University of Technology
Department of Materials Engineering
General Materials Branch

Casting Technology

Lecture Twelve : Three Dimensional Printers and Computer Applications in Metal Casting

Class Code :ofp4npn

Additive manufacturing (AM)

- also known ***as three-dimensional printing, or 3DP***
- is a family of processes used to fabricate a component based on a geometric model of the part that has been generated on a computer-aided design system.
- The AM processes construct the part in layers starting at its base, by adding layers successively, one on top of the previous, to complete its full geometry.

Additive manufacturing (AM)

- When AM technologies were first introduced, they were employed to fabricate prototypes of part designs, As RP technologies evolved, they were increasingly used to produce parts, not just prototypes,
- the term ***additive manufacturing*** emerged. It refers to the same technologies as in RP, all of which work by adding layers of material to an existing part or substrate, so that the item is built one layer at a time.
- One might say that rapid prototyping is a subset of additive manufacturing when the purpose is to make a physical model of a newly designed part

Rapid Prototyping (RP)

- the term ***rapid prototyping (RP)*** was used because the parts could be produced in minimum possible lead time. The traditional method of making part prototypes was machining, which could require several weeks, sometimes longer, depending on geometric complexity, acquisition of materials, and scheduling of equipment.
- Rapid prototyping allows a part to be fabricated in hours or days rather than weeks, given that a computer model of the part has been prepared on a CAD system.

Additive Manufacturing Applications

Applications of AM can be classified into the following categories:

1. Design,
2. Engineering analysis and planning,
3. Tooling,
4. Parts production.

Tooling

- When AM technologies are adopted to fabricate production tooling, the term *rapid tool making* (RTM) is often used.
- RTM applications divide into two approaches :

1- indirect RTM, in which a pattern is made by RP and the pattern is used to fabricate the tool

- Examples of indirect RTM include patterns to make sand molds for sand casting and patterns of low-melting-point materials (e.g., wax) in limited quantities for investment casting.

Tooling

2- direct RTM, in which RP is used to make the tool itself.

- Examples of direct RTM include

1. Mold cavity inserts that can be sprayed with metal to produce injection molds for limited production quantities of plastic parts,
2. Dies made from metal powders followed by sintering and infiltration to complete the fabrication of the die,
3. Sand casting molds and cores fabricated from CAD data, thus avoiding the need for a physical pattern,
4. Electrodes for electric discharge machining

THE SEVEN AM PROCESS CATEGORIES

- All seven AM process technologies are based on slicing a CAD geometric model of a part into layers and forming each layer on top of a previous layer until the full physical geometry has been built.
- What distinguishes each of the seven technologies is their combinations of starting material type (e.g., polymer, metal), physical form of the material (e.g., liquid, powder), layer formation technique (e.g., laser, extrusion), and scanning mode (moving spot, moving line).

THE SEVEN AM PROCESS CATEGORIES

- The seven categories are

1. vat polymerization,
2. powder bed fusion,
3. *binder jetting*,
4. material jetting,
5. material extrusion,
6. directed energy deposition,
7. sheet lamination.

THE SEVEN AM PROCESS CATEGORIES

Process Category	Process Example	Typical Materials	Physical Form	Layer Formation	Scanning Mode
Vat Polymerization	SL	UV Photopolymer	Liquid	Laser	Moving Spot
	MPSL	UV Photopolymer	Liquid	UV	Area
Powder Bed Fusion (PBF)	SLS	Polymers, Metals, Ceramics, Sand	Powder	Laser	Moving Spot
Binder Jetting	3DP	Plastics, Metals, Ceramics, Sand	Powder	Binder Inkjet	Moving Line
Material Jetting	MJM	Photopolymer	Droplets	Inkjet + UV	Moving Line
	Polyjet™	Photopolymer	Droplets	Laser	Moving Spot
Material Extrusion	FDM	Thermoplastic	Filament	Extruder	Moving Spot
Directed Energy Deposition (DED)	LMD	Metals, Ceramics, Plastics	Powder, Wire	Laser	Moving Spot
Sheet Lamination	LOM	Adhesive-backed Paper, Plastic	Sheet	Laser, Knife	Moving Spot
	SDL	Plain Paper, Plastic	Sheet	Inkjet, Laser, Knife	Moving Line, Moving Spot

Key: SL = Stereolithography, MPSL = Mask Projection Stereolithography, UV = Ultra-Violet light source, SLS = Selective Laser Sintering, 3DP = Three-Dimensional Printing, MJM = Multi-Jet Modeling, LMD = Laser Metal Deposition, LOM = Laminated-Object Manufacturing, SDL = Selective Deposition Lamination.

BINDER JETTING

- Like powder bed fusion, the processes in binder jetting operate on powder materials, but instead of fusing the powders, a liquid adhesive is applied to each layer in selected areas to bond the powders together.
- When the original binder jetting process was developed around 1990, it was named *three-dimensional printing* (3DP) today that term has been generalized to apply to all additive manufacturing technologies.

