PROPERTY DEVELOPMENT IN S.G. IRON BY HEAT TREATMENT

A THESIS SUBMITTED IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE DEGREE OF

Bachelor of Technology
In
Metallurgical and Materials Engineering

By

SUHAS .G
10304007
TUSARA KANTA NATH
10304008
&
SUBRAT DAS
10304022

Department of Metallurgy and Materials Engineering
National Institute of Technology
Rourkela
2007

PROPERTY DEVELOPMENT IN S.G. IRON BY HEAT TREATMENT

A THESIS SUBMITTED IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE DEGREE OF

Bachelor of Technology
in
Metallurgical and Materials Engineering

By

SUHAS .G
10304007
TUSARA KANTA NATH
10304008
&
SUBRAT DAS
10304022

UNDER THE GUIDANCE OF

Dr. SUDIPTO SEN

NATIONAL INSTITUTE OF TECHNOLOGY
ROURKELA

Department of Metallurgy and Materials Engineering
National Institute of Technology
Rourkela
2007

National Institute of Technology
Rourkela

certificate

This is to certify that the thesis entitled, "PROPERTY DEVELOPMENT IN S.G IRON BY HEAT TREATMENT" submitted by Sri Suhas.G, Tusara Kanta Nath & Subrat Das in partial fulfillments for the requirements for the award of Bachelor of Technology Degree in Metallurgical and Materials Engineering at National Institute of Technology, Rourkela (Deemed University) is an authentic work carried out by him, under my supervision and guidance .To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other University / Institute for the award of any Degree .

Asst. prof. Dr. S.Sen .

Date:

Dept. of Metallurgical and Materials Engineering

National Institute of Technology

Rourkela - 769008

ACKNOWLEDGEMENT

I wish to express my deep sense of gratitude and indebtedness to Asst.Prof. Dr.S.Sen Department of Metallurgical and Materials engineering, N.I.T Rourkela for introducing the present topic and for their inspiring guidance, constructive criticism and valuable suggestion throughout this project work.

I would like to express my gratitude to Prof. G.S Agarwal (Head of the Department), Prof. A.K Panda, Prof. K.N Singh, Prof. B.B.Verma for their valuable suggestions and encouragements at various stages of the work.

I can not forget to mention thanks to Mr. Sameer ,Mr. Hembram for giving their time in lab for completeing the project inspite of their heavy work load.

I would also like to thank Mr. Bivas Das for provding all the requirements during the project work.

I would love to give thanks to my family members for encouraging me at every stage of this project work.

Last but not least, my sincere thanks to all my friends who have patiently extended all sorts of help for accomplishing this undertaking.

1st May 2007

Suhas G
10304007

Tusara Kanta Nath
10304008
&
Subrat Das
10304022

CONTENT

TOPIC Page

ABSTRACT:

Cast iron is an alloy of iron containing more than 2 % carbon as an alloying element. It has almost no ductility and must be formed by casting . ductile iron structure is developed from the melt of cast iron. The presence of Si in higher amount promote the graphitizarion inhibiting carbon to form carbides with carbide forming elements present the carbon forms into spheres when Ce, Mg, are added to the melt of iron with very low sulphur content having this special microstructure containing graphite in nodular form gives ductile irin thus the ductility and toughness superior to that of any cast iron and steel structure finding numerous success in industrial application however heat treatment is a valuable and versatile too for extending both the consistency and range of properties of ductile iron casting beyond the limits of those produced in as-cast condiotion. Thus to fully utilize the potentioal of ductile iron castings, the designer should be aware of wide range of heat treatment available for ductile irin and its response to this heat treatment. Although ductile iron and steel are superficially similar metallurgically, the high carbon and silicon level in ductile iron results in important differences in their respionses to heat treatment. The high carbon leels increase hardenibility, permitting heavier sections to be heat treated with lower requirements for expensive alloying or severe quenching media also may cause,quench cracking due to the formation of high C martensite. This undesireable phenomena maje the control of composition, austenitising temperature and quenching conditions more critical in ductile iron. Since the formation of martensite is accompanied byu internal stresses, tempering is necessary in order to relieve the internal stresses, decreases the amount of retained austenite and reduces the probability of cracking. Austempering is a critical heat treating process in which austenite transforms isothermally to lower bainite rather than martensite and thus objectively reduces distortion and cracks. It is possible to achieve much larger ranges of tensile strength , ductility with toughness by adopting austempering, heat treatment process of ductile iron.

LIST OF FIGURES

LIST OF TABLES

Table no **page no**

"Cast Iron is brittle." is an outdated but widely held truism which mistakenly implies that all Cast Irons are the same, and none are ductile. In fact, Ductile Iron is far more than a Cast Iron which is ductile. It offers the design engineer a unique combination of a wide range of high strength, wear resistance, fatigue resistance, toughness and ductility in addition to the well-known advantages of Cast Iron - castability, machinability, damping properties, and economy of production. Unfortunately, these positive attributes of Ductile Iron are not as widely known as the mistaken impression of brittleness is well known.

The discovery of Ductile Iron was announced at the 1948 American Foundry men's Society Annual Conference and this gave a new lease on life to the Cast Iron family. By combining the castability of gray Iron and the toughness of steel, Ductile Iron compelled a wide recognition as an economical choice for high performance complex ferrous parts. Fifty years of research and development have led to a material whose properties can be tailored for applications requiring high toughness, corrosion resistance or high tensile strength. In this paper, the state-of-the-art of Ductile Iron technology is reviewed. It is shown that, although considered as a mature technology, recent process and product developments open new avenues to this family of materials.

During the past decade the development and commercialization of austempered Ductile Iron (ADI) has added a new star to the Ductile Iron family. Combining the strength, ductility, fracture toughness and wear resistance of a steel with the castability and production economies of a conventional Ductile Iron, ADI offers the designer an exceptional opportunity to create superior components at reduced cost. Only one factor has detracted from this story of forty years of Ductile Iron technology - the promotion of this material to designers has been a poor second to its technical development. In fact, the lack of knowledge and understanding among some potential users about the properties and uses of Ductile Iron is astounding.

Again the experiments has shown that proper heat treatment methods can improve the properties if Cast Iron to such an extent that in certain cases it may even overshadow the advantages of steel over Cast Iron. A large number of researches are going on this field, particularly for austempered Cast Iron which shows very good combination of properties.

TYPES OF CAST IRON:

Cast Iron is an alloy of Iron and Carbon containing more than 2% Carbon as an alloying element. This has almost no ductility. The presence of such high amount of Carbon increases the % of brittle phase Fe_3C in the matrix and as a result any shape cast as a product cannot be further subjected to any mechanical working as it will fail. So any shape that is to be produced is to be cast directly to the near net shape. That's why it is called as Cast Iron.

