

Casting Procedure: Futuristic Approach

Dr Divya Dahiya¹, Dr Anita Hooda², Dr J. Gulia³

¹Professor, Department of Prosthodontics and Crown and Bridge, PGIDS Rohtak

²Senior Professor, Department of Oral Anatomy, PGIDS Rohtak

³Professor, ENT Department, PGIMS, Rohtak

INTRODUCTION

Metal casting processes are being adopted for manufacture of parts for equipment and machines for thousands of years. Over the years improvements and innovations have been deployed to make the processes more productive to increase output and at the same time making them cost effective.

Definition

Casting is defined as something that has been cast in a mold, an object formed by the solidification of a fluid that has been poured or, injected into a mold.

History

- Dr. Swasey (1890) was the first to introduce a technique of making solid gold inlay.
- Martin (1891) was the first to use wax for making gold inlays.
- Dr. Philbrook (1896) introduced pressure casting method of producing gold inlays.
- Dr. Taggart (1907) presented a paper before the New York Odontological Group, in which he discussed his casting technique and machine.
- Taggart's success was mostly due to his improved casting machine, since his casting technique was not original; the idea of using wax to form the pattern was that of Martin (1891), and using pressure to cast the alloy was that of Philbrook (1896).

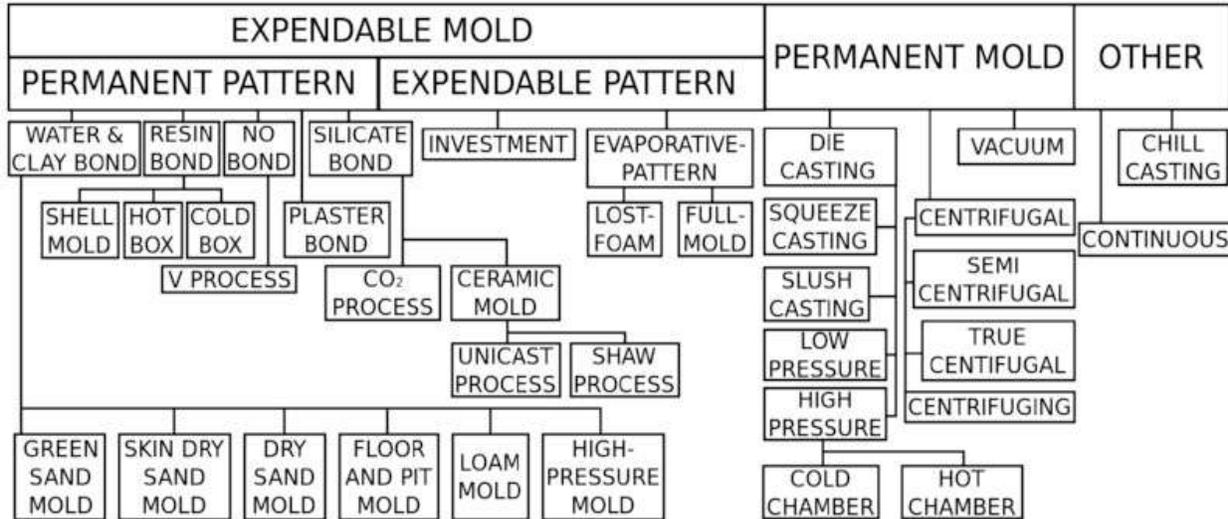
The basic steps involved in the casting of crown and fixed partial denture are-

- Tooth preparation.
- Impression and die preparation.
- Wax pattern preparation.
- Spruing.
- Investing.
- Burnout.
- Casting of molten alloy.
- Recovery of casting, cleaning.
- Finishing and polishing.

A mold is just a hollow container that holds and shapes materials in a liquid state (e.g. wax or metal). Casting molds are generally divided into two main categories: **expendable** and **non-expendable**.

Expendable mold casting is a generic classification that includes sand, plastic, shell, plaster, and investment (lost-wax technique) moldings. This method of mold casting involves the use of temporary, non-reusable molds.