Binder-jet Printing

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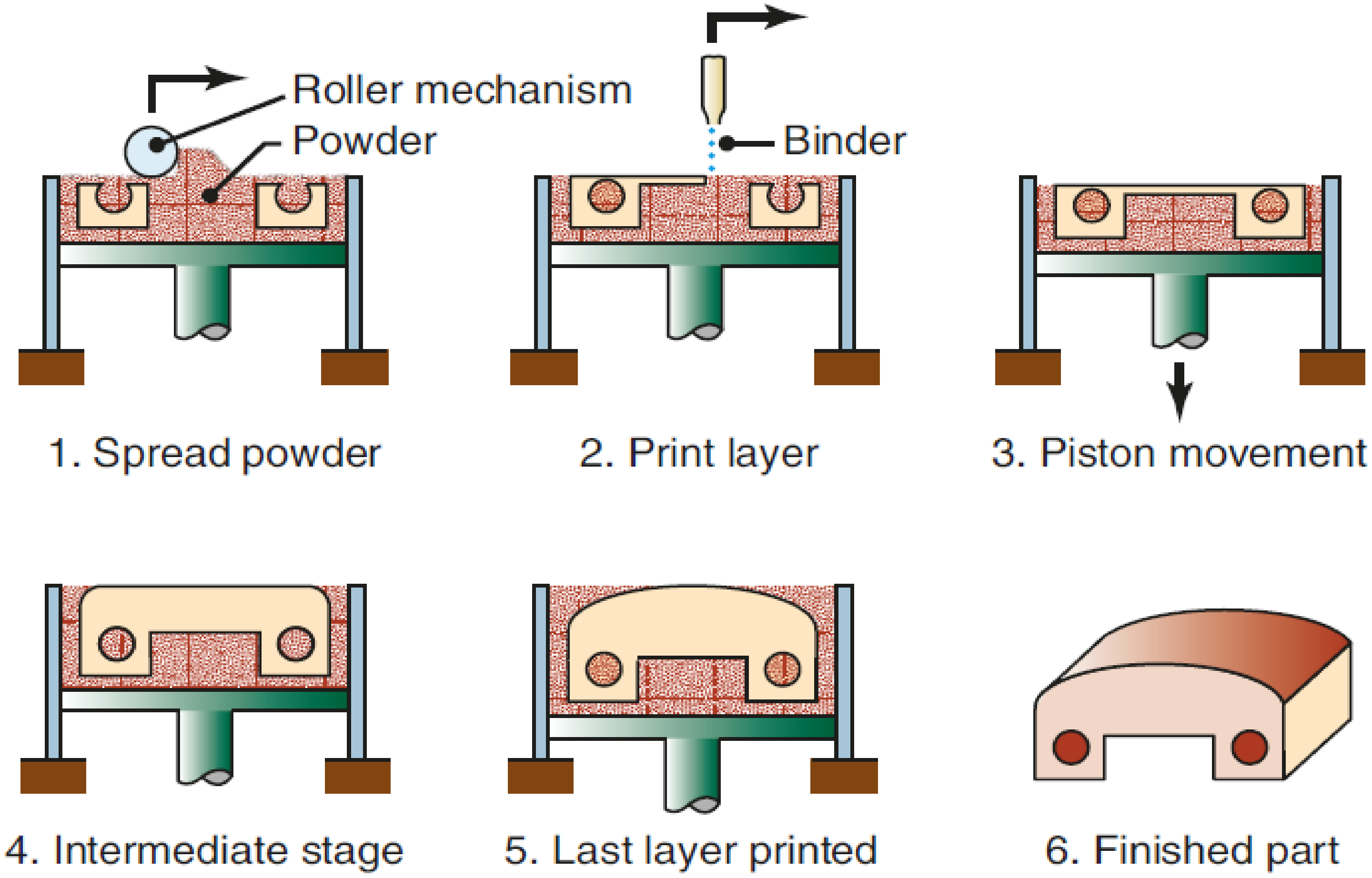


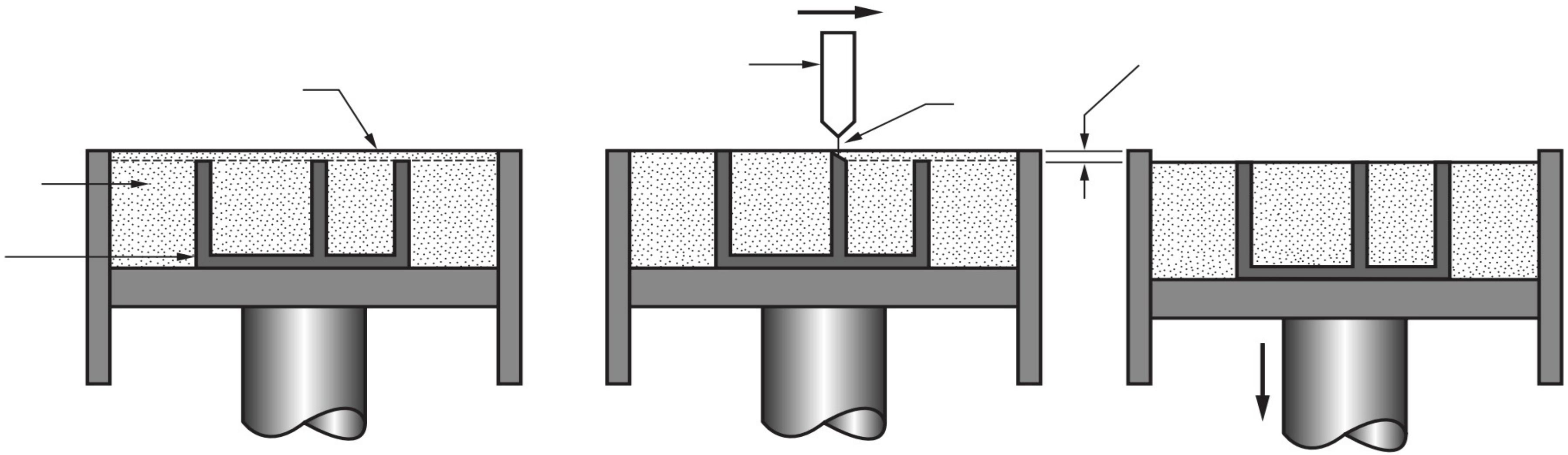
the Advantages of The Binder jetting processes

- The binder jetting processes share many of the advantages of material jetting relative to other AM processes. With respect to MJ, binder jetting has some distinct advantages.
- First, it can be faster since only a small fraction of the total part volume must be dispensed through the print heads. However, the need to distribute powder adds an extra step, slowing down binder processes somewhat.
- Second, the combination of powder materials and additives in binders enables material compositions that are not possible, or not easily achieved, using direct methods.
- Third, slurries with higher solids loadings are possible with BJ, compared with MJ, enabling better quality ceramic and metal parts to be produced. As mentioned earlier, BJ processes lend themselves readily to printing colors onto parts.

Binder Jetting in Sand casting

- An important and more recent development in mold and pattern making is the application of additive manufacturing to directly produce molds.
- In sand casting, for example, a pattern can be binder-jet printed with complex shapes and self-supported cores to produce hollow sections, greatly easing mold assembly.
- There are several rapid prototyping techniques applicable to casting, and can produce molds or patterns; they are best suited for small production runs.

