

Guidelines for Producing Good Quality S.G. Iron

**Compiled By
N. Ramamurthi**



46/A GIDC, Phase-1, Near Kiran Bus Stop, Vatva, AHMEDABAD – 382 445.
Phone: +91-79-2583 0222, 2583 1594 Fax: +91-79-2583 1594
E-mail: info@kastwel.com Web: <http://www.kastwel.com>

Guidelines for Producing Good Quality S.G. Iron

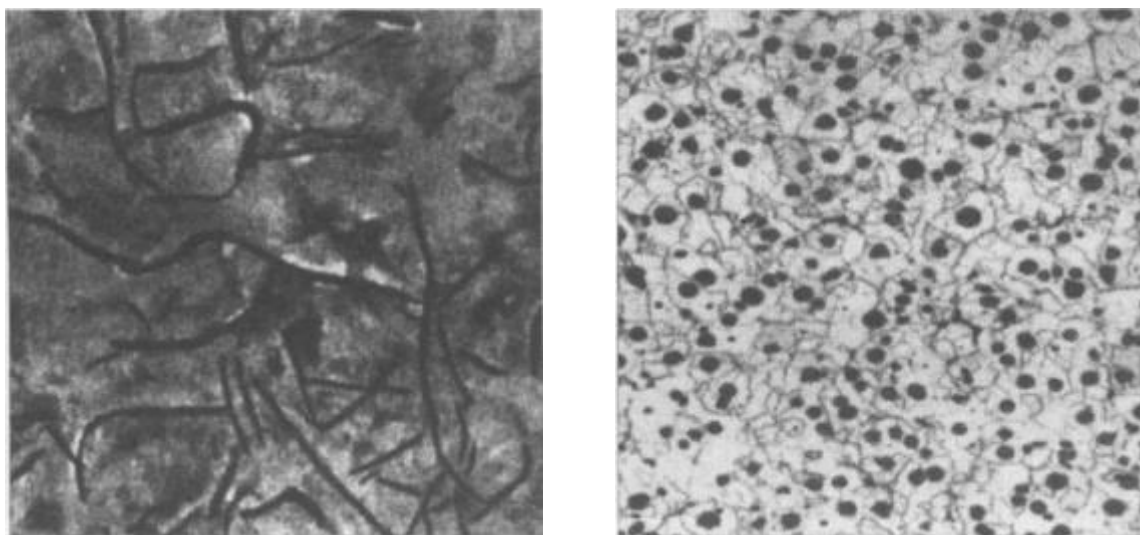
Table of Contents

1.	About S.G. Iron	2
2.	Chemical Composition	4
3.	Melting	7
4.	Magnesium Treatment	9
5.	Inoculation	14
6.	Quality Control	17
7.	Microstructure Evaluation	19
8.	Defect Analysis and Prevention	24

1 ABOUT S.G. IRON

Most of us are familiar with "gray cast iron". They are Iron-Carbon-Silicon alloys with more than 2.5% carbon. Carbon in excess of 0.8% is present as finely dispersed graphite shapes (flakes). The flakes act as stress raisers and help in "crack propagation". Hence, gray cast irons are weak, (the max. tensile strength being about 350 MPa i.e. 50,000 psi) and have no ductility.

In S.G. Iron, suitable treatment of the molten metal causes the graphite to precipitate 'as spheroids', and not as flakes. The spherical shape of graphite helps in "arresting crack". This results in an iron with high tensile strength and good ductility.

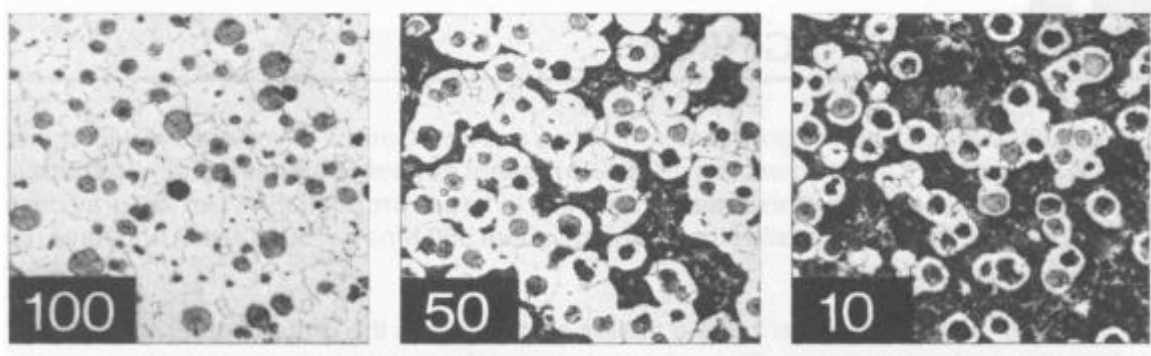


Micro photograph of cast iron and S.G. Iron

Majority of S.G. Iron is produced in as-cast condition without the need for heat-treatment, in the following three groupings:

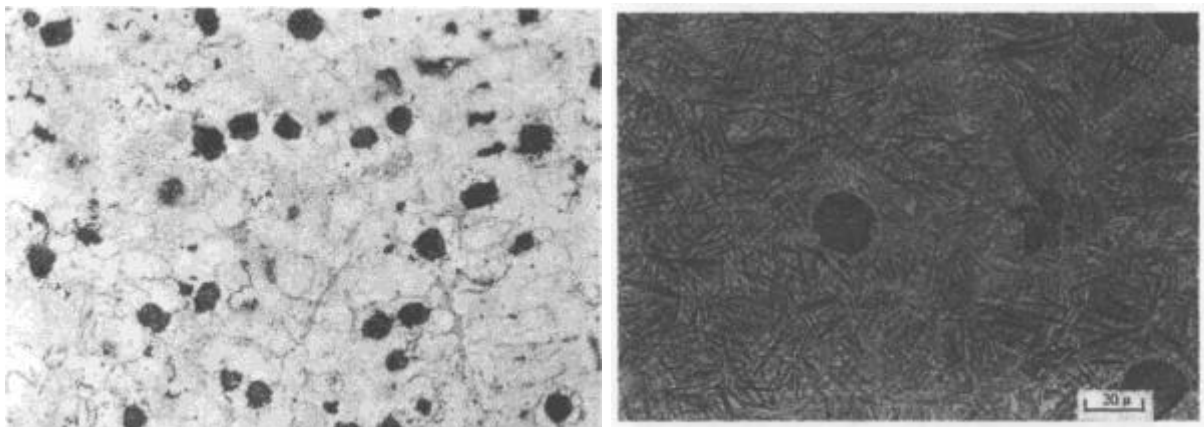
- (a) **Ferritic S.G. Iron:** (Grades {GGG} 450/10, 400/15, 400/18 or 350/22)*
Graphite spheroids in a matrix of ferrite, which is almost pure iron. High impact resistance, good machinability and fairly good corrosion resistance, moderate strength.
- (b) **Ferritic – Pearlitic S.G. Iron** (Grades 500/7)*
Graphite spheroids in a mixed matrix of ferrite and pearlite. Good machinability, easy to produce. Properties between those of ferritic and pearlitic grades.
- (c) **Pearlitic S.G. Iron:** (Grades 600/3 or 700/2)*
Graphite spheroids in a matrix of pearlite, which is a fine mixture of ferrite and cementite. High strength and wear resistance. Fairly good machinability. Moderate impact resistance.

* (Indian Standard for S.G. Iron Castings: IS-1865:1991)



Micro photographs of the three broad types of S.G. Iron

There are other special types of S.G. Irons Austenitic S.G. Iron and Austempered Ductile Iron (ADI). The first one is used for corrosion resistant applications and the second, a recent development, for high strength application.



Micro photographs of Austenitic S.G. Iron and Austempered Ductile Iron

Since its invention a little over 60 years back, use of S.G. Iron (also known as Ductile Iron or Nodular Iron) has been growing steadily over the years. The current global demand is estimated at about 20 million MT annually. The current level of production in India is only about 400,000 MT / year (i.e. merely around 2% of global production). Progressive design engineers during the 50 years have changed over to S.G. Iron castings from steel, malleable iron castings and even from steel forgings and fabricated assemblies due to one or more of the following advantages:

- **Improved "Strength: Weight" ratio**
- **More strength per unit cost**
- **Reduced component weight**
- **Good dimensional accuracy**
- **Good machinability**

Worldwide, nearly 40% of S.G. Iron production is for water pipes, about 30% for automotive castings and the balance for general engineering castings.