Cast Iron can be divided into several types according to the metallographic structure. there are four variables to be considered which lead to the different types of Cast Iron, namely the Carbon content, the alloy and the impurity content, the cooling rate after freezing and the heat treatment after casting these variables control the condition Carbon as well as the physical form of the parent matrix phase present**.**

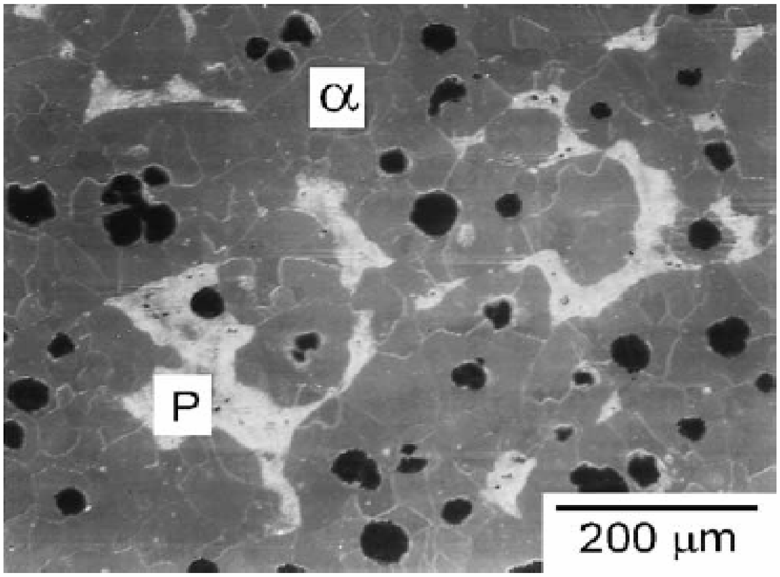


Fig: 2.1 As-cast microstructure of the ductile iron observed in SEM, where P is pearlite and α is ferrite.

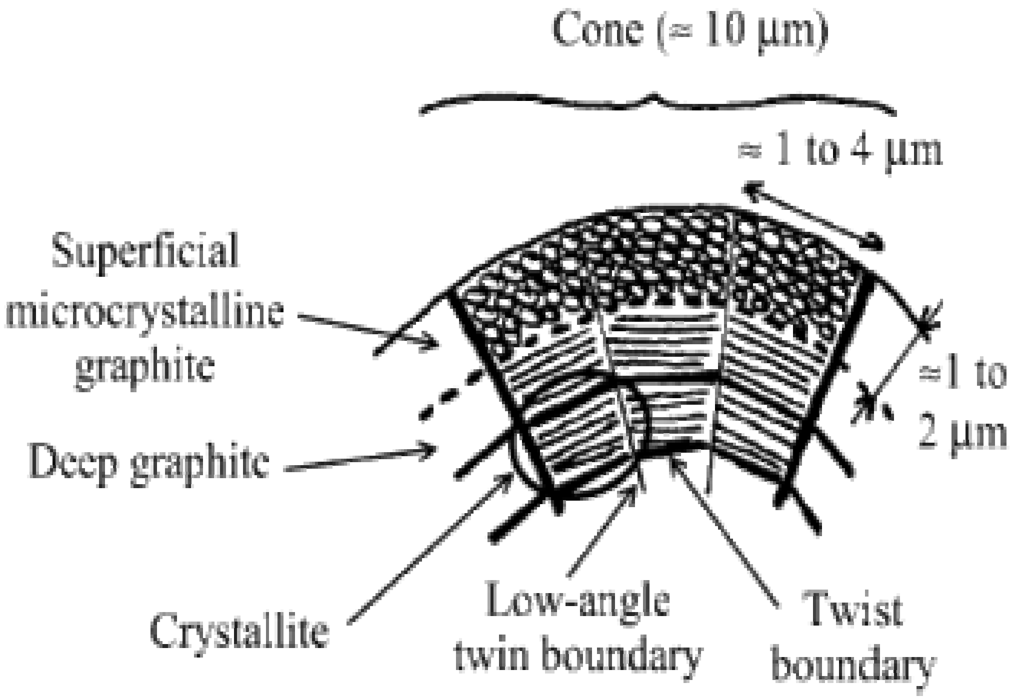


Fig :2.2 schematic representation of the microstructure of the spheroids in the as-cast state

Hence the different types of Cast Irons can be discussed as:

White Cast Iron: - the type of cast Iron in which the Carbon is present in the combined form as cementite is called as white Cast Iron. The name suggests the color of the fracture surface to be white. White cat Iron is obtained by rapid cooling of alloy from a temperature above liquidous line.

Demerit: - Excessive brittleness and poor mach inability.

Grey cast Iron: - Carbon in the form of graphite is more stable than carbide form. Hence during cooling of molten metal above liquidous if it is subjected to controlled cooling with adequate amount of alloying then Carbon will precipitate out as graphite flakes. This product is called as grey Cast Iron.

Demerit: - Low impact resistance and lack of ductility.

Malleable Cast Iron:- As Fe3C is a meta stable phase when white Cast Iron is subjected to a process called Malleablization combined Carbon present get converted into irregular nodules of temper Carbon(graphite) and ferrite. The process of Malleablization involves two stages of annealing known as first stage of annealing and second stage of annealing.

Demerit: - Section thickness limitation and prolonged annealing cycle necessary.

Nodular Cast Iron: - presence of Carbon in flake form or tempered Carbon form makes it unsuitable for uses in many fields. So by special alloy addition and adopting proper cooling rate the Carbon can be converted to spherical forms which are the most important type of Cast Iron.

Chilled Cast Iron: - in this type of Cast Iron a white Cast Iron layer at the surface is combined with a grey Iron interior.

Such types of Cast Iron are obtained while cooling metals against metal chillers. Here the surface metal gets cooled at a much faster rate sufficient enough to produce white Cast Iron. But while going inside the rate of cooling gradually decreases as a result a grey

Cast Iron core is formed at the centre. Hence in between there is a transition between white Cast Iron and grey Cast Iron.

Demerits: - there are every chances of development of stress gradient due to formation of two different type of Cast Iron.

Alloy Cast Iron: - when the properties of structure of any Cast Iron can be altered by addition of any alloying element then its called alloy Cast Iron.

The alloy Cast Iron and chilled Cast Iron are generally not considered as parent type of Cast Iron as these are slight modification of the other four types of Cast Iron.

Looking back on the first four decades of Ductile Iron reveals the classical pattern of the research, development and commercialization of a new material. So this chapter involves a detail study on types of S.G Iron and their properties in details.

AVERAGE COMPOSITION OF S.G. CAST IRON

- Carbon – 3.0 - 4.0 %
- Silicon – 1.8 – 2.8 %
- Manganese – 0.1 – 1.00 %
- Sulphur – 0.03% max.
- Magnesium – 0.01 – 0.10 %

Types of Cast Iron as per different phases present:

Depending upon the matrix phase S.G. Iron can be classified into three more groups.

1. Ferritic
2. Pearlitic
3. Martensitic

Generally the S.G Iron is of ferritic type. But due to its very high ductility and low its yield strength its field of application becomes limited. Hence intentionally if some amount of Carbon is left to be in the form of Fe_3C then the property gets enhanced by many folds. Such type of S.G Iron is called as pearlitic S.G Iron.

But if the rate of cooling is very high then it may happen that the matrix will become martensite. This type has also limited application due to the ductile nature.

Alloy	Condition	Microstructures	Tensile strength (Mpa)	Yield strength (Mpa)	Elongation (%)
T Ferritic h	Annealed	Ferritic	414	276	18
e Pearlitic	As- cast	Ferritic Pearlitic	552	379	6
Martensite c	Quenched & tempered	Martensite	828	621	2

Table-2.1, mechanical properties of different types of cast iron

Comparative study of the properties of various types shows that ferritic S.G. Iron has very good ductility i.e. 18% as compared to that of the other two. On the other hand the martensitic has very high yield strength as high as 828 MPa as compared to that of ferritic and perlitic S.G. Iron.