Three-dimensional printing



POURING PRACTICE

- Some type of pouring device ,or ladle, s usually required to transfer the metal from the melting furnace to the molds. The primary considerations for this operation are

1. To maintain the metal at the proper temperature for pouring
2. To ensure that only high-quality metal is introduced into the molds

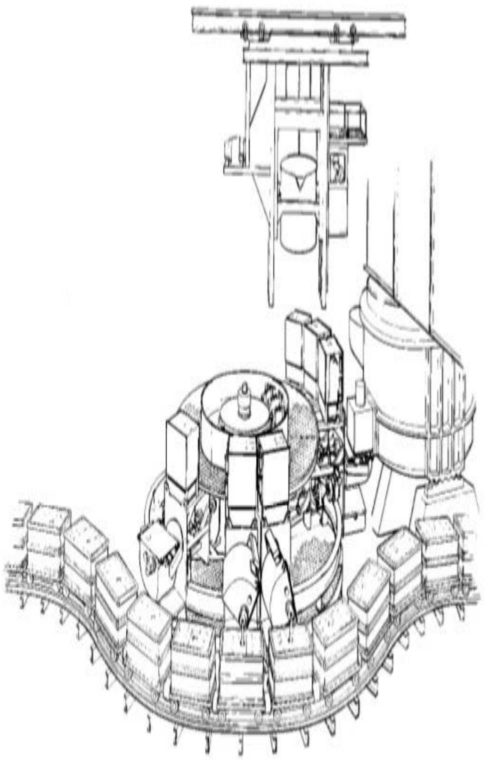


FIGURE 13-19 Automatic pouring of molds on a conveyor line. *(Courtesy of Roberts Sinto Corporation, Lansing, MI.)*

AUTOMATION IN FOUNDRY OPERATIONS

- Robots can do the following

1. Dry molds,
2. Coat cores
3. Ventilate molds,
4. Clean or lubricate dies.
5. They can tend stationary, cyclic equipment, such as die-casting machines

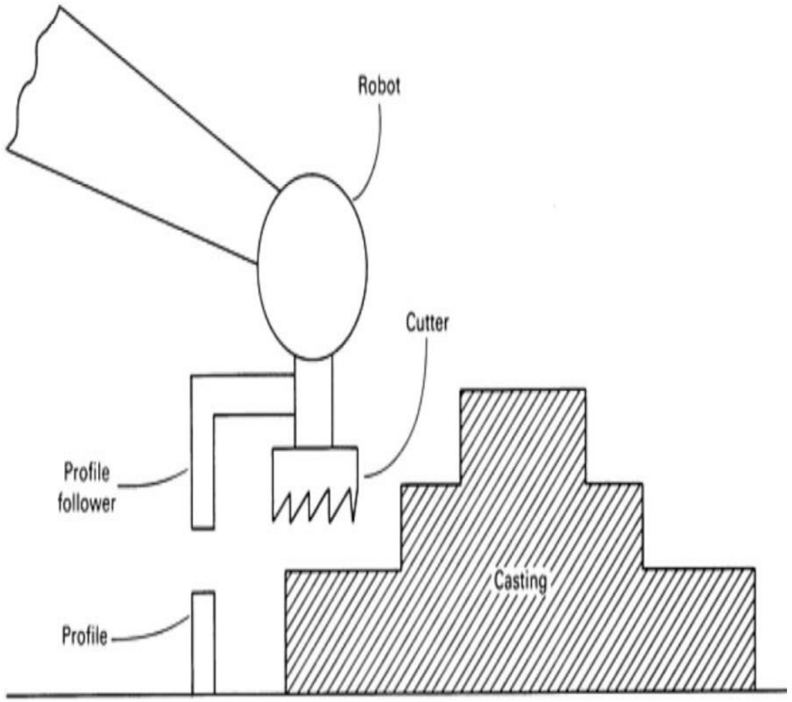


Fig. 2 Guidance template used to control the movement of the robotic arm

Benefits of Robotic Use in foundry

1-Increased productivity
2- Reduced costs
3- Improved casting quality
4- High-speed precision
5- Performance flexibility
6- High uptime
7- Inflation resistance
8- Round-the-clock output
9-Improved worker morale

Robotics in Die Casting

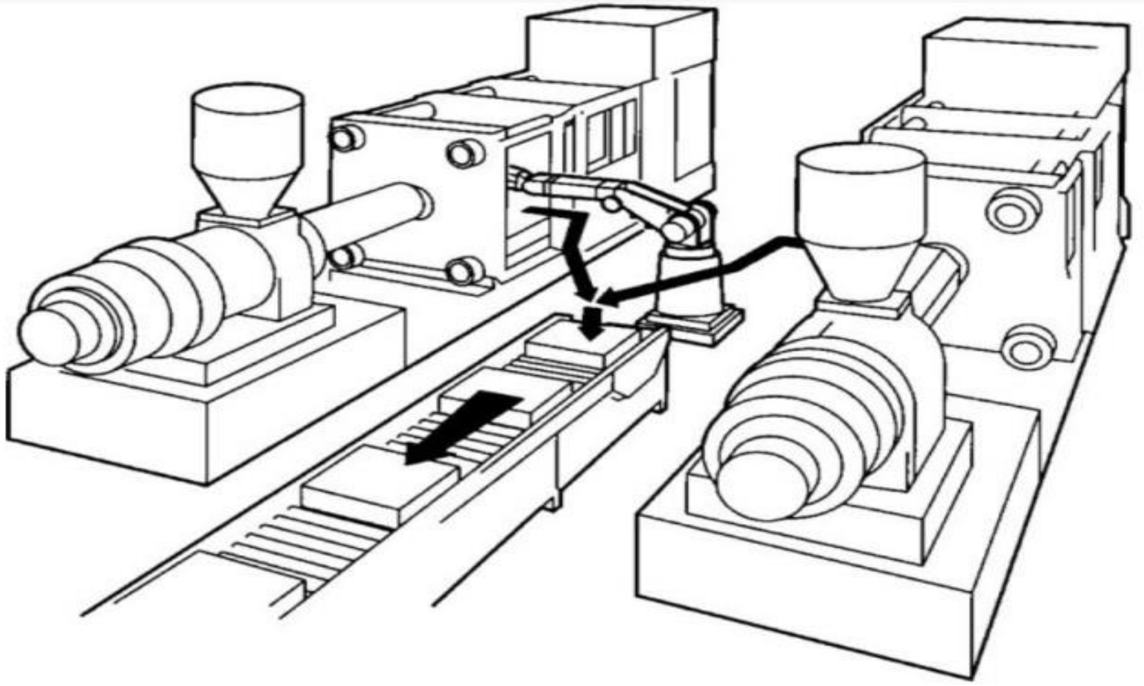
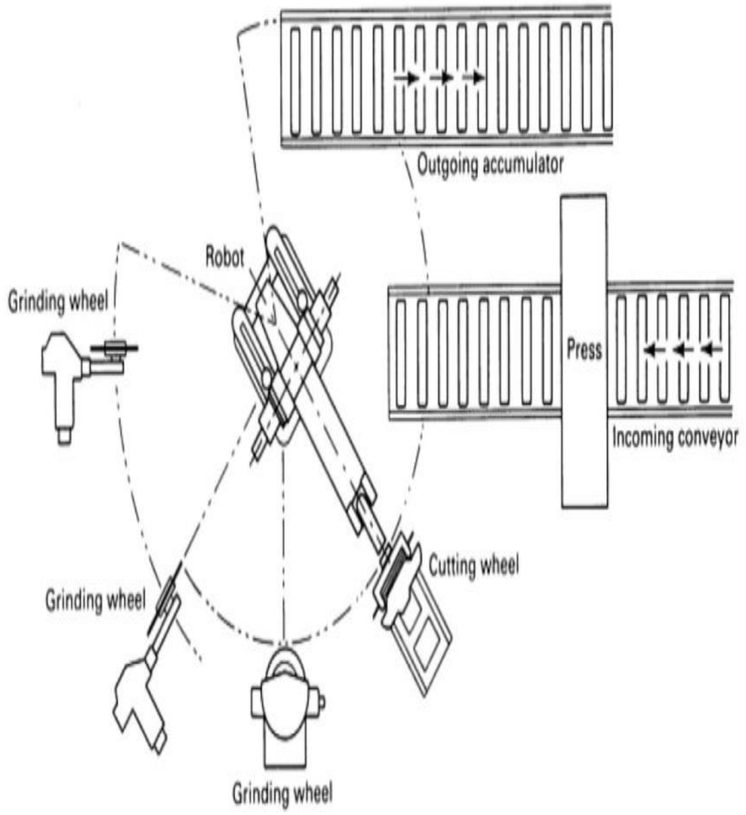


