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REVIEW ARTICLE

CASTING PROCEDURE AND DEFECTS

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ABSTRACT:
According to (GPT-9) the action of pouring or injecting a flowable material into a refractory mold. The object formed is also referred to as "a casting". There are various steps of fabrication of a simple full metal crown. Casting failures of alloys in dental technology should be the exception, not the rule. They have to be detected in time and associated with possible causes. For the experimental part base metal alloys single tooth restorations were achieved using the conventional lost wax process for casting in order to be evaluated. Some casting defects obtained during the experimental part are exemplified: incomplete castings, absence of the castings, voids, distorsions, nodules, porosities. Selecting the appropriate casting techniques for each alloy and dental restoration and accurate following of the technologycal steps are essential to avoid casting defects.
Keywords: casting procedures, investment, sprue,casting defects, porosity

INTRODUCTION:

The objective of the casting process is to provide a metallic duplication of missing tooth structure, with as much accuracy as possible. The first procedure in the casting of an inlay or crown for the lost wax process is the preparation of a wax pattern. The cavity is prepared in the tooth and the pattern is carved, either directly in the tooth or on a die that is a reproduction of the tooth and the prepared cavity.[1]Each material has dissimilar components, properties, behaviour and method of manipulation. Despite that, the final product mismatch or discrepancy should not exceed 0.05 – 0.1%. [2]

WAX PATTERN FABRICATION :

The A.D.A. Specification No.4 for dental inlay casting wax covers 2 types of inlay wax : Type I is for medium wax employed in direct techniques, and Type II is for soft waxes used in the indirect techniques. Inlay wax is the preferred wax for preparation of inlays or crown, mainly because it does not leave any residue in the walls of the mold during the burn out procedure.[3] It burns out, forming carbon which is later eliminated by oxidation to volatile gases. The other properties which makes it desirable is its colour which contrasts with the die material, or the tooth, smooth texture when it is softened, its rigidity, dimensional stability and ease of carving. [4]

THE SPRUE FORMER :

The purpose of a sprue former or sprue pin, is to provide a channel through which molten alloy can reach the mould in an invested ring after the wax has been eliminated. [5]

Purpose of Spruing the Wax Pattern [6]:

i) To form a mount for the wax pattern.
ii) To create a channel for elimination of wax during burnout.
iii) To form a channel for the ingress of molten alloy during casting
iv) To compensate for alloy shrinkage during solidification.

SPRUE FORMER MATERIAL[7] :

The sprue former material should not rust or react with the environment or else the by-products formed can react with the restorative materials or can act as dislodged pieces or foreign bodies.

Most commonly, 3 types of sprue formers are available i.e. resin, wax and metal.

SPRUE FORMER DIAMETER[8] :

The sprue former diameter should be approximately the same size as the thickest area of the wax pattern.A sprue former with larger diameter is preferred than with small dia compared to wax pattern because : -

Advantages : Acts as a reservoir therefore continuous supply of molten alloy.

Disadvantages : Distortion of wax pattern if large sprue dia attached to smaller wax pattern.

The diameter of the sprue is the most important factor in determining the speed with which the molten metal enters and fills the mould. Velocity is directly proportional to the diameter of sprue.

SPRUE FORMER LENGTH [9]

Sprue former length depends on length of the casting ring. The length of the sprue former should be adjusted such that the distance between the wax pattern and the open end of casting ring is 6 mm for gypsum bonded and 3-4 mm for phosphate bonded investment.

This allows for minimum thickness of the investment that can both withstand melt impact, and also it allows for the escape of the mould gases. If these gases are not completely eliminated, porosity may result. 3-4 mm is sufficient for phosphate bonded investments because of its higher strength and least porosity. If distance is less than 3-4 mm then molten metal may lead to blast within the investment.[10]

NUMBER OF SPRUES[11] :

If the wax pattern is designed such that attachment of the sprue former at the bulkiest portion allows the metal to flow uninterrupted from the sprue to the farthest end of the mould, then a single sprue is adequate. However, if the wax pattern has a thin area between the sprue and

the periphery of the pattern, the melt will solidify at the reduced cross-sectional area, preventing the complete filling of the mould. Here 2 sprues can be used. If multiple sprues are used, they should join together at the crucible former level in a reservoir larger in diameter than all the sprues combined.

