

A PRIMER
ON
FERROUS FOUNDRY
PRACTICE
&
METALLURGY

- G.M.RAJENDRA PRASAD. M.E., (I.I.Sc.)

FORWARD NOTE.

As you read this book you will see voice of a person , who is eager to pass on the knowledge he has acquired, in his career to the young and old alike in a very simple –understandable language-and for those who had learnt metallurgy & foundry practice in their academics, a reading material which will rekindle their forgotten knowledge.

The gregarious knowledge outburst has been consolidated in such a short time and in a simple language for those who had forgotten Metallurgy and Material sciences.

To say a few things about the author Sri Rajendraprasad, who had joined our company as an enthusiastic youngster always seeking and exploring the knowledge of Material science and technology . He had a very keen analytical mind-never say never die attitude-and an excellent human being always keen to pass on the knowledge to others in simple terms. He is a great storey teller in Foundry practice and Metallurgy. He showed lot of interest and keenness in learning Methoding in Foundry and the feeding of castings.

We come across problems in FOUNDRY, which are challenging to a keen learner and from my point of view it is the only production practice to have innumerable variables, and a tricky mind teaser, each and every minute of our lives, through the industry.

Can you read this book with an open mind?

If so you will see the world of Metallurgy & Foundry, through the eyes of Mr Rajendra Prasad, and you may expand your mindset about Metallurgy in totality.

THIS BOOK IS FOR YOUR KNOWLEDGE BANK OF THE FUTURE.

Begur R Rao Niranjana

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No Man is an island unto himself. Every human being is , what ever he is, because of Society.

The Members of this Society who have contributed to this book, directly or indirectly are :

My daughter, Ms Vasudha. Gulyam, who put the IDEA of writing a book, in me.

Mr.B.R.Niranjan , who in 1978, who not only introduced me to the fascinating field of METHODING of STEEL CASTINGS , lead me through.

Mr.T.Kumar , from whom I learnt a sense of Discipline in Life, particularly in Working Life, sense of Impartiality & Systemic Thinking.

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I am eternally Grateful to the above People for EVERY THING .

**To
THAT COSMIC FORCE, WHICH CONCEIVED
THIS BOOK & HAD IT WRITTEN BY A CREATION OF HIS.**

PREFACE

There is more than one reason for attempting to write this book.

At the outset, let me confess that I have never authored any thing before.

1) There is a severe man-power crunch in Foundry Industry, because of prevailing favourable job opportunities.(in other areas) In a situation like this, the foundries will have to make do with whoever is available.

In my 30 years of experience in various foundries, one thing that I have learnt is that in foundry you need **KNOWLEDGE,HUNCH and AT TIMES DIVINE INTERVENTION.**

As regards to the last point it may sound as a NON-SCIENCICAL SCIENCE.

But believe me it is true as I have had several experiences.

Let me tell you some thing with all the sincerity and the honesty that I can muster, **FOUNDRY SCIENCE** is a combination of several subjects ,which are often considered” Difficult.”

To name the subjects :FLUID MECHANICS.

HEAT TRANSFER.

SOLID MECHANICS.

MATERIAL SCIENCE.

It is a combination of Subjects from Mechanical engineering & Metallurgy.

Mechanical fellows are not comfortable with metallurgy and vice versa.

Hence ,it is time universities started a post of **PROFESSOR OF CASTING TECHNOLOGY**, instead of a mechanical or a metallurgy professor working on foundry.

This trend has started in **UNIVERSITY OF BIRMINGHAM**. I am very happy to note this change of perception.

Some people are likely to be offended by the above statement. For them I have only one answer “ **THOSE WHO MATTER DON’T MIND & THOSE WHO MIND DON’T MATTER.** Whole world is crying hoarse about pollution control **FOUNDRY** happens to be the second most polluting industry. Mining being the first one. But mining activity in Australia can’t be out-sourced to **INDIA**, but castings can be bought from Indian Foundries. Hence Foundry Industry is going to see a boom.

But to-day a Inter passed boy with a knowledge of English prefers to go to BPO. So Foundry industry will have to make do with who so ever is available.

(B.E, B.Sc, D.M.E’s have stopped considering a job opportunity in a Foundry)

In a situation like this it occurred to me as to why not share my 30 years of industrial experience with these boys, so that their awareness of foundry increases.(I am talking of boys who have come to foundry, as they had no option)

After my B.E(Met)(Honours) from R.E.C, Rourkela (present day NIT) and M.E.(FOUNDRY) from INDIAN INSTITUTE OF SCIENCE,BANGALORE in 1978,I have worked in several foundries for last 30 years. I started my career as a METHODS Engineer and subsequently went on to learn so many other things on my own initiative. In the process so many people have helped me.

In this world of ours nothing is permanent.

By the grace of GOD I have an enquiring mind and hence I don't take any body's statement as a WORD OF GOD till I am convinced about it. This statement may sound as though I am an ARROGANT fellow, but that does not bother me even a wee bit. My personal philosophy (?) has always been " I AM LIKE THIS, TAKE IT OR LEAVE IT"

In a situation like this, it occurred to me that whatever I think I know is not mine, it has come from a COSMIC FORCE and hence I have no MORAL right to carry it to my GRAVE. So I decided to share my knowledge with people who want to know about Foundry science.

Our ancient sages and seers did penance to appease GODS to get an ETERNAL KNOWLEDGE.I am no sage or seer nor I can give you an eternal knowledge.

Among people who seek the knowledge of foundry science are two types.

1) People who are working in foundries for several years but they do not know what is what. I have absolutely no qualms in saying this as I have met hundreds of such people.

2) Fresher's or New comers to foundry.

I would teach you the following PATTERN ,METHODING ,MELTING, MOULDING, FETTLING, HEAT TREATMENT,INSPECTION AND TESTING and finally some basic of METALLURGY which is relevant to you. Here I ask of you only one thing i.e. you must know ENGLISH. Rest you leave it to me. I will try, for all I am worth, to do justice so that your life in foundry becomes more cheerful and not drudgery.

I have yet another pre-requisite i.e.

THINK,THINK.THINK.THINK.THINK.THINK.THINK.THINK.THINK.THINK.

Animals have an INSTINCTIVE INTELLIGENCE and human being has an INTELLECTUAL INTELLIGENCE. Animals can't think and human being does not think. Do you find any big difference between animals and human beings ,tell me honestly .when I make this statement, it not is out of arrogance but with a deep sense of ANGUISH.

When I was studying an elective subject "NUCLEAR METALLURGY" in my final year B.E in 1975,I knew that India didn't have enough of Uranium, had plenty of Thorium .Even after 33 years we are going around the world begging for Uranium.

If this does not speak volumes about our scientific and thinking capability or lack of it ,what else can. That is the reason I am paying so much importance to

THAT COMPONENT OF THINKING.

I am as much an INDIAN as all of you are, so do not jump to a conclusion that I am denigrating INDIA.I AM NOT.

Your parents sent you to school, when you were 5 years old. Why did they send you to school, because they knew that you didn't know any thing.(this includes me).You know what is the maximum weight you can lift, you know how much you can eat, you know how far you can see with your naked eye, etc but do you know what your MIND can do or can't do. Your MIND is yours only, endowed to you by GOD almighty HIMSELF OR HERSELF OR ITSELF. When you don't use such a POWERFULL TOOL, are we not SINNING against GOD. Would it be wrong if GOD concludes HE OR SHE OR IT has made an "APATRA DHANA "i.e. giving a gift to an UNDESERVING FELLOW. So, my friends I request you ,beg of you to THINK. YOUR MIND IS YOUR BRAMHAstra,ICBM AND MIRV ALL IN ONE. I have said what I have said with a belief that CRITICISM IS AN ELEMENT OF FAITH AND NOT OPPOSITE OF FAITH.

This book will not be like a conventional book. This book will not be written in third person like other books. Instead this book will be interactive and conversational in nature and so read this book like you would read a novel.

Excepting the data and some diagrams, every thing is extempore. I will talk about the problems I faced and solutions I got. I will give you precautions and warnings to be adhered to in a foundry operation.

As I started my career as a METHODS engineer of STEEL castings, it is more likely than not that this book will show certain amount of bias towards STEEL. I have also worked in S.G Iron foundry, hence I will tell you about S.G. Iron making, and more importantly S.G. Iron FEEDING.

As regards to S.G Iron feeding many people think that S.G. Iron should be fed like STEEL, nothing is farther from TRUTH.

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INTRODUCTION

I deliver lectures on the following topics for practicing foundrymen, design engineers and some engineering college teachers.

The topics I handle are:

- 1) Metallurgy for Non-Metallurgists.
- 2) Methoding of Steel and S.G. Iron castings
- 3) Steel and S.G. Iron foundry practice.

As is my wont I start my classes by asking a very ,very simple question.

“ WHAT IS ENTROPY” Believe me till date, in my last 35 years, I have not met a person who has given the CORRECT answer including most of my teachers. The word entropy has got philosophical overtones.

Invariably the answer given was / is ENTROPY IS DEGREE OF DISORDER Or ENTROPY IS DEGREE OF RANDOMNESS. As far as I am concerned they are not only silly answers but WRONG answers.

The word “ENTROPY” comes from 2nd law of Thermodynamics, which in turn had it’s origin in Physics.

The above kind of answers are like saying that man is “SICK”. Sick of what ? Has got AIDS, cancer, arthritis, ulcer etc.

Above answers for ENTROPY are so slimy and slippery, you can never make use of it. Besides that Thermodynamics is a QUANTIFIABLE Science and not a QUALITATIVE SCIENCE.

If a Mechanical, Metallurgical and a Chemical engineer, who studies THERMODYNAMICS as a part of HIS course, is unable to define ENTROPY, properly, he is not an engineer worth his salt.

Before I explain ENTROPY to you, let me tell you categorically, in unambiguous terms, with out any vestige of doubt, ENTROPY decides your growth, development and progress. Man who taught me ENTROPY is not an ENGINEER or SCIENTIST but A FINANCE MAN by name JEROMY RIFKIN. JEROMY RIFKIN wrote a book entitled “ENTROPY—A WORLD VIEW.”

It is out of print now. Those of you who would want to get this book now, will have to look for those groups who are in the business of selling old books in USA.

(IT IS ORIGINALLY PRINTED BY BANTOM BOOKS,USA)

Let us get into explanation of ENTROPY.

In 1970-75, there was a motorbike called “ JAWA”, it used to give a mileage or Should I call it a kilometreage of 25km per litre of petrol.

There after came a motorbike called as ‘RAJDOOT’, which used to give us a mileage of 45 Km per litre of petrol.

Then came a motorbike called ‘YAMAHA-CRUX’ Which gives a mileage of

74 Km per litre of petrol.

Now let us look at it this way, in a matter of 15 years mileage went up from 25 Km to 74 Km per litre of petrol. HOW MUCH MORE IT CAN GO ?

Now a days there are vehicles which claim a mileage of 110 Km per litre.

Now we have come from 25 to 110 Km per litre of petrol. It is almost 4 times the Our first value of 25 Km per litre of petrol.

One litre of petrol has 9100 Kilocalories of heat energy. First law of thermodynamics states that energy can neither be created nor destroyed, it can only be converted from one form to another.

If we convert 9100 KCal of heat energy to work energy, for a weight of 150 Kg (100 Kg-motor-bike weight + 50 Kg is the man's weight) One litre of petrol should give 180 Km per litre at 100 % efficiency.

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Let us look at one vehicle after an other.

JAWA-----180—25 = 155 Km

Total available energy is 180 Km per litre of petrol.

What is made use of is only 25 Km.

Achievable energy – achieved energy = A MEASURE OF ENTROPY

180 Km –25 Km = 155 Km (unachieved energy) ENTROPY—JAWA.

180 Km –45 Km = 135 Km (unachieved energy)ENTROPY----RAJDOOT

180 Km –74 Km = 106 Km (unachieved energy)ENTROPY-----CRUX

180 Km –110 Km = 70 Km (unachieved energy) ENTROPY----PRESENT DAY VEHICLES.

If you look at the UNAVAILABLE ENERGY, it has come down from 155 Km to 70 Km. THIS IS ENTROPY.IS'T THIS A PROGRESS AND ADVANCEMENT. IT IS THIS ENTROPY,WHICH SETS US THE DIRECTION IN WHICH WE CAN PROGRESS.

IN OTHER WORDS,WHAT WAS HITHERTO UNAVAILABLE ENERGY IS CONVERTED TO AVAILABLE ENERGY.REDUCING ENTROPY IS EQUIVALENT TO IMPROVEMENT IN ENERGY EFFICIENCY.

Now do you understand that ENTROPY is not a slippery or a slimy term like DEGREE OF DISORDER OR DEGREE OF RANDOMNESS. It is a perfectly a quantifiable term.

IDEALLY SPEAKING IF ENTROPY BECOMES ZERO,SYSTEM CANNOT BE IMPROVED UPON FURTHUR.THAT IS THE DEAD-END.

Now let us talk of ENTROPY OF DEED. This is the difference between what You are capable of achieving and what are you actually achieving. If this happens to be negative, then there is ENTROY at play and you have ample scope to improve on your achievement. Thus reducing ENTROPY.

This can be partly achieved by employing the principles of “OPERATIONAL RESEARCH”, a subject in MANAGEMENT and MATHAMATICS. This is a

A case of “OPTIMISATION”

ENTROPY OF THOUGHT: Here you have no one to guide you, except your own EFFORTS towards SELF-IMPROVEMENT.

Every day identify some thing about which you don't know anything.

Animals can't do this, only HUMAN BEINGS can do it. Then, is it not the time you started? There is a saying “WHERE THERE IS A WILL, THERE IS A WAY”

You know as to how much weight you can lift.

You know as to how much you can eat.

You know as to how far you can see.

You know as to from how far you can hear.

BUT DO YOU KNOW AS TO WHAT YOUR MIND CAN DO OR CAN NOT DO ? HENCE THINK INTENSELY.

Now you will realise what is the POTENTIAL of MIND.

My dear friend you have only one OPTION, THINK—THINK INTENSELY.

To close this chapter, I will give you an other example on ENTROPY.

If you have a savings bank account in a bank with cheque facility, willy-nilly, you have to keep a minimum balance of Rs 1000. If you have a balance of Rs 20000 in your account, you can withdraw only Rs 19000 and leave Rs 1000 untouched. Don't you think that THIS Rs 1000 is ENTROPY as it is your money and yet it is not available to you.

Before I close, I want to tell you some thing.

Any subject (CURRICULAM) will have about 15 chapters.---100 %

In examination they give about 8 Questions covering about 10 chapters—66 %

You are asked to answer 5 Questions, if all of which will fetch FULL MARKS

You will get 100 %-----for 33 % of the subject

If you are a just first class student (60 %)-----for 20% of the subject.

THINK & REFLECT ON IT.

TOPICS COVERED

1. PATTERNING
2. METHODING
3. MELTING
4. SAND PLANT
5. MOULDING
6. MOULD FINISHING
7. POURING
8. KNOCK OUT
9. FETTLING
10. HEAT TREATMENT
11. INSPECTION & TESTING
12. MANAGEMENT & LAYOUT
13. FERROUS METALLURGY

ABBREVIATIONS USED

UTS	ULTIMATE TENSILE STRENGTH IN Kg / mm ²
YS	YIELD STRENGTH IN Kg / mm ²
%E	PERCENTAGE ELONGATION
%RA	PERCENTAGE REDUCTION IN AREA
BHN	BRINNEL HARDNESS NUMBER
Ra	ROCKWELL HARDNESS-A Scale
Rc	ROCKWELL HARDNESS-C Scale
Mc	MODULUS OF THE CASTING
Mf	MODULUS OF THE FEEDER
Mn	MODULUS OF THE NECK
B.C.C	BODY CENTERED CUBE
F.C.C	FACE CENTERED CUBE
B.C.T	BODY CENTERED TETROGONAL
DEGREES	DEGREES CENTIGRADE
M.P	MELTING POINT
Cp	SPECIFIC HEAT
L.H	LATENT HEAT
K	THERMAL CONDUCTIVITY
Dm	DECIMETRE (100 mm)
Psi	POUNDS PER SQUARE INCH
TOUGHNESS	HIGHER VALUES OF %E,%RA &IMPACT STRENGTH
IMPACT STRENGTH	STRENGTH OBTAINED ON HIGHER RATE OF LOADING
A	ANNEALING
N	NORMALIZING
AQ	AIR QUENCHING
OQ	OIL QUENCHING
WQ	WATER QUENCHING
T	TEMPERING

Metals can be Rolled, Forged & Cast.

When your mother takes a dough of wheat flour and water, gives a round shape with a wooden round piece, it is ROLLING

When a blacksmith heats a long piece of metal and hammers it, it is called FORGING.

During Christmas and Makara Sankranti, people distribute toy like things made of sugar to children. A slurry of sugar and water or milk is made and this slurry is poured into wooden dies (whose inside shapes can be a horse, elephant or any shape of your choice). This slurry is allowed to dry for while in the die itself for while till it attains some amount of strength for handling, there after it is dried in SUN LIGHT so that it becomes strong enough. Here a liquid sugar syrup has become solid.

Now let us see the differences between Rolling, Forging and Casting.

Rolling and Forging are the operations made **in solid state of Metal** to change the shape of the metallic piece into desired shape.

For example, your M.S. sheet is a Rolled product, the steel hammer you use for driving a nail into a wall is a Forged product. As these operations are done in solid state, you can't get complex shapes.

In casting, a metal is melted and poured into a container, whose shape it will take. Remember your horse, elephant made out of sugar syrup.

In case of Casting, metal is melted and molten metal is poured into a container whose shape is pre-determined. This liquid metal is allowed to solidify to become solid in the container.

Casting is an old art but a young Science. Even now there are several things **in castings about** which we don't know much.

So it is very essential to keep your mind openly open and keep thinking

When you keep your mind open and work, you will discover something every day. Your life becomes exhilarating. For a person with job satisfaction other things become insignificant.

Life is full of mysteries for a person who can think.

IT IS BELIEVED THAT THERE ARE ONLY 26 DISEASES FOR WHICH EMPIRICAL CURE IS KNOWN. REST IS ALL GUESS WORK.

INCIDENTALLY DO YOU KNOW THAT EVEN TO THIS DAY WE DONOT KNOW THE EXACT CURE FOR "COMMON COLD"

THAT IS PROBABLY THE REASON FOR SAYING-----

COLD GETS CURED IN 7 DAYS TIME IF YOU TAKE MEDICINE,

COLD GOES AWAY ON IT'S OWN IN A WEEK'S TIME EVEN IF YOU DONOT TAKE MEDICINE.

PATTERN

Patterns are replicas of component to be made with certain allowances. You should also remember that your casting can only be as good as your Pattern and certainly not better.

When you see a Brass tap (a cast product) in your house, don't you marvel at it's complexity and elegance.

3000 years back, our fore-fathers made statues of DANCING NATARAJA out of metal, it was a cast product.

Patterns can be several types:

Solid pattern.

Split pattern.

Skeleton pattern.

Cored pattern

Cover cored pattern.

Patterns can be made of wood, metal polymer, plaster of Paris etc.

A pattern made by a pattern maker and a pattern designed by a Methods engineer may look totally different. I would like to state in no uncertain terms, that the fate and eventual cost of the casting, depends to a great extent on Pattern design.

A pattern maker is only concerned with taking the pattern out of the mould. (mould—British English & mold---American English)

Whereas a Methods Engineer takes a holistic view. His goal is a good casting.

In the process a Method's Engineer's pattern may altogether look different.

A Methods Engineer can be compared to a GYNECOLOGIST; OBSTETRICIAN & PAEDIATRICIAN all packed in one.

Can you think of any of the above medical practitioners having a callous attitude towards pregnant mother, growing foetus, or the baby after birth.

Similarly a Methods engineer, worth his salt, must envisage all the phases a pattern or a casting goes through, identify probable problems which are likely to manifest at various stages of Foundry operation.

In other words I am calling a" METHODS ENGINEER " a complete foundry man.

For all I am worth, to the best of my ability with a dash of divine intervention, I hope I will able to do justice to the TASK on hand. Also familiarise you with all facets of a foundry operation.

Your are probably feeling bit heavy. So let us digress a bit. There is a saying " IT TAKES ALL SORTS TO MAKE A WORLD " How true. Remember you are not a nonentity. Do you know why ? With out you this world of ours will not be complete.

I need to tell you a story now. There was an Indian scientist by name S.N.BOSE. He was a physicist and a young man. He wrote a paper on Theoretical physics. Like any youngster, he wanted second opinion from an other theoretical physicist. He sent his paper to none other than Einstein himself. At that time Einstein was still in Germany. He did not know English. A kind soul he was he got the paper translated to German. Read the paper, made some corrections and published a paper jointly in the name of BOSE & EINSTEIN. That paper was titled "BOSE-EINSTEIN STATISTICS" which is like a Bible for all Theoretical physicists even to this day. He identified a particle in the process and he named the particles as "BOSONS" after S.N.BOSE. What a commendable act of kindness.

Let us go to the other end of the Spectrum.

One Mr Chandrashekar ,again a physicist and a theoretical physicist. He went to LONDON and delivered a lecture on ASTROPHYSICS at ROYAL SOCIETY. In the audience there was PROF EDDINGTON. EDDINGTON was a NOBEL LAUREATE himself. He tore Chandrashekar into pieces.

A dejected, demoralised, demolished and depressed Chandrashekar left the shores of BRITAIN once for all. He went to UNIVERSITY OF CHICAGO in USA. Chandrashekar worked on Astrophysics. After full 50 years later Chandrashekar got a NOBEL PRIZE for the same theory he had proposed 50 Years earlier at ROYAL SOCIETY OF LONDON.

To day there is what is called "CHANDRASHEKAR LIMIT" in Astrophysics. Do you see the extreme contrast between EINSTEIN & EDDINGTON.

Now back to work.

METHODING OF CASTINGS

Methoding of castings is the HEART & SOUL of making a sound CASTING. As I have already told you Foundry is an old art but young science. Till 1939 castings were made by trial and error method. What we call FEEDERS now were called RISERS because workers used to see the way liquid metal was raising in the mould. The name RISERS got stuck, but to-day it is an inappropriate word. FEEDER is the appropriate word

Let us understand the word FEEDER. When we heat any thing it expands.

When a metal is melted, it takes the heat in 3 stages. 1) Solid state, $\text{Mass} \times \text{Cp1} \times (\text{melting point} - \text{room temperature})$ - **Sensible Heat**, 2) Melting (Solid to Liquid) $\text{Mass} \times \text{Latent Heat}$ At it's **Melting point**, this is called as **Latent Heat**, 3) $\text{Mass} \times \text{Cp2} \times (\text{pouring temperature} - \text{melting temperature})$ - **Super Heat**. To give you an example, Pure Iron melts at 1539 degrees.

But you can not pour at 1539 degrees as it will become solid while pouring itself, so we give an additional heat to this liquid so that the metal remains above 1539 degrees till the cavity in the mould is filled & metal takes the shape of the casting. So we pour our metal at about 1640 degrees. As we all know when ever some thing is heated it expands, as we have put in 3 different heats namely Sensible Heat, Latent Heat & Super Heat-there is a great deal of expansion. While cooling, loss of Super Heat leads to Liquid - Liquid Shrinkage, the loss of Latent Heat leads to Solidification Shrinkage.

While loosing Sensible Heat, it occurs in Solid state, hence to counter the contraction the Pattern is made bigger to accommodate that contraction.

We need a **Reservoir of liquid metal** to compensate for other two shrinkages.

That comes from **FEEDERS**.

Imagine a CONE solidifying and a ROD solidifying. Would there be any difference. In a Cone solidification starts from the tip and gradually solidification moves towards the base of the cone. This pattern of solidification is called DIRECTIONAL SOLIDIFICATION. Where as in a ROD, there is a concurrent solidification taking place across the length of the rod. This kind of solidification that takes place in a rod is not conducive to a SOUND CASTING. Where as THE SOLIDIFICATION PATTERN that takes place in a CONE is conducive to a SOUND CASTING.

SO THE METHOD OF MAKING ANY CASTING SOLIDIFY LIKE A CONE TOWARDS THE FEEDER, LEADS TO A SOUND CASTING.

IN ONE WORD THIS IS THE CRUX OF "METHODING"

This is achieved by making use of temperature gradients which result in Directional Solidification. By this we are making all the SHRINKAGE move out of the casting and go to feeder where a reservoir of liquid metal is available to compensate for the shrinkage which otherwise would have occurred in the casting itself. This process of taking this shrinkage

from casting into a feeder is called **Directional Solidification. The Engineering of this is called METHODING.**

In 1939, one person by name CHEVERINOV came up with an equation, Called CHEVERINOV'S EQUATION. It looked like this:

$$t = 0.75 \times V^2 \times Q^2 \times S^2 / (SA)^2 \times T^2 \times k \times D \times Cp$$

Where t = Solidification time

V = Volume of the liquid metal

Q = Heat content of the metal

S = Density of the metal

SA = Surface area through which heat content of the liquid metal was lost to facilitate solidification

T = Solidification temperature

K = Thermal conductivity of mould material

D = Density of mould material

Cp = Specific heat of mould material

There are some terms which need further explanation.

Q-Heat content of Metal.

= Weight of metal x Specific heat (Cp1) x (Melting point – Room temp) ----1

= Weight of metal x Latent heat (at melting point)-----2

= Weight of metal x Specific heat (Cp2) x(Pouring temp---Melting point)----3

The sum of 1+2+3 = Total amount of heat required till pouring temp

Specific heat is the amount heat required to raise the temp of a unit mass(weight) by 1degree centigrade—calories / gram/ degree C

This specific heat is not a constant figure.

Imagine that you are climbing 1000 steps to reach a temple, you will climb first 50 steps easily with out getting tired. There are after raising each and every step needs an extra effort. We human beings being intelligent we rest for a while and start climbing again. Even the people who built the steps provide what is called “LANDING” for resting.

But metals have no such advantage. The extra effort(heat) needed to raise the the temp by every 1 degree keeps raising.

For the most part, Cp of pure metals at room temp are available in

Physical constants tables. But Cp at higher temp are not available at all even for pure metals and for ALLOYS it is not available at all.

Then again we have Cp1 and Cp2.If Cp1 itself is not known properly what to talk of Cp2.

The atoms of the metal are BOUND or BONDED by a FORCE. For our

convenience sake ,let us assume that each atom of metal is BOUND BY A SPRING with another atom of metal. On heating the strength of the spring strength deceases. Here (1) is called SENSIBLE HEAT.

LATENT HEAT is the amount of heat required to CONVERT one unit mass of metal from SOLID TO LIQUID at it's MELTING TEMPARATURE.

For pure metals this data is available. Alloys do not melt at ONE temp rather OVER A RANGE OF TEMPERATURE. Here we do not know the Latent Heat. Now do you see in what sort of unchartered territory we are working in.

We virtually know nothing.

ON SEVERAL OCCASSIONS I HAVE FELT THAT WE METALLURGISTS OR FOUNDRYMEN ARE NEITHER SCIENTISTS NOR ENGINEERS.

When solid becomes liquid several bonds(springs in our case) are broken and hence liquid has a mobility which solids didn't have.

Information :Even in liquids all the bonds are not broken. That is the reason why it can be held in a container, but once you cross BOILING POINT all the bonds are broken and alloy becomes a GAS. Can you imagine holding a gas in an open container.

1) SENSIBLE HEAT- room temperature to melting point.

2)LATENT HEAT- at the melting point itself.

3) SUPER HEAT- from melting point to pouring temperature.

THE SUM OF 1+2+3 is the heat required to bring the metal to a temp where it can be poured into a container called MOULD.

Here I need to clarify a point, that is A SINGLE METAL (GOLD) is pure metal. But the moment we put some other element(ALL ELEMENTS ARE PURE) into a pure metal it becomes AN ALLOY.

Look at the RING you have on your finger, though we call it a GOLD RING, in actuality it is a GOLD ALLOY RING.

Pure Gold (24 carat) is too soft and hence to give it some strength, we add small amount of COPPER or SILVER. Now your GOLD ALLOY RING is 22 carat.

Most of us have a misconception about the amount heat required to bring the metal to pouring temp.

For example Iron has a melting point of 1539° C

Copper-----do-----1083° C

Aluminium-----do-----660° C

Hence we conclude that heat required to melt one unit weight of Fe > that of Copper > that of Aluminium .

Nothing is farther from truth.

Let us say we pour our metals at a superheat (melting temp + 100) degrees.

IRON AT 1539 +100 = 1639° C

COPPER AT 1083 + 100 =1183° C

ALUMINIUM $660 + 100 = 760^{\circ}\text{C}$

Now look at the amount of heat required to raise temp to a super heat of 100°C .

IRON ----349 KILOCALORIES PER Kg

COPPER—186 KILOCALORIES PER Kg

ALUMINUM 281 KILOCALORIES PER Kg

Hence heat required by $\text{Fe} > \text{Al} > \text{Cu}$

This is all because of combination of specific heats and latent heats.

So make sure you don't fall into this trap.

Now let us take a look at the some of the constants in CHEVERINOV'S EQUATION about which we are not certain.

Q---heat content of metal. Do we know C_p , LH and Melting point to any degree of certainty. NO. WE DON'T.

C_p –Specific heat of pure metals at high temp are not known, where is the question of knowing C_p of Alloy either at room temp or at high temperature ?

LH—Alloys do not solidify at ONE temp But over a range of temp, so we are not sure of latent heat of alloys.

Melting Point—Since alloys solidify over a range of temp, which temp do we take? HIGHEST,AVERAGE or LOWEST. We don't know.

Then coming to MOULD MATERIALS, we may know their Thermal conductivity and specific heat at room temp, but temp at which HEAT IS EXTRACTED(during solidification mould temp is not ROOM TEMP.) we do not know these values.

WITH SO MANY UNKNOWNNS OR NOT-SURE-OF PARAMETERS how can we use this EQUATION with any degree of confidence.

There appeared a person in early 1960's who simplified our problem a great deal. His name is R.WLODAWER.

Before we discuss Wlodawer's equation, let us have bit of a breather.

In early 70's a movie came whose name was SIDDHARTHA .Do not get confused this SIDDHARTHA with GOWTHAMA BUDDHA. He is different. It is a story of a young man who leaves his home and family on a quest for the truth. Embarking on a journey that takes him from the austerities of renunciation to the profligacy of wealth. That leads him through the range of human experiences from hunger and want, to passion, pleasure, pain, greed, yearning, boredom, love, despair and hope. A journey that finally leads him to a RIVER, where he gains PEACE AND EVENTUALLY WISDOM.

This classic is written by HERMANN HESSE, a NOBEL laureate in Literature.

In this book SIDDHARTHA was asked several times about what he can do.

*His answer was always, I CAN WAIT, I CAN FAST & I CAN THINK.
(DOES THAT MEAN WE DON'T OR CAN'T DO ANY OF THESE).
As regards to conclusion I leave it to your own judgement ?*

*There is a SPIRITUAL classic called "I AM THAT" by Nisargadutt Maharaj.
This man was a carpenter and unlettered BUT a realised SOUL. When he
was asked a QUESTION about his impression of the WORLD. His answer
was whose world yours or mine. This statement made a deep impression on
me, made me to conclude that world is an illusion. Each person has his own
WORLD IN HIS MIND.*

Now back to business.

Wlodawer came out with a concept called MODULUS. The word modulus means VOLUME / SURFACE AREA.

Wlodawer's premise is that since both mould and feeder are made of same material, why bother about their physical properties.

So Wlodawer stated that $M_f = 1.2 \times M_c$ will give a sound casting.

For a feeder Sphere is the Best. As it has got lowest surface area for a given volume. In other words a Sphere has got the highest modulus for a given volume. But a spherical feeder has got moulding problems. The next best shape is a CYLINDER. A cylinder has no mouldability problems.

When a feeder is kept on a casting, casting solidifies (shrinks) and results in a vacuum and as a result of it metal is "SUCKED IN" from feeder to casting. As a result volume of metal in feeder reduces. In the process a conical void is formed in feeder. To begin with, surface area of top of the feeder is a circular. On feeding the volume of feeder reduces and because of formation of a conical void, surface area of feeder increases. Thereby M_f decreases.

When we start off with $M_f = 1.17 \times M_c$, after complete solidification, $M_f = M_c$ as M_c is not changing and M_f is reducing because of increase of surface area and decrease of volume. Thus he provided a safety factor of 0.03 i.e. $1.17 + 0.03 = 1.2 \times M_c$. There by at the end of solidification, $M_f = 1.03$ as against a M_c of 1.0. This ensures a sound casting. (see figures in end)

In Wlodawer's equation we are not dealing with any factor which we cannot measure. We can measure volume and surface area. For the most part, that is all required.

M_f (volume / surface area of the cylinder) = $1.2 \times M_c$ (volume / surface area of the casting)

Let us take a cube as an example. volume of the cube of side ,say 200 mm is equal to $200 \times 200 \times 200 = 8000000 \text{ mm}^3$, surface area is equal to $200 \times 200 \times 6 = 240000 \text{ mm}^2$. Its modulus is $8000000 / 240000 = 33.33 \text{ mm}$.

Let us look at the modulus of feeder. $M_f = 1.2 \times M_c$.

$$M_f = 1.2 \times 33.33 = 39.996 \text{ mm.}$$

Here we have made a mistake. That is we have taken 6 surface areas for a cube. But once we put a feeder, as there is no heat loss between casting and feeder junction, we have only 5 cooling surfaces. Volume of cube being the same i.e. 8000000 mm^3 , surface area reduces. $200 \times 200 \times 5 = 200000 \text{ mm}^2$.

$$\text{Now the } M_c = 8000000 / 200000 = 40 \text{ mm.}$$

$$\text{If } M_c = 40 \text{ mm, } M_f = 1.2 \times 40 = 48 \text{ mm.}$$

Now let us look at a cylindrical feeder.

Volume of a cylinder = $0.785 \times d^3$ (if $h / d = 1.0$) and it's surface area is equal to $0.785 \times d^2$ (top) + $3.14 \times d^2$ (sides). Bottom of the cylinder, as it is , sitting on the cube is a non-cooling area..

$$\text{Now } M_f = \text{volume} / \text{surface area} = 0.785 \times d^3 / 0.785 \times d^2 + 3.14 \times d^2 = d / 5$$

$$M_f = d / 5 = 0.2 d = 48 \text{ mm (see above).}$$

$$d = 48 / 0.2 = 240 \text{ mm dia.}$$

i.e. for a cube of $200 \times 200 \times 200 = 8000000 \text{ mm}^3$, you need a feeder of 240 mm dia and 240 mm height sand cylindrical feeder.

A cube of 200 mm side needs a feeder of 240 mm dia x 240 mm height.

Here there is a lacuna. If we deal in terms of mm(which are large numbers) we are likely to make mistakes, while dealing with large numbers.

Hence a simple solution is $10 \text{ mm} = 1.0 \text{ cm}$, $10 \text{ cm} = 1.0 \text{ dm}$.

So we deal with decimetres. $1.0 \text{ decimetre} = 100 \text{ mm}$. then calculation becomes simple. For $200 \text{ mm} \times 200 \text{ mm} \times 200 \text{ mm} = 8000000 \text{ mm}^3$ becomes ,

$$2 \text{ dm} \times 2 \text{ dm} \times 2 \text{ dm} = 8 \text{ dm}^3. \text{ Now compare the above values.}$$

$8000000 \text{ mm}^3 = 8 \text{ dm}^3$. The chances of your making mistakes are greatly reduced.

So we deal with dm only. Not in cm or in mm.

$1.0 \text{ dm}^3 = 8.0 \text{ kg}$. since the figure is on the higher side, we consider $1.0 \text{ dm}^3 = 7.8 \text{ kg}$ while dealing with casting weight. 7.6 kg while dealing with feeder weight(liquid). You are already incorporating a safety factor.

(DENSITY OF STEEL FOR CASTING----- $7.8 \text{ Kg} / \text{dm}^3$.)

(DENSITY OF LIQUID STEEL IN FEEDER---- $7.6 \text{ Kg} / \text{dm}^3$)

Now to familiarise ourselves with calculations in dm, let us repeat the process.

A $200 \text{ mm} \times 200 \text{ mm} \times 200 \text{ mm}$ cube will have a volume of $2 \text{ dm} \times 2 \text{ dm} \times 2 \text{ dm} = 8 \text{ dm}^3$. surface area = $5 \times 2 \text{ dm} \times 2 \text{ dm} = 20 \text{ dm}^2$.

$$\text{Volume} = 8 \text{ dm}^3$$

$$\text{Surface area} = 20 \text{ dm}^2$$

$$\text{Modulus of casting} = 8 / 20 = 0.4 \text{ dm i.e. } M_c = 0.4 \text{ dm}$$

$$\text{Modulus of feeder} = 1.2 \times M_c = 1.2 \times 0.4 = 0.48 \text{ dm} *$$

(Remember we have taken only 5 surfaces into consideration as feeder is kept

on top surface area and hence it becomes a NON-COOLING AREA)

Let us have a cylindrical feeder whose diameter is d and whose height is also d
This we call $h/d = 1.0$. Now let us do the calculations.

$$\text{Volume} = \pi / 4 \times d^2 \times h \quad (\text{where } \pi = 3.14)$$

$$\text{Volume} = 3.14 / 4 \times d^2 \times d \quad (\text{as we have assumed } h/d = 1.0 \text{ and hence } h = d)$$

$$\text{Volume} = 0.785 \times d^3 \text{-----(a)}$$

$$\text{Surface area} = \pi / 4 \times d^2 \text{ (top) } + \pi \times d \times h \text{ (side)}$$

$$\text{Surface area} = 3.14 / 4 \times d^2 + 3.14 \times d^2.$$

$$\text{Surface area} = 0.785 \times d^2 + 3.14 \times d^2 \text{-----(b)}$$

$$\text{Mf} = \text{volume} / \text{surface area} \text{----- (a) / (b)}$$

$$\text{Mf} = 0.785 \times d^3 / 0.785 \times d^2 + 3.14 \times d^2$$

$$\text{Mf} = 0.785 \times d^2 (d) / 0.785 \times d^2 (1 + 4) \quad \text{-----} 3.14 / 4 = 0.785$$

$$\text{Mf} = d / 5 = 0.2 \times d$$

We have already calculated our $\text{Mf} (*)$ which is 0.48 dm.

$$\text{Mf} = 0.2 \times d = 0.48 \text{ dm}$$

$d = 0.48 / 0.2 = 2.4 \text{ dm}$ which is equal to 240 mm (which we had got earlier)

So a CUBE of 200 mm x 200 mm x 200 mm NEEDS a SAND CYLINDRICAL FEEDER of 240 mm DIAMETER x 240 mm HEIGHT.

Now let us look at a feeder with a $h/d = 1.5$.

$$\text{Volume} = 0.785 \times d^2 \times 1.5 d = 0.785 \times 1.5 \times d^3$$

$$\text{Surface area} = 0.785 \times d^2 \text{ (top) } + 3.14 \times d \times 1.5d \text{ (side) (bottom-non-cooling)}$$

$$\text{Mf} = \text{Volume} / \text{surface area}$$

$$\text{Mf} = 0.785 \times 1.5 \times d^3 / 0.785 \times d^2 + 3.14 \times 1.5 \times d^2$$

$$\text{Mf} = 0.785 \times d^2 \times 1.5 \times (d) / 0.785 \times d^2 (1 + 4 \times 1.5)$$

$$\text{Mf} = 1.5 \times d / (1 + 6) = d \times 1.5 / 7 = 0.214d$$

$$\text{Mf} = 0.214d \quad (h/d = 1.5)$$

If $h/d = 1.0$, $\text{Mf} = 0.2d$

If $h/d = 1.5$, $\text{Mf} = 0.214d$

For the same Mf of 0.48dm, in case of $h/d = 1.0$, $d = 0.48 / 0.2 = 2.4 \text{ dm}$

For $h/d = 1.0$ feeder size is 240 mm dia x 240 mm height

$$\text{Weight of liquid metal} = 0.785 \times (2.4)^3 \times 7.6 = 82.47 \text{ Kg. } (*1)$$

For $h/d = 1.5$, $\text{Mf} = 0.48 = 0.214d$,

$$d = 0.48 / 0.214 = 2.2429 = 2.25 \text{ dm dia ---height} = 2.25 \times 1.5 = 3.37 \text{ dm}$$

$$\text{weight of liquid metal} = 0.785 \times (2.25)^2 \times 3.37 \times 7.6 = 101.78 \text{ Kg } (*2)$$

COMPARE (*1) WITH (*2)---101.78 Kg—82.47 Kg = 19.31 Kg of EXCESS metal is being consumed to cater to same MODULUS.

$$19.31 \text{ Kgs (excess metal) } / 82.47 \text{ Kgs (actual metal in } h/d = 1.0)$$

23.4% Excess metal being used in $h / d = 1.5$ to cater to a same MODULUS VALUE.

Hence always use $h / d = 1.0$ feeders only unless you have some genuine constraints.

Let us look at it from a different angle.

Weight of Cube = $2 \text{ dm} \times 2 \text{ dm} \times 2 \text{ dm} = 8 \text{ dm}^3 \times 7.8 \text{ Kg} / \text{dm}^3 = 62.4 \text{ Kg}$.

Plain Carbon steel has liquid-liquid shrinkage(superheat) + solidification Shrinkage (latent heat) of 6.0 %.

i.e. $62.4 \text{ Kg} \times 0.06 = 3.744 \text{ Kg}$. This is the feed metal requirement to get a sound casting.

Now let us look at 240 mm dia x 240 height feeder has 82.47 Kg of metal, assuming that 10 % of the total metal is available for feeding the casting, $82.47 \times 0.1 = 8.247 \text{ Kg}$ are available, which is more than adequate.

Now let us look at 225 mm dia x 337 mm height feeder, it has 101.78 Kg Of metal. Assuming that same 10 % metal is available for feeding the casting

To be sound, see how much metal we are getting. $101.78 \times 0.1 = 10.1 \text{ kg}$.

If 240 mm dia x 240 mm ht is giving 8.2 Kg as against a requirement of 3.8 Kg .A $h / d = 1.5$ feeder of 225 mm dia x 337 mm ht is giving 10.1 Kg which is much more than adequate.

So I repeat use only $h / d = 1.0$ feeder only unless you have some genuine constraint.

I am beginning to hear lot of alarm bells or shall I call them warning bells ringing in your mind as to why we should we provide so much extra metal i.e. 8.2 Kgs as against a requirement of 3.8 Kg.

This doubt is perfectly understandable and valid too.

A FEEDER HAS TWO FUNCTIONS.

1) IT SHOULD SOLIDIFY AFTER THE CASTING HAS SOLIDIFIED.

2) IT SHOULD HAVE ADEQUATE FEED METAL TO GIVE A SOUND CASTING.

A FEEDER HAS TO TAKE CARE OF BOTH THE CRITERIA.

IF YOU LEAVE OUT ONE AND TAKE CARE OF AN OTHER YOU END UP WITH A DEFECTIVE CASTING.

I have gone through this experience with a non-weldable, defective, HCHCr—2.0% C ,12 %Cr alloy. Only option left was to cut the casting with expensive cutting electrodes rather than relatively cheaper OXYGEN-ACETYLENE gas.

When I realised my mistake I felt miserable.

SO I REPEAT YOU HAVE TO SATISFY BOTH ASPECTS.YOU HAVE NO FREEDOM THERE. Treat this as a WARNING from a person who has burnt his fingers once way back in 1979.

R.WLODAWER wrote a book on “ DIRECTIONAL SOLIDIFICATION OF STEEL CASTINGS “Originally this book was written in GERMAN & Subsequently translated to ENGLISH in 1966.I have been having this book

from 1978, but I can't say with any degree of certainty that I have read every thing in this book.

There are two kinds of castings---CHUNKY CASTINGS(thick) & RANGY CASTINGS(thin). Example of chunky castings is a CUBE, for RANGY CASTINGS is a plate casting. In chunky castings $V_c \gg$ surface area of castings. In a rangy castings $V_c \ll$ surface area of castings. In chunky castings **Modulus** is more important, in a rangy castings **available metal** is more important, like in a PLATE. At the outset you have no means of knowing which is rangy or chunky casting. **Do your calculation for MODULUS & AVAILABLE LIQUID METAL, which ever diameter of feeder satisfies both the conditions, employ that feeder.**

Wlodawer, in his book(page-149)writes an equation.

SOLIDIFICATION TIME IN MINUTES = $2.1(M \text{ in cm})^2$ FOR GREEN SAND MOLDS.

John Nash ,a brilliant mathematician, got a NOBEL prize in Economics. He had the habit of inventing or discovering things for himself, including Pythagoras theorem.

Let me confess something to you today, I am against $h / d = 1.5$ feeder, but the explanation I used to give till yesterday is different from what I have given today. when I look back at my old explanation I feel silly. Because I had ignored something which would have been obvious to any body, but not to me .

AWARENESS OF ONE'S IGNORENCE IS THE BEGINNING OF LEARNING.

He who knows not, knows not that he knows not, is a fool, shun him.

He who knows not, knows that he knows not, can be taught, teach him.

He who knows, but knows not that he knows, is asleep, wake him.

He who knows, knows that he knows is a prophet, follow him.

Generally people write books on what they know.

But RICHARD FEYNMAN, a NOBEL LAUREATE IN PHYSICS WRITES ABOUT WHAT HE DOES NOT KNOW IN HIS "THE FEYNMAN LECTURES ON PHYSICS" which went on to become an international best Seller.

1) Feynman says "I was born not knowing and have only had little time to change that here and there" If this is not height of humility, what is?

2) Science is a way to teach how something gets to be known, what is not known, to what extent things are known(for nothing is known absolutely),how to handle doubt & uncertainty, what the rules of evidence

are, how to think about things so that judgements can be made, how to distinguish truth from fraud.

3) Feynman talked of how to build an automobile smaller than a dot. It was only after 20 years this field got its name "NANOTECHNOLOGY" so Feynman was intellectual father of legion of self-described nanotechnologists.

4) Feynman believed in "great value of satisfactory ignorance & how doubt is not to be feared but welcomed."

5) Feynman was happy to embrace ignorance & doubt.

6) A colleague of Feynman & a scientist himself commented that when some body does some thing new, we felt that we could have also done it, but with Feynman we were never sure.

Extracted from "GENIUS-THE LIFE & SCIENCE OF RICHARD FEYNMAN" BY JAMES GLEICK.

Let us get back to work.

Solidification time is dependent on rate of heat extraction by the moulding medium.

Moulding material Solidification time of 150 mm dia STEEL sphere

	Moulding material	Solidification time(in Minutes)
1	Copper chill mould	4.2
2	Steel chill mould	4.3
3	Graphite mould	5.1
4	Copper shot bonded	6.3
5	Steel shot bonded	9.0
6	Silicon carbide bonded	10.4
7	Magnesite bonded	11.2
8	Alumina bonded	12.1
9	Chrome ore bonded	13.4
10	Zircon bonded	13.8
11	Olivine bonded	15.8
12	Silica sand bonded	17.0
13	Thermit-silica bonded	31.0
14	Exothermic compound(45 mm thick)	48.0
15	-----do------(80 mm thick)	90

Now that you know the volume of the sphere, surface area of the sphere and Solidification time in minutes, you can calculate the CONSTANT.

Solidification time in minutes = $k \times (\text{modulus in cm})^2$

Now going back to our cube- 200 x 200 x 200 (all dimensions in mm)

We had got a sand feeder of 240 mm dia x 240 mm height.

Since cube is only 200 mm and feeder dia being 240 mm dia. there will be a 20 mm Projection of feeder on each side. This projection will be in touch with the mould material, which will result in faster cooling. This faster cooling will result in premature solidification of feeder, which result in defective casting. To avoid this problem THE TOP PORTION of the cube is made bigger by adding a metallic pad at the top of the cube(becomes a part of the casting) so as to accommodate 240 mm dia feeder. This would give a SOUND casting. But it would increase the fettling work on the casting viz. cutting and grinding that extra portion which adds to cost of production.

This problem can be solved by INSERTING a BREAKER CORE (BRC) in between casting and feeder.

As BRC is made of sand ,**it's dimensions are always governed by sand feeder.**

Circular opening of BRC is 40 % of sand feeder dia and it's thickness is 10 % of sand feeder dia. As our sand feeder dia is 240 mm dia. The opening of the Breaker core is $240 \times 0.4 = 96$ mm dia. Thickness of BRC is $240 \times 0.1 = 24$ mm. Along the thickness there is a TRIANGLE WHOSE BASE IS 24 mm. Angle of the top of the triangle is 90 degrees. DIA of BRC from inside edge to the opposite end is 96 mm.

Now look at the benefits that will accrue.

Earlier you had to cut 240 mm dia & pads then grind them.

At the minimum $0.785 \times 2.4 \times 2.4 = 4.52$ dm² + was to be cut & ground.

Now $0.785 \times 0.96 \times 0.96 = 0.723$ dm² is to be cut & ground.

$0.723 / 4.52 \times 100 = 15.99$ % or 16 %. Your savings in cutting & grinding will be more than 84%.you save on gas, grinding wheel, time and labour charges.

Note : no matter what feeder you use, sand, insulating or exothermic your BRC dimension will remain that of sand feeder as BRC is made of SAND.

Now we change gears.

A Sand feeder will have an available metal of 10%, in other words, if a sand feeder has 10 Kgs of liquid metal in it, only 1.0 Kg of liquid metal comes down to feed the shrinkage. This 10% metal is called AVAILABLE METAL.

This figure in case of an INSULATING SLEEVE is 20%. The same in case of an EXOTHERMIC SLEEVE is 30 %.

In order to IMPROVE the YIELD i.e. CASTING WEIGHT / TOTAL METAL used for getting a SOUND CASTING, we need to reduce the metal used in FEEDERS. This is achieved by using insulating & exothermic sleeves.

This reduces the total metal used per casting & thus improving the YIELD.

An insulating feeder will have a MODULUS EXTENSION FACTOR(MEF) of 1.3 to 1.5 i.e. sand feeder dia / 1.3= diameter of insulating sleeve.

In our case $240 / 1.3 = 185$ mm dia x 185 ht

A sand feeder of 240 mm dia x 240 mm ht will have 82.47 Kg of metal.

An insulating feeder with a MEF of 1.3 will give 185 mm dia x 185 ht. This takes a metal of 37.77 Kg. $82.47 - 37.77 = 44.7$ Kg of liquid metal savings.

It works out to $44.7 / 82.47 \times 100 = 54.2\%$ savings of liquid metal.

An insulating sleeve will have an available metal of 20 %

$37.77 \times 0.2 = 7.554$ Kg of liquid feed metal is available against our requirement of 3.8 Kg.

If you use an exothermic sleeve, it will have a MEF of 1.5

$240 / 1.5 = 160$ mm dia x 160 ht

$0.785 \times (1.6)^3 \times 7.6 = 24.4$ Kg.

An exo sleeve gives anywhere between 25 to 30 % available metal.

$24.4 \times 0.25 = 6.1$ Kg.

Now let us look at what we need and what we get.

Required metal = 3.8 Kg.

Sand feeder 240 dia x 240 = 82.47 Kg—available metal = 8.24 Kg

Insulating feeder-185 dia x 185 ht = 37.77 Kg available metal = 7.55 Kg.

Exothermic sleeve 160 dia x 160 ht = 24.43 Kg available metal = 6.1 Kg.

All the three figures are more than required---3.8 Kg.

In any foundry, an Induction furnace is the costly equipment with a limited capacity. So our endeavour should always be to get more Kg of Casting per ton of liquid metal. This is called YIELD IMPROVEMENT.

This is achieved by changing from SAND FEEDERS to INSULATING FEEDERS to EXOTHERMIC FEEDERS.

Let us say a Sand feeder of dia D has a solidification time of (a), an Insulating feeder of dia D will have a solidification time of (b), an Exothermic feeder of dia D will have a solidification time of (c).

If you look at the solidification times of all the three-- $c > b > a$. As our casting being same we need a certain solidification time so as to get a sound casting.

For argument's sake let us say a sand feeder with a solidification time (a) is adequate for our casting, then an insulating feeder with the same solidification time of (a) is adequate for our purpose. But solidification time of an insulating feeder of same dia as that of sand feeder has a longer solidification time (b).

In order to get a solidification time of (a) in an insulating feeder, we need to use a smaller insulating feeder to get a solidification time of (a). Thus saving in amount of liquid metal that goes into an insulating feeder. The argument holds good for an exothermic feeder, which will be even smaller than an insulating feeder for the same solidification time of (a). Thus we save on weight of liquid metal that goes into feeder per Kg of casting.

There by our total liquid metal requirement per Kg of casting comes down.

Hence we can produce more weight of castings per ton of liquid metal.