FIGURE 19.10 Universal robot for unloading parts from two-injection molder.

- Dexterity and versatile memory allow universal robots (articulated) to unload parts from two injection molders on a moving conveyor

Foundry Robotic Applications

1. Level 0: This robot registers no information from the surroundings
2. Level 1: Capable of monitoring contact between two surfaces t. *An example of such a foundry application would be robots attached to core making machines*
3. Level 2: these robots incorporate visual and nonvisual imaging sensors. *Examples would include adaptively controlled grinding and torch cutting operations*



Advantages of Computer Modeling

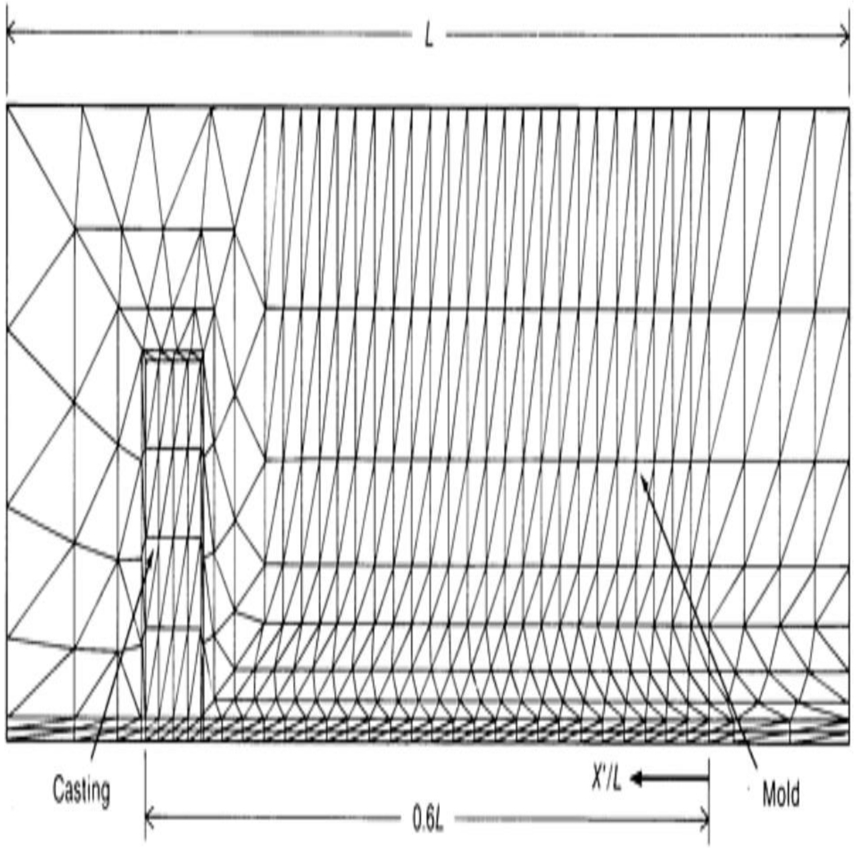
1. Increased casting yield per pound of metal poured
2. Improved casting quality (absence of unsoundness)
3. Enhanced productivity of casting system
4. Geometric models provide casting volume, weight, and surface area data, allowing rapid cost-estimating
5. permitting efficient rigging design

Advantages of Computer Modeling

6. Automated enmeshment for general purpose heat transfer simulators permits shorter design time
7. Automated machining of patterns, which in turn reduces costs
8. Fewer prototypes to be experimentally evaluated; shorter lead times from design concept to product
9. Easier implementation and evaluation of engineering changes
10. Enhanced ability to deal with batch production of castings of different design

Type of Casting Software

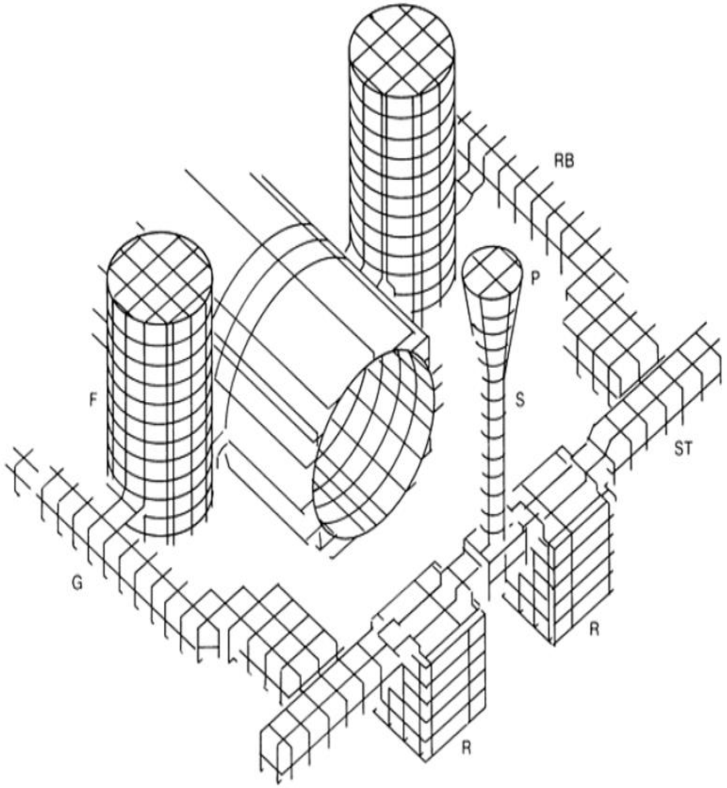
1. Special-Purpose Programs
2. Knowledge-Based Expert Systems
3. Finite Elements Software(FEM)



