L6 : DESIGN, METHODING AND TESTING OF CI CASTINGS

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PART - I METHODING

General Aspects :

Methoding of castings is a complex science. It involves the basic selection of :

(i) Design and construction of pattern equipment
(ii) Processes and practices for moulding, core making and core setting
(iii) Risering and gating system

Apart from the above technical parameters, due consideration should be given for economic factors while methoding the castings. The following points should be considered :

1. Type of moulding and core making process
2. Position of the casting in the mould box
3. Suitable joint line
4. Suitable mould box size
5. Type of mould and core making materials
6. Material specification
7. External and internal chills if permissible
8. Chaplets if permissible
9. Mould and core checking and setting gauges
10. Sequence of core setting

11. Provision of vents and flow offs.
12. Number of pieces to be produced
13. Type of material for pattern and core boxes
14. Pattern and core box details
15. Placement of identification codes
16. Indication of surfaces for marking and machining
17. Estimated yield percentage of the castings

While deciding the suitable method of manufacturing the intricacies of the concerned job should be analysed from all the angles and the final acceptable casting concept decided, considering the resources available within the foundry.

The details of the various information that are to be generally incorporated in the methods drawing would be as follows :

Stage-1 : Fixing the position of casting in the mould

The following questions may lead to a suitable solution for the above stage :

1. What is the component and its overall size ?
2. Sand thickness between the casting and the mould box ?
3. How much machining allowance required ?
4. Can the holes and slots be cored or can they be cast solid ?
5. What are the areas of thick concentrated masses those need feeding ?
6. What are the tolerances on the unmachined dimensions ?
7. Are there any objections for the use of internal chills and chaplets ?
8. What will be the most suitable mould and core making processes and materials ?
9. Are there any mechanical and physical difficulties in making moulds & cores ?

10. Are the cores stable or else could they be suitably modified ?

The final desired position of the castings in the mould satisfying all or the majority of the above questions may be considered for further critical scrutiny. Appendices A to D give various allowances and minimum wall thickness of cast metals.

Stage-2 : Selection of mould parting line

The following points should be considered while deciding the mould parting line :

1. What are the available sizes of the moulding boxes and the machines ?
2. What is the permissible pattern draw of the moulding machine ?
3. How much of the casting part in the drag and cope may be taken advantageously ?
4. Is there any additional core required for avoiding under cuts ?
5. Does this joint line assists in checking the mould, core setting and assembly to the maximum extent prior to its closing ?
6. Do we get adequate sand thickness around the mould cavity both from the stability and strength point of view ?
7. Is this joint line suitable to the moulding skills and practices available with the foundry ?
8. Does it assist the direct placement of risers required on the mould joint line ?

Stage-3 : Preparation of pattern making drawing

The final conclusion and requirements by satisfying stages 1 & 2 should be spelt out on the component drawing for the convenience of the pattern maker. This drawing gives all the possible working details for the pattern maker and normally covers the following aspects. This is referred as pattern making drawing and should incorporate the following details :

1. Necessary sectional views of the components with clear identification of the mould joint line.

2. Top and bottom parts of the pattern

3. Machining allowances provided on the surfaces required to be machined.

4. Pattern draft for easy withdrawal from the mould.

5. Provision of cores & core print tapers for setting and closing as per the standard practices of the foundry.

6. Indication of the ramming surfaces of the cores and the special features for the core boxes if required.

7. Suitable provision for chills and chaplet marks or prints.

8. Provision of necessary padding if required

9. Provision of general purpose ribs and straightening ribs

10. General contraction values for pattern and core boxes

11. Core checking and setting gauges as and when required

12. Provision of rubbing and joining fixers for important and split cores

13. Mounted or loose pattern supply

14. Provision of lifting and rapping tackles in the case of loose pattern

15. General notes for the pattern makers' guidance with respect to the identification letters, pattern and core box construction practices etc. Other essential details on pattern design and moulding are given in Appendices E to H.

Stage-4 : Selection of Risering system :

The basic function of riser is to supply feed metals to compensate the liquid and solidifying contractions those occur during solidification. When an alloy of solid solution type cools from the liquid state to room temperature, the following types of contraction take place.

1. Liquid contraction – as the pouring temperature drops to the liquidus temperature

2. Solidification contraction - as the casting solidifies completely.

3. Solid contraction - as the temperature cools from the solidus to the room temperature.

The first two types of contractions are compensated by feed metal from the riser, while the last type is taken care of by the pattern makers' shrinkage rule. The contraction allowance is different for different metals. Generally it is 2% for steel, 1% for gray iron and S.G. iron and 2.5% for high alloy steel.

There are various methods available for riser calculation viz.

1. Heuver's Inscribed circle method
2. Caine's method
3. Shape factor method (NRL)
4. Modulus method (Wlodawar)

I. Inscribed Circle Method

In this method the heavier sections in the casting are isolated and the largest possible diameters of circles are inscribed. The diameters are the measure of the mass concentrations in the casting and are known as hot spots.

A stepwise procedure of calculation is as follows :

1. The Sections of the castings which require riser are drawn to a convenient scale together with the machining allowance.

2. Diameter of the largest circle 'd' that can be inscribed in the section is then determined. This is usually termed as 'hot spot' diameter.

3. The diameter of the riser 'D' is obtained from the relation : D = fd where f is arbitrarily taken as 1.5 to 3 depending upon the section to be fed and partly experience with similar castings.

4. Riser height H = 1.5 D except in cases where exothermic compounds are added to the risers.

5. Number of risers are obtained from the relation that a riser can feed upto a distance of 2.5 times its diameter. A final adjustment in the riser diameter as determined in Step-3 may be required before finalising their number.

6. Riser is then joined to the hot spot by providing suitable padding to the casting section for promoting directional solidification.

7. Chills are used for hot spots where it is not convenient to provide riser.

2. Caine's Formula :

Chorinov's rule (solidification time in proportional to $(V/A)^2$) has been elaborated by Caine by introducing a factor called the relative freezing ratio (X). Relative volume ratio (Y = $\frac{\text{V riser}}{\text{A casting}}$ is plotted against

$$X = \frac{(A/V)\ \text{casting}}{(A/V)\ \text{riser}}$$

The curve obtained experimentally divides the area into two regions - sound and unsound. Any point in sound region can be used for riser design. This is laborius and so not popular.