Classification



Investment casting

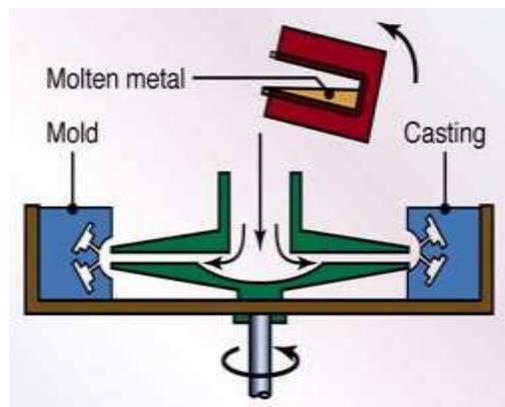
- also known as lost wax casting
- Investment casting involves investing (surrounding) a pattern with a refractory material and can be applied for casting stainless steel, brass and aluminum alloys.
- The liquid metal is poured into a cavity in a refractory material. Investment casting creates products with an exceptionally high-quality surface.

CENTRIFUGAL CASTING

- Centrifugal casting is a process in which the molten metal is poured and allowed to solidify in a revolving mould.
- **The centrifugal force due to the revolving mould holds the molten metal against the mould wall until it solidifies.**
- The material used for preparing moulds may be cast iron, steel, sand or graphite (for non-ferrous castings).
- The process is used for making castings of hollow cylindrical shapes.
- The various centrifugal casting techniques include:
 - True centrifugal casting
 - Semi-centrifugal casting and
 - Centrifuge casting.

Centrifuging Process

- *In true and semi centrifugal process, the axis of the mould/cavity coincide with the axis of rotation.*
- Where as in centrifuging process, the axis of the mould cavity does not coincide with the axis of rotation.
- The mould is designed with part cavities located away from the axis of rotation.
- Hence, this process is suitable for non-symmetrical castings.



Die casting

- During the die casting process, molten metal is forced into the cavity under high pressure, usually using nonferrous metals such as zinc, copper, and aluminum-based alloys. Die casting is widely used for applications where many small parts with numerous details, as well as a high-quality surface are required.

Sand Casting (sand molded casting)

- Sand casting, also known as sand molded casting, is a metal casting process characterized by using sand as the primary material for molds.
- The main part of all metal castings are manufactured via sand casting. Despite the fact that sand molds can only be used just once, they are still much cheaper than other types of molds. For this method, sand is mixed with a bonding agent like clay.
- The most common type of sand casting is called green sand molding and is frequently used to make molds for small to medium-sized metal parts. Green sand is an aggregate of sand, bentonite clay, pulverized coal, and water.

ALTERNATIVE TECHNIQUES OF CASTING

Lost Foam Casting (LFC)

- LFC process is a pioneering casting technique and an innovative alternative and addition to conventional foundry methods. It permits the production of complex components, and opens up new scope for casting
- Lost foam casting employs the use of expanded polystyrene (EPS) foam for pattern making.
- The first step of this process is creating a foam tool from which foam pieces are made. After the foam is ready, it's coated in a refractory wash and placed inside a flask.
- When dry, loose sand is poured around the foam while the flask is vibrated. The liquid metal is then poured into the flask, burning up and replacing the foam. After cooling, the part can be post-processed.