Let us take a relook at the difference between $H/D=1.0$ & $H/D=1.5$

Mf in Cm	H/D=1.0 Dia in mm	Weight in Kg	H/D=1.5 Dia in mm	Weight in Kg	Weight Difference
1	60	1.15	54	1.22	0.07
2	120	9.5	107	10	0.5
3	180	30.5	160	34	3.5
4	240	75	214	82	7
5	300	143	266	150	7

This is extracted from Wlodawer's DIRECTIONAL SLOIDIFICATION OF STEEL CASTINGS.

Conclusion: For same Mf – $H/D = 1.5$ consumes more metal.

Hence reduces YIELD + increases conversion cost of returns to melt.

It gives you an advantage of less cutting and grinding cost as the dia ($h/d = 1.5$) is less .Eventual positive VALUE ADDED has to guide you as to which feeder to be used.

Left to me I would rather use $H/D = 1.0$,but I am unable to put my finger on the reason.

(I am 58 yrs old and have 30 years of experience , if I am having a dilemma, what about youngsters and those who have been working in foundries but have no proper exposure to foundry technology. That is foundry for you I had not thought of this problem in this direction in last 30 years, why all of a sudden when I am writing a book. Could it be a DIVINE INTERVENTION ?)

Let us digress a bit.

1) One Prof JOHN BARDEEN had come to I.I.Sc, long time back, you are probably wondering as to who this BARDEEN is. He is only person on face of the earth who has got TWO NOBEL PRIZES IN THE SAME SUBJECT-PHYSICS (SEMI-CONDUCTORS AND SUPERCONDUCTORS).When some body asked him a question, with out even batting his eye lid he said that he does not know the answer.

2) Prof EINSTEIN was with INSTITUTE OF ADVANCED STUDIES,PRINCETON in USA. One day a little girl from the neighbourhood went to him and asked him if he would teach her Physics. Einstein in turn asked her as to how much she would pay him. The girl said my weekly pocket money is 10\$ and she would pay him 5\$ per week. Einstein is supposed to have said that no university in the world had paid him half of it's income, so he will teach her free. Einstein was already a famous and well respected man. One day the girl's mother went to Einstein and apologized to him about her daughter disturbing him and told him that she

would stop her daughter from disturbing him. Einstein is supposed to have told her not to do any such thing, as he was learning more from the girl rather than her learning from him.

3) In BRITAIN, there was very well known Chemist by name HENRY CAVENDISH. One day Cavendish saw a small, poor boy tinkering with some thing on road side. CAVENDISH asked that boy if he would go with him to his place where he could do what he liked and he would be provided with food and shelter. The boy readily agreed and went with him.

One evening Cavendish was stirring some solution. Then his wife came and reminded him of a party for which they had been invited (Cavendish & his family use to live up-stairs).Cavendish told the boy to keep stirring and he would come back soon. When they returned from the party it was late in the night. Cavendish straight away went to bed. Next morning when Cavendish went to the lab what he saw surprised him. The boy was still stirring. That boy later on became a famous scientist himself. He is none other than MICHAEL FARADAY.

Back to our work.

Solidification times of 100 mm dia x 100 mm ht feeders in **minutes**

(bottom is a cooling surface. No treatment means sand feeder with no top cover)

	No Treatment	Top Insulation only	Side Insulation only	Top & Side Insulation
Steel	5	13.4	7.5	43
Copper	8.2	14	15.1	45
Aluminium	12.3	14.3	31.1	45.6

Solidification time in minutes = $2.1 \times (Mf)^2$ where Mf is in cm.

Let us find out the geometrical modulus of the cylinder.

Let us take the case of STEEL with no treatment

It has 3 cooling surfaces. Bottom, top and side.

As the dimension of the feeder are 100 mm dia x 100 ht—for our calculation purpose 1 dm dia x 1dm ht.

$$\text{Volume} = 0.785 \times (1.0)^2 \times 1.0 = 0.785 \text{ dm}^3$$

$$\text{Surface area 1\&2 (top + bottom)} = 2 \times 0.785 \times (1.0)^2 = 1.57 \text{ dm}^2$$

$$3 \text{ (side)} = 3.14 \times 1.0 \times 1.0 = 3.14 \text{ dm}^2$$

$$\text{Add 1+2+3} = 4.71 \text{ dm}^2$$

$$Mf = V / SA = 0.785 / 4.71 = 0.1666 \text{ dm or } 1.67 \text{ cm.}$$

Solidification time in minutes = $2.1 \times (1.67)^2 = 5.85$ minutes.

But what we are getting in our case is only 5.0 minutes

Why is this difference?

As the temp of a thing raises(after it looks bright red) radiation losses become predominant. Radiation losses are proportional to T^4 . Here T is a temperature which is not centigrade but Kelvin or Absolute.

(Information: zero degree Kelvin is supposed to be an Ideal temperature which is still not achieved. 0 degree centigrade = 273 degree K)

Let us assume that we pour our steel at 1640 degree centigrade which is equal to $1640 + 273 = 1913$ degree Kelvin .(T)

Heat loss due to radiation is proportional to $(1913)^4$ ---it is indeed a huge loss.

Though we have assumed that heat loss from bottom and top are same, it is not true. Heat loss from top is far, far more than what heat is being lost from bottom.

So the top Surface area is not 0.785dm^2 but more. This change of area leads to an area which is more than 0.785dm^2 . This area is called APPARENT SURFACE AREA. This becomes evident when you cover the top. Solidification time has gone up to 13.4 minutes.

IN ANY FERROUS FOUNDRY, IN ORDER TO GET THE BEST OUT OF THE FEEDER(BE IT SAND, INSULATING OR EXOTHERMIC) COVER TOP AT LEAST WITH “PADDY HUSK.” INCIDENTALLY PADDY HUSK IS QUITE EFFECTIVE. THIS INCREASES SOLIDIFICATION TIME OF FEEDER. SO WE CAN USE A SMALLER FEEDER THEREBY INCREASING THE YIELD.

Calorific Values of certain materials which can be used as ANTI-PIPING Compounds, which can reduce RADIATION LOSS from liquid metal from the top are given here.

Material	Calorific value in KCals / Kg
Dry cow dung cake powder	2100
Dry fire wood powder	4500
Coconut coir dust	4200
Coconut shell powder	7800
Paddy Husk	3800

For a given casting, we can't alter the volume, but we can alter the APPARENT SURFACE AREA by using various materials whose list is given earlier .

If you observe here a 150 mm diameter STEEL sphere has a solidification time of 17.00 minutes in normal SAND MOULD. But this solidification time for the Same casting can be VARIED from 4.2 minutes to 90.0 minutes.

As a rule, we attempt to hasten the solidification time of casting and delay the solidification time of the feeder. This is done by altering the APPARENT SURFACE AREA. If APPARENT SURFACE AREA(ASA) OF A SAND

CASTING WITH A SAND FEEDER is 1.0. The ASA can be altered to less than 1.0 or more than 1.0.

In a normal sand casting with sand feeder, with $M_f = 1.2 \times M_c$, as the liquid metal begins to become solid, a vacuum is created in the casting, as a result of vacuum in the casting and the atmospheric pressure acting on top of the liquid metal in feeder, liquid metal from feeder is sucked into casting. This process goes on during the entire period of solidification.

When casting is solidifying in the mould, liquid metal is also getting solidified in the feeder, as a result we get a CONICAL shrinkage in feeder. At $M_f = 1.2 M_c$ THE TIP OF THE CONICAL SHRINKAGE STAYS INSIDE THE FEEDER, DOES NOT ENTER THE CASTING. This results in a SOUND CASTING.

Supposing I use **STEEL CHILLS to extract heat from casting faster**, solidifying metal in feeder would begin to suck liquid metal from feeder sooner than later.

As a result, height of the shrinkage cone in feeder decreases and its base at the top (opening of the shrinkage WIDENS). We can go on altering the rates of HEAT EXTRACTION FROM THE MOULD AS WELL AS FEEDER TO SUCH AN EXTENT THAT WE CAN TOTALLY ELIMINATE THE SHRINKAGE CONE AND MAKE IT FLAT. This condition will give you BEST condition of FEEDING AND HIGHEST YIELD.

What is this YIELD ?. YIELD is the total weight of good casting obtained per, every 100 Kg of liquid metal poured into mould. Higher is the YIELD more efficient is your Methoding practice.

Now let us take an example and do a feeder calculation.

Let us take a plate (ignoring the length of the casting, if width (W) is equal 5 x Thickness (T) or more, it is called, a PLATE, if $T = W$, it is called a BAR.

Let us take a casting 250 x 250 x 50 (all dimensions in mm)

Let us find out the volume. $V = 2.5 \times 2.5 \times 0.5 = 3.125 \text{ dm}^3$.

Surface areas—there are 6 surfaces.

1) $2.5 \times 2.5 \times 2 = 12.5 \text{ dm}^2$
2) $2.5 \times 0.5 \times 4 = 5.0 \text{ dm}^2$
TOTAL = 17.5 dm^2

$M_c = V / SA = 3.125 / 17.5 = 0.1785 \text{ dm}$

$M_f = 1.2 \times M_c = 1.2 \times 0.1785 = 0.2143 \text{ dm}$

We all ready know that if $H / D = 1.0$, $M_f = 0.2d$.

$0.2d = 0.2143$, $d = 0.2143 / 0.2 = 1.0715 \text{ dm dia} \times 1.0715 \text{ mm ht.}$

1.0715 dm (107.15 mm) For sake of convenience assume it to be 1.1 dm

We have taken care of Modulus of the casting.

Now we need to take care of FEED METAL requirement.

Our $V = 3.125 \text{ dm}^3 = 3.125 \times 7.8 \text{ (density) } = 24.375 \text{ Kg} = 24.4 \text{ Kg}$

A liquid steel poured, at 1640 degrees, has liquid-liquid shrinkage (because of superheat)and a solidification shrinkage (because of Latent heat) has a total shrinkage of 6.0 % (this varies from alloy to alloy) in Plain C steel.

24.4 Kg say 25 Kg x 0.06 = 1.5 kg i.e. 1.5 Kg of liquid metal has to come down from feeder (this is called Available Metal)

From Modulus calculation, our dia of sand feeder is 110 mm dia x 110 ht. Let us find out the total metal in this feeder.

$0.785 \times (1.1)^3 \times 7.6 = 7.94$ Kg. Assuming that a sand feeder has 10 % available metal, this sand feeder of 110 mm dia x 110 mm ht has 7.94 Kg.

It can give $7.94 \times 0.1 = 0.794$ kg. But our requirement is 1.5 Kg.

If 10 %----- 1.5 Kg

100 %----- $1.5 / 10 \times 100 = 15.00$ Kg. Our feeder should have 15.00 Kg of metal to deliver 1.5 Kg of FEED METAL or AVAILABLE METAL.

$$15 = 0.785 \times (d)^3 \times 7.6$$

$$D^3 = 15 / 0.785 \times 7.6 = 2.514$$

$$D^3 = 2.514 \text{ dm}^3 \quad (1.35 \times 1.35 \times 1.35 = 2.46 \text{ not adequate})$$

$$\quad (1.40 \times 1.40 \times 1.40 = 2.744 \text{ is adequate})$$

D = 140 mm dia x 140 mm ht. This 140 mm dia x 140 mm ht sand feeder has adequate feed metal to give a sound casting.

INFORMATION: In case of our cube, feeder size obtained by METHODS calculation itself had more than adequate feed metal, but in the case of the plate it is not so. Hence you need to CALCULATE FEEDER DIMENSION from both angles. Whichever FEEDER is BIGGER should be USED.

Solidification Time in minutes = $2.1 (\text{MODULUS in cm})^2$ --- for sand castings of Steel casting.

Now by using different materials, we can alter the solidification times. The Materials details are already given. For given casting (Which can't be changed) We can only change materials of FEEDERS so that these materials DELAY the Solidification .Hence increase the solidification time. But we want the same Solidification time as our casting as remained the SAME.

Let us view it this way.

$$T(\text{solidification time in minutes}) = 2.1 (\text{M sand in cm})^2$$

$$T(\text{solidification time in minutes}) = 2.1 (\text{a x M sand in cm})^2$$

$$T(\text{solidification time in minutes}) = 2.1 (\text{b x M sand in cm})^2$$

HERE a and b are CONSTANTS for insulating materials(a) and exothermic materials(b). Insulating materials are like your WOOLLEN SWEATER ,they do not allow your body heat to be lost, so you stay warm irrespective of out side temp. In other words insulating materials DELAY heat loss. As we are interested in the time the sand feeder took to solidify, we can REDUCE the SIZE of INSULATING FEEDER to such an EXTENT that it solidifies in the

same TIME as our ORIGINAL SAND FEEDER. This factor (a) is called MODULUS EXTENSION FACTOR(MEF)FOR INSULATING SLEEVES IT IS ABOUT 1.3 TO 1.5.

THAT IS IF OUR ORIGINAL SAND DIA WAS 100 mm, THE INSULATING FEEDER SIZE WILL BECOME $100 / 1.4 = 71.4$ mm dia x 71.4 mm ht. As we can't get each and every size we want, we have to accept the nearest available size which is 75 mm dia x 75 mm ht. Unlike sand feeders (which used to give a feed metal of 10 % of it's total weight) insulating feeders are supposed to give a feed metal of about 20% or more of it's own weight.

Let us imagine , on New Years eve you are in Kashmir, it is so cold there ,your sweater alone is inadequate to keep you warm. Then you light a CAMP FIRE to get additional heat so that you stay warm. Exothermic materials are like camp fire. These materials not only generate heat, they are also insulating as a result of this their solidification times are much longer than a SAND OR INSULATING FEEDER OF SAME SIZE. Hence exothermic sleeves can be smaller than an insulating sleeve for same solidification time.

MEF of EXO sleeve can be as high as 1.5 to 1.7.

For a 100 mm dia sand feeder can be replaced by $100 / 1.6 = 62.5$ mm dia x 62.5 mm ht exo sleeve. like earlier we have to take the nearest available size.

As the sizes of insulating sleeves and exo sleeves are much less than sand feeder, they consume lesser amount of liquid metal than what sand feeders would have taken. Hence Total requirement of liquid metal per casting is reduced. It results in increasing of yield. In other words you pour more number of castings per ton of molten metal.

Never trust any body's material (such as sleeves, mould paints, metal generating exothermic compounds etc,) unless a free trial is done and a good casting is obtained. In the event casting gets rejected, will he make good the loss you have incurred.(If you deeply look at it, it will have many hidden things such as loss of capacity, failure to meet commitments etc)

I am personally of the opinion, FOSECO'S materials are best. Let me hasten to add I have nothing to do with FOSECO in any form.

FOSECO is an acronym for FOUNDRY SERVICES COMPANY OF U.K.

They have plants all over the world. For a stringent condition if you want a material, they can import it from ENGLAND,GERMANY,FRANCE OR USA.

But they are bit expensive, to over come this problem have an annual contract.

Feeling bit heavy:

There are two laws. For your own good learn to respect them.

1) MURPHY'S LAW: ANY THING THAT CAN GO WRONG WILL GO WRONG.

2) PARKINSON'S LAW : EVERY BODY REACHES HIS LEVEL OF INCOMPETENCY SOONER OR LATER.

As far as I am concerned CONSTANT THINKING AND STUDY are the only solutions. Our Ex-President, Dr ABDUL KALAM in his book “ WINGS OF FIRE” states that TO AVOID FAILURES ANTICIPATE THEM.

Now take an example of a plate ,whose dimensions are 1000 mm x 200 mm x 25 mm.

$$\begin{aligned}\text{Volume of this plate} &= 10 \text{ dm} \times 2.0 \text{ dm} \times 0.25 \text{ dm} \\ &= 5.0 \text{ dm}^3\end{aligned}$$

$$\begin{aligned}\text{Weight of the casting} &= 5.0 \text{ dm}^3 \times 7.8 \text{ Kg} / \text{dm}^3 \\ &= 39.00 \text{ Kg.}\end{aligned}$$

$$\begin{aligned}\text{Surface area of the casting} &= 10 \times 2 \times 2 = 40 \text{ dm}^2 \\ 10 \times 0.25 \times 2 &= 5 \text{ dm}^2 \\ 2.0 \times 0.25 \times 2 &= 1.0 \text{ dm}^2\end{aligned}$$

$$\text{Sum of all these surface areas are} = 40 + 5 + 1 = 46 \text{ dm}^2$$

$$\text{Modulus of the casting} = V / \text{SA} = 5.0 / 46.0 = 0.109 \text{ dm}$$

$$\text{Mf} = 1.2 \times \text{Mc} = 1.2 \times 0.109 = 0.139 \text{ dm}$$

$$\text{Mf} = 0.2 \times d = 0.139$$

$$d = 0.139 / 0.2 = 0.695 \text{ dm} = 0.70 \text{ dm} = 70 \text{ mm dia} \times 70 \text{ mm ht}$$

$$\text{Here } V = 5.0 \text{ dm}^3 \times 7.8 \text{ Kg} / \text{dm}^3 = 39.00 \text{ Kg.}$$

$$39 \times 0.06 = 2.34 \text{ Kg feed metal required.}$$

$$\text{Weight of feeder} = 0.785 \times (0.7)^3 \times 7.6 = 2.046 \text{ Kg.}$$

$$\text{Sand feeder} = 2.046 \times 0.1 = 0.204 \text{ Kg available Metal}$$

$$\text{Insulating feeder} = 2.046 \times 0.2 = 0.409 \text{ Kg available Metal}$$

$$\text{Exothermic feeder} = 2.046 \times 0.3 = 0.612 \text{ kg available Metal}$$

None of the above three have enough available Metal to give a Sound casting.

Now let us find out a feeder which has enough feed metal.

Feed metal required is 2.34 Kg.

If 10 % is 2.34 Kg

100 % ---- $2.34 / 10 \times 100 = 23.40 \text{ Kg}$ is the total metal in the sand feeder.

$$23.4 = 0.785 \times d^3 \times 7.6 = 5.966 \times d^3$$

$$d^3 = 23.4 / 5.966 = 3.922 \text{ dm}^3$$

$d = 1.6 \text{ dm}$ (closest value) = 160 mm dia x 160 mm ht sand feeder. Though this sand feeder has ENOUGH FEED METAL, this will not give you a SOUND CASTING.

Having made this statement, the onus is on me to tell you as to how to get a sound casting.

Here I need to INTRODUCE A NEW CONCEPT CALLED “ FEEDING DISTANCE.”

1) Now a days, virtually, every one uses a CELL PHONE. When you make a call on CELL you get an answer, at times, THE PERSON YOU ARE TRYING TO REACH IS BEYOND REACH or OUT OF REACH. IT MEANS THAT THAT PERSON IS BEYOND THE REACH OF SIGNALS FROM THE NET

WORK TOWER.DOES THIS MEAN THAT THE TOWER HAS A REACH, BEYOND WHICH IT DOES NOT WORK? SHALL WE CALL THIS REACH UPTO WHICH THE PERSON IS REACHABLE A “ FEEDING DISTANCE “ of the SIGNALS.

Any communication is complete only when the communication is received by the person to whom it was meant to be and understood by the receiver. otherwise it is called “UN SOUND COMMUNICATION”

2)There was a train called “ MAHALAKSHMI EXPRESS” between BANGALORE AND BOMBAY. This train used to travel between BANGALORE and MEERAJ on METRE GAUGE. From MEERAJ to BOMBAY on BROAD GAUGE. It was a connecting train for BOMBAY bound Passengers. Obviously TRAIN from MEERAJ should leave after Train from BANGALORE has arrived at MEERAJ. So train from BANGALORE was FEEDING passengers to “ MAHALAKSHMI EXPRESS” at MEERAJ. For some unknown reason if the train from MEERAJ left MEERAJ before the arrival of the train from BANGALORE. BOMBAY bound passengers are stranded at MEERAJ. So in effect train from BANGALORE has not been able to feed Passengers to BOMBAY bound train at MEERAJ. **The is a failure in the System. This kind of thing happens in castings. The stranded passengers have nowhere to go. These stranded passengers are compared to CENTERLINE SHRINKAGE.**

3) Here your is another **Example**. Please pay a greater attention to it and imagine a bit. **You will understand it**. Hold your RIGHT PALM(partly closed) in such a way that your THUMB is facing towards your FACE. This is supposed to be the TEMPARATURE GRADIENT. But temp gradient is NEVER straight. If it were to be straight it would not be called a gradient. When your are climbing a hill, there is gradient----slope. Now close your palm inside to a very small degree. Now it is like a > with a large angle inside. As this > moves it closes.

As regards to why it closes, I will tell you little later. When the slope is steep, the angle inside the > is more. Assuming that the rate of closing is same, no matter what is the angle, if the angle inside > is more (which is less than 180 degrees.) > traverses a longer distance before the angle inside the becomes ZERO. The initial inside angle of > is decided by the THERMAL CONDUCTIVITY of the CASTING alloy. For a pure metal, which has got the HIGHEST thermal conductivity ,any addition of different elements is an impurity ,We add different alloying elements for our purpose, the Thermal conductivity is REDUCED. It is this Thermal conductivity which decides the angle of gradient. Lower is the Thermal conductivity (in high alloy steels) larger is the angle inside > . So it has to traverse a longer distance before the angle becomes ZERO. In case of Plain Carbon steels & low alloy steels ,

Thermal conductivity is higher & hence inside angle of > is smaller. So it traverses a shorter distance before the angle inside > becomes ZERO. In a CASTING, thermal gradient (SLOPE) starts at the end & it is steepest at the end because of 1) flat portion & 2) 4 corners.

A thermal gradient, so started closes while traversing ,towards the feeder, because the path available closes because of concurrent solidification taking place from 4 sides. The point up to which this > traverses, from the END, before the angle of > becomes ZERO is called END EFFECT. By the time gradient becomes ZERO, an other gradient starts under the INFLUENCE of feeder & this ends in the feeder itself. This distance is called FEEDER EFFECT.

Sum of these END EFFECT & FEEDER EFFECT IS CALLED TOTAL FEEDING DISTANCE.

In case of Plain carbon steels, as thermal conductivity is high, hence the angle of gradient is less. Hence it closes faster and thus a shorter feeding distance.

$$2.5T \text{ (END EFFECT)} + 2.0T \text{ (FEEDER FEEECT)} = 4.5T$$

That is why in the above example 1000 mm x 200 mm x 25 mm, I said you will never get a sound casting, even if your feeder has enough FEED METAL.

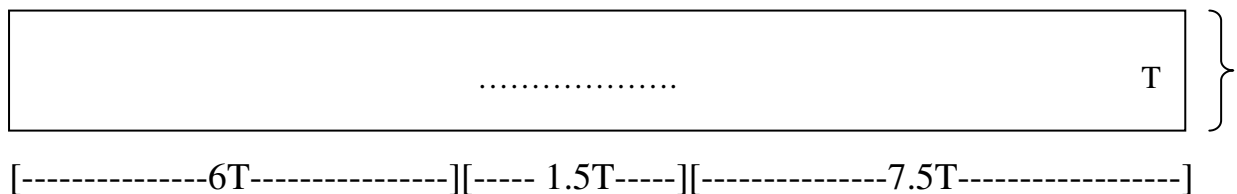
In our example, at both ENDS we will have 2.5 x 25 mm = 62.5 mm SOUND PORTION.(per end) Then adjacent to FEEDER on both sides you will have 2.0 x 25 mm =50 mm sound portion(per side).So in effect we have a TOTAL SOUND PORTION of 62.5 mm +62.5 mm + 50 mm + 50 mm = 225 mm SOUND PORTION.OUT of 1000 mm length ,only 225 mm is sound.

The rest 1000 – 225 = 775 mm will have what are called CENTRE LINE SHRINKAGE on either side.

When you look at the Thermal conductivity of stainless steel (18 Cr / 8 Ni), it is 1/ 3 rd of carbon steel. Does that mean that angle of gradient , in case of Stainless steel, is 3 TIMES more. Hence it would traverse 3 TIMES longer distance than Plain C steel before gradient's angle becomes ZERO.

i.e. $4.5 T \times 3 = 13.5 T$.

To CHECK this I poured a stainless steel (18 Cr / 8 Ni) plate of 15 T. on radiography, it was found that THE END EFFECT WAS 7.5 T & THE FEEDER EFFECT WAS 6.0 T. Sum of these two are 13.5T.



6T is the FEEDER EFFECT, 7.5 T is the END EFFECT, 1.5T is the defective zone, these defects are called CENTER LINE SHRINKAGE which is not acceptable in radiography. Let us ask ourselves a QUESTION as to why did

the centreline shrinkage come about. The reason is temperature gradient angle became ZERO at 7.5T from the end. Another gradient wasn't ready immediately after 7.5T. So a **parallel solidification front was running** for 1.5T & it resulted in centreline shrinkage. Another > started after this 1.5T.

Do you still remember “stranded passengers in Meeraj”

For getting a sound casting SOLIDIFICATION FRONT should be CONICAL.

If a casting has 6 numbers of feeders, from the above conclusion we need to have 6 numbers of conical fronts. The tip of the conical front starts from the END and base of the cone is in the FEEDER.

The **management** of formation of these conical fronts for each casting ensures a SOUND CASTING having moved all the SHRINKAGE from casting to feeder is **METHODING**. To facilitate this aspect we have the following tools at our disposal, they are CHILLS(metallic & non metallic), pads (metallic & non metallic-insulating & exothermic), feeders- sand, insulating & exothermic.

TO PUT IT SUCCINCTLY, IT IS LIKE MANAGEMENT OF TRAFFIC IN A BIG CITY. THE WORD TRAFFIC MANAGEMENT IS INTENTIONALLY USED TO CONVEY TO YOU THAT YOU ARE DIRECTING THE FLOW OF LIQUID METAL FROM FEEDER IN ONE DIRECTION & MOVEMENT OF SHRINKAGE INTO FEEDER IN AN OTHER DIRECTION BY EMPLOYING THE PRINCIPLES OF HEAT TRANSFER.

Even to this day I do not know as to how 4.5 T was arrived at for C steels. Is it only an experimental outcome or it has a theoretical basis.

A bar has a cross section of 1:1(T:W) & plate has a cross section of 1:5 or more.

Variation in Feeding Distances between bar , bars, plate

Width	Thickness T	Total Feeding Distance
5T	100 mm	450 mm - 4.5 T
4T	100 mm	425 mm - 4.25T
3T	100 mm	400 mm - 4.0T
2T	100 mm	375 mm - 3.75T
1T	100 mm	275 mm - 2.75T

IN PLAIN CARBON STEEL CASTINGS.

For getting a sound casting. there should always a gradient, outside the gradient is solid metal & inside > is always liquid metal. No parallel solidification front is acceptable as it leads to centreline shrinkage.

For our 1000 mm x 200 mm x 25 mm plate, we need to treat like this.

$1000 \text{ mm} / 25 = 40 \rightarrow 4.5T + 9.0 T + 9.0 T + 9.0 T + 9.0 T + 4.5 T = 45 T$

So we need to keep 4 numbers of feeders which can take care of MODULUS & FEED METAL. In between Feeders are there are NO EDGES, hence it will give you only $2.0 T + 2.0 T = 4.0 T$. So we need to create an END by keeping CHILLS in between FEEDERS. These chills, immediately above them hasten the solidification rate and thus NARROWING the flat path above the chill, which in effect acts as ENDS. So between the FEEDERS we get $4.5 T + 4.5 T = 9.0 T$ instead of $4.0 T$

Earlier we have specified the solidification rates of Steels with various moulding Materials .

When we put a metallic CHILL, it extracts heat faster from liquid steel, so the solidification time is shorter.(as it's heat absorption capacity is more than that of sand)

Despite the fact, size, shape, volume & material has remained the same, the Solidification rate has altered to a shorter time.

For a 150 mm dia steel sphere,

Solidification time with silica sand is----- 17 minutes

Solidification time with a STEEL CHILL is ----- 4.3 minutes.

Since solidification time in minutes = A constant x (modulus in cm)²

As the VOLUME has remained the SAME ,the ONLY thing that is changing is the SURFACE AREA. This new surface area is called APPARENT SURFACE AREA.

PRECAUTION : While using METALLIC CHILLS ensure that they are clean. free from DUST,OIL,RUST or any other unwanted item which could affect the QUALITY OF THE CASTING. If required grind, sand blast the CHILL so that the CHILL is clean in the real sense of the term.

THERE ARE NO SHORT CUTS HERE. CHILL THICKNESS SHOULD BE EQUAL TO CASTING THICKNESS.

The Chills used should be of same thickness as the Casting. Ensure that there is a gap between two Chills to the extent of Chill thickness to prevent **TEARS**.

Let us take a CUBE of 100 mm. $V = 1.0 \text{ dm}^3$, $SA = 5.0 \text{ dm}^2$ (on top feeder will be placed, hence it is a non-cooling area)

$$Mc = V / SA = 1 / 5 = 0.2 \text{ dm}$$

Supposing we keep a chill at the entire bottom, it is EQUIVALENT to increasing the surface area **BY THREE TIMES AS THERE IS NO LOSS OF CONTACT AS THE CHILL IS AT THE BOTTOM.**

Now our new surface area is $3 \times 1 + 4 \times 1 = 7.0 \text{ dm}^2$.

Our new $Mc = 1 / 7 = 0.14 \text{ dm}$ instead of 0.2 dm .

If we put chills in the sides, **they lose the contact as the casting shrinks**, so the APPARENT SURFACE AREA is **ONLY TWICE THE ACTUAL SAND SURFACE AREA.**

Now let us have 5 chills on all 5 sides. Bottom = 3 ,sides = $4 \times 2 = 8$,the total APPERENT surface area is $3 + 8 = 11$

Our new $Mc = 1 / 11 = 0.09$ dm instead of 0.2 dm.

By reducing the Mc you have been able to REDUCE THE DIA OF THE FEEDER required, but you must ensure that it has adequate FEED METAL.

(There won't be any change in feed metal requirement. It still remains $7.8 \text{ Kg} \times 0.06 = 0.468 \text{ Kg}$.)

What is talked about is EXTERNAL CHILLS.

We have INTERNAL CHILLS also. According to Wlodawer 0.3 Kg of internal chill makes 1.0 dm³ of material defect free. Precautions to be taken for INTERNAL CHILLS remain same as external chill.

Unfortunately many people are afraid of internal chills needlessly. Metals have no mind of their own, hence they do not become cunning like human beings and misbehave. It is our business to understand as to how metals behave and treat them accordingly.

Here I would like to share an experience of mine. We were making Ni-Hard Casings (WHITE IRON – BRITTLE). This casting had 12 Mild steel inserts for drilling holes. (Ni-Hard is too hard you can't drill holes). We were finding cracks around the M.S. Inserts. Our rejection rate was almost 70 %.

At that time I was in charge of MELTING & MOULDING. To make up for the rejected castings, we were making moulds again and pour metal into the moulds, again the same story repeated. There was no solution in sight.

I was driven to the wall and felt helpless. Since no help was coming from any side, I started doing some IDLE thinking. A thought came which was some thing like this.

As M.S. (Mild Steel) has a high melting point, it did not become soft enough to accommodate the contraction of Ni-Hard liquid metal while solidifying, so I thought if I put CARBON on M.S, this C would diffuse into M.S. thus reducing it's melting point and softens a bit thereby accommodating the contraction of Ni-hard which in turn would reduce cracks. But how to put C into M.S.? I dipped the M.S. Inserts in furnace oil, torched with Oxygen-acetylene flame thoroughly so that absolutely no wetness was left, only a dry carbon soot was left on the inserts. Then we made the castings with those inserts.

BELIEVE me the problem got sorted out .

So I suggest when ever you have a problem for which you have no solution, leave it to your SUB-CONSCIOUS MIND. You are likely to get a solution.

A small story—one Organic Chemist wanted to know the BENZENE ring.

No matter how much he tried ,he could not get it. One night he had a DREAM.

The content of the dream was, he saw a SNAKE WITH IT'S TAIL IN ITS MOUTH. Next day he wrote the BENZENE ring. Famous author Cohello in his book "ALCHEMIST" writes that if you WILL something intensely the WHOLE OF COSMIC ENERGY CONVERGES TO FULLFIL YOUR

WILL.

Let me say some thing about ourselves i.e. INDIANS.

- 1) we don't play as a group (I am not talking of games)
- 2) I know every thing and I don't need to ask any body.(attitude)
- 3)After getting into a job we hardly do any intellectual work. In actuality that is the time to do that kind of work as you are financially secure.

“AN EXPERT IS ONE WHO KNOWS MORE & MORE ABOUT LESS & LESS”

Thomas Alva Edison is supposed to have succeeded in perfecting incandescent BULB in his 250th attempt. Some body asked him if he was a failure. Edison's answer was “I am the only person in the world who knows 249 ways how not to make a bulb” THAT INDEED IS EXPERTIZE

Those of you who are really interested in METHODS Please read WLODAWER'S “DIRECTIONAL SOLIDIFICATION OF STEEL CASTINGS”

As he was practicing foundryman, he is most reliable.

Before we go any further let us do a RECAP

- 1)Check your modulus calculations after you have done it for the first time(for each drawings. We are all liable to make mistakes. Few extra minutes spent on rechecking is better than loosing, repairing the casting.
- 2)Use preferably feeders of $H / D = 1.0$
- 3)Use exothermic sleeves up to 150 dia only.
- 4)you can use insulating sleeves up to any size.
- 5)After pouring is over cover the feeder with
 - a)Dry paddy husk
 - b)Anti-piping compound, bought out or made in-house.
 - c)Use clean CHILLS, if required sand blast them before using.
 - d)Use special refractory sands like Zircon, Chromite sands where you cannot use chills.
 - e) Establish the effectiveness of sleeves for yourselves. Do not take any body's word for granted.
 - f) Be careful with internal corners.(because heat concentration & hence shrinkage, such area should be provided with adequate radius & put Zircon sand to extract heat faster)
 - g)If there is a cylindrical casting, if it's ID is less than 27 % OD .Make it coreless, otherwise you will have lot of sand fusion problems.
 - h)Use vents carefully. vents purpose is to let the air in the mould to get out as the metal level is raising .vent should solidify as soon as the metal enters vent hole. It should be so small in dia that it should not give any shrinkage problem to casting.
 - i)Breaker core (BRC) opening should be 40 % SAND FEEDER DIA & it's thickness should be 10% sand feeder dia.

j) Breaker cores should be of highly collapsible sand. (Binders used are Organic so that they burn out & sand becomes loose resulting in easier removal of sand)

k) BRC reduces cutting & grinding costs. For 150 dia feeder, area is $0.785 \times (1.5)^2 = 1.766 \text{ dm}^2$ (with out brc)

BRC dia is $150 \times 0.4 = 60 \text{ mm} = 0.6 \text{ dm}$ Area = $0.785 \times (0.6)^2 = 0.2826 \text{ dm}^2$

See the difference $0.2826 / 1.766 = 0.16 \times 100 = 16 \%$

A savings of 84 % in cutting & grinding.

l) BRC are made of sand and hence DIA of BRC remains same whether you use SAND FEEDER OR INSULATING FEEDER OR EXOTHERMIC FEEDER

m) Before cutting the feeders, gates & vents with gas or arc apply wet slaked lime on the surface of the casting, so that molten metal generated during does not stick to casting, hence cleaning & chipping work is reduced.

FEEDING OF CAST IRONS

Grey Irons: Because of GRAPHITISATION that takes place & as Graphite has a density of about 2.3 gm / cc as against a density of pure iron 7.87 gm / cc, Graphite occupies a greater volume than Iron, it counters the shrinkage of Iron and as a result total shrinkage of Grey iron is about 2 to 4 % as against 6 to 8 % of Steels.

White Irons : White Irons have no Graphite & have only carbides besides Steel matrix. Carbides have the same density as that of steel, and hence these are treated like steel. White irons could be simple, unalloyed white iron, Cr White irons, Cr-Mo White irons or Ni-Hard type White irons. Since white irons are BRITTLE, they can't be cut with gas or arc, hence A BREAKER CORE is provided so that the feeder can be easily knocked off.

S.G.IRONS: Many people seem to think that S.G.IRONS are fed like STEELS. Nothing is farther from truth. In any casting you can have a defective Casting & obviously a defective Feeder. After all FEEDER is meant to collect all defects. You can also have a sound casting & a defective feeder. CAN YOU THINK OF A DEFECTIVE CASTING & A SOUND FEEDER. YOU CAN'T. IT HAPPENS IN S.G IRON ONLY.

IN ALL ALLOYS(BARRING Al—25 % Si ALLOY) METAL FLOWS ONLY IN ONE DIRECTION. FEEDER TO CASTING. NEVER FROM CASTING TO FEEDER. IT HAPPENS IN S.G.IRONS.

In S.G. Iron % C is about 3.7 & Si is about 2.7 %. If you take the CARBON EQUIVALENT (C.E) = $3.7 + 2.7 / 3 = 3.7 + 0.9 = 4.6$

C.E being 4.6, it is a HYPER-EUTECTIC iron. Melting point of iron with a C.E. of 4.3 is 1130 degree centigrade. Let us say melting point iron with a C.E. of 4.6 could be about 1150 degree centigrade.

All liquid steels will have a superheat of about 100 degree centigrade

So is the case with Grey Iron, White Iron.

BUT S.G.IRON is tapped at 1380 to 1400 degree centigrade.

It's superheat is $1400 - 1150 = 250$ degree centigrade.

From 1400 degrees, because of liquid-liquid shrinkage in the casting, metal flows from FEEDER to CASTING. Between 1150 to 1130 degrees, PRIMARY GRAPHITE forms. This Graphite ,occupies a larger volume, because of it's low density, hence PUSHES liquid metal back into FEEDER. At 1130 degrees, when EUTECTIC reaction starts, there is CONCURRENT precipitation of Expanding (EUTECTIC) Graphite & Shrinking Austenite form. The expansion & shrinkage should compensate each other. At this point, NECK should CHOKE.

LET US COMPARE LIQUID STEEL WITH LIQUID S.G.IRON

	STEEL	S.G.IRON
SUPERHEAT ° C	100	250
FLOW OF METAL	From Feeder to Casting	From Feeder to Casting
		From Casting to Feeder
METAL FLOWING OUT OF FEEDER	Impossible	Possible
FEEDERLESS CASTING	Impossible	Possible

In S.G. Iron there are two GRAPHITES 1)PROEUTECTIC GRAPHITE

2) EUTECTIC GRAPHITE

When S.G. Iron is cooling from 1400 degrees to 1150 degrees, because of liquid-liquid shrinkage liquid metal flows from feeder to casting,

between 1150 to 1130 degree, because of FORMATION OF PRO—

EUTECTIC (PRIMARY) graphite, an expansion takes place, hence

Metal travels from casting to feeder. At 1130 degrees, while Eutectic graphite is being formed, the neck should choke so that expansion of graphite & shrinkage of metal compensate each other. We end up with a good S.G. Iron casting.

Quebeck Titanium Co has done a great deal of work on S.G. Iron.

During the process of extraction of Titanium, they got a by-product called "SOREL METAL" which was an ideal pig iron for S.G. Iron.

To create a market for this “Sorel metal” they did lot of work on S.G. Iron. Dr Karsay of QIT went on to write 4 books on S.G. Iron. These books were given freely to anybody who showed little interest in “SOREL”.

One Dr H.Roedter of QIT, Germany, published a paper in German on PRESSURE COTROL FEEDING OF S.G. Iron. In that paper he has given a **GRAPH** ,from which one can get Mn &Mf if you know Mc.

Mc is on Y-axis, Mn & Mf are on X-axis. But there is a lacuna in this paper, i.e. It does not give the dimensions of the NECK.

The same paper was translated into ENGLISH & published in April,1986 issue of INDIAN FOUNDRY JOURNAL. The lacuna still persists.

In 1984,when I was in NAGPUR,I had to do S.G. Iron but I did not know a thing about S.G. Iron. A friend of mine who was working in a S.G. Iron foundry at NAGPUR, asked me to teach him STEEL METHODING.

So we bartered our knowledge. He taught me S.G. iron METHODING & I taught him STEEL METHODING. While teaching S.G. Iron methoding he filled the MISSING GAP.

After you have got your Mc (on Y axis) draw line parallel to X-axis, which cuts the curve, from that point draw vertical line on to X-axis. You get both Mf (Mr) & Mn.

DIAMETER OF A BLIND SAND FEEDER WITH AN INTEGRAL WILLIAM’S CORE

FEEDER 1) $H / D = 1.5$,

FEEDER DIA = 5 Mf –6 Mf,---7 Mf (if more steel scrap is used in the melt)

DIAMETER OF A BLIND SAND FEEDER WITH AN INTEGRAL WILLIAM’S CORE 2) $H / D = 1.0$

FEEDER DIA =5.5 Mf—6.5 Mf---8.5 Mf(if more steel scrap is used)

NECK----ROUND **SQUARE**

D = Mn, L= Mn SIDES= Mn x Mn L = Mn

RECTANGULAR NECK W = 6Mn ,T =3 Mn ,L = Mn

THE GRAPH ,FEEDER SHAPE & NOTCH are GIVEN in the DRWING

PRECAUTION: All the feeders & neck should receive hot metal from a RUNNER.EVEN IF THERE IS ONE FEEDER WHICH GETS IT’S METAL FROM CASTING RATHER THAN THRU NECK ,YOU WILL HAVE PROBLEM IN THAT FEEDER

In Steel casting all the feeders should be gated into, but if it not done nothing serious will happen.

IN S.G IRON METAL SHOULD FLOW FROM RUNNER TO EACH FEEDER BOTTOM & THRU EACH NECK TO CASTIGN ONLY.

IN THE EVENT YOUR CASTING CONFIGURATION IS SUCH THAT YOU HAVE NO OPTION BUT TO USE A TOP FEEDER.

DO USE IT, BUT IT SHOULD BE BLIND WITH BREAKER CORE WHOSE DIAMETER IS 0.35 x DIA OF SAND FEEDER

(DIA OF BRC IS 35 % SAND FEEDER DIA IS TO CHOKE IT)

(WHERE AS IN STEEL IT SHOULD REMAIN OPEN HENCE 40 % SAND DIA)

WHAT EVER I HAVE SUGGESTED, ABOVE, I HAVE PRACTICED PERSONALLY FOR FULL 3 YEARS WITH OUT ANY PROBLEMS

(The above data is not available in Karsay's books also)

(the graph & neck design are given in the end along with other drawings)

CONTRIBUTION OF % SHRINKAGE PER 1.0% ALLOY IN STEEL AT 1600 DEGREES

ALLOYING ELEMENT	% SHRINKAGE PER 1.0 % ADDTION
TUNGSTUN	-0.53
NICKEL	-0.0354
MANGANESE	+0.0585
CHROMIUM	+0.12
SILICON	+1.03
ALUMINUM	+1.7

Now that we have almost come to the end of METHODING, we need to talk of means by which we can save money, a small part of this benefit may be passed on to customer, which will make you more competitive. we can make some of these things yourselves thru a sub-contract & save money. I have personally made these things & they worked beautifully.

INSULATING SLEEVES.

- 1)WOLLASTANITE-----30 TO 40 %
- 2)VERMICULATE----- 20 %
- 3)PAPER PULP----- 15 %
- 4)DRY PADDY HUSK-----15 %
- 5)SHELL RESIN +HEXA-----5 TO 10 %
- 6)THINNER----- 10 %

Make a mix of all these in a mixer. Make sleeve of your choice in a core box.

Take it out of the core box ,ignite it, thinner will burn & give adequate strength. It will attain a GOLDEN yellow colour. It is ready for use as an insulating Sleeve.

EXOTHERMIC SLEEVE.

To the above material, add 10 to 20 %of the following

- 1)Fine RED oxide OF IRON-----50 %
- 2)—200 # pure ALUMINUM POWDER---45%
- 3)Potassium Nitrate----- 5%

ANTIPIPING COMPOUND

a.)

- 1)paper pulp----- 20 %
- 2)Dry coconut shell powder--- 10 %
- 3)Dry paddy husk----- 30 %
- 4)Wollastanite----- 40 %

b) Coconut shell Powder + Coconut coir powder

METAL GENERATING EXOTHERMIC COMPOUND

- 1)Red oxide of Iron (150 #)--- 100 grams
- 2)Aluminium powder (150 #) 80 grams
- 3)Potassium Nitrate ----- 5 grams
- 4)Wollastanite (-150 #)-----500 grams
- 5)Paper pulp (-60 #)----- 250 grams

(IF YOU WANT MORE METAL USE MORE OF ITEM 1,2 &3)

Wollastanite can be bought from M/s Wolkem Industries,Nobel House, Swaroopsagar,Udaipur-313 004,Rajasthan,
e-mail:mktg@wolkem.com, wolkemindia@vsnl.net
vkt@wolkem.com, smahajan@wolkem.com

Ask for KEMOLIT-M-60 or KEMOLIT-A-60(k) which ever is more insulating. Cost of this material is around Rs 7000 per ton + taxes + transportation. The rest of the material could be bought locally.

This will save your cost by as much as 80 to 100 %

In these 1)Insulating sleeve ---for delaying solidification

2)Exothermic sleeve ---- for further delay of solidification because of Thermit mixture

3)Anti-piping compound---drastically reduces radiation loss from feeder top.

4)Metal generating exothermic compound---Gives you very hot metal to the top the feeder ,If you have been able fill only 60% feeder, you can still get a GOOD casting by putting this material. It gives hot metal, heat & insulation.

BASIC ADVANTAGE IS YOU DON'T HAVE TO STOCK EXPENSIVE SLEEVES. IF THE SLEEVES BREAK, YOU CAN STILL MAKE SLEEVES OUT OF THESE OR USE IT AS APC.

AS REGARDS TO METHODING, WE HAVE COME TO THE END. DRAWINGS ARE ALSO PROVIDED. PLEASE SEE THEM .IF YOU STILL HAVE PROBLEMS CONTACT ME DIRECTLY. I HAVE ALREADY GIVEN THE DETAILS OF MY PHONE NO, E-MAIL ID .

MELTING PRACTICE

Pure Iron has a melting point of 1539 degree centigrade. But we seldom use pure Iron for it's low mechanical properties. Incidentally PURE IRON is very EXPENSIVE. You are probably wondering as to why.

There are TWO words which are interchangeably used. They are ORE & MINERAL.

Many people think that they are one and the same. THEY ARE NOT.

The word ORE has Economics attached to it. When you EXTRACT some thing from a COMPOUND(?) in our case ,it is Fe₂O₃,this is also called

RED OXIDE OF IRON, it must fetch a PROFIT.THE WORD

PROFITABILITY is attached to ORE. Where as such restrictions are NOT attached to the WORD MINERAL. In your back yard if you get 1000 Kg of Iron ore(?),it is called a mineral as it can't be EXPLOITED to make IRON economically.

Simply put ORE----- PROFITABILITY

MINERAL-----NO PROFITABILITY.

Look at KOLAR GOLD FIELDS(KGF),extraction of GOLD was profitable earlier, then it was called GOLD ORE .Now KGF is CLOSED. It is not that GOLD is not present there, it is still present ,but it's(GOLD) extraction is no longer ECONOMICALLY VIABLE or PROFITABLE. Hence it is closed. Now available GOLD in KGF is called GOLD MINERAL.

Earlier, I said PURE IRON is EXPENSIVE. WHY ? Our present process of getting IRON from IRON OXIDE is through BLAST FURNACE in a STEEL PLANT. One could ask a Question as to why make IRON in a STEEL PLANT, WHY NOT IN AN IRON PLANT. To give you a simple example if the cost of IRON is x ,cost of steel is nx, where n>1, and cost of products made out of this steel, such as STEEL PLATE,ROD, BEAM etc is mx. Where m>n>1.Hope you have understood now as to why there are no EXCLUSIVE IRON PLANTS.

Now coming back to our old Question as to why PURE IRON is more expensive than plain C steel.

The IRON ORE we get(not only in INDIA, but all over the World) has lot of impurities. These impurities are removed or reduced to their elemental form in a BLAST FURNACE, where the source of HEAT is COKE, made from COAL. Coke has lot of Carbon. The reaction that takes place is mainly $Fe_2O_3 + C = Fe + CO + CO_2$,so along with IRON we get several other things whether we like it or not.

OUTPUT of a blast furnace is called PIG IRON. This pig iron consists of Fe, C, Mn, Si, S,P etc .In a STEEL making furnace these impurities are reduced.

Just to give you a birds eye view C -4.0% to 0.20%,Si—1.5 % to 0.3%

Mn 1.0 % to 0.5%, S -0.3 % to 0.04 % P-0.3% to 0.04%.This whole process

has a time & a cost factor to it. If we want to remove all other things except iron, it will take a longer time & higher process cost is involved. The PURE IRON so obtained will be more expensive than STEEL.

Hope you have understood by now as to why PURE IRON is more expensive than STEEL. It is not that pure iron is not available, it is available but it is made ELETROLYTIC PROCESS, which is quite expensive.

(The purpose of giving the above information is to make you little more comfortable information-wise)

As I have already told you, pure iron has a melting point of 1539 degrees.

It is too soft for any engineering application. So we alloy it with elements like C, Si, Mn, Cr, Ni, Mo etc. With the addition alloying elements we loose some amount of toughness but gain good deal of Strength.

The words like strength & toughness need to be explained.

Take a rubber piece & hammer it , it will not break. This capacity of a material to take some shock loads is an indication of Toughness.

Let us take a mud brick, a stone , an Aluminium piece, a Copper piece & a steel piece. If we hammer these, mud brick will break immediately-it has no strength.

With Stone you need to hammer it harder or longer. So a stone has some Strength. With Aluminium it will not break but **stretch**. What you need to

Observe here is Aluminium did not break but it stretched. This Quality of not breaking is because of it's higher strength & substantial stretching is called TOUGHNESS. Similarly Copper piece will have still higher strength, in case of steel Strength will further increase but you could see some cracks developing. This tells you that steel is strongest of all these, but as cracks have developed, steel is not toughest of these.

If you recall, in earlier times when LPG was not available, People used wood as a fuel for cooking. People used to buy wooden logs. A man with a steel axe used to break these logs with the help of an Axe. He used to make a notch at one end like a V, may be slightly deeper & then holding that portion with V on both sides, he used to tear it apart.

Now imagine two wooden logs of same wood, one of which is DRY & an other is WET. While separating the DRY log he had to apply MORE force & it would tear faster. This MORE FORCE is an indication of STRENGTH.

When it came to WET log ,THE FORCE required was less ,but it would not separate faster, it took longer time to break or separate. This resistance to cracking is an indication of TOUGHNESS.

So we alloy iron(Fe) with other elements so as to make it stronger and in the process we loose some toughness the pure iron would have had.

The liquid metal or steel is poured with a superheat of about 80 to 100 degrees depending on section thickness. Higher is the section thickness lower is the superheat. Lower is the section thickness higher is the super heat.

If superheat is more than what is required, you will have several problems

Viz.

- 1) Excess power consumption.
 - 2) More gassy metal. (more oxygen in metal)
 - 3) To remove this additional gas, you will have to add more deoxidizers---- additional cost. (deoxidizers are elements which have strong affinity for oxygen than Steel like Aluminium, Silicon etc)
 - 4) This will increase inclusion content, which will reduce the properties of steel.
 - 5) Liquid-liquid shrinkage will increase which needs larger feeders. This will reduce the yield.
 - 6) Sand fusion will occur, resulting in higher fettling cost.
 - 7) Time taken per melt increases, this will reduce total production of metal per day. Loss of productivity.
 - 8) Life of furnace lining comes down,
 - 9) More frequent furnace lining. Lining cost per ton of metal goes up.
- All these will have a direct bearing on your costs, which will increase. In order to avoid these problems you need to know Melting points of all alloys.

Elements	Reduction of Solidification by the addition of 1.0% element to Steel, in degree centigrade	Limits of contents of selected elements in the metal, %
Carbon	65	0.00—0.99
	70	1
	75	2
	80	2.5
	85	3
	91	3.5
	100	4
Nitrogen	90	0.00 to 0.03
Oxygen	80	0.00 to 0.03
Phosphorous	30	0.00 to 0.70
Sulphur	25	0.00 to 0.08
Tin	10	0.00 to 0.03
Silicon	12	0.00 to 3.00
Manganese	5	0.00 to 1.50
Copper	5	0.00 to 0.30
Nickel	4	0.00 to 9.00
Molybdenum	2	0.00 to 0.30
Vanadium	2	0.00 to 1.00
Chromium	1.5	0.00 to 18.00
Aluminium	0	0.00 to 1.00
Tungsten	1	0.00 to 18.00

A Steel containing 1.0 % C, 0.60% Mn, 0.033 %P, 0.04 % S & 8.0 % Ni
 $1.0 \times 70(\text{C}) + 0.60 \times 5.0 (\text{Mn}) + 0.033 \times 30 (\text{P}) + 0.04 \times 25 (\text{S}) + 8.0 \times 4.0 (\text{Ni})$
 $70 + 3 + 1 + 1 + 32 = 107$ degrees

Melting point of IRON -----1539 degrees

Melting point of our Alloy---- $1539 - 107 = 1432$ degrees

Pouring temperature of our Alloy -- $1432 + (80 \text{ to } 100) = 1512$ to 1532
 Degrees

Steel can be made in an ARC Furnace or an INDUCTION Furnace.