ADVANTAGES OF S.G. IRON:

Tensile strength of S.G. Iron will be about 47-55 kg/sq. mm with an elongation of 10-25%. Therefore, its physical property is strikingly higher than that of ant other Cast Iron, including malleable Cast Iron. The stress-strain curve produced by the S.G. Iron closely resembles that if steel having a direct relationship between stress and strain until a distinct yield point is reached. The yield point is high and is superior to malleable Cast Iron; therefore, S.G. Iron can sustain higher loads without permanent deformation. It possesses the favorable fluidity and low melting point advantage of grey Cast Iron and does not suffer from section thickness limitation as in case of malleable Iron.

Brinell hardness of S.G. Iron is usually some 20-40 points higher than flake graphite Iron of similar matrix structure. For given hardness the tensile strength of S.G. Iron may be taken as twice as great as that of flake graphite Iron.

The applications of S.G. Iron are numerous and can be found almost in every branch of industry. While, several of the existing application involves substitution of other materials. A stage has been reached in the development of the material to merit serious attention to design components to suit its own properties to drive full economic and technical advantage from the use of material. The characteristic properties of S.G. Iron that merit the attention of designers may be summarized as follows: -

1) Excellent fluidity enabling intricate shapes to be cast readily.

2) Feasibility of producing spheroidal graphite structures in an almost unlimited range of section sizes with very little falling off in mechanical properties.

3) Feasibility of developing, by suitable heat treatment and alloying, tensile

strengths over 90 kg/mm^2 with limited shock resistance over elongation of over 15-20% coupled with a tensile strength of nearly 50 gm/mm^2

4) Good wear resistance, which can be further improved by a surface-hardening treatment.

5) Corrosion resistance properties, superior to those of low Carbon cast steels.

6) Resistance to growth and scaling at elevated temperatures, much superior to that of flake graphite grey Cast Iron,

By virtue of its versatile properties, S.G. Iron has replaced not only the other types of ferrous castings but also steel forgings in many applications.

ROLE OF MAGNESIUM.

It is generally supposed that magnesium removes impurities such as Sulphur and oxygen, which may tend to segregate to free surfaces of molten metal, thereby lowering surface tension. Similarly, these impurities lower the interfacial tension between the graphite and metal. When they are removed, this interfacial tension rises to a higher value and it is often presumed that it constrains the graphite to reduce its surface area per unit volume, which it does by assuming a spherical shape.

Solidification of the spheroidal Graphite Cast Iron

Weak interaction by elements, which form a chocked boundary layer. The element Sulphur is noted to lower the graphite melt interfacial energy when present in solution. It therefore allows graphite crystallization at temperature closer to the equilibrium one and thus acts in a manner opposite to these elements promoting kinetic and constitutional super cooling.

Surface energy models of spheroidal graphite growth in CI:

The energy between graphite crystal faces and the melt depends on the presence of

Sulphur. This element is surface active. When it is removed from the melt by the presence of reactive additions like Mg, the melt-graphite interfacial energy is increased. These researches suggested that the graphite then grows in spherulitic form, which is energetically more favorable. The crystal becomes bounded energy (0001) surface, which have the lowest energy. This is an application of equilibrium theory.

Change of free energy ΔG for crystallization of a flake or graphite as a function of the interfacial free energy between the melt and solid γ_{sI} . ΔG_0 represents the energy stored in the interior of the sphere by the low angle boundaries of graphite Spherulite.

An alternative growth theory was also proposed. The increase of surface energy in absence of ‘S’ recurred greater under cooling for growth. A spherulitic crystal resulted from the ensuring changes in the growth rate.

A number of properties such as mechanical, physical and service properties are of important in assessing materials suitably for any application. The mechanical properties of interest are tensile strength proof stress, elongation, hardness, impact strength, elastic modulus, and fatigue strength, notch sensitivity while the physical properties of interest are damping capacity, machinability and conductivity. The service properties generally involved are wear resistance, heat resistance, corrosion resistance.

Mechanical property:

Because of the spheroidal nature of the graphite, the tensile properties hardness and impact strength of S.G Iron approach nearly those of the matrix. The as cast matrix consists varying properties of pearlite and ferrite and also cementite depending upon the metal composition & rate of cooling or in other words, section thickness of the casting. The elimination of carbides, changing the proportion of pearlite and ferrite and refining of pearlite can be achieved by different types of heat treatment such as quenching and tempering, normalizing and tempering, normalizing, controlled cooling, full annealing and sub critical annealing. The proportions of the different constitution of the matrix are also affected by the amount and types of alloying elements present. The matrix strength is also increased by alloy addition such as nickel and molybdenum in particular.

The fatigue properties of a material are considerably influenced by the notch sensitivity factor, which is the ratio of notched and unnotched fatigue strengths. A lower notch sensitivity factor implies superior actual working fatigue strength. Thus this property is of special significance in application like the crankshaft. S.G Iron is advantageously placed in this regard as the graphite in S.G Iron acts like a number of notches , and the effect of external notches in lowering the strength of an already notched material will be less unlike in the case of steel.

Physical property:

Although the special nature of the graphite decreases damping capacity compared to flake graphite grey Cast Iron, it is still significantly higher compared to steel. The damping capacity of steel, S.G Iron & flake graphite Cast Iron may be taken in the ratio of 1.1: 8: 5. The relative higher damping capacity of S.G Iron compared to steel is a certain application as it causes less tool chatter and noise emission in gearing.

Like flake graphite Cast Iron, the machinability of S.G Iron is also good, being the same for the same hardness. For the same strength, S.G Iron is the most readily machinable ferrous material. However, unlike in the case of grey Cast Iron, the chip formation while machining S.G Iron will be continuous & the techniques should therefore be more akin to those used for steel. Machinability decreases as the matrix exchanges from more of ferrite to more of pearlite. Presence of carbides particularly impairs machinability. The ferrite type of S.G Iron has relatively higher thermal conductivity compared to the pearlite types.

Service property:

The service property that has led to the extensive use of S.G Iron in many applications is its outstanding wear resistance. Crankshaft, metal working rolls, punch dies. Sheet metal dies are representative examples. In some cases the corrosion resistance of S.G Iron is similar top that of grey Cast Iron but in some cases it shows a decided improvement. Compared to attack by aggressive atmosphere, seawater, alkalis and some weak acids. So these have a wide range of use in petroleum and chemical industries. S.G Iron is dimensionally much more stable at high temperature, since the graphite spheroids are isolated from each other and do not provide paths for the penetration of gases , as do the network of graphite flakes in ordinary Cast Iron. Surface oxidation of S.G Iron is also less.

APPLICATION

The possible applications of S.G Iron are very wide. The properties are such as to extend the field of usefulness of Cast Iron and enable it, for some purpose, to replace steel casting, malleable Cast Iron, and non-ferrous alloys .But S.G Iron is not recommended as a replacement for all castings at present made in flake graphite Irons, sometimes the inherent properties of the flake graphite Iron are adequate for the purpose of exiting designs. The use of S.G Iron is suggested where improved properties are dictate a replacement of other material or where the use of S.G Iron will permit an improvement in the design. Some popular uses of S.G Iron for various engineering application are for –

1. Support bracket for agricultural tractor.
2. Tractor life arm.
3. Check beam for lifting track.
4. Mine cage guide brackets.
5. Gear wheel and pinion blanks and brake drum.
6. Machines worm steel.
7. Flywheel.
8. Thrust bearing.
9. Frame for high speed diesel engine.
10. Four throw crankshaft.
11. Fully machined piston for large marine diesel engine.
12. Bevel wheel.
13. Hydraulic clutch on diesel engine for heavy vehicle.
14. Fittings overhead electric transmission lines.
15. Boiler mountings, etc.