Process INVOLVED

- The first step in the process is pattern making. A pattern is made from polystyrene foam, which can be done in many different ways. For small volume runs the pattern can be hand cut or machined from a solid block of foam; if the geometry is simple enough it can even be cut using a hot-wire foam cutter. If the volume is large, then the pattern can be mass-produced by a process similar to injection molding. Pre-expanded beads of polystyrene are injected into a preheated aluminum mold at low pressure. Steam is then applied to the polystyrene which causes it to expand more to fill the die. [1] The final pattern is approximately 97.5% air and 2.5% polystyrene. Pre-made pouring basins, runners, and risers can be hot glued to the pattern to finish it.
- In the next step, the foam cluster is coated with ceramic investment, also known as the refractory coating, via dipping, brushing, spraying or flowcoating. This coating creates a barrier between the smooth foam surface and the coarse sand surface. Secondly it controls permeability, which allows the gas created by the vaporized foam pattern to escape through the coating and into the sand. Controlling permeability is a crucial step to avoid sand erosion.
- Finally, it forms a barrier so that molten metal does not penetrate or cause sand erosion during pouring. After the coating dries, the cluster is placed into a flask and backed up with un-bonded sand. The sand is then compacted using a vibration table.
- Once compacted, the mold is ready to be poured. Automatic pouring is commonly used in LFC, as the pouring process is significantly more critical than in conventional foundry practice. There is no bake-out phase, as for lost-wax. To be sure that the desired result is achieved during series production, a consistent foam model quality is essential.
- The vital factor here is even density distribution and optimum welding together of the particle foam. When the molten metal meets the EPS model, the high temperature of the metal causes it to decompose into smaller fragments (depolymerization) and evaporate.
- The metal is then able to enter the vacated cavity

Mouldless casting

- In the new method of rapid manufacturing, the molten metal is dropped on a substrate, making layers after another.
- This method has the potentiality to be used for complicated castings which are difficult to make their molds and patterns as usual ways.

- In droplet-based manufacturing process the castings are constructed by molten metal droplets having proper flow rate, temperature and diameter.
- A new system is designed and constructed which makes 3D parts and patterns by depositing molten metal droplets.
- Raw material wire melts and droplets are generated in droplet generating head.
- Molten metal Droplets deposit on a high temperature bed making the first layer.
- Next layers place on the previous ones to shape the final arbitrary part.
- These droplets are surrounded by natural air. Here tin60%, lead40% alloy wire is used.
- It is possible to apply other materials or wires having different diameters just with a little change in system.
- The wire is fed in special speeds which lead to different rates of droplets leaving the nozzle.
- Droplets have three properties which affect the layers and depositing way.
- These properties are **droplet temperature and volume and their deposition rate.**
- To control them several parameters of the system must be adjusted appropriately.
- At first it is assumed that these machine parameters are outlet nozzle diameter and feeding wire speed and also droplet temperature which affect droplet volume and deposition rate.
- Droplet temperature is measured exactly where they leave outlet nozzle.
- Droplet volume is estimated by several experiments, which lead to learn how different machine parameters create various droplet volumes.
- By knowing droplet volume and feeding wire speed, droplet rate can be calculated

Ice Casting Formation

- ▶ Ice formations were recorded primarily by using ice tracings or hot wax moldings.
 - Use of tracings to record ice formations results in a loss of three-dimensional detail.
 - Hot wax molding preserves much three-dimensional detail, but introduces new problem .
- ▶ The hot wax method involve dipping a piece of ice (removed from the body on which it has accreted) into a container of molten beeswax. After a sufficient layer of wax has accumulated and after the ice has completely melted, the mold is opened and the water is drained. The mold is then filled with casting plaster that is allowed to harden. When the cast is solid, the wax is melted away, leaving a casting of the ice shape.

Shortcoming of hot wax method

- This not only destroys information about the location of the ice formation relative to the body on which it was produced, but often damages the ice itself(which can be extremely fragile) and destroys any ice remaining on the body.
- Dropping a piece of ice into molten wax also has some effect on the ice shape.
- Second, using plaster as the casting material limits the value of the cast because its coarseness causes some surface texture and detail to be lost. Plaster is also inherently brittle, thus preventing the casts from being used in dry wind tunnel test programs for studying aerodynamic performance degradation due to icing.
- The goal of the work being reported herein was to achieve excellent reproduction of ice formations by utilizing modern molding and casting materials and techniques in place of hot wax and plaster.
- To do this, the mold must cure below 0 degree C within a reasonable time, and the ice must also be allowed to remain on the body on which it has accreted.
- To ensure no ice melt, the curing process must not be at all exothermic. Temperature dependency is important in selecting a molding material.
- Molding materials are designed to cure at room temperature and may not cure below 0 degree C the cast produced must retain.
- ▶ In molding, all materials must be kept below 0 °C at all times. Every effort was made to minimize the exposure time at room temperature. The filled mold boxes were cured in the freezer at -5 °C to retain all ice sample details a freezer temperature of -5 °C was used for all molding operation.