LOCATION OF SPRUES[12] :

The sprue former should be attached to the bulkiest part of the wax pattern because ;

i) It decreases the effect of released residual stresses by the heat of attaching the sprue.
ii) Continuous supply of the molten metal.
iii) Flow from thicker to thinner area, therefore thin areas will also be filled completely.

ANGULATION OF THE SPRUE FORMER[13] :

The sprue former should be directed away from any thin or delicate parts of the pattern, because the molten metal may abrade or fracture investment in this area and result in a casting failure. An angle of 45^{o} to the proximal wall is considered appropriate. If it is directed at 90^{o} to flat area or broad surface The melt may impinge the mould surface and can create a concavity in this area opposite to the sprue. The mould concavity will be reproduced as a convexity in the restoration, preventing its seating and making the restoration rock.

RESERVOIR[14] :

It is made around 1-2 mm from the pattern. The purpose of the reservoir is to provide molten metal to prevent localized shrinkage porosity. When molten metal strikes against the mould wall at 90^{o} and if the mold metal temperature difference is more, it creates a hot-spot, the molten metal in this area will solidify last. Leading to localized shrinkage porosity, if there is no continuous supply of molten –metal. The reservoir provides the moltent metal to compensate for this localized shrinkage porosity at the casting sprue junction [15].

REMOVAL OF WAX PATTERN AND SPRUE FORMER FROM THE DIE OR THE TOOTH:

Stresses will be present during the removal of wax pattern from the die or tooth.
Therefore to decrease stresses ;

i) Use a sprue former for removing the pattern.
ii) Use 2 fingers i.e. thumb and forefinger on both sides of the pattern and gently remove it.
iii) A staple, may be attached to the furthest ends of the wax pattern by sticky wax (the staple may be made by wire of the alloy is used for the cast restoration)[16].

CASTING RING [17]:

The metal used in the construction of a ring should be non-corrodible, hard with a thermal expansion similar to the investment used. Stainless steel is the material of choice because its thermal expansion is 12% at 700^{o}C which is compatible with the expansion of the investment. The average diameter of the casting ring is 29 mm in diameter, and 38 mm in height.

CASTING RING LINER :

A resilient material placed inside the casting ring which will provide a buffer of pliable material against which the investment can expand to enlarge the mold.

Function of Liner[18] **:**

a) For mold expansion :
b) Thermal insulator :
c) Separating media :

Ringless Casting : Casting ring made of plastic or cellulose (casting ring not used during burnout).

A. Investment poured into the casting ring.
B. Once the investment sets, it is pushed out of the ring. Then it is kept for burnout.
C. This provides better thermal expansion and is usually done for cast partial denture[19].

INVESTMENT OF THE WAX PATTERN :

As mentioned earlier, the wax pattern is cleaned from debris or grease, before it is positioned in the ring by a cleanser or detergent. This will decrease the surface tension and increase the wettability of the wax pattern. Therefore it ensures the complete coverage of the wax pattern by the investment [20] .

INVESTMENT METHODS :

i) Manual investing ii) Vacuum investing

PRECAUTIONS TO BE TAKEN DURING INVESTING :

Air bubbles might remain in the mix, even with vacuum mixing. Therefore slightly tilt the ring. The air bubbles rise to the surface and thus can be eliminated.

Avoid excessive vibration of mix.

a) Solids in investment will settle down leading to free water accumulation next to wax pattern. Therefore surface roughness.
b) Sprue former may get dislodged → can result in miscast [21] .

BURN-OUT / THERMAL TREATMENT OF THE INVESTMENT / WAX ELIMINATION AND HEATING :

After investing, and leaving the casting ring aside for 1 hour, burnt out procedure is carried out. The investment should not completely dry out. To prevent drying, it is placed in humidor at 100% humidity. It should be slightly wet because the water present within the investment decreases the absorption of wax and when it vaporizes it flushes out the wax.

Objectives of Burnout [22] **:**

i) Complete elimination of wax.
ii) To increase the temperature of mold and investment comparable to fusion temperature of cast alloy.
iii) For thermal expansion of investment and wax-pattern mold for compensation shrinkage.