2 CHEMICAL COMPOSITION

The properties of Gray Iron are dependent mainly on the type and size of graphite flakes. In S.G.Iron, however, the mechanical properties are not dependent so much on the size of the spheroids or on nodule count as on the matrix structure.

The carbon and silicon levels of low strength S.G.Iron (Ferritic) and of the high strength S.G.Iron (Pearlitic) are almost the same.

Table (1) gives the recommended chemical composition for S.G.Iron sand castings. As can be seen Carbon, Silicon and C.E are dependent on Section Thickness (Modulus).

The chemical composition must be such that:

- Carbide free structure is obtained as-cast.
- The shape and distribution of graphite must be satisfactory (min. 85% nodularity).
- Desired matrix structure must be obtained.

(A) Role of Major Elements:

Carbon:

- High carbon will mean higher graphite fraction in the iron.
- Less shrinkage
- Possible Carbon Floatation or Exploded Graphite.
- Lower Fluidity and hence, more Dross

Silicon:

- Lower strength, particularly, in Ferritic S.G.Iron
- Silicon reduces Chilling and Carbides
- If Silicon is high, impact properties will be low and hence keep Silicon as low as possible.
- A minimum level of Silicon is essential to get full graphitization and benefit of inoculation.

Manganese:

- Mn segregates to the last metal to solidify and hence advisable to keep same below 0.30%.
- It is advisable to keep Mn low, particularly in heavy section castings.
- Mn also reduces impact properties and so necessary to keep Mn low (0.25% or even lower) for S.G.Iron grades requiring impact properties

Sulphur:

- High Sulphur will need more Mg Alloy for treatment.
- High Sulphur also causes more slag/dross
- Keep Sulphur less than 0.02% before Mg treatment.

Phosphorus:

- Phosphorus segregates to grain boundaries and increases brittleness.
- Keep phosphorus as low as possible (not more than 0.03%).

Copper:

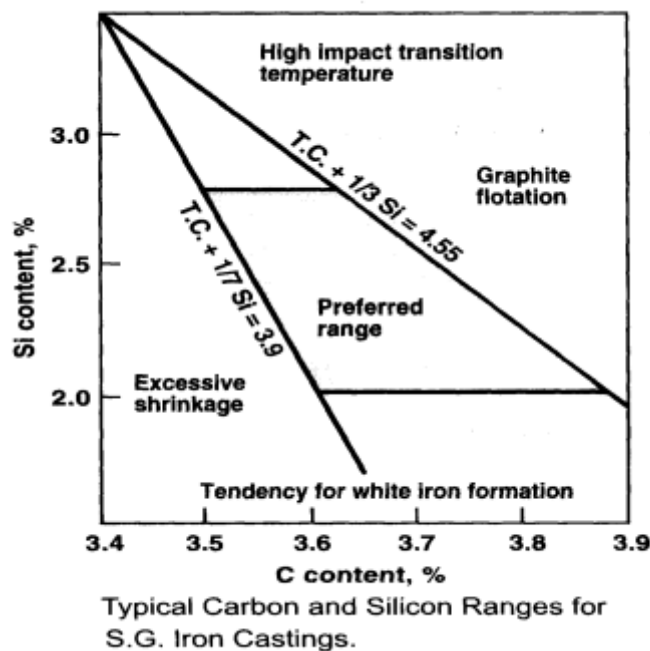
- This is the best addition to get pearlite in the matrix.
- For Manganese level of 0.3% suggested Copper additions are –

Grade 500/7	-	0.2-0.35%
Grade 600/3	-	0.5-0.7%
Grade 700/2	-	0.8-1.2%

(B) General Guideline to Carbon & Silicon Levels:

- (i) Carbon + 1/7 Silicon $\geq 3.9\%$ (to avoid excessive shrinkage in castings)
- (ii) Carbon + 1/3 Silicon $\leq 4.55\%$ (to avoid graphite floatation in castings)

Minor adjustments will have to be made to get the ideal composition for each casting.

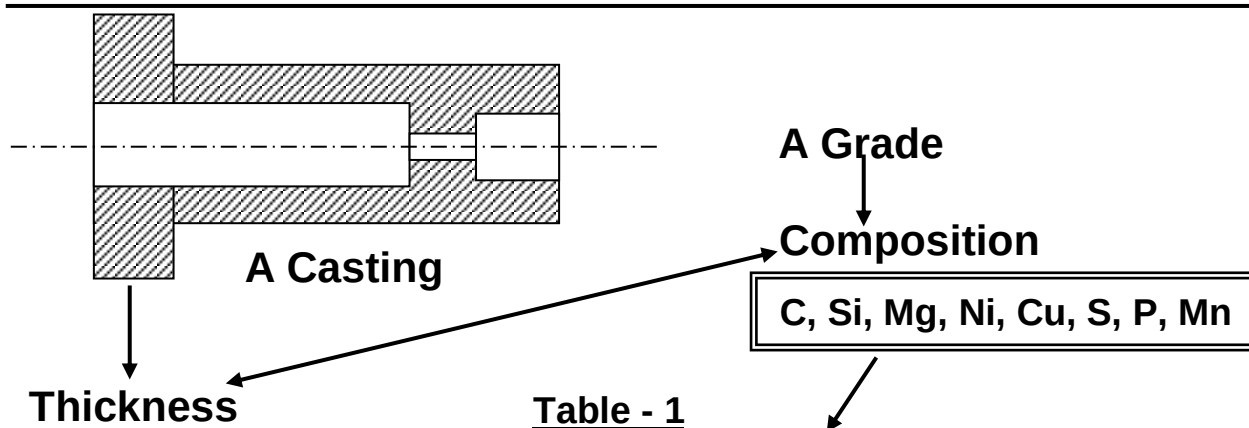


(C) Practical Tips:

To maintain the final composition as given earlier we have to note the following –

- (i) There is a carbon loss of 0.15-0.25% during Magnesium treatment. This depends on level of severity of reaction, amount of cover material and whether Magnesium treatment is in open or covered ladle.
- (ii) Mg alloy normally contains 40-45% Silicon. This increases the silicon level of the metal. In addition, post inoculation is also done with silicon containing alloys, which increase the silicon level further.

Hence, the base metal must have about 0.2% higher Carbon and about 1.0% lower Silicon as compared to the final chemistry. This will have to be confirmed for each foundry, separately, so that final composition as per Table (1).



Overall Thickness: mm					
	12	25	50	100	150
In general, except otherwise stated					
S Max.	0.012	0.012	0.012	0.012	0.012
P Max.	0.03	0.03	0.03	0.03	0.03
Cr Max.	0.05	0.05	0.05	0.05	0.05
Ce Max.	0.025	0.025	0.025	0.025	0.025
Ni Max.	0.1	0.1	0.1	0.3	0.4
EN-GJS-400 – GGG 40 – 400/12					
C	3.7	3.55	3.4	3.35	3.3
Si	2.6	2.5	2.35	2.25	1.9
Mn Max.	0.2	0.2	0.2	0.2	0.2
Cu Max.	0.1	0.1	0.1	0.1	0.1
EN-GJS-500 – GGG 50 – 500/7					
C	3.7	3.55	3.4	3.35	3.3
Si	2.6	2.5	2.35	2.25	1.9
Mn Max.	0.2	0.25	0.25	0.25	0.25
Cu Max.	0.25	0.3	0.35	0.4	0.5
EN-GJS-600 – GGG 60 – 600/4					
C	3.7	3.6	3.45	3.4	3.3
Si	2.45	2.35	2.25	2.15	2
Mn Max.	0.25	0.3	0.3	0.3	0.3
Cu Max.	0.5	0.6	0.7	0.8	0.9
EN-GJS-700 – GGG 70 – 700/3					
C	3.7	3.6	3.45	3.4	3.3
Si	2.45	2.35	2.25	2.15	2
Mn Max.	0.25	0.3	0.3	0.3	0.3
Cu Max.	0.8	1	1.2	1.4	1.6
EN-GJS-800 – GGG 80 – 800/2					
C	3.7	3.6	3.45	3.4	3.3
Si	2.45	2.35	2.25	2.15	2
Mn Max.	0.3	0.3	0.3	0.3	0.3
Cu Max.	0.8	1	1.2	1.4	1.6
Ni	0.4	0.7	1	1.3	1.6

Source: Rio Tinto Iron & Titanium

3

MELTING

(A) Melting Unit:

Medium frequency Induction Furnaces (about 500Hz) are best suited for melting the base metal of S.G.Iron.