Rough surface and Fins on casting

PROBLEM	CAUSE	PRECAUTION
Rough surface	Investment breakdown	Avoid overheating of the mould and the alloy
	Air bubbles on wax	Correct use of wetting agent Vacuum investing
	Weak surface of investment	Avoid dilution of investment from application of too much wetting agent
Fins on casting	Cracking the investment	Avoid rapid heating of investment
Irregular voids	Shrinkage on cooling of alloy	Use correct sprue thickness Attach sprue at thick part of wax pattern Use Reservoir
	Inclusion of foreign particles	Heat the mould upside down so that particles fall out
Spherical Voids	Occluded gases in molten alloy	Avoid overheating and prolonged heating of alloy
Rounded margins	Back pressure effect	Use porous investment Use adequate casting force Use vents
Porosity	Turbulent flow of molten alloy into the mould	Correct placement of the sprue

NEWER INVESTMENT MATERIALS

Modified gypsum investment : Addition of fine silica, alumina, silicon carbide and polypropylene to gypsum improve bonding, increase investment strength and thermal resistance and also increase spaces for escape of gases.

Carbon free, phosphate bonded investment: These investment material are used for precision castings of precious, semiprecious and Pd base alloys for use in both quick heating and slow heating procedures.

Advantages :

- With special attention to complicated implant casting
- Carbon free creamy consistency
- High fluidity and wettability
- Very smooth surfaced
- Controllable expansion
- Eg - GC Fujivest super, GC Fujivest II and GC Stellavest

Refractory investment (polyvest)

It is an extremely fine-grained phosphate investment with an ample working time of 4-5 minutes .It can withstand repeated firings at furnace temperatures of up to 1,200 degrees and is compatible with high-expanding porcelain.

Magnesia based investment

More recently new investment materials have been marketed for casting commercially pure titanium. These investments are based on alumina, spinels, zirconia and magnesia. The objective in developing these investments has been to minimize the interactions between molten titanium and the investment moulds on casting so as to lower the levels of a-case formation. In the magnesia-based investment the expansion is controlled using zirconium, which is converted to zirconia on heating. As this reaction occurs, the investment expands.

LATEST CASTING WAXES

Master scan-able wax



This latest technology of scan-able wax allow us to wax up and scan without using powder spray; it also builds up fast and is designed to be stable and carve-able.

RPI (Reciprocal Parallel Interface Wax



RPI (Reciprocal Parallel Interface Wax) is designed to create parallel surfaces in post and core cases and anti rotational grooves, where inconspicuous undercuts are available. RPI wax will reproduce all details of minor undercuts and it will prevent distortion during the removal of the wax up without the use of a block out wax.

Black margin wax



This new generation of Margin Wax rivals its competitors due to its high visibility, carve-ability, and smooth surface, which helps to eliminate jagged margins, over extended margins and rough margins.

Light cured waxes

- Based on principal of converting wax pattern into acrylic pattern.
- The wax patterns of the metallic frameworks of the removable partial dentures could be made directly on the cast, using profiled waxes like: Ti-Light or LiWa (light curing waxes).
- These waxes eliminate duplicating techniques for the working models and saves time.
- Used for all types of metal works, crowns, bridges, implants.
- After modeling these waxes can be cured by any standard lab UV or halogen light