HYGROSCOPIC LOW-HEAT TECHNIQUE [22]**:**

This technique involves the immersion of the casting ring with the investment in water bath at 37^{o}C. Compensation of shrinkage is by 3 means.

i) At 37^{o}C water bath, the wax pattern expands. It is kept in water bath for 30 mins and 30-45 mins after the pouring of the investment.
ii) Since placed in water bath, the water enters the investment and provides for hygroscopic expansion.

iii) During burn out procedure at 468^{o}C → provides for thermal expansion of investment.

THERMAL (HIGH HEAT) TECHNIQUE [22] :

This approach depends upon almost entirely on high heat burnout to obtain the required expansion, while at the same time eliminating the wax pattern. Additional expansion may occur by slightly heating the gypsum investment on its setting, (therefore wax pattern expands), and a small amount of hygroscopic expansion (from the wet liner).

TIME ALLOWABLE FOR CASTING :

For low heat technique → Casting should be done quickly.

For high heat technique → a short period can elapse that is 1 min or less should be given for casting because if more time is given investment will loose its heat and mould contracts, also there will be the variations between the temperatures of investment and molten metal thus molten metal will solidify faster leading to casting defect.

CASTING / INJECTION MOLDING :

Objectives : To fill the mold with cast material as completely, efficiently and quickly as possible.

3 basic steps :

A) Fusing the metal alloy
B) Heated investment should be carried to the casting machine
C) Forcing / Casting the metal alloy into the mold.

CLEANING THE CASTING :

Quenching :

After the gold button has lost its glow,remove the casting ring with the tongs and place it into a pan of cold water.The ring is then immersed in a container of water. The water absorbed into the investment pores will undergo immediate vaporization within the hot mass. Steam in large amounts will be produced, cracking the investment into small pieces and most of the time, peeling it off the casting.

RECOVERY OF CASTING:

The investment is peeled off from the casting and can be facilitated by using a brush or sharp explorer.

SAND BLASTING:

The casting is held in sandblasting machine to clean the investment from its surface.

PICKLING:

Often the surface of the casting appears dark because of surface oxides and tarnish. This surface film can be removed by pickling. The best pickling solution for gypsum – bonded investments is 50% HCl solution. The disadvantage of this solution is that fumes from the acid are likely to corrode office and laboratory metal furnishings.[23] A similar solution of sulphuric acid (H_2SO_4) is more advantageous in this respect. Its action is enhanced by addition of potassium dichromate. The casting is placed in a test tube or dish and acid is poured over it. The acid may be heated but boiling is avoided because of the excessive fumes produced. After pickling, the acid is poured off and the casting is removed. Gold based and Pd based metal ceramic alloys and base metal alloys are bench-cooled before it is removed from the investment. Usually they are not pickled.[23]

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CASTING DEFECTS

1) Distortion
2) Surface roughness, irregularities
3) Porosity
4) Incomplete / Missing detail castings
5) Rounded margins
6) Discoloration

1) **DISTORTION** [24]: Distortion in casting is due to distortion in wax pattern.

a) During manipulation, there may be release of stresses.
   Avoid by → Proper handling and manipulation of the wax i.e.
   i) Manipulation of wax at high temperature. If at low temperature, stresses are introduced.
   ii) Investing the pattern within 1 hour after finishing.
   iii) If storage is necessary, store in refrigerator.

b) Due to uneven movement on the walls of the pattern when the investment is setting. The gingival margins are forced apart by the mold expansion, whereas the solid occlusal bar of wax resists expansion during the early stage of setting.
   Avoid by : Not much can be done to avoid this.

2) SURFACE ROUGHNESS, IRREGULARITIES [25] **:**

Difference between surface roughness and surface irregularities.
Surface roughness : Is defined as relatively finely spaced surface imperfections whose height, width and direction establish the predominant surface pattern.
Surface Irregularities : Isolated imperfections, such as nodules that do not characterize the total surface area.
Surface roughness, irregularities due to :

a) Air bubbles on wax pattern
b) Water films causing ridges and veins on surface
c) Too rapid heating → resulting in fins or spines.
d) Underheating causing incomplete elimination of wax.
e) Inappropriate water / powder ratio
f) Prolonged heating
g) Temperature of alloy too high
h) Casting pressure too high
i) Foreign bodies
j) Impact of molten alloy
k) Pattern position
l) Composition of the investment

a) Air Bubbles on wax-pattern [25]

- Seen as small nodules on casting
- May be due to manual investing
- Excess of wetting agent will dilute the investment, causing irregularities.