- It is possible to adjust Carbon and Silicon within close range
- It is possible to maintain temperature within close limits.
- It is also possible to reduce sulphur by adding desulphurisers to the bath or in the ladle after which metal can be returned to the furnace.
- Since the bill for electricity has a portion for maximum demand charges, it is advisable to use the induction furnace for longer period (at least two shifts per day.)

(B) Charge Materials:

1. Pig Iron (S.G.Grade)
2. Steel Scrap (CRCA Scrap)
3. Steel Stampings
4. Foundry Returns (of same grade of S.G. Iron only)
5. Carburizers
6. Ferro Silicon – (70-75% Silicon containing)

Charging Sequence:

1. Start melting with Pig Iron (S.G. grade) or heavy foundry returns.
2. Then add CRCA or Steel stampings and Carburizer in stages.
3. Add 5% of pig Iron at the end to increase nucleation.
4. Ferro Silicon should be added just 5-10mts before tapping for Mg Treatment.

(C) Practical Tips:

1. Charge (Scrap & returns) must be free from rust, oil, grease and paint. All scrap should be low in undesirable elements – Cr, Bi, Ti, Pb, B, Sn, As and Sb.
2. Steel scrap should not be very thin so that maximum power can be drawn from beginning of the melt.
3. All carburizers - graphite or CPC or Coconut Shell should be added with steel scrap between 40-75% of charging. This will help in maximum pick-up and minimum of sticking to the lining.
4. Aim for carbon value slightly higher than required, say 3.85 or 3.90%. Carbon can be reduced easily by addition of steel scrap. But increasing carbon is very difficult and recoveries are erratic.
5. Do not super heat more than required. This consumes more energy. Also, melt quality becomes poorer.
6. **ALL INPUT MATERIALS SHOULD BE WEIGHED.**
7. **SLAG SHOULD BE REMOVED COMPLETELY FROM METAL BEFORE TREATMENT.**

(D) Recarburization:

The process of addition / increasing the carbon in the metal is known as recarburization. The most common recarburizers are –

- | | | |
|-------------------|---|---|
| (a) CPC | - | 85% recovery – Medium Sulphur (1-1.5%) |
| (b) Graphite | - | 90% recovery – Very low Sulphur (0.1-0.2%) |
| (c) Coconut Shell | - | 55% recovery – Very Low Sulphur (0.2-0.25%) |

Preferable to use a carburizer with low sulphur, so that base metal sulphur is kept below 0.02%.

For medium and large furnaces, Coconut shell charcoal gives good techno-commercial solution to increase carbon. Though it is low in carbon recovery, it is low in sulphur.

Full dissolution of carbon takes place only at temperature of 1450-1480 °C. Hence, all sampling for carbon and C.E should be done after metal has reached temperature of 1450 °C.

(E) Desulphurization:

The process of removal of sulphur from liquid metal is known as desulphurization.

Most common desulphurisers are –

- (a) Calcium Carbide (CaC_2)
- (b) Soda Ash (Na_2CO_3)

1. Should be done if sulphur in melt is more than 0.03%.
2. Addition of Soda Ash – Na_2CO_3 required is about 2% of the melt.
3. This should be added in 2 stages and slag removed each time.
4. Desulphurization is very effective at high temperature (>1450 °C). This is possible in induction furnaces as well as in ladles but it consumes time and energy.
5. All slag must be removed from furnace after desulphurising.

(F) Metal Testing:

The basic tests required for S.G. Iron base metal are:

- a) Carbon Equivalent (C.E.)
 - b) % Carbon & % Silicon
 - c) Chill value
1. C.E. Meter gives CE (carbon equivalent), Carbon and Silicon, using a tellurium coated cup so that iron solidifies white.
 2. It is advisable to cross-check carbon results with Strohlein apparatus.
 3. Chill value in samples poured before superheating at about 1300-1350 °C temperature, is a true indicator of metallurgical condition of the melt.
 4. Emission spectrometer gives reliable results of various elements including sulphur. Sample should be fully white for the results to be accurate. Carbon and silicon analysis of spectrometer are less reliable as compared to other methods.

4

MAGNESIUM TREATMENT

There are many processes by which S.G. Iron can be produced. But it always involves the use of some type of magnesium alloy.

There are a number of inherent problems with the addition of magnesium to molten iron.

- Mg has a low boiling point of 1107 °C much lower than the melting point of iron. Hence, “Mg gas” results in considerable agitation and violence during the reaction.
- Mg has low solubility in Iron (both in liquid and solid iron). Hence master alloys of Mg and Iron cannot be easily prepared.
- Mg has low specific gravity of 1.74, as compared to about 7.0 for iron. Hence, all Mg alloys tend to float, leading to losses during treatment.
- During treatment, MgO and MgS are formed which may remain suspended in liquid and lead to dross defects in castings. MgO is continuously formed on the skin due to contact with air and this also may lead to dross defects.

(A) Magnesium Treatment Processes:

There are many processes used to introduce magnesium into the molten metal. The most common processes are:

- Ladle Treatment
 - Open Ladle (Pour Over or Sandwich)
 - Covered Ladle (Pour Over or Sandwich)
- Plunging
- Porous Plug
- Cored Wire
- Converter
- In-Mould

Among all above processes, Ladle Treatment is the most widely used method to produce S.G.Iron.

(i) Open Ladle Sandwich Process

This is the most commonly used process.

A well / pocket is made at the bottom of ladle in which Mg alloy is placed.

Small pieces of steel scrap, punching or S.G. Iron turnings are placed on top. This is about 1.5-2.0% of metal treated.

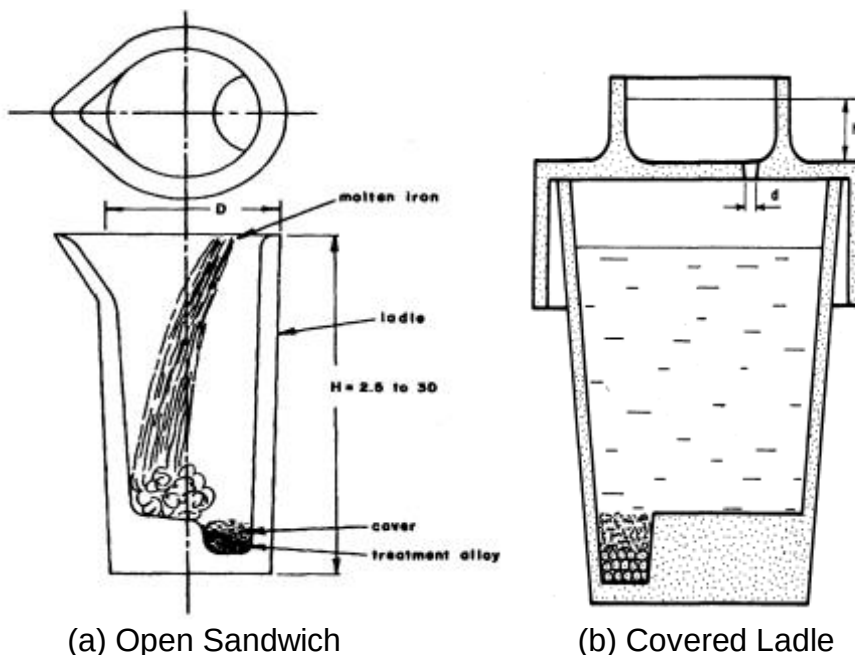
In some foundries 0.2-0.3% Fe-Si granules are also placed on top so that some inoculation is done at the same time if same treatment ladle is used for pouring.

(ii) Covered Ladle:

The method is same as open sandwich except that a cover is kept on the ladle during treatment, thro' which liquid metal is poured in to the treatment ladle.