ARC FURNACE :For long time ARC Furnace was the mainstay of a Steel foundry. Particularly for larger capacity Foundries. The main advantage of an ARC Furnace is you can make any thing from any thing.

I can charge PIG IRON into an ARC furnace and make Stainless steel out of it.

An ARC Furnace capacity can be as big as 25 tons.

But most medium scale Steel Foundries have switched over to INDUCTION FURNACES.

INDUCTION FURNACE :In case of an induction furnace there are several things you can't do, which you could have done very easily & affectively in an arc furnace Viz. Oxygen lancing, Desulfurization, Dephosphorisation.

In case of an **INDUCTION FURNACE YOU GET OUT WHAT YOU PUT IN.**

Let us look at an INDUCTION FURNACE in detail.

An Induction furnace is like an Electric transformer. An Electric transformer has a PRIMARY & a SECONDARY coils. Similarly an Induction furnace has a WATER COOLED COPPER COIL which acts as PRIMARY, the METALLIC charge itself acts as SECONDARY.

When current is passed through primary coil. it sets up a MAGNETIC field, which is intersected by the charge. When magnetic field is cut by the charge, HEAT is GENERATED with in the charge because of I^2R , where I is the CURRENT & R is the RESISTANCE of the charge. This is probably the cleanest heat you can get.

Induction Furnaces can be classified as :

- 1) Mains Frequency Furnace,
- 2) Medium Frequency Furnace,
- 3) High Frequency Furnace.

Mains Frequency Current is what we receive at our homes, a 50 cycles / second. If there is a mismatch between frequency & tons capacity, it could lead to

several problems. The details of which are given little later.

For a 500 Kg furnace, if we use Mains frequency, it results in lot of churning of metal, which contributes to :

- 1) High gas content,
- 2) High inclusion content,
- 3) Oxidation of some alloying elements,
- 4) Higher lining wear.

Further in Mains Frequency Furnace, there is big disadvantage. That is furnace can't be emptied completely. We need to keep a "HEEL" metal for next melt.

This restrains you from change of alloys. This is like a L.P.G. stove telling me as to what I can cook or I what I can't. If we want to start a new alloy i.e. change over from a low alloy steel to stainless steel, we need to completely empty the furnace and put a STARTIG BLOCK of new alloy, which will take a longer time to melt. This results in loss of output per hour.

This problem is eliminated by switching over to a Medium frequency furnace. Here we can empty out the furnace completely. Hence our freedom of choosing the alloy of our choice is restored.

Here also we have "OUR" usual problems of gas, inclusion, lining wear & loss of alloying elements etc. In steels only three elements are not lost. They are Cu, Ni & Mo.

Let us digress a bit. Why do metals become gassy? Fe_2O_3 is sitting pretty in Mother Earth's crust for millions of years. Fe_2O_3 is the most comfortable state, for it, energetically. But we human beings, may be out of greed or our ingenuity we have mined Fe_2O_3 and converted it to Fe. Now it is very uncomfortable.

When a baby gets a fever, baby's mother puts a wet clothe on baby's fore head. That is to give some comfort to baby.

In a foundry, we are melting, already uncomfortable iron & in the process making it even more uncomfortable. Like in baby's case, the liquid metal absorbs some gas to derive some comfort.

The iron is making every effort to go back to it's natural state of Fe_2O_3 .

That is the reason why iron rusts. Rust is nothing but Fe_2O_3 . Now you are likely to pounce on me & ask as to why Aluminium does not RUST(?) or oxidize.

It is in deed a good question. The fact is Al is so reactive none of us have seen PURE ALUMINIUM surface. What we see is a film of Al_2O_3 .

Take an Al vessel & as long as you use it for cooking rice or boiling milk, it remains in tact, but the moment you put lemon juice or tamarind juice, pitting starts. Do you know why NOTHING HAPPENS TO GOLD. PURE GOLD is at a lower energy level than an OXIDE OF GOLD. That is the reason why gold is available in the form of PURE GOLD in earth's crust.

As regards to stainless steel it is covered by a layer of Cr_2O_3 film. Hence no

corrosion.

Back to work.

A relation exists between frequency & capacity in Kg so that the metal CHURNING is least.

What is given underneath are considered as,

MEDIUM FREQUENCY FURNACES.

Capacity in Kg	Frequency in cycles per second
100	2500
300	1000
500	800
750	500
1000	450
2000	300
3000	200
4000	180
5000	100
7500	70
10000	50(though it is a MAINS FRQUENCY---it behaves like a MEDIUM FREQUENCY FURNACE

Problems resulting in too low frequency are :

- 1) Difficult starting.
- 2) Excessive number of coil turns with small water passage & hence frequent Coil clogging.
- 3) Wild stirring resulting in lining wear, inclusions & gassy metal.

Problems resulting from too high a frequency.

- 1) High voltage drop in bus bars.
- 2) Highly expensive equipment resulting in higher investment per Kg melted.
- 3) Too little stirring, inadequate for proper alloying.
- 4) Poor average efficiency due to high capacitor loss, increased Coil losses & Losses due to converter inefficiency.

Because of attendant problems with low & high frequency furnaces, The frequency Vs weight given above are optimal.

LINING:

Induction Furnace is lined with Magnesite Ramming Mass for Steel or Silica Ramming Mass with Boric Acid as a binder for Grey & S.G. Iron.

While ramming the lining 3 types of ramming tools are used.

- 1) FORK----- 3 numbers depending on the size of the furnace.

2) WEDGE--- 3 numbers depending on the size of the furnace.

3) FLAT -----3 numbers depending on the size of the furnace.

As ramming mass is powdery it has to be made harder(Physically) by ramming. Lining is hardened in stages. Supposing a lining takes about 1000 Kg of mass per lining, this can be hardened in 15 or 20 stages. It has to be arrived at by your own experience.

An Example :If you put ,say.50 Kg of Mass, in the annular space between the M.S. former & Copper coil covered with Asbestos, use the FORK to begin with. Fork hardens the bottom portion of the loose mass. Then use the Wedge for ramming. Wedge hardens the middle portion of the mass. Then use the Flat rammer. This hardens the top portion of the mass.

After having hardened the mass, scratch the top surface of the mass to create an extra surface area. Like you rub the wooden door with a SAND or EMERY paper before PAINTING.

PRECAUTION: If 3 people are involved in lining work, all the 3 people should have the same tool in their hands. If it is Fork,3 Forks at a time and not each person having different tool in his hand. This gets reflected in number of melts you get per lining. 20 or 100.

I have seen this MISTAKE being made in one OLD foundry and were getting only 20 melts. Each person was using different tool at the same time, as a result lining remained soft and used to wear out faster in 20 melts.

When the system was changed to **EACH PERSON HAVING THE SAME TOOL at any given point of time**, lining became harder and subsequently it gave 100 melts.

COMMAN SENSE IS NOT SO COMMAN.

While making the bottom you fix AN ANTENNA(SPIDER) in it which in turn is connected to a meter on the panel board. THIS ANTENNA is a safety device.

No material is a PERFECT CONDUCTOR OR a PERFECT INSULATOR. Even a Ramming mass, an oxide, considered to be a bad conductor, it still does conduct some amount of current. This in deed is a blessing in disguise. This leak is sensed by the antenna at the bottom. The amount of current leaked is an INDICATION OF CONDITION of the lining.

If current leak is higher, it is a warning that the condition of the lining is deteriorating or there is a localised erosion or a crack in the lining. Furnace immediately trips. Then you can empty the furnace & check the lining condition & suitable action may be taken. Let God forbid it ,should a PUNCTURE take place, it would take several days to repair it, at a cost obviously.

These Antenna wires, made of stainless steel, should always be in contact with LIQUID metal. While patching the lining make doubly certain that

the antenna are exposed to liquid metal.

Magnesite has a very high THERMAL EXPANSION. So frequent heating & cooling will result in cracks. So an Induction furnace should run from 6.00 hrs of MONDAY to 22-00 hrs of SATURDAY. Break the lining on SATURDAY night itself. In case of Magnesite ,if the lining thickness is say 100 mm, only about 15-20mm adjacent to liquid metal ,in the furnace, is hard. Rest of the material behind it will be powdery. Some times this powdery material saves you from punctures. But don't bank on it.

(Powder of Magnesite, obtained while breaking the lining can be used in ladle, while pouring liquid metal into ladle, it will remove slag.)

In case of SILICA ramming mass, after SINTERING the entire mass becomes hard.

As regards to SINTERING CYCLE each foundry establishes it's own cycle.

The Purpose of sintering is TWO folds.

- 1) TO ACHIEVE A CHEMICAL BOND.
- 2) TO ALLOW THE MASS TO EXPAND AND CONTRACT IN A CONTROLLED WAY.

A Sintering cycle could be something like this.

CHARGE THE FURNACE WITH METAL TO BE MELTED UPTO THE BRIM.

- 1) 10 % power ON for 10 minutes. (If the TOTAL POWER OF YOUR FURNACE IS 500 KW, START WITH 50 KW)
- 2) NO POWER----- for 10 minutes.
- 3) 20% power on -----for 10 minutes.
- 4) power OFF-----for 10 minutes.
- 5) 30% power on -----for 10 minutes.
- 6) power off-----for 10 minutes.
- 7) 40 % power on ---for 10 minutes.
- 8) power off-----for 10 minutes.
- 9) 50 % power on-----for 10 minutes.
- 10) power off -----for 10 minutes.
- 11) 60 % power on ---for 10 minutes.
- 12) power off-----for 10 minutes.
- 13) 70 % POWER ON CONTINUOUSLY TILL MELTING.

Make it a point to take a PLAIN CARBON STEEL as a sintering heat , as it has the highest melting point among all steels, the lining sinters faster. This is only a suggestion.

Sintering melt will be gassy. Take care of it. I have already explained as to why metals become gassy. A gassy metal can be easily identified by the sparks on the melt. To remove this gas plunge about 500 grams of ALUMINUM per ton of Melt. Then send a sample to CHEMICAL LAB FOR SPETROGRAPHIC ANALYSIS. Which will give you the entire composition of the alloy. If the

alloy is as per your requirement tap into a PREHEATED LADLE. If not make additions to get THE RIGHT ALLOY. WITH OUT COMPOSITION APPROVAL FROM LAB DON'T TAP THE METAL.

Make suitable ladle addition to the empty ladle or into the first stream of metal which falls into the ladle.

I want to tell you a story. In Nagpur we wanted to make both steel & S.G. Iron castings. We had two crucibles. One of 1000 Kg & an other of 500 Kg.

We lined both crucibles with MAGNESITE, thinking that if MAGNESITE can withstand STEEL, S.G. Iron is nothing for it. We used to get 70 to 80 melts in STEEL, but when it came to S.G. Iron we were not getting even 20 melts.

We simply did not understand as to what was happening.

We called the Supplier of MAGNESITE & told him that his material was not Good. That man was 70+ years old(in 1984) & he was also a B.Sc(ENGG) in CEREMICS from BHU. He had also worked for TATA REFRACTORIES till his retirement. He asked one logical question that if his material was bad we could not have got 80 melts of Steel. That was a perfectly acceptable answer. But he did not know as to why we were getting only 20 melts, in S.G. Iron whose tapping temperature was only 1380 -1400 degrees, while Steel was being tapped at 1640 degrees. What ever data I have given you on melting point for each alloy was not with me. It did not even occur to us that there was an other foundry in Nagpur making S.G. Iron & we could have asked them. We did not know as to what to do. Then by the grace of GOD an idea occurred to me. Our S.G. Iron had a CARBON EQUIVALENT of 4.4.

An iron of C.E of 4.3 has a melting point of 1130 degrees. Any iron with C.E of 4.4 will have a melting point of 1140 or 1150 degrees. But we pouring S.G. Iron at 1400 degrees. A superheat of 250 degrees unlike 100 degrees in steels. At 250 degrees superheat metal becomes very searching(seeps) between the grains of Magnesite & PLUCKS it out thus resulting in terrible wear of lining. A Magnesite lining is so soft it be broken in 30 Minutes FLAT. Then we changed over to SILICA for S.G. Iron & magnesite for Steels. Then our problems got sorted out.

This kind of self discovery makes you very HAPPY.

There are lot of things we don't know in METALLURGY & FOUNDRY.

There are two ways of looking at it.

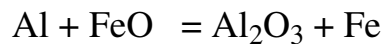
1) Feel Helpless & get disgusted.

2)As there are many things we don't know, it is almost like virgin territory, you can find out many things for your selves. Nothing gives you greater pleasure than this SELF-DISCOVERY.

(To give you an example for THIS extra superheat, metal's surface tension reduces & hence metal becomes searching. When your clothes become very dirty, you give it for a PETROL wash. As PETROL has a much lower surface tension than water or even soapy water, petrol seeps below the DIRT & dislodges it. Hence clothes become clean after PETROL wash)

Now back to work.

Molten steel absorbs OXYGEN and forms FeO. When we treat this metal with Aluminium, the reaction that takes place is given below.



You need to know some thing about this Al_2O_3 or Alumina.

It has a melting point of 2050 degrees and hence it remains as a SOLID in liquid melt, which are called “INCLUSIONS”. This material is also very hard.

In Mineralogy, we have a hardness scale called MOH'S HARDNESS SCALE.

- 1)Talc (SOFTEST)
- 2)Gypsum.
- 3)Calcite.
- 4)Flourite.
- 5)Apatite.
- 6)Orthoclaze.
- 7)Quartz (our regular SAND)
- 8) Topaz
- 9)Corundum (ALUMINA---- Al_2O_3)
- 10)Diamond (Hardest)

Now our friend Alumina, being second hardest, can cause lot of problems.

One could ask a question as to what is wrong in having such hard material, which will make our steel very hard.

When you want to break a wall, if you did it little carefully, you can reclaim old bricks. Where was the bond between brick & mortar.

Supposing you have hand kerchief. one with no holes in it and another with lot of holes in it. Which one do you think is stronger. Obviously one without holes. An inclusion is like an ISLAND it has no physical bondage between Steel& Alumina. So it is as good as a hole. In the language of METALLURGY it is called as “INCOHERENCY” These inclusions make the metal DIRTY and thus reducing the MECHANICAL PROPERTIES.

For every melt in an Induction Furnace, a predetermined charge is put. This is because in an induction furnace you have no room to play like you have in an ARC furnace.

Charging solid metallic charge into the furnace is an ART itself. Some people fill the charge to the brim & take REST as though they have lifted HIMALAYAN MOUNTAIN. This is a BAD practice. The problems that could occur are **over heating of the metal, bridging of the charge** leaving the DELICATE lining vulnerable.

Solid metal should be so charged that the liquid metal is always VISIBLE to you so that you can take any corrective action if required.

An young mother , with small child who has started to crawl or move around on all four, **KEEPS AN EYE ON THE CHILD** even if she is busy in household activity. If you ignore the liquid metal, it can cause lot of

problems for you. Hence **PAY GREAT DEAL OF ATTENTION TO LIQUID METAL**. BEST way of charging is to put solid charge directly into liquid metal. This is the SAFEST method. If you charge more, it is not going to melt faster as it is decided by POWER INPUT. By haphazard & careless charging YOU ARE ASKING FOR PROBLEMS.

When the metal is ready, after chemical analysis, remove slag & partly deoxidize the metal in the furnace, measure the temperature of the melt with a dip type pyrometer.

There is an other way of measuring the temperature. Though it looks crude it is effective. I have done it for several years. At the predetermined pouring temperature, **with same superheat**, whether it is 1640 or 1590 or 1520 degrees liquid metal has same FLUIDITY. Because of induction churning liquid metal is moving from the centre of the melt towards the lining. Drop a grain of ramming mass to the centre of the melt & count 1,2,3,4,5(FAST) if within this time grain reaches the lining surface. Temperature is good. If it takes more numbers, metal has not reached pouring temperature. If it takes less number of counting, metal temperature is high. It needs SOME PRACTICE. I CAN ASSURE YOU THAT IT IS EFFECTIVE.

Molybdenum & Nickel are imported. Some times in the market you don't get FerroMoly or Mo, FerroNickel or Ni, in a situation like this MoO & NiO can be used for Ni & Mo. FeO being stronger than NiO & MoO, it releases Ni & Mo.
 $Fe + MoO = FeO + Mo$, $Fe + NiO = FeO + Ni$.

PRECAUTION: These two oxides should be added to **AN EMPTY FURNACE** & subsequently make your usual charge additions. Even by mistake if you make these to addition the furnace with full metal, **WHOLE LIQUID METAL WILL BE ON THE FURNACE PLATFORM**.

BE CAREFUL. In some of our homes don't we keep RAT POISON etc, don't we handle them carefully. Similar care is required here.

As regards to LADLE ADDITIONS there can be several variations.

- 1) Aluminium
- 2) FeSi + FeMn
- 3) Mischmetal
- 4) Calcium Silicide.
- 5) FeSiZr
- 6) Magnesite sand.

Aluminium removes Oxygen.

FeSi + FeMn are also deoxidizers.

Mischmetal consists of Ce, La etc & they are very strong sulphide & oxide formers. Hence they reduce Sulphur, which improves % E, % RA etc Calcium Silicide can act as a sulphur reducer & since it has low melting point, it can take out inclusions while it is floating up.

FeSiZr is also a deoxidizer & grain refiner.

ROASTED or DRY MAGNESITE SAND is a wonderful material.

It has a very low density & a melting point of 2800 degrees. Hence it is totally unaffected by the liquid steel, IT SIMPLY FLOATS UP LIKE A ONE WAY LIFT, IN THE PROCESS COLLECTS LOT OF INCLUSIONS, & CLEANS UP THE METAL OF LOT OF INCLUSIONS. SO MUCH SO THAT YOUR % E & % RA GO UP BY 2 TO 3%.

Salem, in TAMILNADU, is a place where you get this Magnesite in plenty. % of ADDITIONS.

Al----- 1.0 Kg per ton of Steel.

Mischmetal—0.10 % of total metal.

FeSiZr 0.05 %

CaSi 0.10 %

Magnesite Sand 1.0 Kg per ton.

These additions are made into to the FIRST STREAM OF LIQUID METAL WHICH FALLS INTO THE LADLE. This avoids any burn-out of any addition as some of them are highly reactive(if put to pre-heated empty ladle).

In steels, grain boundary is stronger than grain. Hence total grain boundary length should be as long as possible, or in other words GRAINS SHOULD BE AS SMALL AS POSSIBLE. That is the reason we always ask for FINE GRAINED STEELS. This can be achieved by the addition of a small amount of FeTi or FeZr.(0.05 % to 0.10 %)

In Steels, you have two BIG enemies. They are S & P. They go to the Grain boundary & make it weaker and also make the alloy less tougher.

That is lower % E & % RA. That is the reason why all steels specify S & P as 0.04 % MAX.

Attempts can be made in Steels to reduce these rogue elements in steels. (Excepting FREE CUTTING STEEL where % S is kept high)

DEPHOSPHORISATION needs the following conditions.

- 1) High Basicity.
- 2) Oxidizing condition.
- 3) Low temperature.

For HIGH basicity, use SODA ASH or SODIUM CARBONATE, say 5.0 Kg per ton of Steel (in ladle). There will be some pollution problem, so have exhaust fans installed.

For Oxidizing Condition, do not deoxidize the metal in the furnace at all.

For the 3rd condition, pour the metal into ladle at least 30 to 40 degrees less than pouring temperature.

Take the metal back to ladle. REMOVE the slag.

DESULFURIZATION needs the following conditions.

- 1) High Basicity.
- 2) REDUCING CONDITION.
- 3) High Temperature.

FOR condition 1) follow the same procedure you followed in the FIRST case.

For 2) deoxidize the metal in furnace itself thoroughly

For 3) take temperature to the pouring temperature

POUR the metal into ladle

Take the metal back to the furnace, remove the slag & then pour the alloy in the normal way.

As regards Basic slag, DO NOT WORRY. Your lining is any way BASIC.

I have done DESULFURISATION for S.G. Iron in a SILICA (Acidic) lined crucible. As the time of residence of slag in the crucible was so short, we had no problem what so ever.

Instead of specified 0.04 max for both S&P, even if you bring it down to 0.03 % you stand to gain in terms of Higher % E & % RA. Your quality of Steel will be appreciated by the customer. You are likely to become A FAVOURED SUPPLIER OF QUALITY STEEL CASTINGS.

Do not be too generous with Al, if the residual Al content is more, it will form Aluminium Nitride, which goes to GRAIN BOUNDARY & make your steel brittle.

If your alloy has got elements like Mn, Cr, Si (on the higher side) which are prone to oxidation loss, do not allow the liquid metal to become GASSY at all. Like a priest goes on throwing flowers on the deity, you also keep throwing ALUMINIUM PELLETS into liquid metal so that metal does not get oxidized at all.

For Mechanical testing, there are Standards like ASTM(American),

BS(British), IS (Indian),JIS (Japan),GOST (Russian) & DIN (German).

In Tensile Testing Specimen, ASTM wants $L / d = 5.0$, DIN wants $L / d = 10.00$.

DIN specifications are so stringent, that if you can satisfy DIN Standards, you can satisfy any other Standard.

May be that is the reason when you think of CARS what comes to your mind is BENZ,AUDI,BMW,PORCHE & VOLKSWAGON do you know what is the common factor in all these. They are all GERMAN CARS.

After having finished with STEEL MAKING IN FOUNDRY, let us go to

S.G.IRON

These days S.G. Iron is becoming very popular because of it's versatility.

S.G.IRON is a CAST IRON. You will get to know the details of difference between Steel & Cast irons.

Simply put, if STEEL is like a HOUSING COLONY developed by a CITY DEVELOPMENT AUTHORITY, CAST IRON is like a SLUM.

But Cast irons also have their UTILITY where TOUGHNESS & STRENGTH together are not deciding criteria.

S.G.IRON is closer to Steel, in orderliness, than Grey or White cast irons.

S.G. Iron stands for SPHEROIDAL GRAPHITIC IRON.IT IS ALSO

CALLED NODULAR IRON.

S.G. Iron has a normal composition of 3.8 % C, 2.7 % Si, 0.30 % Mn & 0.03 % S

Metallurgy of Steel, Grey iron, White iron & S.G Iron will be talked in greater detail later when we discuss Metallurgy.

It is generally, unusual to talk of FOUNDRY PRACTICE before talking of METALLURGY.

Generally, people have a perception that Metallurgy can't be understood, so you mug it up, pass the exam & forget about it.

I will try, for all I am worth, to make you UNDERSTAND Metallurgy the same way you are getting to know Foundry

Until then please take my statements as they are told.

This book will have about 100 pages of written matter & about 60 drawings.

By the time you finish this book you will feel comfortable & confident about FERROUS METALLURGY & FOUNDRY PRACTICE.

There is a diagram called Fe-C diagram. From this diagram you get to know that up to 2.0 % C, it is called STEEL & beyond 2.0% C, it is called CAST IRONS.

In cast irons we have grey, malleable, compacted, white & S.G irons.

They are called by different names because of different phases. It is this phase difference which is responsible for different behaviour of each alloy.

S.G.IRON OR NODULAR IRON

S.G. iron is made in an Induction furnace with a lining of SILICA RAMMING MASS.

In this furnace we put a charge of steel, pig iron, S.G. iron returns(GATES & FEEDERS), Fe-Si etc.

Here we melt the alloy the way we melted steel.

In Fe-C diagram you also see a point called 4.3 % C. This point is called Eutectic Point at 1130 degrees. Any alloy which has less than 4.3 is called HYPOEUTECTIC CAST IRONS. AN ALLOY WHICH HAS MORE THAN 4.3 is called HYPEREUTECTIC CAST IRONS.

S.G. Iron is a hypereutectic iron. Otherwise most of the irons we deal with are hypoeutectic irons.

In S.G. Irons we maintain a C % of 4.4 or 4.5. The Carbon we are talking of is no different from GRAPHITE you get in a PENCIL used for WRITING.

The Si that we have in S.G Iron is provided in 3 stages.

- | | |
|---|-------|
| 1) Liquid metal in Induction Furnace--- | 1.3% |
| 2) From Fe-Si-Mg treatment----- | 0.7 % |
| 3) From Inoculation----- | 0.7 % |
| Total Si content of the alloy----- | 2.7 % |

When we finish melting, the liquid metal will have about 4.0 %C & 1.3 % Si.

If the S is more than what is required, metal is treated with soda ash to remove

S. This has already been explained in STEEL MELTING.

S.G. Iron ladle looks different from a steel ladle. S.G. Iron ladle will have a WELL to place Fe-Si-Mg lumps. It is because of Mg vapour in liquid metal surface tension of the melt is increased, which does not allow Graphite to take any shape other than a SPHEROIDAL SHAPE.

Mg has a boiling point of 1107 degrees. while our pouring temperature is 1380 to 1400 degrees.

Fe-Si-Mg lumps are placed in the WELL & covered with M.S. borings or a thin M.S. plate. Liquid metal from the Furnace is poured over it.

By the time you pour about 50 to 100 Kg of liquid metal vaporisation of Mg starts. From the practice, I am familiar with, in less than 6.0 minutes the entire 1000 Kg of metal has to be emptied to hand ladles(WHERE 1.0% Fe-Si is added as an INOCULANT --which gives about 0.7 % Si) to moulds. If the pouring is delayed all the Mg vapour will escape & we do not get S.G. Iron. This is called FADING. The iron so obtained after fading is called COMPACTED GRAPHITIC IRON. It is inferior to S.G. Iron, but Superior to grey iron. All said & done we didn't get what we wanted.

It was at this point an Idea occurred to me. If Mg vaporisation reaction is delayed I can save on Fe-Si-Mg & also delay the pour out time.

What I did was a simple experiment & it turned out to be effective also. The well of the preheated ladle was cooled with compressed air. Fe-Si-Mg lumps were dumped into the well. The top of Fe-Si-Mg was covered with Sodium Silicate Sand. This sand cover became rock-like(because of heat) subsequently the sand cover was pierced with 30 mm M.S. rod with a sharp point at the end. On pouring the liquid metal over it, unlike before no reaction started till the ENTIRE 1000 Kg of metal was poured.

There after I had to wait for 1.0 minute for a minor explosion to occur.

As 1000 Kg of metal was above Fe-Si-Mg, FERROSTATIC HEAD had increased, obviously our fading time got delayed.

As we were already equipped for emptying the entire 1000 Kg in less than 6.0 minutes. Now for the same fading time, my consumption of Fe-Si-Mg came down FROM 18 Kg per ton of melt TO 12 Kg per ton of melt.

A Savings of 33 % in consumption(7 % Mg content in Fe-Si-Mg) occurred. After I explained what I did, it does not sound out of the ordinary or anything special.

All that it requires is "WANTING TO DO SOME THING DIFFERENTLY" NEVER BE AFRAID OF FAILURES. ONLY A PERSON WHO ATTEMPTS TO SOME THING, FAILS & SUCCEEDS.

SAVINGS THAT ACCRUED WAS A SAVINGS OF 33 % Fe-Si-Mg PER MONTH WHICH WAS ONE MONTH'S WAGE BILL.

Even to this day when I see people making S.G. Iron as though it is steel or Grey Iron as regards to feeding & gating, not having a proper ladle, having

open feeders like you have in steel & grey iron.

I have already given the details feeding S.G. Iron.

WE INDIANS HAVE SERIOUS PROBLEM IN SAYING “ I DON’T KNOW”

AWARENESS of IGNORANCE is the BEGINNING OF LEARNING.

Let me confess something to you, even to this day I am a computer illiterate.

Like it is said **NECESSITY is the MOTHER OF INVENTION.**

Once I decided to write **THIS BOOK I LEARNT HOW TO WORK ON “ M S WORD”**

Please remember **RICHARD FYNMMAN’S SAYINGS.**

Once entire 1000 Kg is poured out, how to check whether what you have got is S.G. Iron or not. For every hand ladle I used to pour a pencil of the metal.

whose diagram is provided. On a grey iron cube, if you hit with a **STEEL ROD**

the sound you get is **TUN (METALLIC SOUND)**,if you did the same thing

with S.G. Iron ,sound you get is **TUNG (Slightly less metallic sound) & if you**

did the same thing with a **GREY IRON ROD**, sound is **TUCK(non metallic)**

Let us look at the specification of S.G. Iron & grey Iron.

	Kg / mm²	% E
Grey iron	25 to 30	1 to 2
S.G Iron IS 1865-1968	80 Minimum	2 minimum
	70	3
	60	5
	50	7
	42	12
	37	17
S.G. Iron IS 1865-1991	MPa min	% E min
	900	2
	800	2
	700	2
	600	3
	500	7
	450	10
	400	15
	400	18
	350	22

(1.0 Kg / mm² = 10.20 MPa)

In case of a grey iron all the Graphite are interconnected & it is a path of

least resistance. So the metallic matrix hardly contributed to strength.

(An artistic impression of interconnection is provided)

Now do you realise how superior is S.G. Iron compared to Grey iron.

There is an other variety of S.G. Iron called "AUSTEMPERED S.G.IRON."

It is cooled from 930 degrees to about 500 degrees in a SALT BATH &

held there for the transformation to complete (Bainite)

This alloy gives you a strength of 120 Kg / mm^2 & % E of 1 to 3.

(In case of S.G. Iron, Graphite Spheroids are separate & are not connected in any way. Hence, the Matrix has a greater role to play in UTS , % E.

As Graphite nodules are ROUND , they reduce the Stress Concentration factor a great deal & results in enhanced Strength & % Elongation.)

SAND PLANT & SAND PREPARATION

Sand used for building purpose looks reddish in colour. This reddish colour comes from the presence of Fe_2O_3 . (red oxide of Iron—which we use as paint) This Fe_2O_3 is an impurity. This leads to lowering of refractoriness or Melting point of sand. Hence such sands are not suitable for a STEEL FOUNDRY.

Originally sands used for STEEL FOUNDRIES are SEA sands like COCHIN, MANGALORE, NELLORE SANDS.

The above sands are almost 99.9 % pure SILICA – SiO_2 . Therefore these sands have adequate refractoriness to be suitable for STEEL FOUNDRY.

The word **sand** does not mean silica sand. It is only a size gradation Viz.

Boulder, gravel, sand & flour etc. you can have GOLD sand also.

Green sand mould made of sand, Bentonite & Water is the cheapest moulding medium. Retrieval of sand for further use is maximum. Way back in 1980, the landed cost of Mangalore sand in Bangalore was Rs 120 per ton, where as the cost of sand was only Rs 20 per ton. To day I am told that the landed cost of sand is about Rs 1000 per ton. So reclaiming of sand becomes all the more important.

Normal metal to sand ratio is 1:5. If I were to run a foundry of my own, I would use 1 part fresh sand, 1 part reclaimed sand & 3 parts even construction sand as it does not come in contact with metal anyway, provided it is coarser to allow moisture to escape.

In a Green sand mould, I compare WATER with a COBRA. If cobra had an escape route it would escape without biting any body, but if it's escape route is blocked, it will bite some body. The situation of WATER in mould is no different. It WANTS to get away from HOT METAL as water vapour. So we should provide a PATH for it to get away. This path is defined by PERMEABILITY of sand. Imagine permeability as voids in sand mould which are interconnected.

Technical requirement of Silica Sand :

Chemical composition----

Silica (SiO_2)---- 96 % min.

Iron oxide (Fe_2O_3)--- 1.0 % Max.

Aluminium Oxide (Al_2O_3) --- 1.5 % max.

CaO +MgO----- 0.75 % max.

$\text{Na}_2\text{O} + \text{K}_2\text{O}$ ----- 1.0 % max.

Loss on ignition----- 0.75 % max

The above sand would have adequate refractoriness to withstand the temperature of 1640 degrees of molten metal.

The generally acceptable sand shapes are major portion of rounded and a minor portion of sub-angular.

Average Grain size of Sands:

- 1) Coarse sand----- 0.70 mm to 0.35 mm,
- 2) Medium sand---- 0.35 mm to 0.23 mm,
- 3) Fine sand----- 0.23 mm to 0.125 mm.

Medium Sands are best suited for STEEL FOUNDRY PRACTICE for making moulds & cores. These sands have good Permeability, which helps in escaping of moisture as steam. As the surface area is also less, it consumes less of binder. They are amenable to reclamation & reuse.

Grain size terminology which is in vogue,

Coarse sand----- 22 # to 44#

Medium sand----- 40# to 60#

Fine sand----- 60# to 100#

You are probably wondering as to what is this #. It is called a Mesh. You go home & ask your mother as to what she does to wheat flour after Wheat has been converted to flour. She SIEVES to separate FINES from COARSE flour.

These sieves are designated by sieve size. If 1.0 inch (25.4 mm) length is divided into 10 equal parts. Each part measures 2.54 mm. If a SQUARE is made out of this, it becomes a square of 2.54 mm x 2.54 mm. It is called 10 MESH or 10 #. If 25.4 mm is divided into 60 equal parts, it will become 0.423 mm. A sieve with SQUARES of 0.423 mm x 0.423 mm is called a 60 MESH or 60#. More is the NUMBER finer the material.

Bonding Clays for Foundry Sands :

All clays(the material a POT maker uses is also a CLAY) can be classified as Hydrous Alumina Silicates with a particle size of 0.01 microns (0.00001 mm) to 20 microns(0.02 mm). They have a unique property of becoming plastic-PASTY when wet & hard when dried. The Chemical name of these clays is MONTMORRILLONITES. These are called BENTONITES in every day parlance. There are two kinds of Bentonites: Sodium based & Calcium based. In Steel foundry, Sodium based Bentonites are used. As these have a combination of high bonding strength, high durability & resistance to heat expansion defects.

Bentonite absorbs WATER which is 13 % of it's own original volume.

Sand needs water to WET the sand surface & it is of the order of 1.9 % of sand weight. This water is called TEMPER WATER. 8.0% Bentonite needs $8.0 \times 0.13 = 1.04$ % water.

Water absorbed by for PEAK STRENGTH by different additives is,

ADDITIVES	% water absorbed by each % of additive,
-----------	---

A) Wood Flour	0.275
B) Corn Flour	0.325
C) Cereals	0.135
D) Sea coal	0.060
E) Silica Flour	0.33

The Total Amount of Water required is :

- 1) Weight of Sand ----- a Kg
- 2) Weight of Bentinite ----- b Kg
- 3) Weight of Wood Flour ----- c Kg
- 4) Weight of Corn Flour ----- d Kg
- 5) Weight of Cereal ----- e Kg
- 6) Weight of Sea Coal ----- f Kg
- 7) Weight of Silica Flour ----- g Kg

The Total Water required for PEAK STRENGTH is :

$$1.9 \% \times a + 13 \% \times b + 0.275 \% \times c + 0.325 \% \times d + 0.135 \% \times e + 0.06 \% \times f + 0.33 \% \times g.$$

As regards to amount of additions, it depends on ADDITIONAL properties required.

While moulding use 25 % to 30 % NEW SAND as FACING SAND & the rest is Backing Sand.

For Good Permeability, Sand should be of 40 to 60 # (Facing Sand)

Sodium Bentinite---- 4 to 6 %

Cereals (Starch or Dextrine) -- 0.5 to 0.75 %

Water ----- 2.8 to 3.2 %

Preparation of Sand : There are TWO methods of preparing Sands.

1) MULLING.

2) MIXING.

Let us understand the difference between these two.

When your mother wants to make “Chapathis “ what does she do. She takes wheat flour & puts a small amount of water or may be some amount of milk.

(Incidentally do you know when only Milk is put , Chapathis remain softer for a longer period) Then she SQUEEZES them together & it becomes a DOUGH.

With it she makes Chapathis. Similar is the condition in applying a Paste of Bentonite (Smearing) on every Grain of Sand. This is called Mulling.

For this purpose you have TWO Rollers(which are rotating) in a MULLER, To begin with mull Sand and tempered water, this wets the sand surface , then add Bentonite and it's water requirement and mull. In the process of mulling Sand + water + bentonite get SQUEEZED between bottom plate of the muller & bottom of rollers. Subsequently you make your other additions and corresponding water & mull. The similar process of mulling is followed with Sand and Sodium Silicate.

Now let us look at MIXING. If your mother wants to make Ghee rice or Lemon rice, she mixes the ghee or masala into cooked rice so delicately that the cooked RICE grains do not BREAK. This is called Mixing. This process is adopted in foundries, where the BINDER is a LIQUID. Such as OIL, SHELL RESIN, NO-BAKE etc.

Normal green (WET) strength of your SAND –MIX is about 6 to 10 psi. (POUNDS PER SQUARE INCH). When you want to get your TWO WHEELER tyres filled with AIR, you go to a PETROL BUNK & get them filled with air. While getting them filled, you say 30 in the FRONT & 35 in the BACK. What do these 30 & 35 indicate. They are 30 psi & 35 psi.

If you want to check the adequacy of green strength, there are equipments available. If you want to do it manually, take a hand-full of green sand in your palm & squeeze it into a shape of “ MODAK “. Holding the bottom of the sample in your palm, BREAK the TOP of the sample with your THUMB. On looking at the sample, if you NOTICE your FINGER PRINTS on the sample & sand grains at the EDGE OF BROKEN SURFACE are intact (NOT FALLEN DOWN) then you can conclude that green strength is adequate.

Dry strength of this sand can be around 150 psi. If you do not have an oven to dry the mould, you can even SKIN DRY the surface with L.P.G Flame at LOW intensity so as to remove MOISTURE only & not burn away your additions like DEXTRINE etc.

When you want to make a green sand mould for a CASTING weighing about 200 – 250 Kg, add 1.0% of FIRE-CLAY to your FACING SAND & mull.

On skin drying the mould becomes so HARD that YOU CAN STAND ON IT.

Permeability: Permeability is defined as the air flow through a unit cube of material. It is affected by Grain Size, Grain Size Distribution. Permeability value for Green sand should be about 130 to 200 for easy passage of water vapour to get away from liquid metal. In case dry sand moulds, this value can be about 100.

The other Moulding processes which are popular are :

- 1) Sodium Silicate – CO₂ Process.
- 2) Shell moulding process.
- 3) No – Bake Process.

Sodium Silicate is made by melting Na₂O (Sodium oxide – basic) & SiO₂ (Silica- acidic) in an Arc Furnace. When it is melted, it is poured into water. Sodium Silicate has about 50 % water in it .

To the FRESH sand about 5 % Sodium Silicate is added & mull.

This sand is used as a FACING SAND, the backing sand could be recycled green sand or recycled silicate sand.

The major difference between Green sand & Sodium Silicate sand processes is

bonding is PHYSICAL in Green Sand, While it is CHEMICAL in Sodium silicate Sand. By & large Sodium Silicate sand HARDENS by passing CO₂ gas or removal of Moisture. Passing CO₂ gas results in faster production. This sand, on storing, it sets. So this sand should be covered by WET gunny bags to avoid moisture loss from the sand. Amount of CO₂ gas required is about 10 % of Sodium Silicate. People often consume more than required. It should be controlled. The gas passed gives "SILICA GEL" and that gel acts as a binder between grains. The gas should be passed into several narrow holes made in the mould (5 – 8 mm dia) at a pressure of slightly more than atmospheric pressure. Like your using a FAN in SUMMER. After the mould has become hard , which is made out by feel, at the earliest apply mould coat on the surface of the mould which comes in contact with liquid metal. Other wise surface becomes highly FRIABLE (LOSS OF STRENGTH- HENCE LOOSE SAND) this leads to sand inclusion in the casting. This system is expensive but faster than green sand process. From my exposure to foundry people , lot of people use this process because of fear of moisture .

The major problem with this process are :

- 1) Expensive.
- 2) Poor collapsibility.
- 3) Poor Reclaimability.

One simple way of reclaiming this sand is to PUT BROKEN SAND INTO A WATER TANK & leave it for a day. The Chemical that is present on sand grain is SODIUM CARBONATE which dissolves in water. Sand is taken out of the tank & dried, reused as backing sand.

In this system I found a SILVER LINING i.e. Mix SAND + SODIUM SILICATE + 1 % Bentonite, with this mix you can make small cores & as soon as they attain a green strength good enough to handle, take the core out of the core box & leave it in atmosphere. In a day it becomes as good as a conventional CO₂ core. This does not need CO₂ gas at all. On top of it even if you STORE this CORE for ONE MONTH surface does not become FRIABLE. Since Bentonite has Al₂O₃ in it , collapsibility is improved.

As regards to the size of the core you can make " THIS WAY" has to be arrived at based on your shop flour needs.

The biggest advantage this Sodium Silicate- CO₂ process offers is the size of the casting. It can be as big as 1 ton or more. To improve the collapsibility of this sand ,add small amount of PADDY HUSK to sand while mulling the sand. This paddy husk breaks the continuity of GEL, husk will behave like holes, which in turn weakens the gel, thus improving the collapsibility of the sand.

A piece of Suggestion : Scientists are dealing with well defined laws & with that background they are trying to do some thing new.

But we Foundrymen are like babes in the woods (supposedly ignorant). There is a hill of gold covered by stones & mud is right in front of you. Discover it for yourselves. In foundry art or science, we hardly know anything. To discover something things of relevance to you, you don't need to have formal educational degrees. Oftentimes I feel our system of formal education is a hindrance to thinking. For thinking all that you need is a **CHILDLIKE CURIOSITY**.

Animals have an instinctive mind & we human beings have an intellectual mind, animals can't think & we don't think. What is big difference between human beings & animals. Before the onset of an earthquake, animals act funny because they are aware of the problem in the offing. This is called **PRETERNATURAL SENSE**. We don't have it .

If you recall what Siddhartha said for what he can do, " I CAN WAIT, I CAN FAST & I CAN THINK " Think a bit deep to understand it's implicit meaning . To day ,we can't wait, we want every thing yesterday---we have no PATIENCE. We can't fast. We hog. That is the reason why OBESITY has become a great problem across the board. As regards to the last part of the statement " I CAN THINK", is he conveying a message that most people can't think constructively anyway.

Here I want to tell you some thing which may surprise you.

*Albert Einstein worked as clerk in a Patent Office in Switzerland. He incidentally didn't have many degrees to boast of. While he was working in patent office he had lot of free time & an **ENQUIRING MIND**.*

Even when he was with Institute of Advanced studies, Princeton, New Jersey, USA, he had already contributed a great deal to Physics with his works such as "THEORY OF RELATIVITY", $E = Mxc^2$, " THERMIONIC EMISSION"

He had been awarded a NOBEL PRIZE in Physics for his work on Thermionic Emission. He was highly regarded by scientists across the world, yet he didn't rest on his past laurels. He was working on UNIFIED THEORY OF RELATIVITY, where he didn't succeed. That is when he is supposed to have said that GOD does not play dice with his creation.

*He is also supposed to have said IF I HAD NOT WRITTEN MY PAPER ON THEORY OF RELATIVITY,SOME ONE ELSE WOULD HAVE AS THE IDEA WAS IN THE AIR. Or in other words was he trying to say "**if you want to get new ideas KEEP YOUR MENTAL ANTENNA OPEN.**"*

If a man of the calibre of Einstein had to say this, what to talk of people like us, We need to keep OUR ANTENNA all the more an OPEN (THINK).

Back to work. SHELL MOULDING is a beautiful process. Excepting for it's initial cost of machine & metallic pattern, the product you get is outstanding.

Least consumption of sand, very good finish, high complexity & fantastic collapsibility.

Chemicals used are Acidic Phenol Formaldehyde as binder & Hexa as a catalyst. Mould forms at around 220 degrees. Only constraint it has is weight of the casting. I don't know if you can make a 500 Kg Shell moulding casting.

The next process is a NO-BAKE process

- 1) 3 part system.
- 2) 2 part system.
- 3) Furan system.

With these systems you can make both moulds & cores , like in SHELL, but you will have to work out the COST- BENEFIT analysis. I have no expertise in this area. So I won't talk more about it.

Moulding can be done in several ways.

- 1) Hand rammer.
- 2) Pneumatic rammer.
- 3) Jolt type of moulding machine.
- 4) Squeeze type of moulding machine.
- 5) Jolt & Squeeze type of moulding machine.

WARNING:::::::::: ENSURE THAT THERE IS ALWAYS A SAND TO SAND CONTACT & NOT MOULD BOX TO BOX CONTACT. This will save you from lot of botheration from distorted mould boxes.

Process	Binder %	Compression strength in psi		Bench Life
		Green	Dry or Set	
Green	4—7	5 - 10	80—120	Few hrs
CO2	4---6	0.2	400—700	1-2 hrs
3 parts	4—6	1.5 - 3.0	>1000	30 minutes
Shell	3---6	Nil	>1000	Indefinite
Green Skin dried	4—10	5 - 10	100 -200	Few hrs

Mould Finishing:

Mould finish that we can obtain in an uncoated mould would be like that of a wall which is finished with MORTER (not very smooth)

This would increase our grinding work in Fettling Section.

So in order to get a good as-cast finish we need to coat the mould with a

refractory coat, which is made of powder which is as fine as TALCUM powder. Coats are also called as PAINTS. These are made of ZIRCON, MAGNESITE, OLIVINE & GRAPHITE.

Those who want to make paints on their own to reduce input cost can contact the following:

- 1) Kutch Minerals , Mondvi.
- 2) Department of Chemical Technology, Matunga, University of Bombay, Mumbai.
- 3) Dept of Paint Technology, L. N. Institute of Technology, Nagpur.
- 4) Herbert & Cutler Institute of Technology, Kanpur.

The paints are made of fine particles (--200 #) so that the coat is impermeable to liquid metal penetration. The desired coating thickness is about 0.6 mm in case of heavy castings & in all other cases it is about 0.25 mm.

Thinner based paints are used where a binder is likely to react with water.

(Inorganic binders--- bentonite, sodium silicate etc)

Water based paints are used where binders are Organic.

(Organic binders- shell, no-bake.)

After having closed the moulds, cover all the openings with a LIGHT WEIGHT RETRIEVABLE card board .Remove these covers only before pouring the metal. Immediately after pouring & filling the mould, put APC POWDER or EXOTHERMIC POWDER OR METAL GENERATING EXOTHERMIC POWDER on top the FEEDERS as decided at the stage of METHODING.

Now leave the mould to itself till the casting cools to a temperature of about 500 degrees. Move the mould from pouring bay to knock-out bay. But do not knock out the mould till the casting temperature falls to about 200 degrees.

Do not be hasty in knocking out, even if you have sub-contracted the job.

Always remember **haste makes waste**.

KNOCK OUT:

Your knock out area must be kept clean & knocked out sand should be immediately disposed off. Always remember AREA UNDER THE CRANE IS WORTH IT'S WEIGHT IN GOLD.

After you knock out the mould, you get the FIRST GLIMPSE of your Product. You are better off if you have a **MANUAL SAND BLASTING UNIT**. If you view the casting after sand blasting, you will be able improve upon your **QUALITY ASSURANCE PROCESS**.

Here I have a confession to MAKE. Excepting having a tapered SPRUE, I have not bothered much with gating system. But I did ensure a **DIRECTIONAL SOLIDIFICATION**. May be I did what I did it **INSTINCTIVELY** but instinct is **NO SCIENCE**. So learn about **RUNNERS & GATES** from other source.

FETTLING:

Then casting is moved to fettling section. Where **GATES & FEEDERS** of

Grey Iron, S.G. Iron & White Iron can be knocked off.

But with Steel YOU CAN'T TAKE LIBERTIES. You have to follow the RULES OF THE GAME. That rule in STEEL is CARBON EQUIVALENT.

Don't get confused with this C.E (STEEL) with C.E (CAST IRON).

You will get to know the details of these in METALLURGY at the end.

To eliminate the fear of it in you, I will give you both C.E' s here.

C.E.(Cast iron) = % C + 0.31 x % Si + 0.33 x % P + 0.05 x % Ni + 0.075 x % Cu - 0.06 x % Cr - 0.03 x % Mn - 0.10 x % V - 0.11 x % Mo.

If you observe here you have some (+) & some (--). (+) are Graphite Formers and (--) are Carbide Formers.

C.E.(STEEL) = % C + % Mn + 0.2 x % Cr + 0.2 x % Mo + 0.2 x % V + 0.067 x % Ni + 0.067 x % Cu.

In case of STEELS , it is dealing with EUTECTOID POINT.

All the alloying elements reduce the EUTECTOID C % of 0.8 to a lesser level and thus increasing the possibility of Carbides going to grain boundary, making the alloy brittle.

When you come to Metallurgy proper, you get to hear lot of words like these, Eutectoid, Hypoeutectoid, Hypereutectoid, Eutectic, Hypoeutectic & Hypereutectic etc.

In case of Steels, from Fe-C diagram we know that, under Equilibrium conditions, below 0.8 % C we are safe as there are no brittle materials like carbides on the grain boundary. Else where I have said that we always want to get a fine grained structure because at normal temperatures, grain boundary is stronger than grain. So we would like to have as much grain boundary as possible. Beyond 0.8 % C , grain boundary which was hitherto our source of strength, can make the material vulnerable to premature failures. This happens only because, grain boundary has been made weak by precipitation of carbides on the grain boundary, which makes it brittle.

(There is a temperature called EQUICOHESIVE temperature, below which grain boundary is stronger than grain, room temperature is well below THAT temperature. Hence fine grain boundary is preferred at room temperature)

One of the reasons why you always find me a bit-of an anti Fe-C diagram because it does not tell me the whole story.

That story is told by C.E.(STEEL). From Fe-C diagrams perspective, only C is a troublesome element. From this C.E.(STEEL) you can make out lot of elements can cause problems. Steel is no longer vulnerable only by % C but by other elements also. From a simple Fe-C diagram at 0.3% C you are as safe as a baby in his or her mother's lap. It is no longer the case as all other elements

become co-conspirators by making grain boundary vulnerable even at levels of C where we thought we were safe.

As per Fe-C diagram, you are in trouble only if you cross 0.8 % C, but in reality it is not so any more. A C % of 0.8 & a C.E. of 0.8 are one and the same.

Supposing I have an alloy, which has 0.3 % C & 0.6 % Mn, from C.E we are already in trouble.

$C.E = 0.3 + 0.6 = 0.9$ which is above 0.8 & hence I am already in a danger zone.

At this composition, your steel can be brittle & break if not handled with care.

I would like to narrate an incidence as to how deep seated is our ignorance & ego. For person who thinks that he knows every thing that is to be known, even GODESS of KNOWLEDGE can't help.

In one foundry where I was looking after melting & moulding , we were making Hollow ball casting to be used, in thermal plants, for coal crushing. This was wear-resistant steel casting. To the best of my memory, that alloy had 0.6 % C, 0.5 % Mn ,1.0 % Ni, 1.0 % Cr & 0.4 % Mo. Calculate it's C.E. It works out to 1.447 if I have not made any calculation error.

I am not narrating this incidence to indict any body, but only to prove how one's ego & ignorance can do damages. You simply can't escape from the clutches of Murphy's law.

This casting in question weighed about 1000 Kg.

It had a wall thickness of about 90 mm.

A sand core was in it as there was no access to take it out. you will get to see the diagram.

This alloy was to be cooled in AIR. Required hardness was to be obtained by air cooling. But for some reason, we were not getting the hardness.

A team of people took a decision to water quench it to get the desired hardness. It was around 1.30 p.m. & I was going for lunch, as I saw some activity, I asked them as to what they were doing. They said they were going to quench the ball in water so that they could get the required hardness. I thought for a moment & said the ball will crack if you did that. Nobody even bothered to ask me as to why I was saying what ever I was saying. As they were all my seniors, I had no control on them. So I went away feeling bad. After lunch, when I came back, what I saw was a Hollow ball broken into two pieces.

Now my argument for what I said. C.E of the alloy was more than 0.8 & there was sand inside. By water quenching, even if the outer surface is cooled, but the hot **sand** ,inside, would not cool, carbides would form on the grain boundary. Because of stresses caused by water cooling, would initiate crack from ID (core)side ,crack formed would propagate to the periphery, very easily, as the hardness on the periphery was already more than required (may be Martensite had formed)

Dr Abdul Kalam said in his Book "WINGS OF FIRE", if you want to avoid failures, anticipate them.

In C.E. of Cast Iron, your interest is whether, the alloy in question has a C.E which is more than or less than 4.3.

In C.E. of Steels, your interest is whether , the alloy in question has a C.E. which is more than or less than 0.8.