Advantages

1. Easy to use
2. Economic
3. Cures quickly, excellent strength and elasticity
4. Odorless and stable

RECENT ADVANCES IN CASTING TECHNOLOGY

- Casting technology is undergoing a radical shift and a process of industrialization is taking place in dentistry like in all other industries.
- Computer-assisted design (CAD)/ CAM milling is familiar ground for dentists by now.
- This innovation was followed by scanning (digital impression concept) that emerged as a consequence of technology and equipment from other industries are being adapted for use in dentistry.
- Dental restorations that have long been conventionally produced from metal through the use of casting techniques is getting automated; this technique is a direct import from 3D printing and rapid prototyping technologies used in general manufacturing.
- In the literature, CAM and 3D printing (DLMS) have been used interchangeably, though both are different processes.
- Subtractive manufacturing implies the process of removing material from formed raw material in a controlled manner.
- Historically, subtractive manufacturing received its roots from carving and sharpening of wood, stone, and bone.
- Modern traditional subtractive manufacturing methods rely on high precision computer operated machinery and an entire industry focused on cutting methods in an attempt to more easily accommodate design engineering expectations.
- In most cases, due to the maturity of the subtractive manufacturing industry focused mostly on CNC (computer numerical control) machining, it is cheaper and quicker to design for these techniques.
- CAM milling technology is often referred to as subtractive process, as milling involves taking a block of material and cutting away everything that is not necessary until the final restoration emerges.
- 3D printing technology is an Additive process involve adding material layer by layer to build the final product.

3D printing in dentistry

- Basically four different 3D printing technologies (additive process) are being used in dental industry:
 - stereo lithography apparatus,
 - digital light projection,
 - jet and direct metal laser sintering (DLMS or DMLS or just MLS)
 - FDM (fusion deposition modelling)

Laser Sintering Technology

- Laser sintering process was first introduced by Deckard and Beaman.
- Laser sintering is the newest technology in metal manufacturing.
- Laser sintering is also referred to as “3D printing” because it builds up framework in a series of successively thin layers (0.02–0.06 mm).
- Special CAM software is used to import a CAD file, usually supplied in the STL format from a scanner/CAD software. CAM software further slices the parts into discrete horizontal layers.
- A high powered laser beam is focused onto a bed of powdered metal and these areas fuse into a thin solid layer.
- Another layer of powder is then laid down and the next slice of the framework is produced and fused with the first.
- When all the layers have been built up, the solid copings and bridge frameworks are taken from the machine, sand blasted, polished, inspected and ultrasonically cleaned.
- The unused powder that remains is filtered and used in the next batch.

SLS – Selective Laser Sintering

- Process of using an automated laser to sinter compacted layers of powdered material (typically nylon-based) to form a 3D part.
- Once the base layer is sintered, a new layer of compacted powdered material is dispensed and the laser then sinters the new powder to the previously sintered material.
- This process is fast and functional, not requiring additional supports due to the powder bed acting as a support.

DMLS – Direct Metal Laser Sintering

- Similar to SLS printing, DMLS uses metal powder and a higher powered laser to sinter the material. Common metal powder include stainless steel, titanium, aluminum, and Inconel.
- Disadvantages of DMLS printing are likeliness of surface porosity that can be removed during post processing.