Avoid by :

- Vacuum investing technique
- Vibrate before and after mixing
- Slightly tilt the casting ring, so that entrapped air bubbles might rise to the surface

- Use a wetting agent to reduce surface tension of wax pattern so that intimate contact of investment to wax pattern.
- Air dry the wetting agent to a thin film.

b) Water films

- Wax is repellant to water, and if the investment becomes separated from wax-pattern, a water film may form irregularly over the surface.
- This may be seen if the wax pattern is moved slightly or vibrated after investing.

Clinical Features :

The water films causes **minute ridges or veins** on the surface.

Avoid by :

i. Avoiding movement, vibration of pattern after investment.
ii. Use of wetting agent and painting investment properly on the pattern to ensure intimate contact [26].

c) Too rapid heating

Clinical Features :

i. Can cause **fins / spines** on casting.
ii. Due to rapid heating, flaking of investment occurs when steam forms. Also, the steam may carry some of the salts used as modifiers into the mold.

Avoid by : Heat the mold gradually for 60 minutes from room temperature to 700^{o}C.

d) Under heating :

If heating time is too short or if there is insufficient air in the furnace → can cause incomplete elimination of wax residues.

Clinical Features :

i. Seen as voids / porosity on casting.
ii. Hot alloy comes in contact with these wax residues forming gases to form voids / porosity in the casting.
iii. Seen a black coating because the casting is covered with carbon coating which cannot be eliminated by pickling.

Avoid by : Heat the ring for adequate period of time so that the carbonaceous residue is removed.

e) Inappropriate water / powder ratio

i. Both increased water/ powder and decreased water / powder ratio causes rough castings.
ii. Increased water / powder ratio – rougher the casting.
iii. Decreased water/ powder ratio – investment will be too thick. Therefore cannot be applied properly on the pattern.
iv. During vacuum investing, air might not be removed completely.

Avoid by: Accurate water powder ratio.

f) Prolonged heating [27] :

i. Especially for gypsum bonded investments.
ii. If gypsum bonded investment is heated above 700^{o}C, sulphur compounds are formed which will contaminate the alloy.
iii. Also > 700^{o}C – disintegration of the investment.

Avoid by : Do not heat the ring > 700^{o}C.

g) Temperature of alloy too high.

If alloy temperature is more than temperature of investment, it will attack the surface of the investment causing roughness.

Avoid by [28] :

i. If gas – air fuel is used temperature of alloy will be apt.

ii. If other fuel is used light orange colour of alloy shows the alloy is ready to cast. (It should not be lighter than light orange).
iii. The temperature of alloy should be compatible with the temperature of the investment.

h) Casting Pressure : Increase in casting pressure can cause rough surface on casting.
Avoid by : Pressure should be adjusted.
i. 0.10 to 0.14 MPa in air pressure casting machine.
ii. 3-4 turns of spring in average type of centrifugal casting machine [28].

i) Foreign bodies :
When removing the crucible former, the investment in this area may be loosened. These pieces of investment may be carried into the mold with the molten alloy. Bits of carbon from the flux could be carried into the mold to cause a bright appearing concavity (carbon reacts with O_2 or air in the mold cavity forming CO which is a reducing agent. This CO prevents the oxidation of the surface of the casting gold and thus the cast will be bright and shiny). 'Flux' carried into the mold appears as bright appearing concavities [29]. 'Sulphur' from investment breakdown or from the torch flame having high S content causes surface discolouration and surface roughness.
Avoid by : Heat the mold upside down so that particles fall out of mould.

j) Impact of molten alloy : If sprue former is at 90^o great impact of molten alloy which can strike against the mold and cause concavity opposite to the sprue former which is reflected as raised area in casting.
Avoid by : Sprue former should be directed at 45^o to decrease the velocity of the flow of molten alloy [27].

k) Pattern position : If too many wax patterns placed in same ring, there should be a minimum distance of 3 mm between them. If it is less than 3 mm distance (the expansion of wax is more than the expansion of the investment), the expansion of wax can cause breakdown of investment [27] .
Avoid by : Avoid placing too many wax pattern close to each other in same ring. Minimum distance of 3 mm among the wax pattern.

l) Composition of the investment [26,37]
Coarse silica increases surface roughness
Avoid by : Investment should follow ADA specification No.2, thus there will be decreased surface roughness.