Heat treatment, through its influence on microstructure, has a strong effect on various mechanical properties. The heat treatment procedures usually adopted for S.G Iron casting are as follows

1. Stress relieving
2. Annealing
3. Normalizing
4. Hardening and Tempering
5. Surface hardening
6. Austempering

Casting of complicated shapes with S.G Iron as casting material require stress relieving treatment to relieve internal stress developed after solidification. Natural way at stress relieving is natural aging i.e. storing the casting in still air from 6 to 15 months. This treatment relieves about 30 to 50 % of the stress .A better and faster method .used most commonly present time is annealing the casting at 500 to 550°c for 6 to 8 hrs. For this process a heating rate of c to 150°c per hour is recommended the cooling rate in the range from 500 to 200°c should be 30-60 per hour .This treatment almost completely eliminates internal stress.

Annealing

Annealing softens Ductile Iron by producing a carbide-free, fully ferritic matrix. These procedures range from a low temperature or sub-critical anneal used to ferritize carbide-free castings, to two-stage and high temperature anneals designed to break down carbides. The primary purpose of annealing, or ferritizing, Ductile Iron is the production of castings with maximum ductility and toughness, reduced strength and hardness.

There are various methods of annealing:

1. Heating the casting to 900-950 °c and holding for 1hr. plus 1hr per 25 mm cross section of casting, for heavy casting holding time may be up to 8 hrs. After this casting is called and maintained at temperature below the lower critical temperature.

2. When impact strength is not signification carbides can be tolerated in the casting under such conditions casting are heated just below lower critical temperature and hold there for sufficient time depending upon section thickness, and cooled at furnace maintained at lower temperature for superior machinability Mn, P and alloying elements such as Cr, Ni and Mo should be as low as possible. These are carbide formers .Of these, chromium carbides takes longest time to decompose at 925°c.

Normalizing

Normalizing involves the austenitizing of a Ductile Iron casting, followed by cooling in air through the critical temperature. An as-cast Ductile Iron casting is normalized in order to: break down carbides, increase hardness and strength, and produce more uniform properties above the critical temperature range. Typically, austenitizing temperatures in the range 1600-1650^{o}F (875-900^{o}C) and holding times of one hour, plus one hour per inch of casting thickness, are adequate to produce a fully austenitic structure in unalloyed castings relatively free of carbide. The cooling rate should be sufficiently rapid to suppress ferrite formation and produce a fully pearlitic structure.

Quench Hardening and Tempering

Maximum hardness in Ductile Iron castings is obtained by austenitizing, followed by quenching sufficiently rapidly to suppress the formation of both ferrite and pearlite, to produce a metastable austenite which transforms to martensite at lower temperature. As-quenched hardness depends on the Carbon content of the martensite and the volume fraction of martensite in the matrix. In conjunction with the silicon content, the austenitizing temperature determines the Carbon content of the austenite. For a silicon content of approximately 2.5%, an austenitizing temperature of 1650^{o}F (900^{o}C) will result in the optimum Carbon content and maximum hardness Lower temperatures, 1475-1550^{o}F

(800-845°C), will produce a low Carbon austenite which, on cooling, will transform to a softer martensite.

Tempering reduces the strength and hardness and increases the ductility, toughness and machinability of quenched or normalized Ductile Iron. In addition, tempering quenched castings also reduces residual stresses, decreases the amount of retained austenite, and reduces the probability of cracking. These changes in properties are achieved by holding the castings at a temperature that is below the critical temperature. Tempering is a diffusional process and thus is time and temperature dependent. Tempering conditions are influenced strongly by the desired change in properties, the alloy content, the microstructure being tempered and the nodule count. Low alloy content, martensitic structures and high nodule count reduce tempering temperatures and/or times, while high alloy content, a normalized structure and low nodule count increase tempering times.

Surface hardening:

S.G Iron is also flame or induction hardened. Pearlite types of S.G Iron are preferred for flame or induction hardening as the time required for austenizing is comparatively small. In the case of steel some preliminary heat treatment is required before flame or induction hardening. For S.G Iron also some preliminary heat treatment is given. Some typical application of S.G Iron include heavy duty application such as rolls for cold working titanium , ring gears for paper mill drives and crankshaft for chain drives.

Austempering

This is a special type of heat treatment process in which the austenite is transformed into bainite. The cooling sequence for Austempering superimposed on TTT diagram can be used for study of the process. In general austenite is either transformed into pearlite or martensite during conventional heat treatment processes involving continuous cooling. The nature of TTT diagram is such that a given cooling curve cuts the C curve either above the nose or does not intersect at all.

Austempering consists of heating steel to above austenitizing temperature. It is then quenched in a bath maintained at constant temperature above Austempering temperature above Ms point and with in the bainitic range. (200°C - 400° C in general). The steel is quenched and maintained at a constant temperature in the bath itself till all the austenite is transformed into bainite. After complete transformation, steel is taken out of the bath and is cooled in air or at any desired rate to room temperature. Since the process involves transformation of austenite to bainite at constant temperature it is also known as isothermal quenching or isothermal hardening. As a result lower bainite which has better mechanical properties than tempered martensite. The preferred temperature of quenching bath is on the lower side of bainitic range which has better mechanical properties than even tempered martensite.

The novel matrix structure of austempered ductile Iron consists of two phases mixture of acicular bainitic ferrite and austenite. The volume fraction of austenite in matrix is very large. The Austempering process consists of the following stages.

1. Transformation of matrix to austenite i.e. austenitization.
2. Quenching to the Austempering temperature.
3. Holding at the Austempering temperature to effect isothermal transformation to acicular bainite+stabilized austenite.
4. Cooling to room temperature after the proper holding time.

