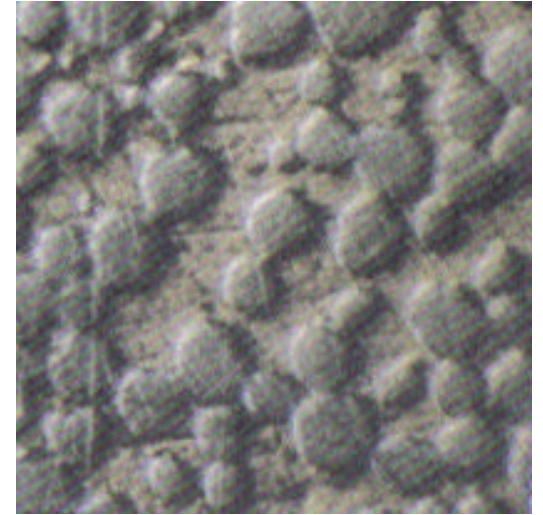
Optical micrograph of a RapidSteel part surface



Sintered part



Partially copper
Infiltrated



Fully copper
infiltrated

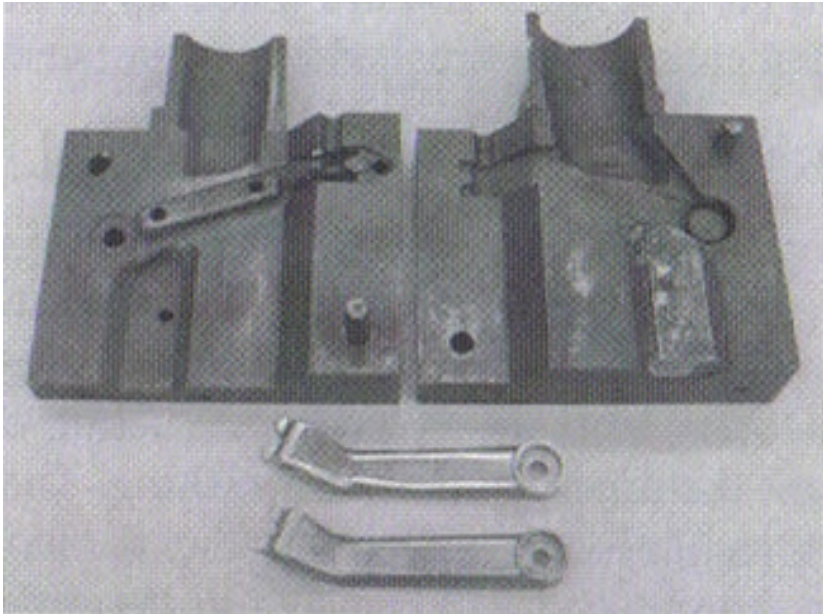
DTM Rapid Tool Process

Rapid Steel

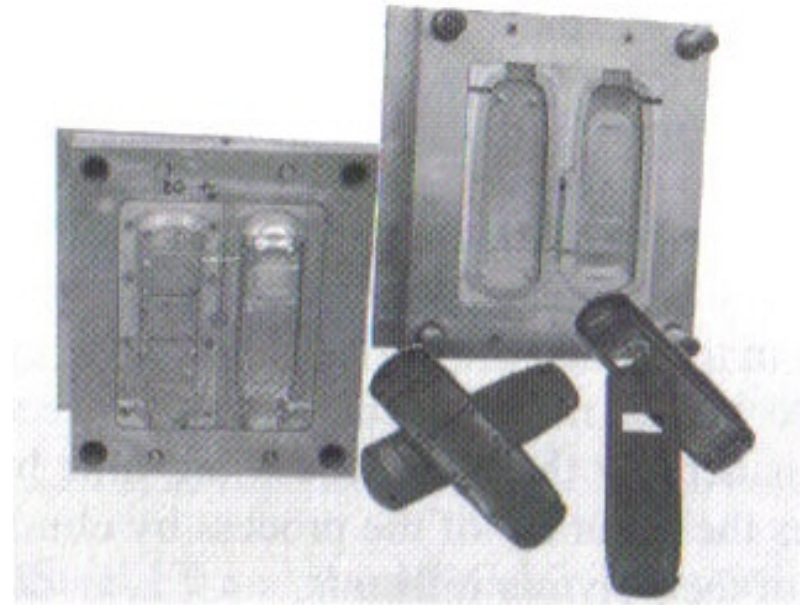
- No restriction in complexity of part
- Excess material must be added on the parting surfaces, shut offs & sides of inserts – machined off afterwards
- The process requires a flat base for proper infiltration
- Simple small features (<1mm) can be omitted from the insert design & added in after
- Can be machined, ground, finished in the same way as a steel part