Type of Casting Software

In solving the basic governing equations, the simulator permits the use of the following boundary conditions:

1. Temperature specified
2. Heat flux specified
3. Radioactive heat transfer specified
4. Convection heat transfer specified



Type of Casting Software

Feature	**Ideal**	**ANSYS**	**MARC**	**MITAS-II**
Ease of setup and use	Easy	Difficult	Moderately difficult	Moderately difficult
Running cost	Low	High	High	Moderate
Ability to account directly for latent heat	Yes	No	Yes	Yes
Dedicated heat transfer code	Yes	No	No	Yes
Accuracy	Good	Very good	Very good	Very good
Pre- and postprocessing capabilities	Good	Good	Good	Poor

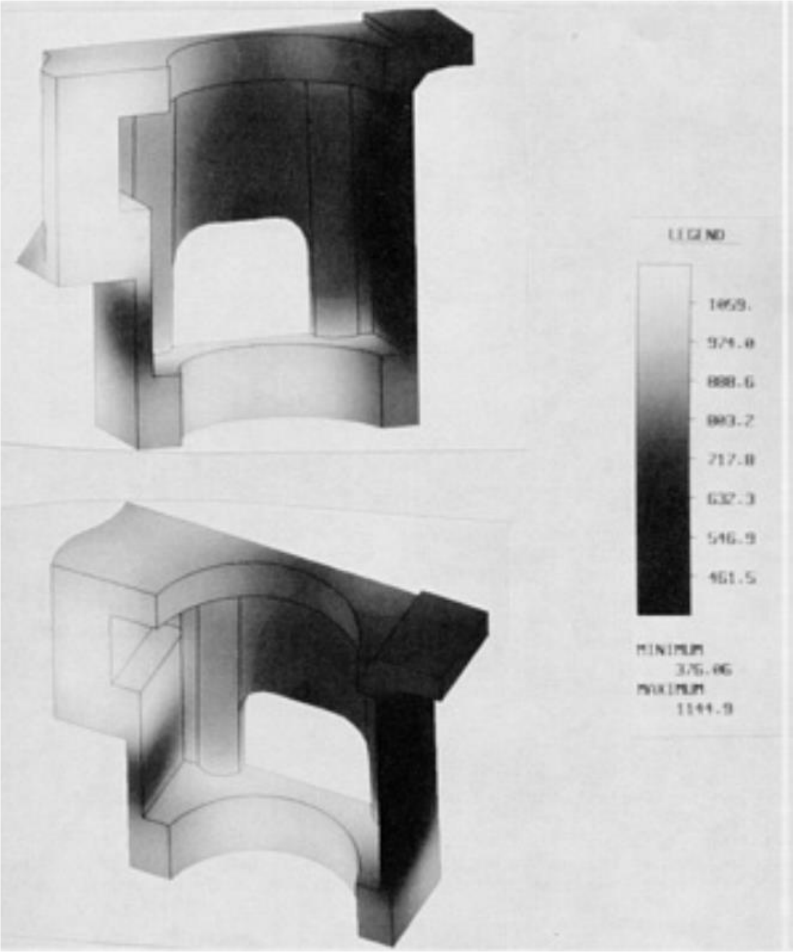
Type of Casting Software

Nonetheless, the reader should examine carefully publications describing these new and alternative computational approaches. Particular attention should be paid to the:

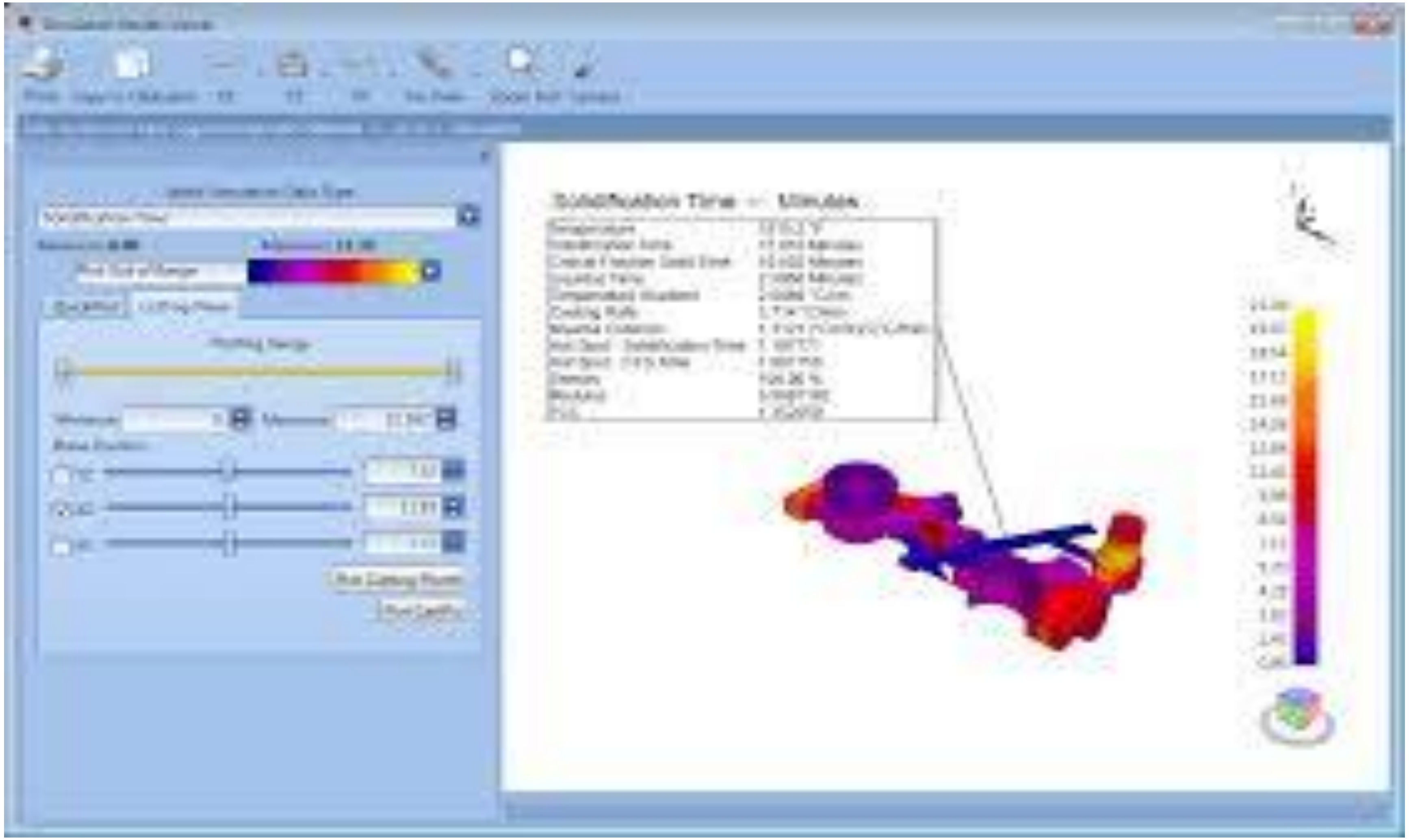
1. Ability to handle complexities of external shape
2. Ability to handle totally enclosed portions of the mold, such as coring
3. Speed of computation and type of computer on which the simulation is run
4. Linkages provided with pre- and post processing packages, in particular the existing commercially available geometric modeler based CAD systems