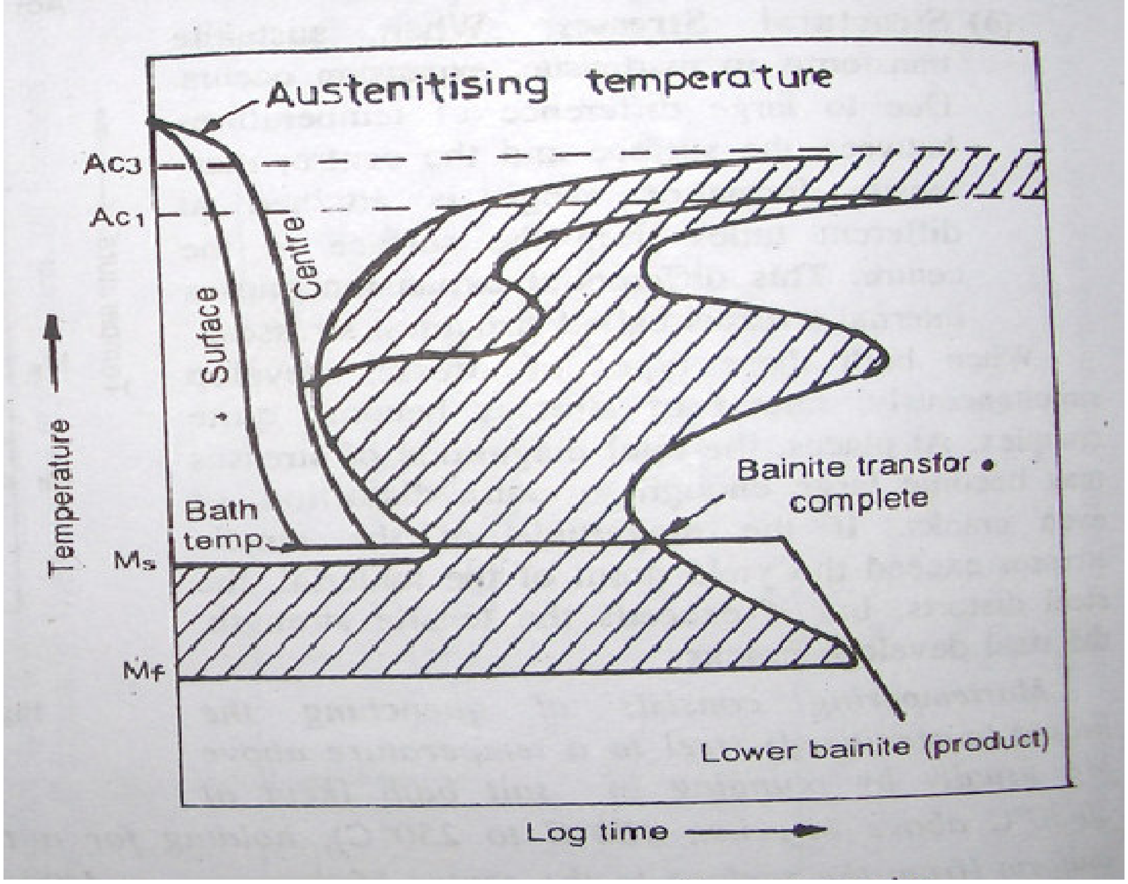


Fig: 4.1 shematic diagram for austempering superimposed on TTT diagram

The experimental procedure for the project work can be listed as :

1) specimen preparation
2) heat treatment
3) harden measurement
4) mechanical property study
5) microstructure study

SPECIMEN PREPARATION:

The first and foremost job for the experiment is the specimen preparation. The specimen size should be compaytible to the machine specifications

Hence during the specimen preparation the following things were to be taken care of

1) the thickness of the aspecimen should be such that it can be gripped properly with the jaws. The instron used for the tensile testing can use specimen of maximum thickness of 6 mm. so the specimen thickness should be less than that. We had taken the specimen thickness to be around 2.5mm.
2) length of the specimen should be less than the distance between the jaws. there is a specific gap between the jaws. Unless the length of the specimen is less than that the specimen cant be held properly. The length taken for the experiment was 14mm.
3) the level of load to be used should also be taken in to consideration. If the specimen will be over sized as per the level of load, it can “impart”. Then the specimen will not break and the experiment cannot be proceeded.. the machine used in our experiment has the maximum load bearing capacity of 100 KN. Again some safety factor must be allowed. Hence the machine is operated maximum up to 90 KN. Taking this in to consideration the size of the specimen should be such that the Intron should be able to break it during tensile loading.

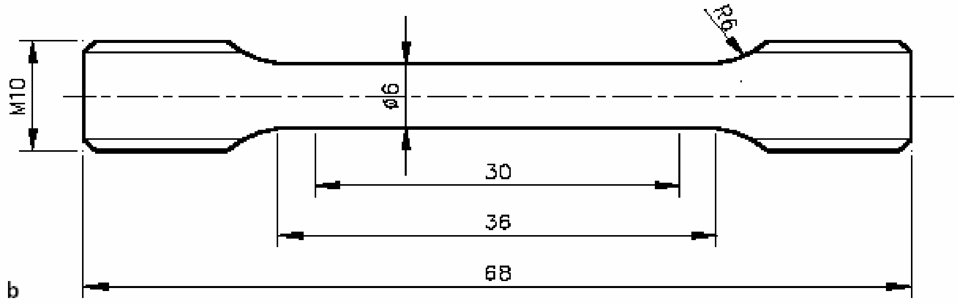


Fig 5.1 schematic diagram of a tensile testing specimen

h

HEAT TREATMENT

The principle objective of the project is to carry oout the heat treatment of SG cast Iron and then to compare the mechanical properties…there are various types of heat treatment processes we had adopted.

ANNEALING

a) the specimen was heated to a temperature of 950 deg celcius
b) At 950 deg celcius the specimen was held for 1 and half hour
c) Then the furnace was switched off so that the specimen temperature will decrease with the same rate as that of the furnace

The objective of keeping the specimen at 950 deg celcius for 2 hrs is to homogenize the specimen. The temperature 950 deg celcius lies above Ac1 temperature. So that the specimen at that temperature gets sufficient time to get properly homogenized

The specimen was taken out of the furnace after 2 days when the furnace temperature had already reached the room temperature

NORMALIZING

a) at the very begening the specimen was heated to the temperature of 950 deg celcius
b) there the specimen was kept for 1 and half hour
c) then the furnace was switched off and the specimen was taken out.
d) Now the specimen is allowed to cool in the oedinary environment . i.e. the specimen is air cooled to room temperature.

The process of air cooling of specimen heated above Ac1 is called normalizing.

QUENCHING

This experiment t was performed to get the hard ness of cast iron. The process involved putting the red hot cast iron directly in to a liquid medium.

a) the specimen was heated to the temp of around 950 deg celcius and were allowed to homogenize at that temp for 1 and half hour.
b) An oil bath was maintained at an constant temperature in which the specimen had to be put.
c) After 1 and hlf hour and the specimen was taken out of the furnace and directly quenched in the oil bath.
d) After around half an hour the specimen was taken out of the bath and cleaned properly.
e) Now the specimen attains the liquid bath temp within few minutes. But the rate of cooling is very fast because the liquid doesn’t releave heat readily.

TEMPERING

This Is the one of the important experiment carried out.th objective of the experiment was to induce some amount of softness in the material by heating to a moderate temperature range.

a) first the ‘9’ specimen were heated to 950 deg cel for 1 and half hour and then quenched in the oil bath maintained at room temp.

b) among the 9 specimen 3 were heated to 200 deg cel. But for different time period of half hour 1 hour and 2 hour respectively.
c) Now 3 more specimens were heated to 400 deg celcius and for the time period of half hour, 1 hour and 2 hour respectively
d) The remaining specimens were heated to 600 deg celcius for same time interval of half hour 1 hour and 2 hour

After the specimens got heated to a particular temperature for a particular time period, they were air cooled

The heat treatment of tempering at different temp for different time periods develops varienty of properties within them.

AUSTEMPERING

This is the most important exp carried out for the project work. The objective was to develop all round property in the material

a) the specimen was heated to the temperature of 950 deg cel and sufficient time was allowed at thast temperature, so that the specimen got properly homogenized.
b) A salt bath was prepared by taking 50% Na N03 and 50 % KnO3 salt mixture. The objective behind using $NaNO_3$ and KNO_3 is though the individual melting points are high the mixture of them in the bath with 1:1 properties from an eutectic mixture this eutectic reaction brings down the melting point of the mixture to 290 deg cel. The salt remains in the liquid state in the temp range of 290-550 deg cel whereas the salt bath needed for the experiment should be at molten state at 370 deg cel
c) After the specimen getting properly homogenized it was taken out of the furnace and put in another furnace where the container with the salt mixture was kept at 370d deg cel.
d) At that temp of 370 dfeg the soecimen was held for 2 hrs

In this time the austenite gets converted to bainite. The objective behind choosing the temperature of 370 deg cel is that at this temperature will give upper bainite which has tsmall grains so that the properties developed in the materials are excellent.

e) an oil bath also maintained so that the specimen can be quenched.
f) So after sufficient time of 2 hr the salt bath was taken out of the furnace and the specimen were quenched in the oil bath.
g) An oil bath is also maintained so that specimen can be quenched.