Take the case of HADFIELD Mn Steel , after Heat Treatment it is a very tough or ductile alloy with a % E as much as 50 %. But in AS-CAST condition it is a very brittle alloy. As it is a Hypereutectoid steel ,with a C.E. more than 0.8 %, carbides are on the grain boundary, thus making the alloy prone to cracks.

While this alloy is fettled, every care is taken to ensure that NO PORTION of the casting gets heated up, which results in THERMAL STRESSES, which lead to cracks.

If I were to RUN a foundry of MY OWN, I would have a WATER TANK, I would PLACE my casting dipped in WATER, other than the portion I am working on, while I am doing any FETTLING work TO AVOID ALL **HEAT AFFECTED ZONE** PROBLEMS. IT IS BETTER TO BE SAFE THAN SORRY.

After having finished CUTTING & GRINDING of GATES & FEEDERS, Casting are sent to heat treatment section.

A WORD OF ADVICE :WITH SO MANY UNKNOWN IT'S BETTER TO BE **SUSPICIOUS** ABOUT WHAT IS BEING DONE IN THE FOUNDRY. WHEN YOU ARE EXPLAINING THINGS TO OTHERS, START WITH **WHAT NOT TO DO** THAN WHAT TO DO.

HEAT TREATMENT:

Heat treatment of Ferrous casting is essential for several reasons.

- 1) Removal of Stresses.
- 2) To get a UNIFORM DESIRABLE STRUCTURE across the casting.

Heat Treatments available are :

- 1) STRESS RELIEVING.
- 2) ANNEALING.
- 3) NORMALISING.
- 4) AIR QUENCHING.
- 5) OIL QUENCHING.
- 6) WATER QUENCHING.
- 7) TEMPERING.
- 8) AUSTEMPERING.

As this is NOT A TEXT BOOK I am not following a conventional text book Pattern.

All your doubts will be clarified when read METALLURGY section & see the Drawings & sketches (Where required explanations are given)

If you look at the Fe-C diagram ,you will see a LINE running from 910 degrees To 723 degrees. This line is called A3 or Ac3. Above this line you will find a Phase called ,Gama or Austenite phase. This phase is the starting point of all Our Heat treatment cycles.

Like a RIVER takes birth in ONE PARTICULAR PLACE & then flows in various different directions. Our heat treatment cycle starts from ONE POINT takes various routs of cooling.

I am just explaining the Physical process of each heat-treatment cycle. Their metallurgical significance comes later.

Every heat treatment cycle of ours' barring Stress relieving & tempering starts from a point in AUSTENITIC phase. For convenience sake, let us say this temperature is 950 degrees.

1) Annealing: Load the casting into the furnace ,heat it slowly(?) &reach the Temp of 950 degrees. HOLD THE CASTING THERE FOR A PRE-DETERMINED TIME. FOR HOLDING TIME, THUMB RULE IS ONE (1) HOUR PER INCH (25.4 mm).Then put off the furnace. Allow the casting to cool to ROOM temperature (theoretically) ,but castings can be taken out of the furnace ,at a temperature where COOLING STRESSES do not distort the casting.

For example: a cube---- at 250 degrees.

a plate-----at 180 degrees

a complex shaped casting, with a combination of thin & thick walled sections-----at 100 degrees.

2) Normalizing: REPEAT ANNEALING UPTO HOLDING TIME, take the casting out & leave it in STILL AIR (NO FANS OR WHERE BREEZE COMES)

3) AIR COOLING: REPEAT NORMALIZING ,BUT COOL WITH INDUSTRIAL FANS.

4) OIL QUENCHING : REPEAT ANNEALING UPTO HOLDING TIME & THEN QUENCH THE CASTING IN AN OIL.

5) WATER QUENCHING : REPEAT ANNEALING UPTO HOLDING TIME & THEN QUENCH THE CASTING IN WATER.

(While quenching in water, steam forms on the surface of the casting, which in turn reduces heat extraction rate, so it is essential to break this steam layer by agitating the water bath.)

One thing you would have noticed is that you are gradually increasing the COOLING RATE OR RESORTING TO FASTER COOLING.

THE PHASES THAT WOULD APPEAR ARE :

1)FERRITE

2) CEMENTITE

3)PEARLITE

4) BAINITE

5) MARTENSITE

6) TEMPERED MARTENSITE

7) GRAPHITES OF VARIOUS SHAPES IN CASE OF CAST IRONS

While you are still in Heat treatment, you can as well know of one more Equation. That equation is called Ms equation:

$$M_s - \text{Temperature in degrees} = 561 - 471 (\% C) - 33 (\% Mn) - 17 (\% Ni) - 17 (\% Cr) - 21 (\% Mo)$$

For your information, Martensite formation starts below Ms temperature.

For most of our low alloy steels Ms is about 200 degrees.

If at all you have to do any welding etc, ensure that the casting is above 200 degree Centigrade so that no martensite forms leading to cracks elsewhere.

*Here I have a Question for which a Design Engineer should have an answer.

A Design engineer calculates the WORKING STRESS. Multiplies it by a Factor of safety(?). How accurate is it? & then he multiplies the working stress with factor of safety. Assumes that to be his YIELD STRESS.

Looks at a STANDARD FOR MECHANICAL PROPERTIES. Which ever set of values of UTS, YS, %E, %RA, BHN has HIS value is selected.

But what does he know about %E, % RA.

Supposing some body wants a UTS of 90 Kg / mm^2 , YS of 80 Kg / mm^2 , % E of 14, % RA of 22. If I give a value of UTS of 88 Kg / mm^2 ,

YS of 79 Kg / mm^2 , but % E of 18, % RA of 25. Would the designer accept it or reject it. Most of them would reject it. Because strength values are lower.

Does he really know a great deal about them. I doubt. How certain is he of factor of safety employed in his calculation. For the same function Russian machines are bigger than Japans' machine.

As a metallurgist I would be inclined to go for second set of values as their %E & % RA are more, hence being tougher, they instil a greater degree of confidence as regards to premature failure not occurring.

INSPECTION & TESTING

The desired properties or Qualities sought by a customer, usually, are,

- 1) Chemical Composition,
- 2) Mechanical properties,
- 3) Radiography,
- 4) Crack Detection,
- 5) Ultrasonic inspection, etc

1) Chemical Composition: It has already been done before pouring the Melt into The mould.

2) Mechanical Properties:

These are UTS, YS, % E, % RA ,Hardness, Impact Strength.

For Mechanical Properties evaluation ,the customer himself tells you as to which STANDARD, the material has to be evaluated.

STANDARDS are ASTM(American), BS (British), IS (Indian) , DIN (German) ,JIS (Japan) , GOST (Russian) etc.

For tensile testing purpose, let us use ASTM-a-370 test block .This test bar Design consumes lesser liquid metal than IS test bar. The drawing of this test Block is given.

As regards to TENSILE TESTING SAMPLE DESIGN there are variations.

	Guage Length / Diameter	
ASTM Design specifies	L / D	4
BS Design specifies	L /D	3.54
IS Design specifies	L / D	5
DIN Design specifies	L / D	10

In Steels, Necking occurs leading to a CUP &CONE fracture.

This Neck is confined to a small portion of L(GAUGE LENGTH).

Let us say FOR a SPECIMAN DIA OF 10 mm,

GAUGE LENGTH' s will be different for different STANDARDS.

	Guage Length	mm
ASTM Design specifies	L	40

BS Design specifies	L	35.4
IS Design specifies	L	50
DIN Design specifies	L	100

Here is an INTERESTING SITUATION ,let us say as per ASTM we require a % E of 25 % & we have got ,on testing, 27 % after having achieved every other STIPULAED VALUE. The material will be accepted as far as it's mechanical properties are concerned.

But with the same ALLOY if you have to meet DIN STANDARDS, you are likely to FAIL. WHY ?.In case of ASTM test bar your gauge length is 40 mm, influence of NECKED LENGTH is predominant. Where as with DIN standards, influence of NECKED LENGTH becomes almost insignificant because of it's GAUGE LENGTH is 100 mm. So in order to get a % E of 25 in DIN Standards, your alloy must be of BETTER QUALITY in terms of % S, % P & other impurities. They must be lower for DIN. So if your are making a steel for DIN standards, IT HAS TO HAVE LOWER % S, LOWER % P & LOWER LEVELS OF IMPURITIES. That is the reason when you mention % E, you have to mention GAUGE LENGTH. IF YOU CAN SATISFY DIN STANDARDS you can satisfy any other standard.

With the advent of ISO STANDARD, L / D might have got universalised .

Just to show you how superior are DIN standards AS REGARDS to metal quality I have taken this example. May be that is the reason why GERMAN CARs Like BENZ,BMW, PORCHE, AUDI, VOLKSWAGON are more famous & durable than any other car in the world barring ROLLS-ROYCE, which is CUSTOM made car or in other words MADE TO ORDER.

It is for you to decide as to what kind of foundry you want to run, an-also-ran kind of foundry or a FOUNDRY which is a " BYWORD " for Quality.

Remember-----NO GAINS WITH OUT PAINS.

While we are still talking about Mechanical Properties, I would like to draw your attention to a small & silly factor, which becomes a head ach many times. Culprits in this case are our DESIGNERS OF COMPONENTS. They often ask for a TEST BAR to be taken out of casting & give same properties as per Standards. The TEST BARS we pour are for a GIVEN COOLING RATE, Hence they give the properties sought by STANDARDS ,but a TEST BAR taken out of a casting may not have gone through similar COOLING RATE. So it will never give you the DESIRED PROPERTIES. Then some concession will have to be given to the properties obtained in a TEST BAR taken out of casting.

Before accepting an order for a casting, Ensure that is a cast alloy & not a wrought alloy. When people ask for 304 casting, my blood boils. Do you know

Why. 304 is a 18 / 8 STAINLESS STEEL & WROUGHT ALLOY. It's Cast equivalent is CF-8. There is a DIFFERENCE in CHEMICAL COMPOSITION & THERE IS A MINOR PHASE DIFFERENCE.

Try rolling CF-8, you simply can't. Do you know why ? It is like making a Chapathi out of a dough which has a uncooked RICE grain in it. you will never be able to do it as it keeps TEARING because the presence of RICE GRAIN.

304 being a wrought alloy should be FREE OF ANY RETAINED FERRITE. But CF-8 can have about 1% RETAINED FERRITE as it is not going to be rolled any way.

In this regard ,I have gone through the problem of making a casting out of EN-24 alloy. When I pulled the test bar I simply did not get the properties despite the fact that our composition , heat treatment cycle & microstructure were spot on.

Do you know why you will never get it ?

WHEN YOU TAKE A 70 mm DIA BAR & FORGE IT TO A 50 mm DIA BAR, WHAT DO YOU EXPECT TO SEE AT THE ENDS. FLAT, BULGE OR A DEPRESSION. WHAT YOU GET TO SEE IS A DEPRESSION. WHY ?

IN A WROUGHT PIECE, MILLIONS OF DEFECTS CALLED AS "VACANCIES" MIGRATE TOWARDS THE FREE END THUS MAKING A WROUGHT ALLOY, with lesser defects at atomic level, SUPERIOR IN PROPERTIES IN COMPARISON TO A CAST ALLOY.

NEVER CAST A WROUGHT ALLOY.

In our tensile test bar, you do get a cup & a cone fracture. Join them together and See ,you will find a CAVITY in between, this is same phenomenon of migration of vacancies.

3) Radiography : When you have a fracture in your arm, the radiographer takes an X-Ray film to see the invisible fracture. Industrial radiography is no different. If you want to see a defects inside a casting viz. shrinkage, inclusion, crack etc you get the Radiography done.

The difference between Medical & industrial Radiography is the SOURCE (Equipment) In Medical radiography, you have a machine which generates X-Rays. In industrial radiography, you have a source of gamma rays, viz. Ir-192 or Co-60. These are like PENCILS, supplied by BABA ATOMIC RESEARCH CENTRE IN MUMBAI. Any body can see the defect & take a Corrective action & reshoot again to see if the defect has been eliminated.

4) CRACK DETECTION: This is ,by & large ,for surface defects.

You are provided with a liquid with VERY low surface tension. Apply this Liquid on the casting surface, allow the liquid to SEEP into the discontinuity & then RUB of the entire surface of the casting. Then SPRINKLE a POWDER On the surface. This powder ABSORBS the liquid which has SEEPED into the

Defects & change of colour of the powder after absorbing the liquid is an Indication of existence of a defect. Corrective action may be taken.

5) Ultrasonic testing : Excepting for the initial investment, this testing is cheaper & more accurate. But for interpretation of the results you need some expertise.

FOUNDRY MANAGEMENT

As this book is written for new comers to foundry, I have included this chapter. A foundry, for that matter any industry, must make profits. Profits accrue from PROPER LAYOUT, PRODUCT MIX, YOUR OWN QUALITY LEVELS, YOUR PRODUCT'S MARKETABILITY & MARKET FORCES.

1) At end of each day the C.E.O of the company should have a fairly a good idea about total money spent yesterday & how much revenue it is going to generate at the end of the CYCLE time.(from moulding to despatch)
Would it make profits ? If so how much ? Can it be further improved upon.
If so ,how ?

2) This should take a Concrete shape by the end of the week.

3) At the end of each month, you should have a detailed data on profits made In each month. A man lives as long as his heart works, similarly a foundry Sustains & survives as long as it makes profits on a daily, weekly, monthly & yearly basis.

RIGHT AT THE BEGINNING OF THIS BOOK WE TALKED ABOUT "ENTROPY." LET US APPLY THAT PRINCIPLE HERE & DECIDE AS TO WHAT IS THE MAXIMUM PROFIT THAT CAN BE MADE. ARE WE MAKING IT . IF NOT, WHY NOT ? HOW DO WE GO ABOUT HITTING THAT "BULL'S EYE".

Any industry should run on SYSTEMS, not on some one's whims & fancies. The systems should be frequently reviewed to eliminate NON-VALUE added activities. So a new system comes into force. This new system , having eliminated visible non-value added activities should earn more profits. Then start looking for non visible non-value added activities.

Every human activity should be QUANTIFIED so much so that SUPERVISION must become redundant.

Every worker gets paid only for what is good.

If a contract labour is attached to a regular employee he should also be benefited. If there is an INCENTIVE SYSTEM it should be INDIVIDUAL & NOT GROUP, as in group some undeserving fellows take away the benefit.

Contract worker also should get incentive.

When ever you employ a new person take him on TRIAL for 2 months.

If he is good keep him & employ him on a regular basis otherwise out he goes
You need to do quite a bit of TIME & MOTION study.

This T&M study should include everybody & every activity.

- There are 8 hrs in a shift.
- Take 10 minutes as a UNIT.
- There are 6 UNITS in an hour.
- There are 48 UNITS IN A SHIFT.
- Deduct-1unit at the beginning of the shift for change of dress.
- Deduct 1 unit for tea.
- Deduct 3 units for lunch.
- Deduct 1 unit for change of dress at the end of the shift.
- You are left with 42 FUNCTIONAL UNITS.
- Deduct 2 units for toilet etc.
- Now you are left with 40 FUNCTIONAL units.
- Every worker should put in 40 units of work per day no matter where he works.
- Units designed is for an average worker.
- If one worker is fast & he has free time & he wants to work, let him work.
- Every worker is responsible for his out put. If it gets rejected, he loses the incentive.

In assigning responsibility for rejection YOU MUST BE IMPARTIAL & TRANSPARENT.

No worker should feel cheated.

From your Methods section, WORKING SHEETS FOR EACH ACTIVITY, FOR EACH CASTING MUST COME TO SHOP.

YOUR PRODUCTION, PLANNING & CONTROL SHOULD ENSURE IT. THESE SHEETS SHOULD TALK OF WHAT-NOT-TO-DO TO BEGIN WITH(IN RED INK) THEN WHAT TO DO.

It is the non-awareness of WHAT-NOT-TO-DO is the main reason for all failures. When your workers become AWARE of all WHAT-NOT –TO- DO they will be like EXPERTS themselves.

Maintain a monthly ACTIVITY card for each worker. This card should have The following columns.

- 1) Date
- 2) Activity performed
- 3) UNITS put in each day
- 4) UNITS lost because of rejection for which he is responsible (each day)
- 5) Total no of EFFECTIVE UNITS per month at the end of the month
- 6) Total Incentive payable for EFFECTIVE units per month
- 7) If there are backlog of UNITS lost, for the last month, it must be brought forward.

FOUNDRY LAYOUT

The purpose of this section is to bring in an awareness about what is the BEST LAYOUT for a FOUNDRY.

Every activity involves WORK. WORK IS ENERGY. Energy costs you money. Be it manual or electrical. WORK is measured in terms of Kgm.

(KILOGRAM METRE--- WEIGHT x DISTANCE TRAVELLED)

This figure should be MINIMUM for each activity & hence for the ENTIRE FOUNDRY.

If you see some of our OLD foundries, you will observe that the INDUCTION FURNACE is kept in a corner, as it is the most expensive equipment, it will be safe in the corner. Nothing is farther from this from TIME & MOTION angle.

Foundry layout diagram is given in this book. If you look at it every thing becomes clear.

Let us look at VARIOUS ACTIVITIES in a foundry.

- 1) Pattern shop
- 2) Sand Storage
- 3) Sand Preparation
- 4) Mould Making
- 5) Core Making
- 6) Mould Finishing
- 7) Mould Closing
- 8) Melting
- 9) Mould Filling or Pouring
- 10) Knock Out
- 11) Fettling
- 12) Heat Treatment
- 13) Inspection
- 14) Return of Melting Returns
- 15) Return of Reusable Sand

If you look at the above list, you will see that MELTING is item no 8, so an INDUCTION FURNACE has no business to be in a corner.

Induction Furnace is so placed ,that the FULL LADLE WITH LIQUID METAL TRAVELS THE LEAST DISTANCE. So the FURNACE should be right in front of POURING AREA

As regards to Kgm ,I would take even TOILETS into consideration.

Instead of several toilets in ONE place for all ,have few toilets at several places so that a worker consumes least Kgm for his toilet visit.

Space requirement for a STEEL FOUNDRY is about 1.5 to 2.0 metre x metre per ton of casting per year. As the land is an ONE time INVESTMENT if you work on the higher side ,you will have space for FUTURE EXPANSION. Area Distribution For Each Section Is As Follows :

- 1) PATTERN SHOP----- 3.0 % OF TOTAL AREA.
- 2) SAND PLANT----- 8.0 %
- 3) CORE SHOP ----- 2.0 %
- 4) MELTING AREA----- 7.0 %
- 5) MOULDING, POURING & KNOCK OUT--- 35 TO 40 %
- 6) FETTLING,HEAT TREATMENT & INSPECTION--- 35 TO 40 %
- 7) STORES,MAINENANCE & MACHINE SHOP---- 5 %

The Whole purpose of this layout is to ENSURE that there is a UNIDIRECTIONAL FLOW OF MATERIAL,WORK & MAN POWER. This is decided by Kgm. A layout which gives the LEAST Kgm is the BEST LAYOUT.

Such of those Foundries, which are running haphazardly with out any regard to Kgm will be loosing MONEY every minute, every hour , every day ,every week every month, every year. If you are in a position to change things to reduce your Kgm please do it. So that the Perpetual loss ,you are incurring because of this invisible higher Kgm can be brought down.

Let us say you want to start a STEEL FOUNDRY making 300 tons per month.

$300 \times 12 = 3600$ tons per annum.

$3600 \times 2 \text{ m}^2 = 7200 \text{ m}^2$

PATTERN SHOP--- $7200 \times 0.03 = 216 \text{ m}^2$

SAND PLANT----- $7200 \times 0.08 = 576 \text{ m}^2$

CORE SHOP----- $7200 \times 0.02 = 144 \text{ m}^2$

MELTING AREA— $7200 \times 0.07 = 504 \text{ m}^2$

MOULDING,POURING & KNOCK OUT – $7200 \times 0.35 = 2520 \text{ m}^2$

FETTLING ,HEAT TRATMENT & INSPECTION— $7200 \times 0.40 = 2880 \text{ m}^2$

STORES, MAINTENANCE & MACHINE SHOPE --- $7200 \times 0.05 = 360 \text{ m}^2$

$216 + 576 + 144 + 504 + 2520 + 2880 + 360 = 7200 \text{ m}^2$

If you follow the concept of JUST IN TIME (JIT) ,you can produce more tonnage with the available area.

With this kind of layout, which has logic & rationale behind it, the foundry operation will go on smoothly.

FERROUS METALLURGY

Let us take an empty transparent GLASS tumbler. Select marbles of same colour & size .Fill the tumbler with marbles. Now you see a tumbler full of marbles . If you observe, all the marbles are in contact with several marbles at the same time. Do you also observe some EMPTY space in between these marbles. If you pour water into the tumbler. Water goes in & occupies these empty spaces.

Let us assume that each marble is AN ATOM & the empty space in between these atoms as VOIDS.

Now let us take few other marbles of SAME SIZE BUT DIFFERENT COLOUR. Take out some marbles from the tumbler & put these NEW marbles & refill the tumbler with original marbles which were taken out to make room for a NEW MARBLES OF SAME SIZE BUT OF DIFFERENT COLOUR.

Let us make some observations.

1) Marbles of SAME COLOUR & SAME SIZE-----PURE METAL

2) You have two sets of marbles. A large number of one type of marbles & few marbles of same size but different colour---- THIS IS AN ALLOY.

When marble colours are same, we are calling it a PURE METAL, if marble colour is changed , though not the size, there must be some difference.

That difference is IT IS A DIFFERENT METAL.

Pure GOLD is 24 carat , but pure gold is very SOFT & hence ORNAMENTS made out of PURE GOLD are very DELICATE. In order to give some strength to pure gold, we add some amount of COPPER or SILVER.

Then our GOLD becomes a 22 carat GOLD . This 22 carat GOLD is an ALLOY & not a PURE METAL.

3) Now we have THREE entities here.

a) Atoms of ONE colour, in large NUMBERS,

b) Atoms of DIFFERENT colour, but in SMALL NUMBERS

c) We seem to have FORGOTTEN the presence of WATER.

A marble of same size but of different colour----**SUBSTITUTED** the ORIGINAL ATOM .

WATER occupied the EMPTY SPACE in between the atoms. These empty spaces are called **INTERSTICES**

When we PUT sugar into water, it dissolves. What does that MEAN

Sugar seems to be more comfortable, being, in water than out side.

This needs further explanation. No matter where you are through out the day

You go HOME for the night as that happens to be the most COMFORTABLE

Place to be in.

An Iron or steel piece exposed to atmosphere will RUST. Why should it rust ?

For millions of years, Fe was present in Earth's crust as Fe_2O_3 . We human beings out of our ingenuity we have extracted Fe out of Fe_2O_3 , this Fe is in a Most UNCOMFORTABLE STATE, given a chance it would go back to Fe_2O_3 . Similarly sugar WOULD like to be in water solution rather than outside. But there is a problem here. The voids we found between marbles had dimensional limitation. That is once that volume is filled, there is NO MORE space is available to accommodate additional sugar in SOLUTION. This SOLUTION, which has no empty space left is called a SATURATED SOLUTION.

As a rule, when we talk of SOLUTION we immediately think of liquids. The major portion is called SOLVENT & minor portion is called a SOLUTE. In our case, water is a SOLVENT & sugar is a SOLUTE.

For arguments sake, instead of putting water into the tumbler with marbles, if we had put TALCUM POWDER(a solid) & jogged the tumbler a bit, this POWDER would have occupied the INTERSTITIAL SPACE which was hitherto occupied by water. Then What would you call it ?

Marble is a solid & powder is a solid. Would you call it a mixture of Marbles & powder. I won't. For a simple reason, in a mixture of anything, position is not defined. In a mixture, anything can be anywhere. But it is not so in a SOLUTION. Like your Residential address is at one particular & specified location, in a SOLUTION, the SOLUTE HAS AN ADDRESS or a SPECIFIC LOCATION.

As Marble is solid & talcum powder is solid, their positions are clearly defined, Would you like to call it a SOLID SOLUTION.

In this solid solution, we have marbles as SOLVENT & powder as SOLUTE. As the solute is in INTERSTICES, shall we call it an INTERSTITIAL SOLID SOLUTION of powder in marble.

Now we have another thing to resolve.

Supposing we had 1000 marbles of ONE SIZE & COLOUR along with 10 marbles OF SAME SIZE BUT OF DIFFERENT COLOUR. (as the colour has changed, it has to be a DIFFERENT ELEMENT) As these 10 marbles of different colour have only SUBSTITUTED the ORIGINAL MARBLES, Would it be appropriate to call this SOLUTION a SUBSTITUTIONAL SOLID SOLUTION.

Does that mean WE have a SUBSTITUTIONAL SOLID SOLUTION & an INTERSTITIAL SOLID SOLUTION. THE ANSWER IS AN UNEQUIVOCAL YES.

BUT IF DIA OF THE SOLUTE ATOM IS DIFFERENT FROM SOLVENT ATOM UPTO ABOUT 8% IN SIZE IT CREATES A STRAIN / STRESS FIELD AROUND IT RESULTING IN STRENGTHENING THE ALLOY. THIS IS CALLED SOLID SOLUTION STRENGTHENING.

This kind of situation exists in METALS. THE C atom in IRON forms an

Interstitial solid solution. Copper in Nickel forms a substitutional solid solution.

Can we BURN Diamond ? Some of you are already wondering as to what a foolish question is this. I say YES. Diamond can be burnt. Heat Diamond to about 800 degrees & pass OXYGEN gas on to it. What was hither to a solid & HARDEST MATERIAL known to man , it becomes CO₂ GAS.

It is because DIAMOND is nothing but C like GRAPHITE. DIAMOND and GRAPHITE are two DIFFERENT forms of C. What are these FORMS . These have DIFFERENT STRUCTURES . This phenomenon of an ELEMENT having more than one STRUCTURE at room temperature is called **ALLOTROPE**. Sulphur has Amorphous & Rhombic Structures. Phosphorous too exhibits a similar nature, they are Red & Yellow Phosphorous with different Structures AT ROOM TEMPERATURE.

There are 14 **DIFFERENT ARRANGEMENT** of ATOMS seen in NATURE When WE filled our glass tumbler with marbles ,we just filled the tumbler, with out bothering about the way we were filling as we did not know anything about 14 different ways of filling .But even THAT filling , we did ,belongs to one of these 14 different ways.

All these atomic arrangements, we are talking about, are at ROOM TEMPERATURE. IF SUCH A CHANGE OF ATOMIC ARRANGEMENT HAPPENS OVER A RANGE OF TEMPERATURE IT IS CALLED AS “ POLYMORPHISM “.

As our subject of interest is STEEL, which is mainly Fe + something .

Let us look at Fe.

From room temperature to 910 degrees, it is B.C.C Structure.

From 910 degrees to 1400 degrees, it is F.C.C. Structure.

From 1400 degrees to 1539 degrees, it is B.C.C. Structure

There can be two houses which look the SAME , but of different dimensions.

That is the difference between TWO B.C.C ‘s you see above. SAME SHAPE BUT OF DIFFERENT DIMENSIONS.

This change of structure from B.C.C to F.C.C to B.C.C. is called POLYMORPHISM. It is because of this SPECIAL nature of Fe, we are able to get several different properties for the SAME CHEMICAL COMPOSITION.

Let us start arranging ORANGES like a Fruit Vendor does. After we have arranged the first layer, you FIND A DEPRESSION AT THE CENTRE OF FOUR ORANGES. Let us arrange one more layer of oranges.

If we call the FIRST layer as “ A “ kind of arrangement ,Second one is not A as these oranges are not SITTING RIGHT ON TOP OF THE FIRST LAYER BUT IN A DIFFERENT ARRANGEMENT. Let us call this arrangement as “ B “.So if we go on stacking oranges like this, we get ABABAB kind of

Arrangement . This is B.C.C. arrangement.

After AB arrangement, you get TWO LOCATIONS TO PLACE YOUR ORANGES. One is obviously A, but the second location is called “ C “.

If we stack our oranges like ABCABCABC pattern ,it is called F.C.C. arrangement.(you will get to see the difference in the sketch given)

We have small little task to do before we take plunge into FERROUS METALLURGY proper.

In Fe we have bcc, Cr is also bcc. So in order to differentiate we call our Fe bcc as FERRITE. But in our system ,we have two bcc's , in order to differentiate, We call bcc BELOW 910 degrees as ALFA FERRITE & bcc ABOVE 1400 degrees as DELTA FERRITE. We are still left with one more naming ceremony left ,that is fcc , Al is a fcc, Cu is a fcc. So to specify our fcc WE call it as GAMMA or AUSTENITE.

Though I have done my M.E.,I had to go through FIRST STANDARD IN SCHOOL ,like wise we have to go through What is called Fe—C Diagram.

This Fe- C diagram is an Equilibrium Diagram.

Now that I have made the MISTAKE of using the word EQUILIBRIUM, I need to explain it. Equilibrium is an END of a process.

Supposing you under take a pilgrimage to KASHI. You leave from your place to KASHI, reach KASHI ,visit the temple, worship the GOD , come out of the temple ,leave for your place of ORIGINAL residence & reach HOME.

As I understand THIS IS THE EQUILIBIUM OF YOUR KASHI VISIT.

How long does it take ?. Let us say 10 days.

When you have come back home from KASHI, you have physically nothing to do with KASHI.

DEATH is an equilibrium. It is end of life , after that nothing .Let us say it takes 80 years. After 80 years of life death or equilibrium came.

Let us add Hydrochloric acid to Sodium Hydroxide, in next to no time, we get Sodium Chloride & Water. This is also equilibrium.

If you cool LIQUID STEEL “ SLOWLY” in our steel sample we get what is shown in Fe- C diagram. But how slow is slow ?

But the MAGIC of STEEL does not lie in the PHASES shown in Fe-C diagram. It lies else where. We will come to that at the appropriate time.

Fe – C diagram is shown in this book.

We are all Indians, but how many of us can draw an INDIA MAP , not many.

I can probably draw from Gujarat to Bengal (downwards). But I can recognise an INDIA MAP when I see one. For me Fe – C diagram is like that. If you can do that, it is good enough.

Metallurgy can be understood if you look at the **MOSAIC** floor .Mosaic floor is made of CEMENT & COLOURED STONES embedded in it. For the sake of aesthetics different coloured stones are embedded. For our purpose let us assume that all stones are of the SAME colour.

Then the MAJOR portion CEMENT becomes MATRIX & MINOR portion

i.e. STONES become PRECIPITATES. The properties of the mosaic are dictated by the INDIVIDUAL properties of BOTH.

If you look at the Fe- C diagram, several things stand out.
ON X—AXIS WE HAVE % C SHOWN & Y AXIS TEMPARATURE IN DEGREES CENTIGRADE IS SHOWN.

Let us look at the Salient Features of Fe-C diagram.

- 1) Solubility of C in Alfa Ferrite, at room temperature, is 0.008 %.
Hence forth, we will not call Alfa Ferrite by that name, we simply call it Ferrite as we are NOT going to deal with DELTA FERRITE at all.
- 2) Solubility of C in Ferrite at 723 degrees is 0.02 %.
- 3) Ferrite completely transformations to AUSTENITE (F.C.C) at 910 degrees.
- 4) Delta Ferrite forms above 1400 degrees.
- 5) Fe melts at 1539 degrees.
- 6) At 1492 degrees, a reaction is taking place. Liquid iron + delta Ferrite is giving a phase called AUSTENITE. The name of this reaction is called PERITECTIC REACTION.
- 7) A Line from 910 degrees to 723 degrees is called A3 line. **This A3 line is the CORNERSTONE of all our HEAT-TREATMENTS**
- 8) Below A3 line an other reaction is taking place.
AUSTENITE = Ferrite + Cementite. This reaction is called EUTECTOID REACTION.
Cementite is carbide of IRON.
- 9) At 1130 degrees ,we have a MAXIMUM SOLUBILITY OF CARBON IN AUSTENITE OF 2.0 %
- 10) This enormous difference in solubility of C in Ferrite & Austenite gives US ENORMOUS DEXTERITY(?) in altering the properties of steel to our liking or advantage.

A Recap: maximum solubility of C in Ferrite is 0.02 %
maximum solubility of C in Austenite is 2.0 %

The difference--- $2.0 - 0.02 = 1.98$ / $0.02 = 99$

If converted to % ,it is **9900 %**.

The whole gamut of properties that can be obtained in STEEL is because of this difference.

- 11) At 1130 degrees, at 4.3 % C, another reaction is taking place.
A Liquid Iron = Austenite + Cementite. This reaction is called EUTECTIC Reaction.

Let us take stock of all the REACTIONS we have in a Fe- C diagram.

- a) PERITECTIC REACTION.
- b) EUTECTOID REACTION.
- c) EUTECTIC REACTION.

For the sake of understanding, let us call the **EUTECTIOD REACTION AS A STEEL REACTION & EUTECTIC REACTION AS A CAST IRON REACTION**

12) UPTO 2.0 % C, it is called STEEL & beyond 2.0 % C , it is called CAST IRON.

13) UPTO 0.8 % C ,it is called HYPOEUTECTOID STEEL.

14) Between 0.8 %C to 2.0 % C, it is called HYPEREUTECTOID STEEL.

15)Below 4.3 % C, it is called HYPOEUTECTIC CAST IRON.

16)Above 4.3 % C, it is called HYPEREUTECTIC CAST IRON.

17) At 6.67 % C, Fe-C ends as 100 % Cementite is formed which is of no use to us.

I AM MAKING A STATEMENT TO REMOVE ANY VESTIGE OF DOUBT IN YOU. THAT IS, THERE IS STEEL IN CAST IRON BUT THERE IS NO CAST IRON IN STEEL

STEEL IS LIKE A HOUSING COLONY BUILT BY A CITY DEVELOPMENT BOARD.

BUT CAST IRON IS LIKE A SLUM.

The above statement should tell you that it is easier to understand STEEL than Cast Irons.

Before we go into the analysis of what forms from what & why, every thing is decided by energies. CAN YOU SLEEP IN A STANDING POSTURE. The answer is a simple NO, because while in standing position You have lot of potential energy in you. When you say you RESTED for a while, it means, you were in a lowest energy level for while.

Monsoon comes in the month of June from Kerala's side. Can we make it come From Assam side. The answer is a no. So all that we can do is to understand NATURE & the way it works. Use it to the advantage of Society.

Let us take a 0.4 % C Steel, heat it 950 degrees. You will be left with only one Phase i.e. Austenite with entire C in solution.

Here we need to know that there are TWO kinds of VOIDS in IRON or SHOULD I say IRON OF STEEL.

1) Octahedral Void (with 8 faces---whose fig is given)

2) Tetrahedral Void (with 4 faces- whose fig is given)

In case of Ferrite (B.C.C.) Tetrahedral void is BIGGER than Octahedral Void.

In case of AUSTENITE (F.C.C.) Octahedral Void is BIGGER than Tetrahedral Void.

But C atoms prefer to go to only Octahedral Void . The reason for this behaviour, is C atom has to do less WORK to get into Octahedral Void than what it has to do if it were to go into Tetrahedral Void.

In case of Ferrite ,C atoms are go into a SMALLER Void & as a consequence of this the amount of C atoms that can go into Solution is limited. (0.02% Max)

Where as in case of Austenite (F.C.C.) C atoms go into a BIGGER Void &

hence the solubility of C in F.C.C. can be as high as 2.0 % at 1130 degrees. When we start cooling a 0.4 % C steel from 950 degrees, as soon as steel's structure changes to B.C.C. Carbon atoms start coming out of SOLUTION. A word of CAUTION : B.C.C. & F.C.C. are STRUCTURES, which can not be seen under a Microscope. But Ferrite, Austenite, Cementite are Phases which can be seen under a Microscope.

The C atom which is almost getting squeezed out of Ferrite, has NO where to go. So the C atoms come together to form a Carbide (Fe_3C) called CEMENTITE. Slower the cooling rate you will get SMALL NUMBER OF LARGE SIZED Cementite. This Cementite has no great freedom either, because from 0.4 % C it has to become Cementite of 6.67 % C.

So you will have a layer of Ferrite & adjacent to it a layer of Cementite. Some body called this group of Ferrite & Cementite, a Pearlite & the name got stuck. This Pearlite is called a Coarse Pearlite.

If the cooling rate is faster, while cooling from 950 degrees, C atoms are compelled to move out of Ferrite faster than earlier, So you get LARGE NUMBER OF SMALL SIZED Pearlite. These are called FINE PEARLITE. I have a DOUBT here. When fine Pearlite forms, there is a likelihood of Ferrite being SUPERSATURATED, with C, to a small degree for want of time. Fine pearlite is harder, because HARDNESS INDENTOR ENCOUNTERS HARD CEMENTITE more often, but for same QUANTITY OF CEMENTITE OR even lower if some supersaturation of Ferrite has occurred, Why should the STRENGTH go up ?

If you have observed, I have used words like coarse Pearlite & fine Pearlite. Our Fe- C Diagram does not even TALK about it.

With out our realising, we have entered into a territory where AUSTENITE is Stable (Quasi stable or unstable) below 723 degrees. As per Fe-C Diagram, it is simply NOT ACCEPTABLE.

This NON- EQUILIBRIUM territory is represented by another diagram Called TTT diagram. This is in reality called Time-Temperature-Transformation curve. Do not worry you get to see these in detail in pictorial Form.

In this diagram, the whole curve is below 723 degrees.

On X – axis you have time & Y-axis you have temperature.

This CURVE IS IN THE FORM OF TWO PARALLEL C's.

The first C which is closer to Y-axis is beginning of Transformation of Austenite to Ferrite & cementite. The second C, which is away from Y-axis is the end of Transformation.

Any body would ask a question as to why it is like a C.

Now I will give you a Metallurgical answer, let us see if you understand.

Now we are talking of 3 parts of C. Top, Middle & Bottom of C Curve.

At the top, UNDERCOOLING IS INADEQUATE, HENCE NUCLEATION DOES NOT OCCUR, THOUGH THE DIFFUSION IS VERY GOOD, TRANSFORMATION IS DELAYED.

At the Middle, BOTH UNDERCOOLING & DIFFUSION ARE GOOD, HENCE FASTER TRANSFORMATION.

At the Bottom, UNDERCOOLING IS VERY GOOD, BUT DIFFUSION IS POOR OR WEAK, HENCE TRANSFORMATION IS DELAYED.

I am doubly certain that TARGET GROUP WOULD not have understood.

In the process of Communication, if the reader does not understand, it only means that there has been a Communication Failure.

To facilitate Communication ,I don't mind coming out of Metallurgical parlance to the mundane world's language .

At the top, it is like a woman becomes pregnant alright, but she aborts the foetus,(not her choice) hence the DELAY in transformation.

At the bottom, it is like a baby is born but terribly malnourished ,hence the DELAY in Growth or transformation.

This diagram is THE most important diagram in Steels. WHY ?

THIS DIAGRAM IS LIKE A THUMB IMPRESSION , PASS PORT , AN IDENTITY CARD FOR EACH STEEL. THAT IS IF THERE ARE 100 DIFFERENT STEELS THEN YOU WILL HAVE 100 DIFFERENT TTT DIAGRAM. ONE DIAGRAM FOR EACH STEEL.

In this diagram, you will find Unstable Austenite, Coarse Pearlite , Fine Pearlite , Coarse Bainite , Fine Bainite , Retained Austenite & Martensite.

Our Whole process of getting these structure is to obtain Higher Strength & Higher Toughness.

In metals Strength is measured in terms of Kg / mm^2 .

Let us try to get a FEEL of this Kg / mm^2 . When you want to fill AIR into the TYRES of your TWO WHEELER, you go to a petrol bunk. At the petrol bunk, You tell the boy 30 in the front & 35 in the back .What are these 30 & 35.

They are 30 psi & 35 psi (pounds per square inch) .

14.7 psi is ONE Atmospheric Pressure (which is acting on all of US all the time) If the pressure falls below this figure of 14.7 psi, you are entering into the realms of VACUME .

$$14.7 \text{ psi} = 1.03 \text{ Kg} / \text{cm}^2.$$

$$30 \text{ psi} = 1.03 / 14.7 \times 30 = 2.1 \text{ Kg} / \text{cm}^2.$$

$$1 \text{ Kg} / \text{mm}^2 = 100 \text{ Kg} / \text{cm}^2.$$

$$30 \text{ psi} = 2.1 / 100 \text{ Kg} / \text{mm}^2 = 0.021 \text{ Kg} / \text{mm}^2.$$

If $0.021 \text{ Kg / mm}^2 = 30 \text{ psi}$.

$1.0 \text{ Kg / mm}^2 = 1428.5 \text{ psi}$ i.e 47.6 times stronger than your air filled tyre (30 psi) Now do you realise how strong is 1.0 Kg / mm^2 as compared to your simple 30 psi tyre . In Metallurgy, we talk of 50, 70 even 100 Kg / mm^2

If we are to compare your 30 psi with 100 Kg / mm^2 , it will be 4760 times stronger.

Let us compare some Strength Figures.

Phase	UTS in Kg / mm ²	% Elongation	Hardness in BHN
Ferrite	28	61	75
Pearlite	85	10	200
Cementite	195	less than 0.5	550

To give a feel for Elongation ,it is an indication of how much you can STRECH before it fails.

What is the purpose our trying to understand TTT diagram ?

It is to understand as to how Mechanical Properties change with different Heat treatments.

	Annealing	Normalising	Faster Air Cooling	Oil quenching
No of Fe ₃ C Particles.	30	50	75	100
% C in Ferrite	0.008	0.028	0.05	0.1
BHN	55	95	150	200
UTS in Kg / mm ²	20	33	53	71

Various Processes of Heat treatments have been explained in sketches.

As the cooling rate goes on increasing, the amount of time available for C to get out of Ferrite decreases, hence Carbides are compelled to take SHAPES which have a larger surface area & become more in number.

Take the case of Annealing, C had plenty of time of time to come out & form a Carbide. So it took a Lamellar shape, what is this lamellar shape ?

All of you have seen a MANGO LEAF both big & small. A mango leaf can be called as lamellar. In case of Annealing, Carbide took the shape of a large Mango leaf, this group of Ferrite & Carbide is called COARSE PEARLITE.

In case of Normalizing , the amount of time available for C to come out reduced, hence Carbides took the shape of small Mango leaf but more in number. This group of Ferrite & carbide is called FINE PEARLITE.

When the cooling rate further increased, i.e. C had to come out more hastily, it took the shape of a leaf which has a greater surface area. One such leaf is that of GRAPES. Grape leaves large & small. Group of Ferrite & large Grape leaf is called COARSE BAINITE. With further increasing in cooling rate, it became a group of Ferrite & small Grape leaf ,this group is called FINE BAINITE.

As we go from Coarse Pearlite to Fine Bainite, STRENGTH increases, HARDNESS increases & TOUGHNESS decreases.

We are happy with Strength & hardness increasing , but we are UNHAPPY with Toughness decreasing. We want the BEST OF BOTH. What is the way out.

So far we are looking at the Phases which have formed from AUSTENITE to Ferrite + different types of Carbides.

Now we change our FOCUS to an area in between Y-axis & First C curve.

This is where our GOLD MINE lies.

Let us say our first C curve is away from Y-axis & we are able to cool our 0.4 % C sample at SUCH FAST RATE, we don't even touch C curve.

At room temperature, we get a PHASE called "MARTENSITE" This Martensite has entire 0.40 % C in it. Where as Ferrite can have only 0.008 % C in for to be COMFORTABLE.

The Extra C present in Martensite is $0.40 - 0.008 / 0.008 \times 100 = 4900\%$ more. It like 100 people staying in a room which is big enough for 2 people only.

This leads to tremendous stress. The Ferrite, which normally has a B.C.C structure BECOMES a B.C.T. Structure.

So Martensite has a B.C.T. Structure. In B.C.C, $a = b = c$ (all are at 90 degrees to one another) but in B.C.T. Structure $a = b < c$ (all are at 90 degrees to one another). B.C.T. stands for Body Centred Tetragonal Structure .

It is like having a SPRAIN in the NECK. How comfortable are you.

On a festival day, you generally eat 2 numbers of sweets , but your mother out of affection made you eat 6 numbers. What will be your PHYSICAL CONDITION after eating more than what you are comfortable with.

UNEASINESS. Matensite goes through the same fate & it manifests in HIGHER HARDNESS & EXPANSION .

%C	0.1	0.2	0.3	0.4	0.5	0.6	0.8
Rc	38	44	50	57	60	63	65

(We have several hardness scales viz. BRINNEL, ROCKWELL, VICKERS etc They are all comparable. They are like Rs, \$, Pounds, Liras different monetary Systems. So don't worry .I will compare them for you later)

This PROCESS of GETTING MARTENSITE FROM AUSTENITE IS CALLED " HARDENING" . If you Quench 18 / 8 Stainless Steel in Water at

ZERO degree, you won't get Martensite, so it is NOT called Hardening. In this uncomfortable state of OVEREATING is there anything which can give you some relief, JUST VOMIT IT OUT. This process of vomiting from Martensite is called TEMPERING. Unlike your vomiting which is NOT CONTROLLED, TEMPERING is controlled.

When ever you see a crack in a BEAM, you immediately drill a round hole at the TIP of the crack. This hole arrests the propagation of crack.

As we have seen earlier, in PEARLITE & BAINITE Carbides had all kinds of funny shapes. But after TEMPERING the CARBIDES we get are ROUND or SPHERICAL. Let us take an example of say a 0.35 % C Steel.

	A	N	AQ	OQ	WQ	T
UTS in Kg /mm ²	50	60	80	100	135	80
YS in Kg /mm ²	35	45	65	90	120	65
% E	30	26	22	15	3	30

A--- Annealing, N---- Normalising, AQ – Air Quenching
OQ--- Oil Quenching, WQ—Water Quenching, T—Tempering.

Now let us compare the properties OF **HADENED & TEMPERED SPECIMEN WHICH IS AS STRONG AS AIR QUENCHED SAMPLE & AS TOUGH AS ANNEALED SAMPLE. THIS IS WHAT I MEANT AS BEST OF BOTH.**

Now we have choice of Getting what we want. SMALL NUMBER OF LARGE SPHEROIDS OF CARBIDES OR LARGE NUMBER OF SMALL SIZED CARBIDE SPHEROIDS.

But why did we take this route. We all pay taxes to Government, the Government then Spends the Money where it is required. In our case MARTENSITE is the Government.

On Tempering, we do not allow c-axis of B.C.T. to become equal to a or b, We still keep it slightly longer than a or b. That is the reason we call the Matrix as Tempered Martensite & not Ferrite.

We started all our heat treatments from an area or point above A3 (in AUSTENITE).

This A3 is alloy DEPENDENT.

$$A3 = 910 - \text{square root of } \% C - 15.2 (\% Ni) + 44.7 (\% Si) + 104 (\% V) + 31.5 (\% Mo) + 13.1 (\% W) - 30 (\% Mn) + 11 (\% Cr) - 20 (\% Cu) + 700 (\% P) + 400 (\% Al) + 400 (\% Ti)$$

All the elements, which have – sign are called as Austenite Stabilizers.

All the elements, which have + sign are called as Ferrite Stabilizers.

In case of Mild Steel or low C steels C curve is INTERSECTED by Y-axis.

Hence you simply can't get Martensite in these alloys.

Barring Al & Co , all other alloying elements move C curve away from Y-axis, thus facilitating HARDENING PROCESS. So that we can get BEST of MECHANICAL PROPERTIES.

In our TTT diagram, we have two lines called Ms & Mf. These are Martensite Start & Martensite Finish lines. They are NOT constant lines. They are dependent on alloying elements. **But Ms & Mf are constant lines for an alloy.**
 $Ms(\text{ Degrees}) = 539 - 423 (\% C) - 30.4 (\% Mn) - 12.1 (\% Cr) - 7.5 (\% Mo)$.

The sketches of FALLING Ms & Mf are shown as Alloying element content increases. In some cases Ms is so LOW, that the Alloys are Austenitic at ROOM TEMPERATURE. 18 Cr , 8 Ni Stainless Steel ,HADFIELD 14 % Mn Steel , 2.0 % C , 25 % Cr Cast Iron are some of the examples.

Let us look at Mechanical Properties variations with TEMPERING Temperature & Time.(For one typical Steel Composition)

	UTS Kg/mm ²	YS Kg/mm ²	% E	BHN
As Quenched in Water	110	97	2	350
Temper at 200 Degrees C for 1 hr	100	93	4	290
Temper at 200 Degrees for 2 hrs	95	89	6	270
Temper at 200 Degrees for 3 hrs	92	83	7	260
Temper at 300 Degrees for 1 hr	86	74	12	230
Temper at 300 Degrees for 2 hrs	82	72	14	220
Temper at 400 Degrees for 1 hr	78	68	16	200
Temper at 400 Degrees for 2 hrs	72	62	20	170

Now I need to tell you to know the following :

- 1) If the % E is less than 5 %, it is considered a BRITTLE material .
- 2) If you know the hardness in BHN, we can convert to UTS in Kg / mm².
 If you know the BHN, $BHN \times 500 = UTS \text{ in psi}$,
 $UTS \text{ in psi} / 1420 = UTS \text{ in Kg} / \text{mm}^2$.

3) Transformations that are taking place while Tempering are MORE responsive to TEMPERATURE than TIME . A 10 degrees raise may be equivalent to 2 hrs raise in TIME .

4) Before doing your TEMPERING Cycle , take a TRIAL & establish what you want. Otherwise you will have to REPEAT EVERYTHING FROM THE BEGINNING.

Hardness obtained on Formation of Martensite is mainly dependent on % C only. Unless you are dealing with alloys, which have alloying elements like Cr, Mo, V, W, Nb or Cb (Nb & Cb are one & the SAME) , Carbides of these alloying elements are much more Harder than Simple Fe₃C.

There is a very important aspect you need to know. 100 % Martensite formation never takes place on Hardening. When Austenite Transforms to Martensite there is an attendant EXPANSION. For example, let us say there are 100 grains in Our area of Interest. If 80 grains form Martensite, as they have expanded, they will SQUEEZE the remaining AUSTENITE , this Austenite is called RETAINED AUSTENITE. If this Austenite has to become Martensite, there must be a space available, but no space is available & hence it can't convert. Presence of retained Austenite is NOT GOOD for the PROPERTIES . It has to be converted . How do we do it? On tempering Martensite **SHRINKS** . This gives room for RETAINED AUSTENITE to expand & form Martensite, for which you NEED to QUENCH again. On Quenching , nothing happens to already Tempered Martensite but Austenite gets transformed to Martensite, which has to be Tempered again to get Tempered Martensite. To give you an example, HIGH SPEED STEEL , a Tool Steel, with 0.75 % C, 18 % W , 4 % Cr & 1 % V is Quenched to get Martensite from almost 1000 Degrees & subsequently Tempered & Quenched from 500 degrees, 3 Times to remove all the RETAINED AUSTENITE.

Having Retained Austenite is reverse of getting A STONE in Rice, while you are having your FOOD.

Austenite is a SOFT PHASE. That is why, all HOT WORKING of Steel, be it Rolling, Forging are done above A₃ temperature (AUSTENITE). In Steel plants a 400 mm ingot is rolled down to 5 to 10 mm when the Steel is in Austenitic Condition. It is called HOT ROLLING.

As regards to variety of Steels, there are several varieties.

- 1) Plain C steels.
- 2) Low Alloy Steels.
- 3) Fe-C-Mn steels
- 4) Fe-C-Mn-Mo steels
- 5) Fe-C-Ni-Cr-Mo steels
- 6) Fe -C -Ni -Cr -Mo Steels

In a low alloy Steels, alloy content is Not More Than 5 %

Each Alloying Element wise,

Mn > 1.0%

Si > 0.80 %

Cu > 0.50%
 Cr > 0.25 %
 Mo > 0.10 %
 Ni > 0.50 %
 V > 0.05 %
 W > 0.05 %
 Al > 0.10 %
 Ti > 0.10 %
 Zr > 0.10 %

To give you an example, I take a Ni-Cr-Mo Steel & show you the Properties Achieved.

Ni 0.45 to 0.60 % Cr 0.50 to 0.80 % Mo 0.15 to 0.30 %

%C	%Ni	%Cr	%Mo	HT	UTS	YS	%E	%RA	BHN
0.24	0.67	0.64	0.18	N	82	52	23	41	238
0.35	0.57	0.55	0.21	N&650 T	80	67	28	40	229
0.29	0.62	0.55	0.17	WQ &540T	116	105	16	44	232
0.4	0.63	0.7	0.23	WQ &480T	132	106	8	12	388

UTS in Kg/mm², YS in Kg/mm²

Your Quenching Mediums are:

- 1) Still air cooling.
- 2) Air blast cooling.
- 3) Oil Quenching.
- 4) Water Quenching.
- 5) Sub- Zero Quenching.