Type of Casting Software

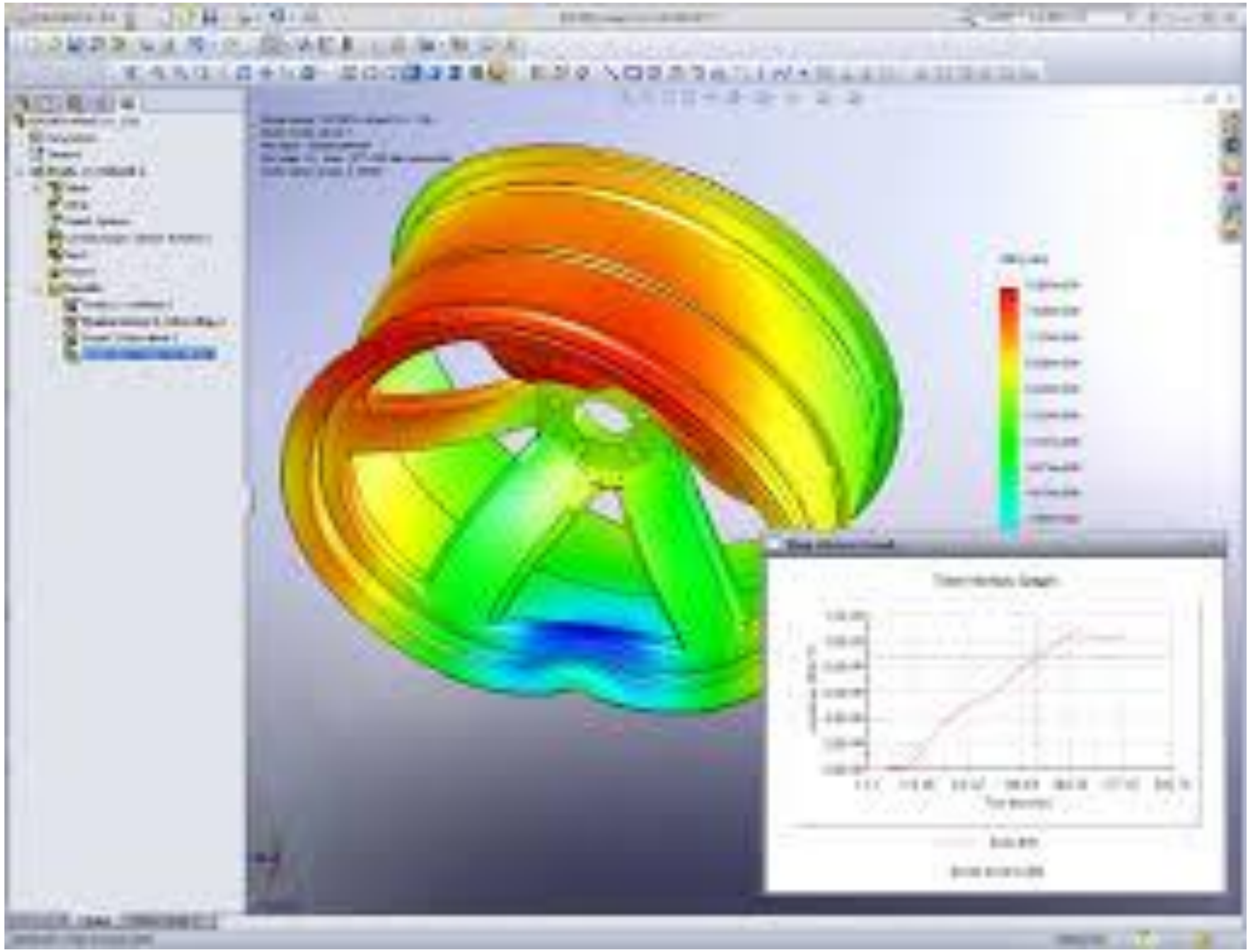
- All mathematical models of the solidification process should possess
  1. An accurate representation of geometry
  2. An adequate treatment for evolution of latent heat
  3. A sensitivity to the thermo-physical properties of the materials involved in this process