Now the specimens of each heat treatment are ready at room temperature. But during quenching in a salt bath, or oil bath or cooling due to slight oxidation of the surface of cast iron, there are every possibility of scale formation on this surface, if the specimens are sent for testing with the scales in the surface then the hardness value will vary and the specimen will also not be gripped properly in the instron

To avoid this difficulties the specimens were ground with the help of belt grinder to remove the scales from the surface. After the scale removal the pecimens are ready for the further experimentations

So the working schedule for heat treatment can be tabulated as:

Sample no	Treatment		Temperature	Holding time
1	As received		-	-
2	Normalizing		900°C	30 min
3	Oil quenching from 900°C C	Tempering	200°C	1/2hour
4	Oil quenching from 900°C	Tempering	200°C	1 hour
5	Oil quenching from 900°C	Tempering	200°C	2 hour
6	Oil quenching from 900°C	Tempering	400°C	1/2 hour
7	Oil quenching from 900°C	Tempering	400°C	1 hour
8	Oil quenching from 900°C	Tempering	400°C	2 hour
9	Oil quenching from 900°C	Tempering	600°C	1/2 hour
10	Oil quenching from 900°C	Tempering	600°C	1 hour
11	Oil quenching from 900°C	Tempering	600°C	2 hour
12	Austempered	Isothermal holding	370°C	2 hour
13	Austemered	Isothermal holding	370°C	1.5 hour

Table 5.1, list of the heat treatment conducted during the project

STUDY OF MECHANICAL PROPERTIES

As the objective of the project is to compare the mechanical properties of various heat treated cast iron specimens, now the specimens were sent to hardness testing and tensile testing.

HARDNESS TESTING

The heat treated specimens hardness were measured by means of Rockwell hardness tester. The procedure adopted can be listed as follows:

1. first the brale identer was inserted in the machine, the load is adjusted to 100 kg.
2. the minor load of a 10 kg was first applied to seat of the specimen.
3. now the major load applied and the depth of indentation is automatically recorded on a dial gage in terms of arbitary hardness numbers.the dial contains 100 division. Each division corresponds to a penetration of .002 mm.the dial is reversed so that a high hardness, which results in small penetration , results in small penetration, results in a high hardness number.

The hardness value thus obtained was converted into C scale b y using the standard converter chart.

ULTIMATE TENSILE STRENGTH TESTING

The heat treated specimens were treated in INSTRON for obtaining the % elongation, Ultimate Tensile Strength, yield Strength. Te procedures for obtaing these values cn be listed as follows;

1) at first the crossecction area of the specimen was measured by means of an electronic slide caliper and then the gauge length was calculated by using the standard formula.
2) Now the distance between the jaws of the instron was fixed to the gauge length of the specimen
3) The specimen was gripped by the jaws of the holder
4) The maximum load was set at 90 KN, gauge length was set and the cross head speed was set at 10mm/ min
5) The specimen was loaded till it fails
6) The corresponding stress vs strain diagrams were plotted by using the softwares.

From the data obtained the % elongation, yield strength and ultimate tensile strength were calculated by using the following formulae: -

% elongation = elongation attained by specimen/ gauge length of the specimen.

Yield strength = load at 0.2% offset yield/ initial cross section area
Ultimate tensile strength = maximum load/ initial cross section area

HARDNESS TESTING

Specimen specification	Time	Hardness
Quenched from 900 and tempered at 200^0 C	½ hour	45
	1 hour	38
	2 hour	31
Quenched from 900 and tempered at 400^0 C	½ hour	37
	1 hour	31
	2 hour	26
Quenched from 900 and tempered at 600^0 C	½ hour	34
	1 hour	30
	2 hour	23
Austempered 370^0 C	1.5 hour	26
	2 hour	27
As recieved		22

Table 6.1, different hardness values in Rc scale for various heat treated s.g iron specimen

Specimen specification	Time (in hr)	Hardness
Quenched from 900 and tempered at 200^0 C	½	45
Quenched from 900 and tempered at 400^0 C	½	37
Quenched from 900 and tempered at 600^0 C	½	34

Table 6.2 :Hardness vs tempering temperature for constant tempering time of ½ an hour

Specimen specification	Time (in hr)	Hardness
Quenched from 900 and tempered at 200^0 C	1	38
Quenched from 900 and tempered at 400^0 C	1	31
Quenched from 900 and tempered at 600^0 C	1	30

Table 6.3: Hardness vs tempering temperature for constant tempering time of 1 hour

Specimen specification	Time (in hr)	Hardness
Quenched from 900 and tempered at 200^0 C	2	31
Quenched from 900 and tempered at 400^0 C	2	30
Quenched from 900 and tempered at 600^0 C	2	23

Table 6.4:Hardness vs tempering temperature for constant tempering time of 2 hour

TENSILE TESTING

Sample	Heat Treatment	Time (in hrs)	UTS in MPa	Yield Strength MPa	Elongation %
A	Quenched from 900 and tempered at 200^0 C	½	820	580	7.2
		1	706	501	9.1
		2	594	369	10.7
B	Quenched from 900 and tempered at 400^0 C	½	598	496	9.68
		1	536	408	9.6
		2	585	371	13.4
C	Quenched from 900 and tempered at 600^0 C	½	513	402	10.3
		1	435	348	12.2
		2	421	383	16.1
E	Austempered 370^0 C	2.0	1052	932	11.0
		1.5	1101	879	10.8
J	As recieved		410	290	6.3
G	Normalizing		693	490	8.5
h	Annealing		390	210	18.1

Table 6.5: tensile properties of various heat treated s.g iron specimens.

Specimen specification	Time (in hr)	UTS in MPa	Yield Strength MPa	Elongation %
Quenched from 900 and tempered at 200^0 C	½	820	580	7.2
Quenched from 900 and tempered at 400^0 C	½	598	496	9.68
Quenched from 900 and tempered at 600^0 C	½	513	402	10.3

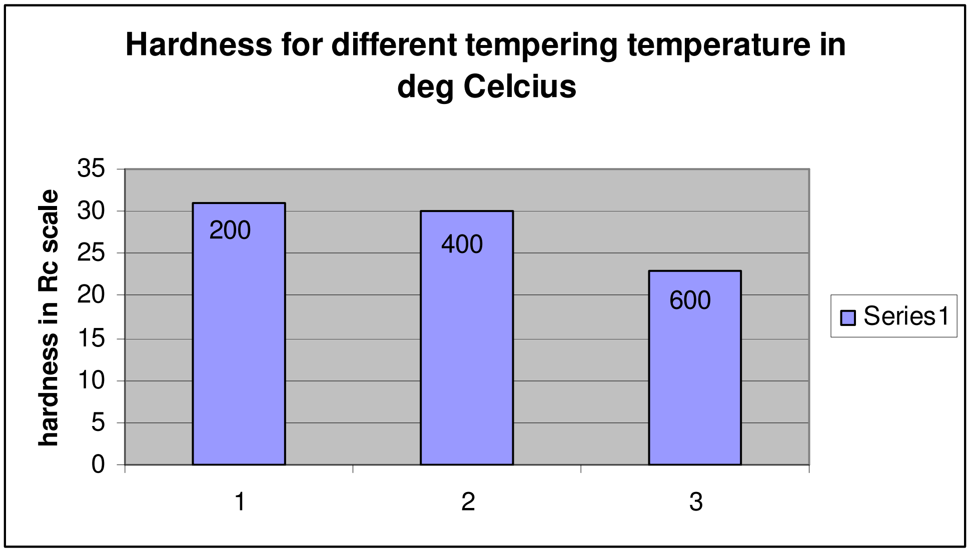
Table 6.6:Tensile properties for different tempering temperature for 1/2 an hour tempering time