3. Shape Factor Method (NRL method) :

In this method a shape factor was introduced to take care of the shape of the casting. It is defined as :

$$S = \frac{\text{Length + width}}{\text{Thickness}} = \frac{L + W}{T}$$

Volume ratio (Y) as diffined above is plotted against shape factor on X-axis. From this graph riser volume can be calculated in the same manner as Caine's method.

The above method lacks accuracy. However, computation in shape factor method is less tedious and quicker than Caine's method.

4. Modulus Method

Wlodawar has recommended a method of riser calculation in which the number of simple geometric shapes that can be accommodated in the casting is first determined. From this, the modulii (V/A) are calculated. The modulus of riser for each geometric shape is obtained from the relation

$$\frac{\text{Modulus of Casting}}{\text{Modulus of riser}} = \frac{1}{1.2} \quad M_R \quad = 1.2\ Mc$$

Consideraing h/d = 1 to1.5, dimension of riser can be determined.

A similar equation for the contact area of riser has also been given. Modulus method is a further simplification over the shape factor method, since a number of suitable graphs are available for modulus calculation. Foundries, which have computers will probably find it more useful to employ these graphs to computerise their riser calculation.

The riser should solidify after casting i.e. solidification time of riser t_R > t_C the solidification time of casting . In view of the above, the modulus of the riser must be about 1.2 times that of the casting. To obtain an absolute guarantee that the neck should not solidify before the casting, the neck modulus is taken as 1.1 times that of the casting. Hence the following relationship is commonly used :

M casting : M neck : M riser = 1:1.1:1.2

Use of Chills :

Metallic chills are used to produce thermal gradients by extracting heat. With the end chills, feeding distance for a plate and a bar casting can be increased by 2 inch and equal to the section thickness respectively.

It has been proved experimentally that for the chill to be fully effective, its thickness should be kept in the following proportions :

(a) Chill thickness for bar (Tc) = 1/2 section thickness to be chilled

(b) Chill thickness for plate (Tc) = Section thickness to be chilled

Chill should be equal to its thickness and the length should not exceed or 3 times the thickness. If the chills are too long, they should be cut to 2Tc length and should be spread 1/2 Tc apart.

Stage -5 : Selection of Gating System :

The purpose of gating system is to introduce liquid metal to fill the moulds cavity without creating any problem are defect in the mould, melt and final casting.

The gating system can be broadly divided into :

1. The entry section - consisting of the pouring basin, sprue and sprue base

2. The distribution section - consisting of the runner and ingots

The entry section has two functions :

1. To supply metal free of entrapped gases, slag and eroded sand

2. To establish a hydraulic pressure head which will force the metal through gating system into the mould cavity.Similarly the distribu tion section has five functions :

   a) To decrease the velocity of the metal stream
   b) To minimise turbulence both in the gating system as well as in the mould cavity
   c) To avoid mould and core erosion
   d) To ensure minimum drop in temperature of liquid metal in the gating system
   e) To regulate the rate of flow of metal into the mould cavity.

In addition to the above, the gating system should be simple to mould. Various types of gating systems are in practice depending upon size, complexity, weight and method of production of castings. They are top gates, bottom gates, horn gates, parting line gates, etc.

Design of gating system -

Stepwise calculation of the gating system are as follows :

(1) Calculate the optimum pouring time using empirical formula :

DIETERT has used an empirical formula as follows :

Pouring time (sec.) $t = k\sqrt{w}$

where k = const = 1.0 to 1.5 (smaller k value for large castings)

w = gross wt of the casting

(2) Calculate the choke area that controls flow rate usingfollowing formula :

Cross sectional area of the ingate = Ag = $\dfrac{W}{0.31\, vt\sqrt{h_{eff}}}$

Where W = weight of the casting including the weight of runner and risers (gross weight) in kg

v = flow coefficient (Table-1)

t = Pouring time (sec.)

heff = Effective ferro static pressure head during pouring

Table - 1 Flow co-efficient v for steel casting

Type of mould	Resistance of mould		
	High	Medium	Low
Green sand	0.25	0.32	0.42
Dry sand	0.30	0.38	0.50

The effective ferro static pressure head can be found out by the formula :

$$h_{eff} = H_o - \frac{P^2}{2C}$$

Where Ho = height of the metal column above the gate (cm)

P = height of the casting above the ingate level (cm)

C = Total height of the casting in as-cast position (cm)

(3) Fixing up of the desired gating ratio :

Gating ratios recommended by various theoreticians in the literature vary over a wide range. For steel castings a mildly pressurized gating system is used. In an un-pressurised gating system, the area of runners and gates are larger than that of the sprue; eg.

1 : 2 : 2 or 1 : 4 : 4

A mildly pressurized gating system of 1:2: 1.5 will minimise air aspiration in gating system and produce uniform metal flow.

(4) Based on the gating ratio select, the down sprue, runner and ingate sizes.

(5) Incorporate the following details in the gating system :-

(a) Take the runner bar in the top box and the ingate in the bottom half of the mould, wherever possible

(b) The runner bar should be extended beyond the last ingate at least by 2inches.

(c) If atmospheric side risers are to be provided, consider the possiblity of gating through risers.

The above aspects of risering and gating principles (as described in Part-I) will be further clarified from the sketches and worked out problems presented along with this text.

Risering in grey iron castings :

The risering of grey iron required special attention because of its solidification history. As per Iron-carbon diagram, solidification of a 3% carbon grey iron occurs in two steps :

(i) Liquidus to entectic temperature (1133°C) in which austenite dendrites separate from the liquid.

(ii) At the entectic tempeature where duplex precipitation of graphite and austenite takes place.