3) INCOMPLETE CASTINGS : It may be due to : -

a) **Inadequate spruing / sprue former too small -** This can cause premature solidification of alloy in the sprue former and thus molten alloy cannot reach all areas of mold.
Avoid by :
i. Use larger size of sprue former.
ii. Sprue former should be placed in thickest area of wax pattern so that molten alloy can flow from thicker to thinner areas [29].

b) **Sprues blocked with foreign bodies** : Foreign bodies block the flow of molten alloy.
Avoid by : Ensure that no debris blocks the sprue ingate. The ring should be held with sprue hole down when removing crucible former and sprue former (if metal).

c) Alloy not hot enough or not sufficiently molten or fluid - Results in viscous alloy which cannot wet all areas of mold cavity.
Avoid : Adequate heating of alloy so that it is 57^oC above the fusion / liquidus temperature.

d) Mold too cold

Avoid by :

i. Mold should soak heat for approximately 1 hour at burnout temperature.
ii. The temperature of the oven should be checked regularly with a pyrometer.
iii. Mold should be removed from burnout oven and casting completed within 1 minute.

e) Insufficient casting force

Avoid by : Use adequate amount of force for casting.

f) Insufficient gold alloy used

Avoid by : Cast enough gold to allow for a good button in the crucible of the ring[30].

4) ROUNDED MARGINS [31,38] :

a) **Incomplete burnout of wax pattern** : Can cause carbon residues in the mold to produce shiny rounded margins.
Avoid by : Ensure adequate burnout time and temperature to cause the carbon to get converted to CO or CO_2

b) **Insufficient heating of alloy before casting** - can make the alloy too viscous or does not stay in liquid state long enough to force the gases out and reach the marginal areas of the mold.
Avoid by : Heat alloy to 57^{o}C above fusion temperature.

c) **Improper diameter / length of sprue** - restricts flow of alloy into the mold. The metal freezes before margins are complete.
Avoid by : Average casting should have 10 gauge sprue and approximately 6 mm long.

d) **Insufficient casting pressure** : When the casting machine is underwound and the force on the molten alloy is insufficient to drive the alloy into the mold before the alloy freezes.
Avoid by : Use adequate casting pressure.

5) POROSITY:

Porosity may occur both within the interior region of a casting and on the external surface. External porosity can cause surface roughness. Internal porosity weakens the casting and if it extends to the surface, it may be a cause for discoloration. If it is severe, it can produce leakage at the tooth – restoration interface and secondary caries may result.

Classification of Porosities :

I. Those caused by solidification shrinkage.
- A. Localized shrinkage porosity
- B. Microporosity

II. Porosities caused by trapped gases
- A. Pinhole porosity
- B. Gas inclusion porosity
- C. Subsurface porosity

III. Due to residual air → Back pressure porosity.

I. Solidification defects :

A. **Localized shrinkage porosity / Shrink spot porosity -** It is caused by the incomplete feeding of molten alloy during solidification. When the alloy solidifies from liquid state, a shrinkage of at least 1.25% occurs. Thus during solidification of metal in mold, if additional molten metal is not available to compensate for shrinkage, then porosity occurs. It can occur if sprue is thin, then the metal freezes in the sprue before it does in the mold. It generally occurs in the sprue-casting junction.[32,39]

a) Suck-Back Porosity :

Shrinkage of alloys takes place in 2 stages : -

1) The transformation of the alloy from liquid to solid.
2) The coefficient of expansion of the solid alloy.

Suck back porosity due to ;

i) Improper sequence of solidification of metal alloy
ii) Difference in temperature of investment at sprue area and at pulpal area.

While the molten alloy is cooling, the temperature eventually reaches the solidification range, causing the alloy to change from liquid to solid. This change of state is accompanied by a large shrinkage.

As long as the remaining alloy is in the liquid state and the casting machine is rotating, molten alloy will feed the solidified portion of the casting, thereby compensating for the shrinkage. The next layer then solidifies, and this process continues until all the shrinkage resulting from the change of state is compensated for by the available molten alloy in the casting, sprue and sprue button.