Computer Modeling of Casting Processes



Computer Modeling of Casting Processes



Computer Simulation

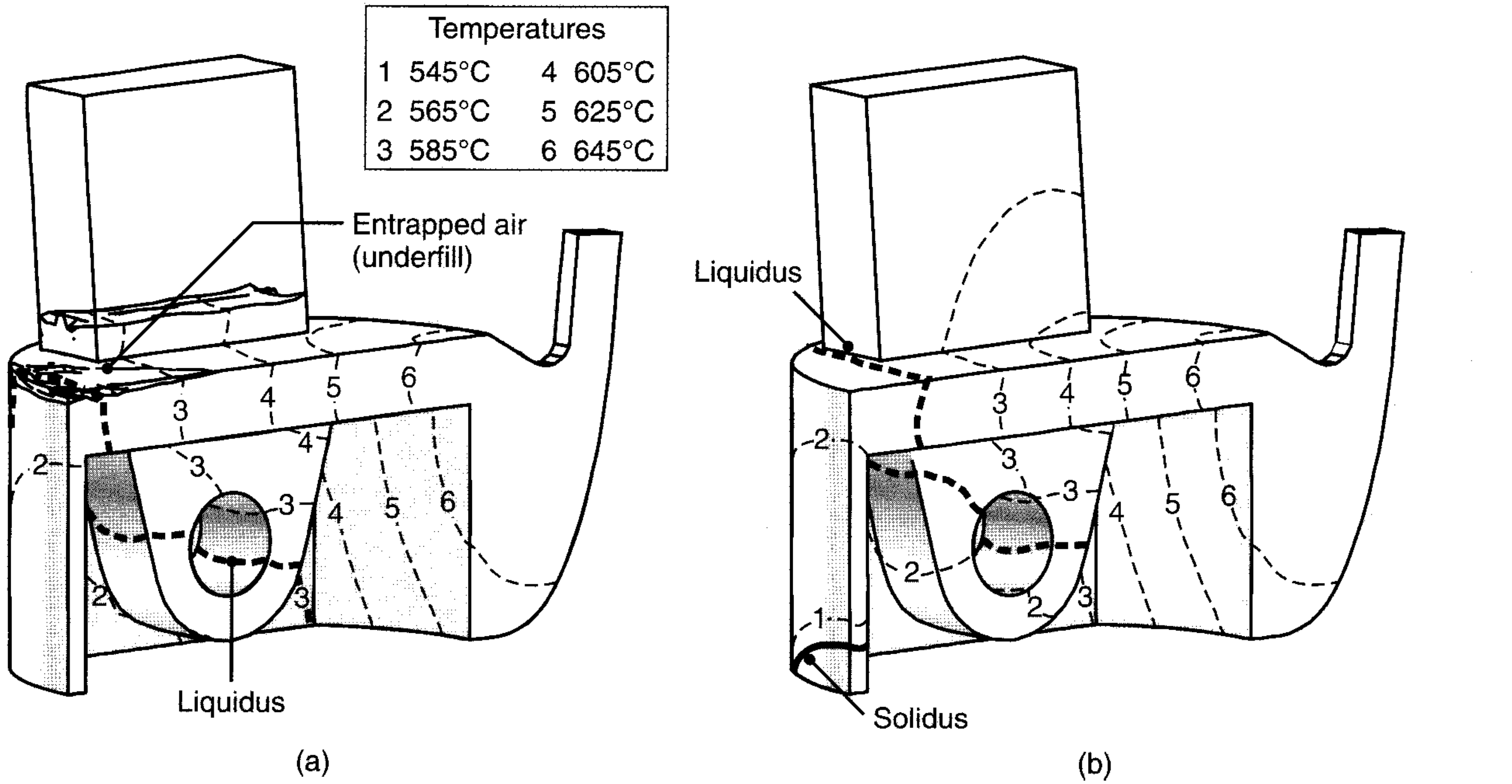


FIGURE 10.17 Simulation of mold filling and solidification. (a) 3.7 seconds after start of pour. Note that the mushy zone has been established before the mold is completely filled. (b) Using a vent in the mold for removal of entrapped air, 5 seconds after pouring. *Source*: After S. Paolucci.

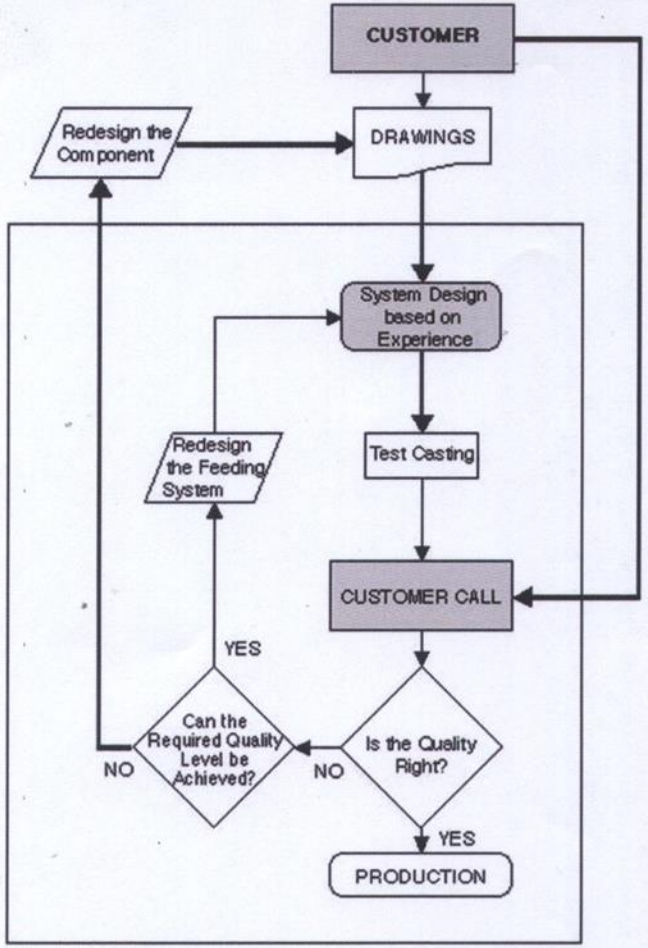


Fig. 1. Flowchart of a traditional procedure of designing component and casting system without the help of numerical simulation and 3D CAD-programs. Large box represents a foundry. Heavy lines indicate expensive operations.