Since austenite is a denser phase than liquid iron, contraction takes place while cooling from the liquidus to the entectic tempeature and therefore feed metal is required from a riser during this interval. During the entectic solidification, however, expansion takes place, since the density of solid entectic structure (γ + graphite) is less than that of liquid phase. At the entectic tempeature, therefore, metal flows back from the casting to the riser. This process is known as purging. If in the grey iron casting, the riser is small, and has frozen at the top, due to purging great pressure will be developed in the casting and it will bbow outwards. Hence care should be taken to keep the riser open to atmosphere so that the pressure in the casting is easily retrieved without any distortion. Rice husk can be put in the riser top to protect radiation and keep the riser hot.

Gating in grey-iron castings

Fluidity is of great importance in the design of gating for grey iron castings. Fluidity of grey iron decreases with decreasing C&Si content and with lowering the pouring tempeature. Maximum fluidity can be obtained more readily oby raising the temperature of pouring rather than stressing very much on the composition factor. Pouring, therefore, should be done at high tempeature and with a fast rate through a cumber of ingotes. There is, however, an optimum pouring rate for grey iron castings. If the pouring velocity is higher than that recommended, the poured metal drags the slag into the mould cavity. High velocity pouring also causes mould erosion and gas entrapment. In low velocity pouring, the metal cools rapidly and may result in misrums. In grey iron casting, the gating ratio is usually of the order of 1:2:1, 1:2:0.5, 1:4:1. 2:7:1 etc. Slag and dirt traps are used in the gating of grey iron castings because of their great tendency for slag and direct formation. The common practice is to keep a full sprue-during the pouring period because full sprue helps to prevent slag from entering the mould. Strainer cores are often used at the sprue base for regulating the flow and maintaining the sprue full.

APPENDIX-E : DETAILD ANALYSIS OF FACTORS INFLUENCING PATTERN DESIGN

Sl. No. (1)	Particulars (2)	Details (3)	Influence on pattern design (4)
A. CASTING :			
(1)	Casting Design	Simple, complicated or highly complicated - intricate shape, heavy core work, nucleus of cores etc. decide moulding and core making materials	Parting line selection, moulding method, number of core boxes pattern material selection
(ii)	Casting size	Very small, small, medium or large or extra large decide moulding method and material	Generally for very small and small size castings metallic patterns are used. For medium and large size - wooden pattern used.
(iii)	Critical wall thickness	Extremely thin, thin, medium. heavy or extra heavy etc. decide moulding method and materials.	
(iv)	Casting material	Iron steel, alloy steel, copper alloy, aluminium alloys etc. and their shrinkage characteristics fludity and metallurgical characteristics decide moulding method. Parting line selection, gating & feeding should be done accordingly	

(1)	(2)	(3)	(4)
(v)	Casting application	**Very critical** - Aeronautics/nuclear/ thermal power applications **Critical** - Automobile precision machine tools **Non-critical** - general ordinary sewage covers	Pattern methoding gating & risering, accuracy & pattern construction material. Selection of which side to be at bottom or top etc.
(vi)	Criticality	Wall thickness & accuracy requirements, sectional variations, tendency towards distortion, cracking, tapers permissible or not	Selection of top and bottom of casting, use of cores, choice of draft, choice of pattern materials sturdiness of pattern etc.
(vii)	Casting - tolerances	Precision required, dimensional and wall thickness, tolerances permissible, machining allowances	To be incorporated in pattern equipment. Selection of pattern construction material and design
(viiii)	Foundry skills	Ability to work with the pattern equipment to produce quality castings and accepted practice in the foundry	To take into account skills available for moulding, core making, setting and closing while selecting pattern design & construction. Also follow acceptable practice. Select pattern design which reduced dependence on skills for quality & productivity
(ix)	Supervision	Quality of supervision available	Select pattern design which can work with least amount of supervision

APPENDIX-F : ANALYSIS OF EFFECTS OF FOUNDRY MECHANISATION AND PRODUCTIVITY TECHNIQUE ON PATTERN DESIGN AND CONSTRUCTION

Sl. No. (1)	Nature of mechanisation productivity technique (2)	Main features (3)	Effect on pattern design & construction (4)
1.	Hand moulding with single piece pattern	Moulding in floor or boxes, preparing the parting line, low productivity, totally dependent on moulding skills	Pattern design simple, no parting line, but number of loose pieces, core boxes are higher, loose pieces for gating and reserving to be provided. Wooden or metallic pattern equipment depending on quantity, size, complexity etc.
2.	Hand moulding with spilt pattern	Parting line preparation is avoided. Skill reduced. Higher productivity than hand moulding.	Pattern to be split at parting line, self core possible, number of loose pieces, core boxes reduced, loose pieces for gating and risering, wooden or metallic mould
3.	Loam moulding/sweep moulding	For sweepable patterns only. Considerable experience & skill required in moulding. Low productivity	Only sweeps are required No regular pattern. Only loose inserts required Gating and resering to be cut by hand, wood/steel plates
4.	Hand moulding	For contoured pattern only, parting line formed by moulding board. Higher productivity with hand moulding. Less dependence on skills.	Solid single piece pattern usable. Moulding board (or match board) to be provided). Gating & risering to be cut by moulder. Wooden or metallic pattern used.

(1)	(2)	(3)	(5)
5.	Machine moulding (pin, lift, turn over or roller)	Spilt patterns fixed on match plates. High production & productivity. Very little dependence on skills. Mass production possible. Reproducibility and consistency in dimension	Pattern split at parting line. As many patterns can be fitted on a pattern plate as space permits. Gating & risering also fixed up on plate. Loose pieces and core work to be suitably designed for mass production. Wooden metallic or araldite depending on quantity, design, dimensional accuracy and complexity
6.	Shell moulding	For superior surface finish & good dimensional tolerances. Very thin walled castings. High productivity	Gun metal, cast iron or steel pattern equipments with provision for heating, ejector, springs/pins, vents, shooting opening. Pattern design also depends on type of heating, heating energy (gas, electricity etc.) and also shell moulding machines, core shooter machine designs & shooting heads
7.	High pressure moulding	For precise and mass produced castings with high productivity and production	Metallic pattern equipment, cast iron, steel or alloy steel, heavy duty mounted on heavy pattern plates with integral gating and risering systems (involves tool room work)
8.	Investment casting	To produce casting shapes of high intricacy and without parting lines	Wooden or metallic pattern equipment for wax pattern & gating systems only. To incorporate contraction for wax& metal. High precision & finish required. Multiple cavity pattern equipment for wax. To incorporate ejection arrangement