The benefits of covered ladle process are:

- (a) Reduction of smoke and flare
- (b) Improved and Consistent Mg Recovery
- (c) Reduced Temperature Loss



(B) Typical Recovery in Magnesium Treatment Processes:

Process	Over Pour or Sandwich		Tundish Cover	Plunging	Cored Wire	Converter	In-mould
Mg Alloy Suitable	Ni-Mg	Fe-Si-Mg	Fe-Si-Mg	Fe-Si-Mg	Fe-Si-Mg or Mg	Mg	Fe-Si-Mg
Mg-Content (%)	4-15	3-10	3-10	10-40	20-100	100	3-10
Mg-recovery (%)	45-90	35-70	50-80	30-60	30-50	30-50	30-50

(C) Spheroidising Alloys / Nodularisers:

Magnesium is the most common element used in producing S.G. Iron. Since it is difficult to use pure Magnesium, it is commonly alloyed with iron and silicon. It is called Ferro Silicon Magnesium alloy. FeSiMg alloy also contains some amount of calcium and Rare Earth elements like Cerium, Lanthanum etc.

The amount and composition of nodularisers required depends on sulphur content in the melt, treatment temperature, total pouring time etc. among other factors. Various compositions of the FeSiMg alloys are given in the Kastwel's catalogue.

• Alloy Sizing:

A wider sizing gives dense bulk packing in the pocket. The alloy then will fuse and react slowly with minimum floating. Lumps floating on the surface are a waste.

Recommended Sizes of Fe-Si-Mg Alloys

Treatment Batch (Kg)	Popularly Used Sizes (mm)	Suggested Size for Better Recovery (mm)
Upto 100	0.2 - 3.0	0.2 - 3.0
100 - 300	3.0 - 6.0	1.0 - 6.0
300 - 500	5.0 - 15.0	3.0 - 15.0
> 500	15.0 - 25.0	5 - 25

(D) Typical Calculations for Magnesium Treatment:

Batch Size	500 Kg.
Treatment Method	Sandwich (Open)
Magnesium Recovery Expected	40%
Sulphur in Base Metal	0.03 %
Pouring Time	8 min.
Treatment Temperature	1540°C
Residual Magnesium required	0.04 %

$$\begin{aligned}
 \text{Total Magnesium required in Melt} &= \frac{0.04}{(40 \times 0.01)} + 0.76(0.03-0.01) \\
 &= 0.10 + 0.0152\% \\
 &= 0.1152\%
 \end{aligned}$$

Using Fe-Si-Mg alloy with 7%Mg,

$$\text{\% Addition of Fe-Si-Mg} = \frac{0.1152}{7} \times 100 = 1.645\%$$

This is just the starting point. After initial trials and estimation of residual magnesium, this will need to be revised.

(E) Factors Influencing Recovery of Magnesium in Ladle Treatment:

1. Sulphur Content in Base Iron

The higher the sulphur, the higher is the addition of Magnesium required.

2. Oxygen Content in Base Iron

Magnesium combines with oxygen before acting as a spheroidiser. So, higher oxygen content of melt will require higher Magnesium addition.

3. Tapping Temperature

Tapping (treatment) temperature should be as low as possible to minimize losses and improve recovery.

4. Slag in Metal/Ladle

Slag should be removed from furnace before tapping and from treated ladle after treatment to minimize loss of Magnesium into the slag.

5. Alloy Cover Steel Punching

The alloy cover in the ladle (small steel punchings) delays the reaction and gives better recovery.

6. Filling Time

Filling / Tapping rate into the ladle should be high to get a good ferrostatic height in the ladle before reaction starts.

7. Inoculation

With good inoculation, good nodularity can be obtained with lesser residual Magnesium. Good inoculation helps to reduce Magnesium Alloy addition.

8. Pouring Time

Magnesium tends to get oxidized / vaporized with time. Hence, pouring time should be minimized, so that initial Magnesium need not be kept high.

9. Ladle design

Diameter: Height ratio should be about 1:2. The pocket should be large enough to carry the alloy and the cover material. Ladle lining should be clean so that heat losses are minimized. A tundish cover is beneficial in improving magnesium recovery.

10. Composition of Nodularisers

The higher the magnesium content, the more violent is the reaction. Calcium and Rare-Earths will reduce reaction intensity and give better recovery of magnesium.

11. Alloy Sizing

A wider sizing gives dense bulk packing in the pocket. The alloy, then, will fuse and react slowly with minimum floating. Lumps floating on the surface are a waste.

12. Density and Purity of Alloy

As-cast denser alloys have been proved to give higher recovery. Also, cleaner alloys, free from oxides and slag, give better recovery. Hence, great care is required in alloy production to minimize slag and to reduce oxidation. Alloy must be cast in dies to minimize segregation and preferably, under protected atmosphere.

(F) Treatment Ladle:

1. Minimize temperature loss in treatment ladle. Keep the ladle covered, preferably with a thermal blanket (ceramic wool cloth)
2. It is better to use fireclay lining than CO₂ sand in treatment ladle.
3. Ladle should be of proper design. Metal height in ladle should preferably be 1.5 times the dia. of the ladle.
4. Size of the pocket in the treatment ladle should be sufficient enough for the whole quantity of FeSiMg Alloy, Covering Material, FeSi / Pre-inoculant.

5. Remaining liquid metal after transfer / pouring should be emptied from treatment ladle. Any slag present in the treatment ladle should be cleaned before new treatment.
6. Periodically use rock-salt along with the FeSiMg Alloy to keep ladle pocket clean.
7. Lining of the treatment ladle should not be very thick. If possible use insulation material between shell and lining of the treatment ladle.

(G) Fading:

Fading of magnesium leads to non-spheroidal structures. This is due to fading of the combined effects of spheroidising and inoculation. In practice, these effects occur simultaneously.

Several studies have proved that the fading effect is complex: Its simplest reaction is the Mg loss by oxidation or combination with sulphur.

The corresponding reactions are:

Mg + O = MgO (Mg vapor from liquid bath with external O₂)

Mg + S = MgS (Mg reacts with sulphur in metal / sulphides in slag)

Possible reaction with silica from lining or slag:

2 Mg + SiO₂ = Si + 2 MgO and

2 MgS + SiO₂ = Si + 2 MgO + S

The **Fading Speed** is influenced by:

- **Initial Mg content** - Higher content gives a faster fading.
- **Temperature** - Higher temperature promotes faster fading.
- **Treatment process** - Certain alloy elements delay fading effect (e.g. Ni).
- **Deslagging** - Must be carried out carefully after magnesium treatment (use slag coagulant for better de-slagging). Allow about ½ -1 minute for slag to float.
- **Refractories** - Use neutral ladle refractories (High Alumina Fireclay is better than Silica lining).

Fading may appear as nodule count reduction or as deterioration of the graphite shape. Fading may happen even when initial Mg or S contents are satisfactory.

5 INOCULATION

(A) What is Inoculation?

Inoculation is the final step in the molten metal preparation of S.G.Iron prior to pouring. It is the addition of a small amount of a material to the molten iron, which produces heterogeneous nuclei for the graphite spheroids to grow upon.

(B) Why Inoculate?

- Removal of Chill
- Increased Nodule Count and so better mechanical properties.
- Uniform properties in varying section thickness.
- Consistent Microstructure and Mechanical properties

Response to inoculation is dependent on:

- Melt Condition
- Temperature of Inoculation
- Quantity /Quality of Inoculants
- Timing of addition

The general principle – “treat first and inoculate afterwards” is traditional and still valid. “Post Inoculation” (meaning after magnesium treatment) is more effective simply because it is done later and at a temperature, that has been lowered by the cooling effect of the treatment.

(C) Inoculation Methods:

There are three methods used to inoculate the metal. These can be used individually or in combination, depending upon the foundry circumstances.

- In the ladle either during or after Mg treatment
- In the stream while pouring
- In the mould.

(E) Inoculants:

There are wide varieties of inoculants available that have varying degree of effectiveness.

Most inoculants contain from 45 -75% Si with some alloying elements like Ca, Al, Ba, Zr, Sr, Mn, RE, etc.

Some of the common types of inoculants in use are shown in our catalogue.

(F) Important Points about Inoculation:

1. Inoculation should preferably be done after Mg-treatment and slag removal. Where treatment batches are small, it is possible to place inoculant on top of the FeSiMg alloy. In any case, slag should be removed completely before pouring.