Look at the Variables you have to achieve what you want to achieve:

- 1) Composition of the alloy.
- 2) Quenching medium.
- 3) Temperature.
- 4) Time.

WORD OF CAUTION: As I have already told you, Grain Boundary is stronger than the Grain, So ,WE always try to get FINE GRAINED STEELS ,but grain boundary happens to be a HIGH ENERGY AREA like IRON (Wanting to rust), given an opportunity Fine Grain would like to become COARSE grained. When you are HOLDING the STEEL above A3, if you hold it longer than necessary, LIKE BIG FISH EATING A SMALL FISH, coarse grains will eat away smaller grains leading to a COARSE GRAINED STEEL, which is not desirable.

Plain carbon steels,
 Low alloy steels,
 Wear resistant Steels,
 Corrosion Resistant steels,
 Heat Resistant steels,
 Tool steels.

There are several varieties of Steels in each Grade of steel.

Before I get into CAST IRONS, I would like to give a HARDNESS
 CONVERSION TABLE For Steels.

Rockwell Hardness		BHN	UTS x 1000 psi	UTS in Kg / mm ²
C	A	(3500 Kgs)		
60	81	614	---	---
59	80.5	600	---	---
58	80	587	---	---
57	79.5	573	---	---
56	79	560	---	---
55	78.5	547	301	212
54	78	534	291	205
53	77.5	522	282	199
52	77	509	273	192
51	76.5	496	264	186
50	76	484	255	179
49	75.5	472	246	173
48	74.5	460	237	167
47	74	448	229	161
46	73.5	437	221	155
45	73	426	214	151
44	72.5	415	207	146
43	72	404	200	141
42	71.5	393	194	137
41	71	382	188	132
40	70.5	372	182	128
39	70	362	177	125
36	68.5	332	162	114
35	68	322	157	111

34	67.5	313	153	108
33	67	305	148	104
32	66.5	297	144	101
31	66	290	140	99
30	65.5	283	136	96
29	65	276	132	93
28	64.5	270	129	91
27	64	265	126	89
26	63.5	260	123	87
25	63	255	120	85
24	62.5	250	117	83
23	62	245	115	81
22	61.5	240	112	79
21	61	235	110	78
20	60.5	230	108	76
Soft steels, Grey Iron, S.G. Iron & most Non-Ferrous metals.				
	60	228	107	
	59.5	222	106	
	59	216	103	
	58	210	101	
	57	200	96	
	56	190	91	
	55	180	87	
	54	176	85	
	53	169	81	
	52	162	78	
	51	159	77	
	50	153	74	
	49	147	--	

If you know the BHN, $295 \times 500 = 147500 \text{ psi} / 1420 = 103.8 \text{ Kg} / \text{mm}^2$
The difference you get is of the order of about 1 to 2 %

If you want to check the value of BHN on the CASTING itself, you can Use “ POLDY” test bars.

CAST IRONS : As I have already called CAST IRON, A SLUM , you need to tread carefully while dealing with Cast irons.

There are several Cast irons.

- 1) Grey Iron.
- 2) Ordinary White Iron.
- 3) Malleable cast Iron.
- 4) S.G. Iron.
- 5) Compacted or Vermicular Graphitic Iron.
- 6) Alloyed Austenitic Grey Irons
- 7) Alloyed Austenitic White Irons.
- 8) Alloyed Martensitic White Irons.
- 9) Alloyed Ferritic Grey Irons.

As I have already said, **STEEL IS PRESENT IN CAST IRONS & HENCE WHAT EVER HEAT TREATMENT IS APPLICABLE TO STEEL IS APPLICABLE TO CAST IRONS ALSO.**

If you look at the Fe-C diagram, you will find a line STARTING from 1492 degrees, it joins a Horizontal line AT 1130 Degrees & 4.3 % C. That line, after 2.0 % C becomes the LIQUIDUS of Cast Iron.

A Liquid = an other Liquid + a Solid----- this reaction is called a EUTECTIC Reaction. Whatever ever STRUCTURAL changes we see in CAST IRONS, happens during this reaction.

For our analysis sake , let us take a Cast Iron with a C % of 3.0 %. As soon as the liquid cast iron touches the liquids of cast iron , Austenite ISLANDS are formed. If you take a re –look at the Fe-C diagram, you will notice that solubility OF C IN AUSTENITE is much less than 2.0 %. So the additional C in SOLID AUSTENITE is thrown out into liquid metal around it. Thus liquid metal is getting enriched with C. This will go on till the C content of liquid reaches 4.3%. At this point, this EUTECTIC LIQUID WITH 4.3 % C Gives TWO SOLIDS. ONE is AUSTENITE & OTHER is CEMENTITE.

But we have already got AUSTENITE earlier, that Austenite is called PROEUTECTIC AUSTENITE, the Austenite that is formed at 4.3 % C & 1130 Degrees is called EUTECTIC AUSTENITE.

This Austenite is a STEEL Phase. We have CHOICE to play with this CEMENTITE. As this **Cementite is not a STABLE phase.**

- 1) Treat the liquid metal with INOCULANTS like Si in the FORM of FeSi, It gives raise to GRAPHITE. This is called **grey iron.**
- 2) If we do not treat the metal with inoculant , Cementite persists in Solid

Condition. This Cast Iron is called **White Iron**.

3) If we Heat treat ,this White iron, for a long time , may be few days, Cementite will break down to give LUMPS of GRAPHITE. This Cast Iron is Called as **Malleable Iron**.

4)If we treat this liquid metal with Mg & FeSi, it gives SPHEROIDS of GRAPHITE, this iron is called **S.G.Iron**

5) If we under treat this alloy with lesser amount of Mg & FeSi , it gives raise to **Compacted Graphitic Iron**

So far we are dealing with Cementite & it's Different modificatons.

We can also Deal with AUSTENITE to get the properties that we got in steels.

Here, at this point I must confess that I have no exposure to Grey iron,

Simple White iron, Malleable iron & Compacted graphitic irons.

My Exposure is to S.G.Iron (about which I have talked in great detail in FERROUS FOUNDRY PRACTICE) & to some extent to Alloyed White Irons.

Let me talk about configuration of Graphite in Grey Iron. If you take ROSE flower, all the petals can be compared to Graphite flakes in Grey Iron. All the Petals of ROSE are connected at the bottom of the flower. We all know that GRAPHITE is a very soft material.

Take an ordinary writing Pencil, rub the black Graphite portion on your finger, Your finger will become BLACK. Now do you realise as to how soft is Graphite. Now this soft Graphite with no Strength of it's own, hence it can not offer any resistance to stresses. On top of it in Grey iron , these Graphite flakes are interconnected like petals of ROSE. NO MATTER WHAT EVER MAY BE THE STRENGTH OF THE METAL MATRX, Crack Initiated on application of load will simply pass through SOFT INTERCONNECTED GRAPHITE & Fracture will occur.

But that does not mean this Grey iron is USELESS. Because of presence of Soft Graphite in it, it will act as a VIBRATION DAMPNER. Imagine hitting a lump of BUTTER with your open PALM. Do you feel as though you have hit a Stone, you feel nothing i.e. there is no reaction to your action. This is called VIBRATION DAMPENING. Grey Iron has a good machinability as the cutting tool continuously encounters Graphite flake, metallic chip breaks. So it leads to easier machining . Here you need to realise that pure ALUMINIUM & STAINLESS STEELS (18 / 8) ARE DIFFICULT TO MACHINE EVEN THOUGH THEY ARE VERY SOFT. This is because, unlike in GREY IRON, Chips won't form rather a Ribbon of Metal forms & it keeps rubbing the Cutting Edge ,which in turn gets heated up & loses it's hardness & further machining becomes difficult. So you need to add a CHIP BREAKER TO your Cutting tool.

WHITE IRON: It consists of Ferrite & Cementite in larger portion than in Steel, Cemantite being hard & brittle, this iron can only be used, only where WEAR-

RESISTANCE is required.

Malleable Iron: From WHITE IRON Malleable Iron is made by resorting to Prolonged heat treatment cycle, which made it expensive. So Malleable iron has gone out of vogue. But I have heard that Malleable Iron is still preferred for CRYOGENIC APPLICATION because of its low Si content.

(Higher Si in S.G.Iron ,increases ductile- brittle transition temperature, hence not a suitable material for CRYOGENIC APPLICATION)

Malleable Iron can be called as PRECURSOR OR HARBINGER of S.G. Iron. Malleable iron is a ductile material like S.G. Iron.

S.G. Iron is an acronym for SPHEROIDAL GRAPHITIC IRON. It is also Called as Nodular Iron.

In this alloy, as the Graphite nodules are separate & unconnected, the metallic Matrix dictates the properties that are achievable. This material has good Machinability & some amount of Vibration Dampening properties because of presence of Graphite

Its properties have been discussed (in Ferrous Foundry Practice)

Compacted Graphitic iron. In Grey Iron ,the flakes of Graphite have Sharp Edges & as there is absolutely NO connection between Metal & Graphite, it is As good as hole being present (INCOHERENCY). These sharp edges act as stress raisers leading to premature Fracture propagation.

In case C,G iron, sharp edges are ABSENT, as a result C.G. Irons do show some amount of ductility.

An undertreated S.G. Iron or faded S.G .Iron would behave like C.G. Iron.

CARBON EQUIVALENT (C.E.) = % C + 0.31 x % Si + 0.33 x %P + 0.05 x % Ni + 0.075 x % Cu—0.06 x % Cr —0.03 x % Mn --0.1 x % V --0.11 x % Mo

C.E. value tells you as to how far are you from 4.3.

There is another problem which we need to understand.

Let us take an alloy with 1.2 % C & 12 % Cr.

C.E. = 1.2 % (C)—0.06 x 12% Cr

= 1.2 -0.72 = 0.48. **THIS MUST BE DEFINITELY STEEL.**

BUT IT IS A CAST IRON.

THIS IS BECAUSE Cr IS A FERRITE STABILIZER. So IT SHRINKS AUSTENITIC AREA. So Our idea of up to 2.0 C.E is STEEL does not hold good any more.

Cast iron starts at a C level much lesser than 2.0.(if Ferrite stabilizers are present. Except Ni, Mn, N all alloying elements are Ferrite stabilizers)

This is not a hearsay, but my practical Experience.

In Grey cast iron, the type of Graphite present decides the properties that can be

Achieved.

The Graphite, can be in several forms.

- 1) Type " A " Graphite flake (Normal & desirable)
- 2) Type " B " Graphite flake (Rosette)
- 3) Type " C " Graphite flake—which occurs in Hypereutectic Grey Irons.
- 4) Type " D " Graphite flake—Under cooled
- 5) Type " E " Graphite flake – inter dendritic

In a Good Grey Iron casting, only " A " type Graphite is preferred .It gives the Best of Properties. Type A Graphite is achieved by Good Inoculation.

Alloy Cast Irons:

Austenitic Irons:

- 1) Corrosion Resistance--- Ni- Resist type.
 - 2) Low Expansion ---Minover type.
 - 3) Non Magnetic----- No-mag type.
 - 4) High temperature Resistance—Nicrosilal type.
- 1) Corrosion Resistance type of cast iron has a composition of :
- % C 2.2 to 3.0.
 - % Si 1.0 to 4.0.
 - % Mn 0.4 to 1.5
 - % Ni 13.00 to 32.00
 - % Cr 1.0 to 4.5.

2) Low Expansion Type:

All though normal Austenitic Steels & Cast Irons have a Coefficient of Thermal Expansion of 18×10^{-6} per degree, a group of High Nickel Irons with 35 to 36 % Ni have a Thermal Expansion varying from 4 to 8×10^{-6} per degree.

3) Non magnetic cast irons :

- % C 3.5
- % Si 2.2
- % Mn 5.0
- % Ni 10 to 11

These alloys have a Ms temperature of --166 degrees.

4)High Temperature Resistance cast irons have a composition of

- % C 1.6 to 2.2
- %Si 4.0 to 4.5
- %Mn 0.6 to 1.2
- % Ni 18 to 22
- % Cr 2.0 to 4.0

These alloys retain high strength & oxidation resistance up to 900 degrees.

Martensitic White Cast irons:

1) %C 2.7 to 2.9

%Si 0.3 to 0.6

% Mn 0.6 to 0.9

% Ni 4.0 to 6.0

% Cr 8.0 to 10.00

As cast Hardness could vary from 320 to 550 BHN depending on section thickness. These alloys are Heat treated at 1040 to 1070 degrees for a period of One Hour per Inch (25 mm), air cooled & Stress relieved at 200 to 240 degrees. This will give hardness of 600 BHN.

2) % C 2.5 to 3.0

% Si 0.8 to 1.5

% Mn 1.5 to 3.0

% Cr 15 to 28

% Ni 1.5 to 3.0

% Mo 0.2 to 0.8

3) % C 2.9 to 3.1

% Mn 0.65 to 0.85

% Si 0.55 to 0.75

% Cr 19 to 21

% Ni 0.9 to 1.10

% Mo 1.60 to 1.75

4) %C 1.25 to 1.35

%Mn 0.50 to 0.70

%Si 0.40 to 0.60

%Cr 11.5 to 12.00

% Mo 0.45 to 0.55

High Silicon Cast Irons:

These are Acid Resistant Cast Irons.

% C 0.35 to 1.0

% Si 14 to 15

% Mn 1.0 max

These alloys have very low strength, highly brittle & highly prone to cracking. A special care is taken while making these castings.

As soon as the liquid metal has solidified, mould is broken, feeders, gates, runners & sprue are knocked out while the castings are still bright red in colour.

Immediately the castings are put in a furnace whose temperature is about 850

Degrees. Castings are allowed to cool to room temperature over a period of 30 to 40 hrs.

This material is very hard. Hence the machining allowance is minimal.

Machining should be done with special carbide tips or grind it.

While transporting the casting in a TRUCK, extra care is taken to see that Castings do not experience any jolt. So a bed of hay (dry grass) is spread on the Truck & castings are so placed in such a way that one casting does not even hit An other casting while the truck is in motion (like carrying damageable fruits in a truck)

IS STANDARDS FOR FERROUS CASTINGS.

Iron Castings:

210	Grey Iron Castings.
1865	S.G. Iron Castings.
4729	Austenitic Iron Castings.
4771	Abrasion Resistant Iron Castings.
5788	S.G. Iron Castings, for Pressure containing parts suitable for elevated temperature
5789	Austenitic S.G. Iron castings, for Pressure containing parts suitable for low temperature applications
6331	Automotive Grey iron castings.

Steel Castings :

276	Austenitic Manganese Steel Castings.
1030	Steel Castings for General engineering purposes.
2644	High Tensile Steel Castings.
2707	Carbon Steel Castings for Surface Hardening.
2708	1.5 % Mn Steel Castings.
2856	Carbon Steel Castings suitable for High temperature service.
3038	Alloy Steel Castings for Pressure containing parts suitable for high temperature service

3444	Corrosion Resistant Steel Castings.
4522	Heat Resistant Alloy Steel Castings.
4898	Steel Casting For Case Carburizing.
3896	Comparison of Indian & Overseas Standards for Iron Castings.
4331	Comparison of Indian & Overseas Standards For Steel Castings.

ASTM Steel Casting Specification :
Carbon & low alloy Steels:

A27	Mild to Medium Strength-Steel Castings for General Application.
A148	High Strength Steel Castings.
A216	Carbon Steel Castings For Fusion Welding For High-Temperature Services.
A217	Alloy Steel Castings For Pressure Containing Parts Suitable For High Temperature Services.
A352	Ferritic Steel Castings For Pressure containing parts Suitable For Low Temperature Services.
A389	Alloy Steel Castings Specially Heat Treated For Pressure Containing Parts

High Alloy Steel Castings:

A128	A 128--- Austenitic Manganese Steel Castings.
A296	A 296---Corrosion Resistant Iron-Chromium and Iron-Chromium-Nickel Alloy Castings (Stainless Steel Castings CA-15,CF-8,CF-8M etc)
A297	A 297---Heat-Resistant Iron-Chromium and Iron-Chromium-Nickel Alloy Castings (HA, HF etc)

Here there is a problem lurking in the corner, i.e. IS 2644 & ASTM A-148 Alloys are HIGH STRENGTH STEEL CASTINGS , But their Composition is Left to YOUR choice (excepting S & P)

A word of advice, even if you get the similar Mechanical Properties in Wrought Steels, you can NEVER get the Properties sought by A-148 at the S & P levels mentioned.

For instance, ASTM A-148-1965, wants 124 Kg / mm²(UTS), 102 Kg / mm² (YS), % E of 6.0, % RA of 12 (All Minimum Values) at a Specified S Of

0.06% max & P of 0.05 max. You will not get these values, if you operate at a S of 0.059 % & a P of 0.049 %. Ensure that you operate at a S of 0.030 % & a P of 0.03 %.

REMEMBER THAT % S & % P ARE ENEMIES OF % E , % RA & IMPACT STRENGTH IN STEELS.

SO OPERATE AT AS LOW A S & P VALUE AS POSSIBLE.

An attempt is made to give you the nearest composition which will satisfy both IS-2644 & ASTM A-148.

IS-2644.

UTS (MPa)	YS (MPa)	%E	%RA	BHN
Min	Min	Min	Min	Min
640	390	15	35	190
700	580	14	30	207
840	700	12	28	248
1030	850	8	20	305
1230	1000	5	12	355

ASTM A-148

UTS (MPa)	YS (MPa)	%E	%RA	BHN
Min	Min	Min	Min	Min
550	276	18	35	160
550	345	22	35	160
620	415	20	35	180
725	590	17	35	210
830	660	14	30	240
1035	870	9	22	300
1210	1000	6	12	350

The values of ASTM A-148 have been converted to MPa.

The values given under are extracted from STEEL CASTINGS HAND BOOK.

1) % C-0.25, % Mn- 1.37, % Si- 0.51-----Normalizing.

UTS-662 MPa, YS-448 MPa, %E-25, %RA- 49, BHN-192.

2) %C-0.28, %Mn- 1.43, %Si- 0.49-----Water Quench & Temper at 430 degree Celsius.

UTS-897 MPa, YS-760 MPa, %E- 20, %RA -41, BHN-260.

3) %C- 0.34, %Mn -1.28, % Si-0.25-----Water Quench & Temper at 530 degree Celsius.

UTS- 1040 MPa, YS-945 MPa, %E-12.5, %RA-23,BHN-300.

4) %C -0.40, %Ni- 0.63, %Cr- 0.70, %Mo- 0.26—Water Quench & Temper at 480 degree Celsius.

UTS-1300 MPa, YS-1035 MPa, %E-8, %RA-12, BHN-388.

The above Compositions cover the ENTIRE GAMUT OF IS-2644 & ASTM A-148 Specifications.

PROBLEMS TO BE LOOKED INTO

1) Make Grey Iron with less than 2.0 % C.

Make a melt of Iron with the following composition.

% C 1.55 to 1.85 , % Si 2.20 to 2.60 , % Mn 0.30 to 0.80, % S 0.05 to 0.2, % P 0.05 max , % B 0.01.

Boron can be added in the form of FeB. Pass Nitrogen gas through the melt, BN forms. It has a lattice coherency with Graphite , hence it results in Grey Iron of Strength as high as 50 Kg / mm² as against 20 to 30 Kg / mm² in Conventional Grey iron .

2) Try to make Spheroidal Carbide Iron. In high Cr cast irons of say % C 2.0, % Cr 12, Chromium Carbide formed is M₇C₃ type. From HAND BOOK OF CRYSTALLOGRAPHY , find out any other any other Compound, with same Lattice parameters as M₇C₃. This compound should be obtainable in-situ in Liquid melt.

3) Take AISI D2 Steel, the word Steel is a misnomer. Because D2 is a White Cast Iron. Hold it at 1050 to 1080 degrees for a prolonged period, sharp edges in Carbide will disappear. (I have done it.) Check the properties.

4) Make P treated Al- 13 % Si & Al – 8 % Si alloys, so that you get Primary Silicon. Compare the properties.

5) Hold P treated Al – 8 % Si alloy at 490 to 500 degrees , to remove sharpness of Si . Check the properties. (I have done it with P treated Al-12 % Si , the sharpness of Si had gone. Si looked like a LUMP rather than a Cuboid.)

6) Make an Insulating Sleeve & an Exothermic Sleeves (with the details given) & Do the Cost- Benefit analysis.

7) A Cube of 100 needs a Sand Feeder of 120 dia x 120 ht.

It needs 10.3 Kgs of Steel.(For FEEDER ONLY)

A Sand Sleeve with an OUTER ANNULAR SPACE was made.

(Shown in the SKETCHES)

The Feeder proper is 95 dia x 95 ht. The outer annular space has a dimension of 135 OD x 115 ID x 85 ht. We got a SOUND CUBE Casting.

Let us do some calculation.

$$1) 0.785 \times (1.35 + 1.15) (1.35 - 1.15) 0.85 \times 7.6 = 2.54 \text{ Kgs.}$$

Molten Steel requirement of annular space.

$$2) 0.785 \times (0.95)^3 \times 7.6 = 5.11 \text{ Kgs (Feeder Proper)}$$

$$1+2 = 2.54 + 5.11 = 7.65 \text{ Kgs.}$$

Savings in LIQUID STEEL is 10.3 Kgs – 7.65 Kgs = 2.65 Kgs.

$$\text{Savings \% } 2.65 / 10.3 = 0.257 \times 100 = 25.7 \%$$

$$\text{MEF} = 120 \text{ dia} / 95 \text{ dia} = 1.26$$

The whole Purpose behind doing this Experiment was to make temperature Gradient **FLAT IN THE SAND ADJACENT TO LIQUID METAL IN FEEDER FOR A WHILE.**

If this experiment is repeated with INSULATING SLEEVE & EXOTHERMIC SLEEVE. It would result in greater benefit.

TRY DOING IT. These kind of Sleeves are not available in the market & hence You will have to make your own Sleeves.

8) Make a Sodium Silicate Core & pass a combination of CO₂ gas and HOT AIR. See the difference between this core & Conventional core. Do the Cost-Benefit analysis.

9) Find out as to why Core made out of Sodium Silicate Sand & Bentonite does not become FRIABLE.

10) Use dry BAMBOO Powder for making Insulating or Exothermic Sleeves.

11) Treat Al – 3 % Fe melt with SULPHUR to see if Fe can be removed as FeS.

12) Find out how effective is PADDY HUSK as APC & also the Effectiveness of Mixture of Paddy husk & dry BAMBOO powder.

13) Try Dry wood waste as an APC & also try to use Coconut shell powder as APC. **The Calorific Values of these have given in the text.**

14) Check up the Effectiveness of Powdered COW DUNG CAKE as APC

15) Check up the effectiveness of a Sleeve made out of COW DUNG CAKE POWDER.

16) Along with the stream of Steel or Grey Iron melt, add 1,2,3,4,5% Fine STEEL SHOTS & Evaluate the Microstructure , Mechanical Properties & Shrinkage pattern

17) For those of you , who want to work on Al –Si & get Primary Silicon , you need to add P-Cu (8 % P) as Al_2P_3 is the nuclei for Primary Silicon. For P to be available in the alloy, alloy must be free from Na, Ca , K & Ba (Alkalis) The cheapest Silicon available is CHINESE SILICON. But it has alkaline elements. P being acidic, alkalines have to be removed before adding P- Cu. Alkaline elements can be removed by TREATING the LIQUID metal of Al-Si with ALUMINUM CHLORIDE (Commercial Grade).

This material, has a SUBLIMATION POINT of 190 degrees.

This material can be had from M/ s Kanoria Chemicals, Renukot, UP.

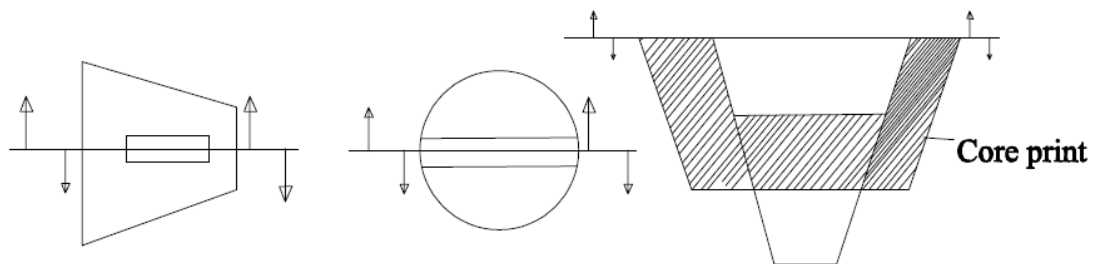
This material is Hygroscopic in nature , Heat the material to remove all the moisture before use. This material does the TWIN work of removing Alkaline elements & acts as a DEGASSER too.

THE PURPOSE BEHIND THIS LIST OF THINGS THAT CAN BE TRIED OUT, IS ONLY TO IGNITE NEW IDEAS IN YOU

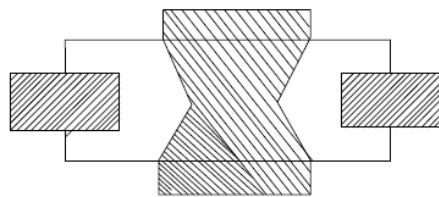
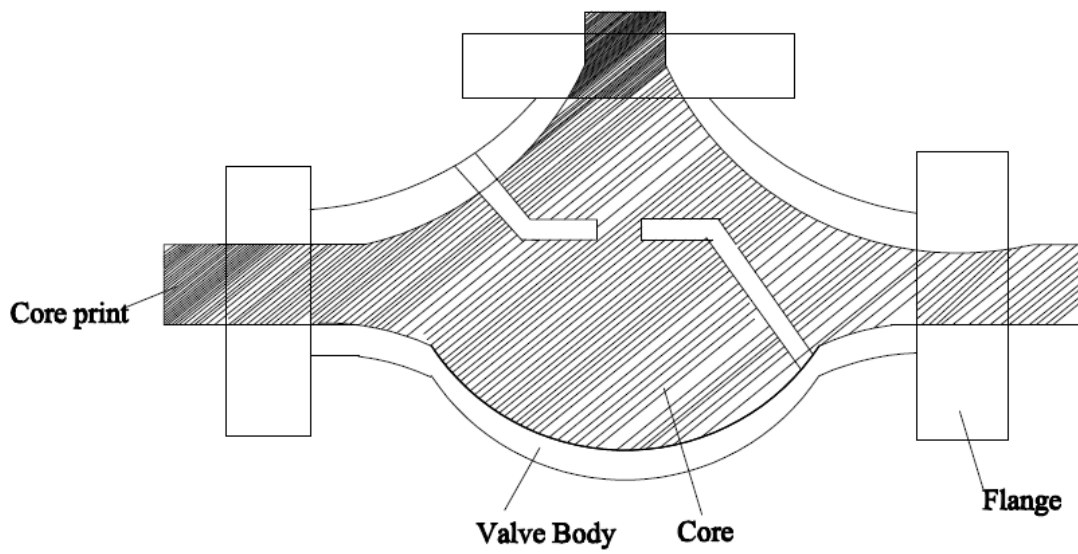
Books Referred to :

- 1) STEELS-----R.W.K. Honeycombe.
- 2) THE PHYSICAL METALLURGY OF STEELS----Leslie.
- 3) THE APPLIED SCIENCE IN CASTING OF METALS—K. Strauss.
- 4) STEEL CASTINGS HAND BOOK--- Steel Founders' Society Of America, 1970.
- 5) CAST IRON : PHYSICAL AND ENGINEERING PROPERTIES---
H. T. Angus.
- 6) THE DIRECTIONAL SOLIDIFICATION OF STEEL CASTINGS—
R.Wlodawer.
- 7) STRUCTURE OF METALS --- Barret & Masslaski.
- 8) INDIAN FOUNDRY JOURNAL--- April ,1986—Institute of Indian Foundrymen.
- 9) P.R.Beeley----Foundry Technology.

PATTERN

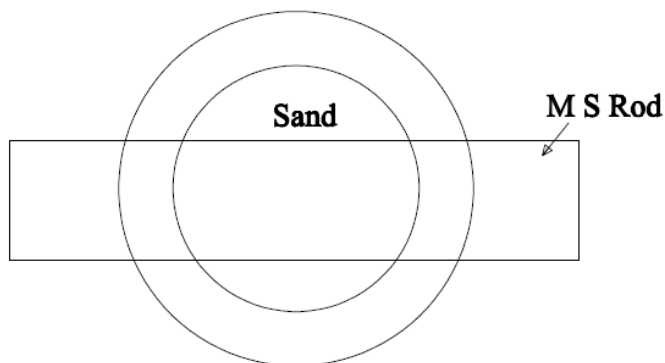


Parting line, taken, should not lead to any casting problem. In the First case a SHIFT in casting can occur, resulting in Casting rejection. No such problem exists in second case.

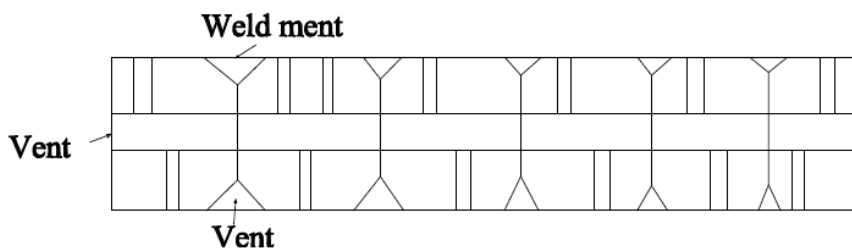


Both sides are of same dimension.

A Badly Designed casting with stringent dimensions will have a soundness problem



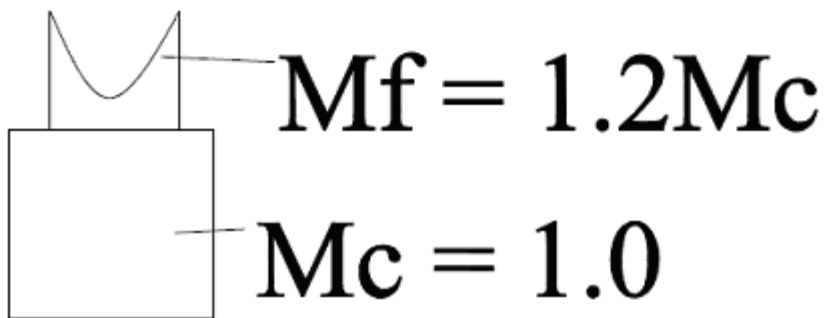
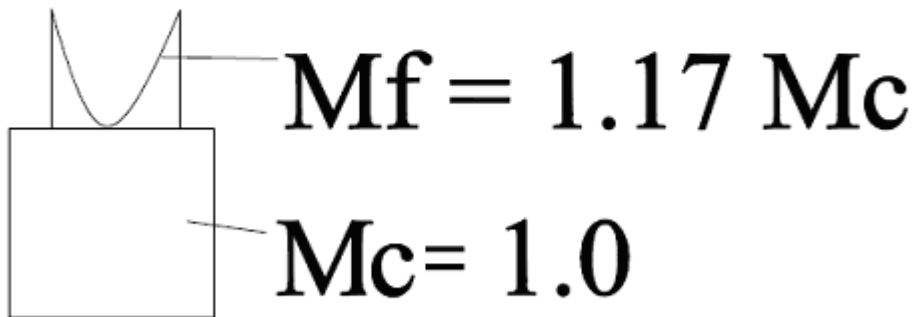
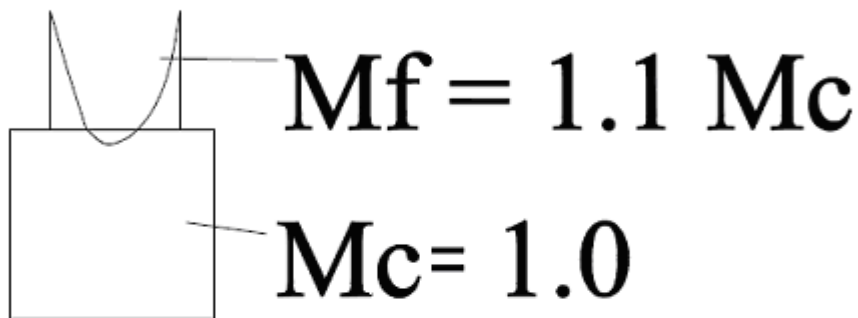
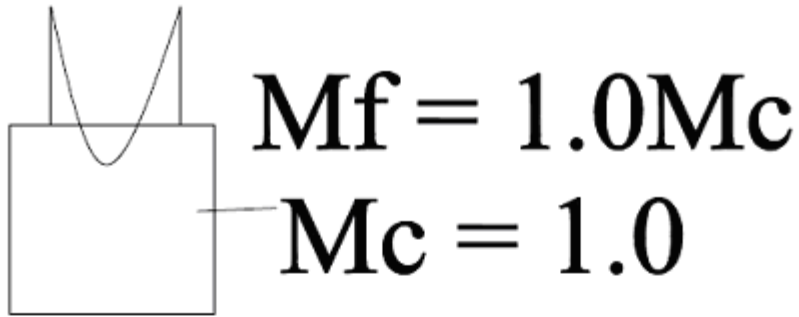
Hollow Ball

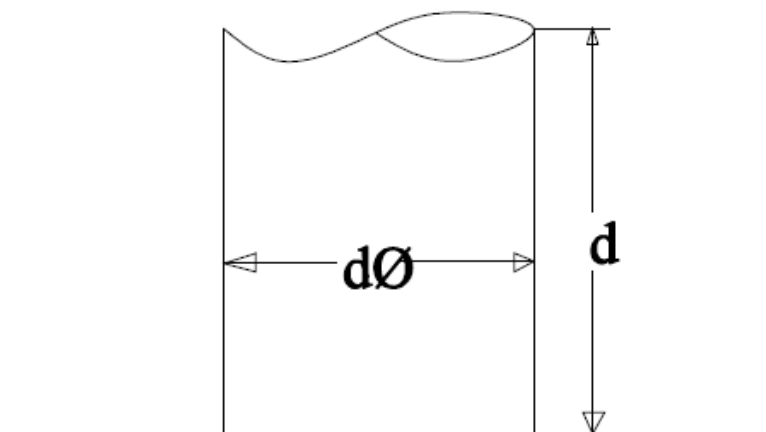
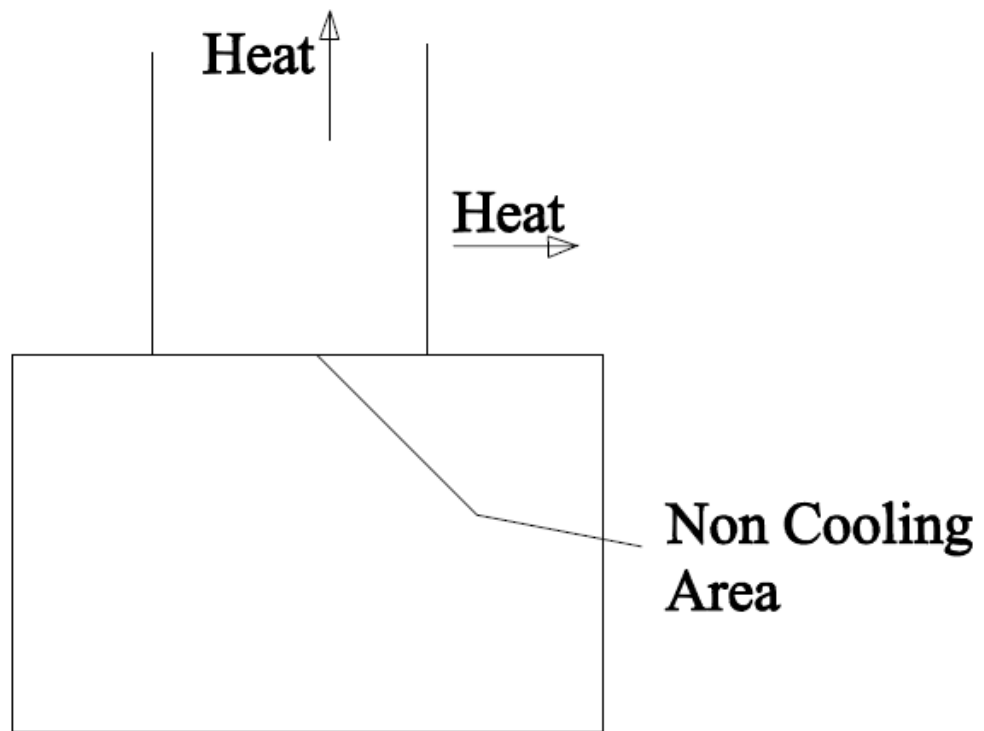


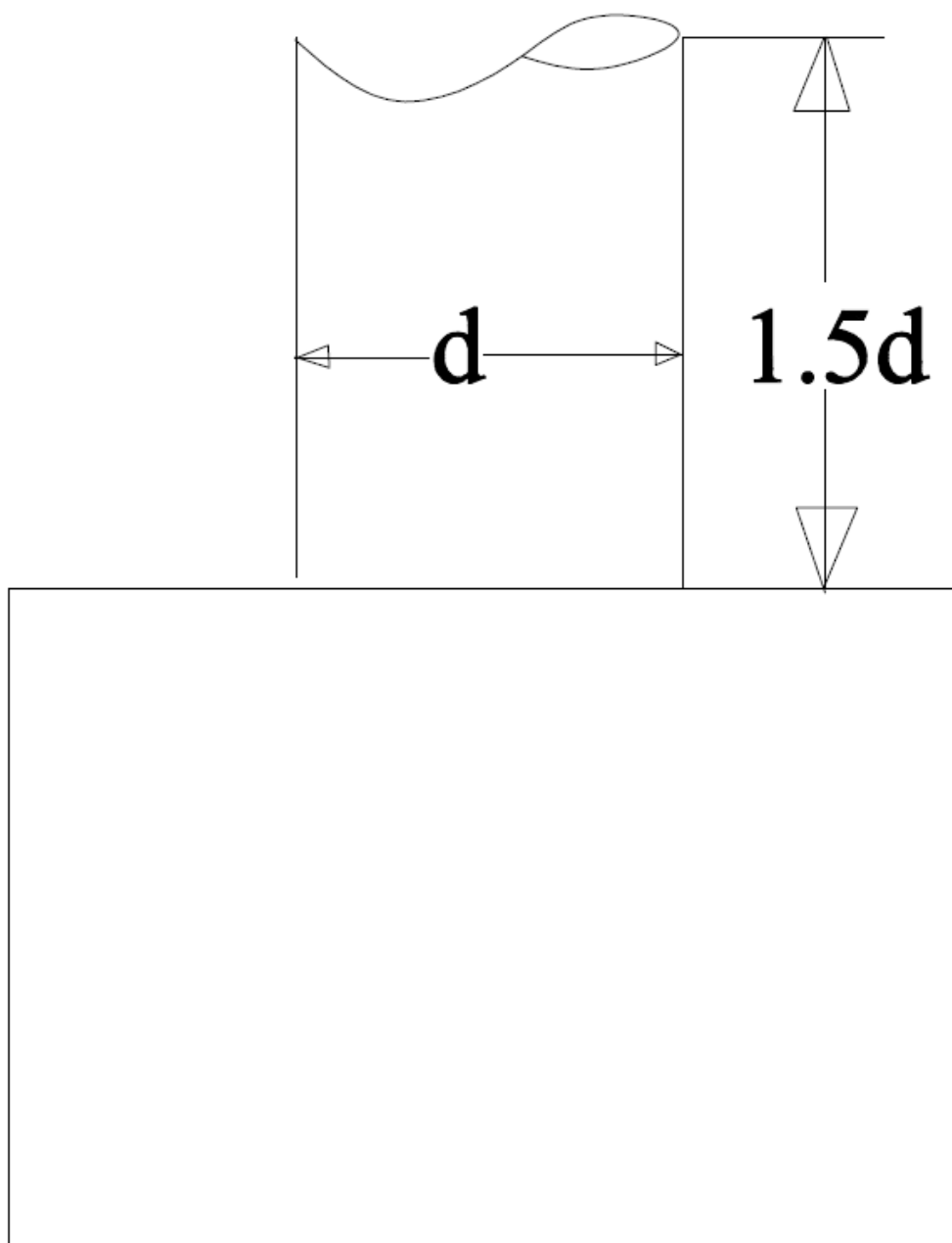
While designing a Casting, the Designer should always bear in MIND that There are NO ISOLATED HOT SPOTS WHICH can not be FED.

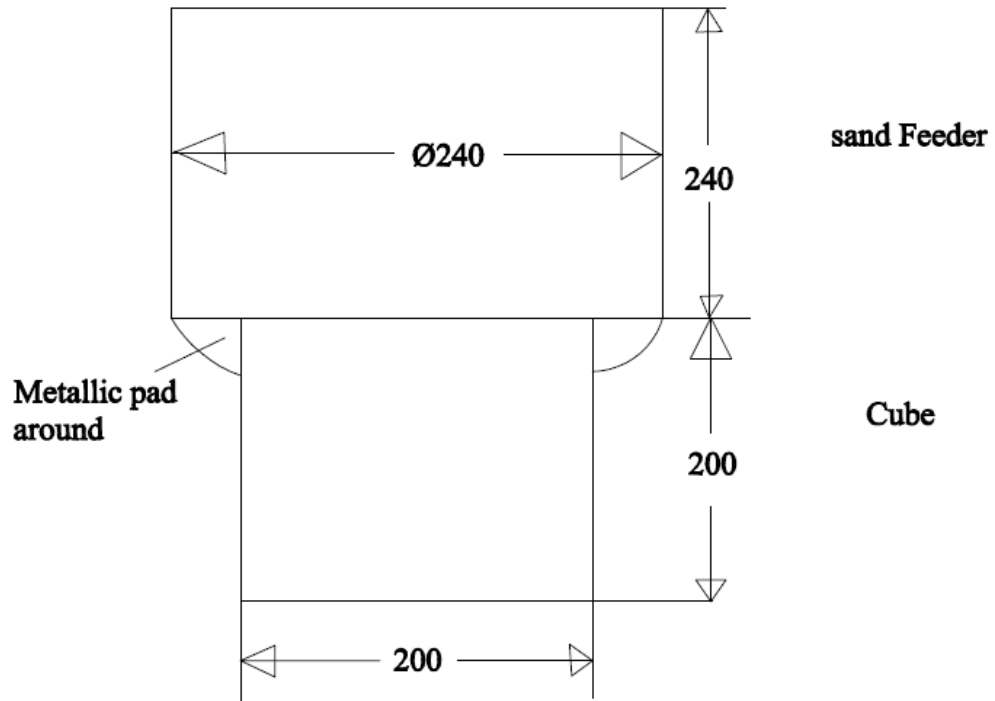
A TAPERED BAR IS AN IDEAL CASTING TO FEED FROM THE POINT OF DIRECTIONAL SOLIDIFICATION.

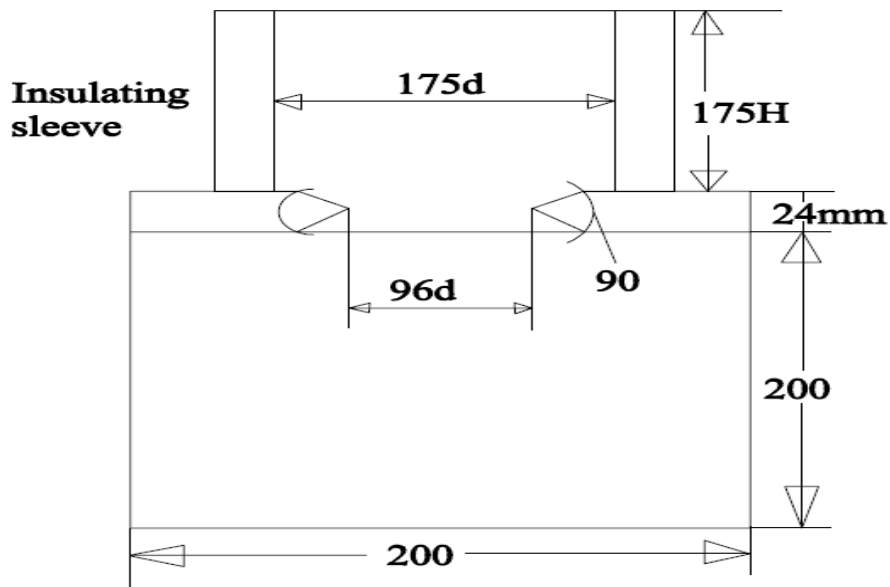
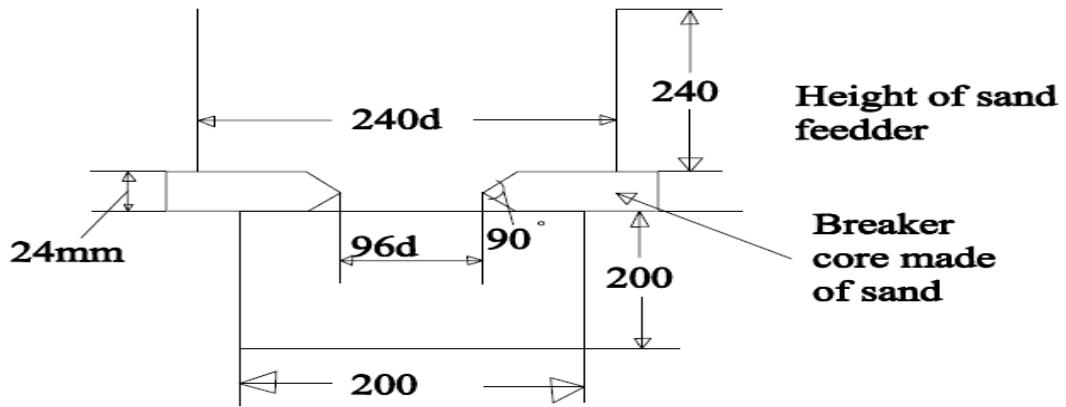
METHODING

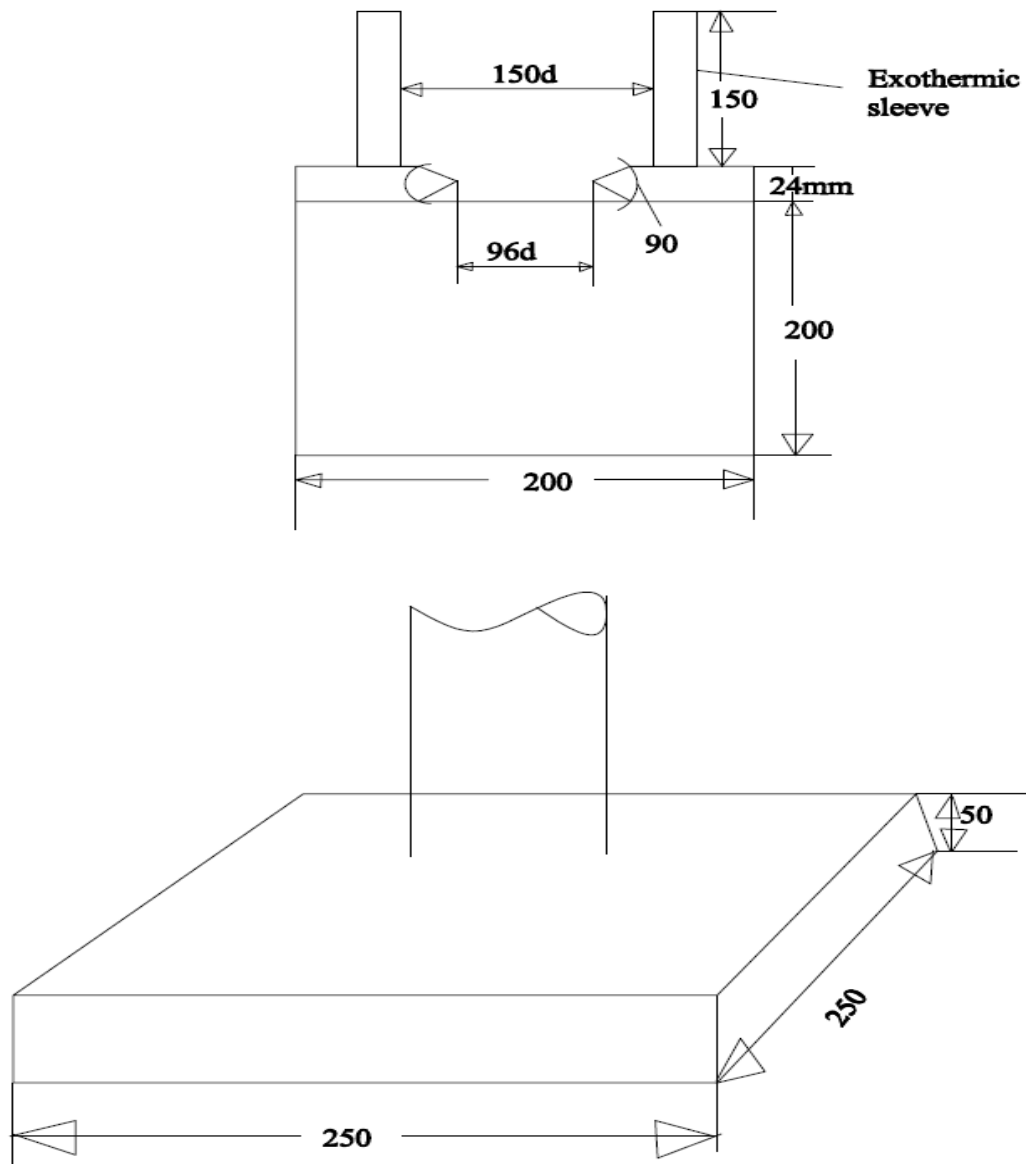


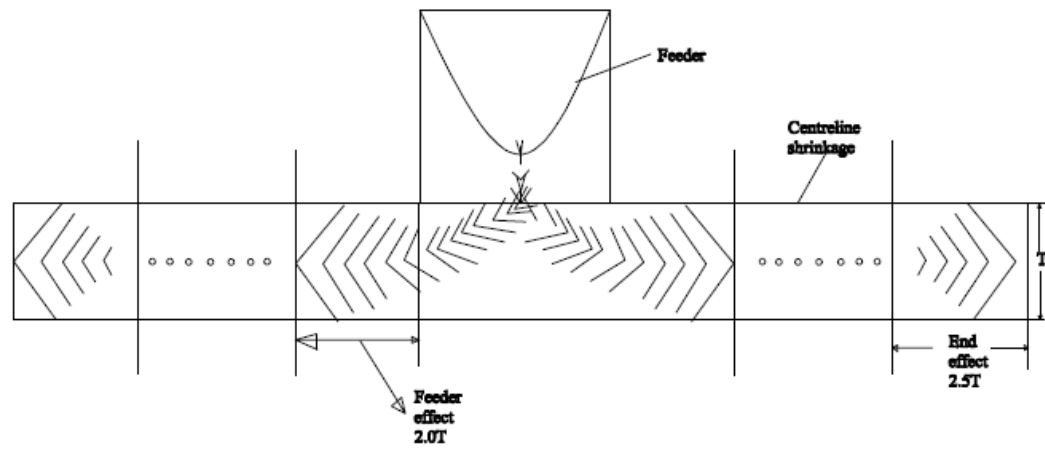




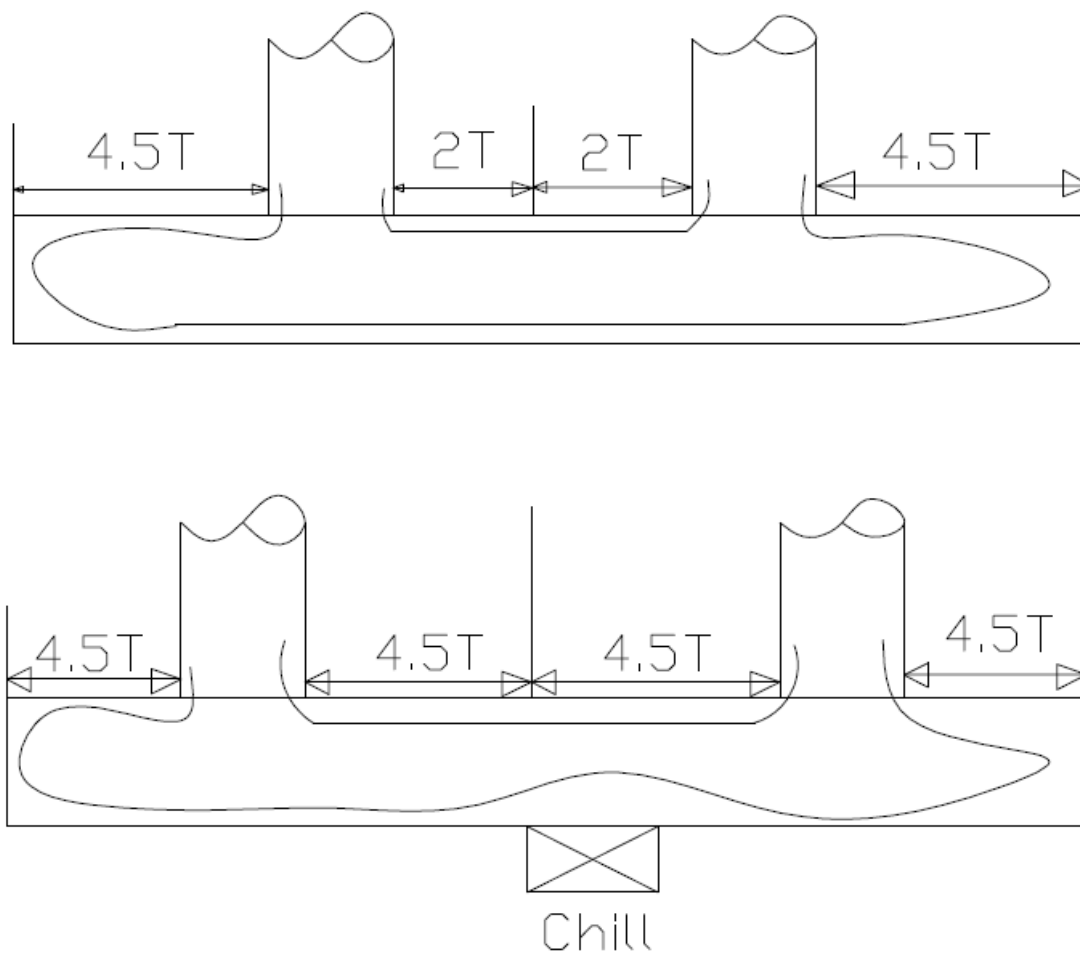




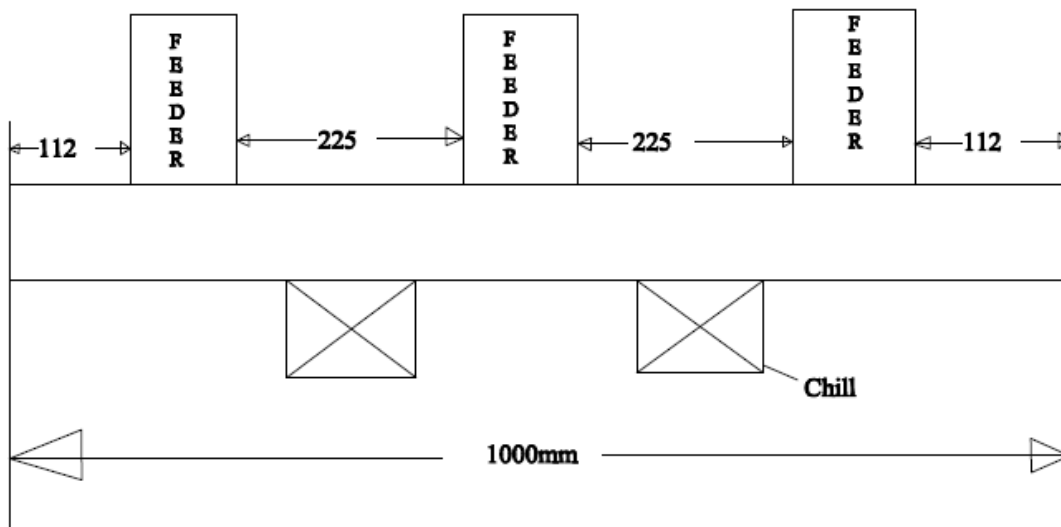
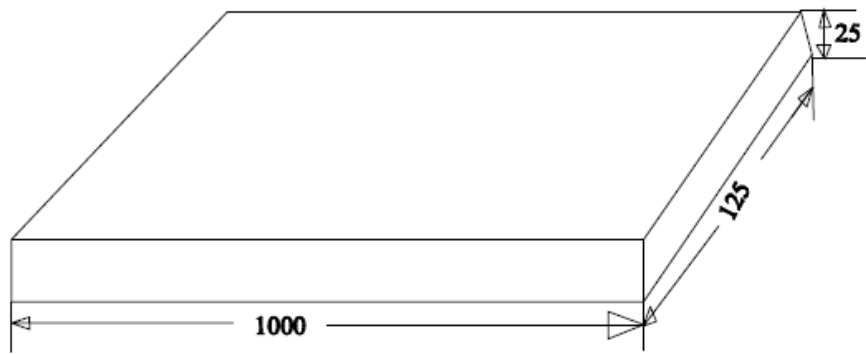