DTM Rapid Tool Process

Rapid Steel



Die cast windscreen wiper arm parts

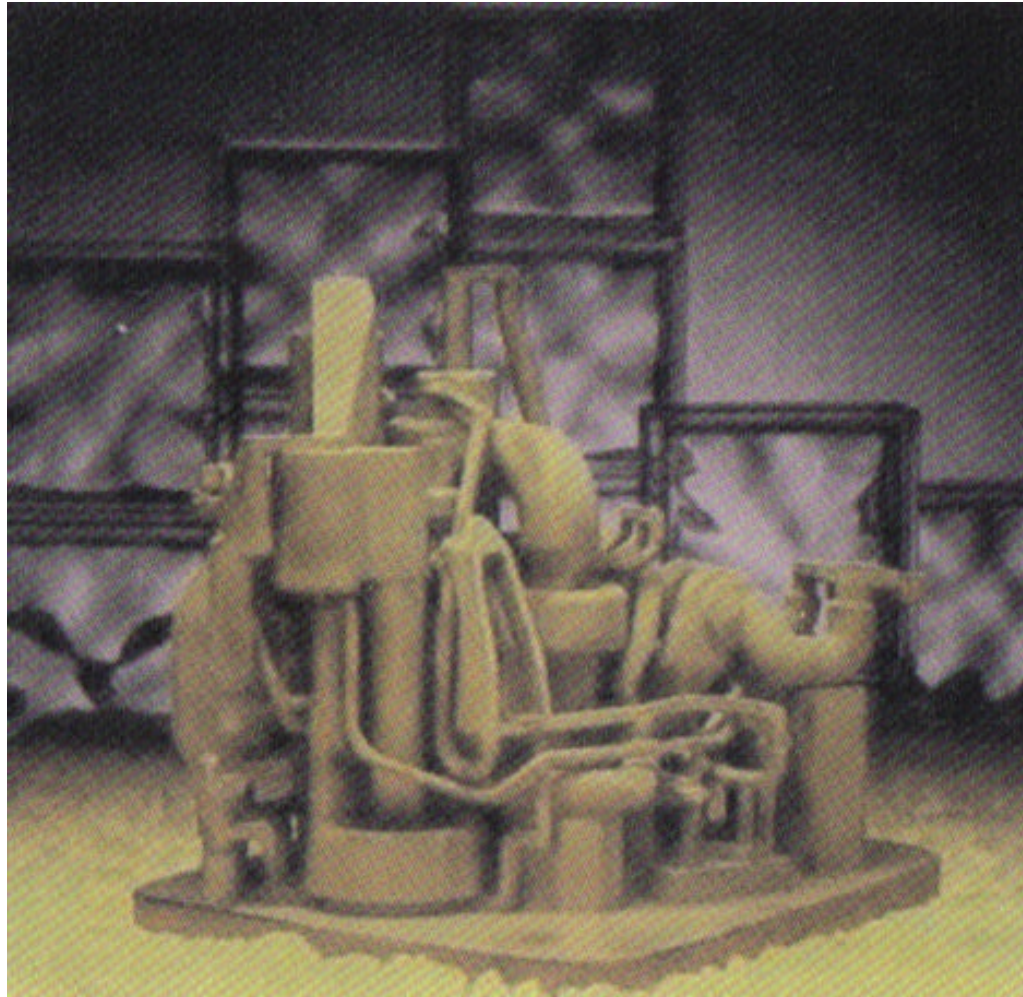


Mobile phone case

SandForm

- Uses SLS process to produce moulds and cores for use in Low pressure sand casting
- Produces moulds / cores directly from 3D CAD data
- Zr & Si (high mp) materials are used as the build materials