2. Inoculation is best done when transferring metal from treatment ladle to pouring ladle.

If there is no transfer, remove slag fully after Mg. treatment, add the inoculant and stir well with steel rod / pavdi.
3. Inoculation effect fades with time, just like the effect of FeSiMg alloy. Hence pour as fast as possible after inoculation.
4. Originally, we all used Fe-Si with controlled amounts of Al and Ca for inoculation. It is still used by some foundries. However, the addition of Fe-Si inoculation should increase the silicon content of metal by about 0.5% silicon. This will not mean more temperature drop in the metal as dissolution of Fe-Si is an exothermic reaction.
5. Now, the trend is to use cast – inoculants, which are available in varying compositions. Some inoculants contain Barium, which reduces inoculant fading. Some contain Zirconium, which is a very potent inoculant. Some contain Mn which reduces melting point of inoculant and makes it easily go into the solution. Some others contain a mixture of two or three of the inoculating elements Ca, Al, Zr, Ba, Bi and Mn.
6. Inoculant size is very important. For small ladles, size is lower and vice – versa. For hand ladles use 0.7 – 3.0 mm.
7. It will appear that cast inoculants are costlier. However, amount of inoculant required is less and also the consistency of addition is much better, making them cost effective.

Kastwel will advise on the inoculant, best suited for your foundry.
8. Metal temperature should be high enough to dissolve the inoculant. If temperature is not maintained at pouring point, avoid mold – stream or late – stream inoculation. This late inoculation may not allow inoculant to dissolve completely and cause inclusions.

(G) Practical Tips for Inoculation:

1. Inoculant should be added after weighing.
2. Add inoculant as late as possible.
3. Size of the inoculant should be selected based on the ladle size and stage of addition. Improper size leads to poor inoculating effect.

Recommended Addition and Size of Inoculants

Method of Inoculation	In-mould	In-Stream	Ladle Inoculation		
			< 50 Kg	50-100 Kg	> 100 Kg
Quantity to be added %	0.07 - 0.15	0.07 - 0.15	0.3 - 0.6	0.3 - 0.6	0.3 - 0.6
Size of Inoculant	0.2 - 0.7 mm	0.2 - 0.7 mm	0.7 - 3.0 mm	1.0 - 3.0 mm	2.0 - 6.0 mm

4. Inoculant should be added to the metal stream. Never put inoculant on the bottom of an empty ladle.
5. Never use inoculants to increase or decrease the final Si content of the iron. Keep the inoculant level constant and adjust the base iron Si content.
6. Inoculant should be stored in a dry place.
7. Over inoculation also leads to defects.

6 QUALITY CONTROL

The basic quality control measures on the shop floor are

(A) Chemical Composition:

Though this is not a requirement of the specification, this helps us to know the consistency of the production process. Make sure that carbon readings are taken from chilled samples and not from drillings.

(B) Micro Examination of Lug attached to casting:

Sample must be poured from last ladle of the treatment.

- Nodularity - 85% min.
- Nodule Count /mm² -125-150 min.

Matrix (as per grade)

- 500/7 - 30-50% pearlite
- 600/3 - 60-80% “
- 700/3 - 80-90% “

(C) Residual Magnesium:

Normally good nodularity is obtained with residual magnesium of 0.035-0.045%. For heavier castings, higher Mg residual will be required.

However **Mg (spectro)** = MgS + MgO + Mg SiO₂ + Mg ZnO₃ + **Mg (residual)**

Only free or residual or **Mg elemental** is useful in nodularisation.

Hence, do not go by Mg (spectro) results alone.

(D) Mechanical Properties:

Check for UTS, YS, % Elongation and Impact from the test samples cast from the last ladle of same treatment. Also check the microstructure of the broken test piece.

(E) Hardness Test:

The Brinnell Hardness Test, using 10 mm ball and 3000 Kg load is the most preferable method for hardness testing of both Gray and S.G. Irons. Test using 5 mm indenter and 750 Kg load is used in many automotive foundries due to thin walled castings.

- Dimensions of Test Blocks for Mechanical Testing:**

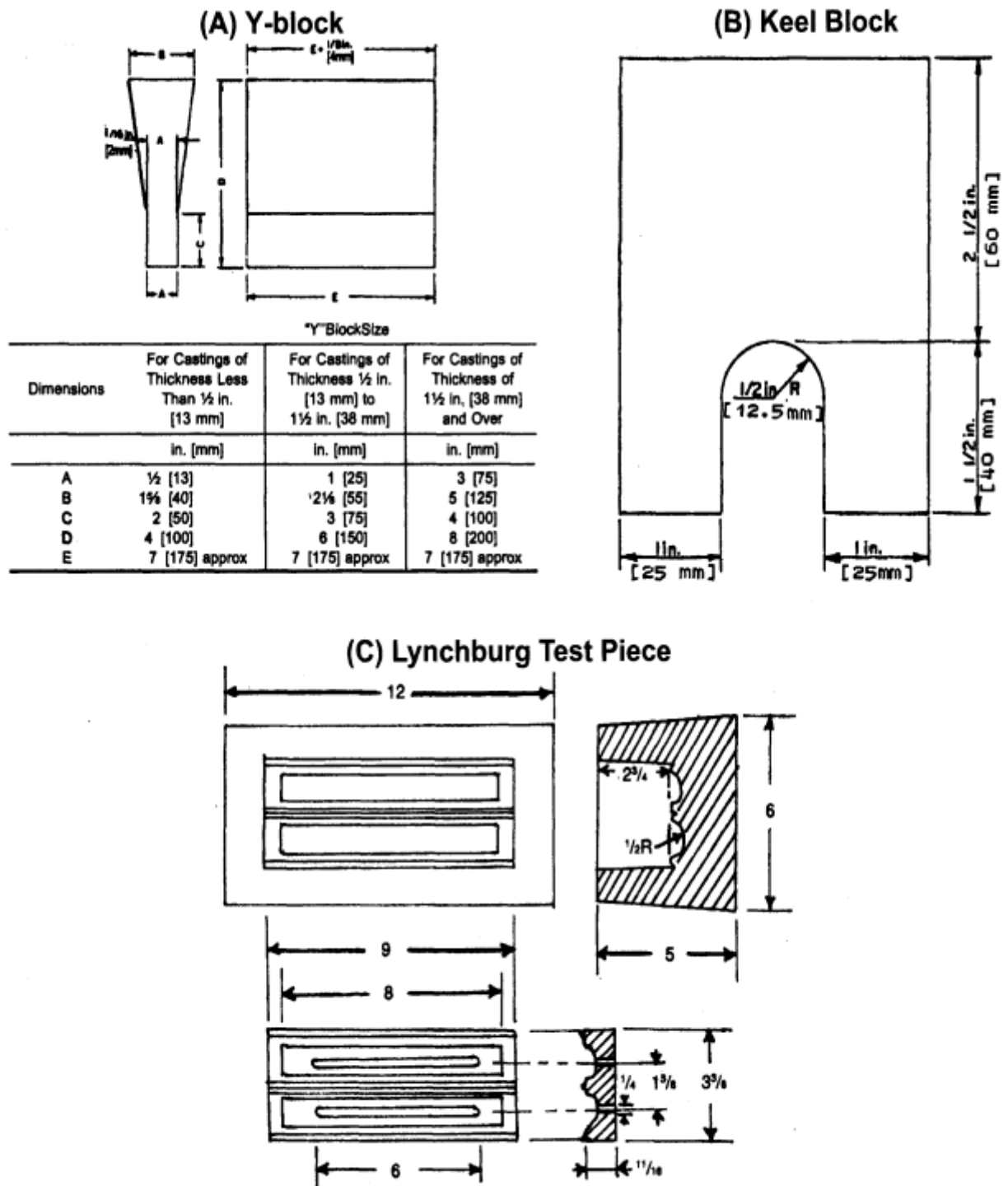


Fig.12.8 Standard Y-Block / Keel Block / Lynchburg Test Pieces.

7

MICROSTRUCTURE EVALUATION

(A) Purpose:

Microstructure evaluation and hardness testing are the basic control measures required in any S.G. Iron foundry, whether small or big.

(B) Objectives:

The microstructure evaluation must basically cover the following -

- **Nodularity (Expressed as %) :**

This states the acceptable graphite nodules as a percentage of total number of graphite spheroids. Average of readings at three locations is considered. Comparative charts are given in Fig. 1

Normally, acceptable minimum is about 80-85%, provided there is no flake graphite present. It is important to note that graphite need not be in form of perfect spheroids to be acceptable.