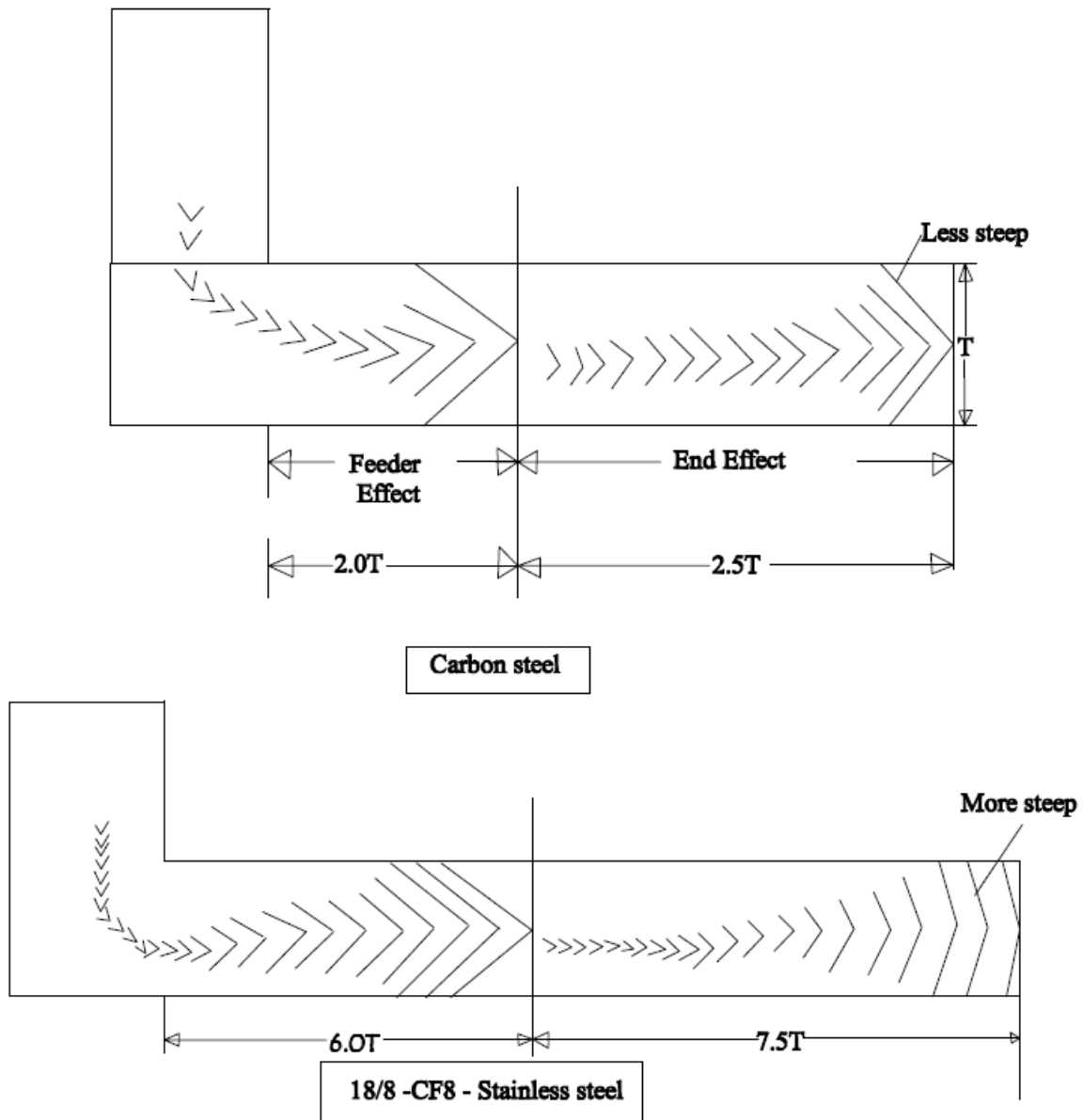


Centreline shrinkage is not acceptable in Radiography. Feeding system Should be so designed that Centreline defect does not occur.

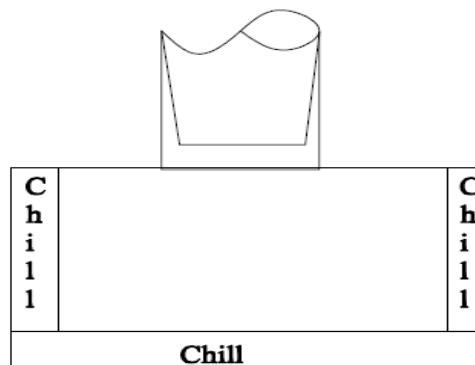
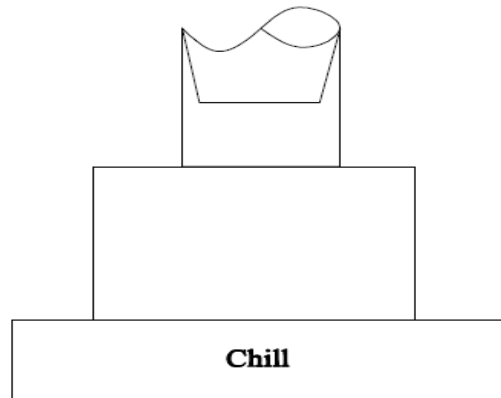
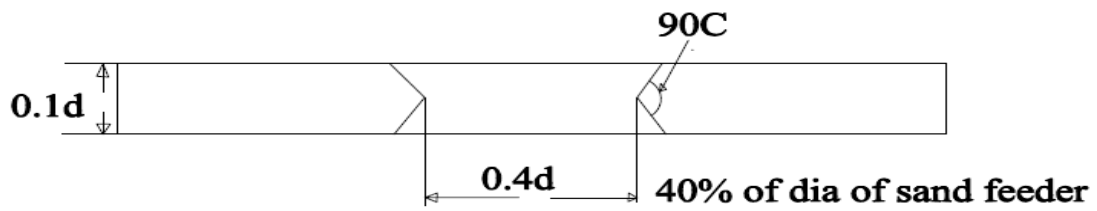


Presence of a Chill, because of its faster rate of heat extraction, creates what is equivalent to AN END. As a result Feeding Distance is increased, which results in LESSER NUMBER OF FEEDERS.

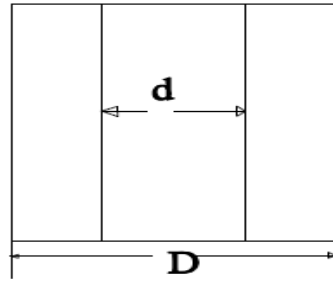




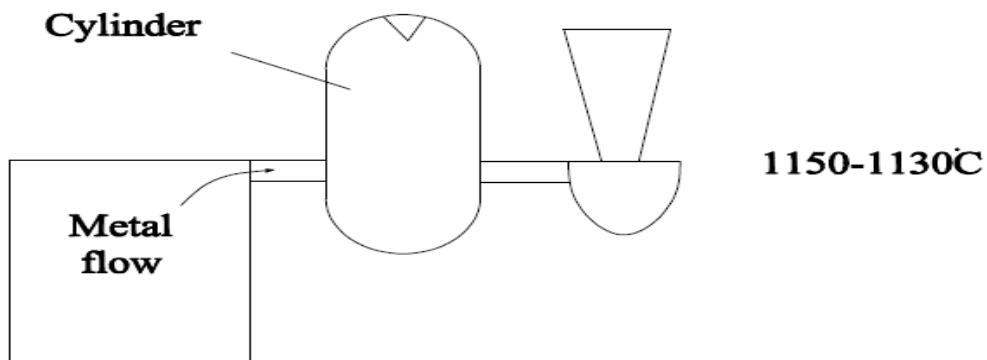
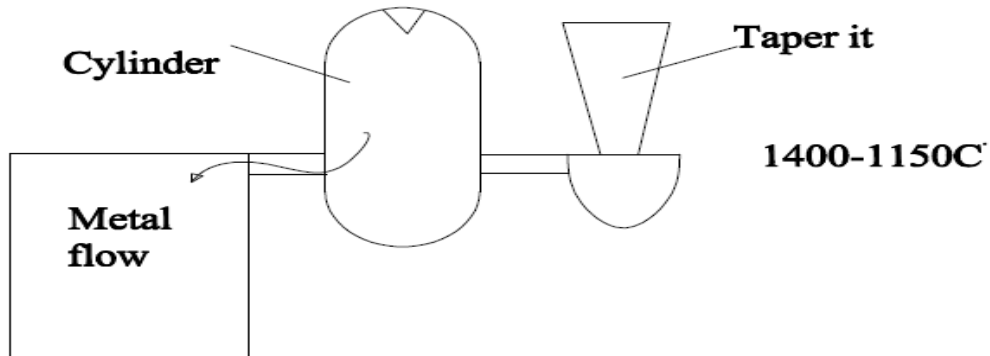
Look at STEEPNESS of temperature Gradient. When it is Steeper, it has to Traverse a longer distance before it closes & hence a longer Feeding Distance. In Plain C Steel, with lesser steepness in gradient, has $4.5T$ as the Feeding Distance. While Stainless Steel, with a greater steepness has a Longer Feeding Distance of $13.5 T$.



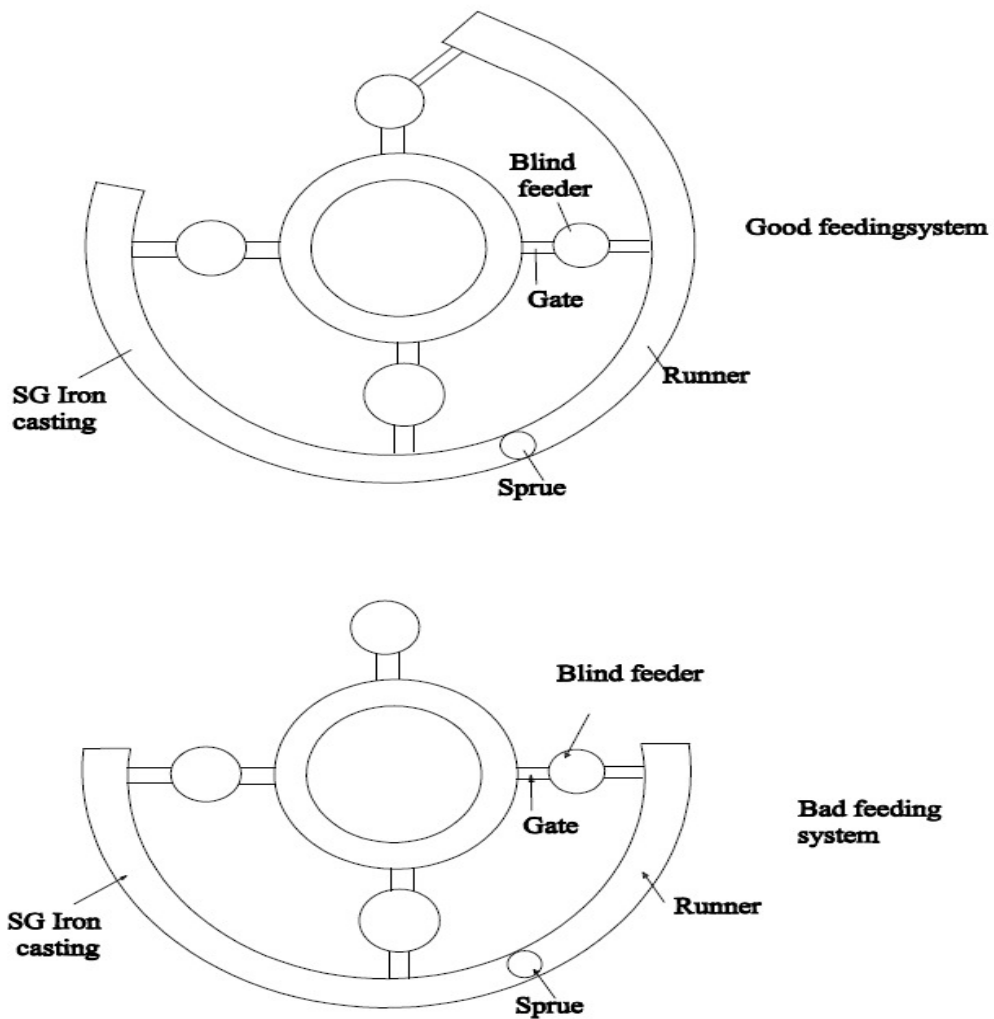
By using Chills, heat extraction rate is hastened. Which is equivalent to Increasing the Surface Area FOR THE SAME VOLUME So the Casting solidifies Faster & as a result DRAWS Liquid from FEEDER faster.



If $d < 0.27D$ - Donot put the core, Make it solid

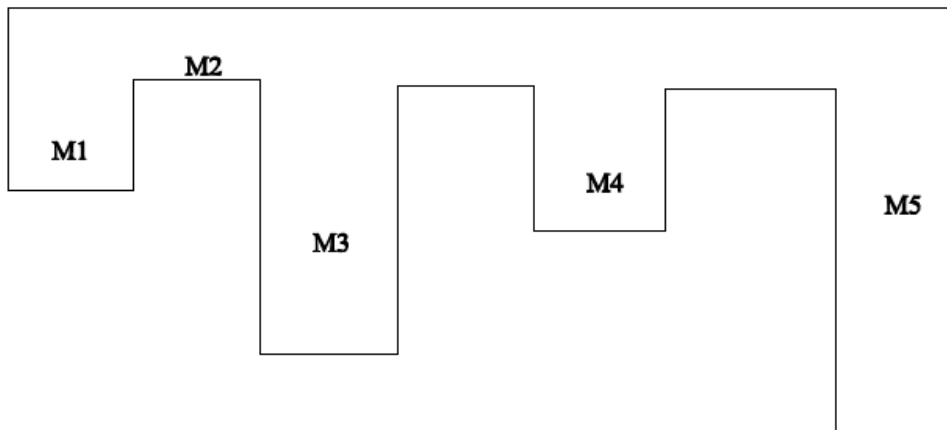


BLIND SAND FEEDER DIA , $H / D = 1.5$, 5.0 Mf to 6 Mf
 7.0 Mf (IF STEEL SCRAP IS MORE IN THE CHARGE)
 BLIND SAND FEEDER DIA , $H / D = 1.0$, 5.5 Mf to 6.5 Mf.
 8.5 Mf(IF STEEL SCRAP IS MORE IN THE CHARGE)
 NECK SIZE, ROUND OR SQUARE $D = Mn$, $L = Mn$
 RECTANGULAR, $W = 6 Mn$, $T = 3 Mn$, $L = Mn$.

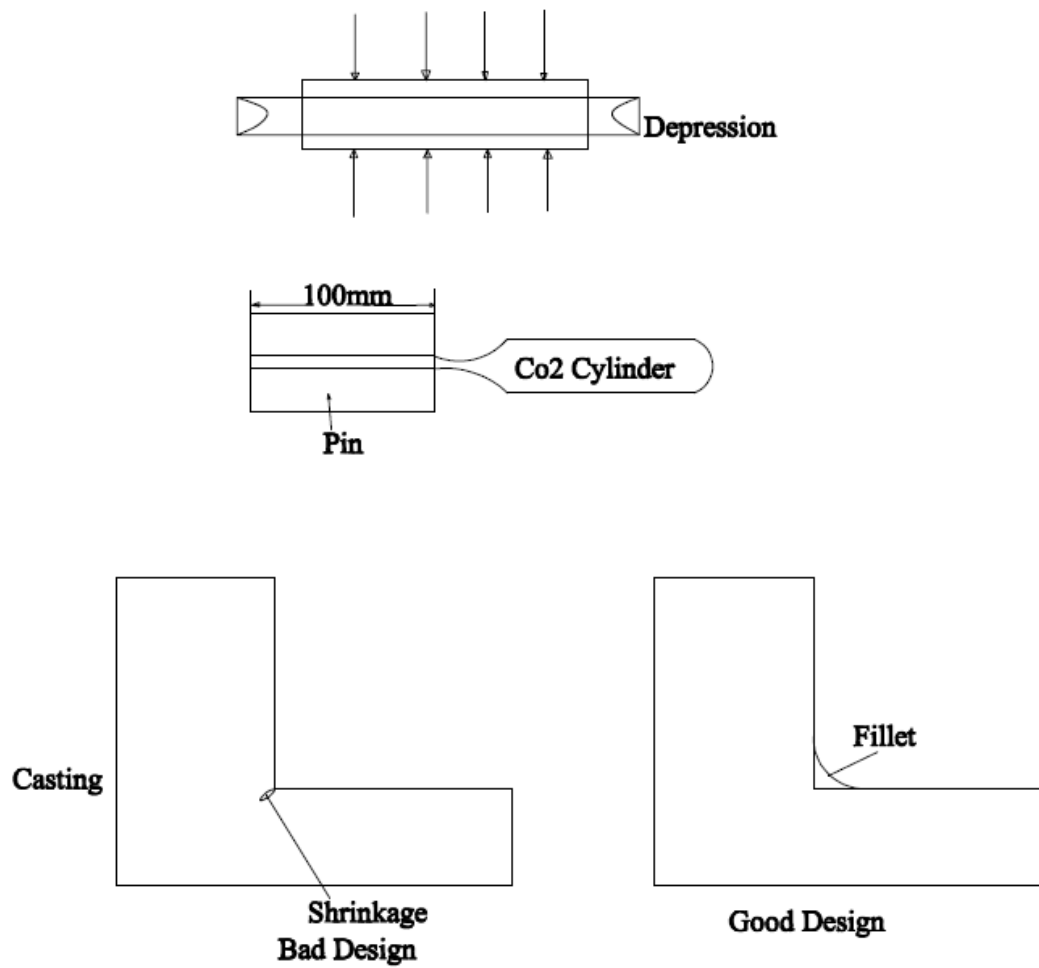


In case of S.G. Iron, metal should flow from Runner to Feeder Bottom & then THROUGH the NECK to Casting. (as the Neck is not Geometrical) Should the metal flow from CASTING TO NECK & to FEEDER, you will Have problems at that point.

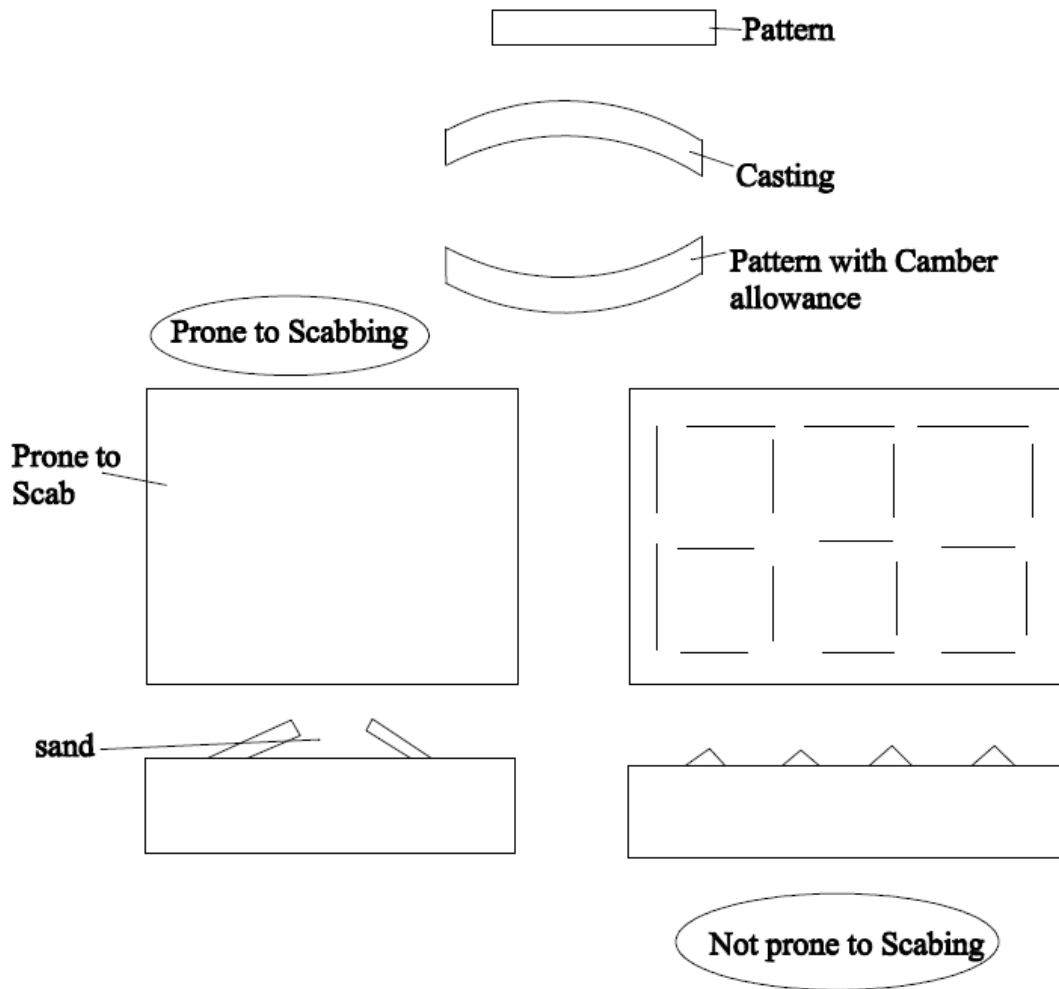
Metal flow SPRUE TO RUNNER TO FEEDER BOTTOM TO NECK TO CASTING FOR ALL FEEDERS.

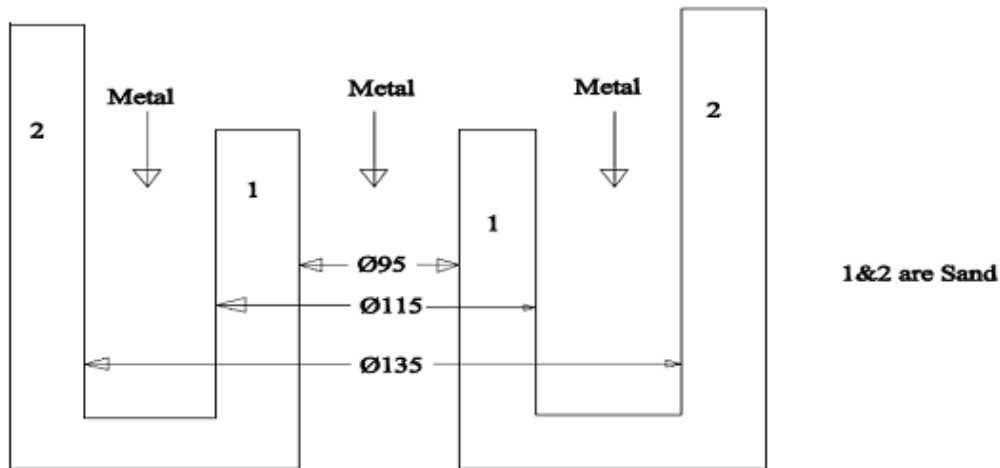


Depending on Modulus they will have to be fed



When a cast bar is FORGED, you find DEPRESSIONS at the ENDS, These are migration of a defect called VACANCY. Because of this absence of this defect, Worked or Wrought alloys are TOUGHER. The cylinder figure is for making SOLID CO₂, which when added to liquid ACETONE, gives a temperature of -60 degrees, which is required for Sub-zero Impact Testing.





A New Feeder Design

A Cube of 100mm, needs 120mm dia x 120mm ht sand feeder, which needs 10.30Kg of metal.

The above NEW FEEDER DESIGN gave a sound 100mm sound cube casting at 95mm dia x 95mm ht.

Metal requirement of the feeder = 5.12Kg

Metal requirement of the annular ring = 2.54Kg

The total metal requirement = 5.12 + 2.54 = 7.66Kg

Savings of metal = $(10.30 - 7.66) / 10.30 \times 100 = 25.70\%$

Modulus Extension Factor = $120/95 = 1.26$.

The purpose of this new design is to make the TEMPERATURE GRADIENT adjacent to the liquid metal in the feeder **FLAT** for a while.

If the same argument is extended to insulating sleeves and exothermic sleeves, we might gain a great deal.

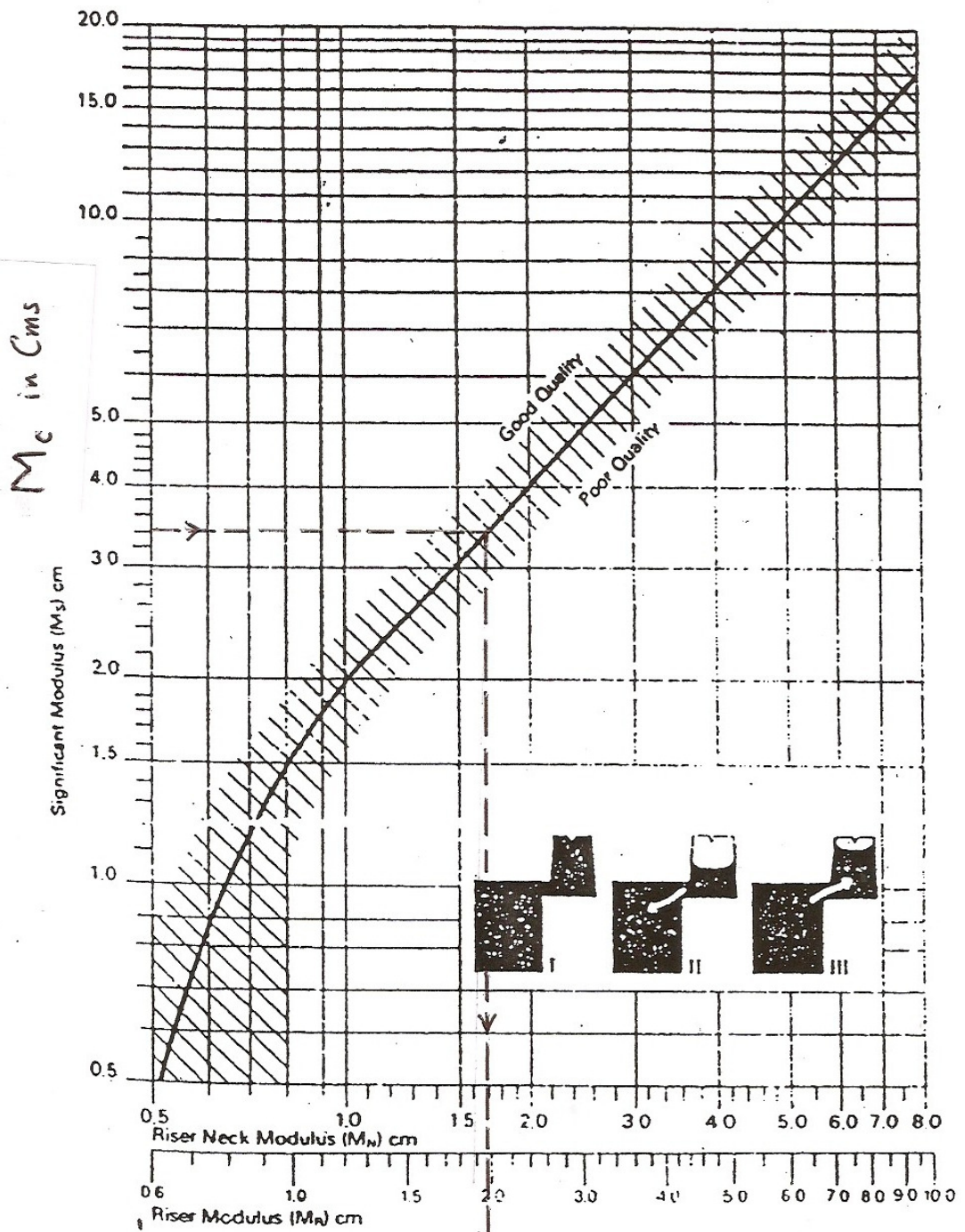


Fig. 7. Relationship Between Significant Modulus (M_s), Riser Neck Modulus (M_n) and Riser Modulus (M_R) in Pressure Control Riser System Design.

FEEDING GRAPH FOR
S0G0 IRON.

BLIND SAND FEEDER

$H/D = 1.5$, Dia = $5.0 M_f - 6.0 M_f$
 $7.0 M_f$ (if more steel scrap is used)

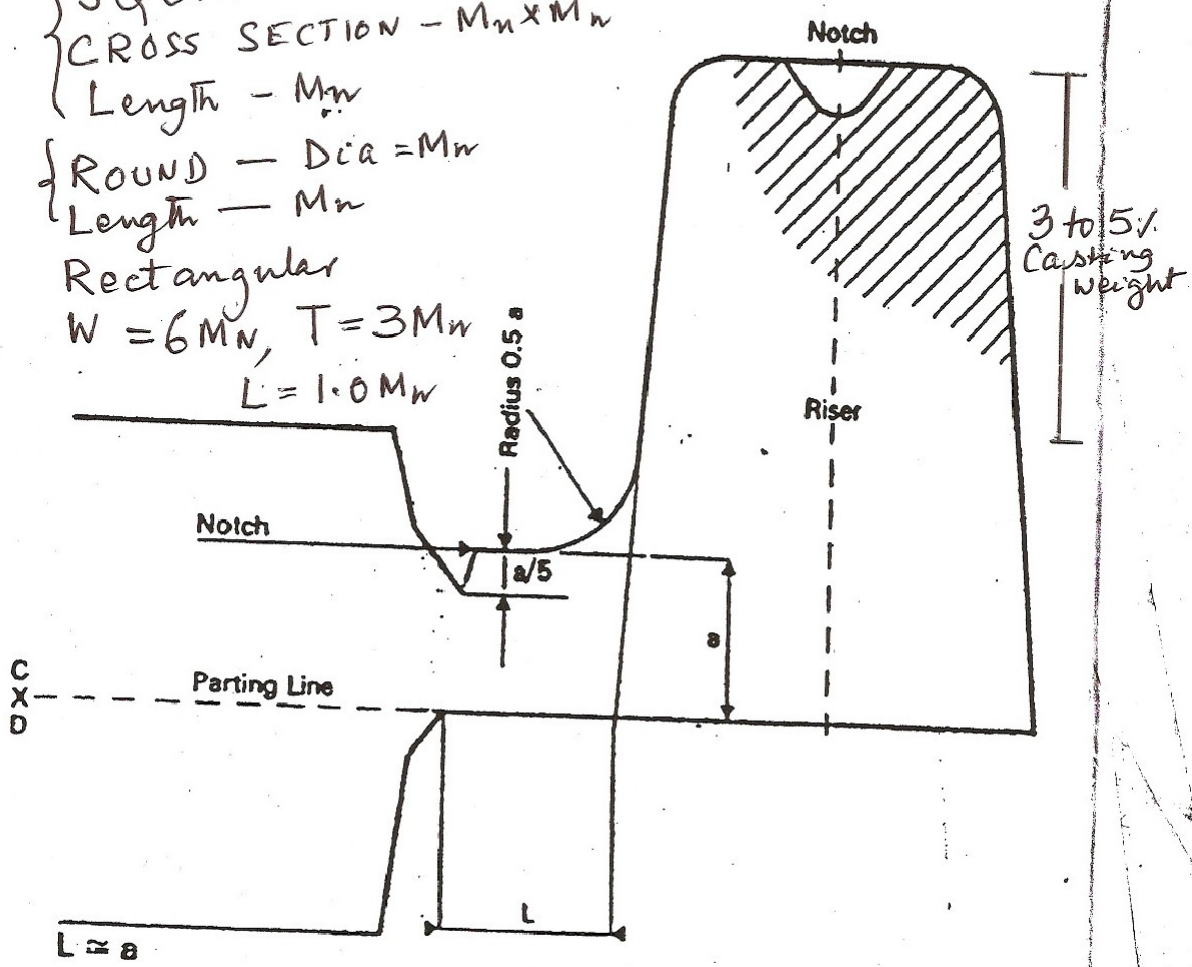
$H/D = 1.0$, Dia = $5.5 M_f - 6.5 M_f$
 $8.5 M_f$ (if more steel scrap is used)

NECK

{ SQUARE
 CROSS SECTION - $M_n \times M_n$
 Length - M_n

{ ROUND - Dia = M_n
 Length - M_n

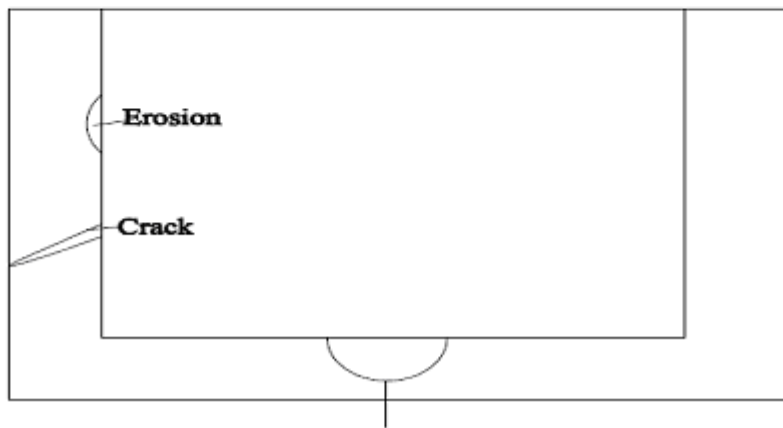
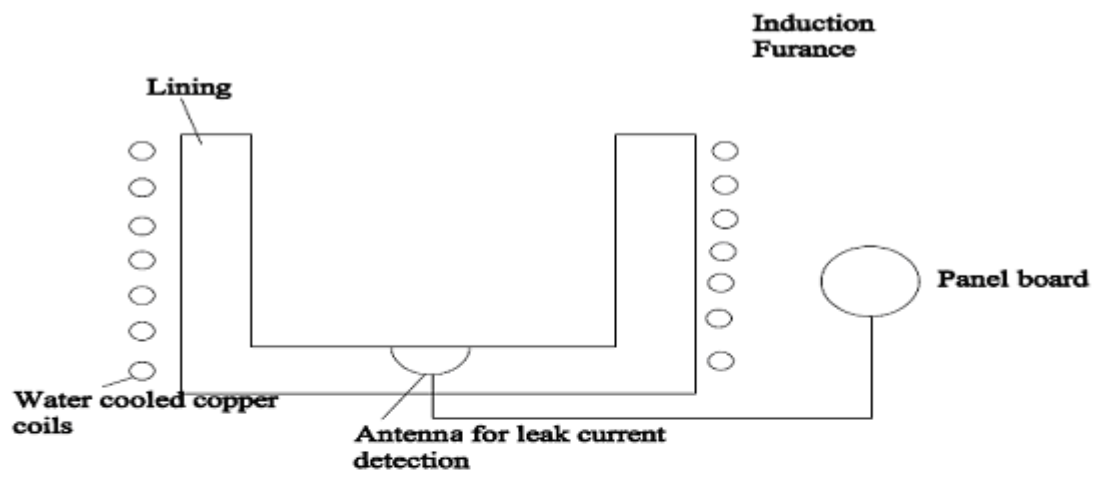
Rectangular
 $W = 6 M_n$, $T = 3 M_n$
 $L = 1.0 M_n$



6 - Arrangement of Riser Neck and Casting

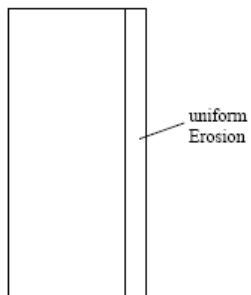
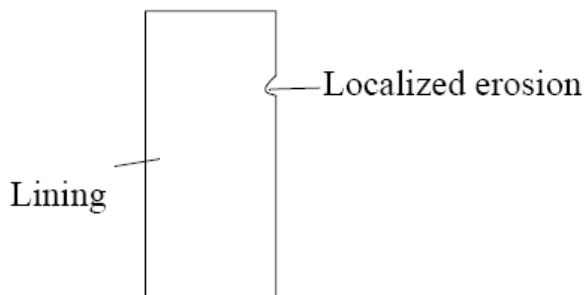
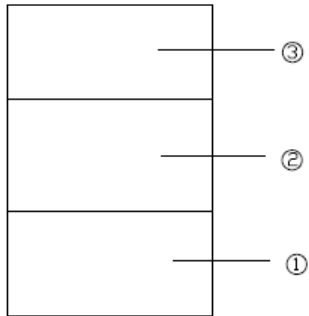
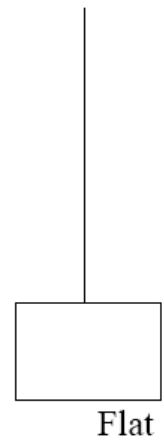
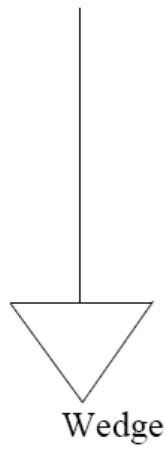
FEEDER FOR S.G. Iron

MELTING

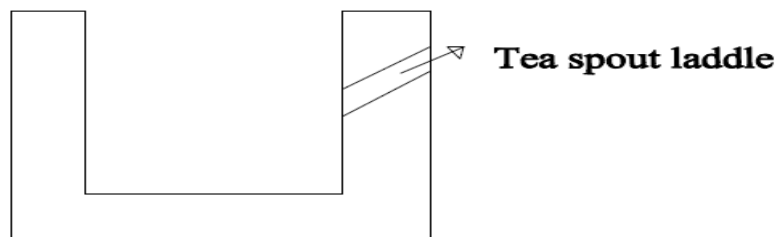
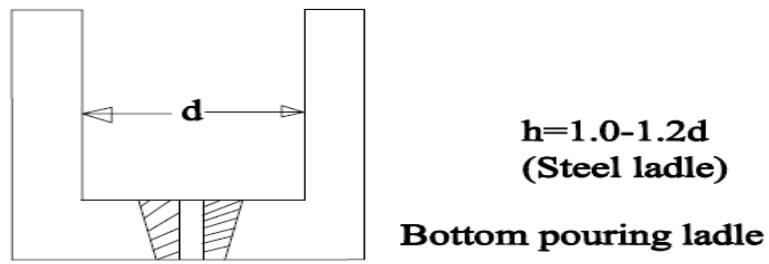
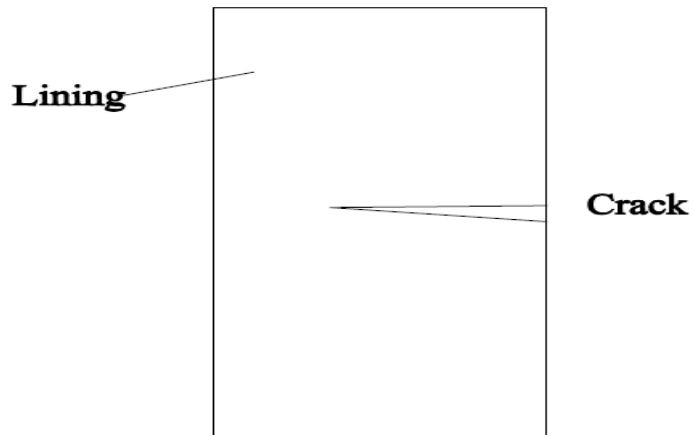


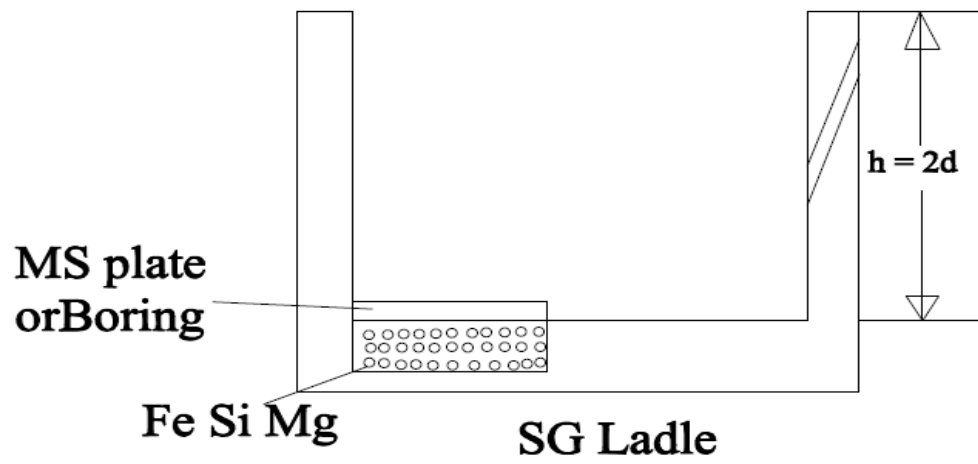
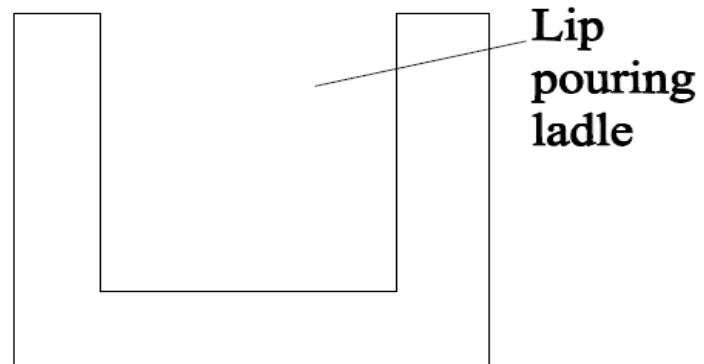
INDUCTION FURNACE

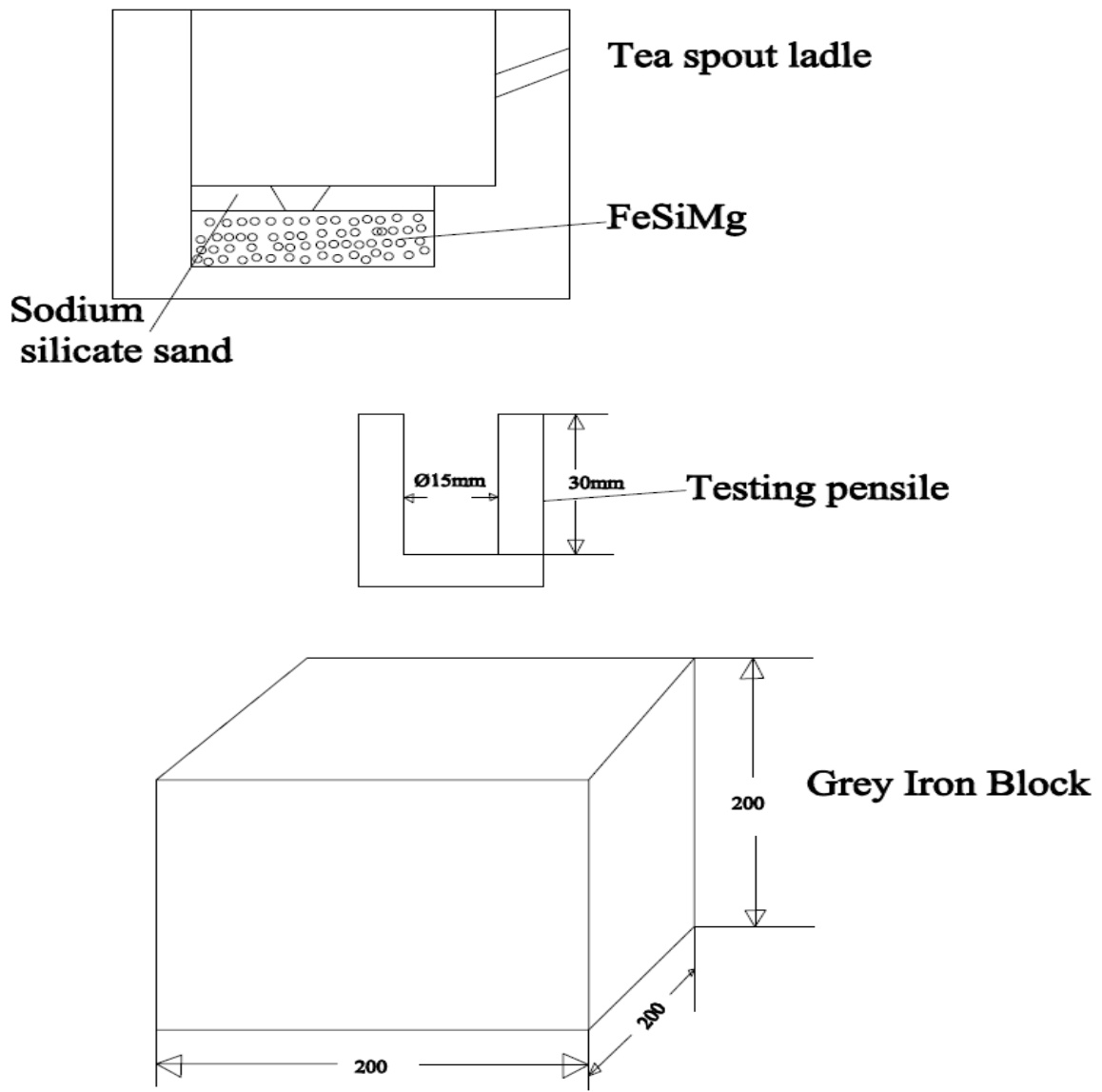
Ramming tools

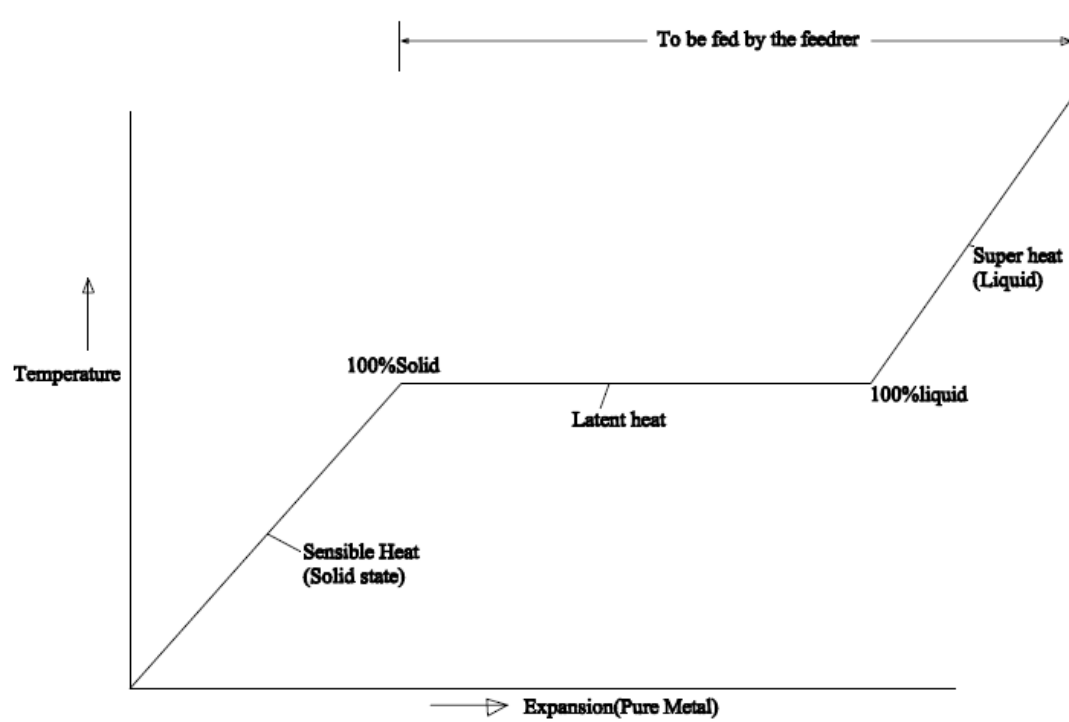


Fork hardens – portion 1, Wedge hardens – portion 2, Flat hardens – portion 3.