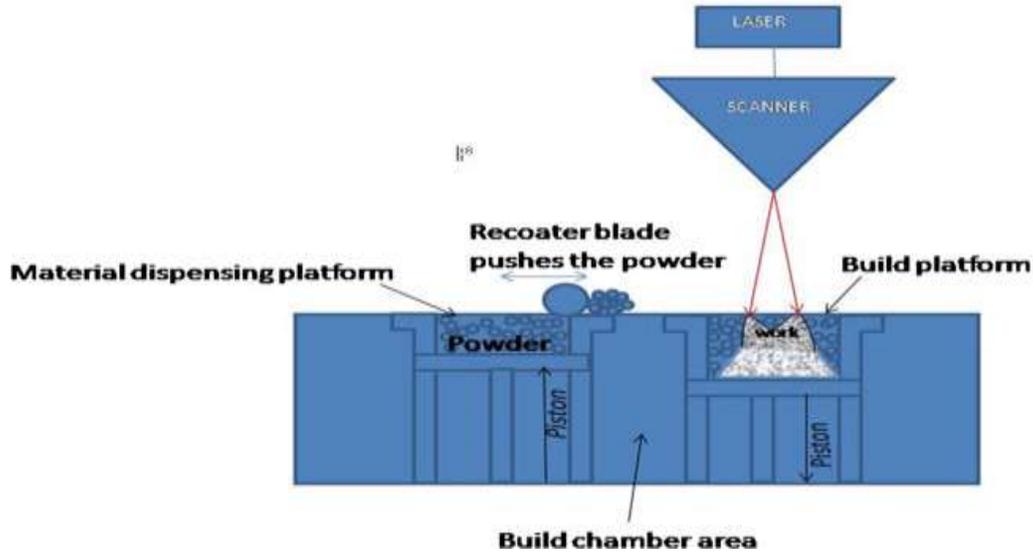
SLM – Selective Laser Melting

- Process of using high powered lasers to fuse metal powders together by locally melting the material, a process similar to standard welding.
- SLM printing generally produces a stronger part with less risk of porosity, but requires more design parameters.
- More heat causes more thermal stresses which can hinder manufacturing and result in poor quality parts or print failure.
- This combined with very fine point laser (0.1 mm) results in a density of 99.9 %, resulting in stronger copings.
- The densely sintered crowns have practically no voids.
- The process results in highly accurate, well detailed restorations.
- Marginal discrepancy is clinically acceptable with the restoration possessing consistent quality and strength.

DLMS

Direct laser metal sintering requires three inputs:

- **Material:** The material used is powder-based working material. The material is a mix of particles of the size of 3–14 μm .
- **Energy :** Energy used is a high powered laser beam (200 W Ytterbium fiber optic laser).
- **CAD model:** The machine reads in data from a CAD drawing and lays down successive layers of alloy powder and in this way builds up the model from a series of cross sections.



Factor affecting the marginal fit

- The CAD/CAM technique contains fewer production steps compared to conventional techniques.
- The three main factors affecting the fit are:
 - precision of the scanner,
 - how effectively software can transform the scanning data into a 3D model in the computer and
 - the precision of the milling machine.
- Scanners have a precision of 20 µm.

Technique	Advantages	Disadvantages
Light cured resin		
Stereolithography (SLA) Light sensitive polymer cured layer by layer by a scanning laser in a vat of liquid polymer	<ul style="list-style-type: none"> • Rapid fabrication. • Able to create complex shapes with high feature resolution. • Lower cost materials if used in bulk. 	<ul style="list-style-type: none"> • Only available with light curable liquid polymers. Support materials must be removed . • Resin is messy and can cause skin sensitisation, and may be irritant by contact and inhalation. <ul style="list-style-type: none"> • Limited shelf life and vat life. • Can not be heat sterilised. • High cost technology.
Photojet – Light sensitive polymer is jetted onto a build platform from an inkjet type print-head, and cured layer by layer on an incrementally descending platform.	<ul style="list-style-type: none"> • Relatively fast. • High-resolution, high-quality finish possible. • Multiple materials available various colours and physical properties including elastic materials. <ul style="list-style-type: none"> • Lower cost technology. 	<ul style="list-style-type: none"> • Tenacious support material can be difficult to remove completely. • Support material may cause skin irritation. <ul style="list-style-type: none"> • Can not be heat sterilised. • High cost materials.
DLP (digital light proce-ssing) Liquid resin is cured layer by layer by a projector light source. The object is built upside down on an incrementally	<ul style="list-style-type: none"> • Good accuracy, smooth surfaces, relatively fast. • Lower cost technology. 	<ul style="list-style-type: none"> • Light curable liquid polymers and wax-like materials for casting. <ul style="list-style-type: none"> • Support materials must be removed . • Resin is messy and can cause skin sensitisation, and may be irritant by contact Limited shelf life and vat life. • Can not be heat sterilised. Higher cost materials.