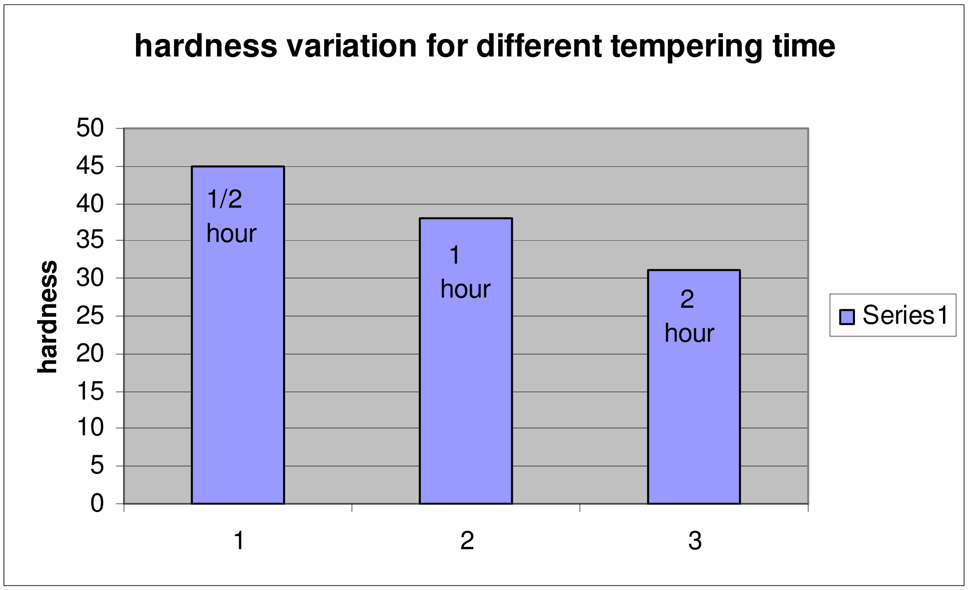
Specimen specification	Time (in hr)	UTS in MPa	Yield Strength MPa	Elongation %
Quenched from 900 and tempered at 200^0 C	1	706	501	9.1
Quenched from 900 and tempered at 400^0 C	1	536	408	9.6
Quenched from 900 and tempered at 600^0 C	1	435	348	12.2

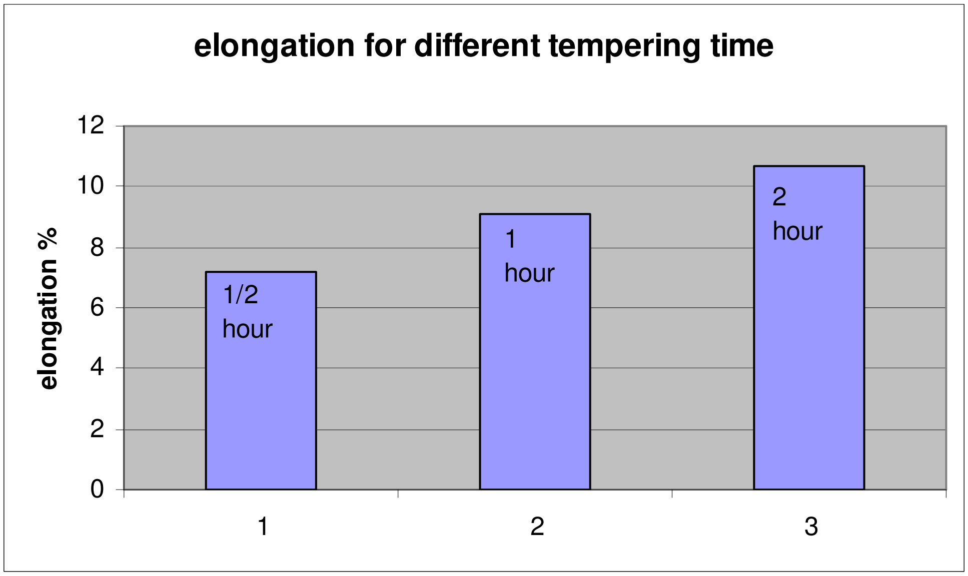
Table 6.7:Tensile properties for different tempering temperature for 1 hour tempering time

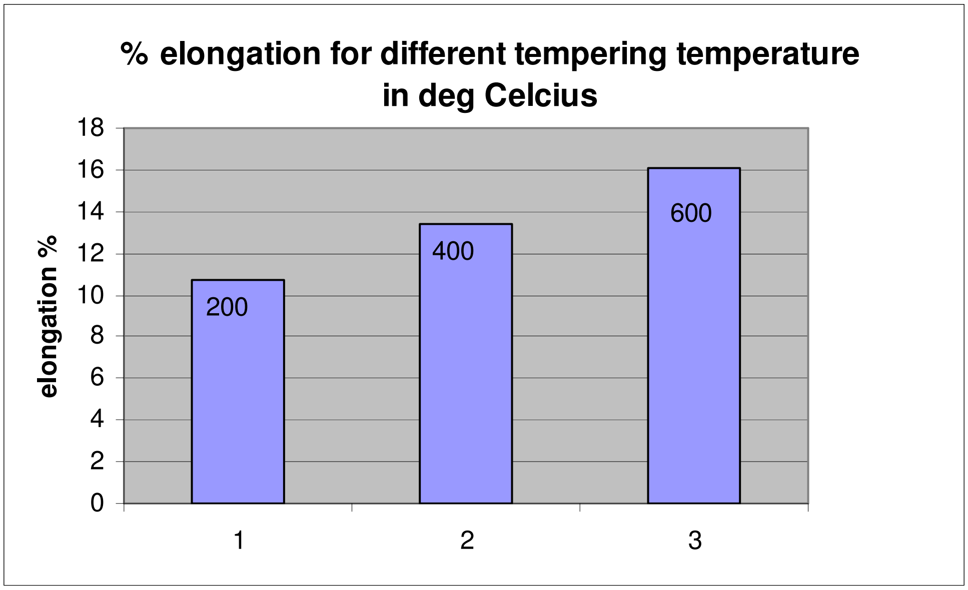
Specimen specification	Time (in hr)	UTS in MPa	Yield Strength MPa	Elongation %
Quenched from 900 and tempered at 200^0 C	2	594	369	10.7
Quenched from 900 and tempered at 400^0 C	2	585	371	13.4
Quenched from 900 and tempered at 600^0 C	2	421	383	16.1

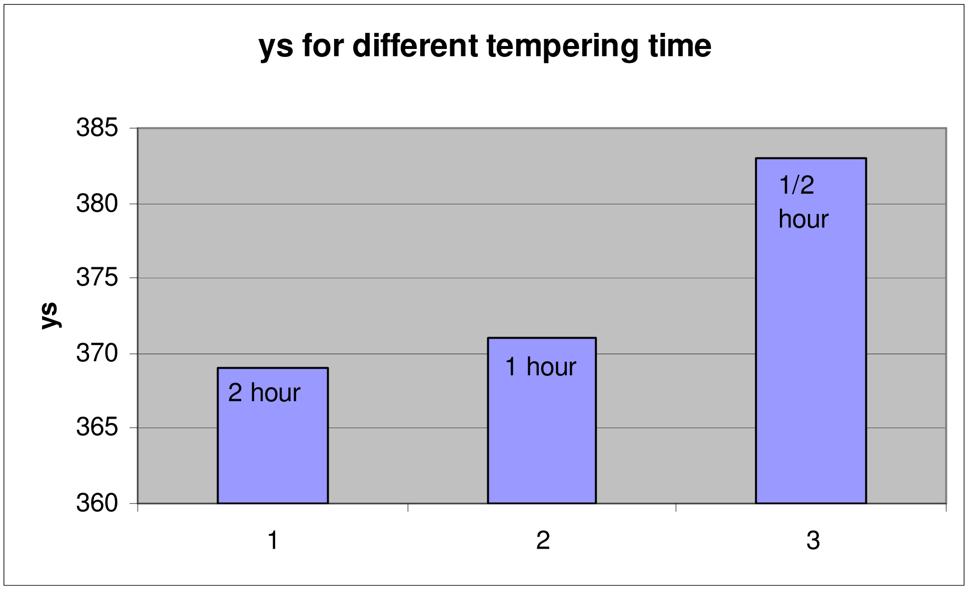
Table 6.8:Tensile properties for different tempering temperature for 2 hour tempering time