Solidification takes place in a systematic manner. Ideally, molten alloy located furthest from the sprue button should freeze first and the molten alloy in the sprue and the sprue button should feed the rest of the pattern, thus compensating for the shrinkage as a result of the change of state.

If solidification does not occur in this systematic manner, and a portion of the alloy freezes before the alloy in the casting, suck back porosity occurs (seen if sprue diameter is thin).[33,40]

Avoid by :

Using a **Y-shaped sprue** instead of a single sprue. Here, only half of the molten alloy enters the mold cavity through each leg of the Y-sprue, so the temperature of the investment in the pulpal floor area (occluso-incisal area/ hot spot area) does not rise very high. The arms of the Y must be widely separated to prevent the investment between the arms from overheating, which could also cause suck back porosity.

Increase the mold temperature from 500^{o}C (which is mostly used with many investments) to 650 – 700^{o}C. With a higher mold temperature the difference in temperature between the investment located around the sprue and the investment in the area of the pulpal floor of the full crown is decreased. This decrease helps the molten alloy at the pulpal floor to solidify before the alloy at the sprue. Or another method is to lower the casting temperature by about 30^{o}C. `[33,41]

b) **Microporosity**[34,42]: Also due to premature solidification of the metal and is the result of solidification shrinkage. It occurs due to rapid solidification of the metal due to low temperature of molten alloy. Too low casting temperature.

Clinical Features : It is seen as small irregular voids.

Avoid by :

i. Increasing temperature of molten alloy
ii. Increasing temperature of casting.

II. **Porosities due to trapped gases** : Due to entrapment of gas during solidification.

a) Pinhole Porosity : Many metals dissolve or occlude gases while they are molten.

For example, copper and silver have great affinity for oxygen. Therefore they dissolve oxygen when they are in liquid state. Platinum and palladium have a strong affinity for hydrogen as well as oxygen. On solidification, these absorbed gases are expelled and the pinhole porosity results.

Clinical Features : Seen as small spherical voids.

b) Gas inclusion Porosities : These are larger spherical Porosities caused by gas occluded from a poorly adjusted torch flame or the use of the mixing or oxidizing zones of the flame rather than the reducing zone.

Avoid by :

i. Premelting the gold alloy on a graphite crucible or a graphite block if the alloy has been used before.
ii. Correctly adjusting and positioning the torch flame during melting.

C. Subsurface Porosity : The exact reason for this has not been established. It may be due to the simultaneous nucleation of solid grains and gas bubbles at the first moment that the metal freezes at the mold walls.

Avoid by : Control the rate at which the molten metal enters the mold.

III. BACK PRESSURE POROSITY / ENTRAPPED AIR POROSITY [35,43]:

Caused by the inability of the air in the mold to escape through the pores in the investment.

Avoid by :

i. Proper burnout so that carbonaceous residues do not decrease porosity of investment.
ii. Adequate mold and casting temperature
iii. Adequate casting pressure
iv. Thickness of investment between the tip of the pattern and the casting ring end should not be greater than 6 mm for gypsum bonded investments or 3-4 mm for phosphate bonded investment.
v. Vents can also be used for gases to be collected here.

7) DISCOLORATION Black casting due to sulphur contamination. Overheating the investment above 700^{o}C will cause its breakdown and formation of sulphur or sulphur compounds. [35,44]

Avoid by : Do not heat the investment above 700^{o}C.

i) **Carbon** inclusion from the investment, torch or crucible. It can contaminate the alloy during casting.
Avoid by : Changing source of heat or crucible etc.

ii) **Copper** contamination during pickling
Avoided by: Avoid the use of steel tongs to hold casting during pickling. The steel tongs should be covered with rubber or Teflon.

iii) Contamination with mercury - If cast gold restoration kept along side with amalgam dies, Hg from amalgam penetrates rapidly into the alloy and decreases the ductility of gold and increases the corrosion. Galvanic cell is formed if cast gold restoration given adjacent to amalgam restoration. Amalgam is the anode and noble metal alloy is the cathode.
Avoid by : Castings should never be placed adjacent to amalgam dies/restorations etc.[36]

CONCLUSION :

All basic steps should be followed in an orderly manner like wax pattern fabrication, investing, burn-out followed by casting and recovery. Proper attention to cleanliness and also the necessary precautions should be taken to prevent casting defects. Having ensured that, a clean, smooth, dense casting is obtained.

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