APPENDIX-H : MOULDING AND CORE MAKING

(i)	Foundry Method	Hand moulding, floor moulding, sweep moulding, box moulding, machine moulding, pin lift, turnover, rollover, high pressure moulding, shell moulding; permanent mould - gravity die, pressure, die investment casting, gasifiable pattern (Polysterene etc.)	Pattern design to be chosen suiting the process adopted - parting line, core work strength, material for pattern and core boxes etc.
(ii)	Moulding material	Green sand, dry sand loam, silicate sand, nobake, shell sand, gravity dies, pressure dies etc.	Pattern & core box design to be chosen to suit the moulding & core making materials used regarding pattern materials, strength requirements, draft, machining allowances, wall thickness etc. also self cores or separate cores loose pieces etc.
(iii)	Mechanization	Moulding machinery - pinlift, turnover, rollover etc. Core shooters mould closing machines, shell moulding. Core shooters	Pattern/core box design to suit the machinery used regarding parting line, size of machines, self core, draft machining allowances etc.
(iv)	Accuracy of machinery and equipment	Quality of moulding machines, jolting, squeezing, pinlift/draw etc. Quality of moulding box bushes, pins & bushes, pattern pins & bushes mould box faces machined or not use of core setting jigs where necessary	This decides the casting tolerances/quality achievable. Accordingly pattern tolerances allowances/drafts have to be finalised.
(v)	Foundry productivity	Good & suitably designed pattern equipment most important for mould productivity	Pattern design to avoid all pattern productivity aimed at by the foundry pattern design, core work, pattern material, strength, life, wear and tear, pattern change on machines, number of patterns etc.
()vi)	Methoding	Gating and risering to be adopted; use of chills, pads, exothermic etc. pouring time to be achieved etc.	Pattern equipment design to suit the methoding adopted.
(vii)	Casting Defects	Expected defects in the castings to be overcome from pattern design itself.	Pattern design to avoid all pattern based casting depute such as mould breakage, sand crush sand fall, dimensional deviations etc.

APPENDIX-G : SUMMARY OF IMPORTANT PATTERN DESIGN CONSIDERATIONS

PATTERN DESIGN

- Choice of materials of combination parting line
- Design of pattern & core boxes
- Gating system
- precision, duplication,

Pattern life based factors

Number of casting
Number of pattern
Pattern storage
Pattern strength,

Casting Design based factors

- Complexity and core work
- Casting material
- Distribution tendency
- Critical wall thickness
- casting dimension
- Dimensional accuracy and tolerances & section thickness

Pattern material based factors

Materials used quality of materials

Casting quality based factors

Criticaly of application machining allowances, expected casting quality; vertical areas of casting

Precision based factors

Casting accuracy, machining allowances, dimensional consistency, accuracy of boxes, pins & bushes, moulding skills

Foundry method based factors

1. Moulding method
2. Moulding machinery
3. Moulding material
4. Gating & Risering
5. Parting line

Cost based factors

- Acceptable pattern cost
- Pattern storage cost
- Pattern repairs & maintenance

PART - II

A. CASTING DESIGN (General)

Objective : (1) To achieve desired internal soundness in casting
(2) To evaluate a design which will reduce moulding, cleaning and machining costs.

GENERAL DESIGN RULES

Rule-1 : Before issuing the final drawing consult a competent foundryman or pattern maker

Casting design poses two problems : One for the engineer, the other for the foundryman. The engineer must know "HOW TO DESIGN A CASTING SO THAT IT WILL ACTUALLY HAVE THE REQUISITE STRENGTH AND FUNCTIONAL PROPERTIES "

The foundryman must be able to ' MAKE THE CASTING SO THAT IT HAS THE STRENGTH AND FUNCTIONAL PROPERTIES THE ENGINEER INTENDED"

Rule-2 : Construct a small model or visualise the casting in the mould

A model to scale or full size in the form of pattern that can be used later will help the designers to see how cores must be designed and placed or omitted. It will help the foundryman to decide how to mould the casting, detect casting weakness (shrinkages & cracks), where to place gates and risers, and answer the questions affecting the casting soundness, cost and delivery.

Rule-3 : Design for casting soundness

Lack of metal soundness in a casting is one reason for lower than optimum mechanical properties. The foundryman by using a sufficient number of foundry techniques such as gating, risering, chills, padding and thermal gradients can usually produce soundness even in exceedingly difficult cases of poorly designed castings. However, if certain principles are observed the job of producing soundness and uniformly good properties can be made easier and less costly.

The most important criterion for soundness is the principle of Directional Solidification. Here solidification is controlled to proceed from the thinnest section, progressing through the heavier sections towards the riser. The common methods of applying this principle are :

Use of i) taper
ii) padding
iii) chills

Taper : Tapered design of a member of a casting is to increase the dimension progressively towards one or more suitable locations to make pattern withdrawal easy and also maintain the temperature gradient.

Padding : If a continuous taper is not possible, the designer employs metal padding to bridge the gap between the heavy section and another isolated heavy section. Padding would increase the cost of the casting. Further if pads are to be removed later from the casting, additional machining expenditure would be involved. So it is advisible not to use pad as far as possible unless it is inevitable.

Chills : Chills are metal objects placed at heavy section to induce faster solidification. They are incorporated into the mould or into a core by ramming sand around them during moulding or core making. Further in silica sand moulds, either chromite or zircon sand, possessing higher thermal conductivity may be used as a chill material.

Rule-4 : Avoid sharp angles and corners

Fillets have three functional performances :

a) to reduce stress concentration in the casting in service,

b) to eliminate cracks, tears and draws at re-entry angles

c) to make corners more mouldable and to eliminate hot spots

Rule-5 : Reduce number of adjoining sections

Rule-6 : Design for uniformity of section

Rule-7 : Proportion dimensions of inner walls :

Inner sections of castings, resulting from complex cores, cool much slower than outer sections and cause variations in strength properties. A good rule is to reduce inner sections to 9/10th of the thickness of the outer wall. Avoid rapid section changes and sharp angles wherever complex cores must be used, design for uniformity of section to avoid local heavy masses of metal.