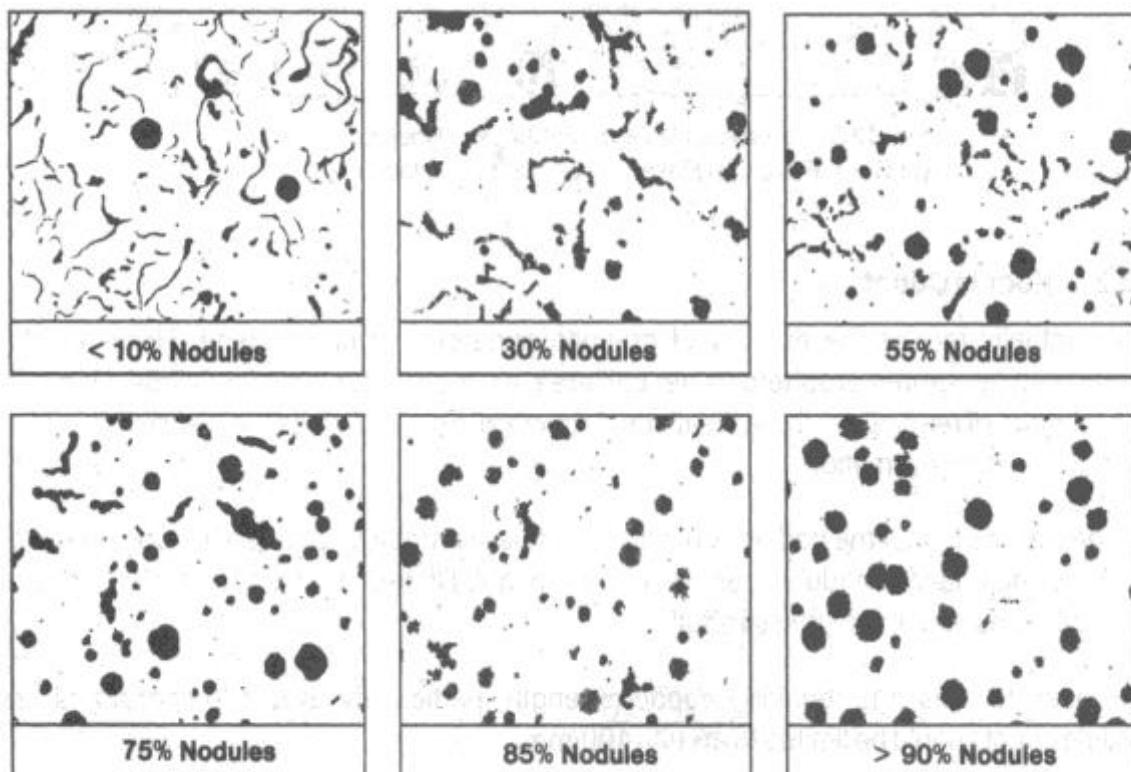


Fig (1) Typical Charts showing % Nodularity. (Unetched - 100 X).

Often, voids at the centre of the test piece are wrongly identified as irregular graphite spheroids. This can be avoided by focusing up or down, when graphite will go out of focus but void will remain in focus, at a different level.

- **Unacceptable Graphite Shapes :**

The four types of objectionable graphite shapes are given in Fig. 2. Of these, Quasi-Flake (Up to 15%) and Exploded Graphite nodules are least harmful, since their detrimental effect on mechanical properties is minimum.

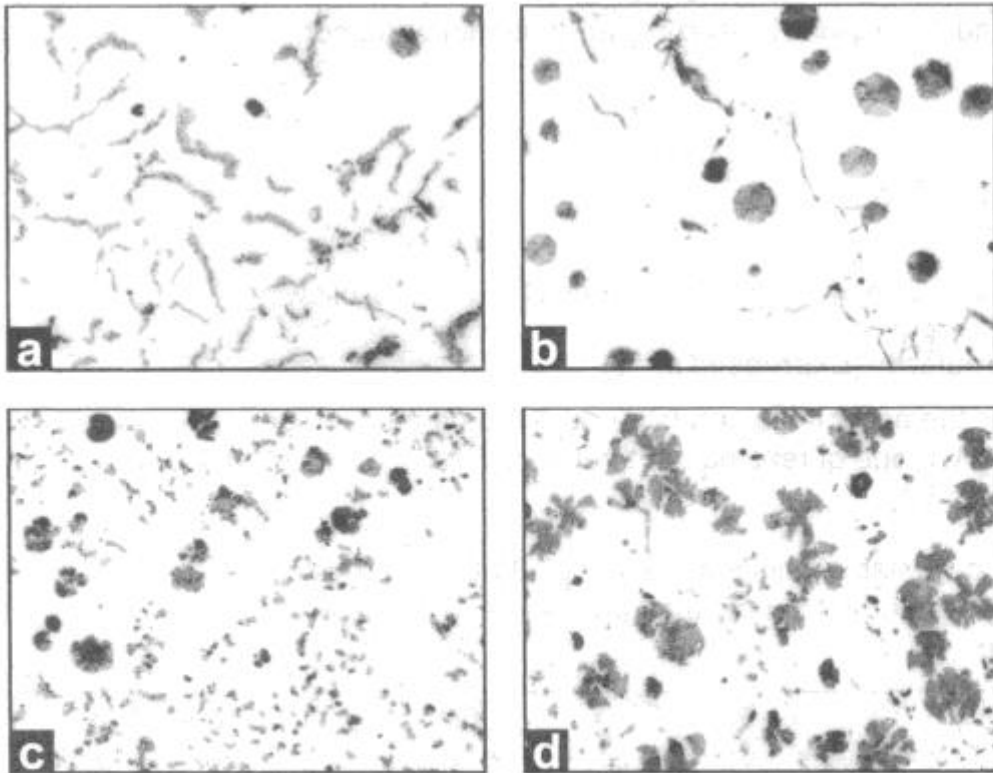


Fig (2) Objectionable Graphite Shapes. (Unetched - 100 X).
(a) Quasi-Flake. (b) Flake. (c) Chunk. (d) Exploded.

- **Nodule Count :**

This actually means the number of graphite spheroids in unit volume. However, it is expressed as number of spheroids per unit area, as seen under the microscope. Normally, the average of readings at three locations is reported. Fig. 3 gives the comparative chart for nodule count estimation.

In general, the higher the nodule count, the better is the metallurgical quality. Common S.G. Iron castings have a nodule count of 100-200/ mm². Higher nodule counts give freedom from carbides and also higher strength.

However, for castings requiring impact strength, particularly at low temperatures, the nodule count should be limited to around 100-150/mm².

Chart of Nodule Count :