SandForm

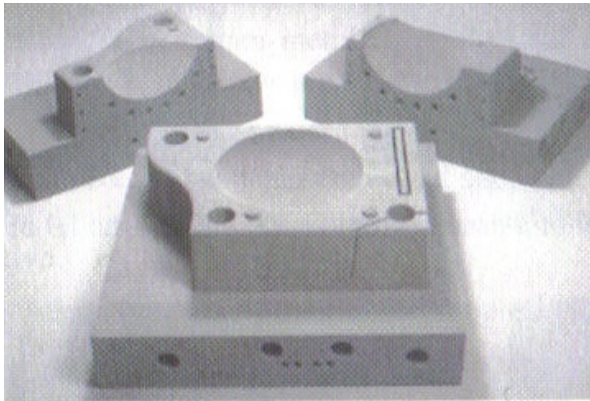


Direct Metal Tooling Using 3DP

- 3D printing technology is employed to build metal parts
- Advances in technology allow steel, stainless steel, tungsten & tungsten carbide components to be made
 - Stage 1 – material particles are bound with a binder material
 - Stage 2 – the bound steel particle layers are sintered in a furnace
 - Stage 3 – the sintered part is infiltrated with a low melting point alloy resulting in a fully dense part

Direct Metal Tooling Using 3DP

A range of direct metal tooling inserts produced using 3D Printing Systems



Injection moulding inserts with cooling ducts



Finished metal inserts

Direct Metal Tooling Using 3DP

Building Ceramic Moulds Directly from CAD Data

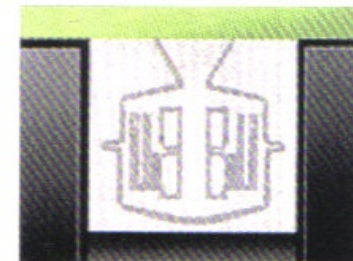
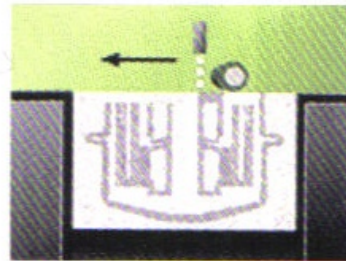
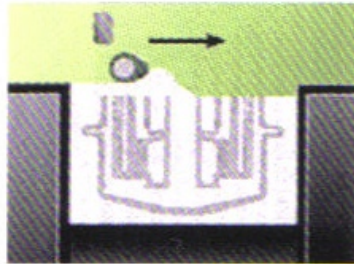
Direct Shell Production Casting



1. CAD model of a casting tree



2. CAD model of a ceramic mould



3. Building the mould using 3D printing process



4. Removal of the unbound powder

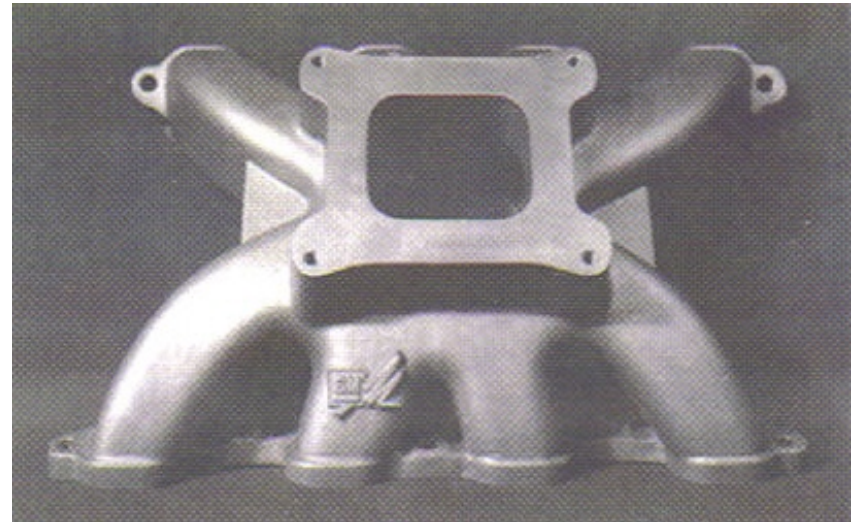


5. Casting the mould

Direct Metal Tooling Using 3DP

Building Ceramic Moulds Directly from CAD Data

Direct Shell Production Casting



Examples of ceramic moulds & castings fabricated using DSPC

Direct Tooling Methods

Summary

- Reduce tool production time
- Reduce inaccuracies
- Restricted range of build materials
- Improvement in materials is under constant development e.g. ceramics for SLA
- Another area of development is the combination of direct rapid tooling & traditional tooling technologies