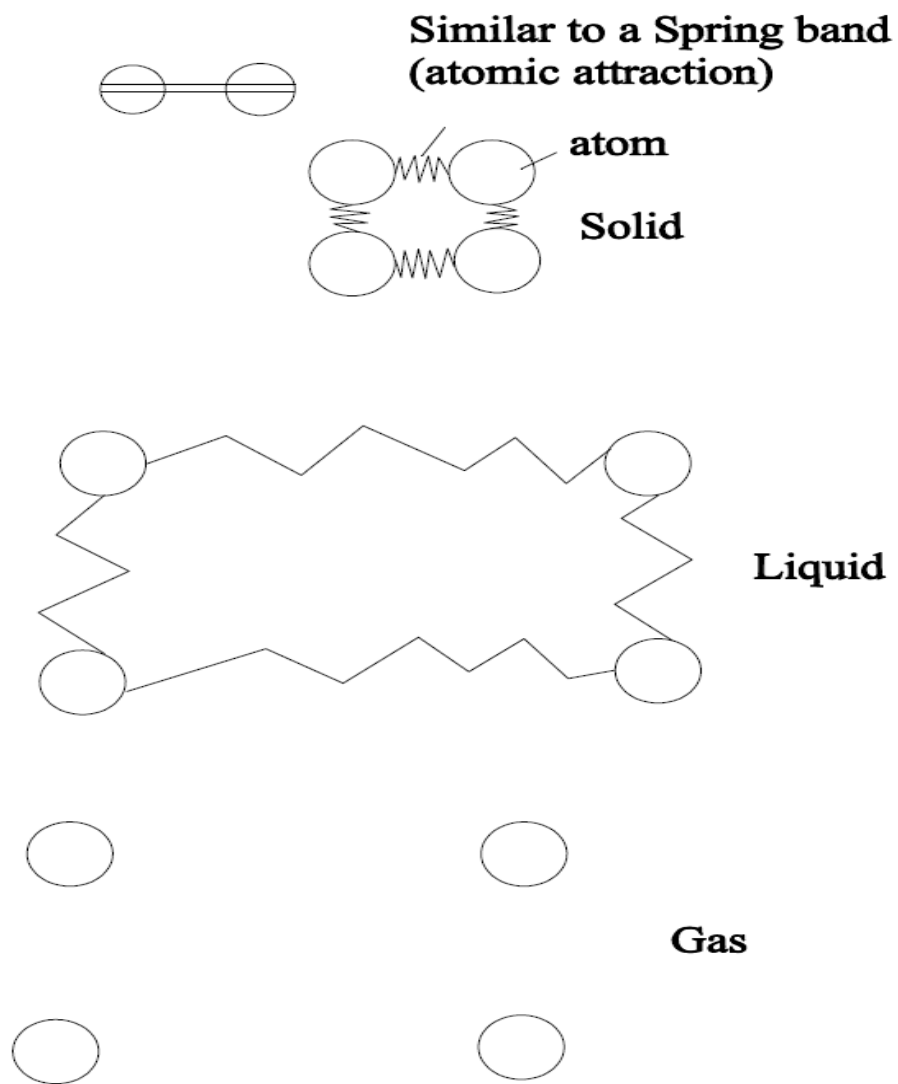




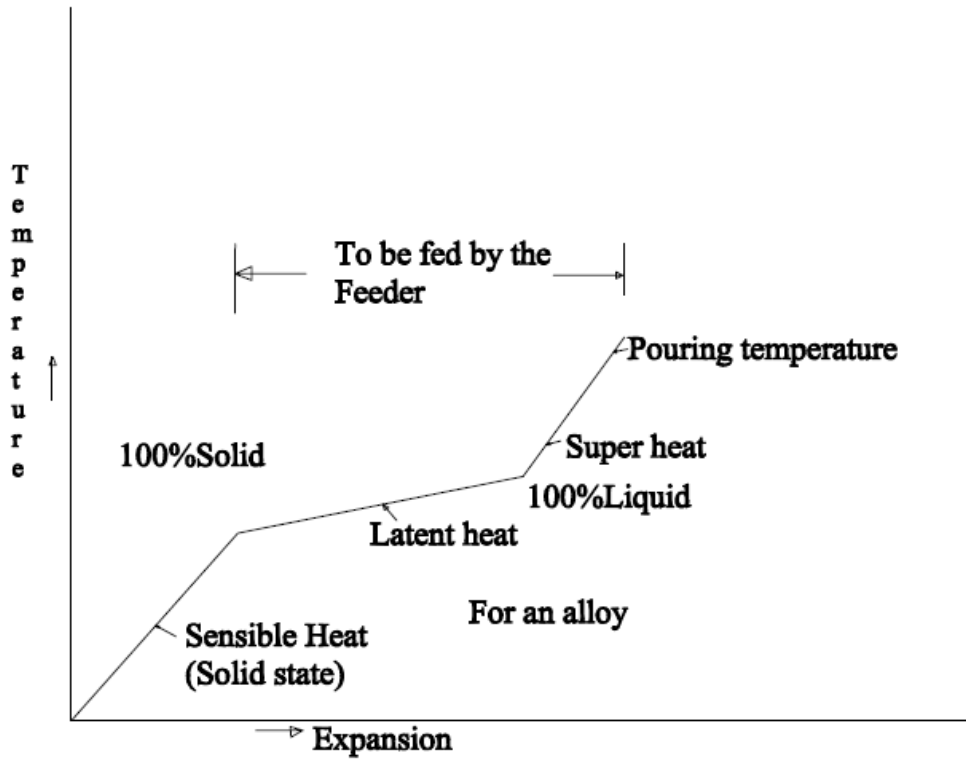




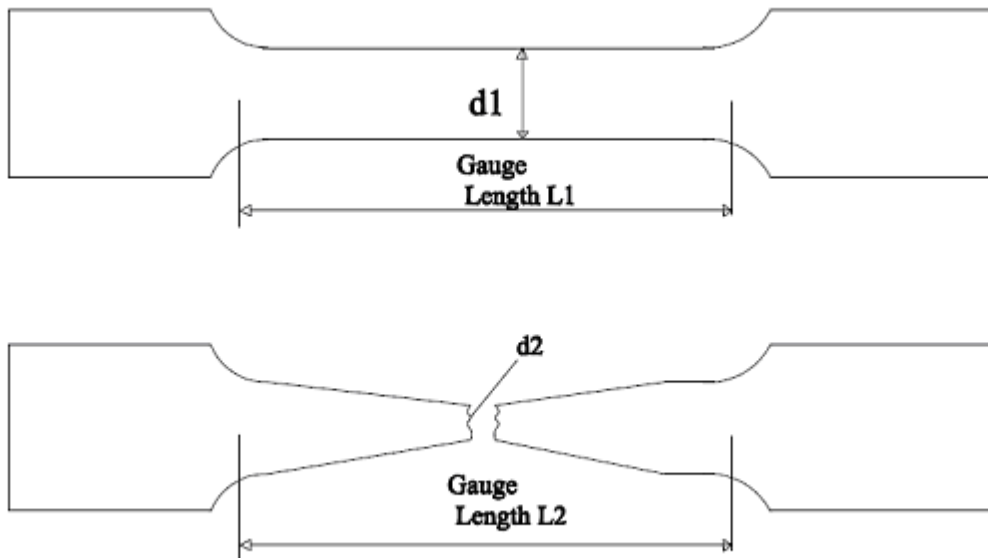
A feeder is required to feed the liquid-liquid shrinkage (super heat) and solidification shrinkage (Latent heat) on cooling.



Because of Latent heats Atomic bonding becomes Weaker & it results in Conversion of Solid To Liquid To Gas



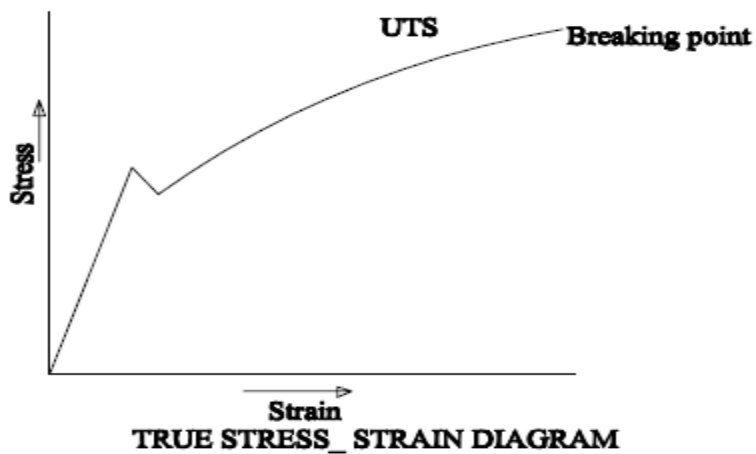
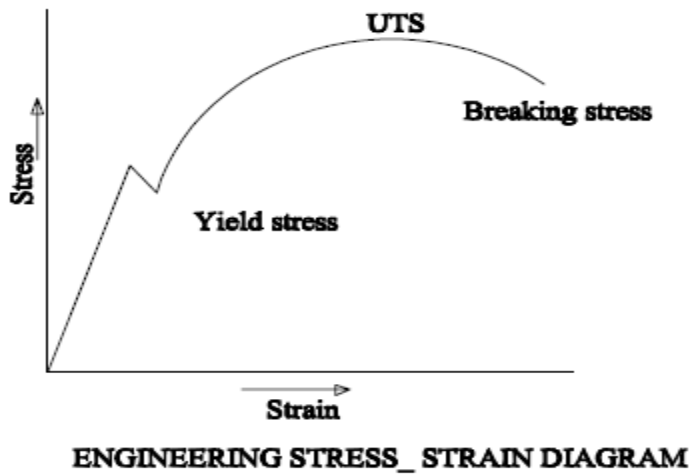
A feeder is required to feed the shrinkages that occur during cooling , i.e. while losing superheat and latent heat.

TESTING

$$\%E = [(L2 - L1) / L1] \times 100$$

$$\%RA = [(A1 - A2) / A1] \times 100$$

The Tensile Test Bars, have different gauge lengths depending on STANDARDS. Higher the % E & % RA tougher is the alloy. That is the alloy is not going to fail suddenly. It gives a great deal Reliability for the alloy while Designing a Casting.

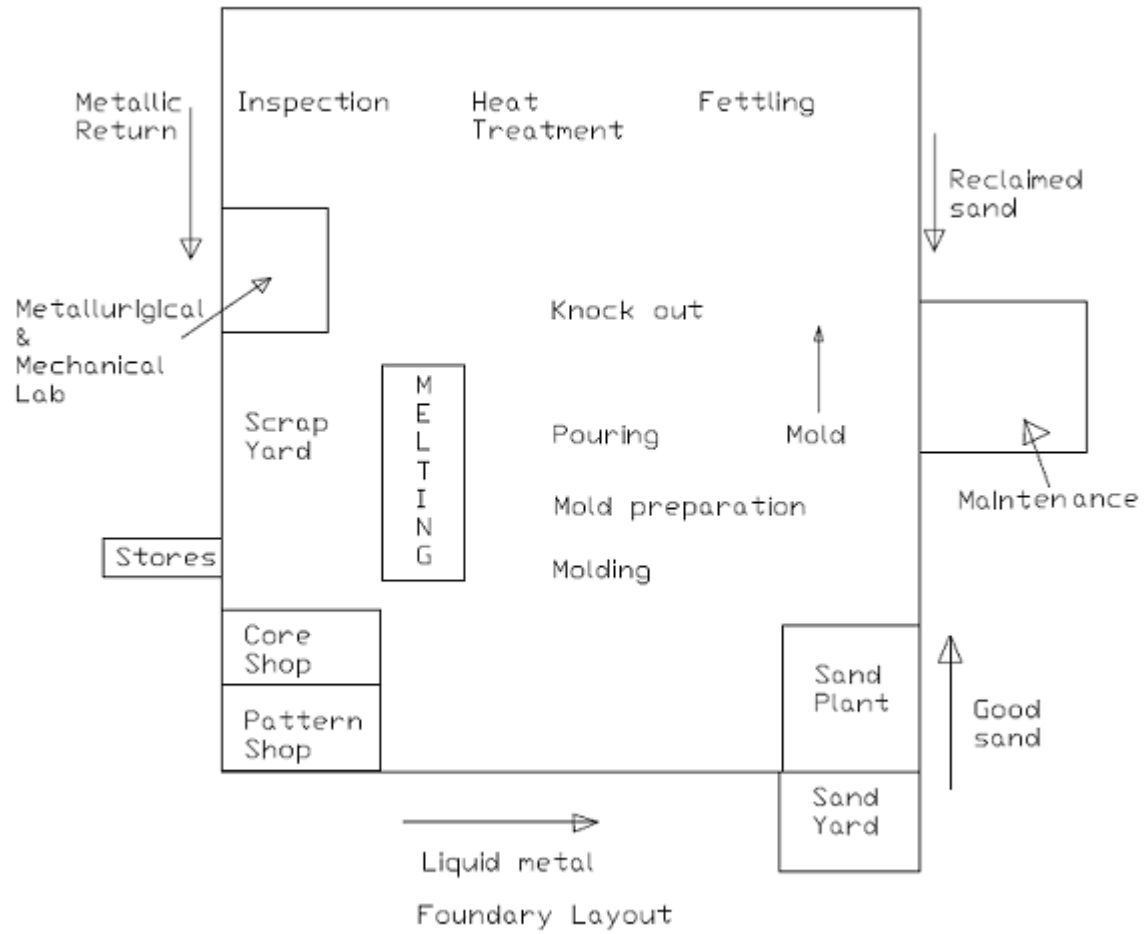


Engineering Stress—Strain Diagram is used by DESIGNERS.

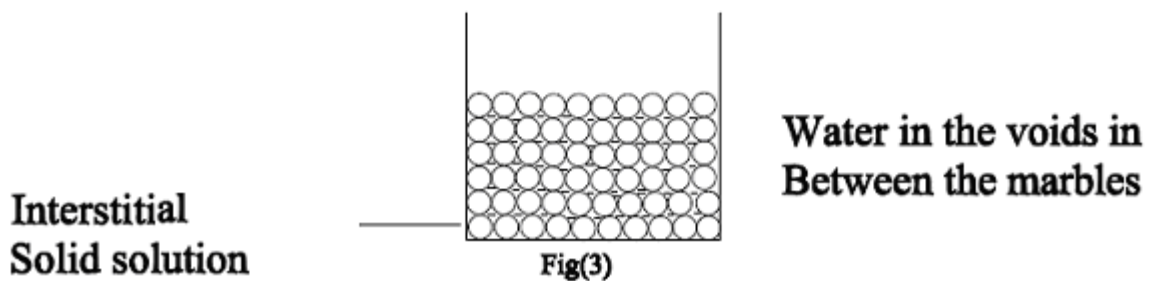
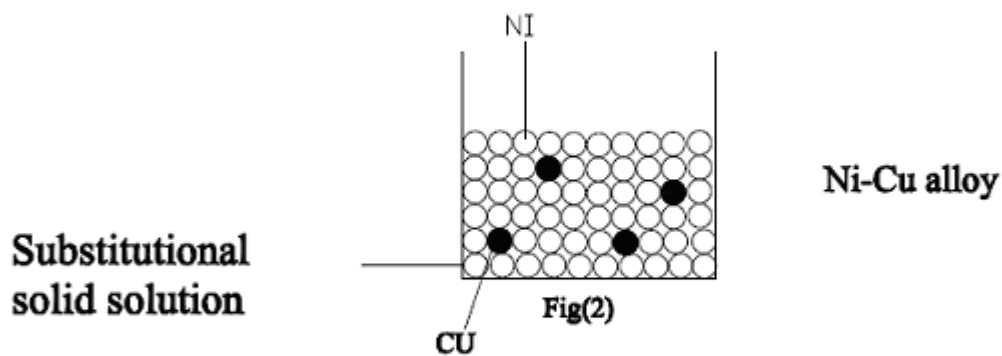
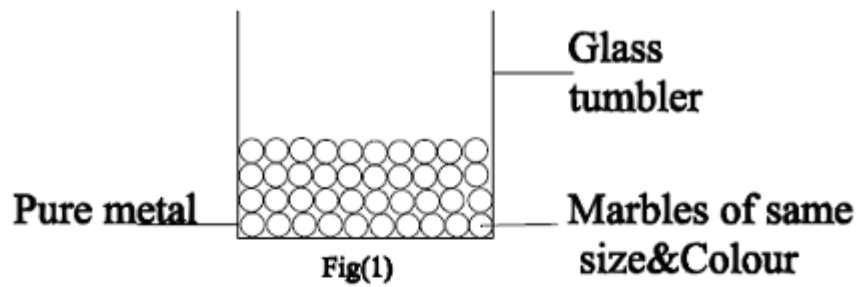
True Stress—Strain Diagram is used by METAL WORKING
People like FORGERS , ROLLERS etc.

In Engineering Diagram ,only Original Cross Sectional Area is taken into account for calculating Stress at any LOAD. But in TRUE diagram , actual Cross Sectional Area at each & every load is taken into Consideration.

FOUNDRY LAYOUT



METALLURGY

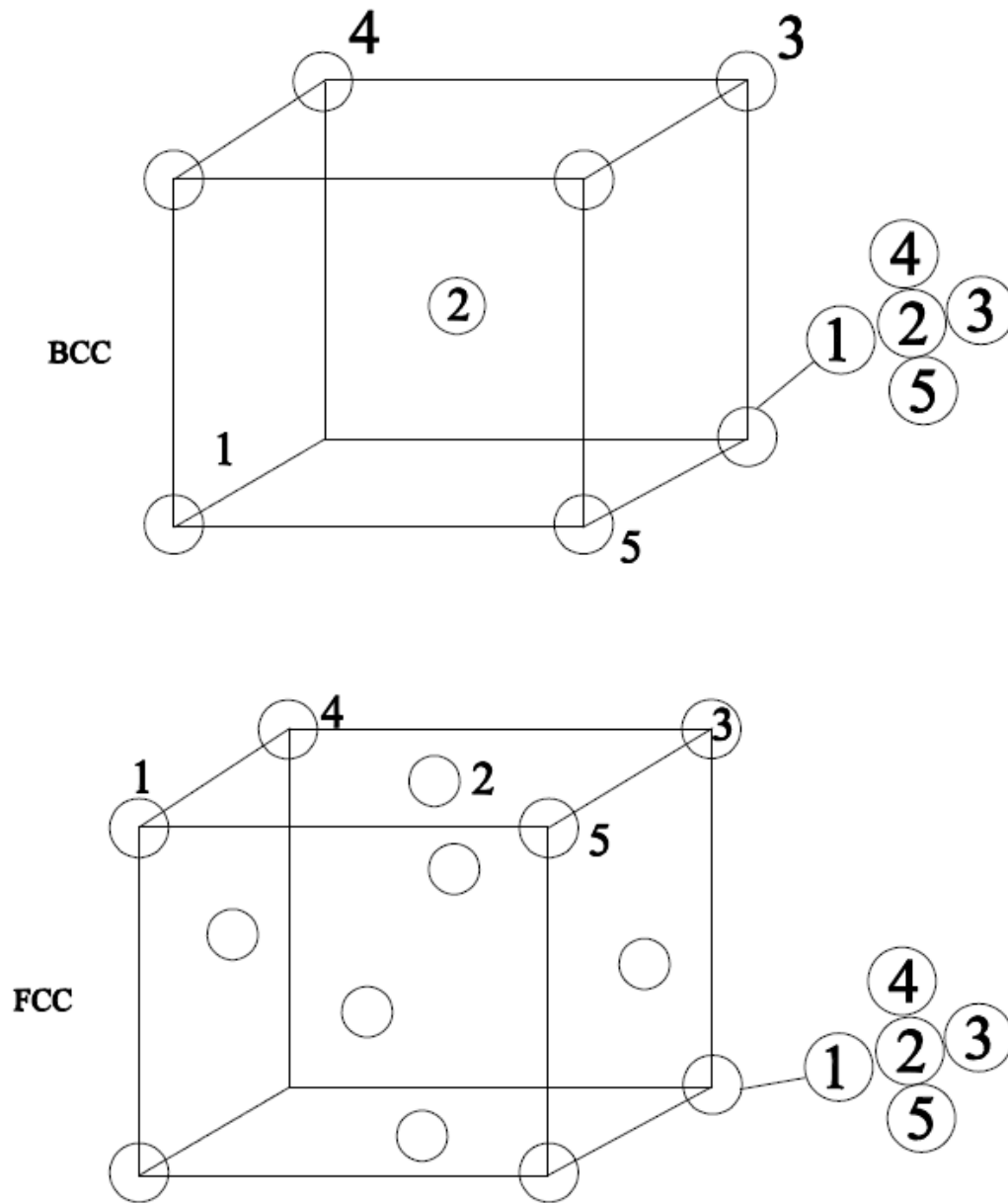


Marbles of same size & same colour indicate that they all belong to the Same ELEMENT. This can be called as PURE METAL.

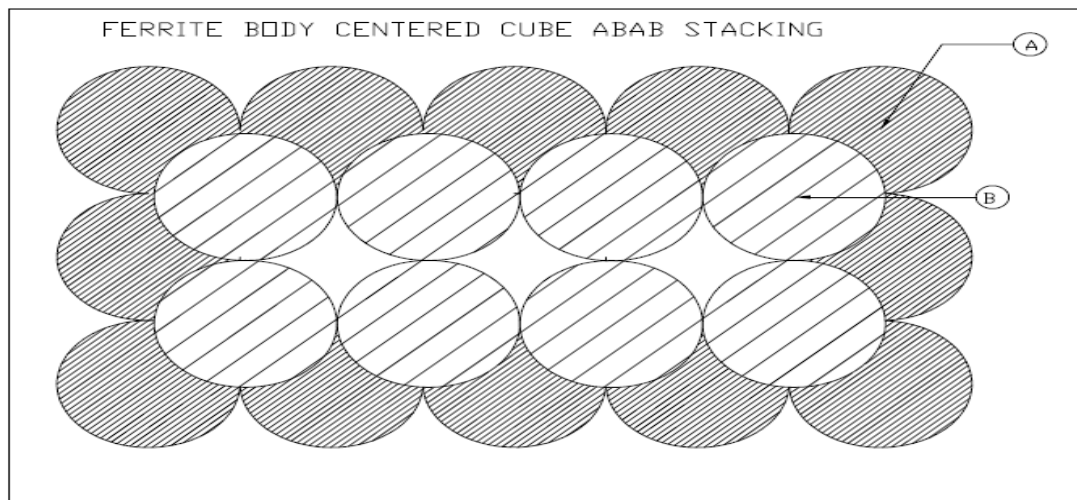
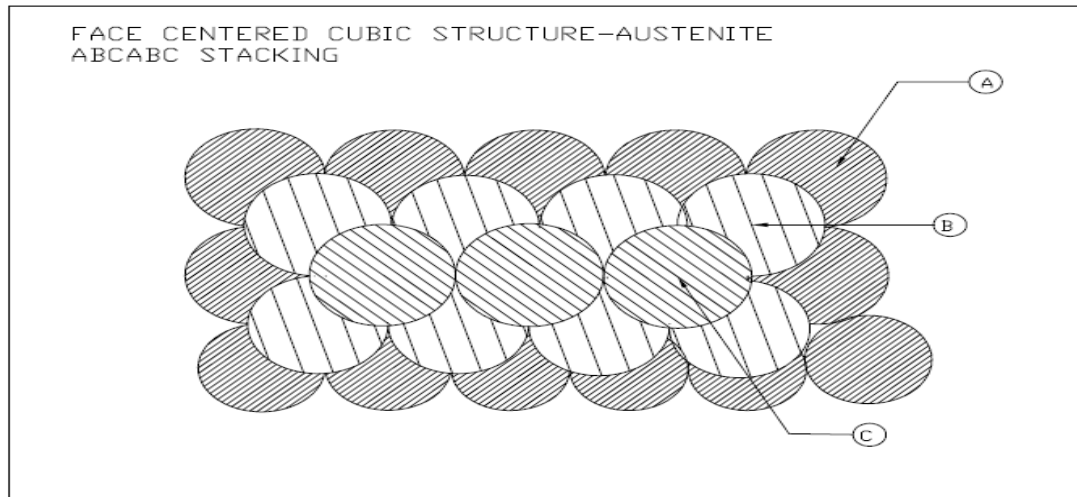
When a marble of different colour & of same size or different size is put, Like above, it is called an ALLOY. When a new marble displaces a original Marble & takes it's place, it is called SUBSTITUTIONAL SOLID SOLUTION. Instead, a new element occupies a place in the VOID like WATER it is Called INTERSTITIAL SOLID SOLUTION.

Ni-Cu is a Substitutional solid solution.

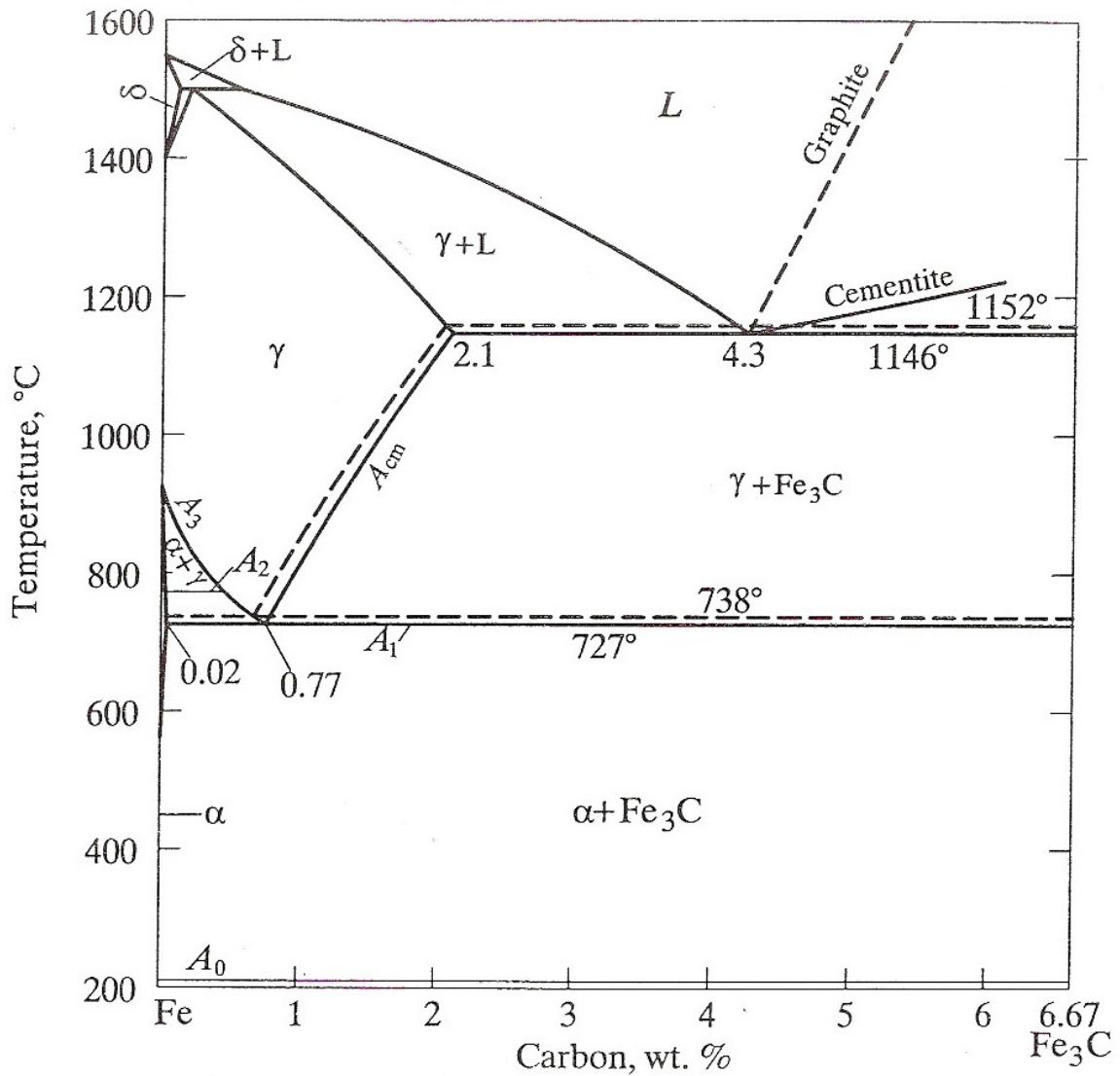
Fe-C is an Interstitial solid solution.



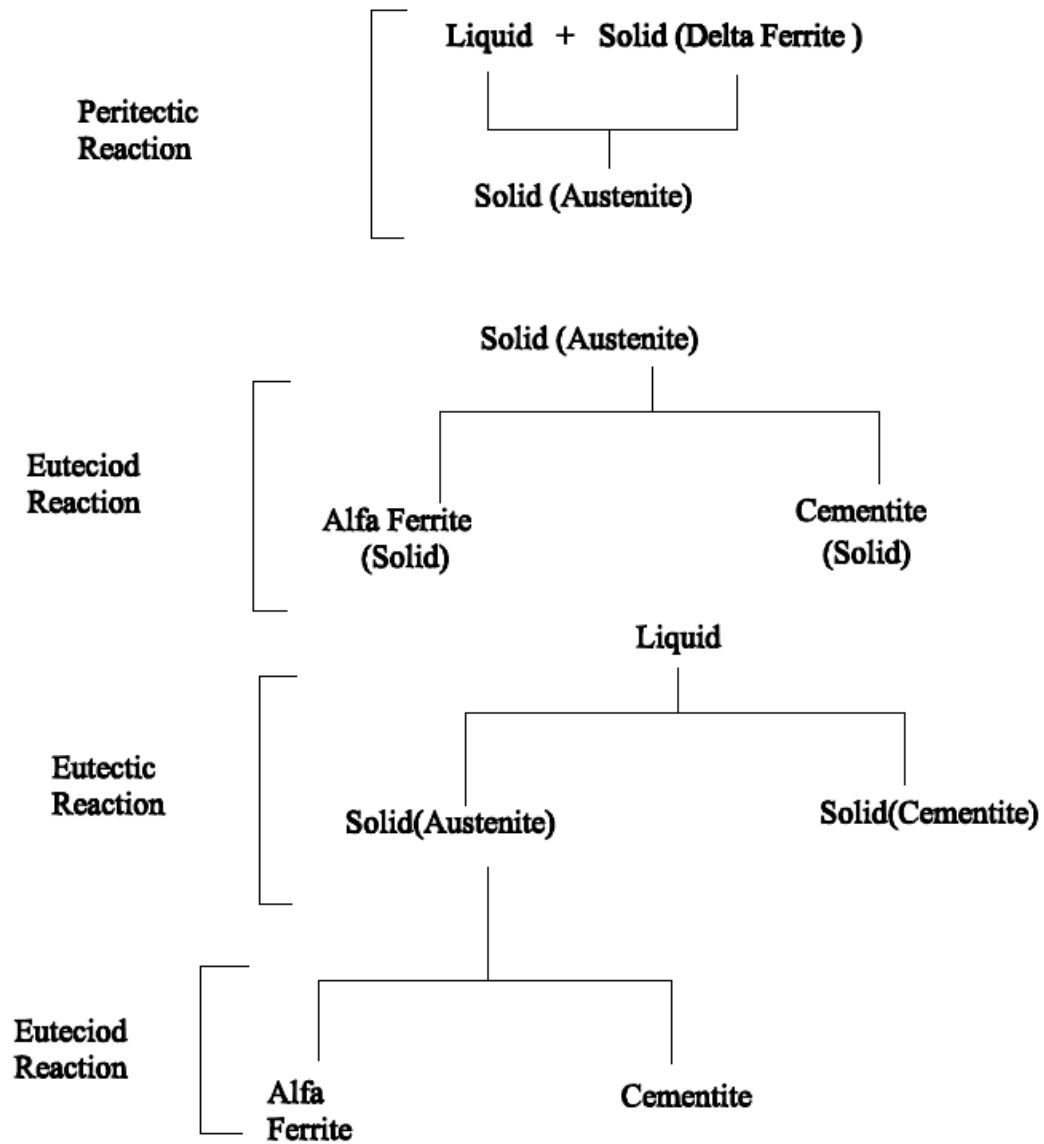
For the sake of understanding , atoms are shown like the above.



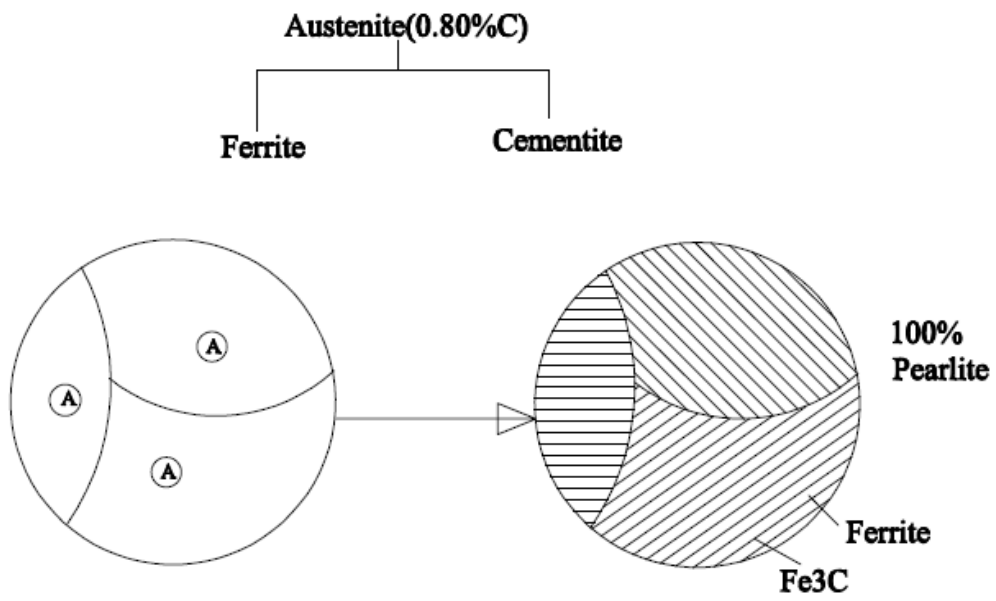
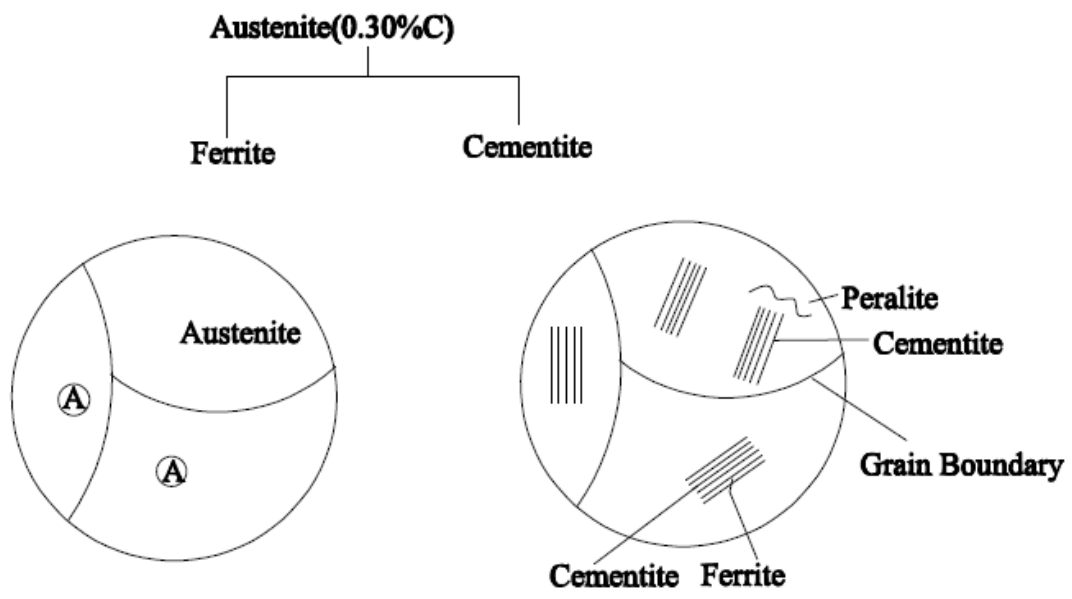
Atomic Stacking arrangement of FCC and BCC

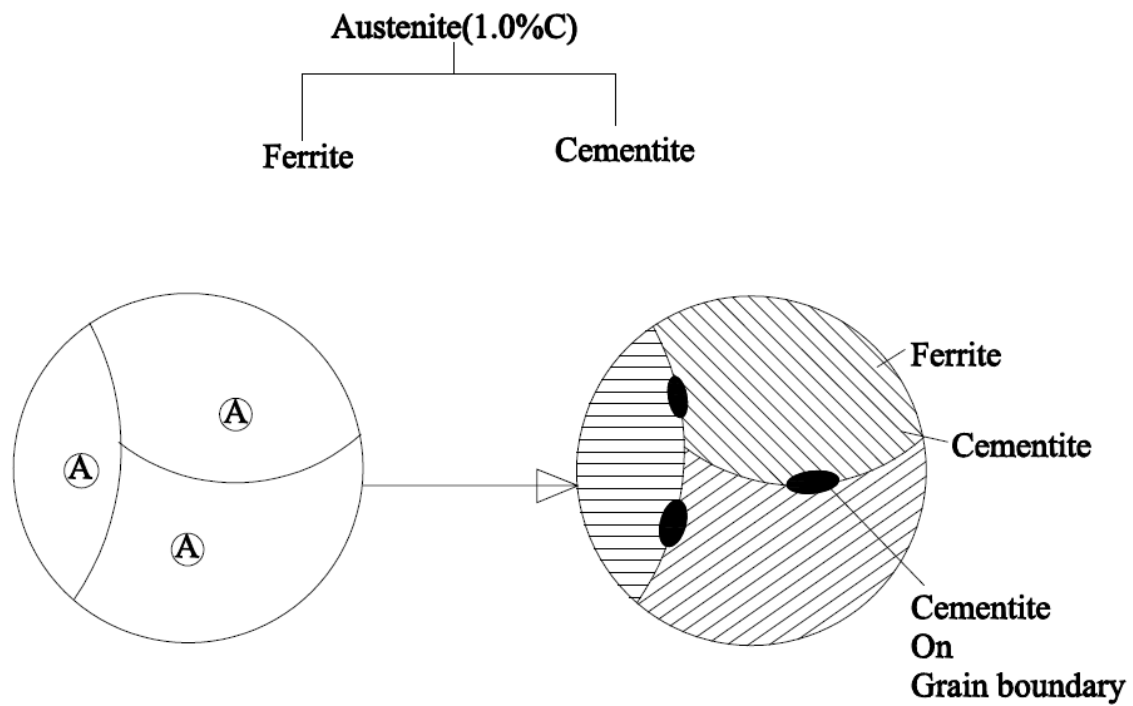


Iron – Carbon Equilibrium Diagram

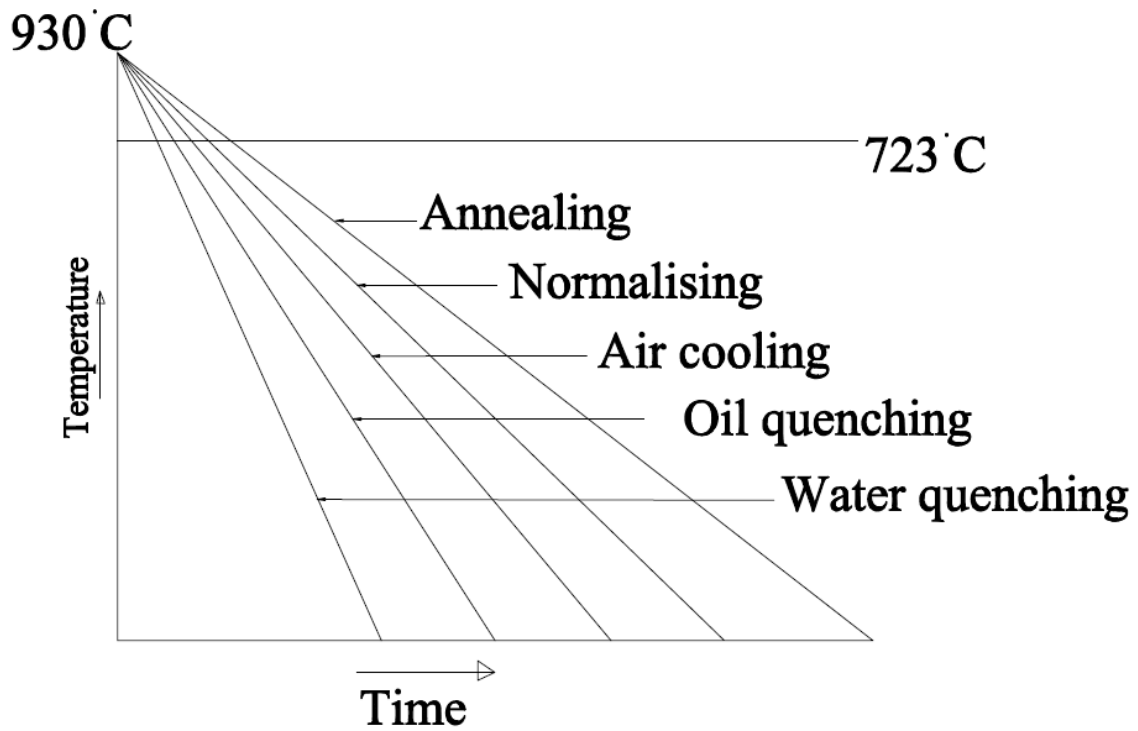


Here you find two Eutectoid Reactions mentioned. The Top one is for Steel. The bottom one is for Cast Iron.

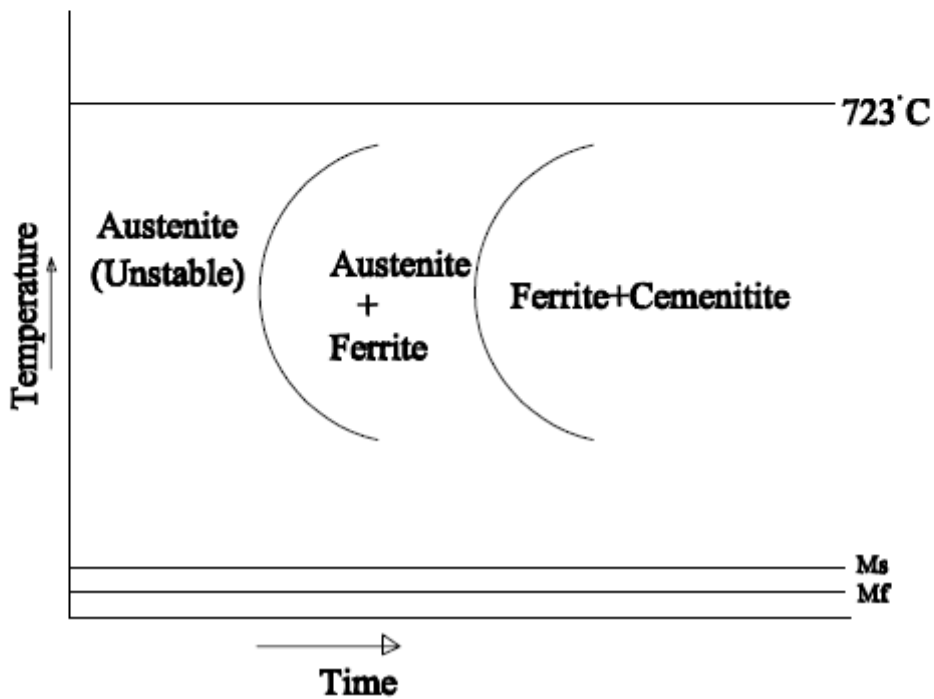
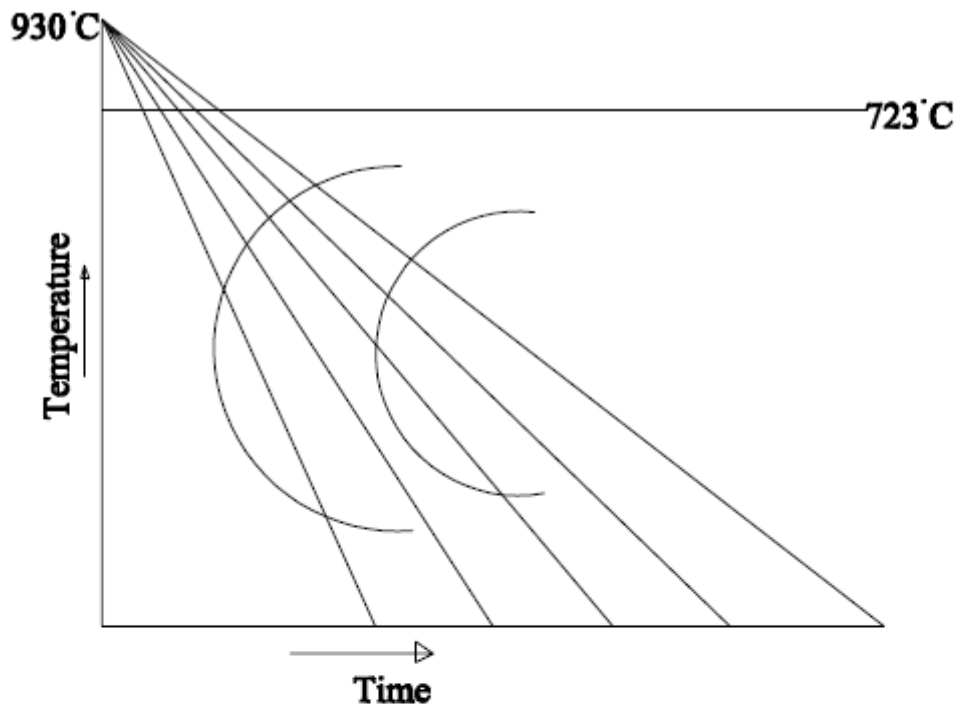




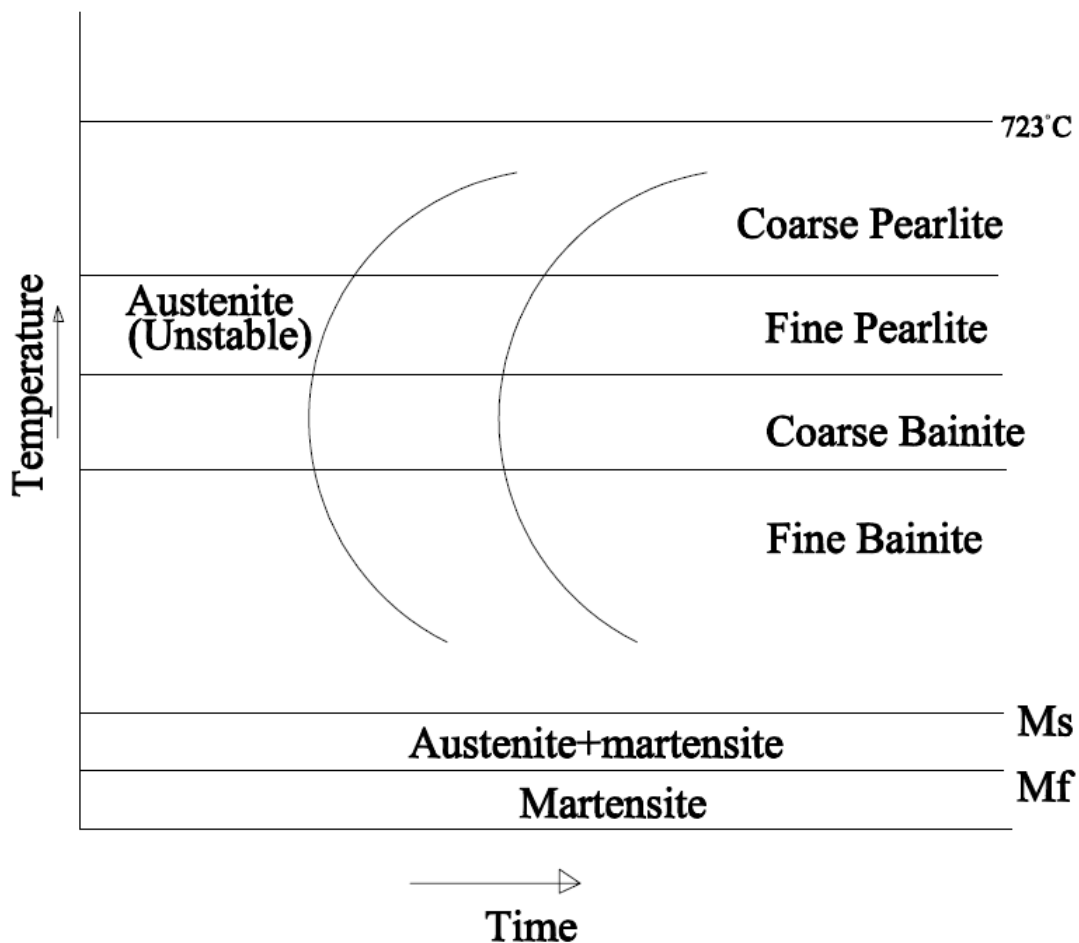
Carbides, being Brittle , make the Steel BRITTLE. Hence Grain boundary Carbides are NOT PREFERRED AT ALL.



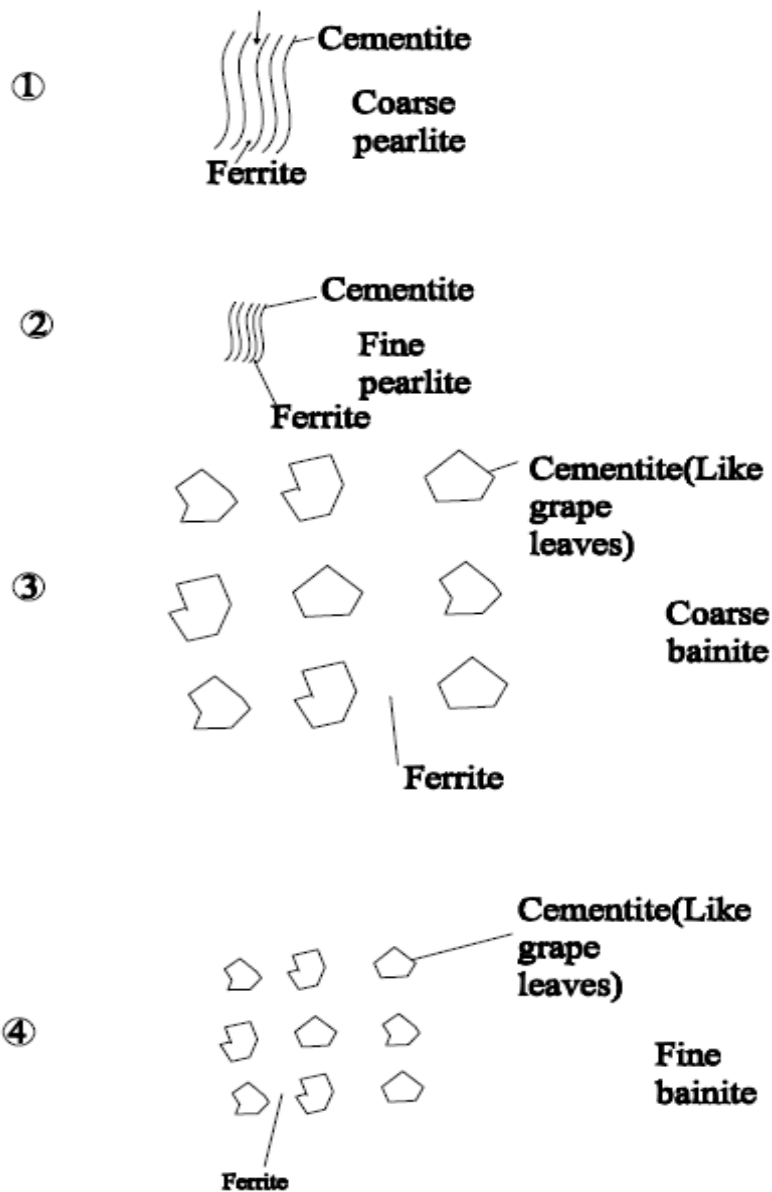
For a given Furnace Size & Casting Size, the COOLING RATE is CONSTANT. Various cooling cycles are adopted to get SUPERIOR & DESIRABLE PROPERTIES.



When C Curve is SUPER IMPOSED ON “ COOLING RATES” , it is called A TIME—TEMPERATURE TRANSFORMATION CURVE. This C curve is like AN IDENTITY CARD FOR EACH ALLOY. EACH ALLOY WILL HAVE ONE “ C “ CURVE OF IT’S OWN.