elevating platform.		
Powder binder		
Plaster or cementaceous material set by drops of (coloured) water from 'inkjet' print head. Object built layer by layer in a powder bed, on an incrementally descending platform.	Lower cost materials and technology. Can print in colour. Unset material provides support Relatively fast process. Safe materials	Low resolution. Messy powder. Low strength. Can not be soaked or heat sterilised
Sintered powder Selective laser sintering (SLS) for polymers. Object built layer by layer in powder bed. Heated build chamber raises temperature of material to just below melting point. Scanning laser then sinters powder layer by layer in a descending bed.	Range of polymeric materials including nylon, elastomers, and composites. Strong and accurate parts. Self-supported process. Polymeric materials – commonly nylon may be autoclaved. Printed object may have full mechanical functionality. Lower cost materials if used in large volume	Significant infrastructure required, eg. Compressed air, climate control. Messy powders. Lower cost in bulk. Inhalation risk. High cost technology. Rough surface.
Electron beam melting (EBM, Arcam) Heated build chamber. Powder sintered layer by layer by scanning electron beam on descending build platform.	High temperature process, so no support or heat treatment needed afterwards. High speed. Dense parts with controlled porosity	Extremely costly technology moderately costly materials. Dust may be hazardous to health. Explosive risk. Rough surface. Less post-processing required. Lower resolution.
Selective laser sintering (SLS) - for metals and metal alloys. Also described as selective laser melting (SLM) or direct metal laser sintering (DMLS). Scanning laser sinters metal powder layer by layer in a cold build chamber as the build platform descends. Support structure used to tether objects to build platform.	<ul style="list-style-type: none"> • High strength objects, can control porosity. • Variety of materials including titanium, titanium alloys, cobalt chrome, stainless steel. • Metal alloy may be recycled. <ul style="list-style-type: none"> • Fine detail possible. 	<ul style="list-style-type: none"> • Elaborate infrastructure requirements. • Extremely costly technology moderately costly materials. • Dust and nanoparticle condensate may be hazardous to health. <ul style="list-style-type: none"> • Explosive risk. • Rough surface. • Elaborate post-processing is required: <ul style="list-style-type: none"> • Heat treatment to relieve internal stresses in printed objects. • Hard to remove support materials. • Relatively slow process
Thermoplastic Fused deposition modelling (FDM) First 3DP technology, most used in 'home' printers. Thermoplastic material extruded through nozzle onto build platform.	<ul style="list-style-type: none"> • High porosity. • Variable mechanical strength. • Low - to mid-range cost materials and equipment. • Low accuracy in low cost equipment. • Some material may be heat sterilised. 	<ul style="list-style-type: none"> • Low cost but limited materials - only thermoplastics. • Limited shape complexity for biological materials. • Support material must be removed.

Computer Aided Milling

- Metal copings are milled from metal blocks.
- In accordance with CAD data, the milling program selects the metal block that will result in the minimum remaining material.
- The infrastructure for ceramic crowns can also milled from a piece of high performance Metroxit Zirconium oxide TZP Bioceramic R.
- To allow removal of the coping from the block, the connecting part between the coping and the remaining block is cut.

- The time required for milling a single crown coping is about 30-45 minutes.
- About 90-120 minutes are required for the three unit fixed partial denture coping.
- The average gap between the coping and the die at the margin is 30 to 50 um.
- This system is able to achieve clinically acceptable marginal accuracy, comparable to that of conventional complete cast crowns, (30-50um and other CAD/CAM systems (50-100um).

Advantages of 3D printing techniques

- For the dentist, chair side time is reduced
- time required in the dental laboratory is enormously less.
- More Precised than conventional procedure.

REVIEW OF LITERATURE

- Anders Ortorp evaluated and compared marginal gap and internal fit in an in vitro study.
- A total of 32 three unit fixed dental prostheses were fabricated in Co–Cr alloy using conventional lost wax method (LW), milled wax with lost-wax method (MW), milled Co–Cr(MC) and DLMS.
- Best fit was found in the DLMS group followed by MW, LW and MC.

CONCLUSIONS

- IC is the most commonly used technology despite the longer manufacturing time.
- This is mainly due to the long history of using casting in dentistry and
- consequentially a large availability of required equipment in dental laboratories.
- 3D printing and SLM are rather novel technologies in dentistry field.

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