Rule-8 : Avoid abrupt section changes - eliminate sharp corners at adjoining sections.

HOT SPOTS, JUNCTIONS, RIBS & BOSSES

A hot spot is a location in a casting where a heavy mass of metal is allowed to solidify compared to neighboring sections. This location will solidify slowly and may contain a shrinkage defect. There are several simple design rules to avoid this problem.

Inscribed circle (Heuver's circle) :

The presence of a hot spot can be easily identified by the method of inscribed circle. Considering a L shaped corner at the junction point the diameter D of a circle drawn will be the greatest of all the inscribed circles. Chvorinov's rule that the solidification time is proportional to the ratio of the volume square to the surface area, is applicable at that location. The increased mass of that junction is proportional to $(D/d)^2$. This ratio must be as small as possible to reduce the problem of hot spots.

L-junction : A sharp internal corner will cause a stress concentration. At the same time, a fillet with a large radius will lead to a bigger hot spot. The fillet radius should be carefully decided.

For steel castings, the general design rules for fillet radius are as follows :

i) for $T < 25$ mm, $r = T$

ii) for $25 < T < 75$ mm, $r = 25$ mm

iii) for $T > 75$ mm, $r + T/3$

These rules can be used for other castings as a general guide. An external corner can be rounded with a radius of 0.1 to 0.2 T.

T, Y and X junctions : In general X-junctions are difficult to cast sound and they also give rise to high stress concentration. They can be replaced by two T-junctions by an offset distance. Another method is to provide a cored hole at the X-junction.

Ribs : A rib can be used to improve the strength of a bracket so that equal section thickness can be provided in the casting. A rib should be as thin as possible but should not be too thin to act as a cooling fin.

It is to be noted that joining a rib to a plate section can be treated as a T-junction.

Bosses & Pads : They can be locations of shrinkage defects. They should be blended into the casting by tapering or flattening the fillets. Further, providing a cored hole at the boss may eliminate shrinkage problem. When there are lugs and bosses on one surface, they should be joined to facilitate machining.

Hot tears and cracks : Hot tears and cracks occur most often in locations of sharp changes in sectional thickness. Hot tears are produced at high temps when the metal is weak while cracks are usually formed at low temps when the ductility is rather low. The design rule is: it is made with a proper fillet or taper.

Rule-9 : Design ribs & brackets for maximum effectiveness :

Ribs have two functions: one to increase the stiffness and other to reduce weight. If they are too shallow in depth or too widely spaced they are ineffectual. Correct rib depth and spacing is a matter of engineering design. Ribs meeting at acute angles cause moulding difficulties, increase costs and aggravate the risk of defective castings. Instead of plus joints or X-joints a honey-comb design creates more uniform cooling conditions. These types of ribbing assures improved strength with minimum risk of distortion and structural weakness.

Rule-10 : Bosses, Lugs & Pads should not be used unless absolutely necessary

Bosses and pads increase metal thickness, create hot spot and cause open grain or draws. Blend into castings by tapering or flattening the fillets. Bosses should not be increased in the design when the surface to support bolts etc. may be obtained by milling or counter sinking. When there are several lugs and bosses on the surface, they should be joined to facilitate machining. If possible use uniform thickness instead of many pads of varying height simplifies machining.

Rule-11 : Design for moulding

The design should be such that moulds can be economically produced. Such features as irregular parting line, undercuts, outside bosses, use of cores & loose pieces all affect labour cost, casting quality and cleaning cost.

The most important consideration is the determination of parting line. Parting in one plane is preferable and simplifies moulding. By changing design to a single parting plane, production cost can be greatly reduced. It is desirable to have heavier sections located at or near the parting line where they are easier to feed by risers

Undercuts require loose pieces for moulding, and in most cases, the casting can be redesigned for avoiding this.

Outside bosses which are not on the parting line require coring or use of loose pieces. Therefore, pattern and moulding costs can be reduced by eliminating the outside bosses.

Efforts to reduce the number of cores greatly minimize moulding and production cost. In general, deep pockets on the surface of the casting increase moulding cost.

Cored versus drilled holes

It is however, important to consider provision of holes by employing cores instead of drilling holes later. In general holes of diameter greater than 15mm can be cored. A cost analysis should be made. Sometimes, instead of placing a core a depression can be provided on the casting surface to reduce the cost of drilling.

Design for core support

It is important that cores are supported well in the mould and have adequate strength. The thickness of the metal section surrounding the core and the length of the core, both affect the bending stresses induced in the core due to buoyancy (lifting) forces of the metal. Therefore, certain minimum core diameters are recommended for cylindrical sections. For instance, consider a hollow cylinder of length in the range of 150-200mm. The minimum core diameter suggested is about 100mm with the metal wall thickness in the range of 100 to 300 mm.

The use of chaptlets for core support should be avoided as far as possible. Chaplets often fail to fuse completely with the casting and result in porous defective areas.

Rule-12 : Design for Cleaning :

The cost of removing cores from casting may be extremely high for certain inaccessible areas. Cast-weld construction can be done to eliminate the core and to avoid cleaning the cavity.

The casting design should provide for openings sufficiently, which permits ready access for the removal of sand core. There should be proper access to clean the internal surface by shot blasting and grinding. The removal of core rods should be easy, otherwise the cleaning cost will go up and casting also may be damaged.

Rule-13 : Design for machining :

When a casting is to be machined to a close tolerance, it is desirable to do as much machining as possible without removing the piece from the machine. For this a chucking extension is suggested. Castings with tapered sides are difficult to hold in a lathe. Pads or flats can be provided. For irregular shapes, lugs can be provided in the casting to facilitate easy clamping on the machine table. Hooks or lugs are provided in the design for easy lifting and transporting of the casting.