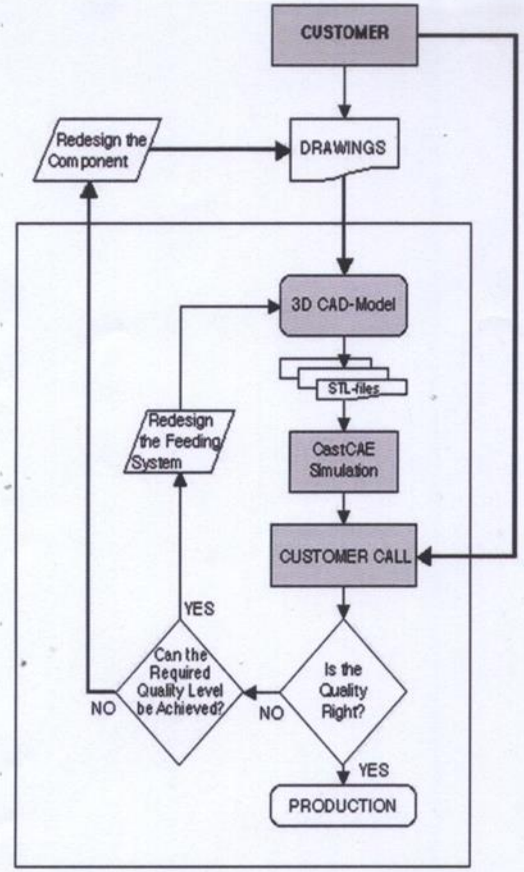
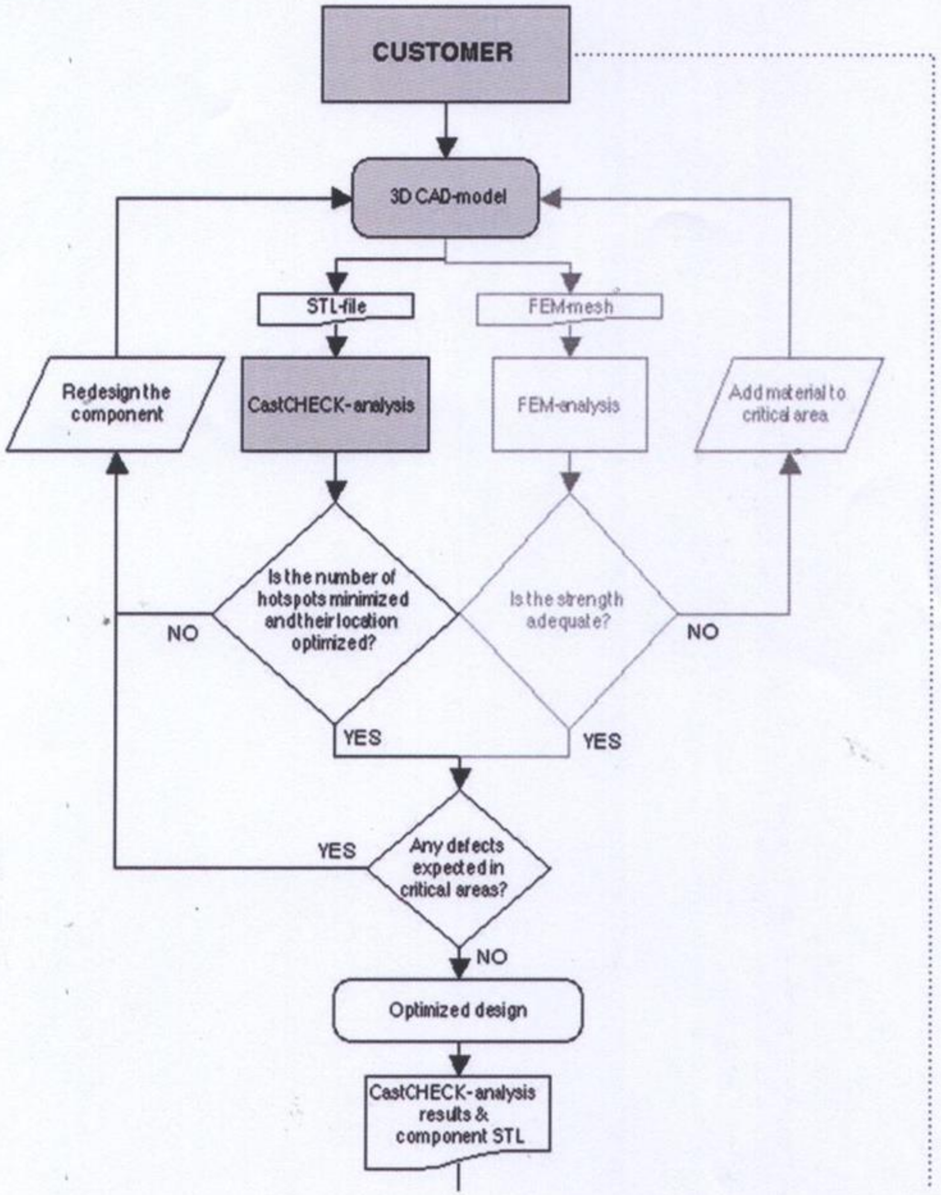


Fig. 2. Flowchart of a design process, in which 3D CAD and simulation are used by the foundry. In Finland this is the most typical situation today. In this procedure simulation results are used, when foundry and the machine shop engineers negotiate about construction and other design changes including the expenses of different design options. Large box represent a foundry. Heavy lines indicate expensive operations.


CUSTOMER
3D CAD-model
STL-file
FEM-mesh
Redesign the component
CastCHECK-analysis
FEM-analysis
Add material to critical area
Is the number of hotspots minimized and their location optimized?
NO
Is the strength adequate?
NO
YES
YES
YES
Any defects expected in critical areas?
NO
Optimized design
CastCHECK-analysis results & component STL

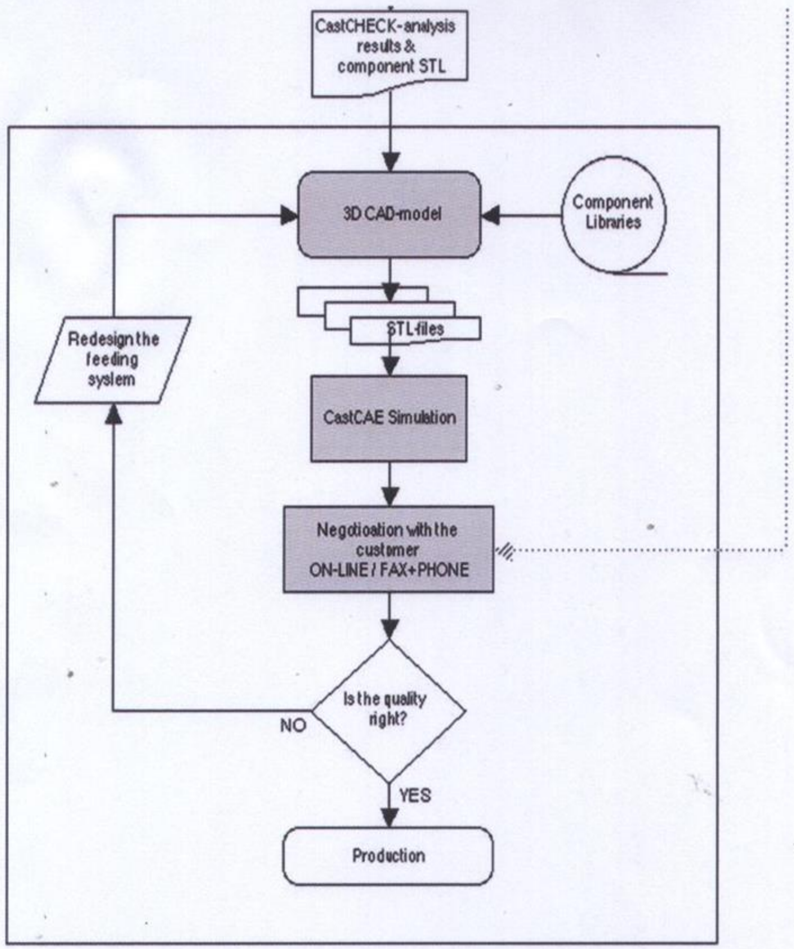


Fig. 3. Flowchart of a process, in which 3D CAD and simulation tools are utilised both by the machine shop and the foundry. This is the procedure which is expected to be reality in most cases of designing new castings in Finland by the end of this year. Large box represents a foundry. Dotted line indicates telephone call/ Internet connection.