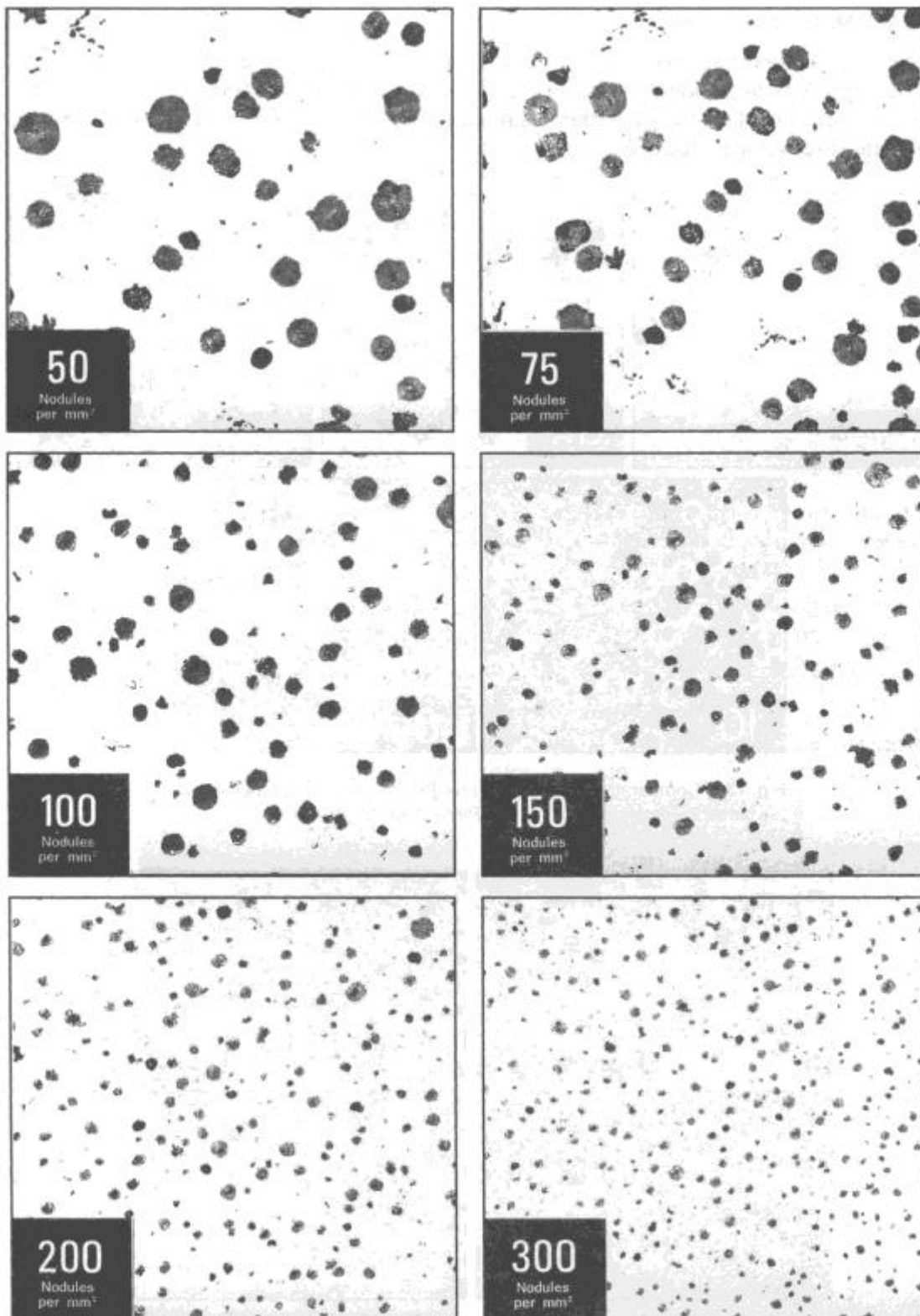


Fig (3) Chart of Nodule Count. (Unetched - 100 X).

- **Matrix Structure :**

The mechanical properties of S.G. Iron are very much dependent on the matrix structure. Most of the S.G. Irons have a mixture of pearlite and ferrite as the matrix. Fig. 4 gives the chart for easy evaluation of the matrix structure. Fig. 5 gives the other types of matrix obtained in special grades of S.G. Iron.

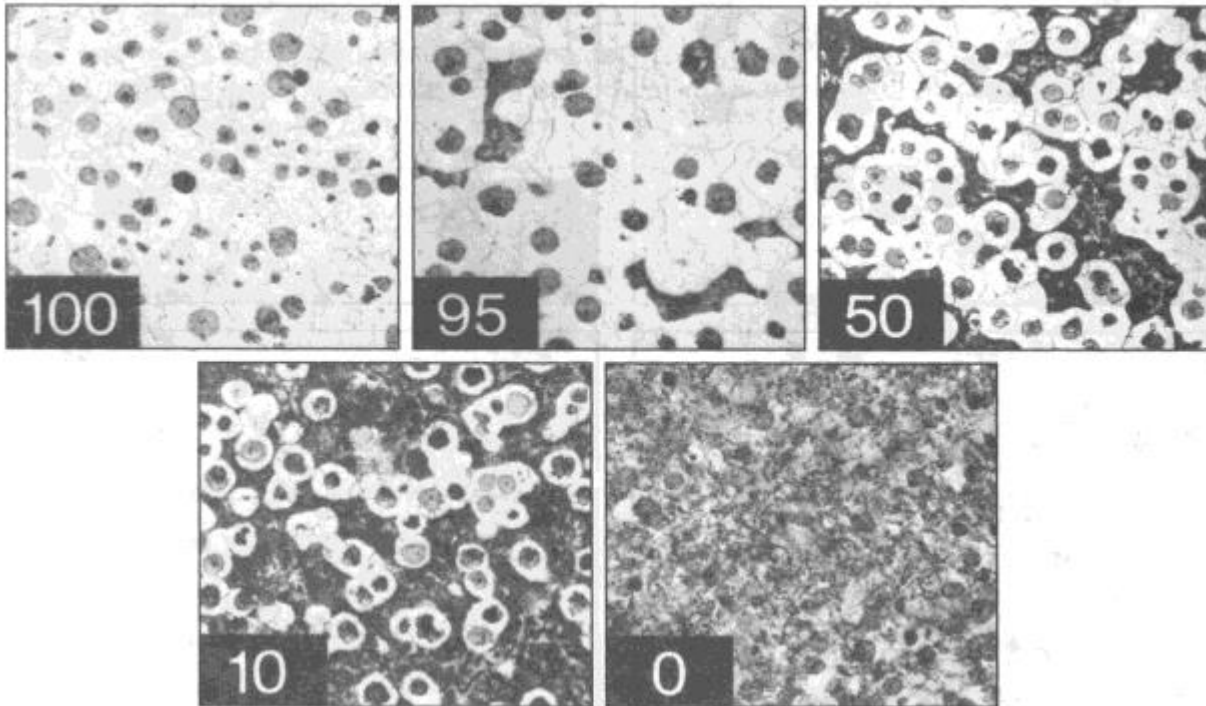


Fig (4) Comparative Charts for Matrix Structures. (The number shows the percentage of ferrite). (Etched in Picral 100 X).

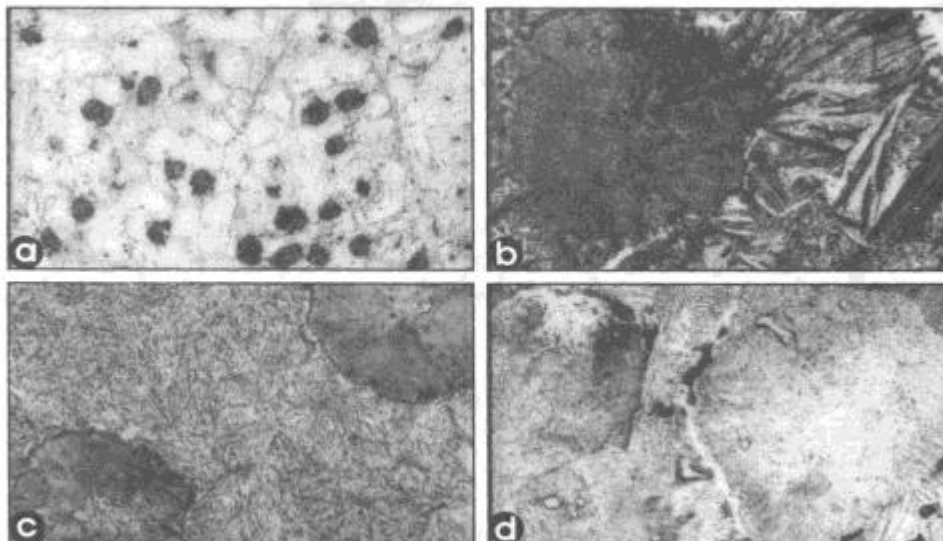


Fig (5) Other Matrix Structures.
(a) Austenite. (b) Bainite. (c) Tempered Martensite. (d) Cell Boundary Carbides.

The aim should be to produce castings free from carbides. However, the micro examination will reveal the extent and the type of carbide present (See Fig. 5). In some cases, these carbides can be removed by heat treatment. For general applications, about 2% carbides in as-cast condition may be acceptable at edges. However, this will increase problems of machining and reduce impact properties.

It is important to note that while evaluating matrix, the graphite portion is not considered. This means the percentages reported are of the total matrix area (which forms about 90% of the area reviewed).

(C) Sample Preparation:

1. Sample should not be over polished. The graphite tends to be removed from surface and the structure will show less number of spheroids.
2. Sample should not have scratches. This tends to distort the graphite shape leading to wrong evaluation. A good spheroid may develop a tail (like a comet) and may be interpreted as unacceptable.
3. The sample should not be over etched. Often, this could be due to evaporation of alcohol (used in Nital or Picral) leaving behind a highly concentrated etchant.
4. It is advisable to use an etchant of lower strength and etch for slightly longer time.
Too dark etching will make it difficult to identify different constituents.
5. After polishing and washing under tap water, the surface should not be touched before it is dried well. It is advisable to use a drier for this purpose.