Rule-14 : Wave construction

This design principle is meant for relieving internal stress and for avoiding formation of cracks. It requires the use of curved members which are slightly waved or curved. A typical example is the use of curved spokes in wheels.

Generally an odd number of spokes is preferred instead of an even number of spokes. The flange section and hub cool at different times and cause a pulling or tearing action on the spoke due to contraction stresses. Consequently an even number of spokes will result in tensile pulling of opposite spokes. This is avoided by having an odd number of spokes.

Rule-15 : Design for elasticity & avoiding cracks

The shrinkage in the castings can vary considerably from one part of the casting to another. These shrinkage variations give rise to internal stresses which show themselves as soon as solidification takes place, the metal then having little strength. They can be the cause of cracks and even fractures, if the profile involved cannot withstand a certain amount of deformation.

Rule-16 : Redesigning

Either fabrication, forging or cast iron component can be redesigned as a steel casting. The benefit of redesign is for improved integrity, reduced cost, greater strength and improved production rate or service life.

Design Stages

For the development of a newly designed casting, the steps are :

1. Make sketches of the casting
2. Determine the forces upon the casting. In some cases this may be difficult.
3. Calculate, if possible the metal sections needed to operate under these forces
4. Fabricate a wood or clay model

5. Make a pattern layout

6. Make the pattern equipments, (temporarily)

7. Make a trial casting (if necessary radiograph for shrinkage defects and correct the design)

8. Perform a brittle coating test for stress analysis, the casting should first be machined as it will be in service

9. Locate areas of high stresses

10. Measure the higher stress with wire strain gauges

11. Remove metal to eliminate or reduce higher stresses. By causing high stress to spread over a large area, these stresses are reduced.

12. Redistribute metal to eliminate or reduce higher stesses

13. Make another trial casting with modified design now.

14. Thoroughly test and make additional changes, if necessary

15. Release for production

16. Make production type pattern equipment. While preparing the drawing of casting, the foundry engineers may provide the following information

    * parting line
    * gate & riser locations
    * draft
    * machining allowances
    * casting tolerances
    * Cores
    * locating points to be used in initial machining.

II-B : CASTING DESIGN OF GREY (FLAKE GRAPHITE) IRON

1. The moulding methods, the casting properties and the casting design as regards to flake graphite iron are inter related. A judicial selection can optimise the casting design. A flake graphite iron poses little problem with regard to foundry defects of the mechanical properties obtained therein actual practice. Care is required to make best use of what is feasible.

2. Flake graphite can have narrow freezing range and form an eutectic at selected compositions. This inherently decreases the tendency to form casting defects like shrinkage and porosity.

3. Graphite expands on solidification and accordingly when the flake graphite iron solidifies, the need for external feeding is greatly reduced.

4. Fluidity of cast iron is much higher compared to various other materials, and hence complicated shapes can be cast with ease.

5. The general rules to avoid the ill effect of hot spot are equally applicable to cast iron.

6. Various moulding processes can be employed for producing flake graphite irons. Sand moulding is one of the most conventional moulding processes employed for producing flake graphite iron. For closer dimensional tolerances of very intricate shapes, shell moulding is adopted. For improved pressure tightness application, flake graphite iron are produced by gravity die casting. High pressure moulding are also adopted for flake graphite iron. Particularly cylinder blocks for automotive vehicles are moulded by this process. The economic feasibility for choosing a particular moulding process for flake graphite iron depends

on the quantum, the minimum section thickness to be cast and the engineering properties those are required. They have to be tackled separately. As a case study, simple shapes like cast iron pulleys can be sand moulded using machine moulding. The quantum here can justify split patterns to machine moulding. The cylinder liner which is a hollow cylinder in shape on the other hand is an example for a centrifugal cast iron. This is so because the cylinder liner is thoroughly machined from all sides. The major criteria here is productivity and high yield. A different machine tool casting like the column for a vertical milling machine is invariably hand moulded. Assembly of cores leads to production of such casting. A scooter cylinder block on the other hand involves casting of thin fins and complex geometry and accordingly a shell moulding can be most optimal process to achieve such intricate castings.

7. Centre line shrinkage is a phenomenon observed when lateral solidification is greater than longitudinal solidification. It not only depends on a casting design but also on the alloy. Flake graphite iron poses relatively lesser problems with regard to centre line shrinkage. When the carbon equivalent is lower, then there is a tendency for more problem than when it is higher. As the composition tends towards more and more eutectic, the tendency to exhibit centre line shrinkage decreases.

8. The pattern materials and gating designs vary according to the type of moulding or casting method.

Pattern can be one piece pattern, split pattern, match plate pattern, multiple pattern, skeleton pattern, sweep pattern.

The pattern material can be wood, metal, epoxy resin or polystyrene."

9. The dimensional tolerance for sand casting and gravity casting for different casting dimensions can be as follows :

Moulding method	Casting dimension (mm)		
	50	100	300
Sand moulding (best pattern)	±1.6	±2.9	±3.5
Gravity casting (die)	±0.5	±0.7	±1.2

10. There are various allowances that are to be given to the patterns. These are draft, shrinkage allowance, distortion allowance, machine finish allowance, rapping allowance. The draft is given to facilitate easy removal of the pattern when it is given on vertical surface. Normally 3° to 1/2° - 3° for hand moulding or shell moulding. For hollow surface, inner taper has to be reversed. No definite allowance rule is available. It is usually based on observation and experience. Machining allowance is provided for removing the surface irregularity. Normally for flake graphite iron 1/8th inch is considered as an optimal machine finish allowance. Rapping allowance is given to facilitate removal of pattern with easy withdrawal.

11. Hot tearing is a phenomenon influenced by casting design. If a crack comes above the solidus, it is known as 'hot tear'. In such cases, the crack exhibits side branches. If the crack is below the solidus, it is due to internal stress and does not exhibit side branches.

Flake graphite irons are rarely susceptible for hot tears. In fact, as the carbon equivalent is higher, they are not at all susceptible to hot tears.