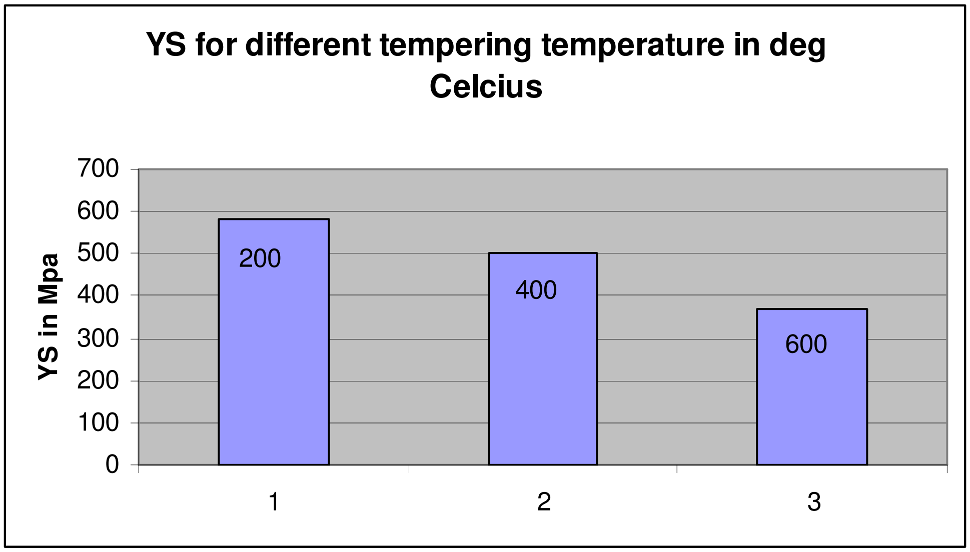



hardness variation for different tempering time
hardness
50
45
40
35
30
25
20
15
10
5
0
1/2 hour
1 hour
2 hour
1
2
3
Series1


elongation for different tempering time
elongation %
12
10
8
6
4
2
0
1/2 hour
1 hour
2 hour
1
2
3


% elongation for different tempering temperature in deg Celcius
elongation %
18
16
14
12
10
8
6
4
2
0
200
400
600
1
2
3


ys for different tempering time
ys
385
380
375
370
365
360
2 hour
1 hour
1/2 hour
1
2
3



O

DISCUSSION:

The hardness value and tensile property of the heat treated cast iron vary in a particular sequence . It can b observed from the figures obtained by plotting the hardness values vs the tempering temperature, i.e fig 1,2,3 (Bar diagrams) that the hardness value of the specimen tempered at lowest temperature ie 200c is the highest one as compared to those at 400c and 600c.so more is the tempering temperature better I is the ductility induced in the quenched specimen. Fig (1,2,3) shows the same thing for 3 different time periods,i.e ½ hour ,1 hour, 2 hour and in all the three cases same thing is concluded.

Similarly by comparing the hardness values for the specimen heat treated in for different tempering time ,but at constant temperature ,it can be observed that with increase in tempering time the softness or ductility induced goes on increasing .so for any tempering specimen tempered for 2 hour gives best ductility than other two time period.

So combinely the specimen quenched from 900c and tempered at 200c for ½ hour attains the maximum hardness value, whereas the specimen tempered at 600c for 2 hour induces maximum ductility in the material.

Comparing the hardness values of tempered specimen with these austempered and normalized ones , it can be concluded that the hardness of normalized is slightly less than that of specimen tempered at 600c for 2 hour and the austempered value is close to that obtained for tempering at 400c for 2 hour.

Hence when hardness is the only criteria specimen tempered at 200c for ½ hour will give the best result

Now comparing the tensile property of various heat treated specimen ,it can be observed from the table-() that for a particular tempering temperature with increase in tempering time the yield strength gradually decreases and the same thing happens to the UTS. On the other hand the % elongation of the specimen increases which signifies that more ductility is induced with increase in tempering time.

Similarly while comparing the mechanical properties with respect to temperature ,from the table –( ) it can be concluded that with increase in tempering temperature ,the ductility increases which is seen otherwise as decrease in yield strength ,UTS or increase in % elongation.

From all the tempered specimen the specimen tempered to 600c for 2 hour has got maximum % elongation and hence maximum ductility has been induced ,whereas for specimen tempered at 200c for 1 hour results in maximum strength .

Bow xoming to the special type of heat treatment given austempered specimen. the yield strength of the specimen is maximum among all the tempered as well as normalized specimen. The strength obtained is even more than the maximum strength obtained among all heat treated specimen i.e tempered at 200c for ½ hour.

Overall comparison of properties of the heat treated specimen gives the information that when hardness is the only criteria quench tempered specimen may give the best result but when the best combination of Y.S ,UTS and % elongation as well as hardness is taken into consideration the austempered specimen is the best one among all.

From the results obtained during the project work It can be concluded that the mechanical property of various heat treated specimen if C.I varies over an wide range. So depending upon the special type of application and properties required any particular heat treatment can be preffered. When the hardness of the specimen is needed to be high , in that case low temperature tempering should be preferred ,it can be used for the purpose where hardness is the only criteria. But the low temperature tempering specimens can not be used for the purposes when strength matters. Similarly when ductility is the only criteria tempering at high temperature for 2 hours gives the best result among all tempering experiments.

But comparing all the heat treatment processes, austempering process gives the best combination of yield strength. UTS and % elongation as well as hardness.

1) Haque M.M, journals of mat. Processing technology ,VOL IV,1999:
2) hafiz Mahmoud Mat. Series and Engg, Vol 340. 15 Jan 2003,
3) Wadysaw Antony, .Cooper C.A Acta Materiatia, Vol 254 Jan 2003,
4) Shishta .T. Wear, Vol 251 Oct 2001, M.Hatate,.
5) TundaA l and Gagne M, Canadian metallurgical quaterly vol 36, dec 2002
6) Camel Cather M, Bayram Ali, sala Baushi Material science and engineering vol 407, oct 2005
7) Zamba J, Sumandi M, Materials and Design Vol 25 august 2004,
8) Putatunda Sushil K Material science and Engineering Vol 315, sept 2001
9) Source Book on Ductile CI, ASM, 1977
10) Principles and application of heat treatment of CI, Isfahan University Iran, 1987
11) Chakraborty.A.K,Journals of tool steel,1997
12) R. lehman , R .Haynes, G.F.Modlen,isothermal transformation of austente in S.G.Iron, british foundry journal,2000
13) R.W.Heine, Carl R.Hopper,Philip.C.Rosenthal