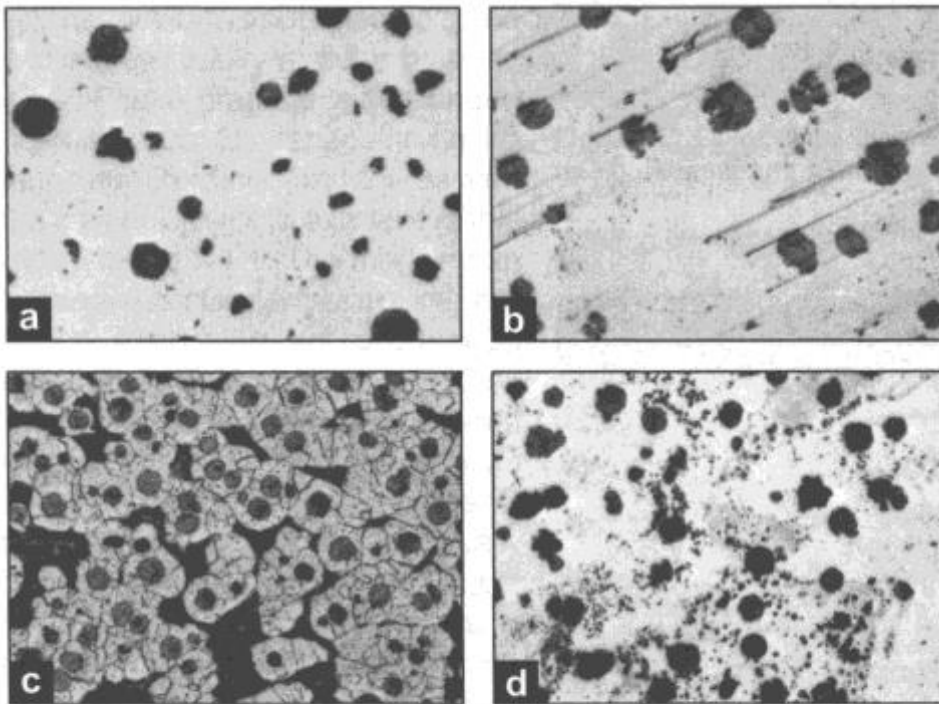


Fig (6) Examples of Improper Sample Preparation.

- (a) **Over polished** - Graphite removed. (b) **Scratches** - Inadequate polishing.
(c) **Surface Attack** - Sample etched too long. (d) **Dirt** - Careless handling and drying.

8 DEFECT ANALYSIS AND PREVENTION

The following are five major problems areas for SG iron castings. Following the problems are common causes and contributing factors. While some factors are specific, others are general, to stimulate a review of a larger area of the founding process.

• Defects Related to Dimensions :

Defect	Contributing Factors	
Thin / Thick Wall	→ Core Float → Wrong Core	→ Pouring temperature
Shift	→ Poor Mold Fit up → Molding Machining	→ Careless shifting
Swell	→ Soft molds → Weak cores	→ High metal pressure

• Defects Related to Hardness :

Defect	Contributing Factors	
High Hardness	→ Composition Low carbon equivalent Low silicon Excessive magnesium Excess rare earths Excess carbide stabilizers	→ Thin sections → Gating Practice → Melting Practice → Low pouring temperature → Insufficient Inoculation
Hard Spots	→ Chill used in the Mold → Chill used in the Core → Casting Design → Thin Sections	→ Undissolved Alloy → Gating Practice → Pouring Time → Careless shifting
Low Hardness	→ Mold Cooling Time → Excessive Ferrite	→ High Nodule Count → Composition

• Defects Related to Metal Cleanliness :

Defect	Contributing Factors	
Sand / Dirt	→ Soft Molds → Low Sand Moisture → Sand Binders → Sand Erosion → Dirty Mold Cavity → Mold Closing	→ Core Setting → Gating Design → Pouring Practice → Weight Shifting → Pouring temperature
Shift	→ Poor Mold Fit up → Molding Machining	→ Careless shifting
Swell	→ Soft molds → Weak cores	→ High metal pressure

• **Defects Related to Slag :**

Defect	Contributing Factors
Slag	→ Silicon Content → Gating Design → Slagging Practice
Dross	→ Composition Excessive Magnesium Excess carbon Excess sulfur Excess C.E. → Gating Design → Pouring Practice → Temperature Control

• **Defects Related to Metal Soundness :**

Defect	Contributing Factors
Cold Shut (Laps)	→ Run-outs → Excessive Magnesium → Low Pouring Temperature → Slow Pour Rate
Run Out	→ Poor Mold Fit up → Excess Cope Seal → Pouring Practice → Insufficient Mold Wall Thickness
Mis-run	→ Slow Pouring Rate → Low Metal Temperature → Gating System
Gas Cavity	→ High Moisture Content → Poor Venting → Metal in Core Prints
Internal Shrinkage	→ Mold Wall Movement → Run-outs → Core Fit up → Riserling → Gating → Composition → Improper Pouring Temperature → Low Mold Hardness → Jacket Shifting → Section Size Change
Hot Tear	→ Hot Spots in Mold → Early Shakeout → Mold or Core Collapsibility
Cracked or Broken Casting	→ Hot Shakeout → Rough Handling → Knock-off Technique

Source of Defects :

Defects can also be classified based on the process variables.

Process Variables	Defects
Raw materials	
Free cutting steels (lead bearing). Impure pig irons - Pb, Ti, Sb, Bi.	Degenerated Graphite
- Poor quality steel scrap - high Cr, Mn - Poor quality steel scrap or pig iron-high P	Carbides and Pearlite. Phosphide eutectic.
High sulphur containing carburizer	Quasi-flake graphite unless Mg alloy- addition is increased.
Melting	
Low total content carburizer.	Shrinkage and Carbide in as-cast structure.
High total carbon content (hypereutectic composition)	Increased risk of dross defects. Floatation of hypereutectic nodules. Poor surface finish.
Low silicon content.	Carbide in as-cast structure
High sulphur content (electric furnace or cupola melting).	Quasi-flake graphite unless Mg alloy addition is increased.
Treatment	
High treatment temperature, high sulphur content, incorrect metal weight, incorrect weighing of magnesium alloy.	Quasi-flake graphite
Low treatment temperature, incorrect metal weight, incorrect weighing of magnesium alloy.	Increased risk of dross defects High residual magnesium content
Inoculation	
Inadequate addition, poor mixing of inoculant and metal, incorrect analysis - low aluminum and calcium contents	Carbide in as-cast structure Poor graphite structure Low nodule count.
Molding Materials	
High moisture content in sand	Hydrogen pinholes, Shrinkage – excess mould dilation.
Low volatile content in sand	Hydrogen pinholes, Shrinkage – excess mould dilation. Increased risk of dross defects.
Poor sand formulation – low shatter index	Shrinkage. Mould dilation.
High nitrogen content in core materials	Pin-holing
High sulphur content in coal dust	Increased risk of dross defects. Flake graphite structure at casting surface

Process Variables	Defects
Pattern	
Long runner systems	Pin-holing – pick of hydrogen. Flake graphite at casting surface
Heavily choked ingate. Incorrect design of runner basin and sprue. Impingement of metal against cores.	Increased risk of dross defects. Metal turbulence.
Inadequate slag traps	Increased risk of dross defects
Incorrect design of feeding system - location, size, neck dimensions	Shrinkage
Molding Methods	
Wrongly or incorrectly maintained machine - poor sand compaction and mould hardness. Low air pressure - poor sand compaction.	Shrinkage – excessive mould dilation
Pouring	
Prolonged pouring period	Flake graphite structure – loss of magnesium. Carbide in as-cast structure. Fade of inoculation; C-loss
Low pouring Temperature	Increased risk of dross defects Mis-run castings
Dirty Ladles	Increased risk of slag and dross defects
Heat Treatment	
Incorrect Cycle	Retention of Carbides. Incorrect matrix structure
Poor seals on furnace	Heavy scaling, decarburization and possibility of pearlite rim being formed.