12. Flake graphite iron is a section sensitive material. Mechanical properties are largely decided by the cooling rate in addition to the chemical composition. The larger cooling rate, the material of identical chemical composition can give higher hardness and strength. Above a particular value of cooling rate the grey cast iron can solidify mottled or at times white. This tendency is referred, as chilling and there is a limitation to minimum section thickness to which a flake graphite iron can be cast without producing chilling. Normally 6mm thickness and above is suggested for flake graphite cast iron. The higher the section thickness is, the higher will be the coarse graphite and more of ferrite in the matrix. This can lead to deteriorating strength levels. For instance, a flake graphite iron casting having 6mm section at one location and 50mm section at another location can recordsignificantly different properties.

13. The tensile strength is assessed on separately cast test bars produced alongwith every batch of castings. At times, specific locations in the casting can be turned out into miniature test pieces which are tested in a tensometer to assess the tensile strength of the casting. The latter method is very reliable as the actual casting can be tested rather than depending on separately cast test bars.

14. The microstructure studied involve assessing the type of graphite flakes, size of graphite and the matrix. There are in all five different types of graphite flakes viz: (1) uniform distribution and random orientation, (ii) rosette grouping (iii) super imposed flake size and random orientation (iv) interdendritic segregation and random orientation, (v) Interdendritic segregation and preferred orientation. These are also known as type A, B, C, D and E graphites respectively.

There are eight different sizes of graphite flakes. An uniform distribution random orientation and finer flake size with a fully pearlitic matrix can give extremely higher strength levels. Higher the number of eutectic cell count, the finer the eutectic cell size and the higher is the strength of flake graphite iron.

15. The surface finish of flake graphite iron casting depends upon the method of casting. A sand cast surface finish is very rough as compared to the shell cast surface finish. A die cast surface finish is the smoothest. Invariably , flake graphite castings are used after machining and hence the surface finish plays a lesser role.

COMPUTER AIDED DESIGN (CAD) PRINCIPLES IN METAL CASTING

Computers are most useful in processes or areas which involve a large nuclear of parameters and/or complex mathematical models and relationships.

Computer aided design is a technique in which man and machine are blended into a problem-solving team, animating coupling the best characteristics of each so that this team works better than either above. Generally, the drive for nano technology is economics and CAD allows an engineering designer to make more decisions per unit time. In fact engineering design is a planning and decision making in order to produce information to ensure correct manufacture or construction. The goal in many engineering design process is always a component, system or technique which will perform the required functions according to the desired specifications and levels of performance with optimum cost in terms of input of effort in running, maintaining, manufacturing, installing etc. Engineering design, therefore, is a highly complicated affair calling for a considerable level of ingenuity which has to be supplemented by a comprehensive knowledge base.

What CAD involves

Fundamental to all design processes are the system concept and "simulation". Simulation may be defined as the duplication of the essence of the system or activity without actually attaining reality itself. Thus the system approach is to develop a manipulative model which will appear to have the same behavioural characteristic as the real system. This is specially relevant to CAD.

In mechanical design by computer, CAD involves the creation of mathematical description of parts or shapes in 3-dimensional space within a computer data base. This mathematical description is used to simulate the mechanical system and to check the various material properties and design criteria of the component. Techniques like mesh generation are used in geometric modelling. Boundary representation, surface generation, sweeping and other constructive solid geometry aspects are occurred in this. Computer graphics can greatly aid drafting and visual picturisation of the final part. 3-D views of the final component provides a clearer view of his objective to the designer. The designer sits at the interactive terminal and design the component from start to the end. The most common design process employed is known as the interactive design process. In this a preliminary design developed leased on experience or a set is then subjected to analysis with respect to certain constraints and suitable modifications made to give a revised design. This is done interactively till a design is produced that satisfied all the given constrains. In the ultimate stage that is envisaged for CAD, the computer is linked directly to the production (such as NC machine, robots etc.) so that the components is manufactured by remove control according to the specification laid out by the designer at his terminal.

Application of CAD metal casting design

The areas within metal casting that are a murable to the use of computer aided design can be identified as follows :

1. Production design
2. Study of moulding techniques
3. Casting design involving feeders, risers, gating system, chilling, practices etc.
4. Process design involving gravity die casting, squeeze casting, continuous casting etc.

Application of CAD in metal casting .. to lead to large savings in terms of effort and material by decreasing the effort required in selecting and implementing suitable processes. For example, considerable amount of trial and error involving costly machine operations to sink the dies can be avoided if CAD techniques are utilised.

The solidification, feeding and other casting behaviour should be such understood if quality castings are to be produced. Research is essential to eliminate costly trial and error methods particularly in gravity die casting foundries.

The principal use of CAD in casting process is in the evaluation of the soundness of the casting. The soundness of casting is determined by the solidification sequence, feeding and mould erosion. The soundness is evaluated by the use of... simulation. These can be used to predict the presence of shrinkage, below holes, hot spots, hat tearing, surface cracks, internal cracks, microstructural segregations etc. all of which are manifestations of unsoundness in a casting. Based on these predictions, suitable modification can be made at the design stage itself to produce a design that will lead to the manufacture of a sound casting. Such modifications may take the form of modifications in the geometry of casting, the riser, the location of the gates, chilling practice etc. The physical processes which can be simulated to evaluate the soundness of a casting are as follows :

* Heat transfer in the casting
* Fluid flow in the casting
* Thermal stresses developed in the casting
* Microstructural developments in the casting

The simulation of the solidification process in the casting from the heat transfer approach involves calculation of the internal temp. distribution in the casting. Some of the parameters that would be involved in the simulation are super heat of the metal, heat transfer co-efficient at the mould metal interface, temperature dependent thermal properties of the mould and metal, mould temperature, latent heat of solidification etc. Simulation is done by the use of numerical methods like FDM & FEM. Such simulations can be used to predict the presence of the shrinkage defects, to determine the effects of chilling practices etc.

Simulation of fluid flaw in castings takes into account the complex relationships between the fluidity, the flow characteristics in the gating system, pouring time etc. These relationships can be integrated into a set of equations which can be applied by the use of CAD to design an efficient gating system for the casting, the simulations can also be used to design an efficient risering system.