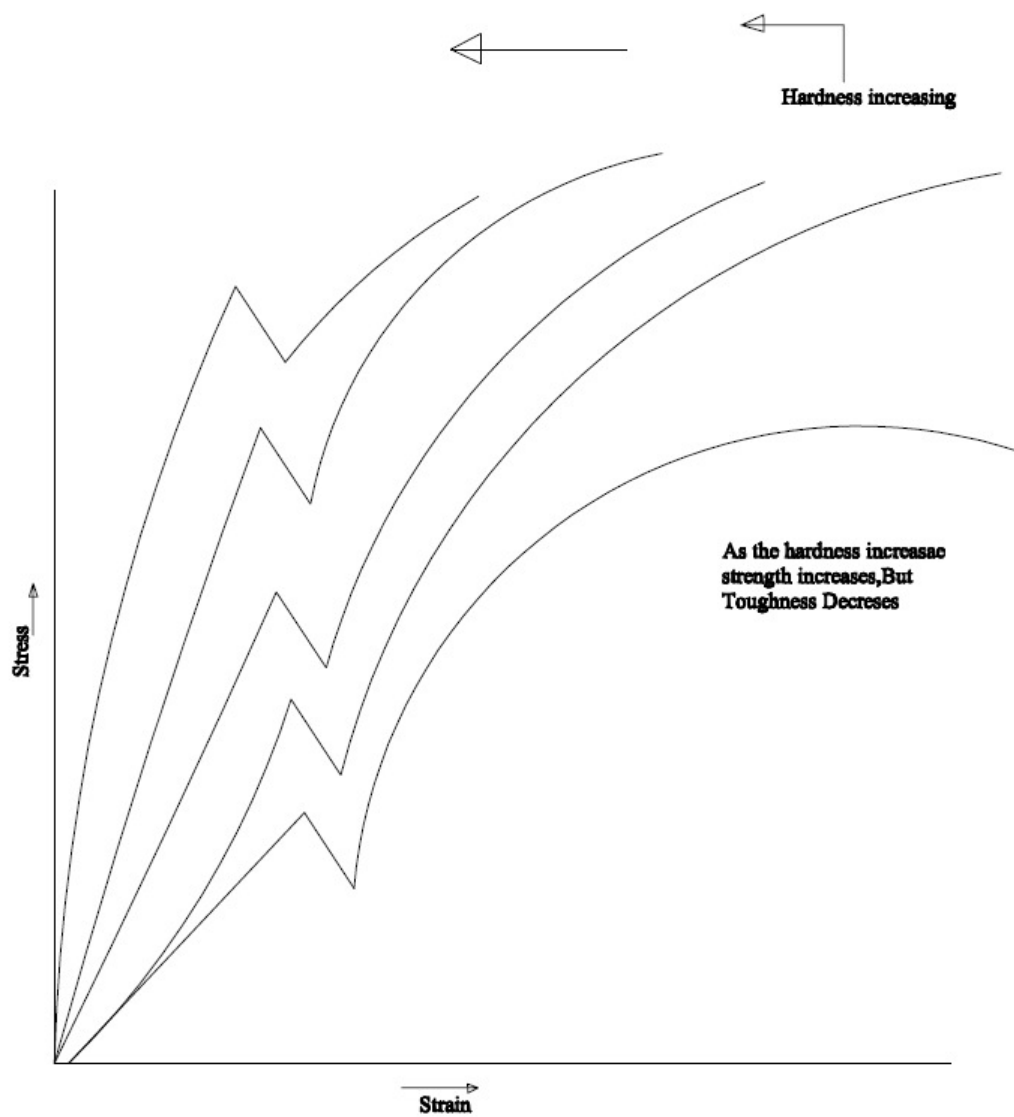


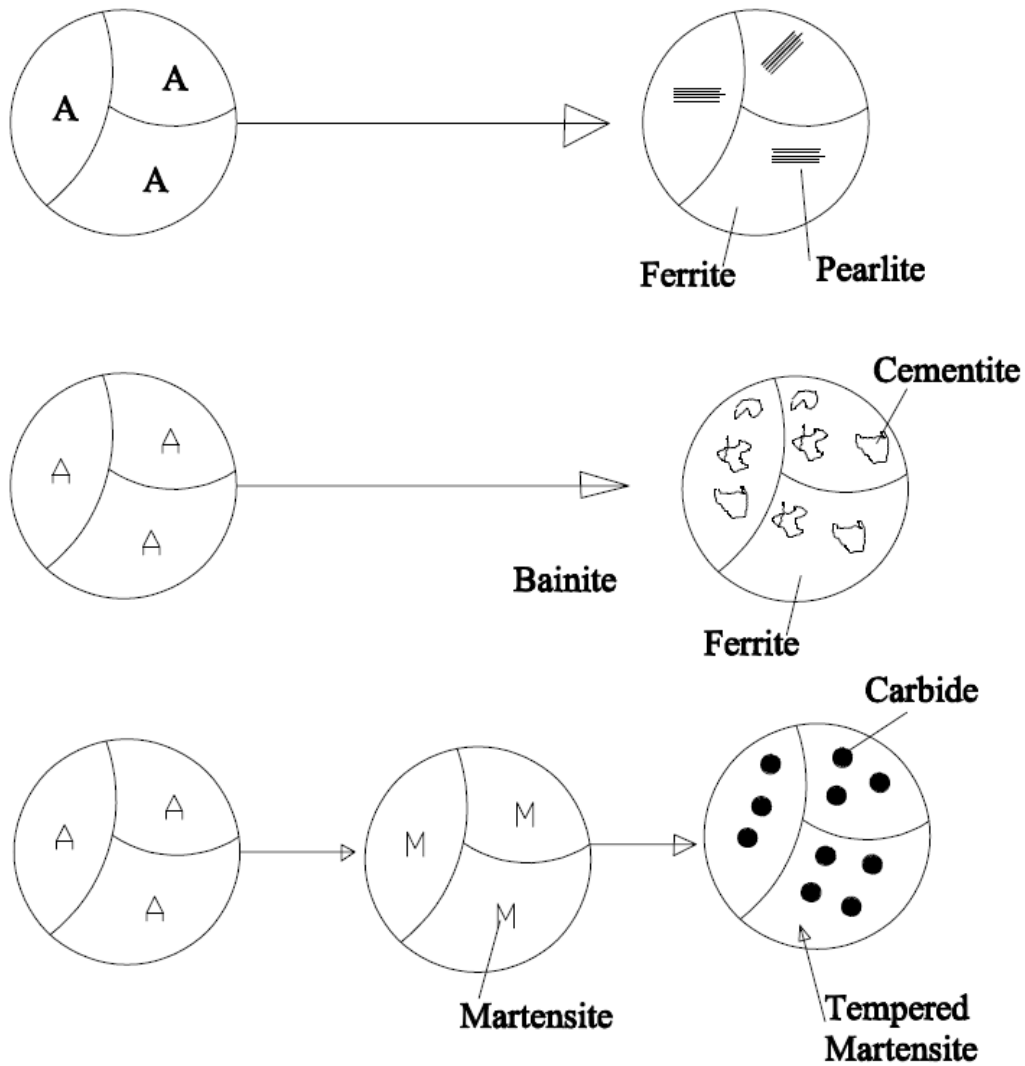
This is a Practical Diagram. With different cooling rates, we can get the PHASES of our CHOICE. Hence we can CONTROL & GET Mechanical Properties of our choice. Ms & Mf are CONSTANT FOR AN ALLOY. Martensite is a B.C.C. which is a SUPERSATURATED SOLID SOLUTION OF C IN Fe. This supersaturation results in distortion of B.C.C. to B.C.T. & concurrent Expansion. As a consequence of Expansion of Martensite, we will be left with certain amount of RETAINED AUSTENITE. This is not good for the Properties. So the retained austenite is converted to Martensite after Tempering. Supersaturation of B.C.C is manifested in the form of Higher Hardness.



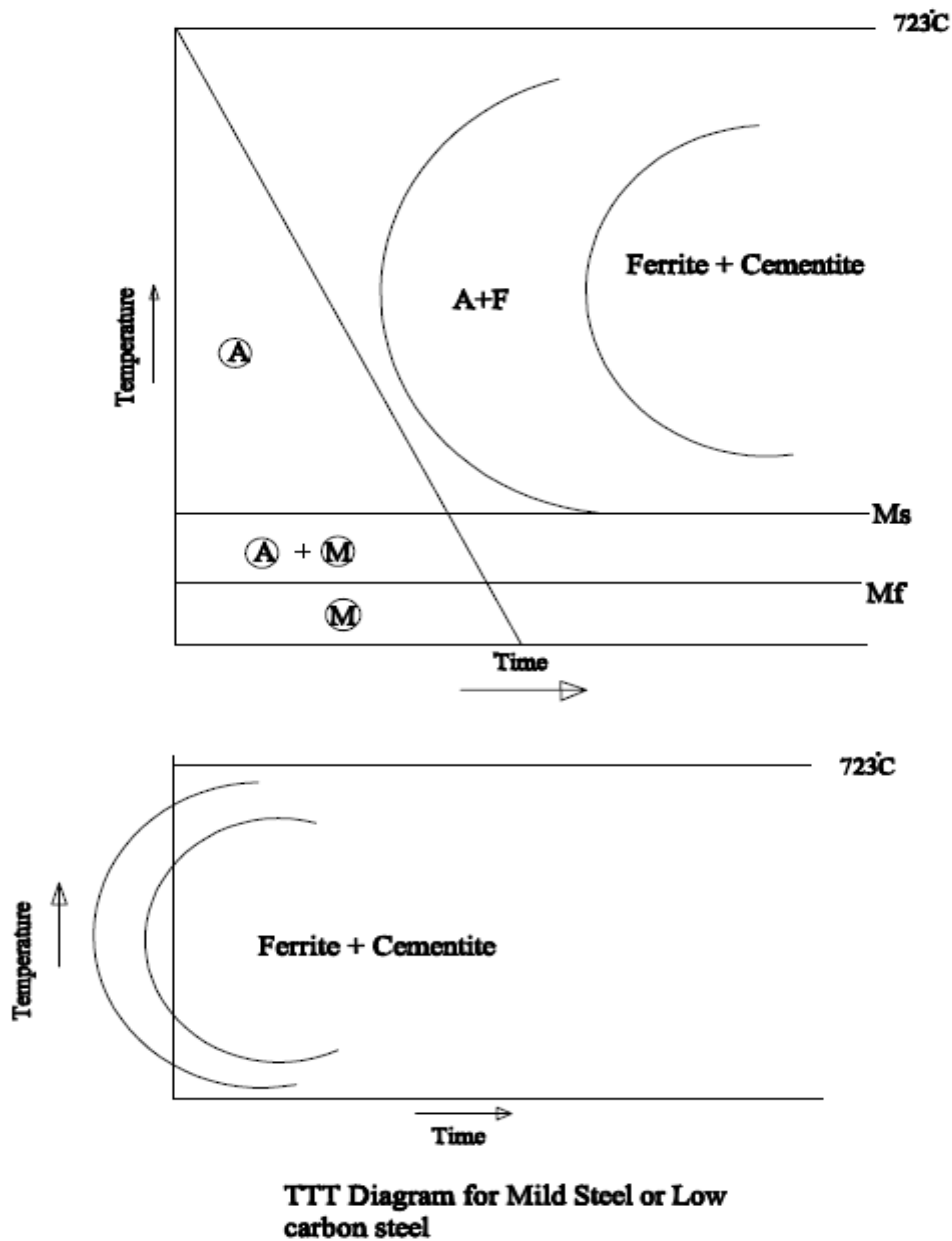
Size of 1>2>3>4

On cooling, as the cooling rate increases, C gets lesser time to get out , as a result, C, which is going to form CARBIDES , will hastily take the shapes which have larger surface area (carbides)& also becomes more in number.



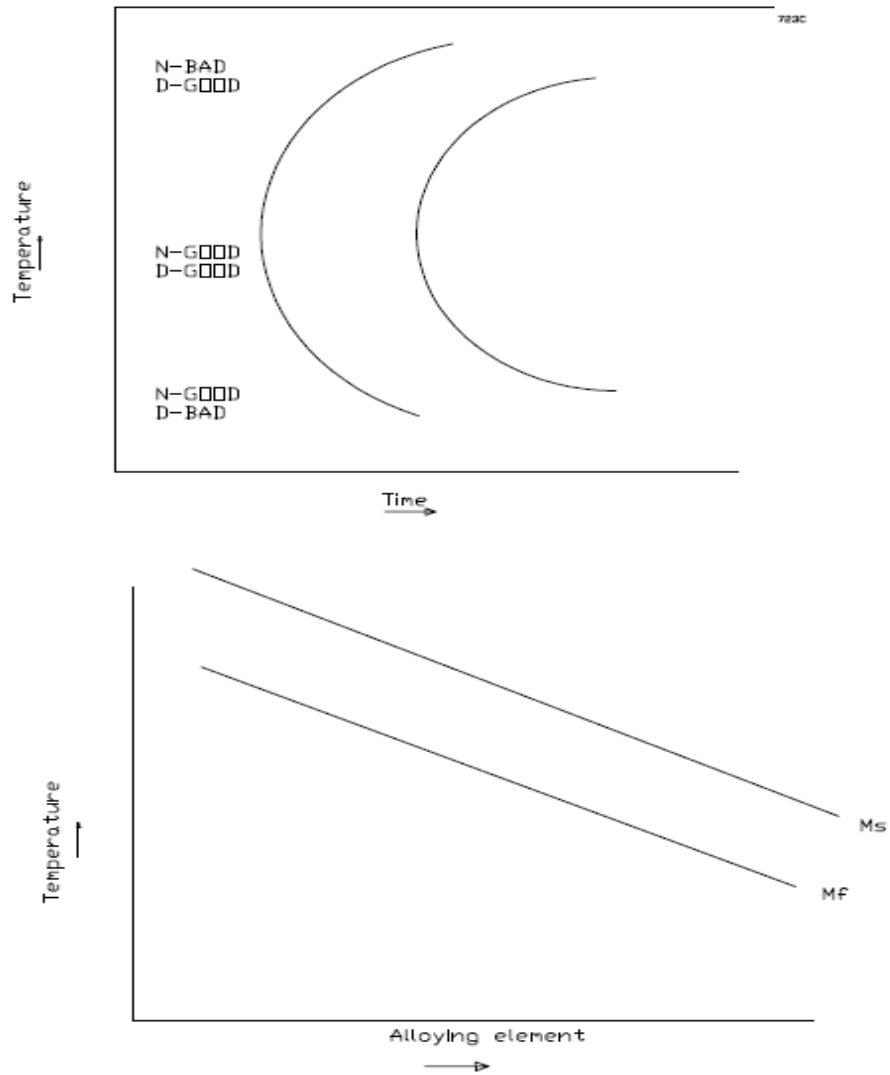


Because of Change of shape of CARBIDES , Stress Concentration is reduced. Tempered Martensite, still a B.C.T. but to a lesser degree. We get a combination of Higher Strength, higher % E, higher % RA & higher Impact Strength.

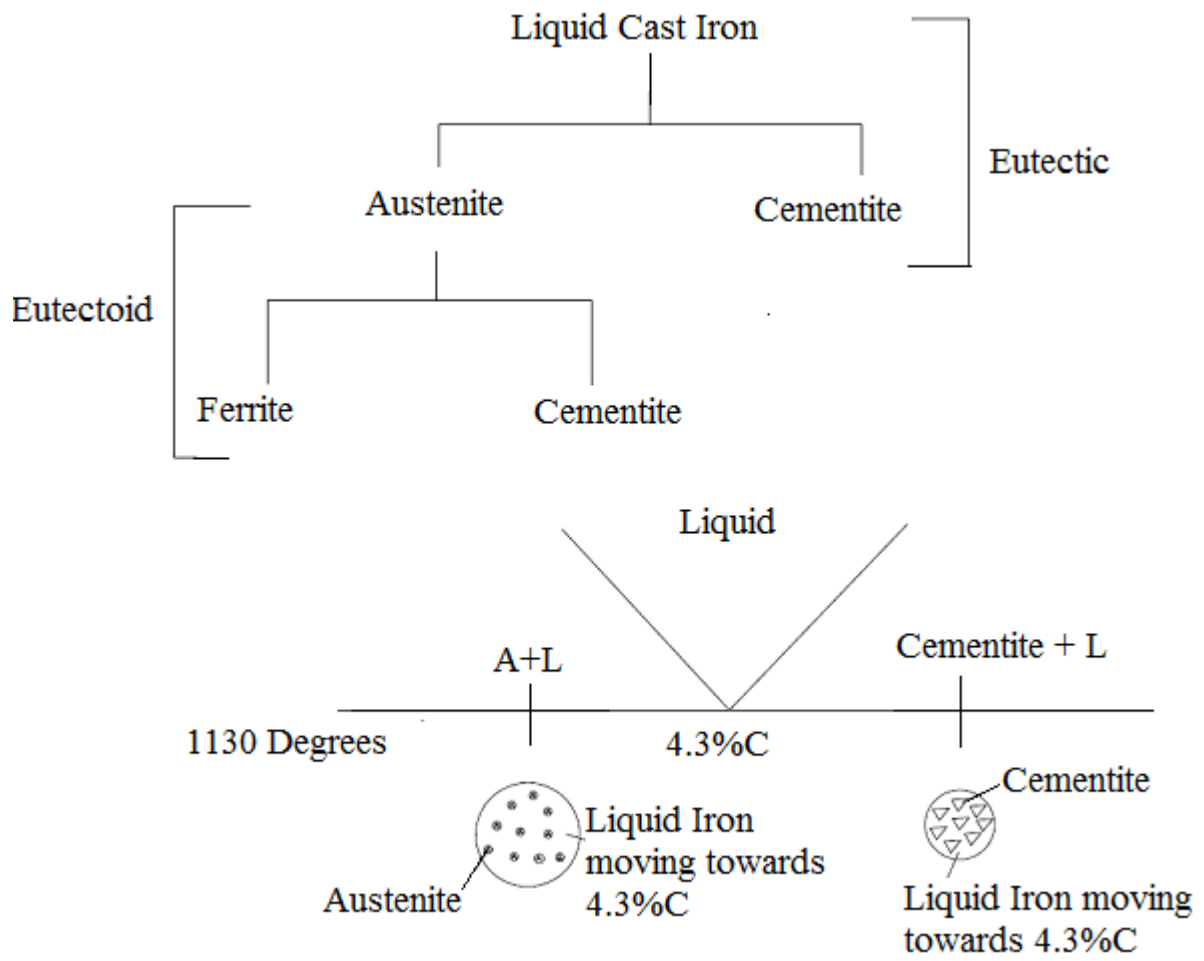


When cooling rate is so fast, the C curve is not intersected, this results in Formation of Martensite.

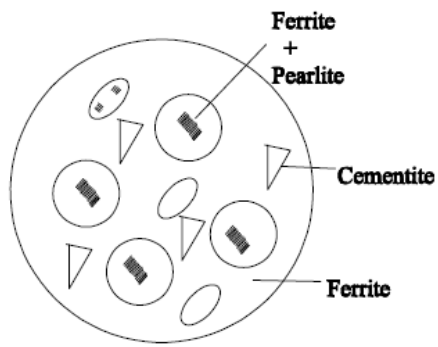
In case of Mild Steel Or low C steels, C curve intersects Y-axis & hence Martensite can not form. Barring Al & Co , all other alloying elements push C curve away from Y-axis. Thus facilitating easier formation of Martensite.



N stands for Nucleation & D stands for Diffusion
 Nucleation is Birth of a New Phase. Diffusion is the atomic movement which helps in Growth of the New Phase.

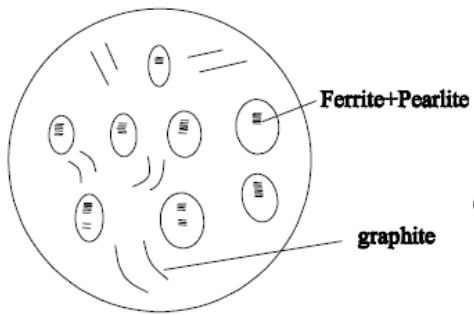
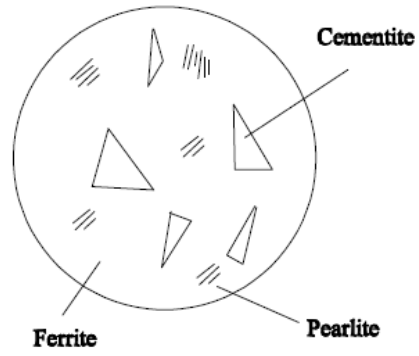


The Transformations that take place in Cast Irons.

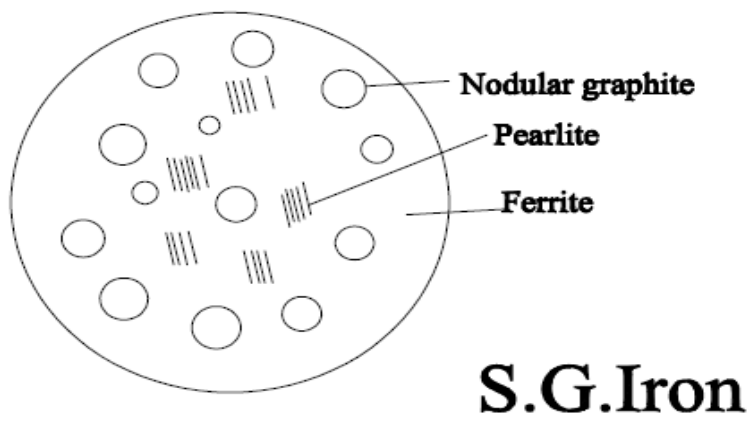
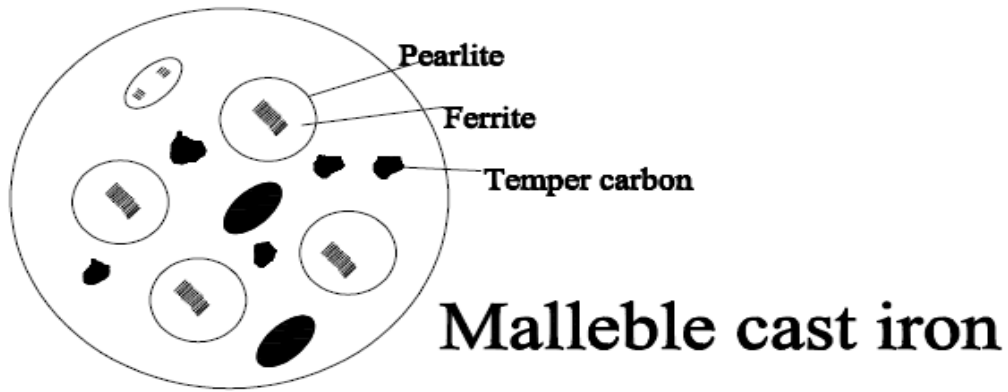


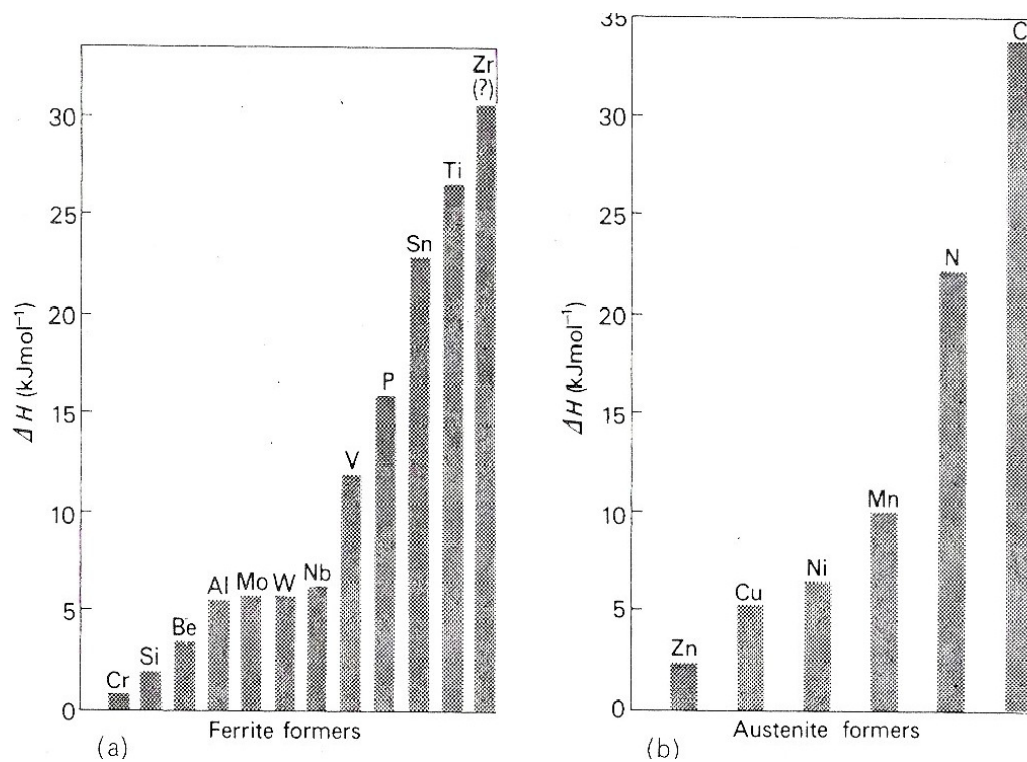
(WHITE IRON)

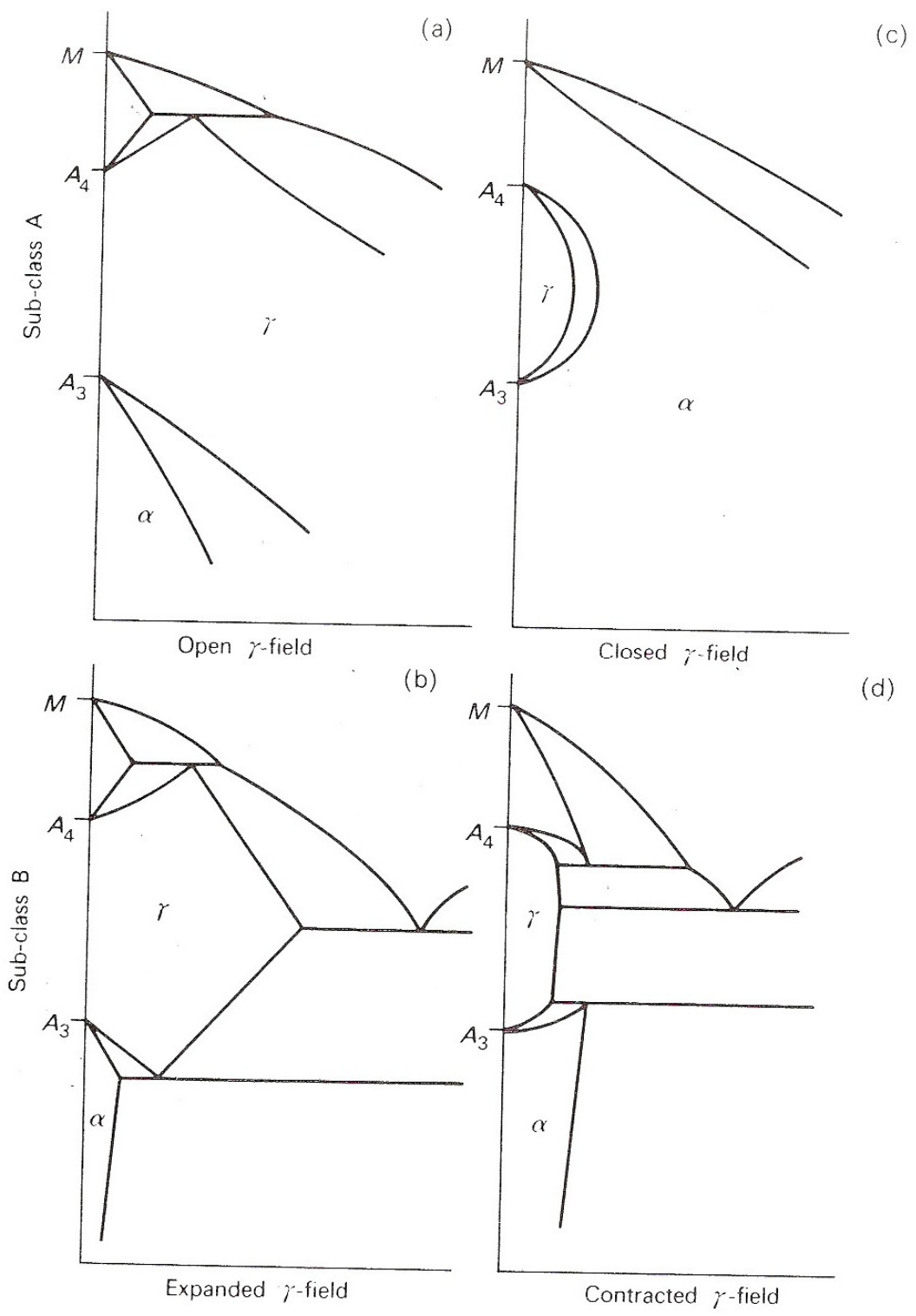
HYPER EUTECTIC IRON

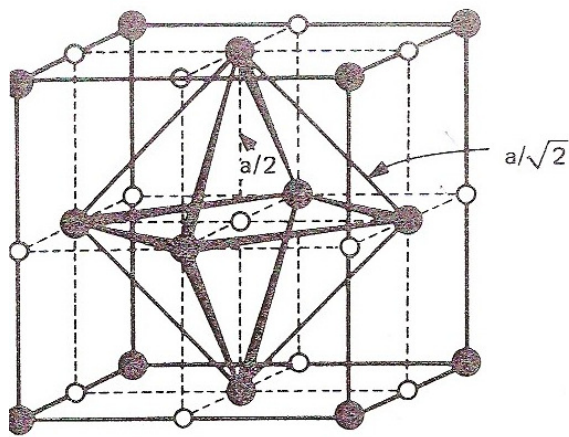


GREY IRON-HYPOEUTECTIC IRON

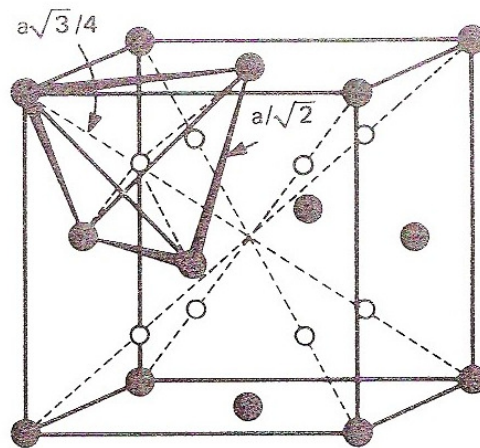






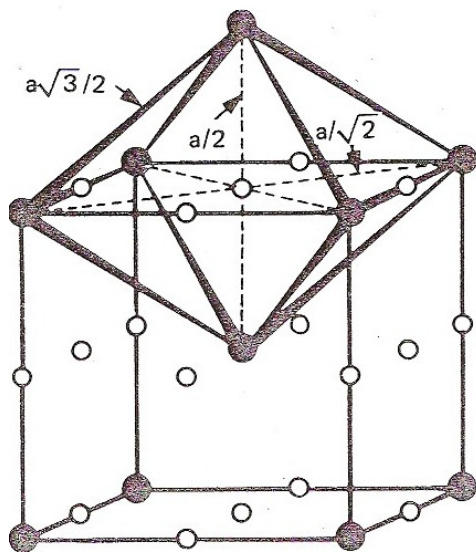


● METAL ATOMS
○ OCTAHEDRAL INTERSTICES

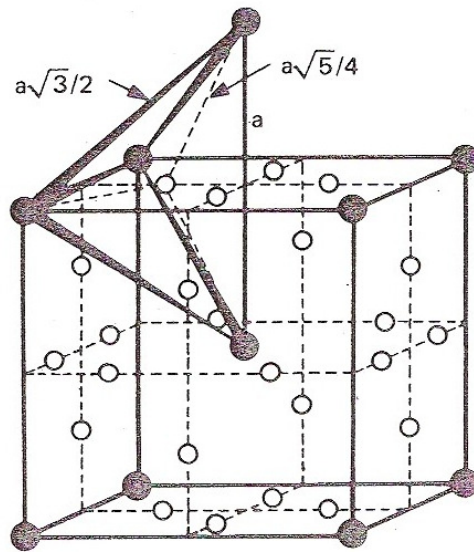


● METAL ATOMS,
○ TETRAHEDRAL INTERSTICES

(a)

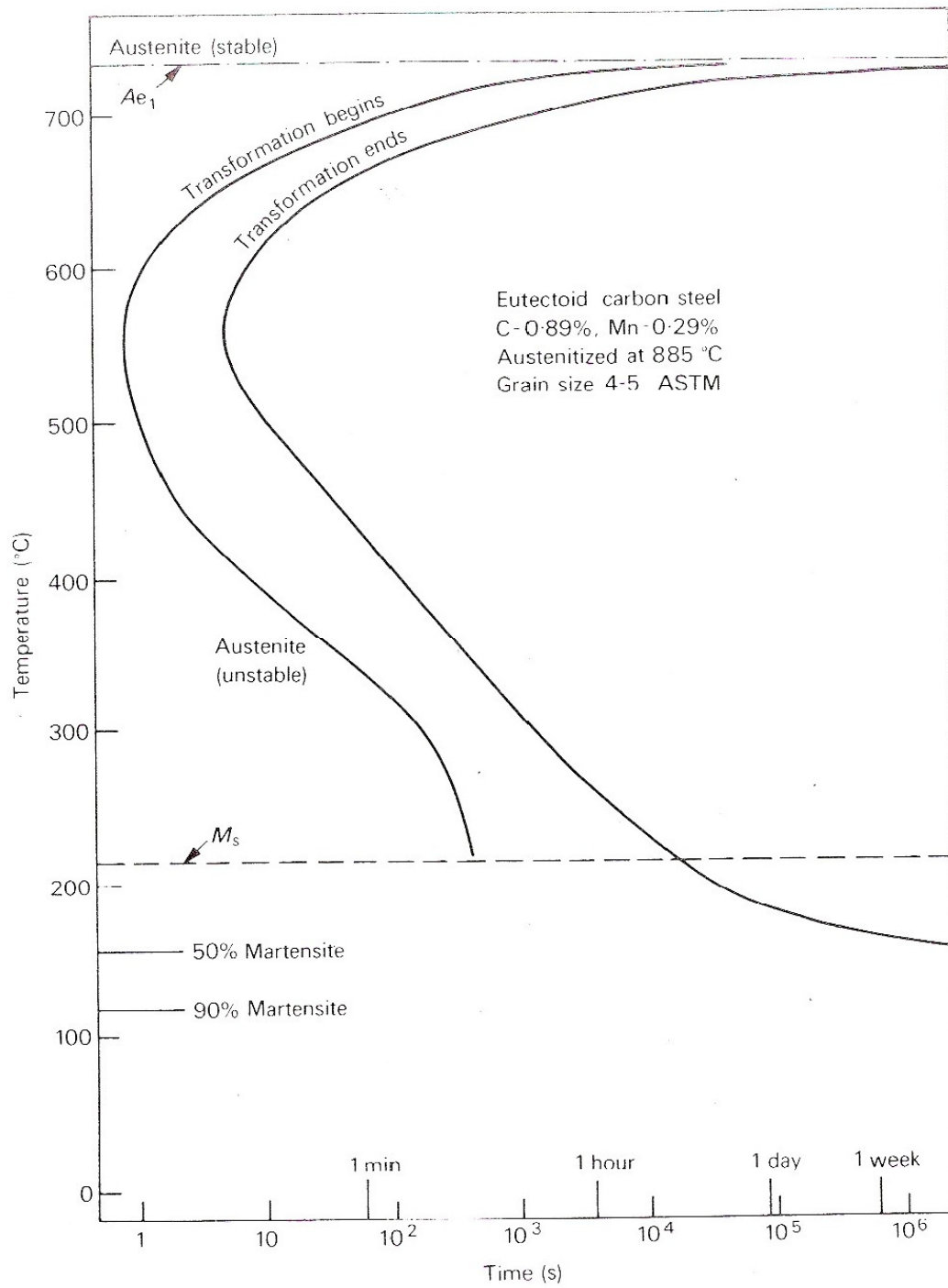


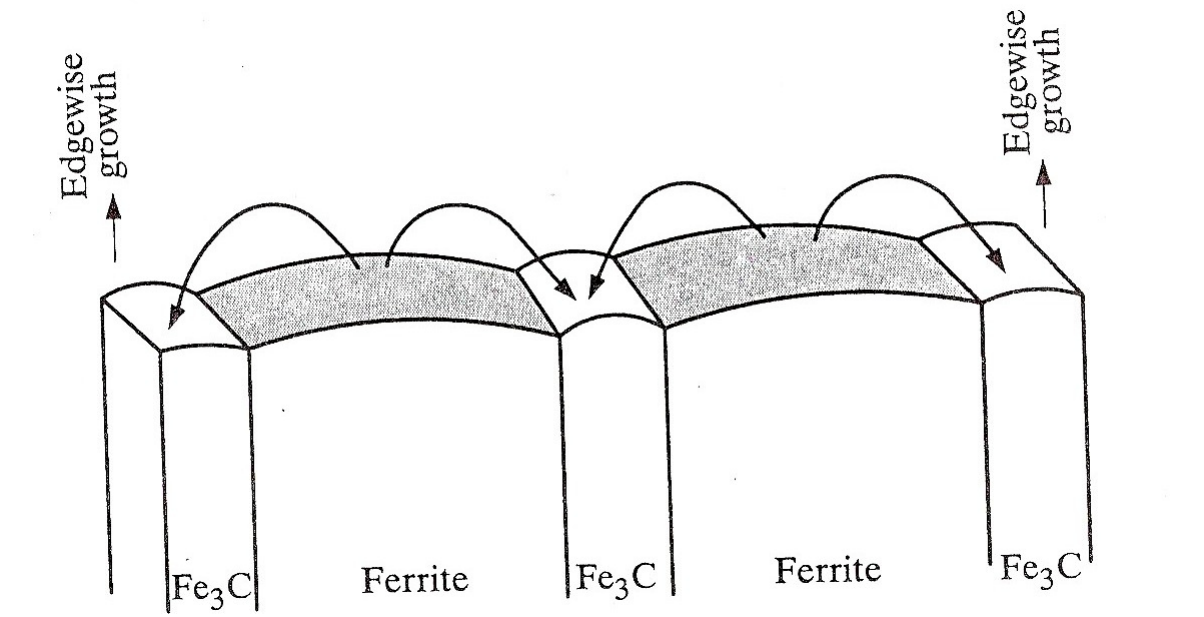
● METAL ATOMS
○ OCTAHEDRAL INTERSTICES



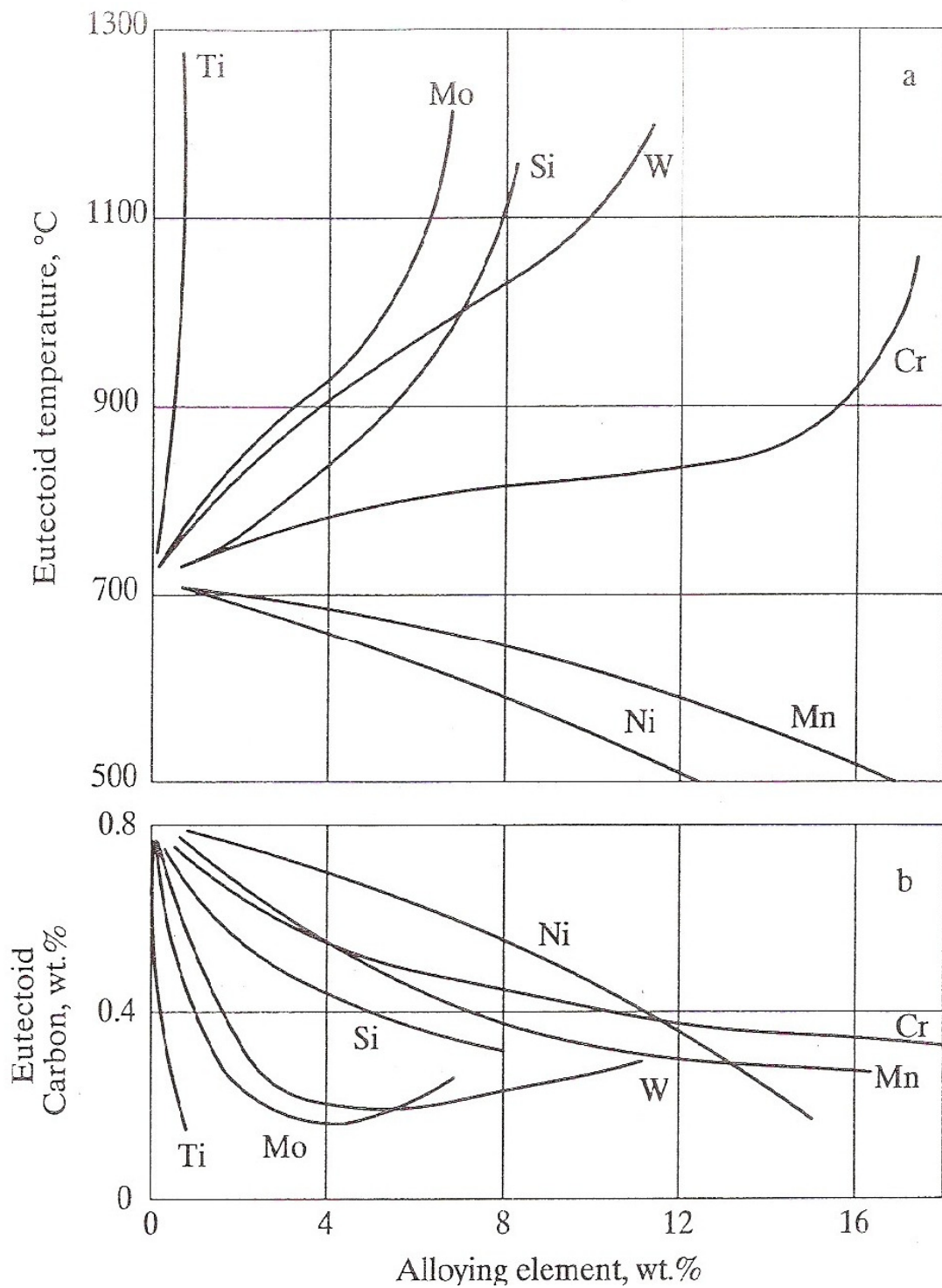
● METAL ATOMS
○ TETRAHEDRAL INTERSTICES

(b)

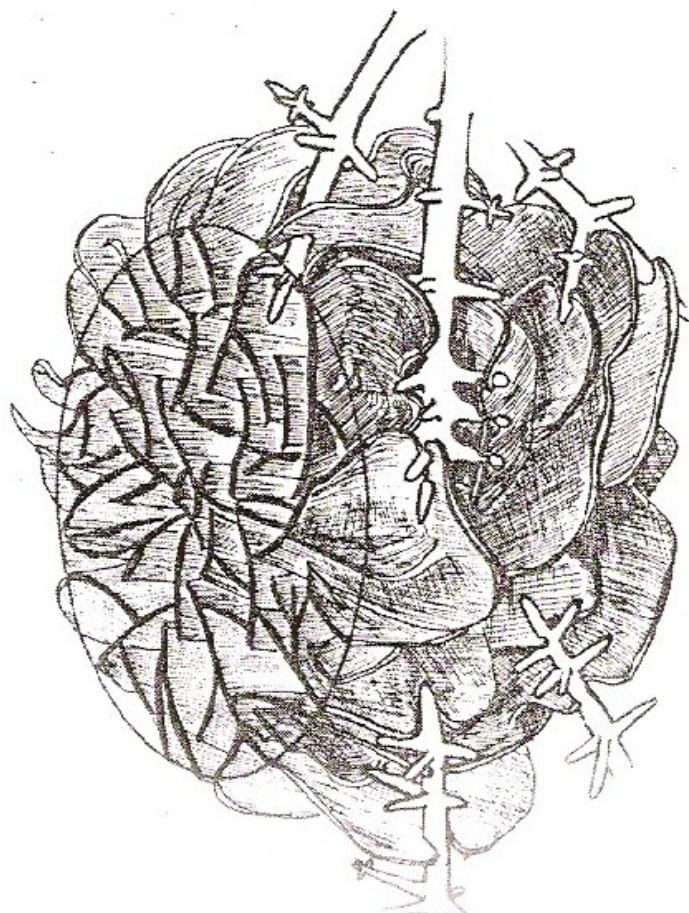
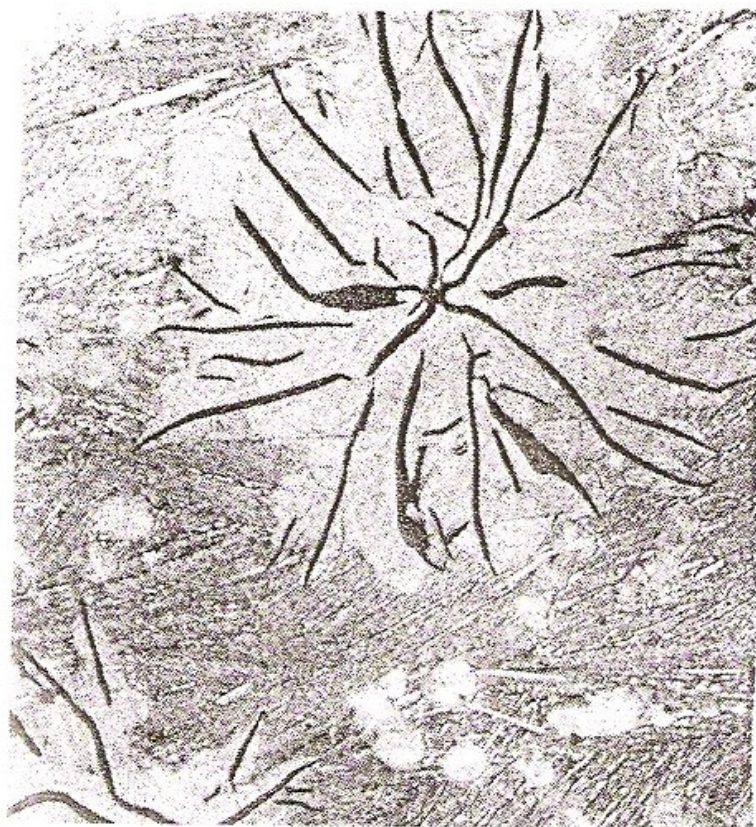




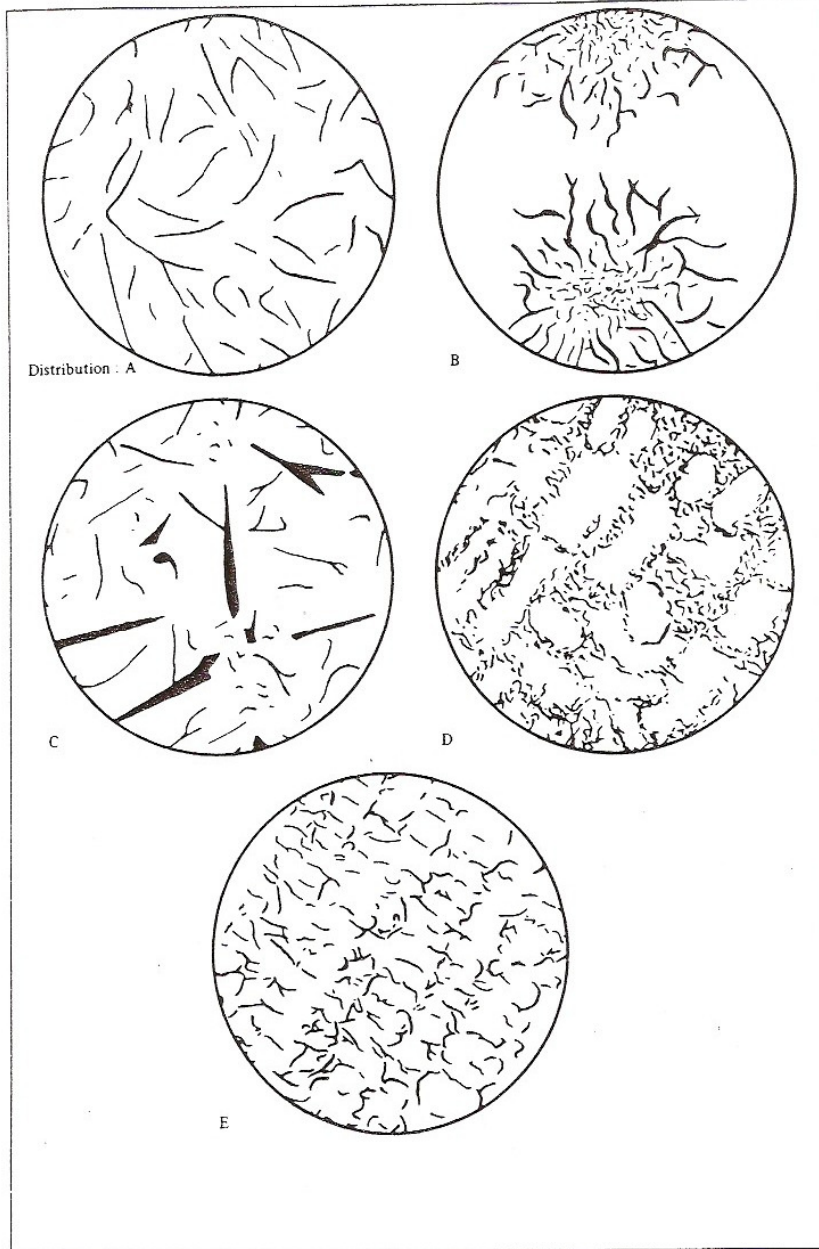
Edgewise growth of Cementite due to Carbon diffusion from converting Austenite leading to Pearlite.



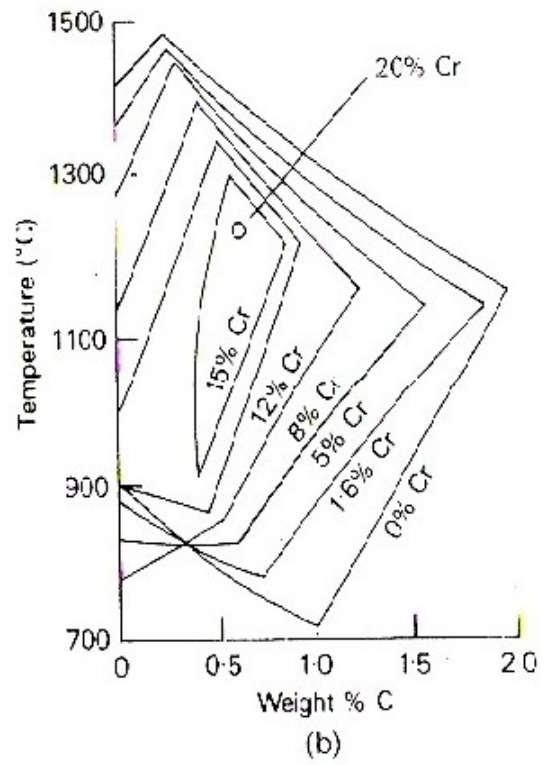
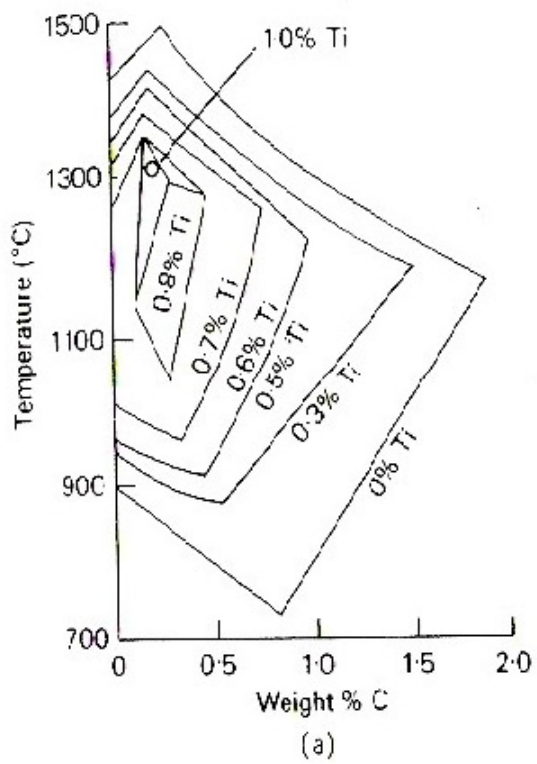
The presence of alloying elements affect both A3 temperature and Eutectoid % Carbon which affects Carbon equivalent of Steel. Reduction in Carbon equivalent of Steel, makes the Steel more prone to HEAT AFFECTED ZONES.



An Artistic view of Graphite Lammele



Graphite Distribution that can be found in a Grey Cast Iron.
Only Distribution 'A' is preferred for good properties.



Ferrite Stabilizers shrink the boundaries of Austenite.