The finite element technique can be effectively employed to assess the thermal stresses in a casting. Simulations so carried out can be used to analyse the effect of size and distribution of porosity in casting etc. Simulation can also be used to predict the microstructure of a casting. This will provide the information about soundness of the casting from the point of view of segregation, impurities etc. And suitable metallurgical modifications can be arrived at to give a sound casting.

APPENDIX A : Contraction allowance

Metal CAst	Contraction allowance
Grey cast iron	1.0
Meehanite and other high duty iron	0.8 to 1.3
S.G. iron	0.8 to 1.3
Blackheart Melleable	0.7
White heart Malleable	1.6
Cast steel	2.0

APPENDIX B : Taper On pattern

Height (mm)		Inclination
Upto	10	3°
	11-20	2°
	21-35	1°
	36 - 65	0°-45°
	66-150	0°-30°
	151-250	1.5mm
	251-400	2.5mm
	401-600	3.5mm
	601-800	4.5mm
	801-1000	5.5mm

APPENDIX C : A guide to machine finish allowance

Casting diameter		Circular shapes Machine allowance on the outside Radius of Rings (spoked shells, spoked gears, circular shaped casting)	
(in)	(mm)	(in)	(mm)
upto 18	upto 457	1/4	6
18 to 36	457 to 914	5/16	8
36 to 48	914 to 1219	3/8	10
48 to 72	1219 to 1829	1/2	13
72 to 108	1829 to 2743	5/8	16
108 and up	2743 and up	3/4	19

Bores

Bore diameter		Machine allowance on bore radius	
(in)	(mm)	(in)	(mm)
upto 1.5	upto 38	upto 3/16 on cast iron	upto 5 on cast solid
1.5 to 7	38 to 178	3/16 to 1/4	5 to 6
7 to 12	178 to 305	1/4 to 3/8	6 to 10
12 to 20	305 to 506	3/8 to 1/2	10 to 13

Bores

Greater dimension (in)	Greater dimension (mm)	Machine allowance (in)	Machine allowance (mm)
upto 12	upto 305	upto 3/16 on cast iron	upto 5 on cast solid
12 to 24	305 to 610	3/16	5
24 to 48	610 to 1220	1/4	6
48 to 96	1220 to 2438	3/8	10
98 and up	2438 and up	1/2	13

Recommended minimum wall thickness of cast metals

			Wall thickness
Sand Casting :	Grey iron	.....	3 - 6
	Malleable iron	....	3
	Steel	....	5 - 13
	Cu-alloy	....	2.5
	Al-alloy	....	3 - 5
	Mg-alloy	....	4
Permanent mould:	Gray iron	....	5
	Al-alloy	....	3

PART - III

A. TESTING OF CASTINGS (General)

1. Objectives

- o To determine the quality of a material before, during or after the casting is over.
- o To determine the mechanical properties such as strength, hardness, ductility etc. after processing
- o To check for flaws within a finished casting
- o To assess the likely performance of the material in a particular service condition.

2. Testing of castings can be divided into 2 groups (1) Destructive Testing(DT), and (2) Non-destructive Testing(NDT).

Destructive Testing(DT)

Hardness
Tensile, Compressive shear
Torsion
Impact, Fatigue & Creep
In all these tests the sample materials are physically damaged or broken. These tests helps in selection of mechanical properties and indirectly assess the defects to facilitate arriving at quality standard specified by the buyer/ standards organisations-Indian or International.

Non-destructive TEsting(NDT)

Liquid penetrant Testing(LPT)
Magnetic electrical or eddy current Testing. ultrasonic, Sonic, Radio-graphic etc.
In these tests the sample material is not destroyed neither physically nor property-wise, hence the name NDT. These steps helps in detection of flaws of defects within a processed or finished casting/component/

Advantages and limitations of DT & NDT

Any single test may not serve the purpose. Sometime a number of tests are to be conducted simultaneously on a single component to arrive at conclusions to decide the property requirements from the point under design. Then any of the test methods are to be selected to meet the requirements.

Advantages of DT	***Advantages of NDT***
Can be often directly and reliably measure response to service conditions	Can be done on production items without any damage on parts.
Measurements are quantitative and readily usable for design or standardization	Tests conducted on individual specimens no necessity of waiting for calculation of results.
Interpretation of results by a skilled technical is not required	Can be done 100% of production or on representative samples
Correlation between test results and service behaviour is usually direct, leaving little margin for disagreement among observers	Can be used when variability in DT is wide and unpreditable. Different tests can be applied to the same sample sequentially. The tests can be repeated on parts in service Cumulate effect of service usage can be measured directly. Test may reveal failure mechanism also. Equipment is portable for use in field.

Limitations of DT

Can be applied only to a sample representing the population

Tested parts cannot be placed in service.

Repeated tests of same item are often an impossibility and different tests need different sizes and shapes of samples

Extensive testing is not justified and may be prohibited with high cast of material or fabrication

Cumulate effects can be measured for different lengths of time.

Difficult to apply to parts in service and terminates the useful life after testing

Extensive machining or other preparation of test specimens is often required.

Capital investment and manpower costs are often high.

Limitation of NDT

Results often must be interpreted by a skilled and experienced Technician.

In absence of proven correlation different observers may disagree on meaning and significance of test results

Properties are measured indirectly and often only qualitative and comparative measurements can be made

Some NDT (e.g. X-ray) require large capital investments

B. PROCESS CONTROL TESTS

Melt and quality tests

The most common methods of testing in process used in foundries today include

- Temperature
- Thermal analysis
- Chill
- Fluidity
- Chemical analysis
- Gas testing

To what extent any of these techniques are used depends upon a variety of factors viz.

- Charge materials
- Nature of final casting
- Moulding Method
- Type of metal
- and a host of other conditions like other testing methods

Strict documentation should accompany any inprocess testing to allow for pin-pointing the cause of casting defects and preventing from further occurrences.

C. NON-DESTRUCTIVE TESTING FOR CAST IRON CASTINGS

Depending on degree of integrity required, the factors to be look into for castings are :

- Surface quality
- Internal discontinuities
- Casting imperfections